MITSUBISHI ELECTRIC

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MOULDED CASE CIRCUIT BREAKERS
EARTH LEAKAGE CIRCUIT BREAKERS

TECHNICAL NOTES

13
A

Contents

■ MCCB

■ ELCB

■ MCCB & ELCB

1. Outline of MCCB

1 Outline of MCCB

1. 1 What is MCCB?

1. 1. 1 Definition of MCCB

MCCB refers to a molded case circuit breaker used to protect a low-voltage circuit with a rating of 600VAC or less and 750VDC or less.

"Molded Case Circuit Breaker" became common after so defined with UL Standard "UL489. It has also known as an MCB, however MCB refers to the "Miniature Circuit Breaker" in Europe and is limited to the miniature breaker used in residential homes.

1. 1. 2 History of Mitsubishi MCCB

The main accomplishments of the Mitsubishi MCCB, which has continually led MCCB industry are listed below.

1933 Japan's first branch circuit breaker for No-fuse panel board released.

1933	Moulded case circuit breaker production begins.
1952	Miniature circuit breaker production begins.
1968	Manufacture commences of short-time-delayed breakers.
1969	Production and sale of first residual current circuit breakers.
1970	170kA breaking level 'permanent power fuse' integrated MCCB is introduced.
1973	Introduction of first short-time delay and current-limiting selectable breakers go on sale.
1974	First MELNIC solid-state electronic trip unit MCCB are introduced.
1975	ELCB with solid-state integrated circuit sensing devices are introduced.
1977-1979	Four new ranges of MCCB are introduced – economy, standard, current limiting, ultra current limiting and motor rated designs – a comprehensive coverage of most application requirements.
1982	Compact ACBs with solid-state trip devices and internally mounted accessories introduced.
1985-1989	Super series MCCB with VJC and ETR are developed and launched – awarded the prestigious Japanese Minister of Construction Prize.
1990	New 200kA level U-series MCCB super current limiting breakers are introduced.
1991	Super-NV ELCB and Super-AE ACBs are introduced.
1995	Progressive Super Series from 30 to 250 amps are introduced.
1997	Progressive Super Series from 400 to 800 amps are introduced.
2001	World Super Series from 30 to 250amps are introduced.
2004	UL489 Listed MCCB are introduced.
2004	World Super-AE ACBs are introduced.
2006	White & World Super Series are introduced.
2011	World Super V Series are introduced.

1. 2 Switching and breaking

A switch or a breaker can be used to turn an electric circuit "ON" and "OFF". The switch is used to turn an electric circuit, in the normal working state, "ON" and "OFF" (this is called switching). The switch cannot turn an abnormal current, such as a short-circuit current, ON and OFF. A current has an inertia, so if a circuit in which a large current is flowing is cut off, the current will not drop to zero immediately even when the contact is released. Instead it will create an arc in the air between the contacts. If this arc exceeds the current that the switch can open and close (switch's switching capability), the contact could overheat, fuse, burn the surrounding insulator, break, cause bodily injury, or result in electric shocks or fires. The degree depends on the extent that the arc exceeds the current. Electricity has a large energy, and for example, if the impedance of a 3-phase 200V 100kVA current is 4% (0.016 ohm), the 3-phase short-circuit current will be approx. 7200A. However, if an 0.016 ohm external resistor is connected to each phase and short-circuited, a 3600A current will flow. This indicates that a total energy of 620kJ flows per second to the external resistor, and the above phenomenon could occur in an instant. Thus, the inertia of a large current, such as a short-circuit current, is tripped with a regular switch, an arc will result and cause damage. The circuit breaker trips this type of large current. In addition to a powerful contact switching mechanism, the circuit breaker has an arc-suppressing unit specially designed to quickly absorb and suppress the generated arc energy. The breaking capacity is the most important value used to evaluate the circuit breaker's capability, and indicates how difficult of a current it can trip. The difficulty to trip a current depends on the size of the current, and also on the voltage, power factor, and arc generation. The size of the current differs according to the closing phase, and the recovery voltage and transient recovery voltage determines whether a trip will occur after arc suppression. Of these elements, part of the voltage, current, power factor, recovery voltage and transient recovery voltage is subject to the circuit conditions, and part of closing phase, arc generation phase, and transient recovery voltage is related to the circuit breaker and it's operation. Thus, when evaluating the breaking capacity, a fair evaluation cannot be made unless the various conditions other than the circuit breaker are average or uniform. These matters are specified in detail in the Standards testing methods, but an allowance is permitted in the circuit structure, so these must be known for strict application. The criterion for the breaking test are also set forth in the Standards, however, these are not fully covered so inevitably each manufacturer's interpretation may differ.

The difference of the switch and circuit breaker is clear as explained above. These and other differences are shown in Table 1-1.

In actual application, these products must be used accordingly as the switch such as a magnetic switch dedicated for switching, and MCCB mainly used for tripping.

Table 1. 1

	MCCB	Magnetic contactor				
Standard	IEC 60947-2	IEC 60947-4-1				
Breaking capacity	Up to rated breaking capacity	Class	AC1	AC2	AC3	AC4
		Tripping	1.5 Im	4 Im	8 Im	10 Im
Closed circuit current capacity	Closing capacity (peak value) (approx.. double the rated breaking capacity)	Closed circuit	1.5 Im	4 Im	10 Im	12 Im
		Im : Breaking and closing current for rated working current				
Switching frequency	Small (i.e., 100A frame is 120 times/minute)	Large (i.e., 1,200 times/hour for No. 1 model)				
Switching life	Small (i.e., up to 10,000 times for 100A frame)	Large (i.e., electrically 500,000 times/more for Class 1)				

1. 3 MCCB and Fuse

1. 3. 1 Overcurrent circuit breaker

Stipulations regarding electrical facilities, such as IEC 60364-1, are intended for the electric circuit’s overload and short-circuit protection and require installation of an overcurrent breaker. Circuit breakers and fuses, etc., are approved as an overcurrent breaker. Examples of circuit breakers and fuses are given in Table 1. 2.

Table 1. 2

		MCCB			Fuse		
Rated current standard A		3 5 6 10 15 20 30 40 50 60 75 100 125 150 175 200 225 250 300 350 400 500 600 700 800 1000 1200 1400 1600 1800 2000 2500 2800 3000 3200 3600 4000 5000			1 3 5 10 15 20 30 40 50 60 75 100 125 150 200 250 300 400 500 600 (700) 800 1000		
Operating characteristics		Rated current A	Operating time 125% of rated current	Operating time 200% of rated current	Rated current A	Class A is operating time 135% of rated current, Class B is 160%	Operating time 200% of rated current
	Minimum operating current MCCB is 125% of rated current	30 or less	60	2	1 to 30	60	2
		30 or more, less than 50	60	4	31 to 60	60	4
		50 or more, less than100	120	6	61 to 100	120	6
		100 or more, less than 225	120	8	101 to 200	120	8
	Fuse: Class A 135% Class B 160%	225 or more, less than 400	120	10	201 to 400	180	10
		400 or more, less than 600	120	12	401 to 600	240	12
		600 or more, less than 800	120	14	601 to 1000	240	20
	Minimum operating current and 200% current operation time Either is within min	800 or more, less than 1000	120	16			
		1000 or more, less than 1200	120	18			
		1200 or more, less than 1600	120	20			
		1600 or more, less than 2000	120	22			
		More than 2000	120	24			

1. 3. 2 Fuse switch and MCCB

The fuse on its own does not have a switching function. However, the fuse and knife switch or cover switch combination provides the fuse switch with a slight switching function and can be used in the same manner as MCCB. Note that the budget, maintenance and installation space must be considered when making a selection. In addition, the points given in Table 1. 3 should be considered.

Table 1. 3 Comparison of MCCB and Fuse • Knife Switch

	Item for comparison	MCCB	Fuse • Knife switch
1	Safety	(1) The entire unit is enclosed with a molded case insulator, so when switching a load current, the arc is not discharged. In addition, this type is (2) safe as the live section is not exposed. The contact switching speed is constant regardless of the handle switching speed. The load current can be switched safely. (Note. Some of the compact circuit breakers are affected by the handle's switching speed.) (3) Equipped with an arc suppression chamber.	(1) This type is safe as the overload and short-circuit current are tripped inside the fuse tube, however with many units the arc is discharged when switching the load current. In many structures, the live section is exposed. (2) When switching a load current, the knife switch's switching speed is not constant. Thus, the load current switching conditions are not constant. (3) Most units do not have an arc suppression chamber.
2	Phase failure protection (Single-phase operation of 3-phase circuit)	Even if the overcurrent flows only to one pole, all poles are simultaneously disconnected, so there is no possibility of phase failure.	If the overcurrent flows to only one pole, only that pole blows and a phase failure results (single-phase operation takes place). The motor, etc., could burn.
3	Load switching capacity (switching of overload current)	In addition to switching the rated current at the rated voltage, the MCCB has the ability to switch a current six times the rating 12 times or more.	Switching of the rated current at the rated voltage is limited.
4	Spare parts (Reusing of parts after breaking an overload current)	Normal use is possible even after tripping an overload current, so there is no need to keep a constant supply of spare parts.	The fuse must be replaced after a short-circuit accident or overload operation, so a constant supply of spare parts is required.
5	Recovery operation (Restoration after overload current or short-circuit current is tripped)	After removing the cause of the accident, the MCCB only needs to be closed again. No extra steps or procedures are required for recovery as with the fuse.	The fuse must be replaced after the cause of the accident is removed, thus it takes time for recovery (the power failure will continue).
6	Deterioration (Changes in operating characteristics after overcurrent passage)	A slight change in operating characteristics after tripping a short-circuit current is permitted in the Standards. However, the operating characteristics will not change with a normal overload, etc.	If a current exceeding the deterioration characteristics flows to the fuse, the fuse will deteriorate, the operating characteristics will change, and the unit may malfunction.
7	Accessories	Remote operation is possible by operating the electricity. Elements required for automatic control, including the undervoltage trip, voltage trip, auxiliary switch and alarm switch, etc., are built in.	If a current exceeding the deterioration characteristics flows to the fuse, the fuse will deteriorate, the operating characteristics will change, and the unit may malfunction.
8	Protective characteristics and operating characteristics	(1) Sufficient load protection is provided overall ranges as the product's characteristics can be checked, and there is no worry of degradation, and the tolerance in respect to load currents can be small. (2) The characteristics are achieved with a combination of the time-delay characteristics and instantaneous characteristics. In addition, each functions independently, so characteristics matching the load are achieved.	(1) In view of deterioration, etc., the fuse's rated current must be increased in respect to the load current. Thus, it may not be possible to protect the load in low over-current ranges. (2) Only the thermal element of the fuse is used, so the characteristics cannot be adjusted according to the load.
9	Breaking capacity	The independent breaking capacity is small compared to the fuse, but incorporating the cascade method with the upstream MCCB can increase the breaking capacity . A current limiting mechanism is required to achieve a large breaking capacity.	A mechanism with a large breaking capacity can be manufactured quite easily. The breaking test must be verified with the fuse and knife switch combination.
10	Current-carrying capacity (selection of rated current in respect to load current)	When selecting MCCB, an allowance of 10 to 20% in respect to the load current is given in consideration of the load equipment's total load current variation and effect of the ambient temperature, etc.	With the fuse, there is a concern of deterioration, so the fuse rating must be approximately double the load current value.
11	Terminal	There are various types of connections (terminal structures) including front surface, back surface, inserted, and embedded.	Typically, only the surface type is available. This is inconvenient when designing panels.

1. 4 MCCB and ACB

1. 4. 1 Comparison of MCCB and ACB

With MCCB, the current-carrying capacity and breaking capacity have increased and the reliability has improved. Because of these improvements, use of MCCB in large capacity circuits where ACBs were conventionally used has increased. MCCB and ACB are both circuit breakers for low-voltage circuit protection, but these have the following differences. It is necessary to select a unit that has the best cost performance for the required circuit requirements, and which has sufficient reliability.

1. 4. 2 Tripping characteristics

MCCB long-delay tripping characteristics are typically fixed, and the ACB's characteristics are basically adjustable. This is so the protective characteristics of the generator of transformer can be achieved easily when using the ACB for a power breaker. When using MCCB for these types of applications, the protective characteristics can be attained easily by using an electronic MCCB that has variable long-delay tripping characteristics.

The voltage trip can also be operated by providing a general MCCB with a voltage trip and using a relay for long-delay protection.

1. 4. 3 Applications

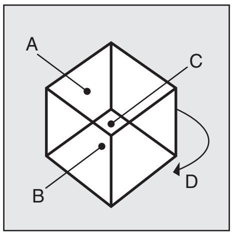
a. The MCCB opening time is small compared to the ACB, so cascade protection using MCCB and ACB combination is not recommended.

b. MCCB has a simple and safe structure that does not require maintenance or inspections. However, the ACB is designed with many updated parts and must be sufficiently serviced and inspected. Thus, MCCB is not suitable for applications intended for frequent short-circuit interruption.

c. The short-time capacity of the ACB is large, and a MCR (making current release) can be mounted. It is easy to structure a selective breaking system, and is suitable for applications as a main circuit breaker.

Table 1. 4 Comparison of MCCB and ACB

Item \ Circuit breaker		MCCB	ACB
Tripping scale	Long-delay tripping	● Typically fixed, variable types available	● Variable (current value, operating time)
	Instantaneous tripping	● Typically compact breakers are fixed. Large breakers are adjustable.	● Variable (current value)
	Short-delay tripping	● Typically not provided with short-delay tripping characteristics ● Electronic MCCB has variable current value and operating time.	● Variable (current value, operating time)
Tripping method		● Long-delay – instantaneous ● Long-delay – short-delay – instantaneous	● Long-delay – short-delay – instantaneous/MCR
Application and features		● For general wiring protection ● Not suitable for applications requiring frequent switching ● Total breaking time is short, and transient energy is small, so suitable for protecting wiring and load devices.	● For generator and transformer protection ● For main circuit ● Rated short-time current is large, so easy to structure selective breaking system.
Maintenance and inspection		● Easy to handle, and does not require much maintenance or inspection.	● Structure is easy to service and inspect ● Parts can be replaced
Compliant standards		IEC 60947-2	



2. Structure and Operation

2 Structure and Operation

2. 1 Molded case circuit breakers (C, S and H class)

2. 1. 1 Outline

MCCB can be operated easily and have excellent switching performance and breaking performance. An example of their structures is shown in Fig. 2. 1.

The major components of MCCB include a **mechanism which makes and breaks a contact** through a toggle link mechanism having a spring which can store tripping force, an **overcurrent trip device** which reacts with overcurrent and short circuit current and trips MCCB, an **Arc extinguishing device** which extinguishes the arc generated upon current interruption, **terminals** for connecting wires and conductors, **contacts** which open and close the circuit and a **molded case** in which these components are integrated and compactly contained.

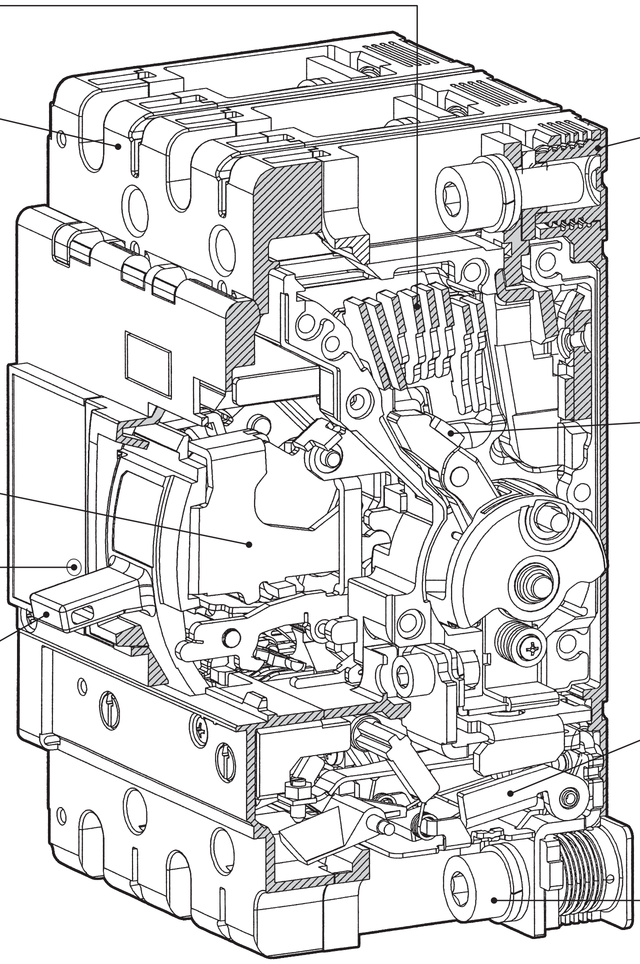


Fig. 2. 1 Construction of MCCB

2. 1. 2 Switching mechanism

The following functions realize excellent switching performance of the circuit breaker.

(1) Quick making and quick breaking

MCCB can be switched by turning the handle to ON or OFF. When the handle is turned to ON or OFF, the line of action of the retracting spring will go over the dead point of the toggle link, the toggle link will suddenly expand when the handle is turned to ON or bend when the handle is turned to OFF, and the contactors will quickly operate regardless of the handle operating speed. In the case of overcurrent tripping, the hook will rotate, the cradle will be released, the upper fulcrum of the toggle link will go over the line of action of the retracting spring, and the toggle link will quickly bend to open the contactors. Since the quick motion of the toggle link mechanism is used as a make-and-break mechanism, the contactors can perform quick making and breaking actions regardless of the operating speed. This is effective in prevention of deposition of the contactors during switching and in simultaneous making of poles.

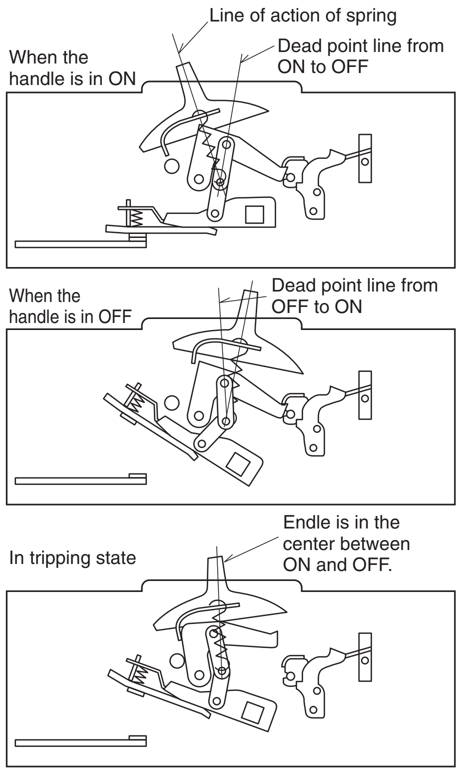


Fig. 2. 2 Switching mechanism

(2) Trip indication

When MCCB trips from ON or OFF, the handle will stop in the center between ON and OFF to indicate the tripping state.

To remake, turn the handle to ON after resetting. Concretely, when the handle is turned over the OFF position, the released cradle and hook will be engaged, and the mechanism will be restored to the OFF state to complete the reset. (Fig. 2. 3)

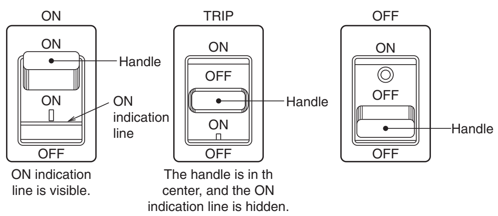


Fig. 2. 3 Positions of MCCB handle

(3) Trip free

The trip free mechanism is designed to avoid hindrance to tripping operation even when the handle is held in the ON position. All MCCB have the trip free mechanism.

(4) Common trip

In any multi-pole MCCB, the poles are electrically isolated by the partitions of the molded case, but the contactors of the poles are firmly secured on one cross bar made of an insulating material. The cross bar is linked with the toggle link mechanism to simultaneously make and break the poles, thereby preventing nonconformities, such as open phases. Therefore, even when a 4-pole MCCB is used for a neutral pole, it can be used without troubles, such as failure in making the neutral line and improper breaking, because it simultaneously makes and breaks four poles.

(5) Isolation function

The isolation function is defined as a function for isolating the power supply from all or part of equipment for safety's sake by separating the equipment and area from all electric energy sources.

When the contact is closed, OFF is not indicated on the handle in any case.

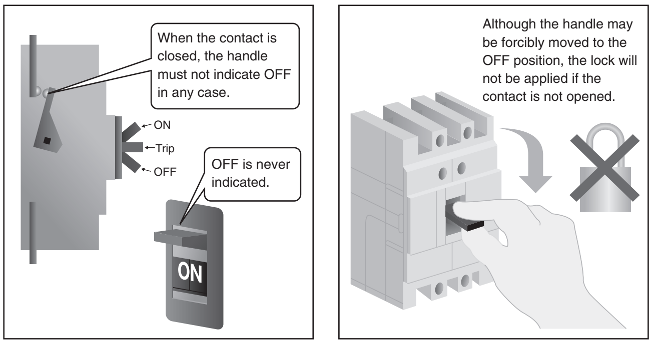


Fig. 2. 4 Isolation function

2. 1. 3 Overcurrent tripping device

The overcurrent trip devices can be roughly classified into thermal electromagnetic type and complete electromagnetic type (or, simply, electromagnetic type) according to the operating principle.

(1) Thermal magnetic type

(a) Structure

As the example shown in Fig. 2. 5, the hook is engaged with the latch of the common trip shaft through the roller trigger. The common trip shaft is supported in a freely rotating state by the support arm fixed on the base of the overcurrent trip device.

Each pole is provided with a bimetal element for time delay tripping as an element for detecting overcurrent and tripping and an electromagnet for instantaneous tripping.

The bimetal is curved in the arrow direction by heat and rotates the common trip shaft in the clockwise direction. When the latch is disengaged, also the hook rotates in the clockwise direction to release the cradle.

The electromagnet consists of a fixed core enclosing a conductor, a movable core and a retracting spring which constantly applies force to the movable core in the separating direction. When overcurrent exceeds a limit, the movable core will be attracted against the retracting spring, and the common trip shaft will be rotated in the clockwise direction by the tripping rod to release the cradle. Since the bimetal and electromagnet are provided for each pole and overcurrent on any pole affects the common trip shaft, all poles can be simultaneously tripped without open phases.

The thermal magnetic type circuit breakers are classified into the following types according to the structure of overcurrent trip device.

① Circuit breakers with or without molded cases.
There are molded-case circuit breakers, so-called “trip units”, with overcurrent trip devices assembled and sealed in their own molded cases and those without molded cases in which the overcurrent trip devices are assembled in the open state.

② Circuit breakers with fixed or adjustable tripping characteristics.
There are circuit breakers with fixed time delay tripping characteristics and instantaneous tripping characteristics which cannot be changed by users and those with variable characteristics which can be changed according to load. The adjustable type circuit breakers include thermal adjustable breakers on which the time delay tripping characteristics can be adjusted and instantaneous adjustable breakers on which the instantaneous tripping characteristics can be adjusted.

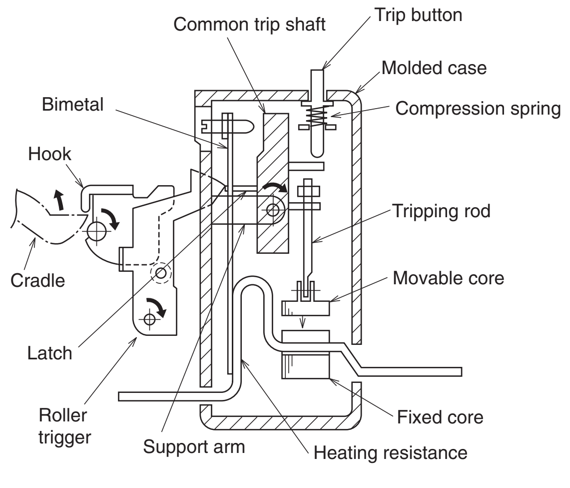


Fig. 2. 5 Structure of thermal magnetic type trip device

- **— Thermal adjustable type**
  The gap between the bimetal and the common trip shaft is adjusted to change the bimetal curvature necessary for tripping, so that the rated current can be adjusted.
- **— Electromagnetic adjustable type**
  The gap between the movable core and the fixed core is adjusted through the cam, so that the tripping current can be adjusted.

③ Bimetal heating methods

- **Direct heating method** —
  Current is applied directly to the bimetal, and the device is operated by the Joule heat generated by the bimetal resistance. This method is generally used for devices with lower rated current.
- **— Indirect heating method**
  A heating resistance is provided, and the heat of the heating resistance is applied indirectly to the bimetal. This method is generally used for devices with larger rated current.
- **— Direct and indirect heating method**
  The above two methods are used.
- **— CT method**
  A kind of the indirect heating method. The Joule heat in the secondary coil generated by the secondary current induced according to the current of the primary conductor passing the core is applied indirectly to the bimetal.
  This method can be used only with AC for the reasons of principle. It is used for devices with large capacities of about 2000 A or more.

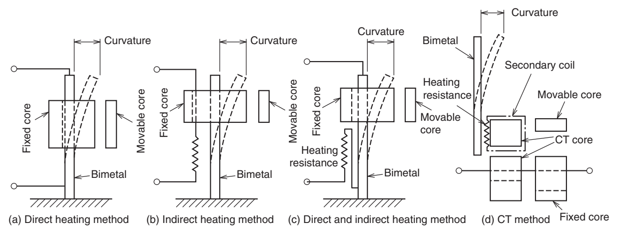


Fig. 2. 6 Bimetal heating methods for thermal magnetic type overcurrent trip devices

(b) Operating principle

If overcurrent flows continuously, the bimetal will receive heat and curve. When the bimetal reaches a certain operating temperature, the tripping operation will be performed according to the displacement of the bimetal. Fig. 2. 7. a shows the relationship among bimetal temperature, current and time. As the current value increases, the time to reach the operating temperature becomes shorter. When this relationship is plotted on the current-operating time scale, inverse time tripping characteristics can be obtained as shown in Fig. 2. 7. b. Upon occurrence of short circuit, it is necessary to break the circuit immediately. In this case, the electromagnetic trip device will instantaneously trip the circuit before the bimetal curves. The instantaneous tripping current value is generally set to 10 times or more the rated current to avoid unnecessary operation due to transient overcurrent, such as magnetizing inrush current of transformer or starting current of induction motor.

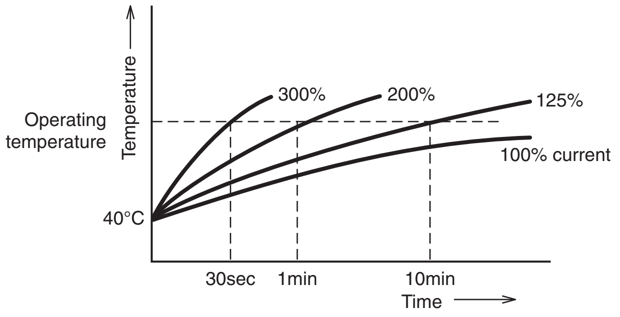


Fig. 2. 7. a Bimetal temperature-time characteristics

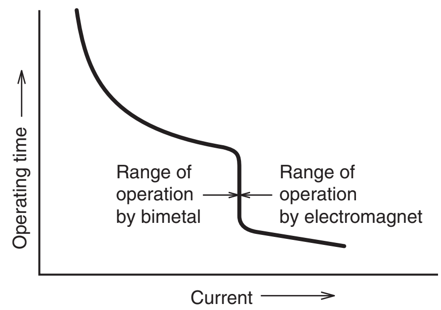


Fig. 2. 7. b Operating time-current characteristics

(2) Hydraulic magnetic type

(a) Structure

Fig. 2. 8 shows an example of the structure of hydraulic magnetic type trip device. In this structure, an electromagnet with an oil dash pot is used as a time delay tripping element. When the current is lower than the rated value, the core is pressed against the pipe bottom by the controlling spring, and the magnetic resistance is high, so that the movable iron piece i s not attracted.

However, if overcurrent flows continuously, the magnetomotive force of the electromagnet will increase, the core will overcome the controlling spring force and move toward the lid from the pipe bottom to reduce the magnetic resistance and disengage the latch, and an overcurrent trip will occur. At this time, the viscous resistance of the damping oil in the pipe causes a .

This time delay operation shows inverse time characteristics that increase the electromagnetic attraction and reduce the operating time as the current increases. If large current, such as short circuit current, flows, the movable iron piece will be immediately attracted by sudden increase in leakage flux to break the circuit before the core moves.

Hydraulic magnetic type devices for low current rating can be made by changing the number of coil turns, and those for special purposes can be made by adjusting the viscosity of damping oil or the gap between core and pipe.

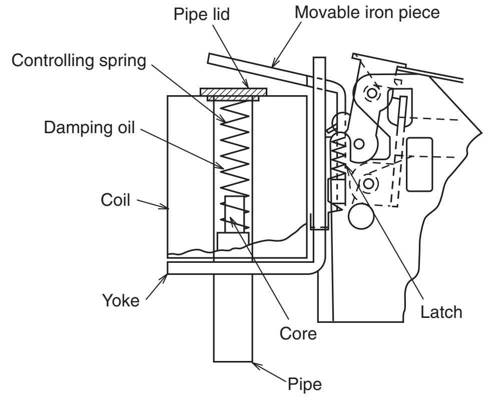


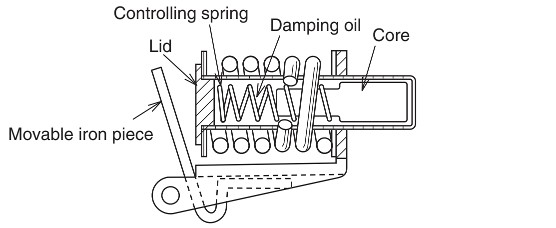
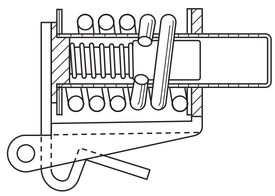
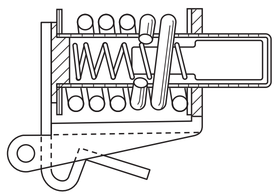
Fig. 2. 8 Hydraulic magnetic type

(b) Operating principle

Hydraulic magnetic type MCCB interrupts overcurrent and short circuit current with the same electromagnet. Therefore, MCCB must have a time limit until a predetermined current value is attained and interrupt the current immediately when the current value exceeds the predetermined value.

To obtain the inverse time characteristics, an electromagnet with an oil dash pot is used. To explain the operation of this device, its condition is classified into the three states shown in Table 2. 1 according to the magnitude of current.

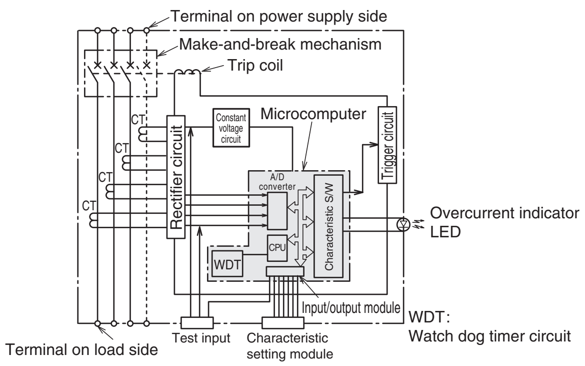
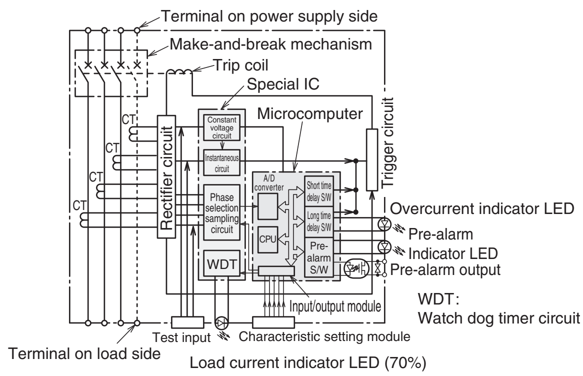
Table 2. 1

Inactive state	 When the current is less than the rated value, the core is pressed by the controlling spring, and the magnetic resistance is so high that the movable iron piece is not attracted.
Time delay operation	 When overcurrent flows continuously, the leakage flux moves the core toward the pipe lid against the controlling spring and damping oil, and the core is attracted by the lid. Then, the magnetic resistance is reduced, the movable iron piece is attracted, and MCCB is tripped.
Instantaneous operation	 When a larger current than a predetermined level flows, the movable iron piece is instantaneously attracted owing to increased leakage flux before the core moves, and the trip device is actuated to immediately trip MCCB.

(3) Electronic trip relay (ETR)

Trip devices which use electronic circuits for overcurrent detection, calculation, control and tripping instruction functions are called electronic trip devices.
Since the long time delay circuit is designed to detect root mean square values, the devices can operate reliably even at distorted wave current and will not operate unnecessarily earlier.
The ETRs feature easy switching of rated current and provision of short time limit characteristics as standard.

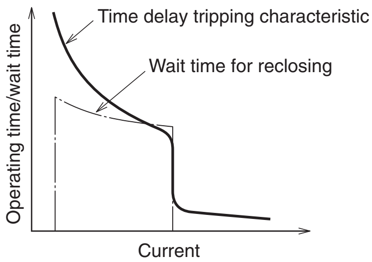
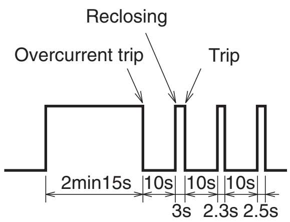
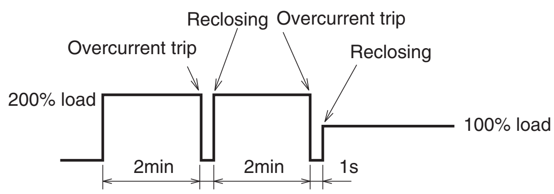
Table 2. 2

	NF125-SEV to NF250-HEV, etc.	NF400-SEW to NF800-REW NF1000-SEW to NF1600-SEW NF1200-UR, etc.
Explanation of operation	(1) When load current flows into the main circuit, the secondary current proportional to the load current flows to the secondary side of CT. (2) The AC secondary current in each phase is rectified by the rectifier circuit, and analog signals in proportion to the rectified currents are sent to the microcomputer. (3) The analog signals are converted to the digital signals by the A/D converter. (4) In the microcomputer, the root mean square value is calculated for each phase, and the signal of the phase having the highest value is used for long time delay tripping and pre-alarm characteristic processing. For short time delay tripping, the value calculated based on the peak is used to turn on the trigger circuit after a lapse of the specified time. (5) For instantaneous tripping, the value calculated based on the peak is used to instantaneously turn on the trigger circuit. (6) The current from the CT flows into the trip coil to trip MCCB. (7) The overcurrent indicator LED lights up when an overcurrent of about 115% or more of the rated current flows.	(1) When load current flows into the main circuit, the secondary current proportional to the load current flows to the secondary side of CT. (2) The AC secondary current in each phase is rectified by the rectifier circuit, and analog signals in proportion to the rectified currents are sent to the instantaneous circuit and phase selection sampling circuit. (3) The phase selection sampling circuit samples the signals of each phase, and the analog signals are converted to the digital signals by the A/D converter. (4) In the microcomputer, the root mean square value is calculated for each phase, and the signal of the phase having the highest value is used for long time delay tripping and pre-alarm characteristic processing. For short time delay tripping, the value calculated based on the peak is used to turn on the trigger circuit after a lapse of the specified time. (5) The instantaneous circuit instantaneously turns on the trigger circuit if the peak value of the analog signal of each phase exceeds the specified value. (6) The current from the CT flows into the trip coil to trip MCCB. (7) The overcurrent indicator LED lights up when an overcurrent of about 115% or more of the rated current flows.
Circuit diagram of electronic overcurrent trip device		

(4) Comparison of thermal magnetic, hydraulic magnetic and electronic types

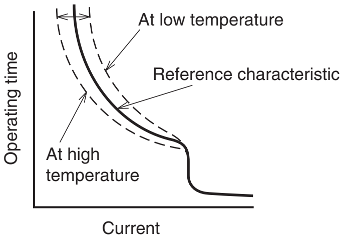
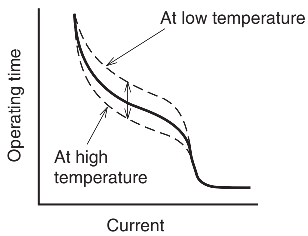
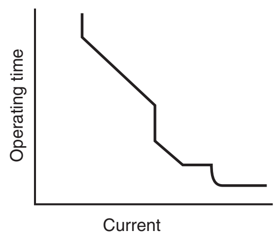
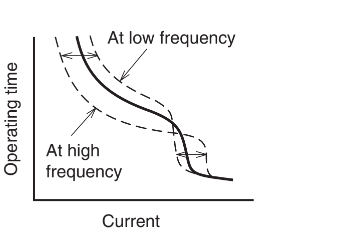
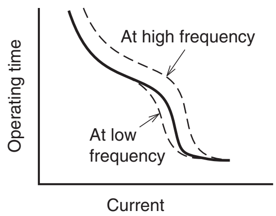
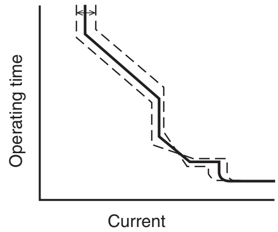
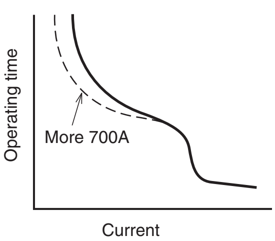
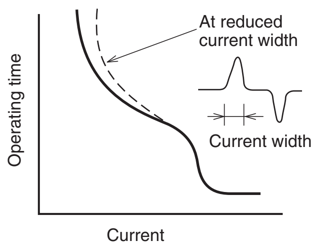
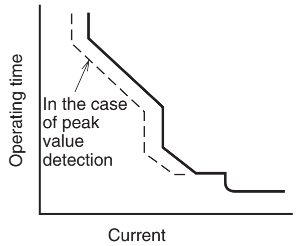
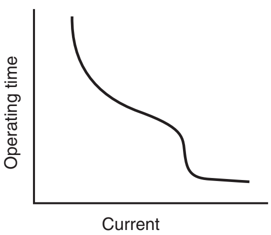
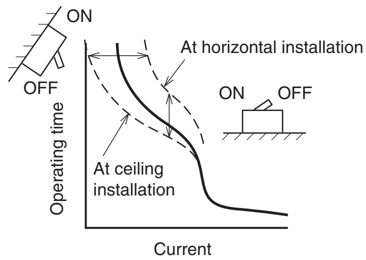
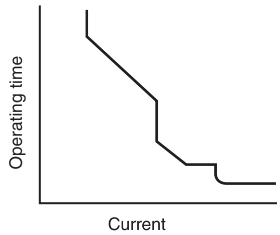
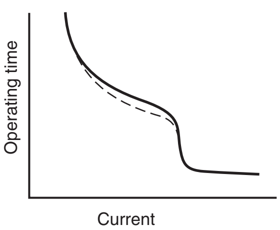
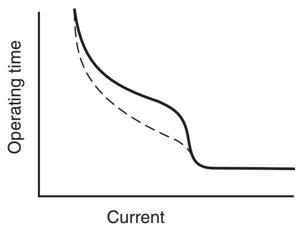
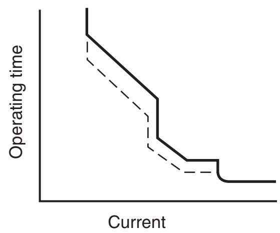
(a) Reclosing after overcurrent tripping

Table 2. 3

	Reclosing in overload range	Reclosing in instantaneous tripping range
Thermal magnetic type	The time required for reclosing varies depending on the magnitude of overcurrent. The longest time is required after tripping due to overload of 125 to 150% of the rated current, and, as the overload current increases, the time required for reclosing becomes shorter. After MCCB is tripped, it is reclosed after a lapse of the time to cool down the bimetal. Since also the electric wire is heated by overcurrent, the cooling time to cool down the wire to a temperature at which current can be applied is secured. This prevents deterioration of the wire insulation.  **Relationship between tripping characteristic and reclosing time**	Since the circuit breaker is tripped in a considerably short time (0.1 sec or less) by the electromagnet before the bimetal operates, almost no heat is accumulated in the bimetal, and it can be reclosed immediately. Generally, the instantaneous trip pickup current of thermal electromagnetic type breakers is 10 to 14 times the rated current and larger than that of the electromagnetic type (normally, 6 to 10 times the rated current). Therefore, the thermal magnetic type breakers are favorable for unnecessary instantaneous tripping caused by starting inrush current of induction motors and primary magnetizing inrush current of transformers.
Hydraulic magnetic type	You may consider that the device can be reclosed immediately after overcurrent tripping and the tripping time after the circuit is reclosed is the same as before. Actually, when the circuit breaker has been reclosed after overcurrent tripping, it will operate rather earlier than before. Even if a circuit with thermal allowance for wiring is reclosed immediately after overcurrent tripping to ensure continuous power supply in case of emergency, continuous power supply cannot be expected because the circuit breaker will operate in a considerably short time after power is applied. If the circuit is restored after tripping and is operating at a steady-state current, power can be continuously applied by reclosing.  **Example of operating time at load of 200%**	The breaker is tripped instantaneously by the movable iron piece and can be reclosed promptly.
Electronic type	After the electronic MCCB trips a circuit, it resets the overcurrent trip circuit to the initial state. Therefore, it can be reclosed immediately after overcurrent tripping, and the tripping time after reclosing is the same as before. If the circuit is restored after tripping and is operating at a steady-state current, power can be continuously applied by reclosing.  **Example of operating time at load of 200%**	The breaker can be reclosed promptly after it is tripped in any of the short time delay tripping range and instantaneous tripping range. Generally, the instantaneous trip pickup current of electronic MCCB is 15 to 20 times the rated current and larger than that of the thermal type (normally, 10 to 14 times the rated current). Therefore, the thermal magnetic type breakers are favorable for unnecessary instantaneous tripping caused by starting inrush current of induction motors and primary magnetizing inrush current of transformers.

(b) Comparison of operating characteristics

Table 2. 4 Thermal magnetic, hydraulic magnetic and electronic types

Comparison item	Thermal magnetic type	Hydraulic magnetic type	Electronic type
Influence of ambient temperature	 Since the bimetal operating temperature is uniform, the current carrying capacity changes.	 Although the current carrying capacity does not change, the operating time changes because the viscosity of damping oil in the pipe changes with temperature.	 Since the trip circuit temperature is compensated to avoid influence of ambient temperature, there is almost no change in the operating time.
Influence of frequency	 The change at 700 A or more is significant compared to that at 600 A. At 60 Hz or less, there is almost no change in the time delay tripping characteristics.	 At a high frequency, the minimum operating current is increased owing to iron loss.	 At high frequencies, the tripping current increases on some models and decreases on other models owing to the influence of CT and trip circuit.
Influence of waveform distortion (higher harmonics)	 At 600 A or less, there is almost no change in the characteristics. At 700 A or more, the current carrying capacity is reduced owing to increase in heat generation.	 If distortion is large, the minimum operating current is increased.	 Devices which detect RMS values show little change in characteristics. Those which detect peak values decrease in current carrying capacity.
Influence of installation posture	 No change	 Since the weight of the core in the pipe has influence, the operating current value varies depending on the installation condition.	 No change
Change in time delay tripping characteristics	 Since the bimetal specifications are determined by the bimetal curvature and temperature necessary for automatic tripping, the operating time cannot be changed so significantly.	 The operating time can be changed relatively easily by adjusting the viscosity of the damping oil in the oil dash pot and the gap between the core and pipe. However, the time cannot be changed once the device is mounted in the breaker.	 The operating time can be reduced relatively easily by changing the constant of the electronic circuit. The operating time cannot be increased for reasons of current overload capacity.
Rated current	It is difficult to manufacture circuit breakers with low rated current values because this type uses heat generated by the bimetal or heater current.	Devices with any rated current can be manufactured by increasing the number of coil turns to obtain a certain magnetomotive force.	Devices with any rated current within the range of 50 (60) to 100% of the maximum rated current can be manufactured. The short time delay tripping current and instantaneous tripping current values can be relatively easily reduced.

2. 1. 4 Contacts

The movable contact and fixed contact are exposed to extremely severe conditions because the circuit is opened and closed through intermittent operation of the contacts.

Large-capacity MCCB have some contacts per pole and are designed so that some of the contacts are used as arc contacts mainly for arc interruption, and others are used mainly for energization. As shown in Fig. 2. 9, generally, at the moment of contact and opening of the contacts, the front end of the movable contact gets into contact, and arc is generated at the end. When the MCCB is in the ON state, the rear end of the movable contact gets into contact, so that the energized part in the ON state is not consumed by the arc and stable contact resistance can be maintained.

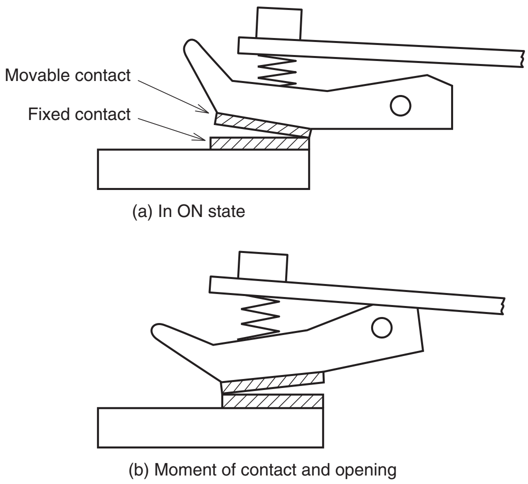


Fig. 2. 9 Opening/closing conditions of contacts

The contacts used must have excellent quality and be made of the most suitable material.

The contacts must meet the following requirements.

① **Low contact resistance**
② **Hard to wear out**
③ **No adhesion**

The low contact resistance can be realized by using silver or alloys with high silver content, but these materials do not have sufficient wear resistance.

High arc wear resistance can be obtained by using tungsten or alloys with high tungsten content, but, to the contrary, these materials have rather higher contact resistance. Actually, various silver alloys conforming to the performance requirements for working voltage and current breaking capacity are used in consideration of the above factors. For example, for contacts to be used mainly for energization, a silver-tungsten alloy with a silver content of 60% or more, a silver-tungsten carbide alloy, etc. are used, and, for contacts mainly for arc interruption, a silver-tungsten alloy with a tungsten content of 60% or more, etc. are used.

2.1.5 Arc extinguishing device

Every time current is interrupted by opening contacts, arc is generated owing to current inertia.

Since the arc is significantly harmful to the contacts and insulating materials, it must be immediately extinguished.

The arc extinguishing device is a de-ion arc extinguishing device having a grid consisting of magnetic plates with V-shaped notches supported by insulating support plates at appropriate intervals as shown in Fig. 2. 10. Arc is extinguished by the following three actions.

① Part of magnetic flux biased by the magnetic plates affects the arc and moves the arc spot (cathode spot) to the back of the V-shaped notches to cool the arc.
② The arc is moved to the back of the V-shaped notches as stated in 1) to expand the arc, and the arc is cut by the grid plates to divide it into short arcs. As the result of this, cathode drop and anode drop are caused in the grid plates.
③ The voltage drop on the arc column is enhanced by expanding the arc, and, when the arc touches the support plates, arc extinguishing gas is discharged from the support plates to extinguish the arc.

In short, if the voltage (arc voltage) necessary to maintain the arc is increased, the supply voltage cannot maintain the arc, and the arc will be extinguished. Alternating current crosses the zero point in each half cycle. Therefore, powerful arc extinguishing effect can be given at this point, and the arc can be extinguished relatively easier than in the case of direct current.

Mitsubishi MCCB have excellent breaking performance because the distance between grid plates, shape of grid and material of support plates are designed appropriately based on the long-term experiences.

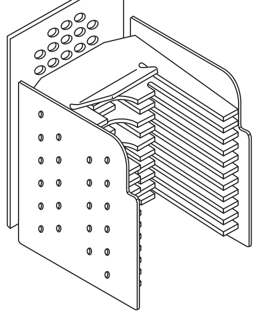


Fig. 2. 10 Arc extinguishing device

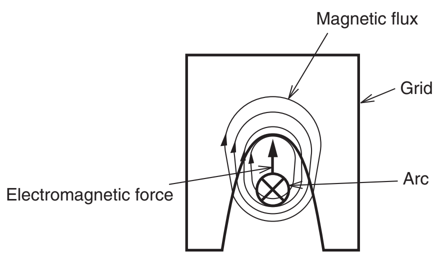


Fig. 2. 11 Principle of de-ion arc extinguishing device

2. 1. 6 Molded case

The molded cases for MCCB are required to have **strength** which can withstand the gas pressure at breaking, **heat resistance** and **arc resistance**.

For early MCCB, **inexpensive phenol** resins were used in many cases. For recent small-sized compact MCCB, **polyester resins** containing glass fibers and **polyamide resins** suitable for complicated shapes and reduced in thickness are used widely.

2. 1. 7 Terminals

The terminals are used to connect MCCB and external conductors. Improper connection may cause abnormal heat generation. Therefore, it is necessary that the terminals can be connected easily and surely. Generally, **crimp-style terminals** and **conductors** which have high reliability are connected.

2. 1. 8 Trip button

The trip button is a pushbutton for mechanically tripping the circuit breaker from the outside. A circuit breaker with a trip button can be easily tripped by pressing the trip button without electrical tripping by a voltage trip device (SHT) or under-voltage tripping device (UVT) or overcurrent tripping by application of current higher than the rated current to the circuit breaker. Therefore, it is easy to make sure that the circuit breaker has been reset and the external operation handle has been operated to reset, and, on circuit breakers with accessories, such as alarm switches (AL), the control circuits can be checked easily.

2. 1. 9 Current limiting

A low-tension power circuit generally consists of power supply, resistance and inductance.

When short fault occurs on a circuit and the flowing current increases with time, electromotive force in a direction opposite to the current flowing direction is applied to the inductance.

The electric energy obtained as the product of the counter electromotive force and the flowing current is stored as the **energy in the circuit magnetic field** and will be released next time the current decreases with time. The energy in the magnetic field of this circuit is different from the **joule heat** generated in the resistance. The actions of the inductance to accumulate and release the energy on the electric circuit are similar to the actions of flywheels.

After a flywheel is rotated to accumulate energy, if a force in the opposite direction is applied to the flywheel, it will get a shock. This means that the energy accumulated in the flywheel is released. Electric circuits have two kinds of energy, energy in inductance which is accumulated and released and energy in resistance which is released as heat. To interrupt short circuit current, it is necessary to examine how to release the energy accumulated in the magnetic field of the inductance to the outside and how to reduce the Joule heat generated in the resistance. If the short circuit current increases with time and reaches io in Fig. 2. 12, energy of $\frac{1}{2}$ Lio^2 (L: inductance) is accumulated in the inductance regardless of how the current increases. The generated heat is proportional to $I^2R.t$ (I: RMS value of passing current, t: time, R: resistance). Since the energy and heat are proportional to the squares of current, if the original short circuit current can be reduced by any method before it flows, or if a current-limiting action can be taken upon interruption, the energy generated upon interruption can be reduced, and a large short circuit current can be interrupted even by a small-sized inexpensive circuit breaker. The reduction of short circuit current, or the "**current-limiting**" action, is regarded as one of important factors of circuit breaker performance because of the above reason.

Among Mitsubishi MCCB, the ultra current-limiting circuit breakers, circuit breakers with VJC and circuit breakers using ISTAC breaking technology are capable of current-limiting breaking.

The current-limiting characteristics are shown in Fig. 2. 19 to Fig. 2. 27.

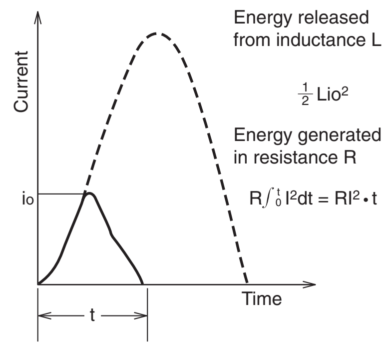


Fig. 2. 12 Current-limiting breaking

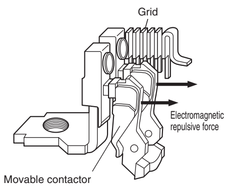
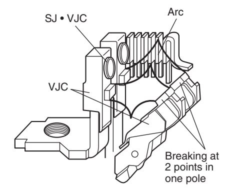
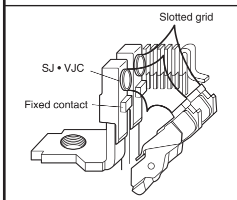
2. 2 Ultra current-limiting circuit breakers (U class)

2. 2. 1 Structure and operation

The ultra current-limiting circuit breakers have remarkably high current-limiting performance, the world's highest class current breaking capacity of 415VAC, 200kA, through connection of the current-limiting units using Mitsubishi unique arc control technology, VJC, to the normal circuit breaker bodies.

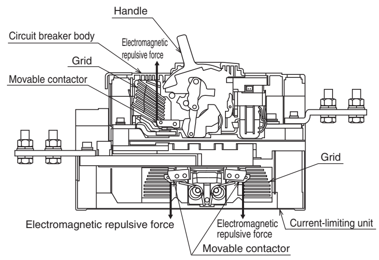
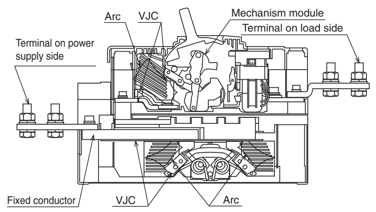
- NF125-UV, NF250-UV

Table 2. 5

Operating principle of current-limiting unit	
	Just after occurrence of shirt circuit current, electromagnetic repulsive force is applied between the conductors, the movable contactor starts to open, and arc is generated.
	The VJC around the contact forcibly diminishes the spot of the generated arc and narrows the arc column. The current-limiting unit has a structure for breaking two points in one pole, and the arc voltage in the current-limiting unit is doubled. Including the contactor of the circuit breaker body, the three serial points are broken in one pole. Therefore, the current-limiting action is remarkably improved. (Triple braking system)
	The arc spot at the fixed contact is transported to the protrusion of SJ-VJC at a high speed, and the arc is cooled by the slotted grid consisting of insulating material sheets located with very narrow gaps. Then, the circuit breaker body performs the tripping action, and the breaking is completed. (SJ-VJC, slot type breaking)

- NF400-UEW, NF800-UEW

Table 2. 6

	Just after occurrence of short circuit current, the movable contactors of the current-limiting unit and circuit breaker body start opening with the aid of the electromagnetic repulsive force between the parallel conductors, and arc is generated. (Electromagnetic repulsive conductor)
	<Repulsion state> The VJC around the contact forcibly diminishes the spot of the generated arc and narrows the arc column. The current-limiting unit has a structure for breaking two serial points in one pole, and the arc voltage in the current-limiting unit is doubled. In addition, the movable contactor in each pole of the circuit breaker body quickly opens independently, and the ultra current-limiting circuit breaker breaks three serial points in one pole. Therefore, the current-limiting action is remarkably improved. (VJC, Triple braking system)

2. 3 Circuit breakers with ISTAC

2. 3. 1 Structure and operation

ISTAC is the abbreviation for Impulsive Slot Type Accelerator. It is a circuit breaking technology for improvement of current-limiting breaking performance by combining with the major circuit breaking technology for Mitsubishi conventional MCCB, VJC (Vapor Jet Control) technology and a new technology using magnetic field. The improved current-limiting performance can minimize the short circuit current, facilitate breaking and reduce the space for arc-extinguishing chamber in the circuit breaker to expand the selective breaking range and improve the cascade breaking performance.

VJC technology

To improve the current-limiting performance, it is necessary to increase the arc voltage at breaking. Mitsubishi unique VJC technology is a method for controlling the arc voltage by covering the areas around contacts with a thick insulating material.

Covering the areas around electrodes with the insulating material can limit:

① the restriction of arc size

② the direction of radiation of high-temperature vapor jet from the electrodes.

As the result of this,

③ the sectional area of arc positive column is reduced.

① Effect of the insulating material

② Since the thick insulating material is located behind the arc leg, the pressure around the arc leg is further increased and the direction of vapor jet generated from the electrodes is limited by the vapor released from the insulating material as the pressure rises.

③ Reduction of arc size ① and limitation of high-temperature vapor radiation direction ② inevitably lead to reduction of the sectional area, and, in addition, the temperature on the outside of the arc is reduced by the vapor generated by the insulating material, thereby further reducing the sectional area of the arc positive column.

The important factors for determination of arc temperature distribution are radiation and expansion cooling based on pressure difference. Therefore, the VJC arc increasing the

pressure in the arc space (particularly in the vicinity of arc leg) and the insulating material vapor having a cooling effect accelerate radiation loss and expansion cooling, thereby increasing the arc energy loss and raising the arc voltage.
Fig. 2. 13 shows the difference in arc size with and without VJC, and Fig. 2. 14 shows the difference in arc voltage.

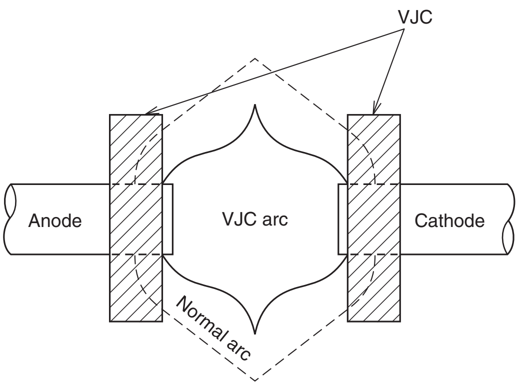


Fig. 2. 13 Difference in arc with and without VJC

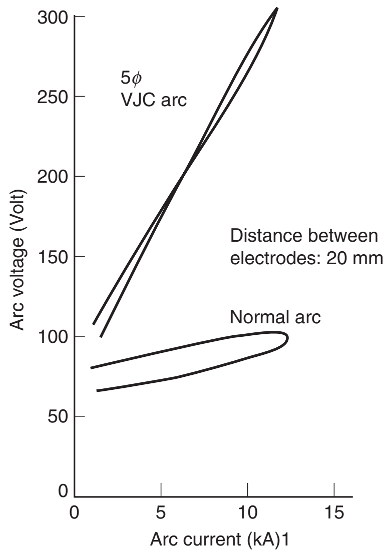


Fig. 2. 14 Difference in arc voltage with and without VJC

ISTAC technology

The ISTAC consists of a mover for accelerating the startup of current-limiting effect for further improvement of current-limiting performance, a high driving force structure for arc and a new insulating material for enhancing the insulation performance at breaking.

ISTAC current paths

If the current-limiting effect occurs sooner at breaking, current limiting is started at lower current, and, as the result of this, the passing current peak value can be reduced. For this purpose, it is important to open the mover earlier at the start of breaking to expand the arc longer. As shown in Fig. 2. 15, according to the fundamental experiment with large current arc, the arc can be expanded by the driving magnetic field only while the current is relatively small. At large current, the electrode vapor jet of arc is intensified, and the magnetic field cannot make the effect. Therefore, the driving magnetic field for expanding the arc is required at the start of opening of the mover before the current becomes large.
When the conventional U-turn stator shown in Fig. 2. 16 is used, the repulsive force caused by current B and current C is applied to the mover, but the attractive force caused by current A and current C is also applied to the mover in the opposite direction. Accordingly, the force for opening the mover is not generated effectively.
On the ISTAC structure, as shown in Fig. 2. 17, all current paths forming the stators at the start of opening are configured in the direction in which the mover and arc are driven. The attractive force generated by current A and current C at the start of opening acts in the direction to open the mover, and also the repulsive force generated by current B and current C acts in the direction for opening the mover. In addition, the arc between the stator and mover of the slot breaking structure explained below generates pressure. These three forces open the mover at a high speed (Fig. 2. 18).

Slot breaking and new insulating material

For ISTAC, the conventional VJC (Vapor Jet Control) technology is used for the stator and mover, and the slot breaking system in which the breaking module is enclosed with the VJC insulating material on the stator side is used. Therefore, the arc resistance is dramatically increased. However, since the area of the VJC insulating material in contact with arc is larger than on the conventional system, the properties of the VJC insulating material significantly affect the breaking performance. For ISTAC, we developed a new VJC insulating material compounded with ceramic fibers and metal hydroxides as fillers based on a nylon resin. The nylon resin is used as the base material because the nylon resin is less carbonized and generates less soot when it gets into contact with arc than the conventional VJC insulating material. The ceramic fibers and metal hydroxides used as the fillers prevent generation of carbides during breaking and improve the insulation restoration just after breaking.

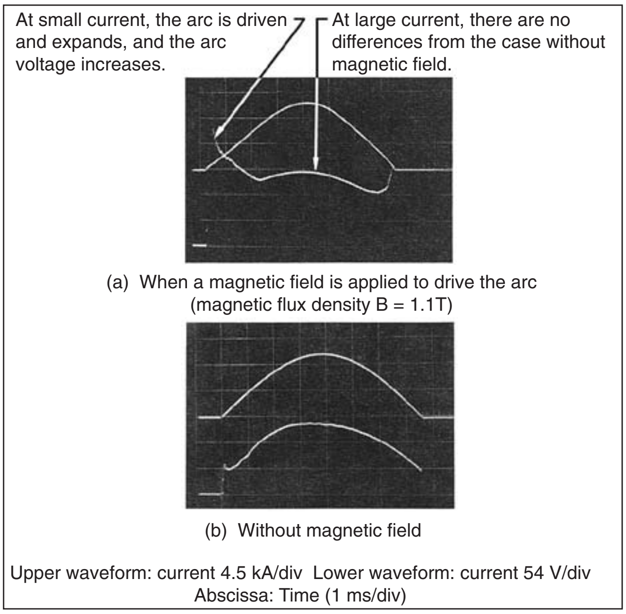


Fig. 2. 15 Current and voltage waveforms with and without magnetic field (Distance between electrodes without VJC in Fig. 2. 13 L = 5 mm)

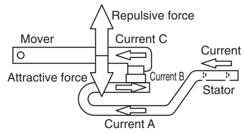


Fig. 2. 16 Conventional system with U-turn stator

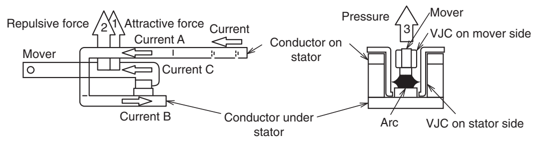


Fig. 2. 17 Structure of ISTAC

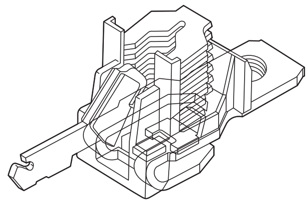


Fig. 2. 18 ISTAC slotted structure

• Current-limiting characteristic diagrams (415 VAC)

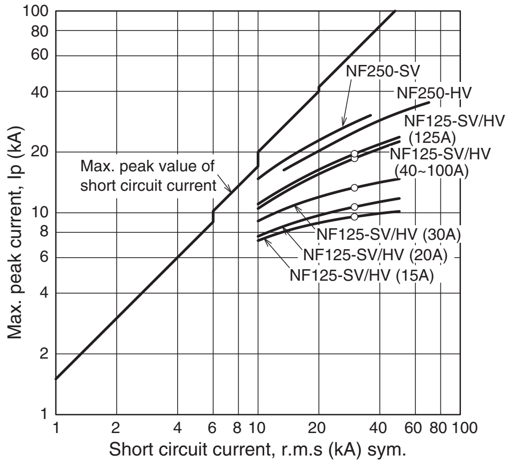


Fig. 2. 19 Passing current peak value characteristics of models NF125-SV/HV and NF250-SV/HV

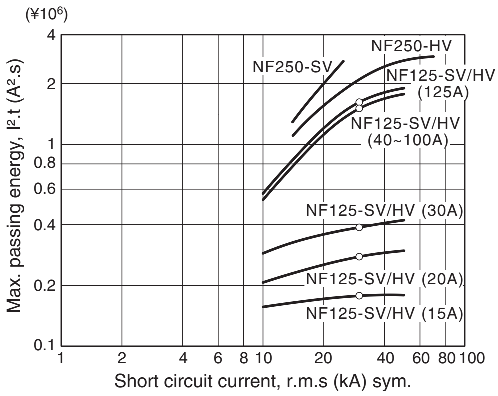


Fig. 2. 20 Passing I².t characteristics of models NF125-SV/HV and NF250-SV/HV

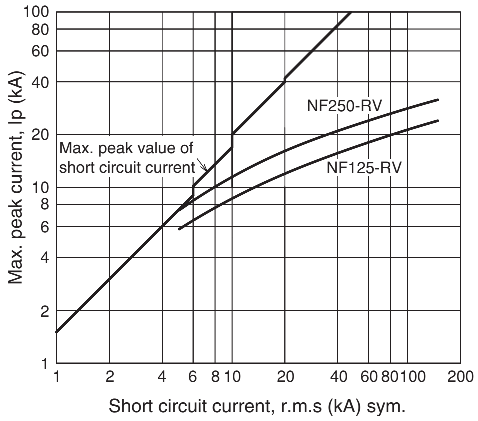


Fig. 2. 21 Passing current peak value characteristics of models NF125-RV and NF250-RV

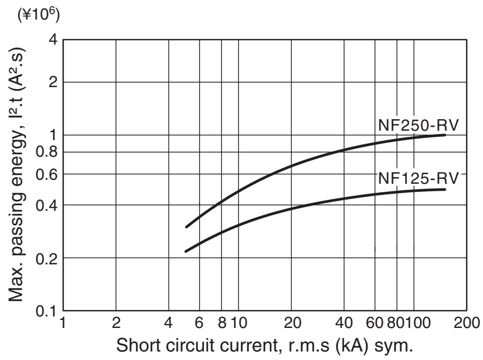


Fig. 2. 22 Passing I².t characteristics of models NF125-RV and NF250-RV

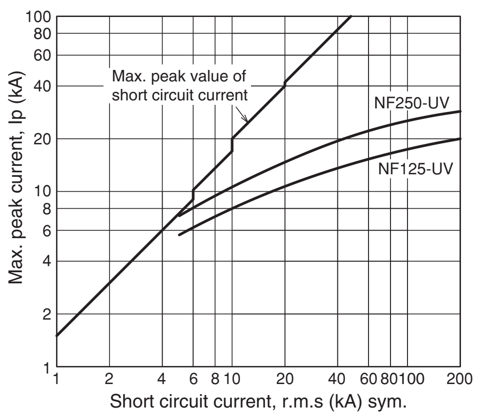


Fig. 2. 23 Passing current peak value characteristics of models NF125-UV and NF250-UV

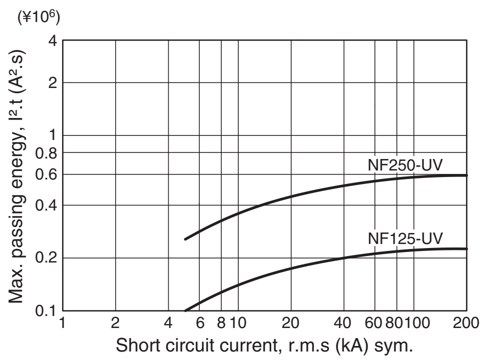


Fig. 2. 24 Passing I².t characteristics of models NF125-UV and NF250-UV

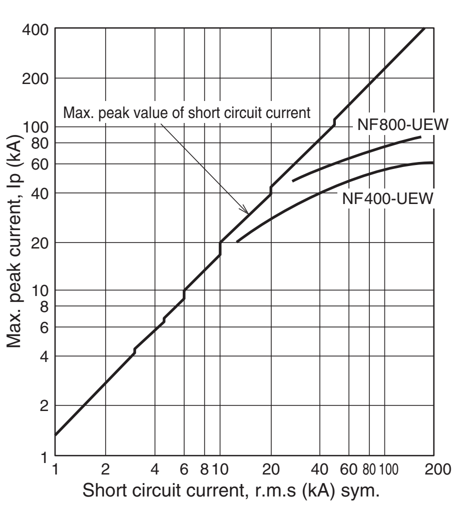


Fig. 2. 25 Passing current peak value characteristics of models NF400-UEW and NF800-UEW

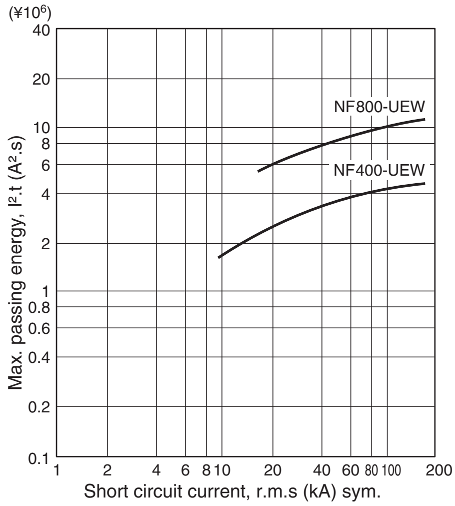


Fig. 2. 26 Passing I².t characteristics of models NF400-UEW and NF800-UEW

2. 4 Electronic circuit breakers

2. 4. 1 Structure and operation

The current flowing to each phase is transformed by CT and full-wave rectified in the rectifier circuit. Analog signals in proportion to the rectified currents are sent to the microcomputer. The analog signals are converted to the digital signals by the A/D converter. The root mean square value is calculated from the signal for each phase. If the obtained value exceeds the specified value, long time delay tripping and pre-alarm characteristic processing are performed.

Then, the trigger circuit outputs a trigger signal to energize the trip coil and trips the make-and-break mechanism. The ETR (Electronic Trip Relay) uses a digital RMS value detection method and prevents deviation of overcurrent tripping characteristics even on a circuit where load current with waveform distorted by electronic device load, such as an inverter, flows to enable high-accuracy protection.

The circuit breakers use a multi-adjustable system with which the six characteristics shown in Table 2. 7 can be individually set, and the flexibility of protection coordination is remarkably improved.

Table 2. 7

Item \ Applicable model	125 to 250A frames	400 to 1600A frames
Rated current: In	●*1	●
Long time delay operating time: TL	○	●
Short time delay tripping current: Is	○	●
Short time delay operating time: Ts	○	●
Instantaneous tripping current: Ii	●	●
Pre-alarm current: Ip	■	●

● : Can be set with the knob on the adjustment module.
○ : Can be set with the portable tester Y-350.
■ : Can be set with the knob on the pre-alarm module in the case of circuit breaker with pre-alarm.
*1 In the case of 100A or less, adjustment functions are not provided (the values are fixed).

Fig. 2. 28 shows the adjustment module for 400 to 1600A frames, and Fig. 2. 29 shows the operating characteristic curves. As shown in Fig. 2. 30, if a multi-adjustable electronic circuit breaker is used, coordination with the power fuse on the high voltage side can be easily achieved, and unnecessary operation caused by inrush current from a load device can be easily avoided.

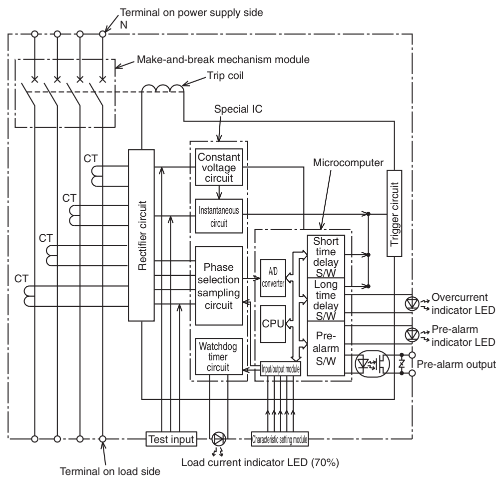


Fig. 2. 27 Circuit diagram of electronic overcurrent trip device

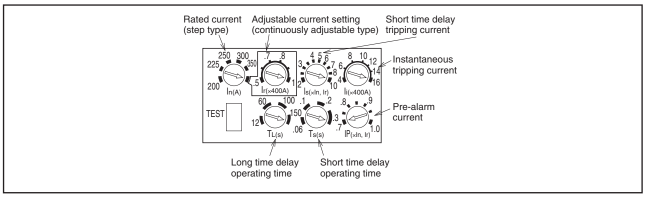


Fig. 2. 28 Adjustment module

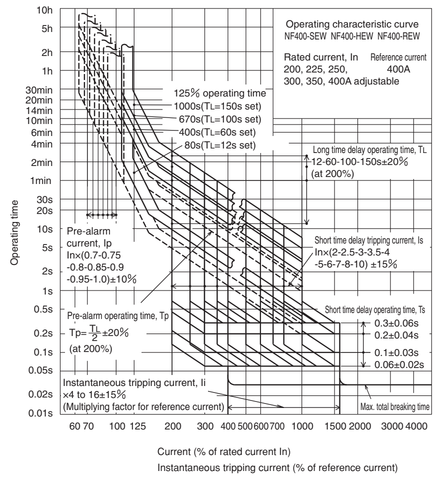


Fig. 2. 29 Example of operating characteristic curves

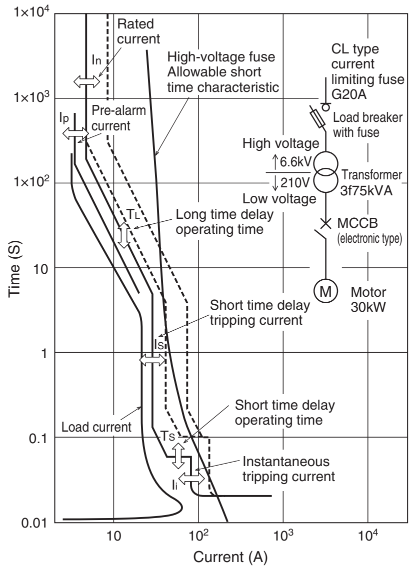


Fig. 2. 30 Overload protection coordination diagram

To facilitate maintenance, MCCB body is provided with an overcurrent indicator LED, and the operating condition can be easily seen. The operating condition is indicated as shown below.

Overcurrent indicator LED “OVER”:

When an overcurrent exceeding approx. 115% of the rated current flows, the red lamp will light up.

Moreover, with the portable tester Y-350 (for 125A to 250A frames) or Y-250 (for 400A to 1600A frames), it is possible to check the operating characteristics of long time delay tripping, short time delay tripping, instantaneous tripping and pre-alarm. Each MCCB has a test terminal. The portable testers Y-350

and Y-250 are sold separately.
The operation test methods are shown below.

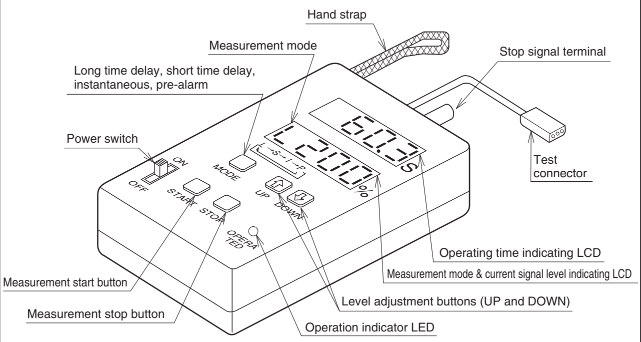


Fig. 2. 31 Appearance of portable tester Y-250

Operation test procedure
Open the test cover of the circuit breaker, and insert the test connector of the portable tester. Do not perform the operation test on any live wire.

Long time delay operation test
Set the measurement mode to the long time delay L, and press the start button. A test signal will occur, and the LCD will display the operating time. The test signal can be set to 30 to 300% of the maximum rated current with the level adjustment button. (On Y-350, it can be set to 30 to 600% of the maximum rated current.)

Short time delay operation test
Set the measurement mode to the short time delay S, and press the start button. Then, the short time delay operating time can be measured.

Instantaneous operation test
Set the measurement mode to the instantaneous I, and press the start button. Then, the instantaneous operating time can be measured.

Pre-alarm operation test
Set the measurement mode to the pre-alarm P, and press the start button. Then, the pre-alarm operating time can be measured. On Y-250, it is necessary to connect the pre-alarm output to the stop signal terminal of the tester.

2. 4. 2 Pre-alarm (PAL)

(1) Structure and operation
To the pre-alarm circuit in the example of the internal connection diagram shown in Fig. 2. 32, a DC voltage signal proportional to the RMS value of load current is applied. When the value is kept higher than the pre-alarm setting for the predetermined time, the output circuit will function to close the pre-alarm output contact. At the same time, the pre-alarm operation indicator LED will light up. The pre-alarm output is a self-holding contact and keeps the operating state until the reset button is pressed or, on some models, the control power is turned off.
This self-holding function enables the user to see the maximum power demand without continuous monitoring by the person in charge of electricity management. The pre-alarm operation display is useful for checking which pre-alarm circuit breaker has output an alarm when the pre-alarm outputs of some pre-alarm circuit breakers are connected in series.
The pre-alarm operation of digital ETR circuit breakers is provided with inverse time delay characteristics to operate the pre-alarm at 1/2 of the long time delay operating time.

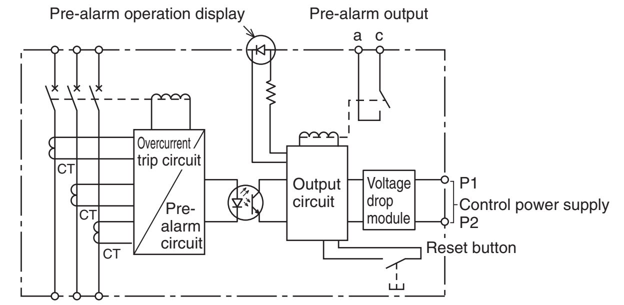
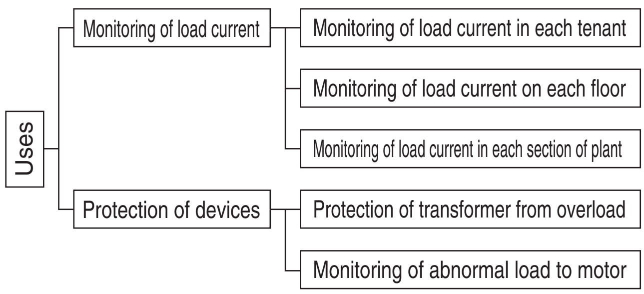


Fig. 2. 32 Example of internal connection diagram of pre-alarm

(2) Uses
The pre-alarm circuit breakers are designed to monitor the load current and protect the load devices as shown below.



2. 5 Measuring display unit breakers (MDU breakers)

2. 5. 1 Structure and operation

The MDU breaker is provided with a measuring display unit (MDU) which measures and digitally displays electric circuit data. The circuit breaker, CT, VT and measuring display unit are combined for wire saving and space saving and to realize monitoring of various electric circuits, energy and load conditions.

(1) Measurement

The measurement items and accuracy of MDU partly differ depending on the series, model and ampere frame.

(a) Operation

As shown in Fig. 2. 33, the current flowing to each phase is transformed by the primary CT and sent to the overcurrent trip circuit and the measuring display unit, MDU, of the electronic MCCB.

The line voltage is converted to a signal proportional to the voltage signal by the resistance, transformed by the CT equivalent to VT and input to the MDU.

The MDU converts the current and voltage signals from the CT and VT to voltage signals and digitalizes the signals in the A/D converter. The CPU calculates the RMS value, demand, electric power, electric energy and high-frequency current.

The measurement items include load current, line voltage, electric power, electric energy and high-frequency current (3rd, 5th, 7th ... 19th and total). Therefore, the MDU facilitates checking of electric circuit conditions and realizes detailed energy control. Table 2. 8 and Table 2. 9 show the items. The voltage, current and electric power are sampled and measured every 0.25s, and the values, such as current values and demand values, are calculated from the measurements. The electric energy is determined by calculating from values sampled every 0.25s. Therefore, when the MDU breaker is used for equipment, such as a resistance welding machine, to which load is applied intermittently, care must be taken.

The electric energy should not be used as data for contract or certification.

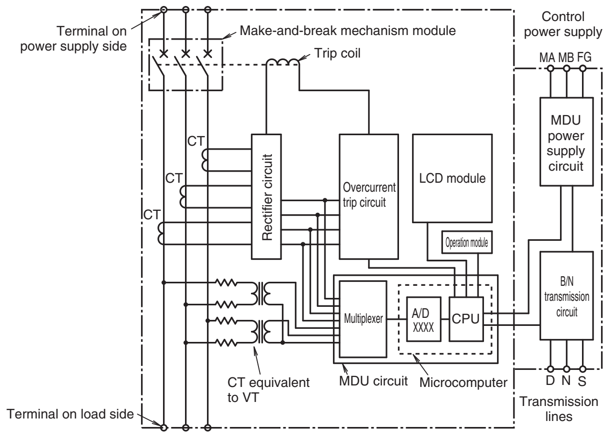


Fig. 2. 33 MDU block diagram

Table 2. 8 List of measurement items (WS-V Series)

Item		Applicable model: NF250-SEV with MDU
Measurement and display	Load current of each phase Accuracy ±1% Current value, demand value and max. demand value	●
	Line voltage Accuracy ±1% Current value and max. value	●
	High-frequency current Accuracy ±2.5% Current value, demand value and max. demand value	●
	Electric power Accuracy ±1.5% Current value, demand value and max. demand value	●
	Reactive power Accuracy ±2.5% Current value, demand value and max. demand value	●
	Electric energy Accuracy ±2%*1 Integrated value, amount for last 1 hour and max. value in 1 hour	●
	32 Reactive energy Accuracy ±3%*2 Integrated value, amount for last 1 hour and max. value in 1 hour	●
	Power factor Accuracy ±5% Current value and max. value	●
	Frequency Accuracy ±2.5% Current value and max. value	●
	Fault current/display of cause of fault	●
	Measured rated current	250 A*3
	Measured rated voltage	440VAC
	Measured max. current value	Twice the measured rated current
	Measured max. voltage value	690VAC
B/NET transmission (Option) *4		
CC-Link communication (Option) *4		
Electric energy pulse output (Option) *4		
MDU control power supply		Common to 100 to 240 V AC/DC, 12 VA

*1 Not for electric power supply and demand based on Measurement Act. ±2% of the true value in the range of voltage (100 V to 440 V) × current (5 to 100% of measured rated current).
*2 ±3% of the true value in the range of voltage (100 V to 440 V) × current (10 to 100% of measured rated current).
*3 125 A in the case of products with low ratings (50, 60, 75, 100 and 125 A).
*4 The B/NET transmission, CC-Link communication and electric energy pulse output cannot be implemented simultaneously..

Table 2. 9 List of measurement items (W & WS Series)

Item		Applicable model: NF250-SW with MDU	NF400-SEP with MDU NF400-HEP with MDU	NF600-SEP with MDU NF600-HEP with MDU	NF800-SEP with MDU NF800-HEP with MDU
Measurement and display	Load current of each phase Accuracy ±2.5% Current value, demand value and max. demand value	●	●	●	●
	Line voltage Accuracy ±2.5% Current value and max. value	●	●	●	●
	High-frequency current Accuracy ±2.5% Current value, demand value and max. demand value	●	●	●	●
	Electric power Accuracy ±2.5% Current value, demand value and max. demand value	●	●	●	●
	Reactive power Accuracy ±2.5% Hourly electric energy and max. hourly electric energy	●	●	●	●
	Power factor Accuracy 5%	●	●	●	●
	Fault current/display of cause of fault	●	●	●	●
	Measured rated current	225 A*2	400 A	600 A	800 A
	Measured rated voltage	440VAC			
	Measured max. current value	Twice the measured rated current			
	Measured max. voltage value	690VAC			
Alarm LED		PAL OVER			
B/NET transmission (Option) *3		○			
CC-Link communication (Option) *3		○			
Electric energy pulse output (Option) *3		○			
MDU control power supply		Common to 100 to 240 V AC/DC, 12 VA			

*1 Not for electric power supply and demand based on Measurement Act. ±2.5% of the true value in the range of voltage (100 V to 440 V) × current (5 to 100% of measured rated current).
*2 125 A in the case of products with low ratings (50, 60, 75, 100 and 100 A).
*3 The B/NET transmission, CC-Link communication and electric energy pulse output cannot be implemented simultaneously..

(b) Measurement accuracy

The accuracies of measurement of current and voltage with MDU are indicated as the percentages of errors to measured rated current and rated voltage. The accuracy of measurement of electric energy is indicated as the percentage of error to the true value of electric energy.

For example, in the case of NF250-SEV with MDU 250A, the current tolerances are determined from the measured rated current, 250 A, as shown below:

250 A × 1% = 2.5 A.

The tolerances in the current range from 0 A to 250 A are ±2.5 A.

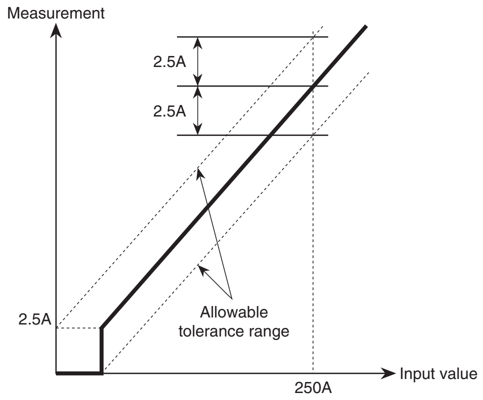


Fig. 2. 34 Measurement accuracy

The demand value is a near mean value in the demand time limit.

The demand time limit (t_0) is time until the input (I) of 95% is displayed as the measurement (I_0) when certain input (I) current is continuously carried. It takes about three times the time limit (t_0) to display the input (I) of 100%. (Fig. 2. 35)

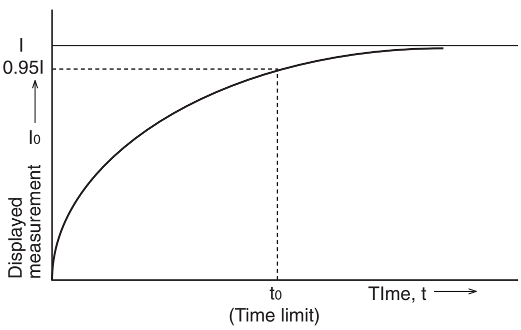


Fig. 2. 35 Demand characteristics

(c) Appearance and installation of MDU

Examples of appearance of MDU are shown in Fig. 2. 36 and 2. 37.

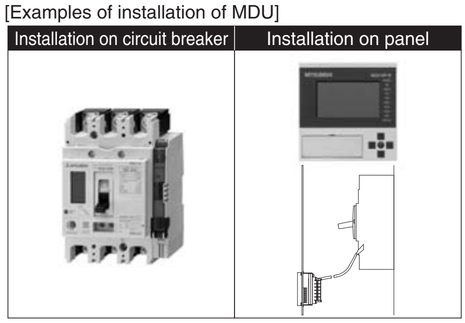
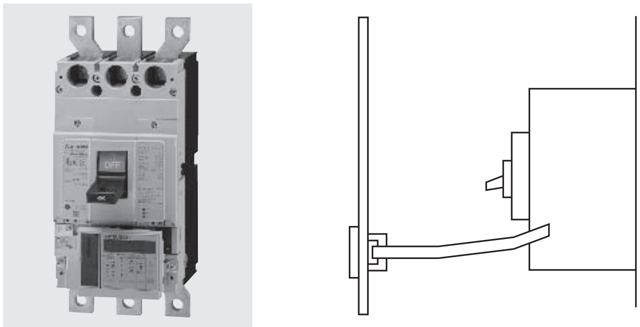


Fig. 2. 36 NF250-SEV with MDU 3P



Appearance Installation on circuit breaker

Appearance Installation on panel

Fig. 2. 37 NF400-SEP with MDU 3P

(2) Maintenance function

To quickly reveal the cause of fault and restore the circuit breaker after tripping, the MDU breaker has a function to measure the fault current that is the cause of fault or the load current upon occurrence of tripping and store the measurement in the nonvolatile memory. In addition, the maximum values of demand current and hourly electric energy are recorded in the nonvolatile memory, so that the condition of electricity use can be easily seen.

(3) Alarm output function

The MDU breaker constantly monitors the load current and, if the load current exceeds the predetermined setting, outputs an alarm.

The function includes the load current pre-alarm (PAL) and overcurrent alarm (OVER).

(4) Communication function

The measured data can be transferred through Mitsubishi wiring control network B/NET (option) or field network CC-Link (option). The unit consumption control data for energy conservation and the electric equipment operation data for preventive maintenance can be automatically collected. The integrated electric energy can be output as pulse output (option). The output can be input directly to the PLC, and the labor for control of electricity use by the PLC can be saved.

2. 5. 2 Withstand voltage test and insulation resistance test

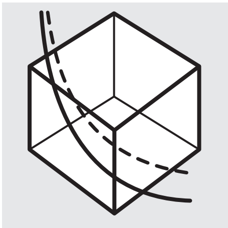
Since a VT is connected between the poles on the load side of the circuit breaker, the withstand voltage between the poles on the load side cannot be measured. (Items marked with × in Table 2. 10)

In the insulation resistance test at 500VDC, lower insulation resistance values are indicated although the circuit breaker is not damaged. (Items marked with △)

The withstand voltage test and insulation resistance test between all main circuits of the circuit breaker and the ground can be performed without any problem.

Table 2. 10 Points of withstand voltage test and insulation resistance test

Measurement point/test			Measurement of insulation resistance		Withstand voltage test	
Position of handle			ON	OFF	ON	OFF
Between live part and ground			○	○	○	○
Between different poles	On power supply side	Between left and center poles	△	○	×	○
		Between center and right poles	△	○	×	○
		Between left and right poles	△	○	×	○
		Between left and neutral poles	△	○	×	○
		Between center and neutral poles	△	○	×	○
		Between right and neutral poles	△	○	×	○
	On load side	Between left and center poles	△	△	×	×
		Between center and right poles	△	△	×	×
		Between left and right poles	△	△	×	×
		Between left and neutral poles	△	△	×	×
		Between center and neutral poles	△	△	×	×
		Between right and neutral poles	△	△	×	×
Between terminal on power supply side and terminal on load side			—	○	—	○



3. Characteristics and Performance

3 Characteristics and Performance

3. 1 Operating characteristics

3. 1. 1 Operating characteristics to overcurrent

MCCB are used originally to protect wiring from overcurrent and short circuit current.
To thermally protect the wiring, MCCB automatically trips the circuit upon occurrence of overcurrent. IEC60947-2 and Mitsubishi company standard specifies an overcurrent tripping characteristic as shown in Table 3. 1

Table 3. 1 Overcurrent tripping characteristics

	Non-operating current	Operating current	Operating time	Test conditions
Annex 1	105% of rated current	130% of rated current	120 min (60 min at rated current of 63 A or less)	105% hot start Simultaneously in all poles
		200% of rated current	Within 2 min (rated current of 30 A or less) Within 4 min (rated current of over 30 A to 50 A) Within 6 min (rated current of over 50 A to 100 A) Within 8 min (rated current of ove100 A to 225 A) Within 10 min (rated current of over 225 A to 400 A) Within 12 min (rated current of over 400 A to 600 A) Within 14 min (rated current of over 600 A to 800 A) Within 16 min (rated current of over 800 A to 1000 A) Within 18 min (rated current of over 1000 A to 1200 A) Within 20 min (rated current of over 1200 A to 1600 A) Within 22 min (rated current of over 1600 A to 2000 A) Within 24 min (rated current exceeding 2000 A)	Cold start In each pole

The operating time to overcurrent has the characteristic (time delay tripping characteristic) of being inversely proportional to the magnitude of overcurrent in a certain range as shown in Fig. 3. 1. The time delay tripping characteristic is called the inverse time tripping characteristic or long time delay tripping characteristic.

The actual tripping characteristics of MCCB vary depending on the manufacturer within the ranges shown in Table 3. 1. However, the tripping time lower limit is restricted by the demand curve determined from the load characteristics. Normally, they include the overshoot of current or mercury lamp starting current on lamp circuits and the motor starting current on power circuits.
Mitsubishi MCCB are designed and adjusted so that the operating characteristics have sufficient allowance for the starting time.

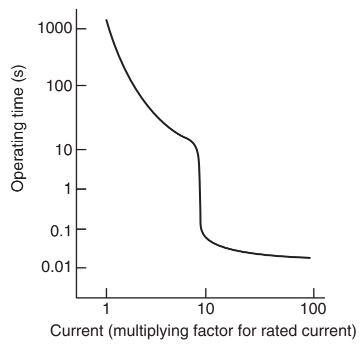


Fig. 3. 1 Example of operating characteristic

3. 1. 2 Influence of ambient temperature on time delay tripping characteristics

(1) Thermal magnetic type

Since the time delay tripping element of thermal circuit breaker uses deflection of bimetal caused by heating, the increase in bimetal temperature necessary for operation is affected by change in ambient temperature, and also the characteristics may change. Fig. 3. 2. 1 shows an example of MCCB temperature correction curve. According to this curve, the test current for obtaining the same operating time as the 200% tripping time at the reference ambient temperature of 40°C is 214% ($200 \times \frac{107}{100}$) at an ambient temperature of 25°C and 190% ($200 \times \frac{95}{100}$) at an ambient temperature of 50°C. The temperature correction curve varies depending on the model and rated current. (The curves are shown in the catalog.)

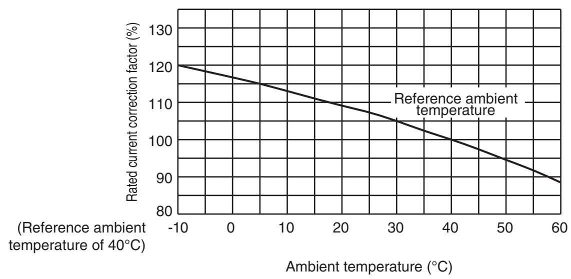


Fig. 3. 2. 1 Example of temperature correction curve

(2) Hydraulic magnetic type

The time delay tripping element uses the viscosity resistance of oil in the oil dash pot. If the oil viscosity changes with ambient temperature, also the oil viscosity resistance changes, and the tripping time is increased or decreased. When an MCCB which has been adjusted at a reference ambient temperature of 40°C is tested at room temperature other than 40°C, the tripping time must be corrected according to the temperature characteristic curve guaranteed for the model.

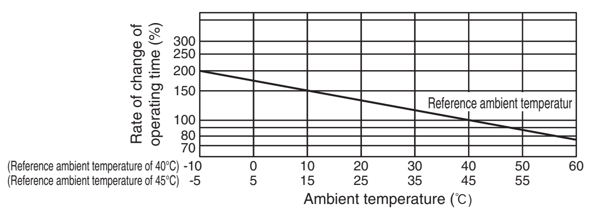


Fig. 3. 2. 2 Example of temperature characteristic curve

3. 1. 3 Reference ambient temperature

The reference ambient temperature of Mitsubishi MCCB is 40°C. This is because it is known that MCCB are used mainly on switchboards and in panels of control centers and the temperatures in the panels are higher than room temperature by about 10K to 15K.

To the contrary, the reference ambient temperature of the wire to be protected is 30°C. Although MCCB reference temperature of 40°C may be regarded as inconsistent from the viewpoint of coordination, it is reasonable that MCCB reference ambient temperature differs from that of the wire as stated above because the wire to be protected is on the outside of the panel while MCCB is in the panel.

3. 1. 4 Hot start operating characteristics

The operating characteristics shown in Table 3. 1 and Fig. 3. 1 show the operating time obtained when energization is started in the state where MCCB is not charged with current (cooled to room temperature). This is called the **cold start operating characteristic**, and the operating characteristic curves contained in the catalogs indicate the cold start operating characteristics unless otherwise specified.

Normally, the overload caused by starting current is examined. Therefore, it is sufficient to examine the cold start operating characteristics. However, for resistance welding machines and motors for intermittent operation, overload may occur when MCCBs have not been sufficiently cooled, and, therefore it may be required to examine the hot start operating characteristics.

The **hot start operation** refers to operation of an MCCB when a specified overload current is carried to MCCB in the state where MCCB is charged with some current. The operating time is shorter than the cold start operation. When the charged current is 75% of the rated current before overload is applied, the operating characteristic is called 75% hot start operating characteristic. The term “hot start operation” refers to 100% hot start operation unless otherwise specified.

However, practically, MCCB are used mainly under 50% or 75% hot start conditions.

Fig. 3. 3 shows examples of hot start operating characteristic curves. The 75% hot start operating characteristic curves for each model are shown in Appendix (p.239).

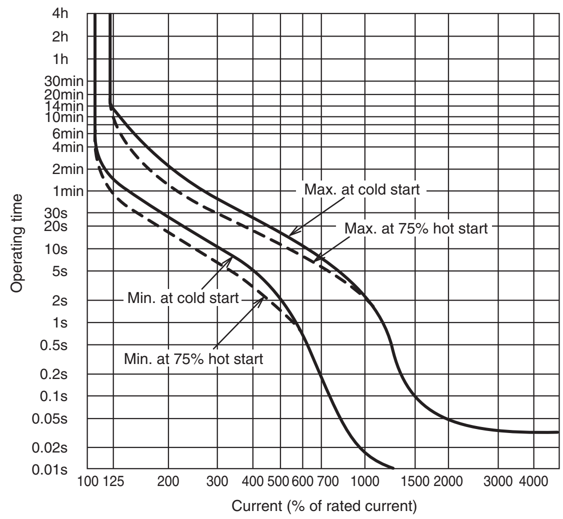


Fig. 3. 3 Examples of hot start operating characteristic curves

3. 1. 5 Instantaneous tripping characteristics

When the magnitude of overcurrent exceeds a certain value, MCCB is instantaneously operated by the electromagnetic tripping element. The current at which the instantaneous tripping operation is started is called the instantaneous tripping current.

In the case of the thermal magnetic tripping method, the instantaneous tripping current value can be set independently from the time delay tripping characteristics, and most of Mitsubishi MCCB have structures in which the instantaneous tripping current is adjustable.

The advantage of this is that protection coordination with other devices can be easily ensured.

For example, to protect an electromagnetic switch against current exceeding the switching capacity of the contact of the electromagnetic switch, it is necessary to set MCCB instantaneous tripping current lower than the switching capacity of the electromagnetic switch. Such setting can be easily performed on the thermal adjustable MCCB. The instantaneous tripping current has an allowance (normally, an allowance equivalent to the rated current), and each MCCB has been adjusted so that it will not operate at the current lower limit and will instantaneously operate at the upper limit. The instantaneous operating time in this case is closely analyzed in Fig. 3. 4.

(1) Relay time (t2-t1)
Time until the tripping latch operates after short circuit occurs
(2) Opening time (t3-t1)
Time until the contact starts to open after short circuit occurs
(3) Arc time (t4-t3)
Time until current to all poles is interrupted from the moment of opening of contact
(4) Total breaking time (t4-t1)
The total breaking time refers to the sum of opening time and arc time. Although the total breaking time somewhat varies depending on MCCB size (frame size), it is 0.5 to 1.0 cycle in most cases.
Particularly, in the case of selective breaking, even if low order branch circuit breakers can break in a time shorter than the total breaking time, the main circuit MCCB may operate after a delay owing to the inertia of the electromagnet and opening time. Therefore, when designing selecting breaking, it is necessary to know the time of restoration of the main circuit MCCB (unlatching time). The approximate values of the time are shown as the relay time averages in Attached Table 1 (p. 240).

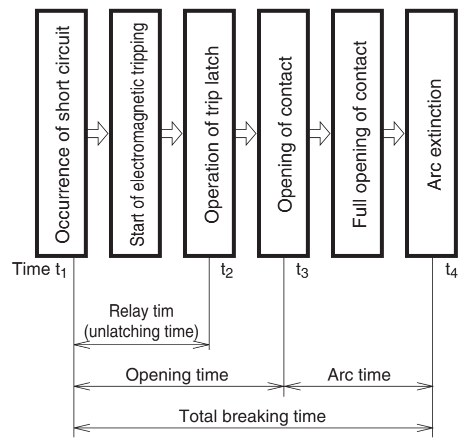


Fig. 3. 4 Instantaneous operation time

3. 2 Changes in operating characteristics

3. 2. 1 Installation posture
The operating characteristics of thermal magnetic type are not affected by the installation posture. However, in the case of hydraulic magnetic type, the operating current values (rated current values) change with the influence of the core weight. Fig. 3. 5 and Fig. 3. 6 show examples. The operating characteristics of Mitsubishi MCCB have been adjusted for installation on vertical surfaces.

3. 2. 2 Connecting method
On MCCB with frame sizes of 1000 A and larger, the instantaneous tripping current is changed by changing the connecting method because the shape of current path is changed.
The degree of change varies depending on the model. Generally, when a MCCB which has been adjusted for front connection is changed to the rear connection, embedded or plug-in type, the instantaneous tripping current will be increased by 1.1 to 1.2 times.
When the connecting method on the power supply side differs from that on the load side, the instantaneous tripping current is determined according to the connecting method on the load side.

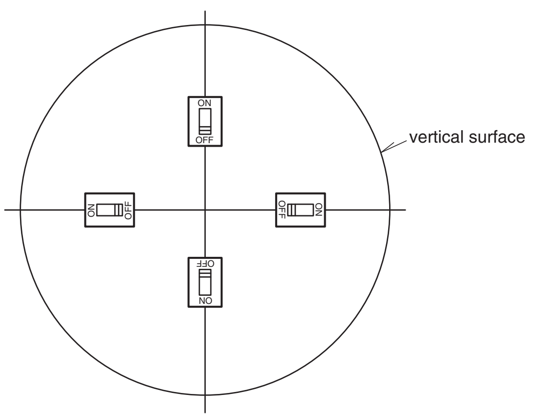


Fig. 3. 5 Installation postures in which the operating characteristics of hydraulic magnetic MCCB can be assured

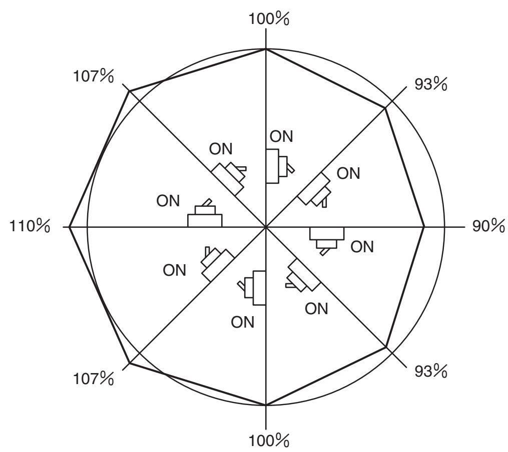
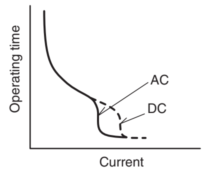
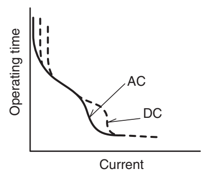


Fig. 3. 6 Changes in rated current due to changes in angle of installation of hydraulic magnetic MCCB

3. 2. 3 Current type (AC or DC)

When the current type is changed between AC and DC, the changes in MCCB operating characteristics vary depending on the tripping method and model. Generally, the differences are estimated as shown in Table 3.2. However, the DC mentioned herein refers to completely smoothed direct current without ripple.

Table 3. 2 Changes in operating characteristics when MCCB for AC is used on DC circuit

Operating characteristics / Tripping method	Time delay tripping characteristics	Instantaneous tripping characteristics	Operating characteristic curve
Thermal magnetic	No change MCCB for AC with frame sizes of 2000 A and larger (bimetal heating with CT) cannot be used on DC circuits.	When the instantaneous tripping current in the case of AC is 100%, that in the case of DC is approx. 130%.	
Hydraulic magnetic	When MCCB for AC is used on a DC circuit, generally, the minimum operating current fluctuates in the range of 110 to 140% of the current on an AC circuit.		

3. 2. 4 Frequency

(1) Characteristics at commercial frequencies

The operating characteristics of Mitsubishi MCCB show almost no changes when the frequency is changed between 50 Hz and 60 Hz.

(2) Characteristics at high frequencies

When using a thermal electromagnetic or electronic type MCCB for a high frequency, take the followings into consideration. Note that hydraulic magnetic type cannot be used for high frequencies.

(a) Thermal magnetic type

① Instantaneous tripping characteristics

At high frequencies, the current carrying capacity and tripping current gradually reduce owing to the conductor skin effect and the influence of iron loss on the structure around the conductor. The rate of reduction somewhat varies depending on the model. At about 400 Hz, on MCCB with the maximum rated current in a frame size, the current reduces to approx. 80% of the rated current, and, on MCCB with the rated current of about 1/2 of the frame capacity, the current reduces to 90% of the rated current.

② Instantaneous tripping current characteristics

Since the instantaneous tripping current is a deexcitation effect caused by eddy current, it rises as the frequency increases. The degree of rise is generally unknown. At about 400 Hz, the current is about twice the value at 60 Hz.

(b) Electronic type

The tripping characteristics are affected by the characteristics of electronic circuit and CT and vary depending on the model. At high frequencies, the tripping current reduces by 10 to 20% on some models and increases on others.

Since heat generation is increased by iron loss, at about 400 Hz, on MCCB with the maximum rated current in a frame size, the continuously applicable current reduces to approx. 80% of the rated current, and, on MCCB with the rated current of about 1/2 of the frame capacity, the current reduces to 90% of the rated current.

(c) Circuit breakers for 400 Hz

These are special circuit breakers adjusted at 400 Hz and have the same characteristics as those of the standard models except the operating characteristics.

3. 3 Connection of power supply and load

To the terminals of general MCCB, the power supply and load are connected by the standard method shown in Fig. 3. 7(a). MCCB except some models can be connected reversely as shown in Fig. 3. 7 (b). However, when using a single-phase three-wire circuit breaker with protection of neutral line open phase, an MDU breaker or a circuit breaker for switchboard/control panel (except model BH), avoid connecting the circuit breaker in the reverse direction because the breaking performance may be degraded. The specification list in the catalog shows whether or not each circuit breaker can be connected reversely.

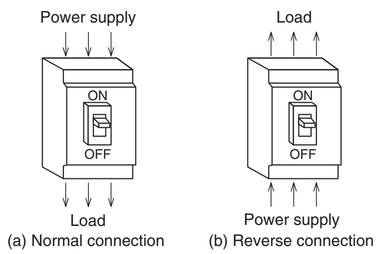


Fig. 3. 7 Connecting methods

3. 4 Operating characteristics depending on special waveforms

3. 4. 1 Operating characteristics affected by higher harmonics on AC circuit

When harmonic components are contained on a 50- or 60-Hz AC circuit due to waveform distortion, the operating characteristics are affected depending on the operation principle as shown in Table 3. 3. 1. When the harmonic content is large and the distortion factor exceeds 100%, avoid using a complete electromagnetic type circuit breaker.

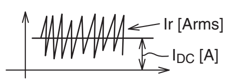
Table 3. 3. 1 Influence of higher harmonics from the viewpoint of operation principle

Type	Operating principle	Influence of higher harmonics on characteristics (comparison with commercial frequency sine wave)		
		Time delay tripping characteristics	Instantaneous tripping characteristics	Temperature rise
Thermal magnetic	Since the bimetal is curved with the aid of the Joule heat generated by the resistance, the characteristics are determined mostly by the generated Joule heat.	Even on a circuit containing higher harmonics to some extent, if the RMS value (Joule heat) is the same, no significant changes occur in the characteristics.	Since electromagnetic force is used, on a circuit containing high frequencies, the characteristics become less distinct owing to the deexcitation current caused by eddy current, and the tripping current becomes higher.	Although heat is generated slightly by the skin effect of conductor, the amount of the heat is negligible, and there is almost no change in temperature rise.
Hydraulic magnetic	An oil dash pot is used to establish the time limit, and the viscosity of the oil in the pipe and the electromagnetic force depending on the ampere turn by the overcurrent coil determine the characteristics.	The characteristics are determined not only by the harmonic content, but also by the waveform. As the frequency rises, the characteristics become less distinct, and the tripping current becomes higher.	Ditto	Since the eddy current loss and hysteresis loss increase with the increase of higher harmonics, the temperature rises.
Electronic	The load current signal is converted to the DC signal equivalent to the RMS value or peak value, and each time limit circuit operates according to the signal value.	Since the signal converted to the RMS value is used, even on a circuit containing higher harmonics, if the RMS value is the same, no significant changes occur in the characteristics.	For short time delay and instantaneous tripping, the signals converted to the peak values are used, and the characteristics vary depending on the peak factor of waveform.	Although heat is generated slightly by the skin effect of conductor, the amount of the heat is negligible, and there is almost no change in temperature rise.

3. 4. 2 Characteristics affected by high-frequency ripple on DC circuit

Direct currents include various currents from completely smoothed direct current to direct current containing a large quantity of high-frequency ripple. Standard circuit breakers for DC circuits are manufactured for completely smoothed direct current. When using such a circuit breaker on a circuit on which direct current containing high-frequency ripple flows, pay attention to the points shown in Table 3. 3. 2.

Table 3. 3. 2 Influence of ripple current from the viewpoint of operation principle

Waveform / Type	Full rectified waveform at 50/60 Hz 	With a large content of high-frequency ripple of 400 Hz or less 
Thermal magnetic	Select MCCB rated current according to the RMS value of load current. The instantaneous tripping current is reduced to approx. 1/1.3.	Select MCCB rated current according to the RMS value of load current. However, MCCB rated current is reduced owing to heat generation caused by iron loss, leave the following margin. $I_{NFB} \geqq 1.4 \times I$ [Arms] ($I = \sqrt{I_{DC}^2 + Ir^2}$ [Arms])
Hydraulic magnetic	Select MCCB rated current according to the RMS value of load current. The instantaneous tripping current is reduced to approx. 1/1.3.	Since heat is generated by iron loss, a circuit breaker selected as shown below can be used only when the ripple content, Ir/IDC, is 0.5 or less. $I_{NFB} \geqq 1.4 \times I$ [Arms]

Note : When the high-frequency ripple frequency exceeds 400 Hz, it is necessary to check the operation of MCCB.

3. 5 Switching performance

Mitsubishi NF are not switches, but circuit breakers. Therefore, their primary duty is to break circuits, and the switching operation is the secondary duty. Normally, on electric power circuits, as a rule, the disconnecting, switching, breaking and protection relay functions must be performed by individual devices. But, on low voltage circuits, these four functions may be performed by MCCB from the viewpoint of economic efficiency. However, for switches, the switching lifetime and switching frequency are critical, and the weight of moving parts and the contact pressure cannot be increased so significantly. On the other hand, MCCB are required to have high arc extinguishing performance and contact pressure, and their switching lifetime and switching frequency are lower than those of switches. Table 3. 2 shows the switching frequencies of MCCB guaranteed by the standard for reference for use as switches.

The trip resistance (electric trip resistance) of an MCCB provided with a voltage trip device or undervoltage trip device to electrically trip MCCB is specified as 10% of the total lifetime by a standard. The trip resistance also in the case of a trip button used for sequence check is 10% of the total lifetime. Since the voltage trip device, undervoltage trip device and trip button are designed as emergency trip devices, note that the use of these devices as regular circuit opening means considerably reduces the life of circuit breaker.

Table 3. 4 Number of times MCCB can make and break (IEC60947-2)

Max. rated current in frame size (A)	Frequency of making and breaking/hr.	Number of times MCCB can make and break (times)		
		Energized	Not energized	Total
100 or less	120	1500	8500	10000
101~315	120	1000	7000	8000
316~630	60	1000	4000	5000
631~2500	20	500	2500	3000
2501~	10	500	1500	2000

3. 6 Short circuit breaking performance

The short circuit breaking performance of MCCB specified in IEC 60947-2 includes the followings.

Abbreviation	Term	Explanation
Icu	Rated limit short circuit breaking capacity	Breaking performance value given at each rated working voltage, and meeting the conditions of operating duty O–3 min–CO
Ics	Rated service short circuit breaking capacity	Breaking performance value given at each rated working voltage, and meeting the conditions of operating duty O–3 min–CO-3 min-CO, ensuring carrying and interruption of rated current after breaking and meeting the condition that the temperature rise is less than the specified value

Operating duty O : Duty to cause the circuit breaker to break when the test circuit is shorted by other making means in the short circuit breaking test where the circuit breaker is closed

Operating duty CO : Duty to cause the test circuit to short and the circuit breaker to break when the circuit breaker is closed in the short circuit breaking test where the circuit breaker is open

It is desirable to replace the circuit breaker with a new one as soon as possible once it breaks the circuit.

3. 7 Insulation performance

3. 7. 1 Withstand voltage performance

The withstand voltage performance includes the followings.

(1) Power-frequency withstand voltage performance

① Voltage application positions

· Circuit breaker ON: Between all live parts and mounting plate and between each pole and all other poles connected on mounting plate

· Circuit breaker OFF/trip: Between all live parts and mounting plate and between all terminals on power supply side and all terminals on load side

② Application time: For 5 seconds

Unit: V

Rated insulation voltage Ui	Test voltage AC RMS value
60 or less	1,000
Over 60 to 300	2,000
Over 300 to 690	2,500

(2) Impulse withstand voltage performance

Apply the test voltage with surge voltage waveform corresponding to the rated impulse withstand voltage.

① Waveform

· Duration of wave front: 1.2 μs

· Duration of wave tail: 50 μs

② Voltage application positions

· Circuit breaker ON: Between all live parts and mounting plate and between each pole and all other poles connected on mounting plate

· Circuit breaker OFF/trip: Between all live parts and mounting plate and between all terminals on power supply side and all terminals on load side

③ Application cycle: 5 times to each of positive and negative poles at intervals of 1 second or more

Mitsubishi MCCB withstand the impulse voltage shown in Table 3. 5.

Unit: kV

Rated impulse withstand voltage Uimp	Test voltage
0.33	0.35
0.5	0.55
0.8	0.91
1.5	1.75
2.5	2.95
4	4.9
6	7.3
8	9.8
12	14.8

Table 3. 5 Impulse withstand voltage of MCCB

Series		Model								Impulse withstand voltage (V)
BH		BH	BH-P	BH-DN	BH-S	BH-PS	BH-D6	BH-D10		7,000
MB		MB30-CS								4,900
MB		NF32-SV	NF63-CV	NF63-SV	NF125-SV	NF250-SV				9,800
NF	S·H	NF32-SV	NF63-SV	NF63-HV						9,800
		NF125-SV	NF125-HV	NF125-SEV	NF125-HEV	NF125-SGV	NF125-LGV	NF125-HGV	NF125-RGV	
		NF160-SGV	NF160-LGV	NF160-HGV	NF160-RGV					
		NF250-SV	NF250-HV	NF250-SEV	NF250-HEV	NF250-SGV	NF250-LGV	NF250-HGV	NF250-RGV	
		NF400-SW	NF400-SEW	NF400-HEW	NF400-REW					
		NF630-SW	NF630-SEW	NF630-HEW	NF630-REW	NF800-SDW	NF800-SEW	NF800-HEW	NF800-REW	
		NF1000-SEW	NF1250-SEW	NF1250-SDW	NF1600-SEW	NF1600-SDW				
	C	NF30-CS								4,900
		NF63-CV	NF125-CV	NF250-CV						9,800
		NF400-CW	NF630-CW	NF800-CEW						
	U	NF125-UV	NF250-UV	NF400-UEW	NF800-UEW					9,800

3. 8 Impedance and power consumption

Table 3. 6 Impedance and power consumption of Mitsubishi MCCB

Model	AC/DC	Rated current (A)	Resistance R (mΩ)	Reactance X (mΩ)	Impedance Z (mΩ)	Power consumption (W)
NF30-CS	AC	3	143.2	93.2	170.7	1.29
		5	39.2	29.4	49.0	0.98
		10	12.3	5.80	13.6	1.23
		15	6	2.98	6.7	1.34
		20	3.3	1.88	3.8	1.32
		30	2.4	0.70	2.5	2.16
NF63-CV	AC/DC	3	180	26.9	182	1.62
		5	98.5	7.69	98.8	2.46
		10	7.0	1.69	7.20	0.70
		15	5.3	1.54	5.52	1.19
		20	4.6	1.37	4.80	1.84
		30	3.8	1.08	3.95	3.42
		40	2.5	0.64	2.58	4.00
		50	1.7	0.46	1.76	4.25
		60	1.5	0.39	1.55	5.40
		63	1.49	0.35	1.53	5.91
NF125-CV	AC/DC	50	1.9	0.56	1.98	4.75
		60	1.5	0.43	1.56	5.40
		75	1.1	0.34	1.15	6.19
		100	0.68	0.27	0.73	6.80
		125	0.62	0.23	0.66	9.69
NF250-CV	AC/DC	100	0.85	0.19	0.87	8.50
		125	0.53	0.15	0.55	8.28
		150	0.48	0.14	0.50	10.8
		175	0.39	0.13	0.41	11.9
		200	0.32	0.11	0.34	12.8
		225	0.29	0.11	0.31	14.7
		250	0.24	0.10	0.26	15.0
NF400-CW	AC/DC	250	0.39	0.43	0.58	24.4
		300	0.26	0.30	0.40	23.4
		350	0.20	0.27	0.34	24.5
		400	0.18	0.22	0.28	28.8
NF600-CW	AC/DC	500	0.13	0.18	0.22	32.5
		600	0.10	0.15	0.18	36.0
		630	0.10	0.15	0.18	39.7
NF800-CEW	AC	800	0.06	0.12	0.13	38.4
NF32-SV	AC/DC	3	180	26.9	182	1.62
		5	98.5	7.69	98.8	2.46
		10	7.0	1.69	7.20	0.70
		15	5.3	1.54	5.52	1.19
		20	4.6	1.37	4.80	1.84
		30	3.8	1.08	3.95	3.42
		32	3.7	1.06	3.85	3.79
NF63-SV	AC/DC	3	259	39.5	262	2.33
		5	130	16.2	131	3.25
NF63-SV NF63-HV	AC/DC	10	7.0	1.69	7.20	0.70
		15	5.3	1.54	5.52	1.19
		20	4.6	1.37	4.80	1.84
		30	3.8	1.08	3.95	3.42
		40	2.5	0.64	2.58	4.00
		50	1.7	0.46	1.76	4.25
		60	1.5	0.39	1.55	5.40
		63	1.49	0.35	1.53	5.91
NF125-SV NF125-HV	AC/DC (HV or AC)	15	16.0	2.54	16.2	3.60
		20	9.0	1.41	9.11	3.60
		30	5.1	1.06	5.21	4.59
		40	2.8	0.79	2.91	4.48
		50	1.9	0.56	1.98	4.75
		60	1.5	0.43	1.56	5.40
		75	1.1	0.34	1.15	6.19
		100	0.68	0.27	0.73	6.80
		125	0.62	0.23	0.66	9.69
NF125-SEV	AC	50	0.23	0.24	0.33	0.58
		60	0.23	0.24	0.33	0.83
		75	0.23	0.24	0.33	1.29
		100	0.23	0.24	0.33	2.30
		125	0.23	0.24	0.33	3.59

Model	AC/DC	Rated current (A)	Resistance R (mΩ)	Reactance X (mΩ)	Impedance Z (mΩ)	Power consumption (W)
NF125-SGV NF125-LGV NF125-HGV	AC/DC	16-20	16.4	2.57	16.6	4.20-6.56
		20-25	11.2	1.50	11.3	4.48-7.00
		25-32	7.41	1.55	7.57	4.63-7.59
		32-40	3.69	1.06	3.84	3.78-5.90
		35-50	2.75	0.79	2.86	3.37-6.88
		45-63	2.14	0.59	2.22	4.33-8.49
		56-80	1.48	0.46	1.55	4.64-9.47
		70-100	1.10	0.43	1.18	5.39-11.0
		90-125	0.89	0.33	0.95	7.21-13.9
NF125-RGV	AC	16-20	17.1	3.22	17.4	4.38-6.84
		20-25	10.3	2.04	10.5	4.12-6.44
		25-32	7.5	1.51	7.65	4.69-7.68
		32-40	4.9	0.95	5.01	5.02-7.84
		40-50	3.5	0.85	3.65	5.60-8.75
		50-63	2.5	0.71	2.6	6.25-9.92
		63-80	1.8	0.54	1.88	7.14-11.5
		80-100	1.2	0.38	1.23	7.68-12.0
		100-125	0.97	0.32	1.02	9.7-15.2
NF160-SGV NF160-LGV NF160-HGV	AC/DC	125-160	0.44	0.17	0.47	6.88-11.3
NF250-SV	AC/DC	100	0.85	0.19	0.87	8.50
NF250-SV NF250-HV	AC/DC	125	0.53	0.15	0.55	8.28
		150	0.48	0.14	0.50	10.8
		175	0.39	0.13	0.41	11.9
		200	0.32	0.11	0.34	12.8
		225	0.29	0.11	0.31	14.7
		250	0.24	0.10	0.26	15.0
NF250-SEV	AC	125-250	0.23	0.24	0.33	14.4
NF250-SGV NF250-LGV NF250-HGV	AC/DC	125-160	0.44	0.17	0.47	6.88-11.3
		140-200	0.40	0.16	0.43	7.84-16.0
		175-250	0.32	0.14	0.35	9.80-20.0
NF250-RGV	AC	125-160	0.9	0.26	0.94	14.1-23.0
		160-200	0.48	0.14	0.50	12.3-19.2
		200-250	0.41	0.12	0.43	16.4-25.6
NF400-SW	AC/DC	250	0.37	0.19	0.42	23.1
		300	0.23	0.16	0.28	20.7
		350	0.19	0.16	0.25	23.3
		400	0.14	0.17	0.22	22.4
NF400-SEW NF400-HEW NF400-REW	AC	400	0.10	0.14	0.17	16.0
NF630-SW	AC/DC	500	0.13	0.18	0.22	32.5
		600	0.10	0.15	0.18	36.0
		630	0.10	0.15	0.18	39.7
NF630-SEW NF630-HEW NF630-REW	AC	630	0.10	0.14	0.17	39.7
NF800-SEW NF800-HEW NF800-REW	AC	800	0.06	0.12	0.13	38.4
NF800-SDW	DC	700	0.07	–	–	34.3
		800	0.07	–	–	44.8
NF1000-SEW	AC	1000	0.035	0.11	0.12	35.0
NF1250-SEW	AC	1250	0.035	0.11	0.12	54.7
NF1250-SDW	DC	1250	0.05	–	–	78.1
NF1600-SEW	AC	1600	0.03	0.11	0.11	76.8
NF1600-SDW	DC	1600	0.03	–	–	76.8

Notes (1) Values per pole on front mounting type (for AC, the values at 50Hz are shown. For NF1600-SEW and above, the values on rear mounting type are shown.)
(2) For 60 Hz, multiply the reactance by 1.2.
(3) There are differences depending on the connecting method and product.
(4) Power consumption per pole when rated current is carried is indicated.

Table 3. 7 Impedance and power consumption of Mitsubishi MCCB and MCB

Model		AC/DC	Rated current (A)	Resistance R (mΩ)	Reactance X (mΩ)	Impedance Z (mΩ)	Power consumption (W)
NF125-UV		AC	15	16.7	2.6	16.9	3.76
			20	9.7	1.5	9.82	3.88
			30	5.8	1.2	5.92	5.22
			40	3.5	0.89	3.61	5.60
			50	2.6	0.66	2.68	6.50
			60	2.2	0.53	2.26	7.92
			75	1.8	0.44	1.85	10.1
			100	1.4	0.37	1.43	13.8
			125	1.3	0.33	1.36	20.6
NF250-UV		AC	125	0.76	0.29	0.81	11.9
			150	0.71	0.28	0.76	16.0
			175	0.62	0.27	0.67	19.0
			200	0.55	0.25	0.61	22.0
			225	0.52	0.25	0.58	26.3
			250	0.47	0.24	0.53	29.4
NF400-UEW		AC	400	0.22	0.37	0.43	35.2
NF800-UEW		AC	800	0.11	0.2	0.23	70.4
BH-P		AC/DC	10	10.95	1.94	11.12	1.095
			15	7.23	1.79	7.31	1.63
			20	5.42	0.99	5.51	2.17
			30	3.34	0.78	3.46	3.01
			40	2.64	0.77	2.75	4.22
			50	2.01	0.67	2.12	5.03
			60	1.5	0.57	1.60	5.4
			75	1.2	0.45	1.28	6.8
			100	0.9	0.35	0.97	9.0
MCB	BH-D6 1P BH-D10 1P	AC	0.5	7041	699	7076	1.76
			1	1699	185	1079	1.70
			1.6	700	67.3	703	1.79
			2	452	42.7	454	1.81
			3	210	17.5	211	1.89
			4	102	11.3	103	1.63
			6	51.8	4.16	52.0	1.87
			10	16.2	1.92	16.4	1.62
			13	12.3	1.33	12.3	2.07
			16	9.06	0.78	9.09	2.32
			20	7.13	0.66	7.16	2.85
			25	4.15	0.31	4.16	2.59
			32	2.88	0.24	2.89	2.95
			40	1.82	0.20	1.83	2.91
			50	1.40	0.17	1.41	3.50
			63	0.99	0.10	1.00	3.93
	BH-DN	AC	6	55.2	1.30	55.2	1.99
			10	16.0	0.95	16.0	1.60
			16	9.50	0.46	9.51	2.43
			20	8.28	0.36	8.29	3.31

Notes (1) Values per pole on front mounting type (for AC, the values at 50Hz are shown.)
(2) For 60 Hz, multiply the reactance by 1.2.
(3) There are differences depending on the connecting method and product.
(4) Power consumption per pole when rated current is carried is indicated.

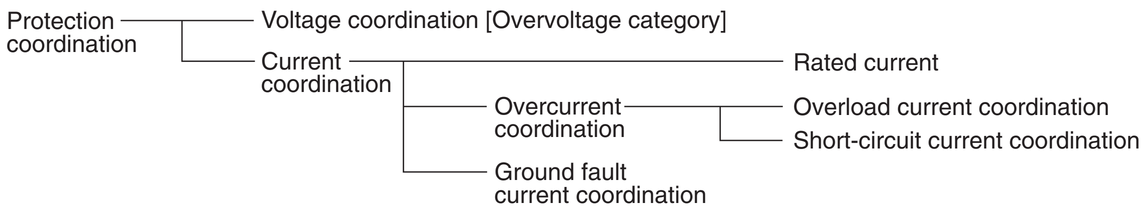
Remark 1J=1W·S

4. Protection Coordination

4 Protection Coordination

4. 1 Concept of protection coordination

An electric circuit has various irregular phenomena including overload, short-circuit, ground fault, overvoltage and undervoltage. These irregular phenomena do not occur frequently, but if sufficient measures are not provided, the damage can be extensive. In addition, spreading of the accident to the upstream system cannot be avoided. Various protective devices are installed on an electric circuit in preparation for the rare accident. However, if these are not selected or used properly, they will not serve as a protective function.
According to the "High-voltage Incoming Facility Policy", Protection Coordination is defined as "the accident circuit must be accurately tripped, and the supply of power continued to healthy circuits past the accident circuit. Adjust the operating characteristics curve of the protective devices to prevent load devices, circuit devices, and breakers from been damaged."
MCCB is used to protect the wiring from burning under an overload or by the short-circuit current. The overload and short-circuit current passing through is interrupted at the installation place so that the spread of the accident can be limited to as small a range as possible. However, it is necessary to use a suitable protection method for the power feed conditions required by the load while taking into consideration matters such as layout of the protective devices and cost efficiency.



4. 2 Selective tripping method

4. 2. 1 Selective tripping method of MCCB

(1) Basics of selective tripping method

The selective tripping method is a protection method with which only the protective device directly related to the accident circuit functions. The other healthy circuits continue power feed. For example in Fig. 4. 1, only MCCB$_2$ functions in reaction to the accident at the S$_2$ point, and the upstream MCCB$_1$ and the MCCB$_3$ for the other branch circuits do not function.
Selective tripping should be used for all overcurrents including the overload and short-circuit. However, in consideration of cost efficiency, measures should be taken to expand the range in which the relation can be retained.

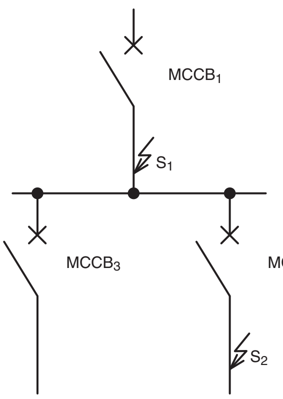


Fig. 4. 1 Selective tripping method

(2) Considering the selective tripping method

Fig. 4. 1 takes a look at using the normal MCCB. The operating characteristics curve of both MCCB$_1$ and MCCB$_2$ are compared. If this relation is as shown in Fig. 4. 2, both do not intersect, so it appears that the selective tripping relation can be retained in all areas. However, since it is confirmed that MCCB$_1$ does not function, a non-operating characteristics curve must be drawn instead of an operating characteristics curve. In other words, the so-called unlatching time (returnable time) of the MCCB$_1$ must be understood.

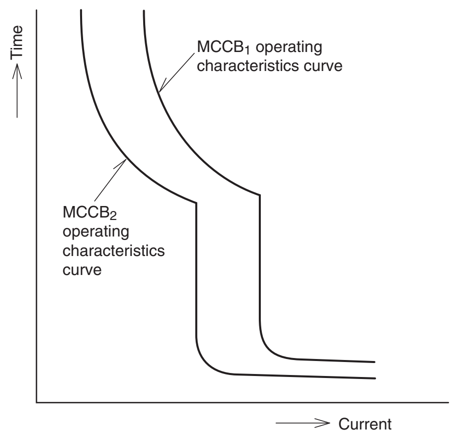


Fig. 4. 2 Operating coordination

The unlatching time refers to the maximum overcurrent passage time that does not result in an operation when a set overcurrent flows to MCCB for a set time. With MCCB, the operating time within the long-time tripping range is long, so the difference between the operating time and the unlatching time can be ignored. However, in the instantaneous tripping range, the tripping time itself is usually 20ms or less and is very short, so the unlatching time cannot be ignored. As shown in Fig. 4. 3, in the instantaneous tripping range of the operating characteristics curve, the unlatching time must be drawn accurately, and must be compared with the branch circuit's MCCB tripping characteristics curve. As stated below, normally T_1 is 20ms or less and depending on the frame size the difference is not great. T_2 is several ms, so $MCCB_1$ and $MCCB_2$ relation is normally as shown in Fig. 4. 4. Both breakers can retain the selective tripping relation only to the cross point of $MCCB_1$ unlatching time and $MCCB_2$ all tripping time. In other words, it is retained only to $MCCB_1$ instantaneous tripping current value I_i.

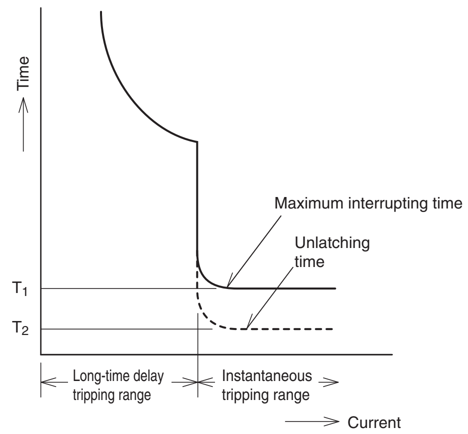


Fig. 4. 3 MCCB unlatching time

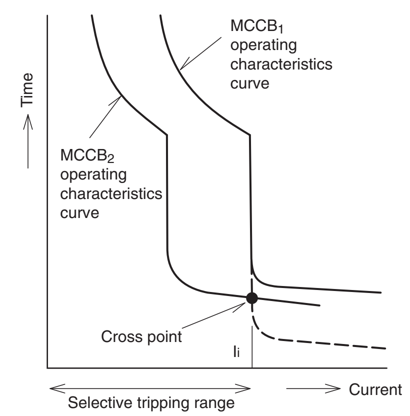


Fig. 4. 4 Selective tripping range for normal MCCB

As explained above, with a main circuit $MCCB_1$ and branch $MCCB_2$ as shown in Fig. 4. 1, the selective tripping range extends to the instantaneous tripping current value for the main circuit $MCCB_1$. However, the S_1 point accident current is considered to the S_2 point's short-circuit current, so the selective tripping function must be retained for the entire range or for all overload currents.

As shown in Fig. 4. 5, to retain the selective tripping relation for the full range, the $MCCB_1$ unlatching time can be extended so that it does no cross with $MCCB_1$ operating characteristics curve. For example, T'_2 could be extended by approx. 30ms. This is the only method available for the MCCB with a short-time delay tripping characteristics.

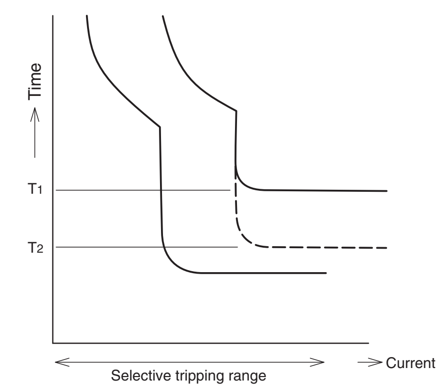


Fig. 4. 5 Selective tripping range for normal MCCB

4. 2. 2 Breaker for protection coordination

(1) Electronic circuit breaker

The electronic circuit breaker has a short-time delay tripping characteristics that can adjust the pickup current as shown in Fig. 4. 6, and is suited for the selective tripping. Since instantaneous tripping is used for large short-circuit currents, the breaking capacity does not drop when the sacrificed high-speed tripping as occurs with the conventional short-time MCCB. The electronic type is equipped with outstanding features as the long-time operating time, short-time operating current, short-time operating time and instantaneous tripping current can be adjusted, so selective tripping can be used in various applications. Fig. 4. 7 shows a photo of the electronic circuit breaker's characteristics setting section. Fig. 4. 8 shows an example of the settings. Fig. 4. 9 shows the coordination relation.

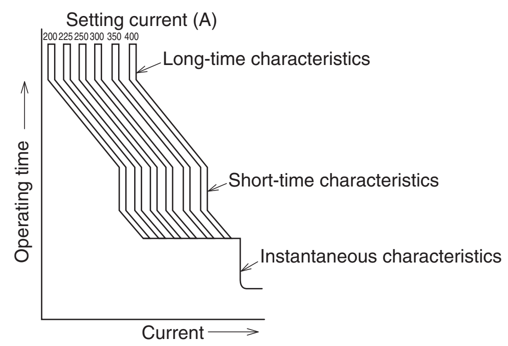


Fig. 4. 6 Electronic MCCB adjustable characteristics

(Example of NF400-SEW)

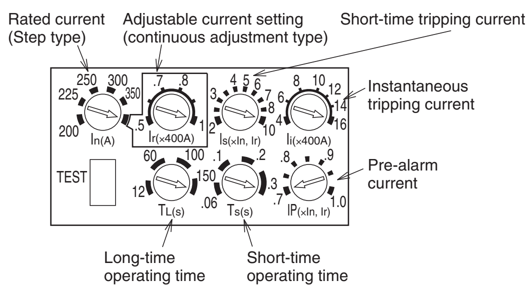


Fig. 4. 7 Electronic type MCCB characteristics setting section

With the circuit configuration shown in Fig. 4. 8, the coordination for operating characteristics is completely attained between the 1st step (NF1600-SEW, 1600A setting), 2nd step (NF630-SEW, 500A setting), and 3rd step (NF250-SV, 150A) as shown in Fig. 4.9. Selective tripping up to 20kA is possible between the 1st and 2nd steps, and up to 10kA between the 2nd and 3rd steps.

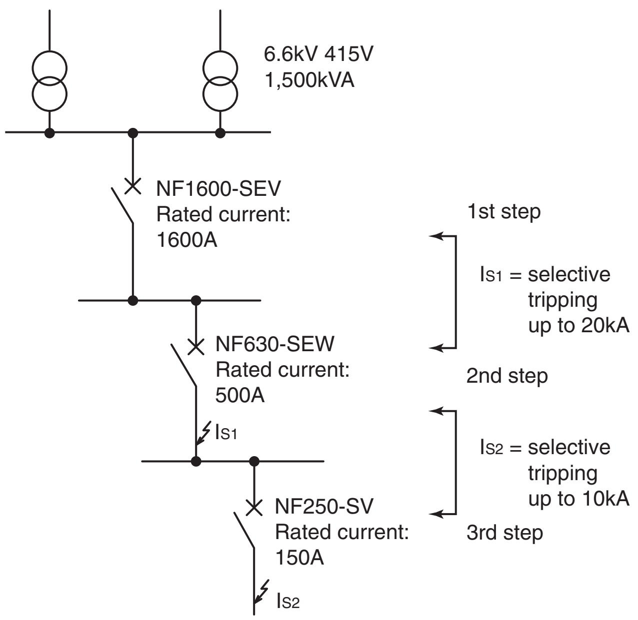


Fig. 4. 8 Example of system

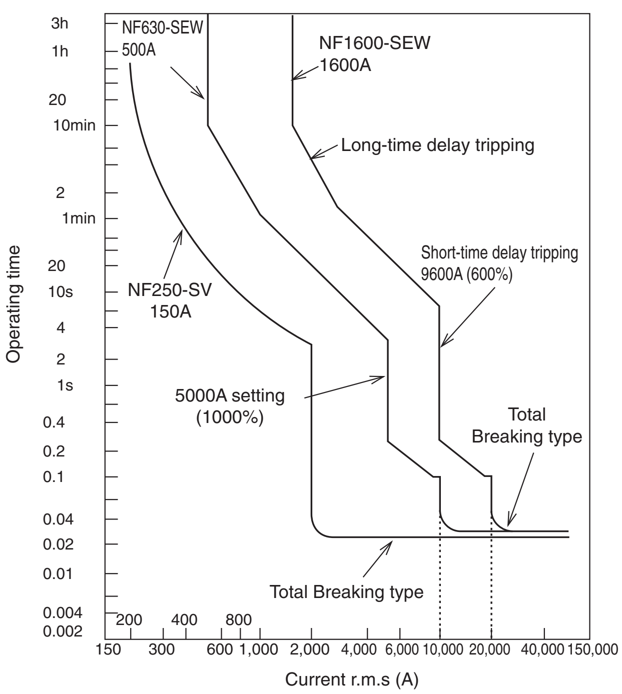


Fig. 4. 9 Coordination characteristics between MCCB using system example (Fig. 4. 8)

(2) Air Circuit Breaker (ACB)

The air circuit breaker (ACB) is mainly used as the trunk breaker of a low-voltage circuit, and is suitable as a protection coordination breaker.

The instantaneous pickup current of the ACB can be set to x16 ± x1 the rated current. If NF1600-SEW in the Fig. 4. 8 system example is exchanged with AE1600-SW as shown in the Fig. 4. 10 system example, the maximum instantaneous pickup current will be 1600A × 15 = 24,000A, and selective tripping up to 24kA is possible between the 1st and 2nd steps.

The selective tripping range can be extended when the ACB is used in this manner as the upstream breaker.

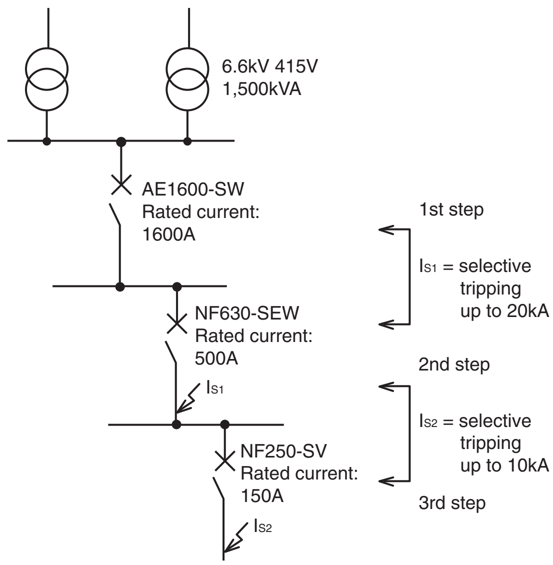


Fig. 4. 10 Example of system

4. 2. 3 Extending the selective tripping range

If the so-called current limiting breaker that limits the short-circuit current that actually flows is used as a branch circuit's MCCB, the trunk line MCCB instantaneous tripping current value will relatively increase, and the selective tripping range is extended.

Consider the case when NF1600-SEW is used for the trunk line and the current limiting breaker NF250-UV and NF250-SV are used as the branch MCCB as shown in Fig. 4. 10.

The instantaneous tripping current of NF1600-SEW is expressed as an active value on the operating characteristics curve, but the actual operation is carried out with the peak-to-peak value.

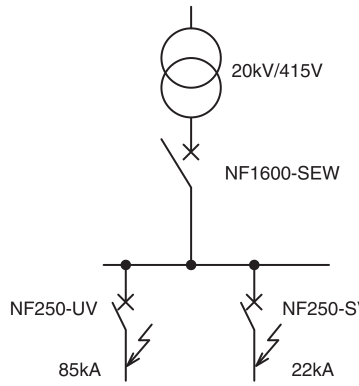


Fig. 4. 11 Case using current limiting breaker for branch circuit

Thus, selectivity is attained if the passing current's maximum peak-to-peak value is $\sqrt{2}$ fold or less of the instantaneous tripping current value.

For example in Fig. 4. 11, the instantaneous tripping current value of the NF1600-SEW is 20kA. Since this value is the symmetric active value so operation will not result unless the passing current's maximum peak-to-peak value exceeds 20 x $\sqrt{2}$ (kA).

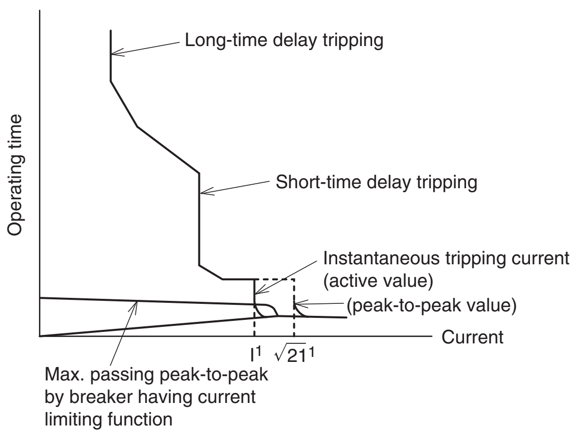


Fig. 4. 12 Current limiting breaker and selective tripping

Take a look at the current limiting breaker NF250-UV.

Even with NF1600-SEW rated breaking capacity 85kA short-circuit current, NF250-UV passing maximum peak-to-peak value does not exceed 20 x $\sqrt{2}$ (kA), so selective tripping is possible up to 85kA (short-circuit current symmetrical value).

On the other hand, when NF250-SV is used as the branch MCCB, the short-circuit current at which selective tripping is possible is 22kA because the current limiting is low. Since this value is a symmetrical value, so asymmetrically the range is up to 25kA. In other words, the selective tripping range varies greatly depending on the type of the branch MCCB. In the actual selective tripping, the current-limited current waveform differs from a sine wave, so the selective tripping range may differ from the value calculated above.

4. 2. 4 Selective tripping combination table

The concept and precautions for the selective tripping MCCB were explained in the previous section. When actually designing the electrical circuit, consider the1se points and use the combination table given in Table 4. 1. Selective tripping is possible to the short-circuit current given for each combination in Table 4. 1.

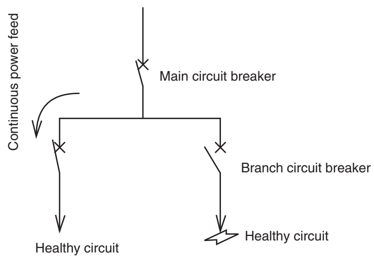


Table 4. 1 Selective tripping combination table

440VAC (IEC 60947-2)

sym.kA

Rated ultimate short-circuit breaking capacity of each breaker	Branch breaker / Main breaker	Icu(kA)	NF125-SEV	NF125-HEV	NF250-SEV	NF250-HEV	NF400-SEW	NF400-HEW	NF630-SEW	NF630-HEW	NF800-CEW	NF800-SEW	NF800-HEW	NF1000-SEW NF1250-SEW	NF1600-SEW
	Icu(kA)		36	65	36	65	42	65	42	65	36	42	65	85	85
NF-S・L・H・NV-S・H	NF32-SV	2.5	1.5	1.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
	NV32-SV	5	1.5	1.5	2.5	2.5	5	5	5	5	5	5	5	5	5
	NF63-SV NV63-SV	7.5	1.5	1.5	2.5	2.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
	NF63-HV NV63-HV	10	1.5	1.5	2.5	2.5	7.5	7.5	10	10	10	10	10	10	10
	NF125-SV NF125-SEV NV125-SV NV125-SEV	25	–	–	2.5	2.5	5	5	10	10	10	10	10	10	22
	NF125-SGV	36	–	–	2.5	2.5	7.5	7.5	15	15	15	15	15	15	36
	NF125-LGV	50	–	–	2.5	2.5	7.5	7.5	15	15	15	15	15	15	42
	NF125-HV NV125-HV	50	–	–	2.5	2.5	7.5	7.5	18	18	18	18	18	18	50
	NF125-HGV	65	–	–	2.5	2.5	7.5	7.5	15	15	15	15	15	15	42
	NF160-SGV	36	–	–	–	–	6.4	6.4	10	10	10	10	10	10	25
	NF160-LGV	50	–	–	–	–	6.4	6.4	10	10	15	15	15	15	25
	NF160-HGV	65	–	–	–	–	6.4	6.4	10	10	15	15	15	15	25
	NF250-SV NF250-SEV NV250-SV NV250-SEV	36	–	–	–	–	–	–	10	10	10	10	10	10	22
	NF250-SGV	36	–	–	–	–	–	–	10	10	10	10	10	10	25
	NF250-LGV	50	–	–	–	–	–	–	10	10	15	15	15	15	25
	NF250-HV NF250-HEV NV250-HV NV250-HEV	65	–	–	–	–	–	–	10	10	10	10	10	10	22
	NF250-HGV	65	–	–	–	–	–	–	10	10	15	15	15	15	25
	NF400-SW NV400-SW	42	–	–	–	–	–	–	–	–	13	13	13	13	20
	NF400-SEW NV400-SEW	42	–	–	–	–	–	–	9.5	9.5	13	13	13	13	20
	NF400-HEW NV400-HEW	65	–	–	–	–	–	–	9.5	9.5	10	10	10	13	20
	NF400-REW NV400-REW	125	–	–	–	–	–	–	9.5	9.5	10	10	10	13	20
	NF630-SW NF630-SEW NV630-SW NV630-SEW	42	–	–	–	–	–	–	–	–	–	–	–	–	20
	NF630-HEW NV630-HEW	65	–	–	–	–	–	–	–	–	–	–	–	–	20
NF-C・NV-C	NF63-CV NV63-CV	2.5	1.5	1.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	7.5	2.5
	NF125-CV NV125-CV	10	–	–	2.5	2.5	5	5	10	10	10	10	10	15	10
	NF250-CV NV250-CV	15	–	–	–	–	–	–	7.5	7.5	7.5	7.5	7.5	7.5	15
	NF400-CW NV400-CW	25	–	–	–	–	–	–	–	–	10	10	10	13	20
	NF630-CW NV630-CW	36	–	–	–	–	–	–	–	–	–	–	–	–	20
NF-R・U	NF125-RGV	125	–	–	2.5	2.5	15	15	30	30	30	42	50	50	85
	NF125-UV	200	–	–	2.5	2.5	15	15	30	30	30	42	50	50	85
	NF250-RGV	125	–	–	–	–	–	–	15	15	15	25	25	25	85
	NF250-UV	200	–	–	–	–	–	–	15	15	15	25	25	25	85
	NF400-UEW	200	–	–	–	–	–	–	9.5	9.5	15	15	15	15	25
	NF800-UEW	200	–	–	–	–	–	–	–	–	–	–	–	–	–

Note (1) Rated currents of branch breakers are 50A or less.

Remarks (1) It is considered that the instantaneous tripping characteristic values of main circuit breakers have been set to the maximum values.

(2) For the selectivity in the overcurrent range, separately check the coordination on the operating characteristic curve.

230VAC (IEC 60947-2)

sym.kA

Rated ultimate short-circuit breaking capacity of each breaker	Branch breaker / Main breaker	Icu(kA)	NF125-SEV	NF125-HEV	NF250-SEV	NF250-HEV	NF400-SEW	NF400-HEW	NF630-SEW	NF630-HEW	NF800-CEW	NF800-SEW	NF800-HEW	NF1000-SEW NF1250-SEW	NF1600-SEW
	Icu(kA)		50	100	85	100	85	100	85	100	50	85	100	125	125
NF-S・L・H・NV-S・H	NF32-SV	7.5	1.5	1.5	2.5	2.5	5	5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
	NV32-SV	10	1.5	1.5	2.5	2.5	10	10	10	10	10	10	10	10	10
	NF63-SV NV63-SV	15	1.5	1.5	2.5	2.5	10	10	10	10	10	10	10	10	10
	NF63-HV NV63-HV	25	1.5	1.5	2.5	2.5	10	10	20	20	25	25	25	25	25
	NF125-SV NF125-SEV NV125-SV NV125-SEV	50	–	–	2.5	2.5	7.5	7.5	15	15	18	18	18	18	50
	NF125-SGV	85	–	–	2.5	2.5	7.5	7.5	15	15	18	18	18	18	85
	NF125-LGV	90	–	–	2.5	2.5	7.5	7.5	15	15	18	18	18	18	85
	NF125-HV NV125-HV	100	–	–	2.5	2.5	10	10	25	25	35	35	35	35	100
	NF125-HGV	100	–	–	2.5	2.5	7.5	7.5	15	15	18	18	18	18	85
	NF160-SGV	85	–	–	–	–	6.4	6.4	10	10	10	10	10	10	50
	NF160-LGV	90	–	–	–	–	6.4	6.4	10	10	10	10	10	10	50
	NF160-HGV	100	–	–	–	–	6.4	6.4	10	10	10	10	10	10	50
	NF250-SV NF250-SEV NV250-SV NV250-SEV	85	–	–	–	–	–	–	10	10	10	10	10	10	50
	NF250-SGV	85	–	–	–	–	–	–	10	10	10	10	10	10	50
	NF250-LGV	90	–	–	–	–	–	–	10	10	10	10	10	10	50
	NF250-HV NF250-HEV NV250-HV NV250-HEV	100	–	–	–	–	–	–	10	10	10	10	10	10	50
	NF250-HGV	100	–	–	–	–	–	–	10	10	10	10	10	10	50
	NF400-SW NV400-SW	85	–	–	–	–	–	–	–	–	13	13	13	13	20
	NF400-SEW NV400-SEW	85	–	–	–	–	–	–	–	–	13	13	13	13	20
	NF400-HEW NV400-HEW	100	–	–	–	–	–	–	–	–	13	13	13	13	20
	NF400-REW NV400-REW	150	–	–	–	–	–	–	9.5	9.5	13	13	13	13	20
	NF630-SW NF630-SEW NV630-SW NV630-SEW	85	–	–	–	–	–	–	–	–	–	–	–	–	20
	NF630-HEW NV630-HEW	100	–	–	–	–	–	–	–	–	–	–	–	–	20
NF-C・NV-C	NF63-CV NV63-CV	7.5	1.5	1.5	2.5	2.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
	NF125-CV NV125-CV	30	–	–	2.5	2.5	7.5	7.5	10	15	15	15	15	15	25
	NF250-CV NV250-CV	36	–	–	–	–	–	–	7.5	7.5	7.5	7.5	7.5	7.5	25
	NF400-CW NV400-CW	50	–	–	–	–	–	–	–	–	13	13	13	13	20
	NF630-CW NV630-CW	50	–	–	–	–	–	–	–	–	–	–	–	–	20
NF-R・U	NF125-RGV	150	–	–	2.5	2.5	22	22	65	65	50	85	85	85	125
	NF125-UV	200	–	–	2.5	2.5	22	22	65	65	50	85	85	85	125
	NF250-RGV	150	–	–	–	–	–	–	–	–	18	50	50	50	125
	NF250-UV	200	–	–	–	–	–	–	–	–	18	50	50	50	125
	NF400-UEW	200	–	–	–	–	–	–	–	–	15	15	15	15	25
	NF800-UEW	200	–	–	–	–	–	–	–	–	–	–	–	–	–
BH	BH-P	2.5	1.5	1.5	2.5	2.5	2.5	–	2.5	–	2.5	2.5	–	2.5	2.5
	BH-D6 TYPE B	6	–	–	–	–	–	–	–	–	–	–	–	–	–
	BH-D6 TYPE C	6	–	–	–	–	–	–	–	–	–	–	–	–	–

4. 3 Cascade breaking method

The primary function of the breaker is to safely interrupt an accident current. The technical standards for electrical equipment state that a breaker with a sufficient breaking capacity for the wiring must be installed. However, there are cases when MCCB breaking capacity can be insufficient when the power packs for the power system increase. In addition, the cost efficiency of the entire system is also an important point. Incorporation of cascade breaking technology between two breakers installed serially to difference positions in the electric circuit is considered.

Cascade Breaking is a method that provides backup protection with the main circuit MCCB or other device when the estimated short-circuit current where the branch circuit's MCCB is installed exceeds the breaking capacity of MCCB in the branch circuit. When breaking, the main circuit MCCB must be released at the same time or faster than the branch circuit MCCB, and an arc must be generated between the contacts to reduce the breaking energy of the branch circuit MCCB.

Basically, when using the cascade breaking method, the selective tripping system is sacrificed and both are not established simultaneously.

Each maker has announced combinations of this cascade tripping method by combining two breakers and data to backup the operation. MCCB wiring path is applied according to this combination. Cascade breaking is also prescribed in Interpretation 37 of the Electrical Installations Technical Standards.

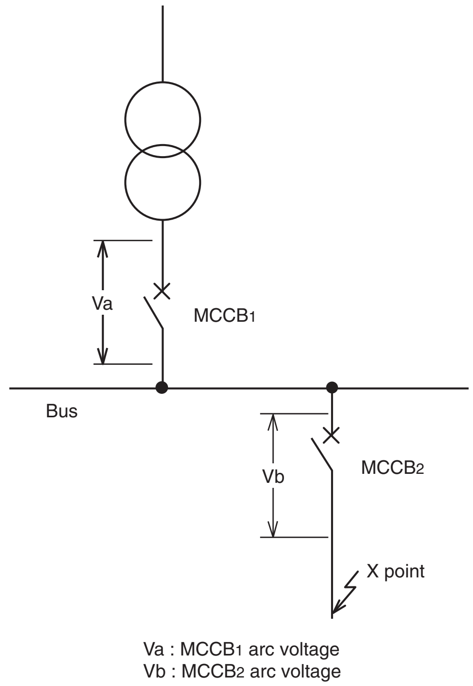


Fig. 4. 13 Cascade Breaking

4. 3. 1 Combination of cascade breaking type breakers

(1) Combination of MCCB units

Focusing on the fact that MCCB opening time is extremely fast, the arc generated at $MCCB_2$ contact and the arc generated at $MCCB_1$ contact are superimposed on the short-circuit current generated at the X point short-circuit accident in Fig. 4. 13. These two cooperate to trip the circuit. This reduction of arc energy applied on the branch $MCCB_2$ is the definition of the cascade breaking method.

The operation that takes place between the two MCCBs for ideal cascade tripping is explained below.

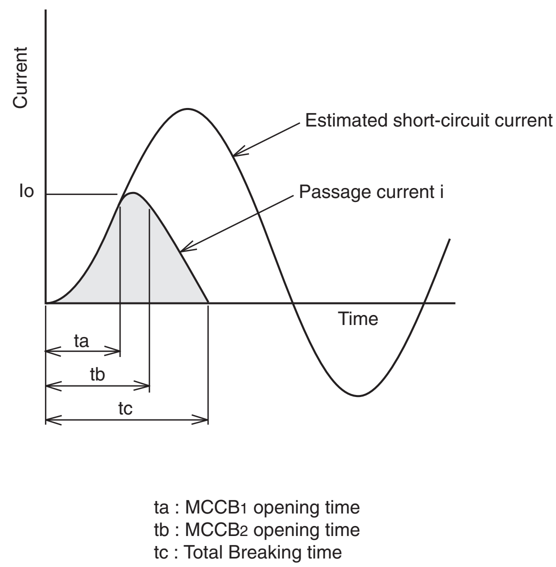


Fig. 4. 14 Cascade Breaking

If a short-circuit current larger than $MCCB_2$ breaking capacity occurs at the X point, $MCCB_1$ opens after ta seconds, and the arc voltage Va occurs. The short-circuit current is limited by this Va, and suppressed to the peak value I_0. Subsequently, $MCCB_2$ opens after tb-ta seconds, and arc voltage Vb is generated. Total breaking is completed after tc-tb seconds, but an arc is generated at both $MCCB_1$ and $MCCB_2$ during that time. When the current for $MCCB_1$ is limited, the arc energy is shared simultaneously to assist $MCCB_2$.

Coordination between the two MCCB units in cascade breaking method refers to this action. $MCCB_1$ must have a current limiting function, and the opening time must be as quick as $MCCB_2$.

MCCB combination for cascade protection is limited to the combinations recommended by the makers. The following conditions must be satisfied for the cascade operation coordination between MCCB units is established.

① The peak current value limited by $MCCB_1$ and $MCCB_2$ must be less than $MCCB_2$'s mechanical strength.

② The maximum passage $I^2 \cdot t$ during the short-circuit current tripping by $MCCB_1$ and $MCCB_2$ must be less than $MCCB_2$'s thermal strength.

③ The intersection with $MCCB_2$ total breaking characteristics curve and $MCCB_1$ opening time must be within $MCCB_2$ breaking capacity.

④ The arc energy ($\int_{tb}^{tc} Vbidt$) generated in $MCCB_2$ must be less than $MCCB_2$ resistance backup and protected by $MCCB_1$.

⑤ $MCCB_1$ must have sufficient breaking capacity by itself in respect to a short-circuit in the bus.

If a short-circuit current exceeding 10,000A is estimated in the branch circuit, it is often economical to use the cascade breaking method. In this case, a breaker with the capability to interrupt a 10,000A or larger short-circuit current is required as the backed up breaker. However, when using two breakers in combination at the same place as one overcurrent breaker, coordination is established between the backup breaker and backed up breaker, and the 10,000A or higher breaking capacity limit does not apply.

The following locations are viewed as the same place:

① Within the same panel board, the same power distribution panel or the line board.

② Within the same cubicle, control center or the line board

③ Within the same electricity room (incoming power room, transformer room)

(2) Combination of fuse and MCCB

There are cases when a fuse is used as MCCB upstream overcurrent breaker for the following purposes:

- The fuse overload range is operated by MCCB so that the fuse does not blow or deteriorate.
- Within the short-circuit range, to provide cascade protection of MCCB in areas where the short-circuit current is extremely large.

The required conditions are as follow within Fig. 4. 15.

① The fuse's tolerable short-time characteristics (a) must not intersect with MCCB characteristics within the overload range.

② The cross point current Ic with the fuse blowing characteristics (b) and MCCB characteristics (d) must be 80% or less of MCCB rated breaking current Is.

③ The fuse's total breaking $I^2 \cdot t$ and passing current peak value ip must be within MCCB tolerable limit.

④ The arc energy generated by the current limited by the fuse and the arc voltage of MCCB that interrupts it must be within the MCCB tolerable limit.

Conditions ① and ② above can be reviewed based on information available in catalogs, etc. However, conditions ③ and ④ cannot be quantitatively reviewed on paper. Thus, in the same manner as cascades between MCCB units, when applying a cascade between the fuse and MCCB, the combinations are limited to those that have actually been tested and verified.

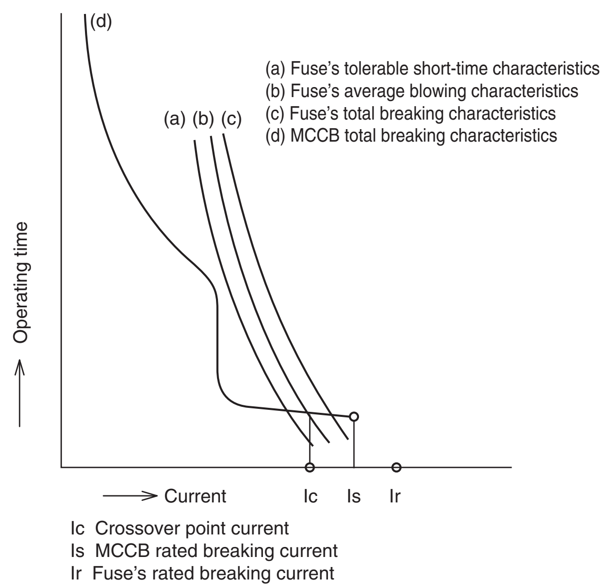


Fig. 4. 15 MCCB and fuse operation coordination

4. 3. 2 Table of cascade breaking capacity

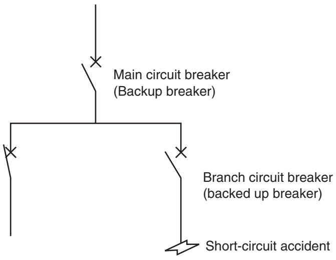


Table 4. 2
440 VAC (IEC 60947-2)

sym.kA

Branch breaker (Rated ultimate short-circuit breaking capacity of each breaker)		Main breaker	NF-S • NV-S • NF-H • NV-H																							NF-C • NV-C				NF-R • NF-U					
			NF125-SV, NV125-SV	NF125-SGV	NF125-LGV	NF125-HV, NV125-HV	NF125-HGV	NF160-SGV	NF160-LGV	NF160-HGV	NF250-SV, NV250-SV	NF250-SGV	NF250-LGV	NF250-HV, NV250-HV	NF250-HGV	NF400-SW, NV400-SW	NF400-HEW, NV400-HEW	NF400-REW, NV400-REW	NF630-SW, NV630-SW	NF630-HEW, NV630-HEW	NF630-REW	NF800-SEW, NV800-SEW	NF800-HEW, NV800-HEW	NF800-REW	NF1000-SEW, NF1250-SEW, NF1600-SEW	NF250-CV, NV250-CV	NF400-CW, NV400-CW	NF630-CW, NV630-CW	NF800-CEW	NF125-RGV, NV125-RGV	NF125-UV	NF250-RGV	NF250-UV	NF400-UEW	NF800-UEW
		Icu(kA)	25	36	50	50	65	36	50	65	36	36	50	65	65	42	65	125	42	65	125	42	65	125	85	15	25	36	36	125	200	125	200	200	200
NF-S • NV-S • NF-L • NF-H • NV-H	NF32-SV	2.5	10	14	14	14	14	5	5	5	5	5	5	5	5	–	–	–	–	–	–	–	–	–	–	5	–	–	–	35	125	35	50	–	–
	NV32-SV	5	14	14	14	14	14	10	10	10	10	10	10	10	10	7.5	7.5	7.5	7.5	7.5	7.5	–	–	–	–	–	–	–	–	50	125	35	50	–	–
	NF63-SV	7.5	14	14	14	20	20	15	15	15	15	15	15	10	15	15	15	15	10	10	10	10	10	10	–	–	10	10	–	50	125	50	50	10	10
	NV63-SV	7.5	14	14	14	20	20	10	10	10	10	10	10	10	10	–	–	–	–	–	–	–	–	–	–	–	10	10	–	50	125	50	50	–	–
	NF63-HV NV63-HV	10	20	30	30	30	30	18	18	18	18	18	18	18	18	15	15	15	14	14	14	–	–	–	–	–	–	–	–	125	125	50	50	–	–
	NF125-SV NV125-SV	25	–	36	36	50	50	36	36	50	–	36	50	42	50	35	35	35	35	35	35	30	35	35	30	–	–	–	–	125	200	125	200	50	35
	NF125-SGV	36	–	–	50	–	50	–	50	50	–	–	50	–	50	–	50	50	–	50	50	–	50	50	–	–	–	–	–	125	200	125	200	50	–
	NF125-LGV	50	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	125	200	125	200	50	–
	NF125-HV NV125-HV	50	–	–	–	–	65	–	–	65	–	–	–	–	65	–	65	65	–	65	65	–	65	65	–	–	–	–	–	125	200	125	200	200	85
	NF125-HGV	65	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	125	200	125	200	200	85
	NF160-SGV	36	–	–	–	–	–	–	–	–	–	–	–	–	–	–	50	50	–	50	50	–	50	50	50	–	–	–	–	–	–	125	200	85	85
	NF160-LGV	50	–	–	–	–	–	–	–	65	–	–	–	–	65	–	65	65	–	65	65	–	65	65	65	–	–	–	–	–	–	125	200	85	85
	NF160-HGV	65	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	125	200	200	200
	NF250-SV NV250-SV	36	–	–	–	–	–	–	–	–	–	–	–	–	–	–	50	50	–	50	50	–	50	50	–	–	–	–	–	–	–	125	200	85	85
	NF250-SGV	36	–	–	–	–	–	–	–	–	–	–	–	–	–	–	50	50	–	50	50	–	50	50	50	–	–	–	–	–	–	125	200	85	85
	NF250-LGV	50	–	–	–	–	–	–	–	–	–	–	–	–	65	–	65	65	–	65	65	–	65	65	–	–	–	–	–	–	–	125	200	200	200
	NF250-HV NV250-HV	65	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	125	200	200	200
	NF250-HGV	65	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	125	200	200	200
	NF400-SW NF400-SEW NV400-SW NV400-SEW	42	–	–	–	–	–	–	–	–	–	–	–	–	–	–	65	65	–	65	65	–	65	65	–	–	–	–	–	–	–	–	–	200	200
	NF630-SW NF630-SEW NV630-SW NV630-SEW	42	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	65	65	–	65	65	–	–	–	–	–	–	–	–	–	–	200
NF-C • NV-C	NF63-CV NV63-CV	2.5	10	14	14	14	14	5	5	5	5	5	5	5	5	–	–	–	–	–	–	–	–	–	–	5	–	–	–	35	125	35	50	5	–
	NF125-CV NV125-CV	10	20	30	30	30	30	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	–	–	14	14	14	125	200	50	125	14	14
	NF250-CV NV250-CV	15	–	–	–	–	–	–	–	–	–	–	–	–	–	30	30	30	–	–	–	–	–	–	–	–	–	–	–	–	–	125	200	50	–
	NF400-CW NV400-CW	25	–	–	–	–	–	–	–	–	–	–	–	–	–	35	35	35	35	35	35	35	35	35	30	–	–	–	–	–	–	–	–	50	50
	NF630-CW NV630-CW	36	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	42	50	50	42	50	50	42	–	–	–	–	–	–	–	–	–	200

Note (1) Rated currents of main breakers are maximum values.

Table 4. 3
230 VAC (IEC 60947-2)

sym.kA

Rated ultimate short-circuit breaking capacity of each breaker	Main breaker / Branch breaker	Icu(kA)	NF-S • NV-S • NF-H • NV-H																							NF-C • NV-C				NF-R • NF-U					
			NF125-SV, NV125-SV	NF125-SGV	NF125-LGV	NF125-HV, NV125-HV	NF125-HGV	NF160-SGV	NF160-LGV	NF160-HGV	NF250-SV, NV250-SV	NF250-SGV	NF250-LGV	NF250-HV, NV250-HV	NF250-HGV	NF400-SW, NV400-SW	NF400-HEW, NV400-HEW	NF400-REW, NV400-REW	NF630-SW, NV630-SW	NF630-HEW, NV630-HEW	NF630-REW	NF800-SEW, NV800-SEW	NF800-HEW, NV800-HEW	NF800-REW	NF1000-SEW, NF1250-SEW, NF1600-SEW	NF250-CV, NV250-CV	NF400-CW, NV400-CW	NF630-CW, NV630-CW	NF800-CEW	NF125-RGV, NV125-RGV	NF125-UV	NF250-RGV	NF250-UV	NF400-UEW	NF800-UEW
		Icu(kA)	50	85	90	100	100	85	90	100	85	85	90	100	100	85	100	150	85	100	150	85	100	150	125	36	50	50	50	150	200	150	200	200	200
NF-S • NV-S • NF-L • NF-H • NV-H	NF32-SV	7.5	42	50	50	50	50	10	10	10	10	10	10	10	10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	125	200	35	50	–	–
	NV32-SV	10	42	50	50	50	50	35	35	35	35	35	35	35	35	14	14	14	14	14	14	–	–	–	–	25	14	14	–	125	200	35	50	–	–
	NF63-SV	15	42	85	85	85	85	35	35	35	35	35	35	35	35	30	30	30	30	30	30	–	–	–	–	25	–	–	–	125	200	85	125	–	–
	NV63-SV	15	42	85	85	85	85	35	35	35	35	35	35	35	35	–	–	–	–	–	–	–	–	–	–	25	–	–	–	125	200	85	125	–	–
	NF63-HV NV63-HV	25	50	85	90	100	100	50	50	50	50	50	50	50	50	50	50	50	50	50	50	–	–	–	–	–	30	30	–	125	200	85	125	–	–
	NF125-SV NV125-SV	50	–	85	90	100	100	85	85	85	–	85	85	85	85	85	85	85	85	85	85	–	–	–	–	–	–	–	–	125	200	125	200	200	125
	NF125-SGV	85	–	–	–	100	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	125	200	125	200	200	125
	NF125-LGV	90	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	125	200	125	200	200	200
	NF125-HV NV125-HV	100	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	125	200	125	200	200	125
	NF125-HGV	100	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	125	200	125	200	200	200
	NF160-SGV	85	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	125	200	200	125
	NF160-LGV	90	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	125	200	200	200
	NF160-HGV	100	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	125	200	200	200
	NF250-SV NV250-SV	85	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	125	200	200	125
	NF250-SGV	85	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	125	200	200	125
	NF250-LGV	90	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	125	200	200	200
	NF250-HV NV250-HV	100	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	125	200	200	200
	NF250-HGV	100	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	125	200	200	200
	NF400-SW NF400-SEW NV400-SW NV400-SEW	85	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	100	–	–	–	–	–	–	–	–	200	200
	NF630-SW NF630-SEW NV630-SW NV630-SEW	85	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	100	–	–	–	–	–	–	–	–	–	200
NF-C • NV-C	NF63-CV NV63-CV	7.5	35	50	50	50	50	10	10	10	10	10	10	10	10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	125	200	35	50	–	–
	NF125-CV NV125-CV	30	35	85	85	85	85	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	–	–	–	–	–	–	–	125	200	85	125	50	–
	NF250-CV NV250-CV	36	–	–	–	–	–	–	–	–	50	50	50	50	50	50	50	50	50	50	50	50	–	–	–	–	–	–	–	–	–	125	200	200	50
	NF400-CW NV400-CW	50	–	–	–	–	–	–	–	–	–	–	–	–	–	85	85	85	85	85	85	85	85	85	85	–	–	–	–	–	–	–	–	200	200
	NF630-CW NV630-CW	50	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	85	85	85	85	85	85	85	–	–	–	–	–	–	–	–	–	200
BH	BH BH-P	2.5	30	42	42	42	42	7.5	7.5	7.5	5	7.5	7.5	7.5	–	–	–	–	–	–	–	–	–	–	–	5	–	–	–	125	200	–	–	–	–

Note (1) Rated currents of main breakers are maximum values.

4. 4 Coordination with wires

4. 4. 1 Protection of wires

MCCB must interrupt the accident current so that the wire temperature rise, caused by the Joule heat generated at the wire in an accident, stays lower than the tolerable value.

The wire's tolerable temperature is determined by the wire's insulation material. This is the limit current that does not degrade the insulation sheath, and is not an isolated value. Even if the wire conductor's temperature increases for a short time, the insulation material will not degrade, and a high temperature can be tolerated. Therefore, the wire's tolerable temperature can be divided into three categories: continuous use, short-time use, and use under short-circuit. Several proposals have been made for the tolerable temperature values for 600V vinyl-insulated wire and 600V rubber-insulated wire, used[*①~④] commonly for low-voltage wiring. However, 60°C for continuous use, 100°C for short-time use, and 150°C for a short-circuit should be acceptable levels.

* ① Indoor wiring regulations (JEAC8001)

② Japan Electrical Manufactures' Association, Wire Overcurrent Investigation Committee "Various characteristics in respect to overcurrent on 600V vinyl wire and 600V rubber-insulated wire" (Institute of Electrical Engineers of Japan Journal Edition 74-791)

③ AIEE Transaction RW Jones, JA Scott "Short time current ratings for aircraft wire and cable"

④ Institute of Electrical Engineers of Japan, Electric Standards Investigating Committee Standards "Tolerable current for 2-cotton insulated wire, 600V rubber-insulated wire, and 600V vinyl-insulated wire" (JEC-135)

4. 4. 2 Continuous use range

In the continuous and overload ranges, the wire conductor temperature is determined by the heat dissipation. Thus, the wire's tolerable current cannot be easily calculated like the short-circuit range. Regarding the use of 600V vinyl-insulated wires and 600V rubber-insulated wires for continuous use, Table 4. 4 shows the wire's tolerable current set forth in the Electrical Installations Technical Standards Interpretation 172 in which the tolerable temperature of the conductor is 60°C (when the ambient temperature is 30°C, the conductor's temperature rise value is 30°C). When the conductor's tolerable temperature is higher than the vinyl wire, such as with a 600V 2-type vinyl-insulated wire (conductor tolerable temperature 75°C) and polyethylene-insulated wire (conductor tolerable temperature 75°C), and cross-linked polyethylene-insulated wire (conductor tolerable temperature 90°C), etc., the values given in Table 4. 5 are compensated by multiplying with the values given in Table 4. 4. Furthermore, with wires laid in a conduit (metal or insulated pipe) are insulated, so the heat dissipation drops and the tolerable current drops. In this case, the above value is multiplied with the coefficient given in Table 4. 6.

Thus, the rated current of MCCB that is supposed to protect these wires must be smaller than the tolerable wire current determined by the above method.

Table 4. 4 Insulation wire's tolerable current Insulation

Conductor			Tolerable current (A)		
			Hard-drawn copper wire or annealed copper wire	Hard-drawn aluminum wire, semi hard-drawn aluminum wire, annealed aluminum wire	Type A aluminum alloy wire or high strength aluminum alloy wire
Single wire (diameter mm)	1.0 or more	Lesss than 1.2	16	12	12
	1.2 or more	Lesss than 1.6	19	15	14
	1.6 or more	Lesss than 2.0	27	21	19
	2.0 or more	Lesss than 2.6	35	27	25
	2.6 or more	Lesss than 3.2	48	37	35
	3.2 or more	Lesss than 4.0	62	48	45
	4.0 or more	Lesss than 5.0	81	63	58
	5.0 or more		107	83	77
Formed single wire and stranded wire (Nominal cross-section mm^2)	0.9 or more	Lesss than 1.25	17	13	12
	1.25 or more	Lesss than 2	19	15	14
	2 or more	Lesss than 3.5	27	21	19
	3.5 or more	Lesss than 5.5	37	29	27
	5.5 or more	Lesss than 8	49	38	35
	8 or more	Lesss than 14	61	48	44
	14 or more	Lesss than 22	88	69	63
	22 or more	Lesss than 30	115	90	83
	30 or more	Lesss than 38	139	108	100
	38 or more	Lesss than 50	162	126	117
	50 or more	Lesss than 60	190	148	137
	60 or more	Lesss than 80	217	169	156
	80 or more	Lesss than 100	257	200	185
	100 or more	Lesss than 125	298	232	215
	125 or more	Lesss than 150	344	268	248
	150 or more	Lesss than 200	395	308	284
	200 or more	Lesss than 250	469	366	338
	250 or more	Lesss than 325	556	434	400
	325 or more	Lesss than 400	650	507	468
	400 or more	Lesss than 500	745	581	536
	500 or more	Lesss than 600	842	657	606
	600 or more	Lesss than 800	930	745	690
	800 or more	Lesss than 1,000	1080	875	820
	1,000		1260	1040	980

Table 4. 5 Tolerable current compensation coefficient

Types of insulator materials	Tolerable current compensation coefficient	
	Ambient temperature 30°C or less	Ambient temperature (θ) 30°C or higher
Vinyl mixture (excluding heat resistant mixtures) and natural rubber mixture	1.00	$\sqrt{\frac{60-\theta}{30}}$
Vinyl mixture (limited to heat resistant mixtures), polyethylene mixture (excluding cross-linked types), and styrene butadiene rubber mixture	1.22	$\sqrt{\frac{75-\theta}{30}}$
Fluororesin mixture	1.27	$0.9\sqrt{\frac{90-\theta}{30}}$
Ethylene propylene rubber mixture	1.29	$\sqrt{\frac{80-\theta}{30}}$
Polyethylene mixture (limited to cross-linked mixtures) and silica rubber mixture	1.41	$\sqrt{\frac{90-\theta}{30}}$
Fluororesin mixture (Note)	2.15	$0.9\sqrt{\frac{200-\theta}{30}}$
Silica rubber mixture (Note)	2.24	$\sqrt{\frac{180-\theta}{30}}$

(Note) When other structural materials will not be affected by the temperature rise of the wire, the sheath encasing it, conduit or duct, etc., resulting from energizing, and

Table 4. 6 Compensation coefficient according to conduit

Number of wires in same conduit	Current compensation coefficient
3 or less	0.70
4	0.63
5 or 6	0.56
7 to 15	0.49
16 to 40	0.43
41 to 60	0.39
61 or more	0.34

4. 4. 3 Short-time use range (overload range)

For the actual time of the short-time range where the conductor tolerable temperature is tolerated to 100°C (for vinyl or rubber-insulated wire), *① above suggested several hours and *③ suggested 20s or more. However, it can be said that it is about the same as MCCB long-time delay tripping time.

Fig. 4. 16 shows the current time characteristics for a 600V vinyl-insulated wire having a wire ambient temperature of 30°C, which starts with a no-load state, and which has a conductor temperature of 100°C. Fig. 4. 19 to Fig. 4. 22 show the coordination of these current time characteristics and MCCB operating characteristics curve (maximum tripping characteristics curve for each rated current). The figure shows when current time characteristics of the wire is higher than that of MCCB, the wire is protected.

Since Fig. 4. 19 to Fig. 4. 22 show the insulated case, the allowance within the short time range may be too much for wires placed in a conduit. However, the wire current time characteristics curve shown in Fig. 4. 17 obtained using the previous Table 4. 6 compensation coefficient is compared with MCCB.

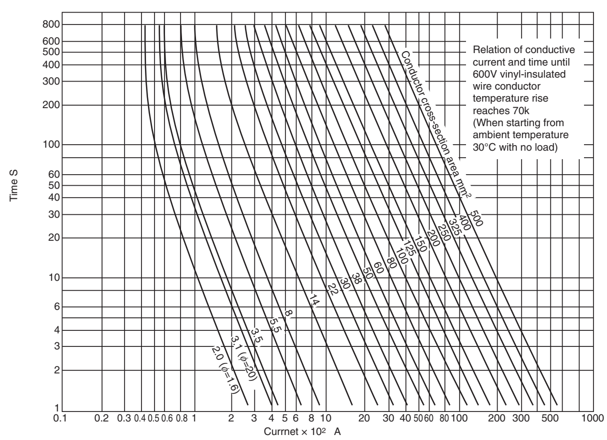


Fig. 4. 16 Current time characteristics for 600V vinyl-insulated wire conductor temperature 100°C to reach rise value 70K

When studying this wire and MCCB, MCCB operating characteristics curve use the reference ambient temperature 40°C and the wire's current time characteristics use the ambient temperature 30°C. Normally, MCCB is installed in a panel to protect the wires outside of the panel, so there is no contradiction in comparing in this state.

Fig. 4. 18 shows the relation of the wires that can be protected and MCCB rated current, as seen with Fig. 4. 19 to Fig. 4. 22.

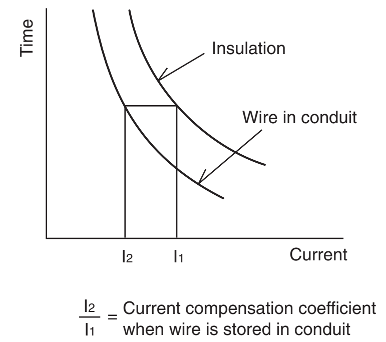


Fig. 4. 17 Compensation according to conduit

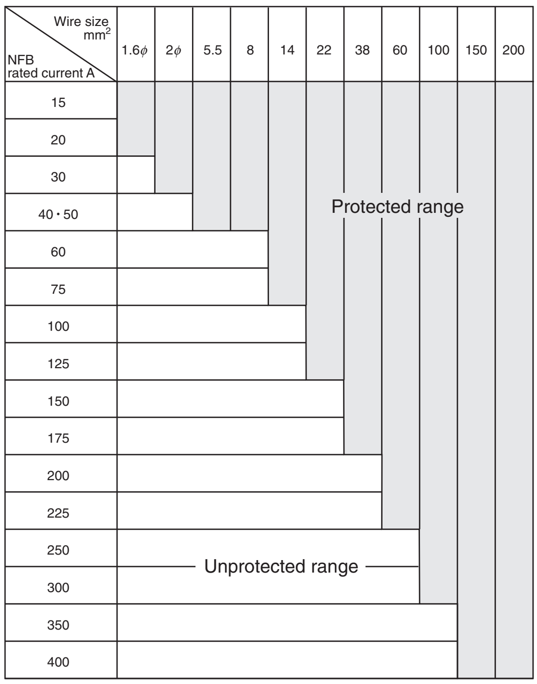


Fig. 4. 18 Coordination of 600V vinyl-insulated wire and MCCB

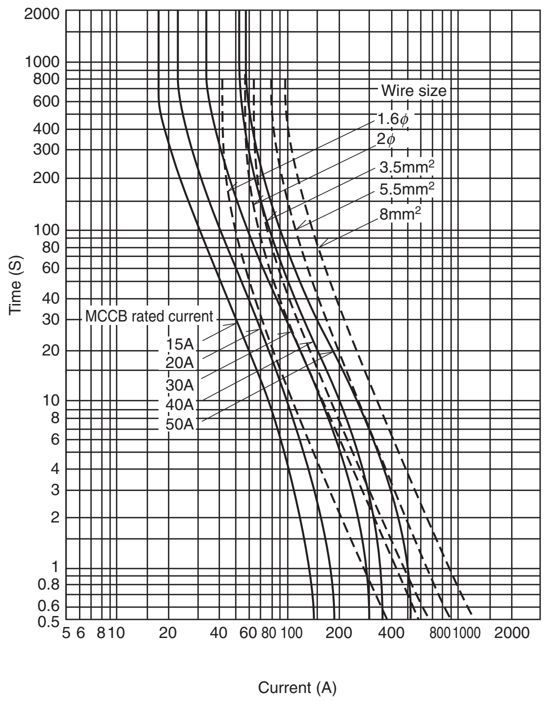


Fig. 4. 19 Coordination of 600V vinyl-insulated wire and MCCB 50A frame

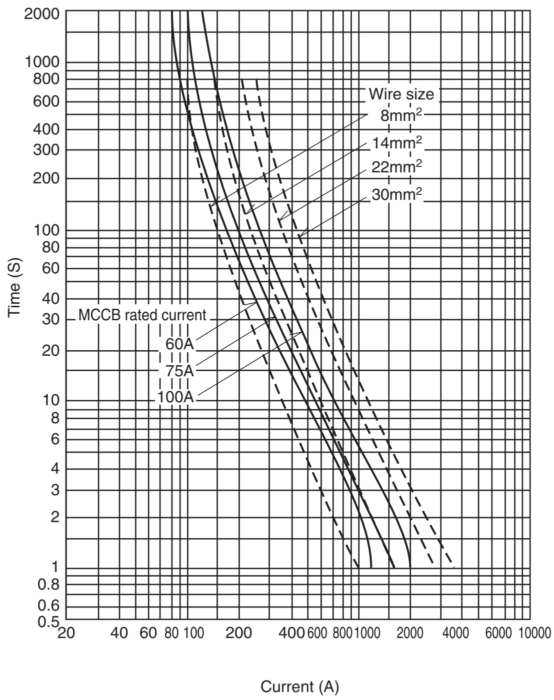


Fig. 4. 20 Coordination of 600V vinyl-insulated wire and MCCB 100A frame

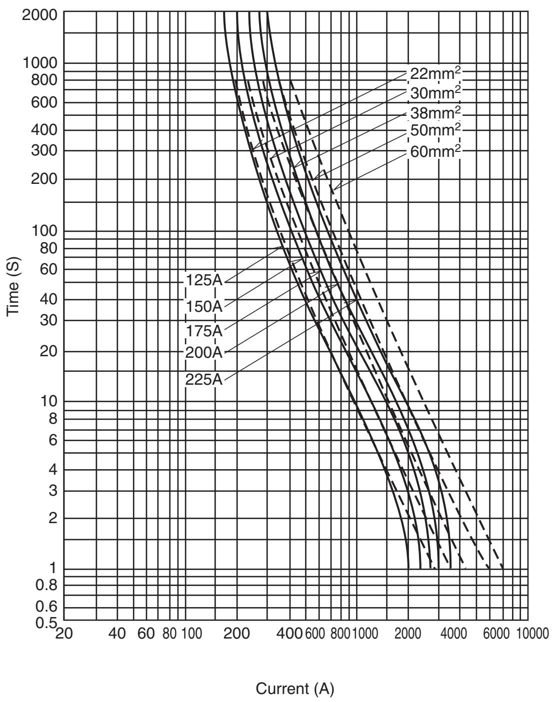


Fig. 4. 21 Coordination of 600V vinyl-insulated wire and MCCB 225A frame

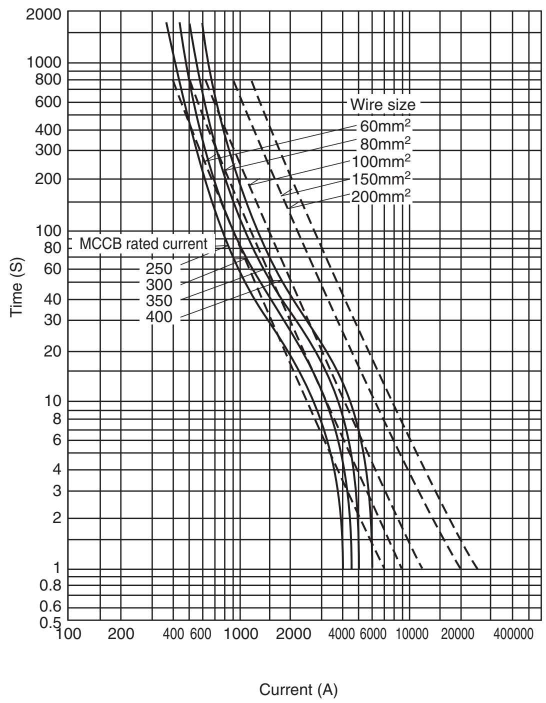


Fig. 4. 22 Coordination of 600V vinyl-insulated wire and MCCB 400A frame

4. 4. 4 Short-circuit range

(1) Thermal capacity

When a large current flows on a wire for a short time (JIS C 0364-4-43: 5s or less), the following formula can be established assuming that all of the generated heat is accumulated in the conductor. (When conductor is copper)

$$\left(\frac{I}{S}\right)^2 \cdot t = 5.05\times10^4 \log_e \frac{234+T}{234+T_0}$$

- I : Short-circuit current active value
- S : Wire cross-section area (mm^2)
- t : Short-circuit current passage time (s)
- T : Conductor temperature at short-circuit (°C)
- T_0 : Conductor temperature before short-circuit (°C)

The relation of this formula is shown in Fig. 4. 23.

It is assumed that the short-circuit occurred when the wire was passing the tolerable current (T_0 = 60°C). If the temperature that can be tolerated as the short-circuit conductor temperature T is 150°C, then based on Fig. 4. 23

$I^2 t = 14000S^2$

The tolerable I^2 t calculated with the above formula is shown in Table 4. 8.

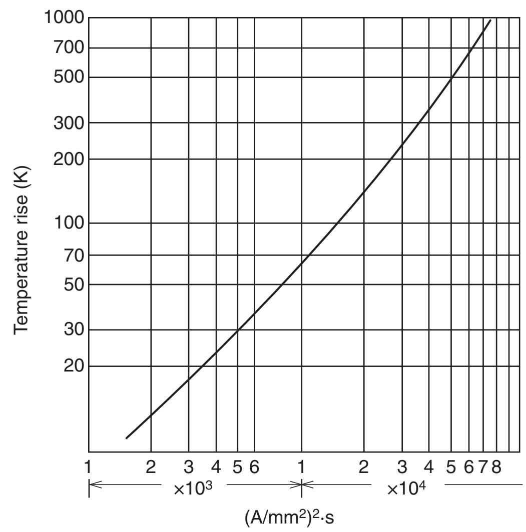


Fig. 4. 23 Conductor temperature rise caused by short-time overcurrent (copper)

Table 4. 7 Wire current capacity in respect to short-circuit current

Wire size mm^2 mm shown in ( )	Tolerable I^2t $A^2 \cdot s$	Is Tolerable short-circuit current symmetrical value limited by tolerable I^2t kA (Pf)	Fa Tolerable compression strength 600 I^2t MPa	ia Tolerable instantaneous current at Fa kA	Ia Tolerable 3-phase short-circuit current symmetrical value when constrained by Fa force kA (Pf)
(1.6ϕ)	0.056×10^6	2.34 (0.9)	1.25	12.7	10.3 (0.9)
3.5	0.172×10^6	4.08 (0.9)	1.6	16.4	13.3 (0.9)
5.5	0.424×10^6	6.24 (0.8)	2	20.5	16.2 (0.8)
8	0.896×10^6	8.41 (0.6)	2.4	24.6	17.8 (0.6)
14	2.74×10^6	14 (0.5)	3.02	31.3	21.3 (0.5)
22	6.78×10^6	15.2 (0.3)	3.63	37.9	22.1 (0.3)
30	12.6×10^6	20.7 (0.3)	3.92	42.5	24.8 (0.3)
38	20.2×10^6	26.2 (0.3)	4.43	47.3	27.6 (0.3)
50	35×10^6	34.5 (0.3)	4.78	52.6	30.7 (0.3)
60	50.4×10^6	41.4 (0.3)	5.07	56.5	33 (0.3)
80	89.6×10^6	55.2 (0.3)	5.73	63.1	36.9 (0.3)
100	140×10^6	69 (0.3)	6.13	68.7	40.1 (0.3)
125	219×10^6	86.2 (0.3)	6.78	76.5	44.7 (0.3)
150	315×10^6	103 (0.3)	7.17	83.1	48.5 (0.3)
200	560×10^6	138 (0.3)	7.98	91.7	53.5 (0.3)
250	875×10^6	172 (0.3)	8.54	101	59.2 (0.3)

Notes (1) Tolerable $I^2 \cdot t$ is calculated with hot start from 60°C, assuming that all generated heat is accumulated in the conductor, and that the conductor tolerable maximum temperature is 150°C.
(2) Fa calculates the tolerable compressive strength when the insulator thickness drops to 60%.
(3) ia is the instantaneous current value at which a suction force equal to Fa is generated, but in a normal circuit, the current flows in the opposite direction and ia will be the reaction force equal to Fa.
(4) Ia indicates the symmetrical active current value when the reaction force relative to Fa or the suction force equal to 1/3Fa is generated in the 3-phase circuit.
(5) Is is the tolerable short-circuit current symmetrical value limited by the tolerance $I^2 \cdot t$ when a half-cycle (10ms) interruption in respect to 14mm^2 or less, and one cycle (20ms) interruption in respect to 22m^2 is considered.

Tolerable temperature of various insulated wires Tolerable temperature at short-circuit (JCS: The Japanese Electric Wire & Cable Makers' Assicuation Standard)

Type	Tolerable max. temperature °C			type	Tolerable max. temperature °C		
	Continuous use	At short-circuit	Basis		Continuous use	At short-circuit	Basis
Butyl rubber cable	80	230	JCS 168	Vinyl cable HIV	75	150	Speculated.
Polyethylene rubber	75	140	JCS 168	Natural rubber cable	60	150	JCS 168
Cross-linked polyethylene cable	90	230	JCS 168	Ethylene, propylene cable	80	230	JCS 168
Cambric cable	80	200	JCS 168	Silica rubber cable	180	300	JCS 168
Vinyl cable IV	60	150	Indoor Wiring Standards Material	Mitsubishi Nonflen, Hitachi Polyflex	105 to 110	230	Confirmed by wire maker

Next, look at the passage energy (∫i²dt) generated by the short-circuit current when MCCB does not have the current limiting effect, if a short-circuit occurs when the passage current is the maximum, then ∫i²dt*1 is:

At power factor 0.5, 10ms interruption (50Hz),

$$\text{approx. } \frac{Ie^2}{71} \ (A^2\cdot s)$$

At power factor 0.3, 20ms interruption (50Hz),

$$\text{approx. } \frac{Ic^2}{34} \ (A2\ s)$$

Table 4. 7 shows the tolerable current (Is) when a half-cycle interruption is applied on a 14mm² or less wire, or a 1 cycle interruption on other wires.

When observing the wire protection during a short-circuit, it can be considered (JEAC8701) that the short-circuit will occur where the wire sheath has been removed, in other words, at XB in Fig. 4. 24. Thus, the short-circuit current that actually flows to the wire can be a current that is reduced by the wire impedance. (The wire protection is irrelevant for XA.)

In actual use, MCCB current limiting effect is applied, and a wire can be used at places where the estimated short-circuit current is larger than Is shown in Table 4. 7.

In other words, the minimum wire that can be protected when a short-circuit occurs at that MCCB is determined by MCCB passage $I^2\cdot t$ and the maximum passage current. This is shown in Table 4. 8. However, since the rated breaking capacity is interrupted, depending on the estimated short-circuit current a thinner wire can be used.

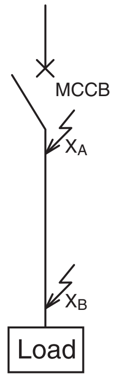


Fig. 4. 24 Wire protection and short-circuit point

Table 4. 8 Minimum wire size protected by circuit with estimated short-circuit current equivalent to rated breaking capacity

Model	Rated current (A)	415 VAC		230 VAC	
		Rated breaking capacity (Sym. kA)	Minimum size (mm²)	Rated breaking capacity (Sym. kA)	Minimum size (mm²)
NF32-SV	32	2.5	1.6φ	7.5	3.5
NF30-CS	30	1.5	1.6φ	2.5	1.6φ
NF63-SV	63	7.5	5.5	15	5.5
NF63-HV	63	10	8	25	8
NF63-CV	63	2.5	1.6φ	7.5	3.5
NF125-SV	30	30	5.5	50	5.5
	125		14		8
NF125-SEV	30	36	8	85	5.5
	125		14		14
NF125-HV	30	50	5.5	100	5.5
	125		14		8
NF125-HEV	30	70	8	100	5.5
	125		14		8
NF125-CV	125	10	8	30	14
NF125-RV	125	150	8	150	5.5
NF125-UV	125	200	5.5	200	5.5
NF250-SV NF250-SEV	250	36	22	85	14
NF250-HV NF250-HEV	250	70	22	100	14
NF250-CV	250	25	14	36	14
NF250-RV	250	150	14	150	8
NF250-UV	250	200	8	200	8
NF400-SW NF400-SEW	400	50	38	85	38
NF400-CW	400	25	38	50	38
NF630-SW NF630-SEW	630	50	38	85	38
NF630-CW	630	35	38	50	38

(2) Electromagnetic mechanical strength

When currents flow in the same direction to a parallel wire, the currents will mutually attract. If flowing in the opposite directions, they will repulse. The size of this force is expressed with the following formula:

$$F = 2\times10^{-7} \cdot \frac{i^2}{D}$$

F : Force applied on conductor (N/cm)
D : Conductor pitch (cm)
i : Current instantaneous value (A)
Geometric mean when currents of two conductors are different

Where, the above formula applies when the length of the section where the parallel conductors run parallel is longer than the pitch D (5-times or more).

The conductor's compression strength and the support's strength must be considered so that the insulated wires do not compress each other during a short-circuit and cause an insulation breakdown.

If the wire's effective compression area is $20\sqrt{C\,(d\text{-}C)}$ (mm^2/cm), then the wire's tolerable compression strength Fa (MPa) will be as shown in Table 4. 7. In the above formula, C is 40% (mm) of the conductor thickness and d is the conductor's outer diameter (mm).

The conductor pitch D during a short-circuit shall be the value (cm) obtained by subtracting the conductor's compression amount from the wire's outer diameter.

$$Fa = 2\times10^{-7} \cdot \frac{i^2a}{D}$$

When the tolerable instantaneous short-circuit current ia is calculated with the above formula, the results are as shown in Table 4. 7.

In the event of a 3-phase short-circuit, each phase's maximum instantaneous value is not attained simultaneously, so the tolerable instantaneous current can be larger than the above ia.

If the active value of the sine wave current distanced by 120° ($=\frac{2}{3}\pi$ rad) is I, then the maximum sum of the instantaneous values in the same direction will be, $\frac{1}{4}(\sqrt{2}\,I)^2$ and $\frac{3}{4}(\sqrt{2}\,I)^2$ for opposing directions. However, when considering the transient direct current element when the switch is turned ON, then, each will be as follows:

$$\frac{1}{4}(\sqrt{2}\,I)^2(1+e^{\frac{\pi R}{X}})^2 \quad \text{and}$$

$$\frac{3}{4}(\sqrt{2}\,I)^2(1+e^{\frac{\pi R}{X}})^2$$

$\frac{R}{X}$ here is the circuit resistance or reactance ratio. If the Ia equal to the square of the above ia is obtained, the following will apply for the currents in the same direction (attraction force)

$$Ia = \frac{\sqrt{2}}{\sqrt{3}\,(1+e^{\frac{\pi R}{X}})} \cdot ia$$

For currents in different directions (force of repulsion):

$$Ia = \frac{\sqrt{2}}{(1+e^{-\frac{\pi R}{X}})} \cdot ia$$

When this tolerable short-circuit current Ia is obtained using the Table 4. 7 tolerable instantaneous current ia, the results are as shown in Table 4. 7.

Generally with a 3-phase electrical circuit, the force of repulsion is larger than the attraction force so the tolerable current from the force of repulsion is smaller. Once the current is repelled and the distance between wires increases, both the attraction force and force of repulsion decrease and try to find a balancing point.

As explained above, if the distance between wires is small, the wires must be mutually be supported strongly taking the above force of repulsion into consideration. Special caution must be taken to prevent excessive force from being applied on the connections and terminals.

Table 4. 9 shows the electromagnetic force when the distance between wires is 10cm and 20cm.

Table 4. 9 Electromagnetic force applied per 1m of conductor (for 3-phase short-circuit) N

Conductor pitch cm / Current symmetrical value kA (Pf)	10	20
10 (0.4)	490	245
18 (0.3)	1860	930
25 (0.2)	4410	2205
35 (0.2)	8720	4360
42 (0.2)	12545	6270
50 (0.2)	17835	8920
65 (0.2)	30185	15090
85 (0.2)	51550	25775
100 (0.2)	71540	35770
125 (0.2)	111720	55860

4. 5 Coordination of MCCB and magnetic contactor

4. 5. 1 MCCB and magnetic contactor

MCCB and magnetic contactor are products with basic purposes, and this must be understood.

The magnetic contactor is intended to provide protection when the motor is in an overload or constrained state. With its basic performance it has a long life with normal start-stop switching operations. Thus, the current that can set or interrupt the magnetic contactor is specified in various standards as 8 to 12-times the rated current. It does not have the capability to interrupt large currents such as a short-circuit current. In other words, this larger range must rely on MCCB, and a coordination style suitable for both products is required.

4. 5. 2 Requirements for protection coordination

The following conditions must be satisfied for favorable protection coordination to be attained between MCCB and magnetic contactor.

① The thermal relay and MCCB operation characteristics must have an intersecting point. There must be seamless protection operating characteristics in all current areas, and the thermal relay's characteristics must be lower at currents lower than the cross point.

② The operating characteristics intersecting point must be a current value less than the breaking capacity of the magnetic contactor.

③ If a short-circuit current flows to the magnetic contactor, the magnetic contactor must not break until MCCB interrupts the current.

Of course, MCCB, magnetic contactor and thermal relay must satisfy the following conditions with their basic functions.

④ MCCB must have a breaking capacity that can accurately interrupt the short-circuit current, and must protect the wires from short-circuits and overloads. It must not malfunction with the motor's starting current.

⑤ The magnetic contactor must accurately close and interrupt the maximum current that could occur in the motor's normal state.

⑥ The thermal relay must have operating characteristics that can accurately protect when the motor is in the overload or constrained state.

Fig. 4. 25 shows the above coordination requirements. Fig. 4. 25 (a) shows a state with the conditions satisfied. Fig. 4. 25 (b) shows the state in which the protection range is cut off, and the protection coordination is not complete. In region (D), the thermal relay melts. However, the width of this region (D) is usually narrow. However, it is rare that the accident current here will develop into a large current region accident, or that it is caused when there is a rare short or ground fault in the motor coil. Thus, the necessity of a complete coordination and the cost efficiency must be considered.

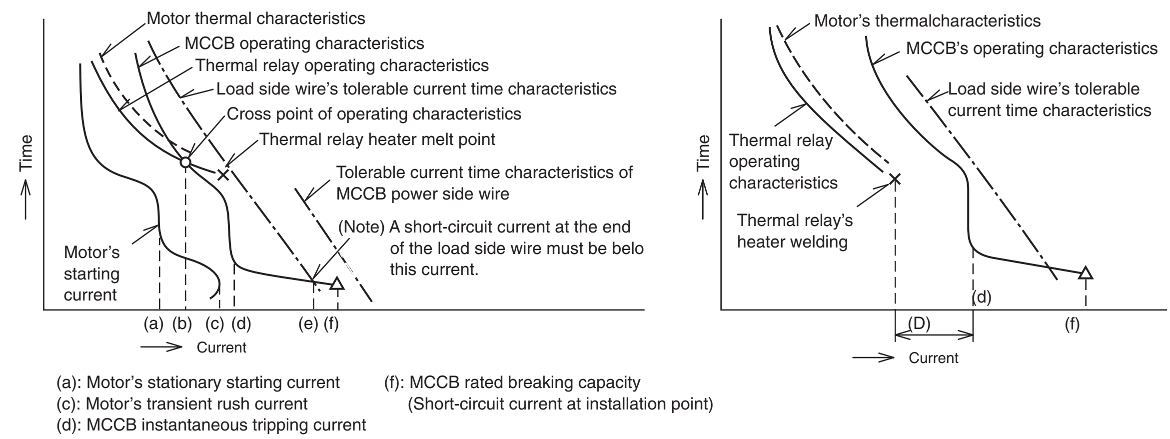


Fig. 4. 25 Motor circuit coordination state

4. 5. 3 Magnetic contactor short-circuit protection by MCCB

If a short-circuit accident occurs, the short-circuit current is interrupted by MCCB. The peak value of the current that passes at that point and $I^2 \cdot t$ relies on the circuit conditions such as the voltage and power factor, and tend to increase when the short-circuit current increases. If a short-circuit current exceeding a certain level flows, MCCB protection to prevent the magnetic contactor from breaking is difficult unless the generation of an arc between the magnetic contactor's contacts is prevented (contacts are prevented from lifting up) or the arc is suppressed to a minimal level.

It may be possible to prevent damage to the magnetic contactor if the short-circuit point is at the end of the load side and the short-circuit current is small.

The required degree of protection coordination must be determined by the necessity and cost effectiveness. IEC 60947-4-1 "Contactors and motor-starters" lists the "Type of Coordination" as shown in Table 4. 10 according to the degree of magnetic contactor damage when a short-circuit occurs. Type 1 is the most inexpensive type that does not require any consideration for most protection coordination. Type 2 requires various consideration, and is expensive.

Table 4. 10 Types of Coordination

Type of protection coordination	Tolerable damage (for contactor, starter)
1	Does not endanger persons or installations Will not then be able to operate without being repaired or parts being replaced 5 Does not endanger persons or installations and will be able to operate afterwards.
2	The risk of contacts being light welded is acceptable if the manufacturer stipulates the measures to be taken with respect to maintenance of the equipment.

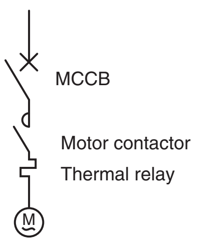
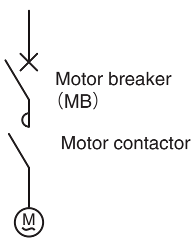
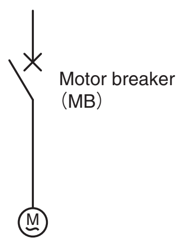
4. 6 Coordination of MCCB and motor

4. 6. 1 Protection of motor

If the motor is overloaded, an overload current will flow, and the motor will burn. Thus, the circuit must be opened quickly.

The branch circuit can be configured with the method shown in Table 4. 11.

Table 4. 11 Motor circuit configuration

Configuration			
Motor protection	The overload is sensed by the thermal relay, and the circuit is opened with the magnetic contactor. Overloads and short-circuit currents exceeding 600% to 800% are protected by MCCB.	The motor breaker has a motor protection characteristic, and can protect the motor from overloads and short-circuits. However, start-stop is performed by the magnetic contactor.	Protection in the overload and short-circuit ranges, as well as starting and stopping are carried out by the motor breaker.
Comparison of features	This is a normal configuration.	The thermal relay can be omitted. Frequent start-stop can be tolerated. The MB could function when starting with a large starting rush current, and is not suitable.	This is the most cost effective, but is not suitable for high frequency start-stop or for remote operations. The MB could function when starting with a large starting rush current, and is not suitable.

4. 6. 2 Coordination with motor starting current

One problem for MCCB in a motor circuit is the unnecessary operation of MCCB caused by the motor starting current when the motor starts up. This is caused by the following two points.

① The starting time is longer than MCCB thermal tripping characteristics.

② Instantaneous tripping operation MCCB caused by starting rush current.

The size of the motor's starting current is unique to the motor and differs according to the maker, model, capacity and number of poles. Normally it is 500% to 700% (in high cases 800%) of the total load current. The time that this starting current flows depends on the load GD^2, and is usually within 15s. Exceeding 30s is said to be hazardous for the standard motor.

What must be cautioned in addition to this start time is the starting rush current mentioned in point ②). This will be explained in detail in the next section. Fig. 4. 26 shows an illustration, which ignores accuracy to give an easy-to-understand explanation of points ① and ② above.

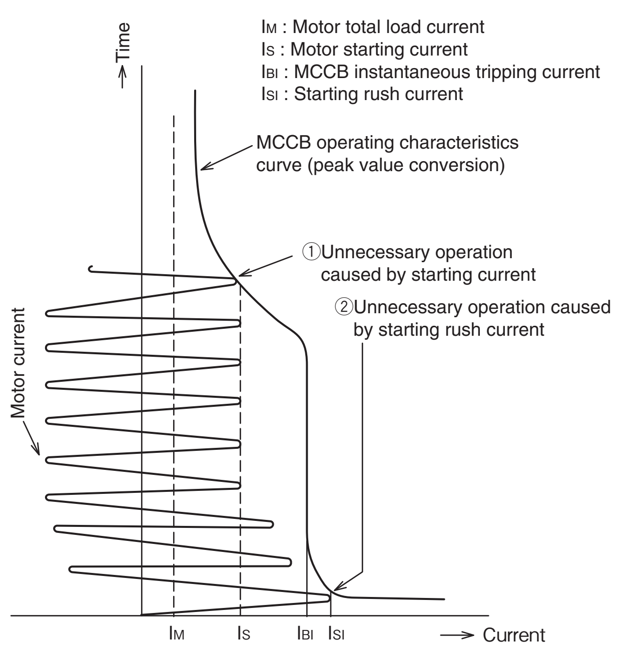


Fig. 4. 26 Coordination of motor and MCCB

4. 6. 3 Coordination with motor starting rush current

The motor's starting rush current is generated during startup, during star-delta changeover, during instantaneous restart and during reverse breaking. Although it is short and only several cycles, this current is much larger than the starting current. The starting rush current is caused by the following points.

① Superimposition of transient direct current element caused by lower power factor of starting current As shown in Fig. 4. 27, a transient rush current flows because of the effect of the direct current element even when the alternating current's amplitude is constant.

If the starting current's power factor is approx. 0.3, the rush current (peak value) will be approximately double the starting current (active value).

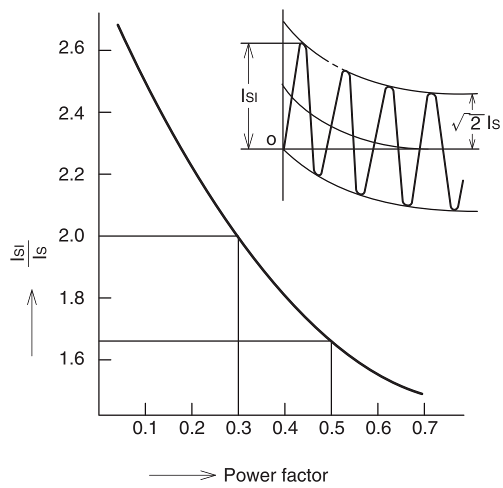


Fig. 4. 27

② Rush current during instantaneous reset caused by effect of residual voltage

When cutting off the motor from the power and connecting it again, there will be a residual voltage if the motor has not stopped yet. The residual voltage is not generated by only the residual magnetism, but because the iron core is excited by the residual current in the secondary coil.

This residual voltage does not cause a problem if the power voltage when reconnecting matches the phase. If not, the state will be the same as direct-ON starting with an overvoltage and will generate a large rush current.

In other words, compared to starting from stopped state

$\left(\frac{\text{Residual voltage + power voltage}}{\text{power voltage}}\right)$ times rush current will be generated.

This fold is maximum two-times during instantaneous starting, and can be maximum $(1 + \frac{1}{\sqrt{3}})$ fold during Y-Δ starting.

③ Effect of magnetic saturation

This starting rush current is short being only several cycles long. however, MCCB instantaneous tripping operation will react even if the time is 1/2 cycle. Thus, MCCB instantaneous tripping current value must be larger than this starting rush-current. The following caution is required depending on the starting method.

(1) Direct-ON starting

When item ①) above is considered, the starting rush current (peak value) is double the starting current (active value). If the maximum starting current is eight times the motor's total load current, then the starting rush current (peak value) will be 16-times the total load current.

Thus, MCCB instantaneous tripping current value (expressed with the active value) must be 12-times or more than the motor's total load current (active value).

(2) Star-delta starting (Open transition method)

When items ① and ②) are considered, the starting rush current (peak value) is 23-times [$8\times1.8\times(1+\frac{1}{\sqrt{3}})$] the total load current (active value.) (When power factor is 0.4.)

Thus, MCCB instantaneous tripping current value (active value) must be 17-times or more than the motor's total load current (active value).

(3) Instantaneous restarting

When items ① and ②) are considered, the starting rush current (peak value) is 27-times [8×1.7×2] the total load current (active value.) (When power factor is 0.5.)

Thus, MCCB instantaneous tripping current value (active value) must be 19-times or more than the motor's total load current (active value).

(4) Plugging

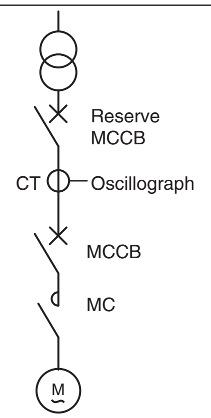
When items ① and ②) are considered, if the effect of the residual voltage and the increment of the starting current so that the slip = 2 is double, the starting rush current (peak value) will be 42-times (8×2.6×2) of the total load current (active value). (When power factor is 0.05.) Thus, MCCB instantaneous tripping current value (active value) must be 29-times or more than the motor's total load current (active value).

4. 6. 4 Experiment on motor's starting rush current

An experiment on the 3-phase 200V rating motor (0.2 to 30kW) was performed to understand the coordination of the Class E motor's starting rush current and MCCB instantaneous tripping range.

Using the circuit shown in Fig. 4. 28, MCCB was switched during the direct-ON starting, and the magnetic contactor was switched for inching and plugging. Based on the oscillograph, the starting rush current flowed for approx. 1/2 cycle and then immediately attenuated to the correct starting current.

These experiments were carried out without controlling the closing phase, and the size of the rush current when starting varies because the size of the residual voltage in the motor winding during inching and plugging vary.

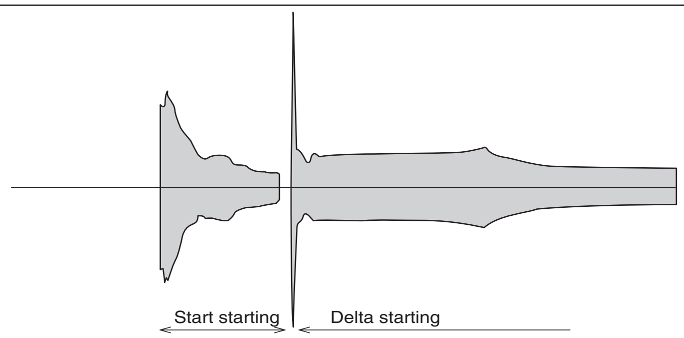


Measured rush current value

Motor state	Scale
Direct ON starting	11.9
Y-Δ starting	16.7
Instantaneous restarting	19.0
Plugging	28.8

Scale = $\frac{\text{Rush current peak value}}{\text{Total load current peak value}}$

Fig. 4. 28



Motor capacity	Direct ON starting time (600%)	Max. starting current during direct ON starting (× total load current)	Starting rush current (× total load current)	
			Direct ON starting	Y-Δ starting
0.2 to 7.5kW	10s	8-times	12-times	16-times
11 to 55	10	8	12	17
75 to 150	10	8	14	18

- The maximum starting current refers to the current active value (value after transient phenomenon is eliminated) when the rotator starts to rotate.
- For Y-Δ starting, the open transition method typically known to have a large transient rush current was applied.

Fig. 4. 29 Normally predicted motor starting conditions

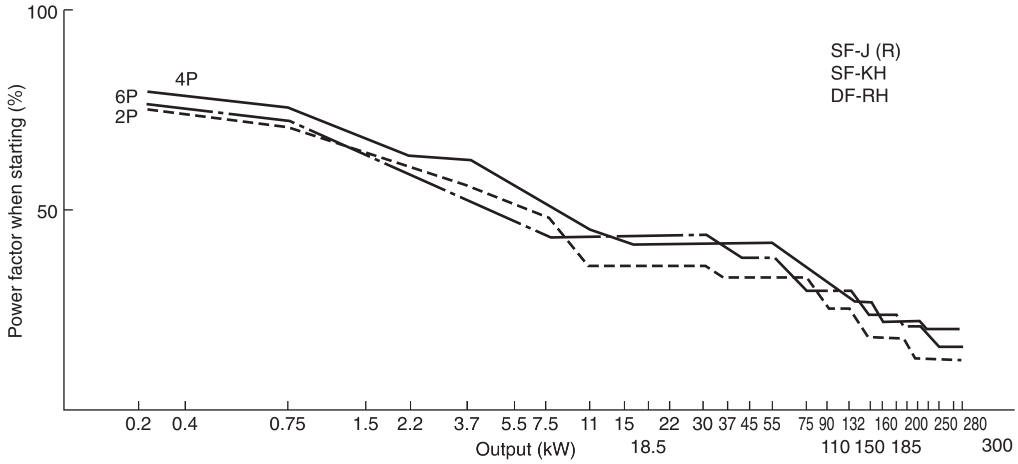


Fig. 4. 30 Example of power factor during motor starting

4. 7 Coordination of MCCB and high-voltage side protection device

4. 7. 1 Coordination of MCCB and high-voltage fuse

When a power fuse (hereafter, PF) is used as the high-voltage side protection device, it must be coordinated with the secondary MCCB. In other words, in the overload range MCCB must always function first, and the PF must not function. In addition, the fuse element must not degrade over repeated overload currents.

In actual use, the PF short-time tolerable characteristics curve (if unknown, the average welding characteristics curve reduced by 20% at the current axis can be interpreted as the short time tolerable characteristics) must be overlapped with MCCB operating characteristics curve (PF converted to secondary side or MCCB converted to primary side), and both must not cross at the overload range.

If this method has already been considered, this may have been experienced, but it is difficult to achieve PF and MCCB coordination at the shaded section shown on Fig. 4. 32. In this case, the arrow shows where the instantaneous tripping current value can be adjusted. Coordination can be achieved by lowering this setting.

However, MCCB instantaneous tripping current value has a difference from the symmetrical value. Table 4. 12 and Table 4. 13 shows actual combinations that take this difference into consideration and attain a favorable coordination relation. In this table, the symbols or numbers that indicate the boundary with the ranges in which coordination can and cannot be achieved indicate the setting dial for the instantaneous tripping current explained earlier. Coordination can be attained with a setting dial less than this number. If a number is not indicated, coordination can be attained with all setting dials.

When considering the coordination with the PF and MCCB, the non-coordinated sections shown in Fig. 4. 32 is the overload range. The current in this range is usually generated after $MCCB_2$ unless there is a high-impedance short-circuit in the electric circuit between $MCCB_1$ and $MCCB_2$.

Thus, coordination with the PF should be considered in the space between $MCCB_2$, and the non-coordination $MCCB_1$ must be tolerated in some cases.

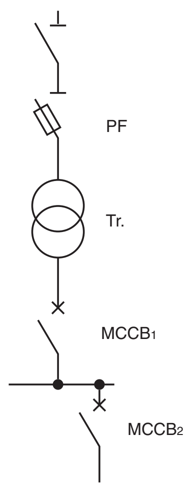


Fig. 4. 31 Coordination of PF and MCCB

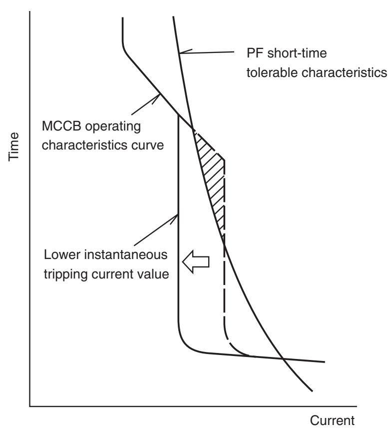


Fig. 4. 32 Advantages of using thermal adjustable type

Table 4. 12 Coordination of MCCB and high-voltage fuse (CL type) 6.6kV/415V

MCCB rated current (A) \ CL rated current (A)		With striker								Without striker					
		5	10	20	30	40	50	60	75	75	100	150	200	300	400
NF32-SV	15														
	20														
	30														
NF63-CV NF63-SV NF63-HV	15														
	20														
	30														
	40														
	50														
	60														
NF125-CV NF125-SV NF125-HV	60			△											
	75			△	△				Range in which coordination is attained						
	100				△	△									
NF125-RV NF125-UV	60														
	75														
	100														
NF250-CW NF250-SW NF250-HW	125			▲	△	△									
	150				△	△									
	175				▲	△	△								
	200				▲	△	△	△							
	225				▲	▲	△	△	△						
NF250-RW NF250-UW	125														
	150														
	175														
	200														
	225														
NF400-SW	250														
	300														
	350														
	400														
NF400-CW	250					▲	△	△							
	300						▲	△	△						
	350						▲	△	△						
	400						▲	▲	△						
NF630-SW	500														
	600														
NF630-CW	500														
	600														

Table 4. 13 Coordination of MCCB and high-voltage fuse (CL type) 6.6kV/210V

MCCB rated current (A) \ CL rated current (A)		With striker								Without striker					
		5	10	20	30	40	50	60	75	75	100	150	200	300	400
NF32-SV	15														
	20														
	30														
NF63-CV NF63-SV NF63-HV	15														
	20														
	30														
	40														
	50														
	60														
NF125-CV NF125-SV NF125-HV	60														
	75			△					Range in which coordination is attained						
	100			△											
NF125-RV NF125-UV	60														
	75														
	100														
NF250-CW NF250-SW NF250-HW	125			△											
	150			△											
	175			▲	△										
	200			▲	△										
	225			▲	△	△									
NF250-RW NF250-UW	125														
	150														
	175														
	200														
	225														
NF400-SW	250														
	300														
	350														
	400														
NF400-CW	250				▲										
	300				▲	△									
	350				▲	△									
	400				▲	▲	△								
NF630-SW	500														
	600														
NF630-CW	500														
	600														

Notes (1) △: Low INST part (6-times)
▲: Low INST part (4-times)
(2) The △, ▲ low INST parts must consider coordination with the load, such as the motor, connected from the MCCB, and must prevent mis-trips when starting.

4. 7. 2 Coordination with electronic MCCB and high-voltage fuse

(1) Characteristics of electronic MCCB

The tripping characteristics of the electronic MCCB can be set by the user. These characteristics are easy to coordinate with the characteristics of other protective devices, making this suitable as a coordination breaker.
(With NF125-SEV / HEV, NF250-SEV / HEV, NF400-SEW / HEW / REW / UEW, NF630-SEW / HEW / REW, NF800-CEW / SEW / HEW / REW / UEW, NF1000-SEW, NF1250-SEW and NF1600-SEW, the long-time delay operating time, short-time delay tripping current, short-time delay operating time and instantaneous tripping current can be adjusted. The setting range is further expanded making coordination easier.)

(2) Coordination of PF and electronic MCCB

Table 4. 14 and Table 4. 15 shows the results of investigating the coordination with the electronic MCCB operating characteristics by converting the PF characteristics to the low-voltage side at a rate of 6.6kV/415V and 6.6kV/210V. These values can be used to consider the coordination of the high-voltage PF and low-voltage electronic MCCB.
As a condition for considering coordination between the PF and MCCB, the PF short-time tolerable characteristics and electronic MCCB characteristics must not cross.
A larger PF rated current is better for facilitating coordination, but the PF rated current is selected with the following method and will be restricted.

① Rated current that is 1.5 to 2-times or more than the load current.
② To protect the transformer during a short-circuit, a current 25-times the transformer's rated current must be interrupted within 2s.
③ To prevent degrading or welding with the transformer's exciting rush current, the short-time tolerable characteristics must be higher than the 10-times the transformer's rated current, and higher than the 0.1s point.
(When using a single-phase winding core transformer, 15-times and 0.1s.)
An example of PF coordination is shown in Fig. 4. 34.

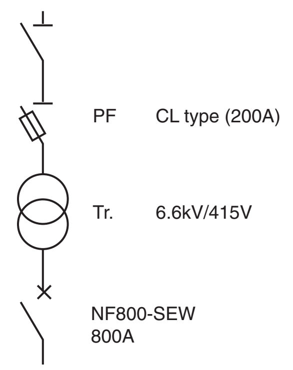


Fig. 4. 33 Example of PF and electronic MCCB coordination

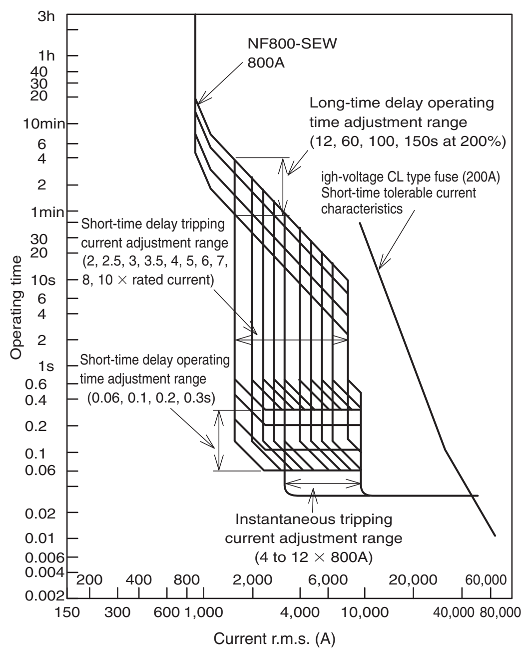


Fig. 4. 34 Example of PF and electronic MCCB coordination

Table 4. 14 Coordination of electronic MCCB and high-voltage fuse (CL type) 6.6kV/415V

MCCB model rated current (A) \ CL rated current (A)		With striker							Without striker					
		5	10	20	30	40	50	60	75	100	150	200	300	400
NF125-SEV NF125-HEV	50		○	○										
	60		○	○	○									
	75		○	○	○									
	100		○	○	○									
NF250-SEV NF250-HEV	125		○	○	○	○	○							
	150			○	○	○	○							
	175			○	○	○	○							
	200			○	○	○	○		Range in which coordination is attained					
	225			○	○	○	○							
NF400-SEW NF400-HEW NF400-REW NF400-UEW	200				○	○	○	○						
	225				○	○	○	○						
	250				○	○	○	○						
	300				○	○	○	○						
	350				○	○	○	○						
	400					○	○	○						
NF630-SEW NF630-HEW NF630-REW	300				○	○	○	○	○					
	350				○	○	○	○	○					
	400					○	○	○	○					
	500					○	○	○	○					
	600						○	○	○					
NF800-CEW NF800-SEW NF800-HEW NF800-REW NF800-UEW	400					○	○	○	○					
	500					○	○	○	○					
	600						○	○	○					
	700						○	○	○					
	800							○	○	○				
NF1000-SEW	500													
	600													
	700													
	800													
	1000													
NF1250-SEW	600													
	700													
	800													
	1000													
	1200													

The numbers and symbols in Table 4. 14 and Table 4. 15 have the following meaning.

(1) ○ indicates that coordination is possible by adjusting the long-term delay operating time, short-time delay tripping current, short-time delay operating time and instantaneous tripping current characteristics to an appropriate setting.

(2) Blank fields indicate that coordination is possible regardless of the notch position.

Table 4. 15 Coordination of electronic MCCB and high-voltage fuse (CL type) 6.6kV/210V

MCCB model	CL rated current (A) / rated current (A)	With striker							Without striker					
		5	10	20	30	40	50	60	75	100	150	200	300	400
NF125-SEV NF125-HEV	50	○	○											
	60	○	○											
	75	○	○											
	100		○											
NF250-SEV NF250-HEV	125		○	○	○									
	150		○	○	○									
	175		○	○	○									
	200		○	○	○									
	225		○	○	○									
NF400-SEW NF400-HEW NF400-REW NF400-UEW	200			○	○	○	○							
	225			○	○	○	○							
	250			○	○	○	○							
	300			○	○	○	○							
	350			○	○	○	○							
	400			○	○	○	○							
NF630-SEW NF630-HEW NF630-REW	300			○	○	○	○	○						
	350			○	○	○	○	○						
	400			○	○	○	○	○						
	500				○	○	○	○						
	600				○	○	○	○						
NF800-CEW NF800-SEW NF800-HEW NF800-REW NF800-UEW	400				○	○	○	○						
	500				○	○	○	○						
	600				○	○	○	○						
	700				○	○	○	○						
	800				○	○	○	○						
NF1000-SEW	500													
	600													
	700													
	800													
	1000													
NF1250-SEW	600													
	700													
	800													
	1000													
	1200													

Range in which coordination is attained

4. 7. 3 Coordination of MCCB and high-voltage side OCR

When there is an OCR on the high-voltage side, the low-voltage side MCCB must establish a coordinated relation with that OCR. The configuration shown in Fig. 4. 35 will be reviewed here.

The power receiving OCR's CT ratio, tap value and dial settings are determined by the coordination with the power company substation's feed OCR. At the same time, the following conditions are considered.

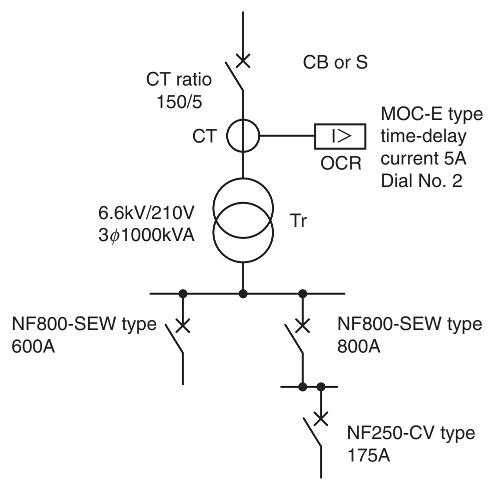


Fig. 4. 35 Coordination of electronic MCCB and high-voltage side OCR

① If an instantaneous tripping element is provided, the setting value must be 10-times or more than the transformer's rated current so the breaker does not malfunction with the transformer's exciting rush current.

② To protect the transformer from short-circuits, the breaker must function in less than 2s when a current 25-times the rated current flow.

Fig. 4. 36 is a figure to review the coordination relation shown in Fig. 4. 35. The figure shows the values converted to the low-voltage side.

Table 4. 16 and Table 4. 17 show the actual selective coordination combinations.

(1) Setting the OCR

The rated primary current is 87.5A, so the CT ratio is 150/5. Due to the relation with the substation's feed OCR, the time-delay dial is normally 0.2s or less at the restricted section. If an instantaneous element is included, it is set to 1s or less. The dial No. 2 operating characteristics for the Mitsubishi general-purpose relay MOC-E are shown here. When considering coordination with the downstream MCCB, the inertia must also be considered and is shown with a dotted line. The instantaneous tripping element is ① shown above, and is set to 30A here.

(2) Setting the electronic MCCB

Consider the 800A and 600A settings for NF800-SEW. For the reasons explained in the next section, the NF800-SEW type short-time delay tripping characteristics are set with the dial to 5-times the rated current.

(3) Coordination of OCR and electronic MCCB

The short-time tripping current value of the NF800-SEW is 2 to 10-times the rated current. When set to 10-times, the 600A setting is 6000A, and the 800A setting is 8000A.

In other words, when set to 10-times, the NF800-SEW short-time delay tripping pickup value is larger than the OCR's pickup value 4710A (secondary conversion). Thus, a favorable relation can be established by setting both to 5-fold so the resulting value is 4710A or less.

The OCR has an instantaneous tripping element and the setting value is 30A (secondary conversion 28.3kA), so the OCR and NF800-SEW selective tripping range is restricted to this current value.

(4) Coordination of electronic MCCB and downstream MCCB

Assume that a 250A frame is provided as the downstream MCCB. The model is NF250-CV (175A), and the maximum and minimum operating characteristics are as shown in Fig. 4. 36.

It can be seen that a favorable selective tripping relation is established and that the maximum operating characteristics curve does not cross the NF800-SEW operating characteristics curve.

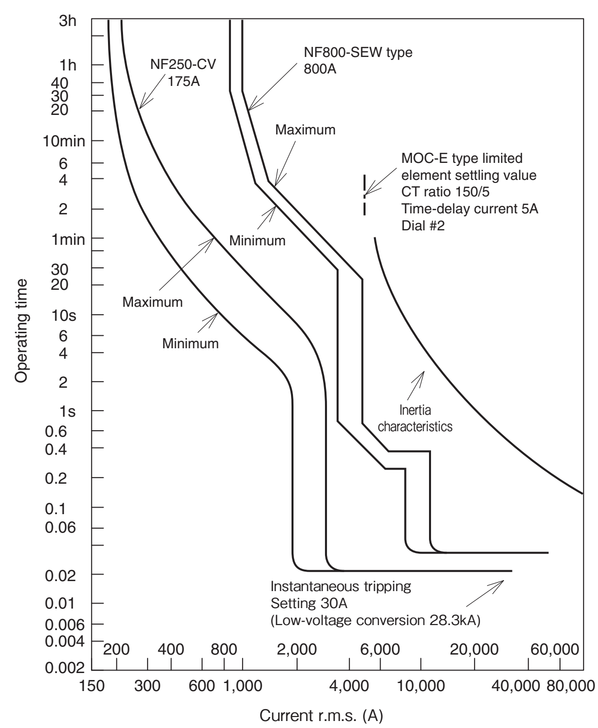


Fig. 4. 36 Example of coordination with high-voltage side OCR

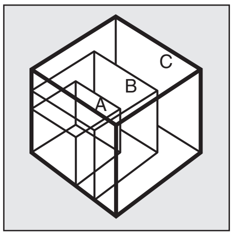
Table 4. 16 Coordination with electronic MCCB and high-voltage OCR (MOC-E type) 6.6kV/415V

MCCB model	Rated current (A) \ Tr capacity 3ϕ (kVA)	300	500	750	1000	1500	2000
	Current (A) primary/secondary	26.2/ 394	43.7/ 656	65.6/ 984	87.5/ 1312	131.2/ 1968	175.0/ 2624
	CT ratio	50/5	75/5	100/5	150/5	200/5	250/5
	Time-delay current	4	5	5	5	5	5
NF125-SEV NF125-HEV	50						
	60						
	75						
	100						
NF250-SEV NF250-HEV	125	○					
	150	○	○				
	175	○	○	Range in which coordination is attained			
	200	○	○	○			
	225	○	○	○			
NF400-SEW NF400-HEW NF400-REW NF400-UEW	200	○	○	○			
	225	○	○	○			
	250	○	○	○			
	300		○	○	○		
	350		○	○	○	○	
	400		○	○	○	○	
NF630-SEW NF630-HEW NF630-REW	300		○	○	○		
	350		○	○	○	○	
	400		○	○	○	○	
	500		○	○	○	○	○
	600			○	○	○	○
NF800-CEW NF800-SEW NF800-HEW NF800-REW NF800-UEW	400		○	○	○	○	
	500		○	○	○	○	○
	600			○	○	○	○
	700			○	○	○	○
	800				○	○	○
NF1000-SEW	500						
	600						
	700						
	800						
	1000						
NF1250-SEW	600						
	700						
	800	Range in which coordination is not attained					
	1000						
	1200						

Table 4. 17 Coordination with electronic MCCB and high-voltage OCR (MOC-E type) 6.6kV/210V

MCCB model	Rated current (A) \ Tr capacity 3ϕ (kVA)	300	500	750	1000	1500	2000
	Current (A) primary/secondary	26.2/ 787	43.7/ 1312	65.6/ 1968	87.5/ 2624	131.2/ 3937	175.0/ 5429
	CT ratio	50/5	75/5	100/5	150/5	200/5	250/5
	Time-delay current	4	5	5	5	5	5
NF125-SEV NF125-HEV	50						
	60						
	75						
	100						
NF250-SEV NF250-HEV	125						
	150						
	175	○		Range in which coordination is attained			
	200	○					
	225	○					
NF400-SEW NF400-HEW NF400-REW NF400-UEW	200	○					
	225	○					
	250	○					
	300	○	○				
	350	○	○	○			
	400	○	○	○			
NF630-SEW NF630-HEW NF630-REW	300	○	○				
	350	○	○	○			
	400	○	○	○			
	500	○	○	○			
	600		○	○	○		
NF800-CEW NF800-SEW NF800-HEW NF800-REW NF800-UEW	400	○	○	○			
	500	○	○	○			
	600		○	○	○		
	700		○	○	○	○	
	800		○	○	○	○	
NF1000-SEW	500						
	600						
	700						
	800						
	1000						
NF1250-SEW	600						
	700						
	800						
	1000						
	1200						

Notes) The OCR dial is set to No. 2.
The numbers and symbols in Table 4.16 and Table 4.17 have the following meaning.
(1) ○ indicates that coordination is possible by adjusting the long-term delay operating time, short-time delay tripping current, short-time delay operating time and instantaneous tripping current characteristics to an appropriate setting.
(2) Blank fields indicate that coordination is possible regardless of the notch position.



5. Selection

5 Selection

5. 1 Regulations for MCCB installation

In selecting MCCB for a particular application, in addition to purely electrical aspects of load and distribution conductor systems, physical factors such as panelboard configuration, installation environment, ambient-temperature variations, vibration, etc. must also be considered.
MCCB are rated for an ambient of 40°C, and where panelboard internal temperatures may exceed this, MCCB installed should be derated in accordance with Table 5. 1.

1. Actual load currents may exceed the nominal-values.
2. Load currents may increase with time, due to deterioration of load devices (i.e., friction in motors).
3. Source voltage and frequency may vary.

Table 5. 1 MCCB Derating Due to Installation Factors

Panelboard max. internal temp. (°C)	Load allowable, due to panelboard temp. (%)
50	90
55	80
60	70

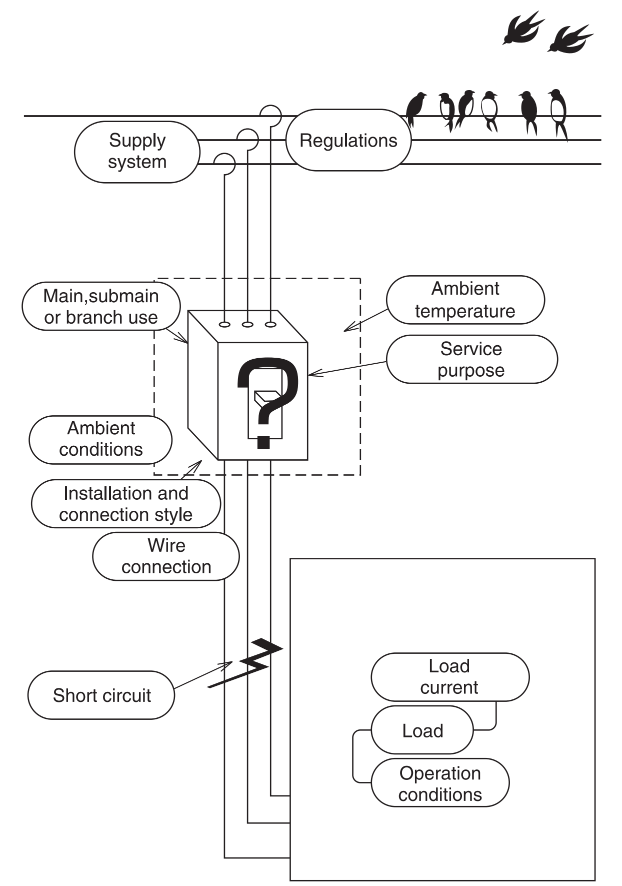


Fig. 5. 1 MCCB Selection Consideration

5. 2 Selection of MCCB on main line and branch circuits

5. 2. 1 Selection of MCCB on main line

(1) When the loads are motors, etc.

When motors, etc. are connected to the main line, MCCB rated current shall be less than the value obtained by multiplying the sum of rated currents of the motors by 3 and adding the sum of the rated currents of other loads to the tripled sum. However, when the sum total exceeds 2.5 times the allowable current of the main line, the rated current shall be less than the value obtained by multiplying the allowable current by 2.5. If the allowable current of the main line exceeds 100A and the value does not conform to the standard rating of any MCCB, it is allowed to select the rating just above the value.

Actually, select MCCB in accordance with the following procedures. Divide the loads on the branch circuits into groups of motors which will start simultaneously. Regard each motor group as one motor (hereinafter, referred to as a synthesized motor) which has the total full-load current of the full-load currents of the motors in the group, and the synthesized motors will start successively. Determine the rated current of the circuit breaker for the branch circuit of each synthesized motor. The maximum rated current is $I_{B\,max}$. When the full-load currents of other synthesized motors is I_1, I_2 ···· I_{n-1}, the rated current I_B of main line circuit breaker can be obtained by the following formula.

$$I_B = I_{B\,max} + (I_1 + I_2 + \cdots\cdots + I_{n-1}) \times D$$

D is the demand factor, and, if it is unknown, it is regarded as 1.

(2) When loads are only lamp and heater circuits

MCCB rated current shall be less than the allowable current of the main line and determined by multiplying the sum total of the rated currents of MCCB on each branch circuit by the demand factor.

5. 2. 2 Selection of MCCB for lamp or heater branch circuit

The lamp and heater circuits refer to circuits on which the starting current and starting time are not so significant that the operation of MCCB is affected. For lamp circuits for mercury lamps, etc. which have rather large starting current × long starting time, select MCCB in accordance with the procedures for motor circuits. It is better to allow a margin between the load current of lamp or heater circuit and the rated current of MCCB for the following reasons.

① MCCB are designed to protect wires on the outside of panels according to the temperatures in the panels. Generally, MCCB are adjusted based on an ambient temperature of 40°C. If the estimated maximum temperature in a panel is higher than 40°C, it is better to reduce the load at a rate of 1% per difference of 1K.

② In addition, it is better to allow a margin of 10 to 15% separately from the margin stated in ① in consideration of difference between nominal value and actual value of full-load current of load device, increase in full load current due to deterioration of load device and fluctuation of supply voltage and frequency.

5. 2. 3 Selection of MCCB for motor branch circuit

When selecting the rated current of MCCB for a motor branch circuit, it is necessary to take into consideration that considerably larger transient currents, such as starting current and starting inrush current, than the full-load current will flow.

Select MCCB rated current to prevent operation of MCCB due to these starting transient characteristics. The relationship between them is shown in Fig. 5. 2.

(1) Starting inrush current

The starting inrush current reaches the maximum value in 1/2 cycle after power is applied and then rapidly attenuates. The starting inrush current was explained in detail in “Protection Coordination” of 4. 5. 3 and 4. 5. 4. If the starting inrush current enters the operating range of the instantaneous tripping element of MCCB, MCCB will trip. Select MCCB which has an instantaneous tripping current higher than the starting inrush current depending on the starting method.

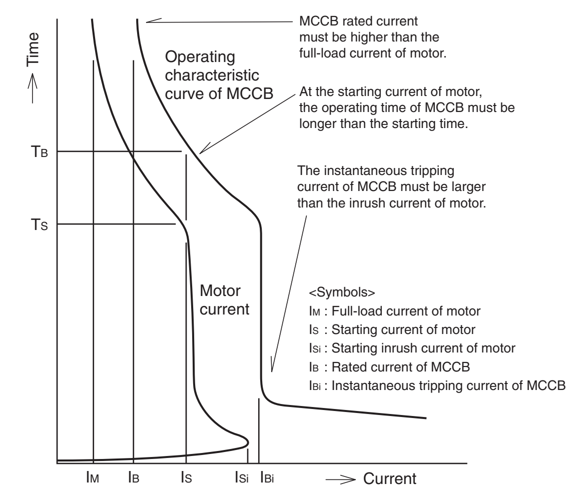


Fig. 5. 2 Characteristics of MCCB and motor

a. In the case of full voltage starting (direct-line starting)

Starting inrush current owing to superposition of transient current caused by low power factor of starting current and reduction of motor impedance caused by saturation of magnetic path may lead to incorrect operation of MCCB. To prevent the incorrect operation, the instantaneous tripping current of MCCB must be approx. 12 times higher than the full-load current.

b. In the case of star-delta starting

If the phase of residual voltage is reversed to the phase of supply voltage on an open transition system, starting at the supply voltage corresponds to starting at overvoltage, and the power factor of current upon switching is improved compared to that upon starting in the stopped state. However, to prevent incorrect operation caused by starting inrush current owing to superposition of transient current, the instantaneous tripping current of MCCB must be approx. 17 times higher than the full-load current. On a closed transition system, the instantaneous tripping current of MCCB is allowed to be almost equal to that in the case of direct-line starting.

c. In the case of instantaneous restarting

As in the case of star-delta starting, if the phase of residual voltage is reversed to the phase of supply voltage, starting at the supply voltage corresponds to starting at overvoltage, and inrush current flows. The instantaneous tripping current of MCCB must be approx. 19 times higher than the full-load current.

d. Plugging

Since there is a phase shift of 120° between residual voltage and supply voltage, starting at the supply voltage corresponds to starting at overvoltage, the power factor reduces considerably, and large starting current flows.

The instantaneous tripping current of MCCB must be approx. 29 times higher than the full-load current.

(2) Starting current and starting time

The multiplying factors stated in a, b and c apply in the case where the starting current is 8 times the full-load current. The duration of starting current is affected by the inertia moment of load. Generally, for standard motors, if the starting time is less than 15 s, they are considered to be improper when the safety time exceeds 15 s.

(3) Selection

Concretely, select MCCB in accordance with the following procedures.

a. When the starting time is relatively short

When the starting current is 600% and the starting time is within 2 to 3 s, a motor breaker can be used. However, the scope of protection is limited depending on the device to be protected as shown in Table 5. 2.

Select the motor breaker in accordance with Table 5. 3.

b. When the starting time is relatively long

When the starting current is 600% and the starting time is within 10 s, apply a combination starter method with MCCB and magnetic switch.

c. When the starting time is remarkably long

In this case, apply a combination starter method, and examine the measures for each case as needed, for example, installation of sufficient overload protection devices.

Table 5. 2 Protection ranges of protective devices

Protective device / Protection from	Thermal relay (TH type)	Thermal relay with 2E (TH-KP type)	Electronic thermal relay (ET type)	Motor breaker (MB type)
Overload	◎	◎	◎	○
Short circuit	△	△	△	○
Open phase (prevention of burnout)	△	○	◎	△
Constraint	◎	◎	◎	○

Note) For general 3-phase squirrel-cage induction motor
◎: Reliable protection can be obtained.
○: Protection can be obtained except special cases.
△: Protection can be obtained conditionally.

Table 5. 3 Selection of motor breaker

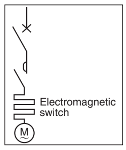
In principle, the operating characteristic curve of a selected motor breaker must be lower than the heat characteristic of the motor.
The following table shows the rated capacities of Mitsubishi's standard squired-cage 3-phase motors (4-pole). The starting conditions are shown in the table.

Model	Motor Protection Breaker	NF32-SV	NF63-CV	NF63-SV	NF125-SV	NF250-SV	
Rated breaking capacity (kA)	230V	7.5	7.5	15	50	85	
	415V	2.5	2.5	7.5	30	36	
600% starting time limit (s)		2	32 A or less: 2 40 A or more: 7	32 A or less: 2 40 A or more: 7	32 A or less: 2 40 A or more: 7	5	
Startup inrush current limit (%)		1200	1200	1200	1200	1100	
Example of rated capacity of motor (kW)		Rated current	Rated current	Rated current	Rated current	Rated current	Model for combination with electromagnetic contactor
200/220V	400/440V						
							N10-N21
	0.4						
0.2							
	0.75						
0.4							
0.75	1.5	4	4	4			
	2.2	5	5	5			
1.5		7.1	7.1	7.1			
	3.7	8	8	8			N11-N35
2.2		10	10	10			
	5.5	12	12	12	(12.5)		N18-N35
							N20-N35 N50
3.7	7.5	16	16	16	(16)		
							N25 • N35 N50 • N65
5.5	11	25	25	25	(25)		
							N35 N50-N80
7.5	15	32	32	32	32		
							N50-N95
			40	40	(40)		
11	22		45	45	45		
							N65-N125
15	30				63		
18.5	37				71		N80-N125
22	45				90		N90-N125
	55				100		N125-N220
	55						
30						125	
37	75					150	N150-N400
45	90					175	N180-N400
						200	N220-N400
55	110					225	

Remarks (1) Fot the rated curent in parentheses, breakers will be manufactured to order.
(2) The approximate values of inrush current at direct-to-line starting are shown below. Up to 7.5 kW: 1000% 11 kW or more: 1200% 75 kW or more: 1400%
When the starting current is large and the starting power factor is low, a combination with an electromagnetic switch selected in accordance with "Table of selection of circuit breaker for motor branch circuit" shown on page 74 is suitable.

Cautions

(1) Note that any circuit breaker operates when the startup inrush current, starting current and starting time exceed the conditions shown in the above table.
Particularly, high-efficiency motors generally have higher starting current and lower starting torque compared to general-purpose motors, and motor breakers cannot be used for such motors.
(2) Note that a circuit breaker may operate when an electromagnetic contactor is opened or closed while a motor is running.
(3) Select a motor breaker having rated current approx. 1.0 to 1.1 times higher than the full load current of motor.



(direct-to-line starting or Y-Δ starting)

Motor is protected from overload by electromagnetic switch.
Circuit breaker is installed to protect circuit from short-circuit.

Table 5. 4 Selection of MCCB for motor branch circuit 200/220VAC for 3-phase induction motor

Starting	For 4-pole motor: Output (kW)	For 4-pole motor: Full-load current (A)	Electromagnetic contactor: Model	Electromagnetic contactor: Heater nominal (A)	Breaking capacity (kA) 230 V AC (Icu sym): 2.5 Model	2.5 Rating	7.5 Model	7.5 Rating	15 Model	15 Rating	25 Model	25 Rating	30(*1) Model	30(*1) Rating	50 Model	50 Rating	85 Model	85 Rating	100 Type name	100 Rating	150(*2) Model	150(*2) Rating	200 Model	200 Rating
Direct-to-line starting	0.1	0.7	N10-N21	0.7	NF30-CS	(3)	NF32-SV	(3)	NF63-SV	(3)	NF63-HV	(10)			NF125-SV	(15)			NF125-HV	(15)			NF125-UV	(15)
Direct-to-line starting	0.2	1.2		1.3																				
Direct-to-line starting	0.4	2.1	N10-N21	2.1	NF30-CS	5	NF32-SV	5	NF63-SV	5	NF63-HV	(10)			NF125-SV	(15)			NF125-HV	(15)			NF125-UV	(15)
Direct-to-line starting	0.75	3.7	N10-N21	3.6	NF30-CS	10	NF32-SV	10	NF63-SV	10	NF63-HV	10			NF125-SV	(15)			NF125-HV	(15)			NF125-UV	(15)
Direct-to-line starting	1.5	6.4	N10-N25	6.6	NF30-CS	15	NF32-SV	15	NF63-SV	15	NF63-HV	15			NF125-SV	(15)			NF125-HV	15			NF125-UV	(15)
Direct-to-line starting	2.2	9.1	N10-N35	9	NF30-CS	20	NF32-SV	20	NF63-SV	20	NF63-HV	20			NF125-SV	20			NF125-HV	20			NF125-UV	20
Direct-to-line starting	3.7	15	N18-N35	15	NF30-CS	30	NF32-SV	30	NF63-SV	30	NF63-HV	30			NF125-SV	30			NF125-HV	30			NF125-UV	30
Direct-to-line starting	5.5	22	N25·N35·N50·N65	22			NF63-CV	50	NF63-SV	50	NF63-HV	50			NF125-SV	50			NF125-HV	50			NF125-UV	50
Direct-to-line starting	7.5	29	N35·N50-N80	29			NF63-CV	60	NF63-SV	60	NF63-HV	60			NF125-SV	60			NF125-HV	60			NF125-UV	60
Direct-to-line starting	11	44	N50-N95	42									NF125-CV	75	NF125-SV	75			NF125-HV	75			NF125-UV	75
Direct-to-line starting	15	55	N65-N125	54									NF125-CV	100	NF125-SV	100			NF125-HV	100			NF125-UV	100
Y-Δ starting	5.5	22	—	22			NF63-CV	50	NF63-SV	50	NF63-HV	50			NF125-SV	50			NF125-HV	50			NF125-UV	50
Y-Δ starting	7.5	29	—	29			NF63-CV	60	NF63-SV	60	NF63-HV	60	NF125-CV	60	NF125-SV	60			NF125-HV	60			NF125-UV	60
Y-Δ starting	11	44	—	42									NF125-CV	75	NF125-SV	75			NF125-HV	75			NF125-UV	75
Y-Δ starting	15	55	—	54									NF125-CV	100	NF125-SV	100			NF125-HV	100			NF125-UV	100
Y-Δ starting / Direct-to-line starting	18.5	67	N80-N125	67									NF125-CV	100	NF125-SV	100			NF125-HV	100			NF125-UV	100
Y-Δ starting / Direct-to-line starting	22	85	N95-N150	82									NF250-CV	150			NF250-SV	150	NF250-HV	150			NF250-UV	150
Y-Δ starting / Direct-to-line starting	30	110	N125-N220	105									NF250-CV	175			NF250-SV	175	NF250-HV	175			NF250-UV	175
Y-Δ starting / Direct-to-line starting	37	130	N150-N220	125									NF250-CV	225			NF250-SV	225	NF250-HV	225			NF250-UV	225
Y-Δ starting / Direct-to-line starting	45	164	N180-N400	150											NF400-CW	350	NF400-SW	250	NF400-HEW	250	NF400-REW	250	NF400-UEW	250
Y-Δ starting / Direct-to-line starting	55	195	N220-N400	180											NF630-CW	500	NF400-SW	300	NF400-HEW	300	NF400-REW	300	NF400-UEW	300
Y-Δ starting / Direct-to-line starting	75	267	N300·N400·(N600)	250											NF630-CW	600	NF630-SW	500	NF400-HEW	400	NF400-REW	400	NF400-UEW	400
Y-Δ starting / Direct-to-line starting	90	320	N300·N400·(N600·N800)	330											NF800-CEW	600	NF630-SW	600	NF630-HEW	500	NF630-REW	500	NF800-UEW	500
Y-Δ starting / Direct-to-line starting	110	385	N300·N400·(N600·N800)	330											NF800-CEW	600	NF630-SEW	600	NF630-HEW	600	NF630-REW	600	NF800-UEW	600
Y-Δ starting / Direct-to-line starting	132	470	(N600·N800)	500																	NF1000-SEW	700		
Y-Δ starting / Direct-to-line starting	160	580	(N600·N800)	500																	NF1250-SEW	800		
Y-Δ starting / Direct-to-line starting	200	720	(N800)	600																	NF1600-SEW	1000		

Notes (1) The breaking capacity of NF250-CV is 36kA.
(2) The breaking capacity of NF1000- to 1600-SEW is 125kA.

Table 5. 5 Selection of MCCB for motor branch circuit 400/440VAC for 3-phase induction motor

Starting	For 4-pole motor: Output (kW)	For 4-pole motor: Full-load current (A)	Electromagnetic contactor: Model	Electromagnetic contactor: Heater nominal (A)	Breaking capacity (kA) 415 V AC (Icu sym): 1.5 Model	1.5 Rating	2.5 Model	2.5 Rating	7.5 Model	7.5 Rating	10 Model	10 Rating	25 Model	25 Rating	30(*1) Model	30(*1) Rating	50(*2) Model	50(*2) Rating	70 Model	70 Rating	150(*3) Model	150(*3) Rating	200 Model	200 Rating
Direct-to-line starting	0.2	0.6	N10-N21	0.7	NF30-CS	(3)	NF32-SV	(3)	NF63-SV	(3)	NF63-HV	10			NF125-SV	(15)	NF125-HV	(15)					NF125-UV	(15)
Direct-to-line starting	0.4	1.1	N10-N21	1.3	NF30-CS	(3)	NF32-SV	(3)	NF63-SV	(3)	NF63-HV	10			NF125-SV	(15)	NF125-HV	(15)					NF125-UV	(15)
Direct-to-line starting	0.75	1.9	N10-N21	1.7	NF30-CS	5	NF32-SV	5	NF63-SV	5	NF63-HV	10			NF125-SV	(15)	NF125-HV	(15)					NF125-UV	(15)
Direct-to-line starting	1.5	3.2	N10-N21	3.6	NF30-CS	10	NF32-SV	10	NF63-SV	10	NF63-HV	10			NF125-SV	(15)	NF125-HV	(15)					NF125-UV	(15)
Direct-to-line starting	2.2	4.6	N10-N21	5	NF30-CS	10	NF32-SV	10	NF63-SV	10	NF63-HV	10			NF125-SV	(15)	NF125-HV	(15)					NF125-UV	(15)
Direct-to-line starting	3.7	7.5	N11-N35	6.6	NF30-CS	20	NF32-SV	20	NF63-SV	20	NF63-HV	20			NF125-SV	20	NF125-HV	20					NF125-UV	20
Direct-to-line starting	5.5	11	N18-N35	11	NF30-CS	30	NF32-SV	30	NF63-SV	30	NF63-HV	30			NF125-SV	30	NF125-HV	30					NF125-UV	30
Direct-to-line starting	7.5	15	N20-N35 • N50	15	NF30-CS	30	NF32-SV	30	NF63-SV	30	NF63-HV	30			NF125-SV	30	NF125-HV	30					NF125-UV	30
Direct-to-line starting	11	22	N25 • N35 • N50 • N65	22		50	NF63-CV	50	NF63-SV	50	NF63-HV	50			NF125-SV	50	NF125-HV	50					NF125-UV	50
Direct-to-line starting	15	28	N35 • N50-N80	28			NF63-CV	60	NF63-SV	60	NF63-HV	60			NF125-SV	60	NF125-HV	60					NF125-UV	60
Direct-to-line starting	18.5	34	N50-N95	35			NF63-CV	60	NF63-SV	60	NF125-CV	60			NF125-SV	60	NF125-HV	60					NF125-UV	60
Direct-to-line starting	22	42	N50-N95	42							NF125-CV	75			NF125-SV	75	NF125-HV	75					NF125-UV	75
Direct-to-line starting	30	55	N65-N125	54							NF125-CV	100			NF125-SV	100	NF125-HV	100					NF125-UV	100
Direct-to-line starting	37	65	N80-N150	67							NF125-CV	100			NF125-SV	100	NF125-HV	100					NF125-UV	100
Direct-to-line starting	45	82	N95-N150	82									NF250-CV	125	NF250-SV	125			NF250-HV	125			NF250-UV	125
Y-Δ starting	5.5	11	–	11			NF63-CV	30	NF63-SV	30	NF63-HV	30			NF125-SV	30	NF250-HV	30					NF125-UV	30
Y-Δ starting	7.5	15	–	15			NF63-CV	40	NF63-SV	40	NF63-HV	40			NF125-SV	40	NF250-HV	40					NF125-UV	40
Y-Δ starting	11	22	–	22			NF63-CV	50	NF63-SV	50	NF63-HV	50			NF125-SV	50	NF250-HV	50					NF125-UV	50
Y-Δ starting	15	28	–	28			NF63-CV	60	NF63-SV	60	NF125-CV	60			NF125-SV	60	NF250-HV	60					NF125-UV	60
Y-Δ starting	18.5	34	–	35			NF63-CV	60	NF63-SV	60	NF125-CV	60			NF125-SV	60	NF250-HV	60					NF125-UV	60
Y-Δ starting	22	42	–	42							NF125-CV	75			NF125-SV	75	NF250-HV	75					NF125-UV	75
Y-Δ starting	30	55	–	54							NF125-CV	100			NF125-SV	100	NF250-HV	100					NF125-UV	100
Y-Δ starting	37	65	–	67							NF125-CV	100			NF125-SV	100	NF250-HV	100					NF125-UV	100
Y-Δ starting	45	82	–	82									NF250-CV	150	NF250-SV	150			NF250-HV	150			NF250-UV	150
Y-Δ starting / Direct-to-line starting	55	96	N125-N220	105									NF250-CV	175	NF250-SV	175			NF250-HV	175			NF250-UV	175
Y-Δ starting / Direct-to-line starting	75	134	N150-N220	125									NF250-CV	225	NF250-SV	225			NF250-HV	225			NF250-UV	225
Y-Δ starting / Direct-to-line starting	90	160	N180-N400	150											NF250-SEV	225			NF250-HEV	225	NF400-REW	225	NF400-UEW	225
Y-Δ starting / Direct-to-line starting	110	192	N180-N400	180													NF400-SW	350	NF400-HEW	300	NF400-REW	300	NF400-UEW	300
Y-Δ starting / Direct-to-line starting	132	233	N220-N400	250													NF400-SW	400	NF400-HEW	400	NF400-REW	400	NF400-UEW	400
Y-Δ starting / Direct-to-line starting	160	290	N300 • N400 • (N600)	250													NF630-SW	500	NF630-HEW	500	NF630-REW	500	NF800-UEW	500
Y-Δ starting / Direct-to-line starting	200	360	N300 • N400 • (N600 • N800)	330													NF630-SW	600	NF630-HEW	600	NF630-REW	600	NF800-UEW	600
Y-Δ starting / Direct-to-line starting	220	389	N300 • N400 • (N600 • N800)	–													NF630-SW	600	NF630-HEW	600	NF630-REW	600	NF800-UEW	600
Y-Δ starting / Direct-to-line starting	250	430	(N600 • N800)	500													NF630-SEW	700	NF630-HEW	600	NF630-REW	600	NF800-UEW	700
Y-Δ starting / Direct-to-line starting	300	500	(N600 • N800)	500													NF800-SEW	700	NF800-HEW	700	NF800-REW	700	NF800-UEW	700

Notes (1) The breaking capacity of NF250-SV and NF250-SEV is 36kA. (2) The breaking capacity of NF400-SW is 45kA. (3) The breaking capacity of NF400- to 800-REW is 125kA.

Remarks (1) Circuit breakers are selected under the starting conditions shown in the right table.
(2) Protection coordination is examined under the condition of cold start at 40°C.
(3) The ratings in parentheses apply to cases where thermal relays with saturating reactor are used.
(4) Although the inrush current upon switching to Δ connection fluctuates depending on the residual magnetic flux at star starting Δ connection closing phase or power supply transformer capacity, in most cases, the inrush current is less than the values shown in the right table.
(5) The maximum starting current is the effective value of current (value after transient phenomena disappear) at the time when the rotator starts to rotate.
(6) It was assumed that the Y-Δ starting would be performed by the open transition method which is a general method but is known to carry large transient inrush current.

Starting conditions for selection

Motor capacity	Direct-to-line starting time (600%)	Startup inrush current (x full-load current): Direct-to-line starting	Startup inrush current (x full-load current): Y-Δ starting
0.2 to 7.5kW	10s	12 times	16 times
11 to 55	10	12	17
75 to 300	10	14	18

Table 5. 6 Selection of ELCB for motor branch circuit 200/220VAC for 3-phase induction motor

Starting	For 4-pole motor Output (kW)	Full-load current (A)	Electromagnetic contactor Model	Heater nominal (A)	2.5 Model	Rating	7.5 Model	Rating	15(*1) Model	Rating	25 Model	Rating	30(*2) Model	Rating	50 Model	Rating	85 Model	Rating	100 Model	Rating	150 Model	Rating
					Breaking capacity (kA) 230 V AC (Icu sym)																	
Direct-to-line starting	0.1	0.7	N10-N21	0.7	NV30-CS	(5)	NV63-CV	(5)	NV32-SV	(15)	NV63-HV	(15)			NV125-SV	(15)			NV125-HV	(15)		
Direct-to-line starting	0.2	1.2		1.3																		
Direct-to-line starting	0.4	2.1	N10-N21	2.1	NV30-CS	5	NV63-CV	5	NV32-SV	(15)	NV63-HV	(15)			NV125-SV	(15)			NV125-HV	(15)		
Direct-to-line starting	0.75	3.7	N10-N21	3.6	NV30-CS	10	NV63-CV	10	NV32-SV	(15)	NV63-HV	(15)			NV125-SV	(15)			NV125-HV	(15)		
Direct-to-line starting	1.5	6.4	N10-N25	6.6	NV30-CS	15	NV63-CV	15	NV32-SV	15	NV63-HV	15			NV125-SV	15			NV125-HV	(15)		
Direct-to-line starting	2.2	9.1	N10-N35	9	NV30-CS	20	NV63-CV	20	NV32-SV	20	NV63-HV	20			NV125-SV	20			NV125-HV	20		
Direct-to-line starting	3.7	15	N18-N35	15	NV30-CS	30	NV63-CV	30	NV32-SV	30	NV63-HV	30			NV125-SV	30			NV125-HV	30		
Direct-to-line starting	5.5	22	N25 • N35 • N50 • N65	22			NV63-CV	50	NV63-SV	50	NV63-HV	50			NV125-SV	50			NV125-HV	50		
Direct-to-line starting	7.5	29	N35 • N50-N80	29			NV63-CV	60	NV63-SV	60	NV63-HV	60			NV125-SV	60			NV125-HV	60		
Direct-to-line starting	11	44	N50-N95	42									NV125-CV	75	NV125-SV	75			NV125-HV	75		
Direct-to-line starting	15	55	N65-N125	54									NV125-CV	100	NV125-SV	100			NV125-HV	100		
Y-Δ starting	5.5	22	–	22			NV63-CV	50	NV63-SV	50	NV63-HV	50			NV125-SV	50			NV125-HV	50		
Y-Δ starting	7.5	29	–	29			NV63-CV	60	NV63-SV	60	NV63-HV	60	NV125-CV	60	NV125-SV	60			NV125-HV	60		
Y-Δ starting	11	44	–	42									NV125-CV	75	NV125-SV	75			NV125-HV	75		
Y-Δ starting	15	55	–	54									NV125-CV	100	NV125-SV	100			NV125-HV	100		
Y-Δ starting / Direct-to-line starting	18.5	67	N80-N125	67									NV125-CV	100	NV125-SV	100			NV125-HV	100		
Y-Δ starting / Direct-to-line starting	22	85	N95-N150	82									NV250-CV	150			NV250-SV	150	NV250-HV	150		
Y-Δ starting / Direct-to-line starting	30	110	N125-N220	105									NV250-CV	175			NV250-SV	175	NV250-HV	175		
Y-Δ starting / Direct-to-line starting	37	130	N150-N220	125									NV250-CV	225			NV250-SV	225	NV250-HV	225		
Y-Δ starting / Direct-to-line starting	45	164	N180-N400	150											NV400-CW	350	NV400-SW	250	NV400-HEW	250	NV400-REW	250
Y-Δ starting / Direct-to-line starting	55	195	N220-N400	180											NV630-CW	500	NV400-SW	300	NV400-HEW	300	NV400-REW	300
Y-Δ starting / Direct-to-line starting	75	267	N300 • N400 • (N600)	250											NV630-CW	600	NV400-SEW	400	NV400-HEW	400	NV400-REW	400
Y-Δ starting / Direct-to-line starting	90	320	N300 • N400 • (N600 • N800)	330													NV630-SEW	500	NV630-HEW	500		
Y-Δ starting / Direct-to-line starting	110	385	N300 • N400 • (N600 • N800)	330													NV630-SEW	600	NV630-HEW	600		

Notes (1) The breaking capacity of NV32-SV is 10kA.
(2) The breaking capacity of NV250-CV is 36kA.

Table 5. 7 Selection of ELCB for motor branch circuit 400/420VAC for 3-phase induction motor

Starting	For 4-pole motor Output (kW)	Full-load current (A)	Electromagnetic contactor Model	Heater nominal (A)	2.5 Model	Rating	5 Model	Rating	7.5 Model	Rating	10 Model	Rating	25 Model	Rating	30(*1) Model	Rating	50(*2) Model	Rating	70 Model	Rating	125 Model	Rating
					Breaking capacity (kA) 415 V AC (Icu sym)																	
Direct-to-line starting	0.2	0.6	N10-N21	0.7	NV63-CV	(5)	NV32-SV	(5)	NV63-SV	(5)	NV63-HV	(15)			NV125-SV	(15)	NV125-HV	(15)				
Direct-to-line starting	0.4	1.1	N10-N21	1.3	NV63-CV	(5)	NV32-SV	(5)	NV63-SV	(5)	NV63-HV	(15)			NV125-SV	(15)	NV125-HV	(15)				
Direct-to-line starting	0.75	1.9	N10-N21	1.7	NV63-CV	5	NV32-SV	5	NV63-SV	5	NV63-HV	(15)			NV125-SV	(15)	NV125-HV	(15)				
Direct-to-line starting	1.5	3.2	N10-N21	3.6	NV63-CV	10	NV32-SV	10	NV63-SV	10	NV63-HV	(15)			NV125-SV	(15)	NV125-HV	(15)				
Direct-to-line starting	2.2	4.6	N10-N21	5	NV63-CV	10	NV32-SV	10	NV63-SV	10	NV63-HV	(15)			NV125-SV	(15)	NV125-HV	(15)				
Direct-to-line starting	3.7	7.5	N11-N35	6.6	NV63-CV	20	NV32-SV	20	NV63-SV	20	NV63-HV	20			NV125-SV	20	NV125-HV	20				
Direct-to-line starting	5.5	11	N18-N35	11	NV63-CV	30	NV32-SV	30	NV63-SV	30	NV63-HV	30			NV125-SV	30	NV125-HV	30				
Direct-to-line starting	7.5	15	N20-N35 • N50	15	NV63-CV	30	NV32-SV	30	NV63-SV	30	NV63-HV	30			NV125-SV	30	NV125-HV	30				
Direct-to-line starting	11	22	N25 • N35 • N50 • N65	22	NV63-CV	50			NV63-SV	50	NV63-HV	50			NV125-SV	50	NV125-HV	50				
Direct-to-line starting	15	28	N35 • N50-N80	28	NV63-CV	60			NV63-SV	60	NV63-HV	60			NV125-SV	60	NV125-HV	60				
Direct-to-line starting	18.5	34	N50-N95	35							NV125-CV	60			NV125-SV	60	NV125-HV	60				
Direct-to-line starting	22	42	N50-N95	42							NV125-CV	75			NV125-SV	75	NV125-HV	75				
Direct-to-line starting	30	55	N65-N125	54							NV125-CV	100			NV125-SV	100	NV125-HV	100				
Direct-to-line starting	37	65	N80-N150	67							NV125-CV	100			NV125-SV	100	NV125-HV	100				
Direct-to-line starting	45	82	N95-N150	82									NV250-CV	125	NV250-SV	125			NV250-HV	125		
Y-Δ starting	5.5	11	–	11	NV63-CV	30	NV32-SV	30	NV63-SV	30	NV63-HV	30			NV125-SV	30	NV125-HV	30				
Y-Δ starting	7.5	15	–	15	NV63-CV	40			NV63-SV	40	NV63-HV	40			NV125-SV	40	NV125-HV	40				
Y-Δ starting	11	22	–	22	NV63-CV	50			NV63-SV	50	NV63-HV	50			NV125-SV	50	NV125-HV	50				
Y-Δ starting	15	28	–	28	NV63-CV	60			NV63-SV	60	NV125-CV	60			NV125-SV	60	NV125-HV	60				
Y-Δ starting	18.5	34	–	35							NV125-CV	60			NV125-SV	60	NV125-HV	60				
Y-Δ starting	22	42	–	42							NV125-CV	75			NV125-SV	75	NV125-HV	75				
Y-Δ starting	30	55	–	54							NV125-CV	100			NV125-SV	100	NV125-HV	100				
Y-Δ starting	37	65	–	67							NV125-CV	100			NV125-SV	100	NV125-HV	100				
Y-Δ starting	45	82	–	82									NV250-CV	150	NV250-SV	150			NV250-HV	150		
Y-Δ starting / Direct-to-line starting	55	96	N125-N220	105									NV250-CV	175	NV250-SV	175			NV250-HV	175		
Y-Δ starting / Direct-to-line starting	75	134	N150-N220	125									NV250-CV	225	NV250-SV	225			NV250-HV	225		
Y-Δ starting / Direct-to-line starting	90	160	N180-N400	150											NV250-SEW	225		225	NV250-HEW	225	NV400-REW	225
Y-Δ starting / Direct-to-line starting	110	192	N180-N400	180													NV400-SW	350	NV400-HEW	300	NV400-REW	300
Y-Δ starting / Direct-to-line starting	132	233	N220-N400	250													NV400-SW	400	NV400-HEW	400	NV400-REW	400
Y-Δ starting / Direct-to-line starting	160	290	N300 • N400 • (N600)	250													NV630-SEW	500	NV630-HEW	500		
Y-Δ starting / Direct-to-line starting	200	360	N300 • N400 • (N600 • N800)	330													NV630-SEW	600	NV630-HEW	600		

Notes (1) The breaking capacity of NV250-SV and NV250-SEV is 36kA.
(2) The breaking capacity of NV400-SW is 45kA.

Remark (1) For the selecting conditions, please refer to the remarks on page 74.

5. 3 Selection of MCCB for welder circuit

5. 3. 1 Selection of rated current of MCCB for spot welder circuit

General spot welders are characterized by intermittent loading with a short period, and the load is switched only on the primary side of the welding transformer as shown in Fig. 5. 3.

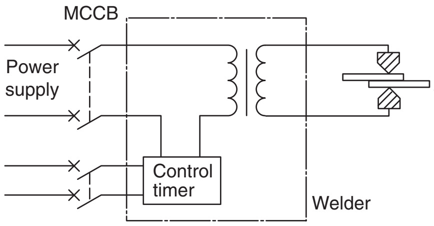


Fig. 5. 3 Spot welder circuit

Unlike for general circuits, for selection of MCCB for a welder circuit, it is necessary to take into consideration the following factors.

① Continuous current equivalent to intermittent load must be calculated.

② Transient magnetizing inrush current caused by switching on the primary side of transformer must be taken into consideration.

(1) Selection of MCCB rated current based on working conditions

Since the temperature rise of MCCB and wire is determined by thermally equivalent continuous current, it is necessary for selection to convert the intermittent current to thermally equivalent continuous current. Select a thermal or electronic tripping type MCCB on which the load current can be detected as the RMS value. The heating value in the energized state as shown in Fig. 5. 4. 1 can be obtained by the following formula.

$W = I_1{}^2Rt_1$, where R is the resistance.

The mean production heat can be obtained by the following formula.

$$\frac{W}{t_1+t_2} = \frac{I_1{}^2Rt_1}{t_1+t_2} = I_1{}^2R\beta = R\,(I_1\sqrt{\beta}\,)^2$$

(where, β is the duty cycle and obtained by $\beta = \dfrac{\text{weld time}}{\text{period}}$)

This value is equal to the production heat obtained when current $I_1\sqrt{\beta}$ is continuously carried. The thermally equivalent current I_e in the example shown in Fig. 5. 4. 1 is $I_e = I_1\sqrt{\beta} = 1200 \times \sqrt{0.0625} = 300$ (A). In this case, the continuous current of 300A and the average temperature are uniform, but the instantaneous temperature fluctuates as shown in Fig. 5. 4. 2, and the maximum temperature shown as Tm is higher than the average temperature Te at the continuous current of 300A. Operation of thermal MCCB is determined based on this maximum temperature. Therefore, it is necessary to select MCCB which will not operate at the maximum temperature, or to make sure that the operating time in the hot start mode is longer than the weld time. (For the hot start curve, see Appendix at the end of this book.) When selecting a magnetic-only MCCB, regard the thermally equivalent current as MCCB rated current.

However, since MCCB rated current contains a margin of approx. 15% for supply voltage fluctuation and dispersion among devices, the rated current shall be just above 345A obtained by the following formula.

$I_{MCCB} = I_e \times 1.15 = 300 \times 1.15 = 345$ (A)

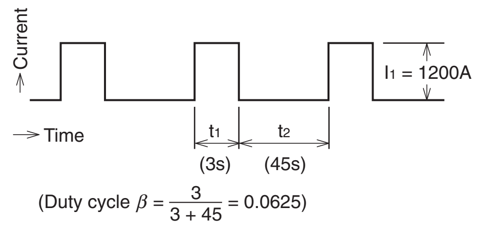


Fig. 5. 4. 1 Example of intermittent current

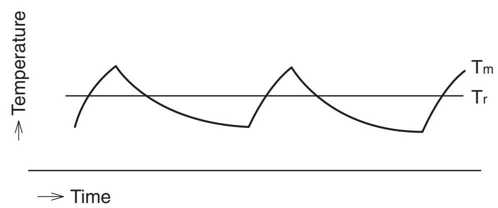


Fig. 5. 4. 2 Temperature rise due to intermittent current

The operating time of electronic MCCB is shorter than that of thermal magnetic MCCB. To select the rated current of electronic MCCB, reduce the wel
d time t1 to 1/2 or less of the lower limit of the characteristic curve, and allow a margin of 40% for the thermally equivalent current.

$I_{MCCB} \geq I_e \times 1.4$

$t_1 \leq$ 1/2 of lower limit of operating time at flowing current I_1

(2) Selection of MCCB based on welder capacity

In Item (1), MCCB is selected based on the welding conditions (working conditions). Since the welder working conditions are changed when the material to be welded is changed, you may think that MCCB must be changed every time the conditions are changed. However, if MCCB has been selected for the maximum working conditions

allowable for the welder capacity and specifications in consideration of the operation limit of the welder, it is unnecessary to change MCCB in each case.
According to JIS C9303 (Stationary type single phase AC spot welding machines), the rated capacities of welders are determined based on the duty cycle of 50%.
When the rated capacity and rated voltage of the welder shown in Fig. 5. 3 are 85 kVA and 200V, the thermally equivalent continuous current Ie is:

$$I_e = \frac{\text{rated capacity}}{\text{rated voltage}} \times \sqrt{\text{duty cycle}} = \frac{85 \times 10^3}{200} \times \sqrt{0.5} \fallingdotseq 300A$$

MCCB rated current is just above the following value.

$$I_{MCCB} = I_e \times 1.15 = 300 \times 1.15 = 345A$$

In this case, the relationship between the duty cycle β at which the operation limit is not exceeded and the maximum input I_β allowed at the duty cycle β is:

$$I_\beta = \frac{I_e}{\sqrt{\beta}} = \frac{300}{\sqrt{\beta}}$$

Fig. 5.5 shows the graph of this relationship obtained by converting the duty cycle β to the weld time with a cycle of 60 seconds. Accordingly, the thermally equivalent current of this welder is constantly 300A, but the operation limit varies depending on the duty cycle as shown below.

At duty cycle of 50% (weld time of 30 sec): Input current of up to 425A
At duty cycle of 6.25% (weld time of 3.75 sec): Input current of up to 1200A
At duty cycle of 1% (weld time of 0.6 sec): Input current of up to 3000A

However, since the primary input of welder is increased only by about 30% compared to the standard maximum welding current even if the secondary side is completely short-circuited, when the standard maximum input of this welder is considered to be 400 kVA, the maximum primary input, $I_{\beta max}$, is:

$$I_{\beta max} = \frac{\text{standard max input}}{\text{primary voltage}} \times 1.3 = \frac{400 \times 10^3}{200} = 2600\ A$$

Therefore, it is allowed to select MCCB for the maximum input I_β of 2600A or less.
The 75% hot start characteristics of Model NF400-SW with rating of 350A are shown by the dashed line in Fig. 5. 5. The welder temperature rise characteristics to the upper limit are shown by the solid line in Fig. 5. 5. Although the allowable time vs. current curve for prevention of burnout of welder is above the solid line, it is necessary to examine whether or not MCCB can protect the welder in each case.

However, in most cases, magnetic-only MCCB are used for protection of thyristors and wire in case of short fault.

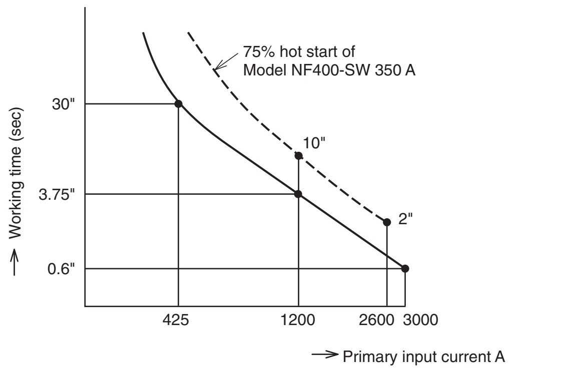


Fig. 5. 5 Working current and working time

(3) Selection of instantaneous tripping current in consideration of transient magnetizing inrush current

When a transformer circuit is closed on the primary side, transient inrush current flows owing to superposition of DC and saturation of transformer core depending on the closing phase. Most of recent welders are provided with synchronous closing system and wave peak control or only with synchronous closing system for prevention of malfunction of protective devices due to the inrush current and for uniform welding conditions.
In this case, the ratio of the RMS value of current in the steady state to the maximum peak value in the transient state is $\sqrt{2}$ to 2 based on actual measurement. In the case of asynchronous closing with soft start, the ratio is 4 or less based on actual measurement.
The maximum instantaneous value of transient magnetizing inrush current in each case is shown below.
In the case of synchronous closing with wave peak control:

$$I_{max} \fallingdotseq \sqrt{2} \times I_{\beta max}$$

In the case of synchronous closing only:

$$I_{max} \fallingdotseq 2 \times I_{\beta max}$$

In the case of asynchronous closing with soft start:

$$I_{max} \fallingdotseq 4 \times I_{\beta max}$$

In the case of asynchronous closing without soft start:

$$I_{max} \fallingdotseq 20 \times I_{\beta max}$$

If the synchronous closing system is used, the transient magnetizing inrush currents in both cases are almost identical. Therefore, for welders other than those of asynchronous closing type, it is allowed to regard I_{max} as $2I_{\beta max}$.
When the maximum primary input ($I_{\beta max}$) is 2600A on a welder with synchronous closing system,

$$I_{max} = 2 \times I_{\beta max} = 2 \times 2600 = 5200A.$$

Since MCCB instantaneous tripping current is shown as the RMS value in the catalog, MCCB instantaneous tripping current (Iinst) can be obtained by the following formula.

$$I_{inst} = \frac{I_{max}}{\sqrt{2}} = \frac{5200}{\sqrt{2}} = 3680A$$

Select MCCB whose Iinst is lower than the lower limit of instantaneous tripping current tolerances.
Examples of selection based on (2) and (3) are shown in Table 5. 8.

Table 5. 8 Table of selection of MCCB (magnetic-only) for spot welder

Rated capacity of welder kVA	Standard max. input of welder kVA	Single-phase, 200 V Circuit breaker (magnetic-only)			Single-phase, 400 V Circuit breaker (magnetic-only)		
		Model name	Rated current A	Instantaneous trip setting A	Model name	Rated current A	Instantaneous trip setting A
12.5	50	NF125-SV NF125-CV	125	600±120	NF32-SV	30	300±60
	62.5		125	750±150	NF63-SV, CV	40	400±80
25	100		125	1400±280	NF63-SV, CV	50,60	600±120
	125		125		NF125-SV NF125-CV	50	750±150
50	200	NF250-SV NF250-CV	225	2250±450		100	1400±280
	250		225	3150±630		100	

Note (1) It is allowed to use a standard MCCB having an instantaneous trip setting higher than the value shown in the table and a rated current of 1.15 Ie or more.
Remarks (1) The values of welders of synchronous closing type are shown.
(2) Select the model name of MCCB according to the rated breaking capacity. All these models are special models.

5. 3. 2 Selection of MCCB rated current for arc welder circuit

An arc welder is an intermittent load specified. MCCB rating can by selected by converting the load current into thermal-equivalent continuous current. If this is taken as the rated current, however, the current duration per cycle will become relatively long, with the attendant danger of thermal tripping of MCCB. In the total period of 10 minutes, if the duty factor is 50%, a 141% overload exists for 5 minutes; if the duty factor is 40%, a 158% overload exists for 4 minutes; and if the duty factor is 20%, a 224% overload exists for 2 minutes. Thus:

$$I_{MCCB} \geq \frac{1.2 \times P \times 10^3}{E}$$

where 1.2 : Allowance for random variations in arc-welder current, and supply-volt-age fluctuations
P : Welder rated capacity (kVA)
E : Supply voltage (V)

The switching transient in the arc welder is measured as 8~9 times the primary current. Consequently, using 1.2 allowance, it is necessary to select instantaneous-trip characteristics such that MCCB does not trip with a current of 11 times the primary current.

5. 4 Selection of MCCB for primary side of transformer

5. 4. 1 Magnetizing inrush current of transformer

When power is turn on to a transformer, significantly large magnetizing current may flow into the transformer. The magnetizing current may have a peak value of 10 times or more the rated current and may cause malfunction of MCCB, and the transformer circuit may not be closed. This current is called magnetizing inrush current.
The magnetizing inrush current varies depending on at which circuit voltage the transformer has been turned on and in which state the core residual magnetic flux was.
The magnetizing inrush current is maximized when the transformer is turned on at point P in Fig. 5. 6. The magnetic flux changes by $2\phi m$ in 1/2 cycle after the transformer is turned on. Since the magnetic flux starting point is the residual magnetic flux ϕr in the center of the core before the transformer is turned on, the magnetic flux will be $2\phi m + \phi r$ after 1/2 cycle and considerably exceed the saturated magnetic flux of the core, and, as the result of this, large magnetizing current will flow. This magnetizing inrush current attenuates with time. There is a tendency that the higher the transformer capacity, the larger the attenuation time constant. Table 5. 9 shows the approximate values of magnetizing inrush current. The values shown in Table 5. 9 are larger than the actual magnetizing inrush current values because the values were determined not in consideration of current limiting due to electric circuit impedance. If the value is unknown, the value in Table 5. 9 should be used. It is recommended to refer to the transformer manufacturer for details.

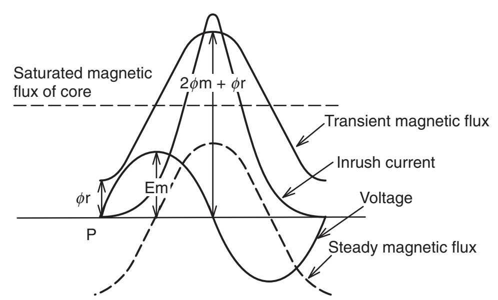


Fig. 5. 6 Magnetizing inrush current

Table 5. 9 **Examples of magnitude of magnetizing inrush current (Mitsubishi molded transformers for low-tension distribution)**

Capacity kVA	Single-phase transformer		3-phase transformer	
	First peak value (multiple) (Note)	Attenuation time constant (cycles)	First peak value (multiple) (Note)	Attenuation time constant (cycles)
5	45	2	32	2
10	43	2	31	3
20	43	3	26	3
30	37	3	24	3
50	35	4	22	4
75	30	6	15	5
100	27	7	15	5
150	24	8	15	6
200	21	10	14	6
300	17	12	12	8
500	19	12	12	15

Notes (1) Multiple: The first peak value of magnetizing inrush current for rated current peak value.

(2) Since the magnitude of magnetizing inrush current considerably depends on the applied voltage, making phase and residual magnetic flux of core, normally, the magnetizing inrush current changes every time a transformer is turned on. The above table shows the maximum values. Note that the magnetizing inrush current caused when the rated voltage is applied to the rated tap may be larger if overvoltage is applied.

5. 4. 2 Selection of MCCB for primary side of transformer

The magnetizing inrush current stated in 5. 4. 1 attenuates with time, and, lastly, only the magnetizing current flows. However, the instantaneous trip of MCCB reacts to transient current. Therefore, it is necessary to select MCCB having sufficiently higher instantaneous tripping current than the magnetizing inrush current of transformer. Thermal magnetic MCCB are more suitable than hydraulic magnetic MCCB because thermal magnetic MCCB with high magnetic tripping current can be manufactured easier.

Example of selection of MCCB for primary side of 3-phase 420V 50 kVA

The rated current I (RMS value) can be obtained as shown below.

$$I = \frac{\text{capacity (kVA)} \times 10^3}{\sqrt{3} \times \text{voltage (V)}} = \frac{50 \times 10^3}{\sqrt{3} \times 420} = 68.7\text{A}$$

The magnetizing inrush current peak value $I\phi$ is 22 times the rated current peak value.

$$I\phi = 22 \times \sqrt{2} I = 23 \times \sqrt{2} \times 68.7 = 2137\text{A}$$

Accordingly, MCCB having an instantaneous tripping current peak value of 2137A or more should be selected. Models NF250-CV and NF250-SV have the following instantaneous tripping current peak value at 150A.

$$I_{inst} = \sqrt{2} \times 150 \times 11.2 = 2376\text{A}$$

These models meet the requirement. Therefore, select Model NF250-CV or NF250-SV 3P150A.

Some models selected as stated above are shown in Tables 5. 10. 1 to 5. 13. 2.

The service life of circuit breaker on the primary circuit of transformer is significantly reduced by the influence of magnetizing inrush current. Install a switch to open and close the circuit.

■Single-phase 210 V

Table 5. 10. 1 MCCB

Transformer capacity kVA	Rated primary current A	Example of transformer excited inrush current ①			Example of transformer excited inrush current ②			Example of transformer excited inrush current ③		
		Crest value of first wave (multiple)	Model	Rating A	Crest value of first wave (multiple)	Model	Rating A	Crest value of first wave (multiple)	Model	Rating A
5	23.8	45	NF125-CV(*1) NF125-CV, NF125-SV, NF125-HV NF125-SEV, NF125-HEV	60 100 50	37	NF63-CV(*1) NF125-CV(*1) NF125-CV, NF125-SV	50 60 75	24	NF63-CV(*1) NF63-CV, NF63-SV NF125-CV(*2) NF125-SV	30 50 (50) 50
7.5	35.7	45	NF250-CV, NF250-SV, NF250-HV NF250-SEV, NF250-HEV	150 125	37	NF125-SEV NF125-CV(*1) NF250-CV, NF250-SV	50 75 125	24	NF63-CV(*1) NF125-CV(*1)(*2) NF125-CV, NF125-SV	50 60(50) 75
10	47.6	43	NF250-CV, NF250-SV, NF250-HV NF250-SEV, NF250-HEV	200 125	37	NF125-CV(*1) NF250-CV, NF250-SV NF250-SEV	100 150 125	24	NF125-CV(*1) NF125-CV, NF125-SV	60 100
15	71.4	43	NF400-CW NF400-SW NF400-SEW, NF400-HEW	400 300 200	35	NF250-CV, NF250-SV NF250-SEV	225 125	23	NF125-CV(*1) NF250-CV, NF250-SV	100 150
20	95.2	43	NF400-SW NF400-SEW, NF400-HEW	400 200	35	NF400-SW NF400-SEW	350 200	23	NF250-CV, NF250-SV NF250-SEV	200 125
30	143	37	NF400-SEW, NF400-HEW NF630-SW	200 500	34	NF400-SEW	200	23	NF400-SW NF400-SEW	300 200
50	238	35	NF630-SEW(*1) NF1000-SEW	300 500	34	NF630-SEW	300	23	NF400-SEW(*1) NF630-SEW	300 300
75	357	30	NF800-SEW(*1) NF1250-SEW	400 600	29	NF800-SEW(*1)	400	22	NF630-SEW	400
100	476	27	NF1000-SEW	800	28	NF1600-SEW	800	20	NF800-SEW(*1)	600
150	714	24	–	–	24	–	–	19	NF1600-SEW	800
200	952	21	–	–	22	–	–	19	–	–
300	1429	17	–	–	18	–	–	16	–	–
500	2381	–	–	–	17	–	–	–	–	–

Table 5. 10. 2 ELCB

Transformer capacity kVA	Rated primary current A	Example of transformer excited inrush current ①			Example of transformer excited inrush current ②			Example of transformer excited inrush current ③		
		Crest value of first wave (multiple)	Model	Rating A	Crest value of first wave (multiple)	Model	Rating A	Crest value of first wave (multiple)	Model	Rating A
5	23.8	45	NV125-CV, NV125-SV, NV125-HV NV125-SEV, NV125-HEV	100 50	37	NV125-CV, NV125-SV NV125-SEV	75 50	24	NV63-CV, NV63-SV NV125-CV NV125-SV NV125-SEV	50 60 50 50
7.5	35.7	45	NV250-CV, NV250-SV, NV250-HV NV250-SEV, NV250-HEV	150 125	37	NV125-SEV NV250-CV, NV250-SV	50 125	24	NV125-CV, NV125-SV NV125-SEV	75 50
10	47.6	43	NV250-CV, NV250-SV, NV250-HV NV250-SEV, NV250-HEV	200 125	37	NV250-CV, NV250-SV NV250-SEV	150 125	24	NV125-CV, NV125-SV NV250-CV, NV250-SV	100 125
15	71.4	43	NV400-CW NV400-SW NV400-SEW, NV400-HEW	400 300 200	35	NV250-CV, NV250-SV NV250-SEV	225 125	23	NV250-CV, NV250-SV NV250-SEV	150 125
20	95.2	43	NV400-SW NV400-SEW, NV400-HEW	400 200	35	NV400-SW NV400-SEW	350 200	23	NV250-CV, NV250-SV NV250-SEV	200 125
30	143	37	NV400-SEW, NV400-HEW NV630-SEW	200 300	34	NV400-SEW	200	23	NV400-SW NV400-SEW	300 200
50	238	35	–	–	34	NV630-SEW	300	23	NV630-SEW NV800-SEW	300 400
75	357	30	–	–	29	–	–	22	NV630-SEW	400
100	476	27	–	–	28	–	–	20	–	–
150	714	24	–	–	24	–	–	19	–	–
200	952	21	–	–	22	–	–	19	–	–
300	1429	17	–	–	18	–	–	16	–	–
500	2381	–	–	–	17	–	–	–	–	–

Notes (1) Examples of selection of high-instantaneous circuit breakers (special models) for primary side of transformer.
(2) The circuit breakers with rating in parentheses are special models.

Remarks (1) For the circuit breakers whose rated current is adjustable, the rated current values are shown.
(2) The crest value of the first wave of excited inrush current shall be calculated based on the multiple for the crest value of the first wave in the table, and the calculated value shall not exceed the lower limit crest value of instantaneous tripping current of circuit breaker. The circuit breakers are selected on condition that the transformer rated current value does not exceed 0.9 times the circuit breaker rated current. If the multiple for the crest value of the first wave is different from that shown in the table, a circuit breaker must be separately selected.

The service life of circuit breaker on the primary circuit of transformer is significantly reduced by the influence of magnetizing inrush current. Install a switch to open and close the circuit.

■Single-phase 420 V

Table 5. 11. 1 MCCB

Transformer capacity kVA	Rated primary current A	Example of transformer excited inrush current ①			Example of transformer excited inrush current ②			Example of transformer excited inrush current ③		
		Peak value of first wave (multiple)	Model	Rating A	Peak value of first wave (multiple)	Model	Rating A	Peak value of first wave (multiple)	Model	Rating A
5	11.9	45	NF63-CV(*1) NF63-CV, NF63-SV, NF63-HV NF125-CV, NF125-SV, NF125-HV	30 50 50	37	NF32-SV NF63-CV, NF63-SV NF125-SV	15 15 15	24	NF32-SV, NF63-CV, NF63-SV NF125-SV	15 40 15
7.5	17.9	45	NF63-CV(*1) NF125-CV, NF125-SV, NF125-HV	50 75	37	NF63-CV(*1) NF63-CV, NF63-SV NF125-CV, NF125-SV	40 60 60	24	NF32-SV, NF63-CV, NF63-SV NF125-SV NF125-CV(*2)	30 30 (50)
10	23.8	43	NF125-CV(*1) NF125-CV, NF125-SV, NF125-HV	60 100	37	NF63-CV(*1) NF125-CV, NF125-SV	50 75	24	NF63-CV(*1) NF63-CV, NF63-SV NF125-CV(*2) NF125-SV	30 50 (50) 50
15	35.7	43	NF125-CV(*1) NF250-CV, NF250-SV, NF250-HV NF250-SEV, NF250-HEV	100 150 125	35	NF125-CV(*1) NF125-CV, NF125-SV	60 100	23	NF63-CV(*1) NF125-CV(*1)(*2) NF125-CV, NF125-SV	50 60(50) 75
20	47.6	43	NF250-CV, NF250-SV, NF250-HV NF250-SEV, NF250-HEV	200 125	35	NF125-CV(*1) NF250-CV, NF250-SV NF250-SEV	100 150 125	23	NF125-CV(*1) NF125-CV, NF125-SV	60 100
30	71.4	37	NF250-SEV, NF250-HEV NF400-CW NF400-SW	125 350 250	34	NF250-CV, NF250-SV NF250-SEV	225 125	23	NF125-CV(*1) NF250-CV, NF250-SV	100 150
50	119	35	NF400-SW NF400-SEW, NF400-HEW	400 200	34	NF400-SW NF400-SEW	400 200	23	NF250-SEV	150
75	179	30	NF400-SEW, NF400-HEW NF630-SW NF630-SEW, NF630-HEW	200 500 300	29	NF400-SEW	200	22	NF400-SW NF400-SEW	400 200
100	238	27	NF400-SEW(*1) NF630-SW NF630-SEW, NF630-HEW	300 600 300	28	NF400-SEW(*1) NF630-SEW	300 300	20	NF400-SEW	350
150	357	24	NF630-SEW(*1)	400	–	–	–	19	NF400-SEW(*1) NF630-SEW	400 400
200	476	21	NF800-SEW(*1)	600	22	NF800-SEW(*1)	600	19	NF800-SEW(*1)	600
300	714	17	NF1250-SEW	800	18	NF1600-SEW	800	16	NF1250-SEW	800
500	1190	–	–	–	17	–	–	–	–	–

Table 5. 11. 2 ELCB

Transformer capacity kVA	Rated primary current A	Example of transformer excited inrush current ①			Example of transformer excited inrush current ②			Example of transformer excited inrush current ③		
		Peak value of first wave (multiple)	Model	Rating A	Peak value of first wave (multiple)	Model	Rating A	Peak value of first wave (multiple)	Model	Rating A
5	11.9	45	NV63-CV, NV63-SV, NV63-HV NV125-CV NV125-SV, NV125-HV	50 60 50	37	NV32-SV NV63-CV, NV63-SV NV125-SV	15 15 15	24	NV32-SV NV63-CV, NV63-SV NV125-SV	15 15 15
7.5	17.9	45	NV125-CV, NV125-SV, NV125-HV	75	37	NV63-CV, NV63-SV NV125-CV, NV125-SV	60 60	24	NV32-SV NV63-CV, NV63-SV NV125-SV	30 30 30
10	23.8	43	NV125-CV, NV125-SV, NV125-HV NV125-SEV, NV125-HEV	100 50	37	NV125-CV, NV125-SV NV125-SEV	75 50	24	NV63-CV, NV63-SV NV125-CV NV125-SV	50 60 50
15	35.7	43	NV250-CV, NV250-SV, NV250-HV NV250-SEV, NV250-HEV	150 125	35	NV125-CV, NV125-SV NV125-SEV	100 50	23	NV125-CV, NF125-SV NV125-SEV	75 50
20	47.6	43	NV250-CV, NV250-SV, NV250-HV NV250-SEV, NV250-HEV	200 125	35	NV250-CV, NV250-SV NV250-SEV	150 125	23	NV125-CV, NF125-SV NV125-SEV	100 60
30	71.4	37	NV250-SEV, NV250-HEV NV400-CW NV400-SW	125 350 250	34	NV250-CV, NV250-SV NV250-SEV	225 125	23	NV250-SV, NV250-SV NV250-SEV	150 125
50	119	35	NV400-SW NV400-SEW, NV400-HEW	400 200	34	NV400-SW NV400-SEW	400 200	23	NV250-SEV	150
75	179	30	NV400-SEW, NV400-HEW NV630-SEW, NV630-HEW	200 300	29	NV400-SEW	200	22	NV400-SW NV400-SEW	400 200
100	238	27	NV630-SEW, NV630-HEW NV800-SEW, NV800-HEW	300 400	28	NV630-SEW NV800-SEW	300 400	20	NV400-SEW	350
150	357	24	–	–	24	–	–	19	NV630-SEW NV800-SEW	400 400
200	476	21	–	–	22	–	–	19	–	–
300	714	17	–	–	18	–	–	16	–	–
500	1190	–	–	–	–	–	–	–	–	–

Notes (1) Examples of selection of high-instantaneous circuit breakers (special models) for primary side of transformer.
(2) The circuit breakers with rating in parentheses are special models.

Remarks (1) For the circuit breakers whose rated current is adjustable, the rated current values are shown.
(2) The peak value of the first wave of excited inrush current shall be calculated based on the multiple for the peak value of the first wave in the table, and the calculated value shall not exceed the lower limit peak value of instantaneous tripping current of circuit breaker. The circuit breakers are selected on condition that the transformer rated current value does not exceed 0.9 times the circuit breaker rated current. If the multiple for the peak value of the first wave is different from that shown in the table, a circuit breaker must be separately selected.

The service life of circuit breaker on the primary circuit of transformer is significantly reduced by the influence of magnetizing inrush current. Install a switch to open and close the circuit.

■3-phase 210 V

Table 5. 12. 1 MCCB

Transformer capacity kVA	Rated primary current A	Example of transformer excited inrush current ①			Example of transformer excited inrush current ②			Example of transformer excited inrush current ③		
		Peak value of first wave (multiple)	Model	Rating A	Peak value of first wave (multiple)	Model	Rating A	Peak value of first wave (multiple)	Model	Rating A
5	13.7	25	NF32-SV NF63-CV, NF63-SV, NF63-HV NF125-SV, NF125-HV	20 20 20	26	NF32-SV, NF63-CV, NF63-SV NF125-SV	20 20	18	NF32-SV, NF63-CV, NF63-SV NF125-SV	20 20
7.5	20.6	25	NF63-CV(*1) NF63-CV, NF63-SV, NF63-HV NF125-CV(*2) NF125-SV, NF125-HV	30 50 (50) 50	26	NF63-CV(*1) NF63-CV, NF63-SV NF125-CV, NF125-SV	30 50 50	18	NF32-SV, NF63-CV, NF63-SV NF125-CV(*2) NF125-SV	30 (50) 30
10	27.5	24	NF63-CV(*1) NF63-CV, NF63-SV, NF63-HV NF125-CV(*1) NF125-CV, NF125-SV, NF125-HV	40 60 50 60	26	NF63-CV(*1) NF63-CV, NF63-SV NF125-CV, NF125-SV	40 60 60	18	NF63-CV, NF63-SV NF125-CV(*2) NF125-SV	50 (50) 50
15	41.2	24	NF63-CV(*1) NF125-CV, NF125-SV, NF125-HV	50 100	26	NF125-CV(*1) NF125-CV, NF125-SV	60 100	18	NF63-CV(*1) NF63-CV, NF63-SV NF125-CV, NF125-SV	50 60 60
20	55.0	20	NF125-CV(*1) NF125-CV, NF125-SV, NF125-HV	75 100	26	NF125-CV(*1) NF125-SEV NF250-CV, NF250-SV	75 75 125	18	NF125-CV(*1) NF125-CV, NF125-SV	75 100
30	82.5	20	NF125-CV(*1) NF250-CV, NF250-SV, NF250-HV NF250-SEV, NF250-HEV	100 150 125	26	NF250-CV, NF250-SV NF250-SEV	200 125	18	NF125-CV(*1) NF250-CV, NF250-SV	100 150
50	137	20	NF250-SEV, NF250-HEV NF400-CW NF400-SW	175 350 250	23	NF400-CW NF400-SW NF400-SEW	400 300 200	16	NF250-CV, NF250-SV NF250-SEV	200 175
75	206	21	NF400-SW NF400-SEW, NF400-HEW	400 250	18	NF400-SW NF400-SEW	350 250	14	NF400-SW NF400-SEW	300 250
100	275	21	NF400-SEW(*1) NF630-SW NF630-SEW, NF630-HEW	350 600 350	17	NF400-SEW	350	13	NF400-SW NF400-SEW	350 300
150	412	17	NF630-SEW, NF630-HEW	500	14	NF630-SEW	500	13	NF630-SW NF630-SEW	500 500
200	550	16	NF800-SEW(*1)	700	13	NF800-SEW	700	12	NF800-SEW	700
300	825	16	NF1600-SEW	1000	13	NF1250-SEW	1000	12	NF1000-SEW	1000
500	1375	–	–	–	11	NF1600-SEW	1600	11	NF1600-SEW	1600

Table 5. 12. 2 ELCB

Transformer capacity kVA	Rated primary current A	Example of transformer excited inrush current ①			Example of transformer excited inrush current ②			Example of transformer excited inrush current ③		
		Peak value of first wave (multiple)	Model	Rating A	Peak value of first wave (multiple)	Model	Rating A	Peak value of first wave (multiple)	Model	Rating A
5	13.7	25	NV32-SV NV63-CV, NV63-SV, NV63-HV NV125-SV, NV125-HV	20 20 20	26	NV32-SV NV63-CV, NV63-SV NV125-SV	20 20 20	18	NV32-SV NV63-CV, NV63-SV NV125-SV	20 20 20
7.5	20.6	25	NV63-CV, NV63-SV, NV63-HV NV125-CV NV125-SV, NV125-HV	50 60 50	26	NV63-CV, NV63-SV NV125-CV NV125-SV	50 60 50	18	NV32-SV NV63-CV, NV63-SV NV125-SV	30 30 30
10	27.5	24	NV63-CV, NV63-SV, NV63-HV NV125-CV, NV125-SV, NV125-HV	60 60	26	NV63-CV, NV63-SV NV125-CV, NV125-SV	60 60	18	NV63-CV, NV63-SV NV125-CV NV125-SV	50 60 50
15	41.2	24	NV125-CV, NV125-SV, NV125-HV NV125-SEV, NV125-HEV	100 50	26	NV125-CV, NV125-SV NV125-SEV	100 50	18	NV63-CV, NV63-SV NV125-CV, NV125-SV	60 60
20	55.0	20	NV125-CV, NV125-SV, NV125-HV NV125-SEV, NV125-HEV	100 75	26	NV125-SEV NV250-CV, NV250-SV	75 125	18	NV125-CV, NV125-SV NV125-SEV	100 75
30	82.5	20	NV250-CV, NV250-SV, NV250-HV NV250-SEV, NV250-HEV	150 125	26	NV250-CV, NV250-SV NV250-SEV	200 125	18	NV250-CV, NV250-SV NV125-SEV	150 125
50	137	20	NV250-SEV, NV250-HEV NV400-CW NV400-SW	175 350 250	23	NV400-CW NV400-SW NV400-SEW	400 300 200	16	NV250-CV, NV250-SV NV250-SEV	200 175
75	206	21	NV400-SW NV400-SEW, NV400-HEW	400 250	18	NV400-SEW NV400-SW	250 350	14	NV400-SW NV400-SEW	300 250
100	275	21	NV630-SEW, NV630-HEW NV800-SEW, NV800-HEW	350 400	17	NV400-SEW	350	13	NV400-SW NV400-SEW	350 300
150	412	17	NV630-SEW, NV630-HEW	500	14	NV630-SEW NV800-SEW	500 500	13	NV630-SEW NV800-SEW	500 500
200	550	16	–	–	13	–	–	12	NV800-SEW	700
300	825	16	–	–	13	–	–	12	–	–
500	1375	–	–	–	11	–	–	11	–	–

Notes (1) Examples of selection of high-instantaneous circuit breakers (special models) for primary side of transformer.
(2) The circuit breakers with rating in parentheses are special models.

Remarks (1) For the circuit breakers whose rated current is adjustable, the rated current values are shown.
(2) The peak value of the first wave of excited inrush current shall be calculated based on the multiple for the peak value of the first wave in the table, and the calculated value shall not exceed the lower limit peak value of instantaneous tripping current of circuit breaker. The circuit breakers are selected on condition that the transformer rated current value does not exceed 0.9 times the circuit breaker rated current. If the multiple for the peak value of the first wave is different from that shown in the table, a circuit breaker must be separately selected.

■3-phase 420 V

Table 5. 13. 1 MCCB

Transformer capacity kVA	Rated primary current A	Example of transformer excited inrush current ①			Example of transformer excited inrush current ②			Example of transformer excited inrush current ③		
		Peak value of first wave (multiple)	Model	Rating A	Peak value of first wave (multiple)	Model	Rating A	Peak value of first wave (multiple)	Model	Rating A
5	6.9	32	NF32-SV NF63-CV, NF63-SV, NF63-HV NF125-SV, NF125-HV	10 10 15	26	NF30-CS NF32-SV, NF63-CV, NF63-SV	30 10	18	NF32-SV, NF63-CV, NF63-SV NF125-SV	10 15
7.5	10.3	32	NF32-SV NF63-CV, NF63-SV, NF63-HV NF125-SV, NF125-HV	15 15 15	26	NF32-SV, NF63-CV, NF63-SV NF125-SV	15 15	18	NF32-SV, NF63-CV, NF63-SV NF125-SV	15 15
10	13.7	31	NF32-SV NF63-CV, NF63-SV, NF63-HV NF125-CV(*2) NF125-SV, NF125-HV	20 20 (50) 20	26	NF32-SV NF63-CV, NF63-SV NF125-SV	20 20 20	18	NF32-SV NF63-CV, NF63-SV NF125-SV	20 20 20
15	20.6	31	NF63-CV(*1) NF63-CV, NF63-SV, NF63-HV NF125-CV, NF125-SV, NF125-HV NF125-SEV, NF125-HEV	40 60 60 50	26	NF63-CV(*1) NF63-CV, NF63-SV NF125-CV, NF125-SV	30 50 50	18	NF32-SV, NF63-CV, NF63-SV NF125-CV(*2) NF125-SV	30 (50) 30
20	27.5	26	NF63-CV(*1) NF63-CV, NF63-SV, NF63-HV NF125-CV(*1) NF125-CV, NF125-SV, NF125-HV	40 60 50 60	26	NF63-CV(*1) NF63-CV, NF63-SV NF125-CV, NF125-SV	40 60 60	18	NF63-CV(*1) NF63-CV, NF63-SV NF125-CV, NF125-SV	40 50 50
30	41.2	24	NF63-CV(*1) NF125-CV(*1) NF125-CV, NF125-SV, NF125-HV	50 50 100	26	NF125-CV(*1) NF125-CV, NF125-SV	60 100	18	NF63-CV(*1) NF125-CV, NF125-SV	50 75
50	68.7	22	NF125-CV(*1) NF250-CV, NF250-SV, NF250-HV NF250-SEV, NF250-HEV	100 150 125	23	NF125-CV(*1) NF250-CV, NF250-SV	100 150	16	NF125-CV, NF125-SV	100
75	103	15	NF250-CV, NF250-SV, NF250-HV NF250-SEV, NF250-HEV	150 125	18	NF250-CV, NF250-SV NF250-SEV	175 125	14	NF250-CV, NF250-SV	150
100	137	15	NF250-CV, NF250-SV, NF250-HV NF250-SEV, NF250-HEV	200 175	17	NF250-CV, NF250-SV NF250-SEV	200 175	13	NF250-CV, NF250-SV	175
150	206	15	NF400-CW NF400-SW NF400-SEW, NF400-HEW	400 300 250	14	NF400-SW NF400-SEW	300 250	13	NF400-CW NF400-SW NF400-SEW	400 250 250
200	275	14	NF400-SW NF400-SEW, NF400-HEW	350 350	13	NF400-SW/SEW	350/350	12	NF400-SW NF400-SEW	350 350
300	412	10	NF630-CW NF630-SW NF630-SEW, NF630-HEW	600 500 500	13	NF630-SEW	500	12	NF630-SW NF630-SEW	500 500
500	687	15	NF800-SEW(*1) NF1250-SEW	800 800	11	NF800-SEW	800	11	NF800-SEW	800

Table 5. 13. 2 ELCB

Transformer capacity kVA	Rated primary current A	Example of transformer excited inrush current ①			Example of transformer excited inrush current ②			Example of transformer excited inrush current ③		
		Peak value of first wave (multiple)	Model	Rating A	Peak value of first wave (multiple)	Model	Rating A	Peak value of first wave (multiple)	Model	Rating A
5	6.9	32	NV32-SV(*1) NV63-CV, NV63-SV(*1) NV63-HV NV125-SV, NV125-HV	15(10) 15(10) 15 15	26	NV32-SV(*1) NV63-CV, NV63-SV(*1) NV125-SV	15(10) 15(10) 15	18	NV32-SV(*1) NV63-CV, NV63-SV(*1) NV125-SV	15(10) 15(10) 15
7.5	10.3	32	NV32-SV NV63-CV, NV63-SV, NV63-HV NV125-SV, NV125-HV	15 15 15	26	NV32-SV NV63-CV, NV63-SV NV125-SV	15 15 15	18	NV32-SV NV63-CV, NV63-SV NV125-SV	15 15 15
10	13.7	31	NV32-SV NV63-CV, NV63-SV, NV63-HV NV125-CV NV125-SV, NV125-HV	20 20 50 20	26	NV32-SV NV63-CV, NV63-SV NV125-SV	20 20 20	18	NV32-SV NV63-CV, NV63-SV NV125-SV	20 20 20
15	20.6	31	NV63-CV, NV63-SV, NV63-HV NV125-CV, NV125-SV, NV125-HV NV125-SEV, NV125-HEV	60 60 50	26	NV63-CV, NV63-SV NV125-CV NV125-SV	50 60 50	18	NV32-SV NV63-CV, NV63-SV NV125-SV	30 30 30
20	27.5	26	NV63-CV, NV63-SV, NV63-HV NV125-CV, NV125-SV, NV125-HV	60 60	26	NV63-CV, NV63-SV NV125-CV, NV125-SV	60 60	18	NV63-CV, NV63-SV NV125-CV NV125-SV	50 60 50
30	41.2	24	NV125-CV, NV125-SV, NV125-HV NV125-SEV, NV125-HEV	100 50	26	NV125-CV, NV125-SV NV125-SEV	100 50	18	NV125-CV, NV125-SV	75
50	68.7	22	NV250-CV, NV250-SV, NV250-HV NV250-SEV, NV250-HEV	150 125	23	NV250-CV, NV250-SV NV250-SEV	150 125	16	NV125-CV, NV125-SV	100
75	103	15	NV250-CV, NV250-SV, NV250-HV NV250-SEV, NV250-HEV	150 125	18	NV250-CV, NV250-SV NV250-SEV	175 125	14	NV250-CV, NV250-SV	150
100	137	15	NV250-CV, NV250-SV, NV250-HV NV250-SEV, NV250-HEV	200 175	17	NV250-CV, NV250-SV NV250-SEV	200 175	13	NV250-CV, NV250-SV	175
150	206	15	NV400-CW NV400-SW NV400-SEW, NV400-HEW	400 300 250	14	NV400-SW NV400-SEW	300 250	13	NV400-CW NV400-SW NV400-SEW	400 250 250
200	275	14	NV400-SW NV400-SEW, NV400-HEW	350 350	13	NV400-SW NV400-SEW	350 350	12	NV400-SW NV400-SEW	350 350
300	412	10	NV630-CW, NV630-SW NV630-SEW, NV630-HEW	600 500	13	NV630-SEW NV800-SEW	500 500	12	NV630-SEW	500
500	687	15	–	–	11	–	–	11	–	–

Notes (1) Examples of selection of high-instantaneous circuit breakers (special models) for primary side of transformer.
(2) The circuit breakers with rating in parentheses are special models.

Remarks (1) For the circuit breakers whose rated current is adjustable, the rated current values are shown.
(2) The peak value of the first wave of excited inrush current shall be calculated based on the multiple for the peak value of the first wave in the table, and the calculated value shall not exceed the lower limit peak value of instantaneous tripping current of circuit breaker. The circuit breakers are selected on condition that the transformer rated current value does not exceed 0.9 times the circuit breaker rated current. If the multiple for the peak value of the first wave is different from that shown in the table, a circuit breaker must be separately selected.

5. 5 Selection of MCCB for capacitor circuit

When selecting MCCB for a capacitor circuit, attention shall be paid to the two points, the circuit opening and closing points, and harmonic current as stated below.

5. 5. 1 Leading current circuit opening surge (at circuit opening)

When a capacitor circuit as shown in Fig. 5. 7 is opened at the time t_1 shown in Fig. 5. 8, the circuit is broken at the zero point t_2 of leading current i. After this, the voltage on the power supply side will change as shown by the Vt curve. However, on the load side, since the voltage is kept at Vc owing to the electrical charge of the capacitor, a potential difference between MCCB contacts will occur as the voltage difference between Vc and Vt, the potential difference will be approx. twice the supply voltage peak value Em at t_3 approx. 1/2 cycle after t_2, and, if the contacts have not opened sufficiently, reignition of arc will occur. Then, the electrical charge of the capacitor will be discharged by the damped oscillation from the voltage magnitude of 4Em on the oscillation circuit determined by the reactance on the electric circuit and the capacitor capacity. After the arc is extinguished, Vc will be maintained at –Em again, and the potential difference between contacts, the difference between Vc and Vt, will increase. While this is repeated, the contacts will sufficiently open, reignition will not occur, and the circuit will open. Mitsubishi MCCB have extremely high contact opening speed and will rarely repeat reignition.

However, note that some MCCB do not have a quick-make/quick-break mechanism. ON such MCCB, if the capacitor capacity is small, the electrical charge is not discharged until the oscillating current is sufficiently attenuated. Therefore, if the arc is extinguished near the peak value in the reverse direction to the oscillation voltage, the capacitor voltage, as shown in Fig. 5. 9, will be maintained near -3Em at the first reignition and will gradually increase to 5Em at the second ignition and -7Em at the third reignition, thereby leading to damage to the capacitor.

Therefore, it is necessary to use MCCB with a quick-make/quick-break mechanism.

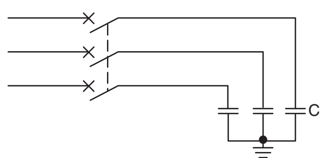


Fig. 5. 7 Example of capacitor circuit

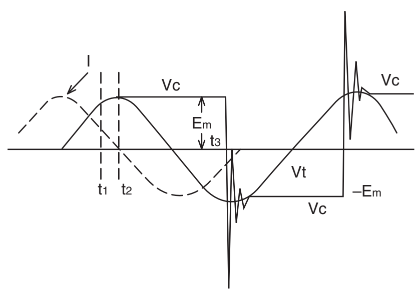


Fig. 5. 8 Breaking phenomenon of capacitor circuit

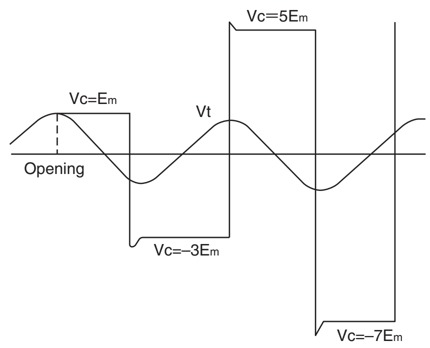


Fig. 5. 9 Example in the case of small capacitor capacity

5. 5. 2 Selection of MCCB in consideration of inrush current (at circuit closing)

When the supply voltage is V (v), capacitor capacity is C (F), frequency is f (Hz) and current is I (A), the relationship with kVA capacity P is determined as shown below.

In the case of 3-phase: $1000P = \sqrt{3}\,VI = 2\pi fCV^2$

In the case of single-phase: $1000P = VI = 2\pi fCV^2$

When the capacitor circuit is closed, the capacitor electrical charge q = CV appropriate to the voltage instantaneous value V in the closing phase must be supplied instantaneously. To supply the electrical charge, large inrush current will flow.

Assume that a circuit containing a capacitor has constants as shown in Fig. 5. 10. 1 and the circuit is closed when the voltage V reaches the supply voltage peak value V = Em.

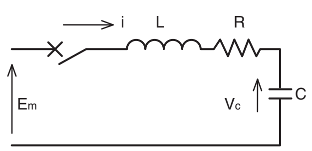


Fig. 5. 10. 1

According to the transient phenomenon theory, the flowing current i is determined as shown below.

$$i = \frac{2Em}{\sqrt{\frac{4L}{C} - R^2}}\,\varepsilon^{-\frac{R}{2L}t} \sin \frac{\sqrt{\frac{4L}{C} - R^2}}{2L}\,t$$

The change in i is plotted in Fig. 5. 10. 2, and the maximum value of current im is determined as shown below.

$$im = \frac{Em}{\sqrt{\frac{L}{C}}}\,\varepsilon^{-\frac{R}{\sqrt{\frac{4L}{C} - R^2}} \arctan \frac{\sqrt{\frac{4L}{C} - R^2}}{R}}$$

At the maximum value, $t = \tau_0$ is:

$$\tau_0 = \frac{2L}{\sqrt{\frac{4L}{C} - R^2}} \arctan \frac{\sqrt{\frac{4L}{C} - R^2}}{R}$$

Although the voltage V is not constant, it is allowed to consider V to be equal to Em until the transient phenomenon disappears because τ_0 is significantly small. Since the transit time is regarded as about $2\tau_0$, for the capacitor circuit, it is necessary to select MCCB having such an magnetic tripping current that MCCB does not operate at the passing current of $i_m \times 2\tau_0$.

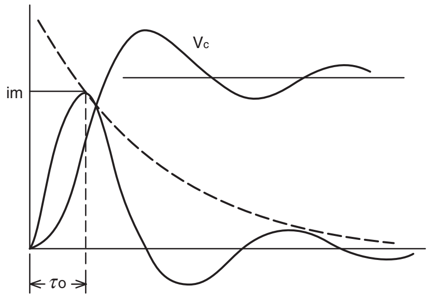


Fig. 5. 10. 2

Then, calculate the time in the following case.
In the case of MCCB for circuit of 3-phase, 200V, 50 Hz, 150 kvar capacitor:
According to calculation, $C = 1.1943 \times 10^{-2}$ (F), and I = 433 (A).
To estimate R and L of the circuit, the circuit short circuit current is assumed to be approx. 100 times the circuit capacity, 50000A.
From

$$Z = \sqrt{R^2 + (2\phi fL)^2} \qquad 50000 = \frac{V}{\sqrt{3}\,Z}$$

$$Z = \frac{200}{\sqrt{3} \times 50{,}000} = 2.31 \times 10^{-3}$$

Assuming that $\frac{2\pi fL}{R} = 5$,

$2\pi fL = 2.3 \times 10^{-3}$ (Ω)
$R = 4.6 \times 10^{-4}$ (Ω) $L = 7.34 \times 10^{-6}$ (H)

Since $Em = \frac{\sqrt{2}}{\sqrt{3}} V = 165$, im and τ_0 can be determined by the following calculation formulas.

im = 6600 (A)
$\tau_0 = 4.62 \times 10^{-4}$ (sec)

Since the transit time is approx. $2\tau_0$, select MCCB having an unlatching time of 0.001 s at a current of 6600A. If Model NF630-SW is selected, since its relay time at 10000A is 0.0029 s, it will not operate at the passing current shown above even if the unlatching time is shorter than this time.
However, to prevent abnormal wear or adhesion of MCCB contacts due to large passing current and to ensure the safety against unnecessary operation, the magnetic tripping current should be set larger than $\frac{6600}{\sqrt{2}} = 4700$A. The rating to ensure that the magnetic tripping current is larger than 4700A is 500A. Therefore, for this example, Model NF630-SW MCCB with rated current of 500A should be selected. In Table 5. 14, applicable MCCB rated current values are shown. If the short-circuit capacity of the circuit is remarkably larger than the rated breaking capacity, it is necessary to examine which model to be selected in accordance with the above example of calculation because MCCB may operate not only for protection against short circuit, but also owing to inrush current applied when the circuit is closed.
The above selection procedures apply in case where one capacitor bank is used and a reactor is not used. If 1 to 6 capacitor banks and a 6% reactor are used, see Table 5. 14.

Table 5. 14 Table of selection of MCCB for circuit of phase advance capacitor for power factor improvement

(No. 1) Single-phase 200 V

Equipment capacity kvar	Rated current of circuit breaker for branch circuit A					
	Total number of banks					
	Reactor 6%					
	1	2	3	4	5	6
5	40	40	40	40	40	50
10	75	75	75	75	75	100
15	125	125	125	125	125	125
20	150	150	150	150	150	175
25	200	200	200	200	200	225
30	225	225	225	225	225	250
40	300	300	300	300	300	350
50	400	400	400	400	400	500
75	600	600	600	600	600	600
100	800	800	800	800	800	800
150	1200	1200	1200	1200	1200	1200
200	1500	1500	1500	1500	1500	1600
250	1800	1800	1800	1800	1800	2000
300	2500	2500	2500	2500	2500	2500
400	3000	3000	3000	3000	3000	3000
500	–	–	–	–	–	–
600	–	–	–	–	–	–
750	–	–	–	–	–	–

(No. 2) Single-phase 415 V

Equipment capacity kvar	Rated current of circuit breaker for branch circuit A					
	Total number of banks					
	Reactor 6%					
	1	2	3	4	5	6
5	20	20	20	20	20	20
10	40	40	40	40	40	40
15	60	60	60	60	60	60
20	75	75	75	75	75	100
25	100	100	100	100	100	100
30	125	125	125	125	125	125
40	150	150	150	150	150	175
50	175	175	175	175	175	200
75	300	300	300	300	300	300
100	350	350	350	350	350	400
150	600	600	600	600	600	600
200	700	700	700	700	700	800
250	900	900	900	900	900	1000
300	1200	1200	1200	1200	1200	1200
400	1400	1400	1400	1400	1400	1600
500	1800	1800	1800	1800	1800	2000
600	2500	2500	2500	2500	2500	2500
750	2800	2800	2800	2800	2800	2800

(No. 1) 3-phase 200 V

Equipment capacity kvar	Rated current of circuit breaker for branch circuit A					
	Total number of banks					
	Reactor 6%					
	1	2	3	4	5	6
5	30	30	30	30	30	30
10	50	50	50	50	50	50
15	75	75	75	75	75	75
20	100	100	100	100	100	100
25	125	125	125	125	125	125
30	125	125	125	125	125	150
40	175	175	175	175	175	200
50	225	225	225	225	225	250
75	350	350	350	350	350	350
100	500	500	500	500	500	500
150	700	700	700	700	700	700
200	900	900	900	900	900	1000
250	1200	1200	1200	1200	1200	1200
300	1400	1400	1400	1400	1400	1400
400	1800	1800	1800	1800	1800	1800
500	2500	2500	2500	2500	2500	2500
600	2500	2500	2500	2500	2500	2800
750	3200	3200	3200	3200	3200	3200

(No. 4) 3-phase 415 V

Equipment capacity kvar	Rated current of circuit breaker for branch circuit A					
	Total number of banks					
	Reactor 6%					
	1	2	3	4	5	6
5	15	15	15	15	15	15
10	20	20	20	20	20	30
15	30	30	30	30	30	40
20	40	40	40	40	40	50
25	50	50	50	50	50	60
30	60	60	60	60	60	75
40	100	100	100	100	100	100
50	100	100	100	100	100	125
75	150	150	150	150	150	175
100	200	200	200	200	200	250
150	300	300	300	300	300	350
200	400	400	400	400	400	500
250	500	500	500	500	500	600
300	600	600	600	600	600	700
400	800	800	800	800	800	900
500	1000	1000	1000	1000	1000	1200
600	1200	1200	1200	1200	1200	1400
750	1500	1500	1500	1500	1500	1800

(1) The rated current of the circuit breaker to be selected is approx. 150% of the rated current of capacitor.
(2) When capacitor banks are switched according to the change in power factor, separately install electromagnetic contactors to open and close the circuit.
(3) To select the rated current of circuit breaker for main line, determine the sum of the capacitor capacities on the branch circuits, and find the appropriate rated current in the column of the number of banks “1” in the above table.
(4) The values at frequencies of 50 Hz and 60 Hz are shown.

5. 5. 3 Selection in consideration of harmonic current

Since capacitors have the property of expanding voltage distortion to several times higher current distortion, if there is a device applying a thyristor which may cause distortion in the voltage waveform near the capacitor, care must be taken in selecting MCCB. It has been reported that the current distortion reached 360% although the voltage distortion was about 19%. If there is a voltage distortion source near the capacitor and the current distortion is large, select a thermal magnetic MCCB for capacitor circuit.

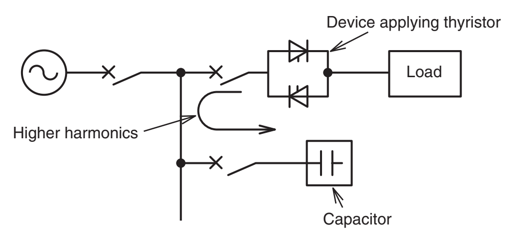


Fig. 5. 11 Higher harmonics source and capacitor circuit

5. 6 Selection of MCCB for thyristor (rectifying device) circuit

To protect thyristors and rectifying devices, it is necessary to examine two kinds of protection, protection from overvoltage and protection from overcurrent, from the viewpoint of their fracture process.
Protection from overvoltage can be ensured by arresters, dischargers or C-R filters, and actually these devices have been used for the protection. This section describes the protection from overcurrent.

5. 6. 1 Selection of rated current

Since MCCB used on thyristor circuits vary in rated current depending on the circuit type, care must be taken when selecting the rated current. MCCB may be installed on the AC side or DC side. The current value varies depending on the place of installation.
In Fig. 5. 12, $MCCB_1$ is installed on the AC side, and $MCCB_2$ is installed on the DC side.
Generally, it is advantageous to install it on the AC side because the rated current can be reduced.
Table 5. 15 shows the relationship between circuit system and current value of each part.
If the load current on the DC side is known from Table 5. 15, select the rated current of $MCCB_1$ to install on the AC side or $MCCB_2$ to install on the DC side. Note that the current of element (generally indicated as an average value in the catalog) is not identical to the rated current of MCCB.

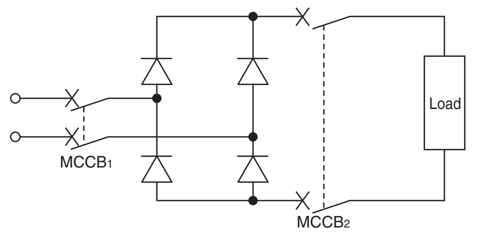


Fig. 5. 12 Example of installation of MCCB on thyristor circuit

5. 6. 2 Faults and overcurrent

On equipment using thyristors and rectifying elements, overcurrent may be caused by the following faults.

(1) Line faults

When a load device is under overload or short circuit occurs, overcurrent flows to the elements, thereby leading to their thermal destruction.

(2) Element faults

The element faults refer to faults that disable the thyristors and rectifying elements from blocking reverse voltage and cause arm short circuit owing to so-called blowout. If such a fault is left unsolved, other sound elements may be damaged. It is necessary to immediately remove the fault. If MCCB is installed on the DC side, fault current will flow as shown in Fig. 5. 13, and the sound elements cannot be protected. Therefore, it is necessary to install MCCB for each element or on the AC side.

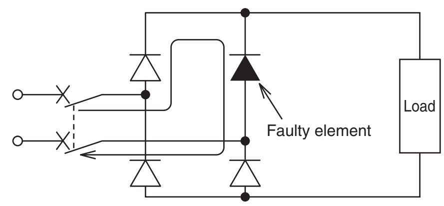


Fig. 5. 13 Example of element fault

(3) Fault of thyristor Leonard system

On a thyristor Leonard system which controls the speed of DC motor using a thyristor, upon occurrence of loss of power during inverter operation (period during which the rotational energy of motor is regenerated to the AD power supply side) or commutation failure owing to inadequacies of the thyristor control circuit, the DC motor will work as a generator with the use of its rotary inertia, and short circuit current as shown in Fig. 5. 14 will flow. To protect the thyristor from this short circuit current, it is necessary to install MCCB on the DC side.

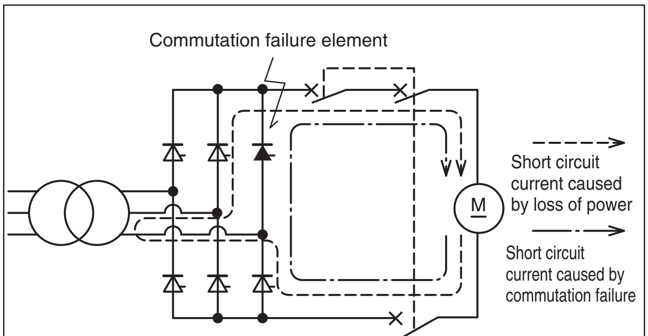


Fig. 5. 14 Faults on thyristor Leonard system

5. 6. 3 Protection from overcurrent

Although it is possible to completely protect elements against all kinds of overcurrent, it is better to examine protection coordination from the total viewpoint of economic efficiency and reliability required for equipment.

For circuits intended mainly to improve economic efficiency, the scope of protection is designed neglecting the overcurrent which will occur with low probability without consideration of protection of whole range.

Where complete protection of elements on an important circuit is required, several kinds of protective devices are used although a high cost may be required.

(1) Protection against overload current

The thermal destruction of thyristor causes loss of control ability owing to increase in junction temperature. After occurrence of this fault, it is necessary to immediately open the circuit to prevent the junction temperature rise from exceeding the specified value. The overload current range is the range indicated by the maximum peak current curve in each element catalog and normally the range in which the element can withstand the current for a time longer than 1 cycle.

Most of the values of the above maximum peak current are indicated as peak values. When examining the protection coordination with MCCB, it is necessary to convert the value to the RMS value.

(2) Protection against short circuit current

When an external circuit shorts or a thyristor element destructs to cause arm short circuit, large current will flow. Therefore, the circuit must be broken in an extremely short time. Since the breaking time at short circuit is generally 1 cycle or less, it is necessary for examination of thermal destruction of element to take into consideration the current squared time product. The relationship (allowable li^2dt of element) > (passing li^2dt of MCCB converted to value to be added to element) must be established, but the value of (passing li^2dt of MCCB) is affected by the magnitude of short circuit current, breaking time or current-limiting characteristics.

The breaking time of MCCB depends greatly on the rate of rise of short circuit current, $\frac{di}{dt}$, of the line circuit on the load side. It is necessary to sufficiently take this into consideration.

If a short occurs on the circuit shown in Fig. 5. 15, the short circuit current i is:

$$i = \frac{E}{R}\left(1 - \varepsilon^{-\frac{R}{L}t}\right)$$

Accordingly, the rate of current rise $\frac{di}{dt}$ is:

$$\left(\frac{di}{dt}\right)_{t=0} = \frac{E}{L}$$

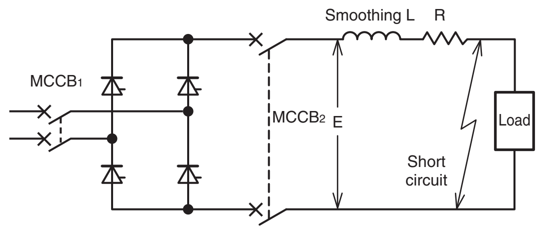
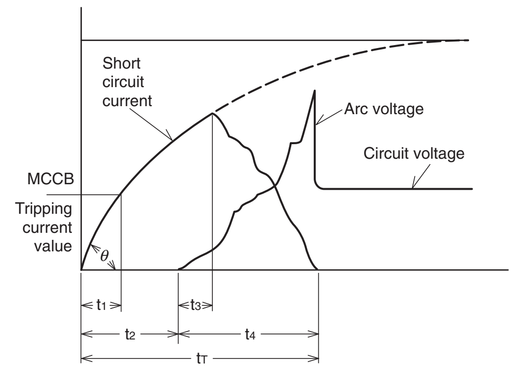


Fig. 5. 15 Short circuit

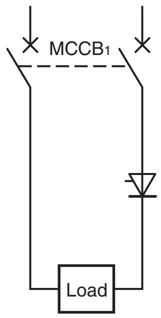
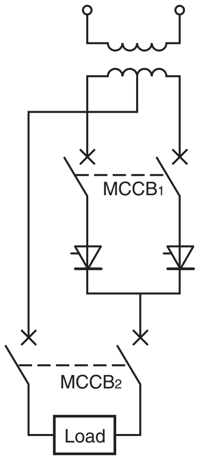
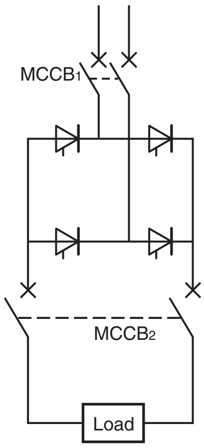
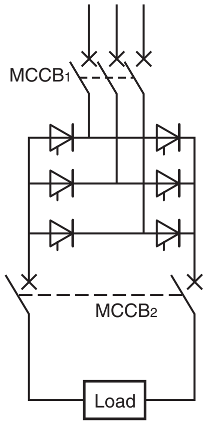
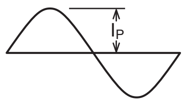
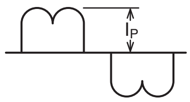
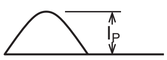
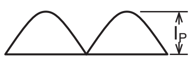
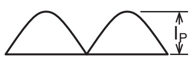
Since the magnitude of inductance on the line or for smoothing significantly affects $\frac{di}{dt}$, if there is a possibility of large short circuit current, it is effective to increase L and reduce the rate of current rise to break the circuit with MCCB before large current flows. Fig. 5. 16 shows this phenomenon on $MCCB_2$.



t_1 : Time until trip setting of MCCB is attained
t_2 : Opening time
t_3 : Time from start of opening of pole to current peak value
t_4 : Arc time
t_T : Total breaking time
θ : Rate of current rise $\frac{di}{dt}$

Fig. 5. 16 Shows this phenomenon on MCCB2.

Table 5. 15 Circuit types and current in each part

	Circuit Ⅰ	Circuit Ⅱ	Circuit Ⅲ	Circuit Ⅳ
Circuit type				
Average current of element, IF (A)	$\frac{I_p}{\pi}$	$\frac{I_p}{\pi}$	$\frac{I_p}{\pi}$	$\frac{I_p}{\pi}$
RMS current of element, Ie (A)	$\frac{I_p}{2}$	$\frac{I_p}{2}$	$\frac{I_p}{2}$	$\sqrt{\frac{1}{6}+\frac{\sqrt{3}}{4\pi}}\,I_p$ ($\fallingdotseq 0.552I_p$)
DC output average current, ID (A)	I_F	$2I_F$	$2I_F$	$3I_F$
Current to MCCB / MCCB1 / RMS current, I_B (A)	$\frac{\pi}{2}I_F$ or $\frac{\pi}{2}I_D$	$\frac{\pi}{2}I_F$ or $\frac{\pi}{4}I_D$	$\frac{\pi}{\sqrt{2}}I_F$ ($\fallingdotseq 2.22I_F$) or $\frac{\pi}{2\sqrt{2}}I_D$ ($\fallingdotseq 1.11I_D$)	$\pi\sqrt{\frac{1}{3}+\frac{\sqrt{3}}{2\pi}}\,I_F$ ($\fallingdotseq 2.45I_F$) or $\frac{\pi}{3}\sqrt{\frac{1}{3}+\frac{\sqrt{3}}{2\pi}}\,I_D$ ($\fallingdotseq 0.817I_D$)
Current to MCCB / MCCB1 / Current waveform				
Current to MCCB / MCCB2 / RMS current, I_B (A)	$\frac{\pi}{2}I_F$ or $\frac{\pi}{2}I_D$	$\frac{\pi}{\sqrt{2}}I_F$ or $\frac{\pi}{2\sqrt{2}}I_D$	$\frac{\pi}{\sqrt{2}}I_F$ or $\frac{\pi}{2\sqrt{2}}I_D$	$\pi\sqrt{\frac{1}{2}+\frac{3\sqrt{3}}{4\pi}}\,I_F \fallingdotseq 3I_F$ or $\frac{\pi}{3}\sqrt{\frac{1}{2}+\frac{3\sqrt{3}}{4\pi}}\,I_D \fallingdotseq I_D$
Current to MCCB / MCCB2 / Current waveform				

Note: The load is a resistance load, and the conduction angle of element is 180°.

When the passing $\int i^2dt$ of MCCB2 for the total breaking time t_T is converted to $\int i^2dt$ applied to the element, the value must be lower than the allowable $\int i^2dt$ of the element.

It is better to confirm whether or not the above relationship is established by experiment than by calculation if the circuit constant has been determined.

Then, in the case where the rate of current rise is large, when the short circuit current on the AC side is $i = I_p \sin\omega t$ and the breaking time of MCCB1 is 1 cycle, $\int i^2dt$ applied to the thyristor is determined as shown below.

Circuits Ⅰ, Ⅱ and Ⅲ

$$\int i^2dt = \int_0^{\frac{1}{2f}} I_p^2 \sin^2\omega t dt = \frac{1}{4f} I_p^2 \text{ (A}^2\text{sec)} \cdots\cdots\cdots\cdots (1)$$

Circuit Ⅳ

$$\int i^2dt = 2\int_{\frac{1}{6f}}^{\frac{1}{3f}} I_p^2 \sin^2\omega t dt = \frac{I_p^2}{f}\left(\frac{1}{6} + \frac{\sqrt{3}}{4\pi}\right) \text{(A}^2\text{sec)} \cdots (2)$$

Ip: Peak value of current flowing to element (A)

f: Frequency (Hz)

If the value of $\int i^2dt$ of the element is known, the allowable passing $\int i^2dt$ of MCCB can be obtained by the above formula (1) or (2). As shown in Table 5. 15, when the breaking time is within 1 cycle, the current flowing to MCCB1 is identical to the current flowing to the element on the circuits Ⅰ and Ⅱ, but the current flowing to MCCB1 is twice the current flowing to the element on the circuits III and IV. Therefore, the passing $\int i^2dt$ of MCCB1 should be less than twice the allowable $\int i^2dt$ of the element. (When the breaking time is within 1/2 cycle, the passing $\int i^2dt$ of MCCB1 must be less than the allowable $\int i^2dt$ of the element.)

Generally, diodes have higher overcurrent strength and can withstand larger passing $I^2 \cdot t$ than thyristors, and protection of diodes is relatively easier for MCCB.

(3) Example of examination of protection coordination with overcurrent

Fig. 5. 17 shows the maximum peak current of thyristor and the characteristics of MCCB plotted on the same time-current diagram. (This figure shows the characteristics of MCCB1. For MCCB2, the diagram can be plotted in the same manner.)

The elements can be protected from short circuit current and overload current in the range Ⅱ. In the range Ⅰ, they cannot be protected by MCCB, and it is necessary to separately install overcurrent relays.

In the range Ⅲ, no problems will occur if large current in the range Ⅲ does not flow when the circuit shorts, but, if there is a possibility of short circuit current in this range, it is necessary to reduce the current by installing an inductance L on the DC side or ensure the coordination by using a high-speed current-limiting fuse.

For the ranges Ⅰ and Ⅲ, it may be allowed to omit the use of overcurrent relay and high-speed current limiting fuse to improve the economic efficiency based on the results of examination of the incidence and probability of faults in these ranges.

The range II is expanded to enlarge the scope of protection by using MCCB having lower magnetic tripping current.

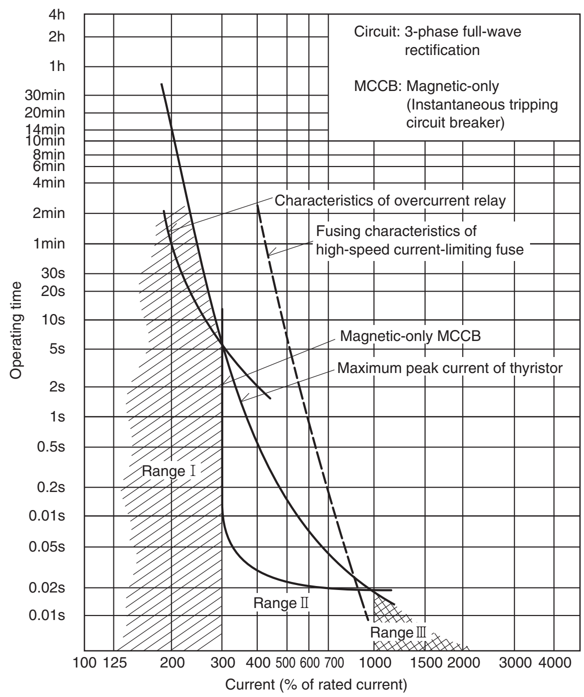


Fig. 5. 17 Protection coordination of thyristor by MCCB

(4) Protection against short circuit current caused by loss of power or commutation failure on thyristor Leonard system

To protect the thyristors from short circuit current caused by loss of power or commutation failure during inverter operation, magnetic-only MCCB which instantaneously operate at current of approx. 3 times the rated current shall be installed on the DC side. As shown in Fig. 5. 14, install 3-pole (or 4-pole) MCCB in series. As shown in the figure, the short circuit current flowing to MCCB is identical to the short circuit current flowing to the element. Therefore, the following condition should be established.

(Allowable $\int i^2dt$ of element) > (passing $\int i^2dt$ of MCCB)

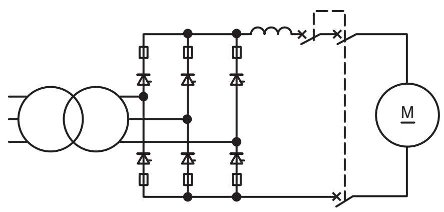
It is necessary to experimentally prove the condition. Table 5. 14 shows the selection of MCCB on the DC side of thyristor leonard system. Select MCCB according to the table.

Table 5. 16 Selection of MCCB on DC side of thyristor leonard system (Circuit voltage 480 VDC)

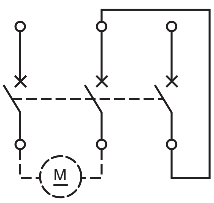
Breaker for protection of thyristor				Short circuit			Passing $I^2 \cdot t$ ($\times 10^4$) ($A^2 \cdot s$)	Example of Mitsubishi thyristor which can be protected by breaker for protection of thyristor		
Model	Number of poles	Rated current A	Electromagnetic tripping current A	Voltage V	Current A	Time constant ms		Model	* Number of parallel thyristors	Allowable $I^2 \cdot t$ ($\times 10^4$) ($A^2 \cdot s$)
NF400-SW	3	275	964±193	480	8340	11 to 26	10 to 19	FT500DL	1P	42
		360	1260±252	480	7320	13 to 20	20 to 29	FT500DL	1P	42
NF630-SW	3	540	1890±378	480	10100	24 to 34	33 to 39	FT500DL	1P	42
NF800-SDW	3	800	2400±480	480	15100	11 to 19	43 to 59	FT500DL	2P	168

Note: * indicates the number of thyristors connected in parallel. "2P" indicates parallel connection of two thyristors.

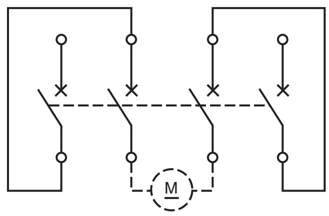
Remarks (1) The quick acting fuse shown in the figure interrupts the short circuit current which flows to the thyristor from the AC power supply when the thyristor is ruptured.



Remarks (2) Connect MCCB in series as shown in the following figure.



Serial connection of 3-pole MCCB



Serial connection of 4-pole MCCB

5. 7 Selection of MCCB for discharge lamp circuit

5. 7. 1 Influence of higher harmonics and measures

On discharge lamp circuits, current containing harmonics caused by nonlinearity of lamps flows also to the stabilizer input side. Therefore, it is necessary to separate the distribution system and examine the wiring design and the stabilizer circuit structure.

The harmonic content of discharge lamp circuit contains mainly the third higher harmonics and, in some cases, 5th, 7th, 9th… higher harmonics.

Normal discharge circuits contain approx. 20% of the third higher harmonics.

When the harmonic content is increased by distortion of supply voltage which significantly affects the distortion of load current, if the discharge lamp circuit contains a power factor improvement capacitor connected to the power supply in parallel, the impedance for higher harmonics will lower, and the harmonic current will increase. Therefore, the considerations stated in 5. 5. 3 shall be taken. In this section, the selection in the case where there is no distortion of supply voltage and the current distortion is caused by the discharge lamp circuit itself.

When selecting MCCB, it is necessary to examine the influence of higher harmonics. Furthermore, the selection conditions vary depending on the discharge lamp circuit type. For mercury-vapor lamp, fluorescent lamp and sodium-vapor lamp circuits, select MCCB in consideration of the followings.

5. 7. 2 Selection of MCCB for mercury-vapor lamps

Since the mercury-vapor lamps do not have a function to maintain the current uniform, they are provided with stabilizers.

Since the lamps are used at 200V in most cases, normally, choke coil type stabilizers are used. For 100V power supply, leakage transformer type stabilizers are used.

The stabilizers include the high power factor type with built-in phase-advancing capacitor and the low power factor type. Also, there are constant power (or constant output) type stabilizers which maintain the current uniform at voltage fluctuation and startup and flicker-less stabilizers which reduce flicker.

For selection of MCCB, the following factors shall be taken into consideration.

① When a general (high power factor or low power factor) stabilizer is used, the starting current is approx. 1.7 times the current in the stable state. Therefore, if the selected MCCB rated current is 1.7 times or more the load current, this means that the influence of higher harmonics is taken into consideration.

② When a constant output or flicker-less type stabilizer is used, the starting current is lower than the current in the stable state. Select MCCB having rated current of 1.3 to 1.4 times the load current in consideration of the influence of higher harmonics.

Select MCCB rated current on condition that the starting current is 170% of the input current in the stable state and the start-up time is 5 min. When selecting MCCB with frame size of 100A or smaller, since the safety current which such MCCB can withstand for 5 min is not so larger than the rated current, select MCCB with rated current next higher than 170% of the input current in the stable state. When selecting MCCB with total current exceeding 100A, since such MCCB can withstand current of approx. 120% for up to 5 min, select MCCB with rated current next higher than 1.4 times (1.7/1.2) the input current in the stable state.

Example of selection of rated current of MCCB for 10 general 100W 100V 50 Hz high-power factor mercury-vapor lamps

Since the input current per lamp in the stable state is 1.35A, select NF32-SV, 30A, the model with rated current next higher than 1.35 × 1.7 × 10 = 23 (A).

5. 7. 3 Selection of MCCB for fluorescent lamps and sodium-vapor lamps

The starting current of these lamps is negligible, but the content of higher harmonic components is high, 10 to 40%. Therefore, it is necessary to set MCCB rated current to 1.4 times or more the load current in consideration of the higher harmonic components.

> The service life of the circuit breaker may be reduced by the influence of inrush current caused when the lamp is turned on depending on the lighting equipment. It is recommended to periodically check the circuit breaker for abnormal temperature rise.

5. 8 Selection of MCCB for inverter circuit

5. 8. 1 Causes of distorted waveform current

Distorted waveform current can be caused by CVCF units with thyristors and transistors used as computer power supply units, various rectifiers and VVVF units for induction motor control for meeting the recent trend toward energy conservation. These units are used to make DC power using the semiconductor switching function or further make the target AC power from the DC power. Generally, a large capacitor is connected for smoothing after a rectifier circuit, and, therefore, pulsed charging current to the capacitor flows to the power supply side every half cycle. Load current generated by superposition of high-frequency current by chopped frequency on the fundamental frequency flows to the load side because the voltage is chopped by higher harmonics in the process of conversion to AC power. Below is described the selection for the VVVF inverters which will be developed as the main control method for widely-used induction motors. There are two VVVF inverter control methods, PAM (Pulse Amplitude Modulation) and PWM (Pulse Width Modulation). The harmonic content generated varies depending on the method. To reduce the harmonic content in the input current, according to Tables 5. 18 and 5. 19 , it is effective to add a DC reactor (DCL) or AC reactor (ACL). In the output current waveform shown in Fig. 5. 20, the harmonic content in the case of PWM is higher.

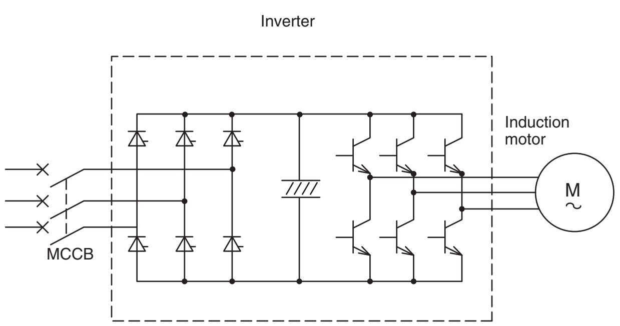


Fig. 5. 18 Example of use of MCCB on inverter circuit

5. 8. 2 Selection of MCCB

For the power supply side of inverter, at first, select MCCB recommended by the inverter manufacturer. If the manufacturer does not recommend any MCCB, correct the relationship between MCCB rated current I_{MCCB} and the load current I as shown below in consideration of changes in characteristics and temperature rise due to distortion of load current waveform.

$I_{MCCB} \geq K \times I$

Thermal magnetic (bimetal) and electronic (RMS value detection) type MCCB use current RMS value detecting systems and ensure correct protection against overload even at current with distorted waveform. It is better to select one of these types.

Table 5. 17 Correction factor

Tripping method of MCCB	Correction factor K
Thermal magnetic (bimetal)	1.4
(Note 1) Hydraulic magnetic	1.4
Electronic (RMS value detection)	1.4

This table applies to the following current conditions.

① $\text{Distortion factor} = \dfrac{\text{RMS value of total harmonic content}}{\text{RMS value of fundamental frequency}} \times 100 \leq 100\%$ or less

② $\text{Peak factor} = \dfrac{\text{Peak value}}{\text{RMS value}} \leq 3$ or less

② The major part of the harmonic content includes the 7th harmonic and lower harmonics.

Note

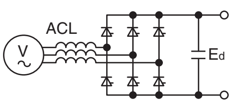
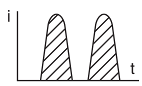
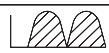
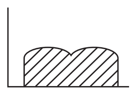
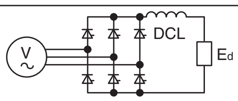
Note (1) Since hydraulic magnetic MCCB may considerably change in characteristics depending on waveform distortion, it is recommended to use thermal magnetic MCCB.

Table 5. 18 Example of data on content of harmonic current on power supply side

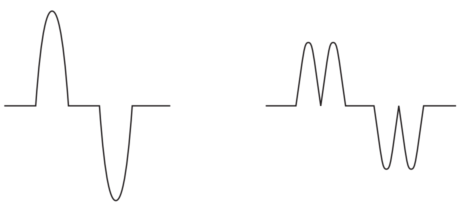
Harmonic order	Content of harmonic current (%)			
	PWM		PAM	
	Without ACL (standard)	With ACL for improvement of power factor	With standard ACL	With ACL for improvement of power factor
BASE	81.6	97.0	83.6	97.2
2	–	–	–	–
3	3.7	–	2.5	–
4	–	–	–	–
5	49.6	21.9	48.3	21.7
6	–	–	–	–
7	27.4	7.1	23.7	7.0
8	–	–	–	–
9	–	–	–	–
10	–	–	–	–
11	7.6	3.9	6.2	3.7
12	–	–	–	–
13	6.7	2.8	4.7	2.6

Note: Without DCL, at output frequency of 60 Hz under 100% load

Table 5. 19 Peak factor of inverter input current

Circuit			Input current			
			Power factor	Form factor	Peak factor	Waveform (half-wave type)
With ACL	Large ← ACL → Small		58.7 or less	1.99 or more	2.16 or more	
			58.7%	1.99	2.16	
			58.7 to 83.5%	1.99 to 1.27	2.16 to 1.71	
			83.5%	1.27	1.71	
			83.5 to 95.3%	1.27 to 1.23	1.71 to 1.28	
With DCL			95.3%	1.23	1.28	

Power factor = (DC voltage × DC current)/($\sqrt{3}$ × effective AC voltage × effective AC current)
Form factor = (RMS value)/(mean value) Peak factor = (max. value)/(RMS value)



(a) PAM method (b) PWM method

Fig. 5. 19 Inverter input current

(a) PAM method (a) Fixed-width PWM method

Fig. 5. 20 Inverter output current

5. 9 Cases of distorted wave current load and measures

5. 9. 1 Equipment provided with machines, such as computers, containing DC power supply as loads

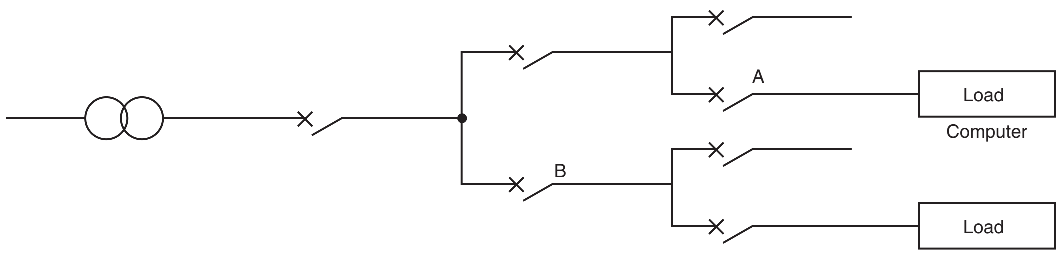


Fig. 5. 21 Measurement circuit

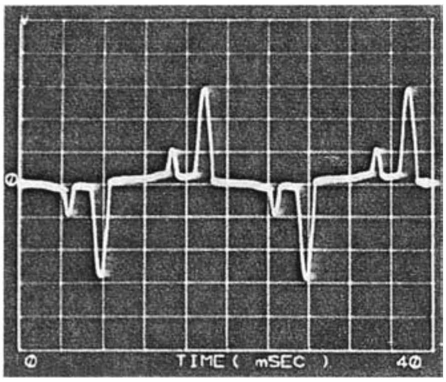


Fig. 5. 22 Current waveform at measurement point A

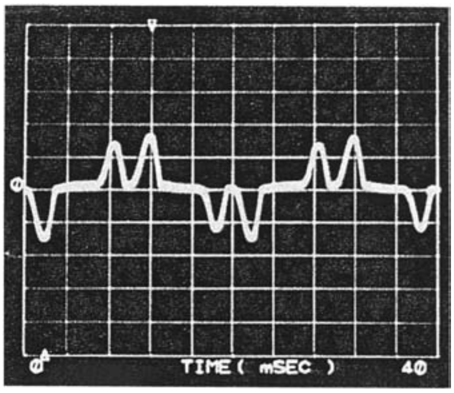


Fig. 5. 23 Current waveform at measurement point B

Table 5. 20 Harmonic content (% of fundamental frequency content)

Measurement point	Current value	3rd	5th	7th	9th	11th	13th	15th	17th	Total distortion factor
A	7.8A	58.6	70.5	62.3	32.9	27.1	24.8	7.5	4.6	122.3
B	19A	12.5	65.6	42.4	2.4	13.2	3.9	2.2	3.8	80.7

Application of MCCB

At this level of distortion, any of the thermal magnetic and hydraulic magnetic MCCB can be used.
The rated current can be selected in the same manner as stated in 5. 8. 2.

5. 9. 2 Equipment containing thyristor control unit on part of system

In this case, large current distortion is caused at another capacitive branch due to voltage distortion caused in the thyristor control unit.

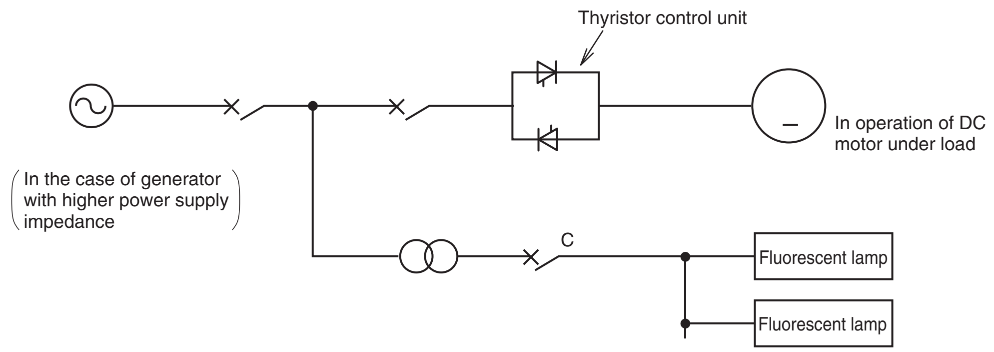


Fig. 5. 24 Measurement circuit

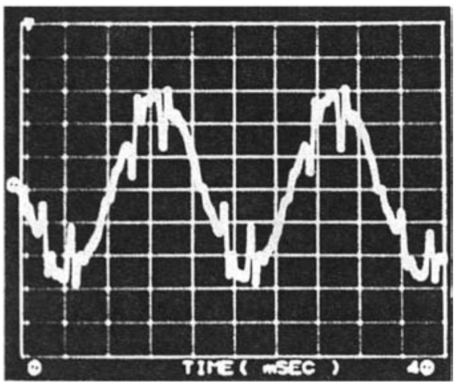


Fig. 5. 25 Voltage waveform at measurement point C

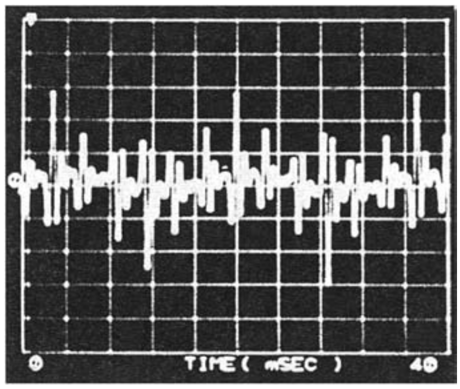


Fig. 5. 26 Current waveform at measurement point C

Table 5. 21 Harmonic content (% of fundamental frequency content)

Waveform	Measurement	2nd	2rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th	17th	18th	19th	20th	Total distortion factor
Voltageu	101.3V	0.5	1.3	1.2	7.7	0.7	5.8	0.5	3.0	2.0	5.5	1.7	6.9	1.0	5.1	2.9	3.3	6.0	6.6	4.9	19.2
Current	19.3A	1.8	3.1	5.0	43.5	9.9	47.9	7.8	15.5	20.9	64.1	44.0	117.2	36.2	45.3	50.6	98.2	177	116.4	68.4	358.6

Application of MCCB

Use thermal magnetic MCCB. Select MCCB rated current I_{MCCB} of twice or more the load current I because the current distortion factor is very high.

5. 10 Example of MCCB selection

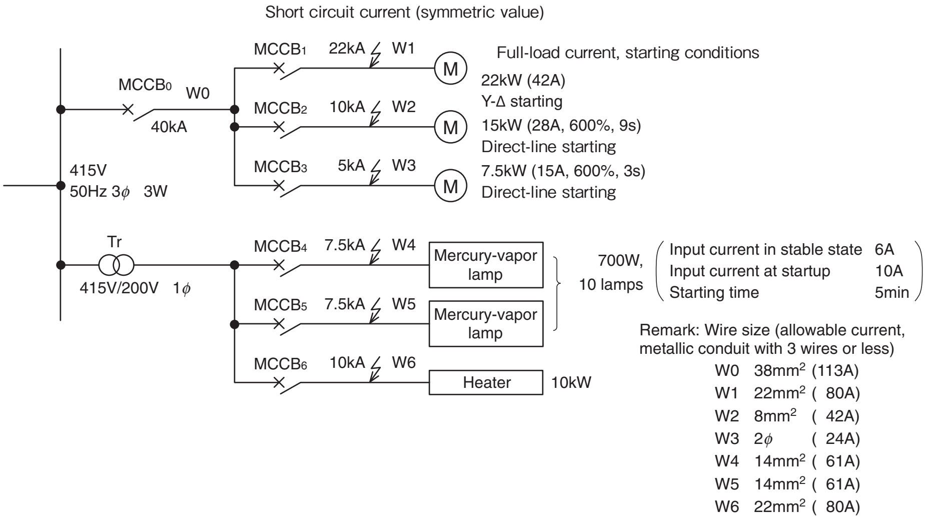


Fig. 5. 27 Example of selection

An example of selection of MCCB in Fig. 5. 27 is shown in Table 5. 22.

Table 5. 22 Example of selection

MCCB 0	MCCB 1	MCCB 2	MCCB 3	MCCB 4, 5	MCCB 6
Select from Table 5. 4 on p. 72. ↓ MCCB rated current 125A ↓ Short circuit current 40kA ↓ Select NF250-HV (breaking capacity 75kA) 125A.	Select from Table 5. 10 on p. 77. ↓ NF125-SV 75A	MB cannot be selected based on starting conditions. ↓ Select from Table 5. 10 on p. 77. ↓ Short circuit current 40kA ↓ NF125-CV 60A.	MB can be selected based on starting conditions. ↓ Select from Table 5. 8 on p. 76. ↓ Short circuit current 5kA ↓ NF63-SV (MB) 16A.	(See 5. 7. 2 on p. 98.) Input current in stable state = 6A × 10 lamps = 60A In consideration of starting current, multiply by 1.5: 6 × 1.5 = 90A Therefore, branch into two 50A lines. According to breaking capacity of 7.5kA, select NF63-SV 50A.	(See 5.2.2 on p. 73.) Load current: $\frac{10kW}{200V} = 50A$ MCCB rated current: × 0.8 ≥ 50A MCCB rated current: 75A ↓ Short circuit current 10kA ↓ NF125-CV 75A.

MCCB 0	MCCB 1	MCCB 2	MCCB 3	MCCB 4, 5	MCCB 6
Check • Wire: Sum of full-load currents of motors × 1.1 = 85 × 1.1 = 93.5A ↓ Allowed because allowable current of 38mm² wire is 113A and 93.5A < 113A. • MCCB rated current ≤ sum of full-load currents of motors × 3 = 255A Allowable current of wire (metallic conduit wiring) × 2.5 = 113 × 2.5 ≒ 283A ↓ Favorable from the viewpoint of electrical technology because MCCB rated current 125A is lower than 255A.	Check • MCCB rated current ≤ allowable current of wire (metallic conduit wiring) × 2.5 = 80 × 2.5 = 200A Therefore, 75A MCCB is favorable.	Check • Wire: Full-load current of motor × 1.25 = 35.4A ↓ 8mm² (42A) Therefore, it is favorable. • MCCB rated current ≤ allowable current of wire (metallic conduit wiring) × 2.5 = 42 × 2.5 = 105A Therefore, 60A MCCB is favorable.	Check • Wire: Full-load current of motor × 1.25 = 19A ↓ 2ϕ (24A) Therefore, it is favorable. • MCCB rated current ≤ allowable current of wire Therefore, 16A MB is favorable.	Check • Favorable because starting current and starting time are 50A and 5min. • Wire and MCCB rating Favorable because wire thickness of 50A branch circuit is 14mm².	Check • Wire and MCCB rating: MCCB 50A or lower because no motor is connected. Therefore, 14mm² wire is favorable. MCCB rated current ≤ allowable current of wire Therefore, it is favorable. MCCB rated current ≤ device rated current × 1.3 Therefore, favorable from the viewpoint of electrical technology.

5. 11 Notes on selection according to load characteristics

For selection of MCCB or ELCB, the following instructions shall be observed because of the load characteristics.

① Depending on the lighting equipment on a lamp circuit, the circuit breaker service life may be reduced by the influence of inrush current caused when the lamp is turned on. Periodically check the circuit breakers.

② If the circuit breaker on the primary circuit of a transformer is used as a switch, the service life will be significantly reduced by the influence of magnetizing inrush current. Install a switch separately.

③ If a circuit breaker (hydraulic magnetic type) is used on a circuit containing an excessively large harmonic content, the circuit breaker temperature will significantly rise, and, in some cases, resulting in fire. Take measures to reduce the distortion of load current or use a thermal magnetic type circuit breaker.

④ Do not install a circuit breaker on the secondary side of inverter circuit. Doing so may cause burnout of the electronic circuit of an earth leakage circuit breaker or abnormal overheating of circuit breaker.

⑤ If the circuit breaker on the primary side of inverter is used as a switch, the service life may be reduced by the influence of transient inrush current. Use another switch for switching.

⑥ On a circuit containing harmonic content, the zero-phase current transformer (ZCT) of the circuit breaker will be overheated owing to iron loss. Use circuit breakers at a load device leakage current distortion of 10kHz or less and at 3A or less. In the case of circuit breakers with frame size of 800A and above, use them at a load device leakage current distortion of 5kHz or less and at 3A or less.

6. Outline of ELCB

6 Outline of ELCB

6. 1 What is ELCB?

6. 1. 1 Definition of ELCB

ELCB is a molded case circuit breaker used in a low-voltage AC electrical circuit to provide electric shock protection and prevent fires from current leakages.

ELCB is called a “Circuit-breaker incorporating residual current protection” (IEC60947-2) or a “Residual current operated circuit breaker” (IEC61009-1). It is also referred to as a “Ground-fault circuit-interrupter” (UL943). There are two types of ELCB, a current-operated type and a voltage-operated type. In many countries, only the more beneficial current operating-type is manufactured. The Japanese Industrial Standards (JIS) apply only to the current-operated type. In terms of ELCB structure, the product is defined as a “device with integrated ground fault detector, tripping device and switch mechanism in an insulated body, and automatically shuts off the electric current in the event of a ground fault.”

6. 1. 2 History of ELCB

The low-voltage electrical circuit is originally a non-grounding circuit. However, after it became possible to use an alternating current to reduce a high-voltage to a low voltage with a transformer, the risk of contact of high and low voltages and the risk of double ground faults increased. Subsequently, the use of grounded systems became mainstream. Of course, there are still some non-grounding circuits, but most are grounded circuits.

In Japan and the United States, priority has been placed on preventing fires from ground faults. Most protective grounding systems reduce the voltage and ground the device frame. Conversely in Europe, 220 V voltage systems are used in homes, so there has been an interest in ELCB from an early stage.

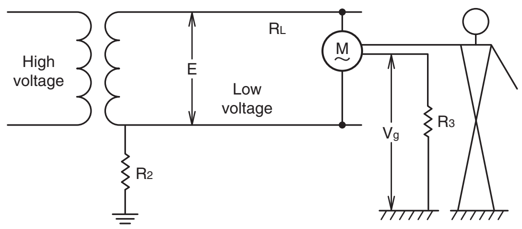
The initial ELCB was a voltage-operated type, and the protection range was small. There were many disadvantages in the use, etc. Today, most units adopt the current operating type.

Year	Worldwide trends	Trends in Japan	Trends at Mitsubishi
1912	○ Votage-operated type developed in Germany		
1930	○ Voltage-operated type standardized with VDE (Germany)		
1939	○ Voltage-operated type standardized with BS-842 (UK)		
1950	○ Current-operated type mass produced in Germany		
1957	○ Current-operated type released in France		
1962		○ Electric fire alarm standardized	
1963	○ Current-operated type		
1965	○ 30mA sensitivity developed in Germany and France		
1968	○ Current-operated type standardized with		○ Mitsubishi ELCB-1 approved by National Institute of Occupational Safety and Health, Japan
1969		○ Ministry of Labor mandates installation of current leakage prevention ○ Stipulated in Electrical Appliance and Material Control Law	
1970	○ Review of ELCB started at IEC	○ Use of 30mA product started widely throughout Japan	○ Mitsubishi ELCB released (up to 50 A frame)
1971			○ Up to 225A frame released, earth leakage relay released
1972	○ Standardized with UL934.1053 (USA)	○ Installation mandated with revision to Electric Equipment technical Standards ○ Standardized with JEM	○ Separated type earth leakage relay released
1973			○ Inverse time relay type released, Awarded the Minister of Construction award
1974		○ JIS-C8371 enacted	○ Shock wave withstand type released ○ Time-delay type released
1975			○ NV Series up to 600A frame released
1977		○ Time-relay type, time-delay type, high-speed type specified by Electrical Appliance and Material Control Law ○ Places requiring installation of earth leakage breakers increased due to revision of Indoor Wiring Regulations.	○ IC incorporated for all models ○ Large capacity NV-SA Series released (up to 1200A frame) ○ Earth leakage relay NV-ZS, NV-SU, NV-ZA Series released ○ NV-ZU awarded Minister of Construction award
1980		○ JIS-C8371 revised	
1983	○ IEC Publication 755 Current-operating type ground fault protection device enacted		
1986		○ Places requiring installation of earth leakage breakers increased due to revision of Indoor Wiring Regulations.	
1987			○ Super ELCB Released Rated voltage 100-200-415V AC common Sensitivity current 3-step changeover
1990	○ IEC 1008 “125A and smaller residual current circuit breaker without overcurrent protection for household and similar uses” enacted	○ Indoor Wiring Regulations revised	
1991	○ IEC 1009 “125A and smaller residual current circuit breaker with overcurrent protection for household and similar uses” enacted		○ New Super ELCB released Higher harmonics and surge compliance Same dimensions as MCCB
1992	○ IEC 60947-2 Annex B “Residual current circuit breaker” enacted	○ Equipment of single-phase 3-wire type electrical circuit ELCB with a neutral wire phase failure protection mandated through revision of Indoor Wiring Regulations. ○ JIS C 8371 revised * Applicable range increased * Coordination with IEC * Matters related to improvement of reliability improved	○ ELCB with single-phase neutral wire phase failure protection upgraded
1995			○ PSS released (30 to 255A frame)
1997			○ PSS released (400 to 800A frame)
2001			○ WSS released (30 to 255A frame), awarded the Minister of Land, Infrastructure and Transport award ○ Earth leakage relay upgraded
2004			○ Compact UL489 Listed no-fuse breaker with earth leakage protection released
2006			○ White & World Super Series released
2011			○ WS-V Series released, awarded the Minister of Land, Infrastructure and Transport award

6. 2 Why is ELCB needed?

Awareness toward electric shock injuries and short-circuit fires has increased in view of saving human life and assets. In addition, places requiring installation of ELCB has increased for legal reasons.

Conventionally, electric shocks were prevented only with protective grounding work. While this was effective, it was found to be insufficient when stricter conditions were considered.



R2: Class B grounding resistance (Ω) E: Voltage (V)
R3: Class D grounding resistance (Ω) Vg: Voltage to ground at ground fault point (V)
RL: Electrical Circuit resistance (Ω)

Fig. 6.1

In Fig. 6. 1 for example, if the motor Ⓜ insulation degrades and generates a potential at the motor frame, the voltage to ground Vg is expressed with the following expression.

$$Vg = \frac{R_3}{R_2 + R_3 + R_L} \cdot E \quad \text{(1)}$$

R_L is a low value that can be ignored compared to R_2 and R_3.

Thus,

$$Vg = \frac{R_3}{R_2 + R_3} \cdot E \quad \text{(2)}$$

With IEC60364-4-41, the contact potential must be 50V or less to protect humans against electric shock. In the 230/400V power distribution system, the maximum voltage to ground of an electric facility that could come in contact with humans is 230V, Thus, if Vg = 50 and E = 230, then expression (3) can be established from expression (2).

$$\frac{R_2}{R_3} = 3.6 \quad \text{(3)}$$

If R_2 is controlled to approx. 20Ω, R_3 must always be kept to 5.6Ω or less to enable electric shock protection with only the protective grounding method. This is not a complete electric shock completion method.

If a residual current circuit breaker is used, the "power supply breaking" means is added to the "protective grounding", and more complete electric shock protection measures are established.

The size of the ground fault current differs according to the grounding method so it is essential to select the appropriate overcurrent breaker that can detect a relatively large ground fault current (MCCB or fuse) or ELCB that can detect a minute ground fault current.

6. 3 Physiological symptoms of electric shocks

6. 3. 1 Effect of overcurrent passing through human body

When selecting the rated sensitivity current of ELCB used to prevent injury from electric shocks, it is necessary to understand the physiological symptoms of the human body in reception to electricity. According to Biegelmeier's report, the human's characteristics to electricity can be classified as shown in Table 6. 1.

When the passing current increases, the heart chamber (heart) starts fibrillating, the pulse is distributed, and the circulation of blood to supply fresh blood throughout the body stops. This is an extremely dangerous current that can lead to death. This current value requires medical experimentation, which were carried out (including animal experiments) in the United States and Germany, etc. The results were documented, and were usually several 10mA.

When intended to prevent electric shocks accidents, it is best to provide protective measures that limit the involuntary current (limit at which separation is possible). However, when the continuity of the power fed, etc., is considered in relation with the circuit's leakage current, providing protective measures for the ventricular fibrillation electrical current is unavoidable.

In various European countries (Germany and France, etc.), protective measures are applied using this ventricular fibrillation electrical current as a reference. Favorable results have been attained.

Dalziel (US) and Koeppen (Germany) are known for their research of the physiological symptoms in respect to currents on human bodies, such as ventricular fibrillation electrical currents. According to their papers, etc., the following type of current cases ventricular fibrillation.

According to Dalziel, the ventricular fibrillation electrical current I passing for an energizing time (Ts) within 5s is expressed as $I = \frac{116}{\sqrt{T}}$ (mA). The human's physiological symptoms are greatly affected by the current square time product. On the other hand, Koeppen found that even if the current value exceeds 50mA, human life can be saved if the energizing time is extremely short. The limit is current time product 50mA・s. The relation of these is shown in Fig. 6. 2.

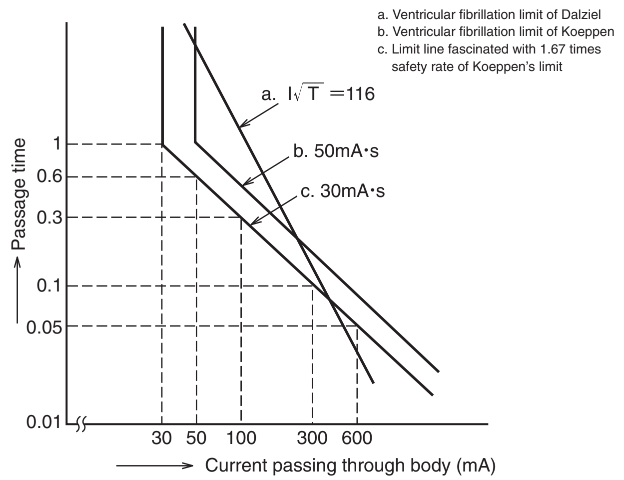


Fig. 6. 3 Ventricular fibrillation electrical current - passage time limit

When both are compared based on the characteristics in this figure, it can be seen that Koeppen's limits are less than Dalziel's limits, so using the safer 50mA・s as a reference is suitable.

Koeppen also writes about this, but using the reference of 50mA・s, 30mA・s is set as the safety factor in Europe. While there are no reports on the effect if a current of 50mA is continuously passed to the human body, typically if a current of 50mA or less is passed, the human would reflectively let go of the conductor. The size of the c urrent that passes through the human body is determined by the human body's resistance and the contact voltage. The human body's resistance varies by individual. It can be affected by race, dryness of skin, state of contact with electrode (contact area or contact pressure, etc.), and the size of the contact voltage. Freiberger (Germany) has reported that when the hand to foot, the most typical current path is looked at, the human resistance is within the range shown in Fig. 6.3. However, in adverse conditions where the skin surface resistance is ignored, the resistance drops to 500Ω. Thus, this value should be adopted when laying importance on safety.

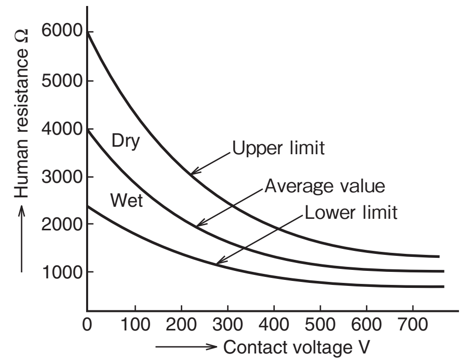


Fig. 6. 4 Relation of contact voltage and human resistance

Based on the above, when considering measures to prevent electric shock accidents, the human resistance in respect to contact voltage must be obtained from Fig. 6.3, and the size of the current passing through the human body must be estimated. In respect to the safe voltage, it is difficult to definitively set the danger voltage in the relation of the human resistance. If the environmental conditions or electrical conditions are poor, the contact voltage must be low. In the IEC Standards the voltage is a safe special low voltage. Within preset conditions, the maximum voltage must be 25VAC or less.

Table 6. 1 Electric shock current and physiological reaction on human body

50/60 Hz current effective value [mA]	Reaction time	Physiological reaction on human body
0 to 0.5	Not dangerous even when continued	Current cannot be sensed
0.5 to 5 (separation limit)	Not dangerous even when continued	Voluntary current range in which human starts to feel current, but does not have spasm. (Able to voluntarily separate from contact state, but feels pain in fingers and arms, etc.)
5 to 30	Several minutes is the limit	Involuntary current range (spasms prevent voluntary separation from constant state) Has trouble breathing, or blood pressure rises. Within tolerable range.
30 to 50	Several seconds to several minutes	Heart beat becomes irregular. Can faint, blood pressure rises, strong spasms occur. Ventricular fibrillation occurs after long time.
50 to several 100s	Less than heartbeat period	Receives extreme shock, but does not cause ventricular fibrillation
	Longer than heartbeat period	Ventricular fibrillation occurs. Faints, traces of current made at contact (heartbeat phase and start of current perception have no special relation)
More than several 100mA	Less than heartbeat cycle	Even if the reaction time is within the heartbeat cycle, ventricular fibrillation could occur if perception starts at a specific heartbeat Faints, traces of current made at contact
	More than heartbeat cycle	Ventricular fibrillation does not occur Recoverable heart failure, fainting occurs Burns could cause death

6. 3. 2 Electric shock protection, rated current sensitivity and operating time

As explained above, there are various theories on the physiological symptoms that occur to a human when currents pass through. If the safety standards were set following the IEC curve given in Fig. 6. 5, the following areas could be could be considered.

- In areas were secondary accidents could result because of electric shocks, the area of curve b and below
- Curve c_1 and below where secondary accidents would not result because of electric shocks.

(1) Taking measures using curve b as protection standard

As shown in Fig. 6. 4, usually there is no hazard to the human body if the passing current is 5mA or less. The 5mA current is a level at which a person generally feels tingling. The person could “let go” at his current, so normally the person can provide his/her own protection. If a person inadvertently and directly touches a 200mA voltage to ground liver wire, a 200mA (human resistance 1000Ω) current will flow through the body. In this case, based on curve b the operating time must be within 0.01 sec.

(2) Taking measures using curve c_1 as protection standard

In levels with a small current value, curve c_1 shows the drop from 50mA in one second and the drop from 40mA after three seconds. In levels with a high current level, curve c1 shows the drop from 500mA at 10ms or less, and from 400mA at 100ms. If the current passing to the human body exceeds 40mA, the risk of a serious physiological effect occurs as the current value and time increase.

(3) **Current passing through human body, time product 30mA・s**

Measures are often using the protection standard of 30mA・s based on Koeppen’s ventricular fibrillation limit. However, even in this case the electric device must be grounded as a rule. If the electric device is improperly grounded (portable or movable device that easily generates a ground), the following two conditions must be satisfied to suppress the current to within the ventricular fibrillation limit even the human touches the high voltage.

- Rated current sensitivity 30mA or less
- Current/time product to ELCB operation Within 30mA・s

Note that grounding work is usually performed, so if the selection maintains the relation of (rated current sensitivity) × (grounding resistance value) ≤ (tolerable contact voltage), then the electric shock protection can be provided at 200mA or 500mA even if the rated current sensitivity is not 30mA.

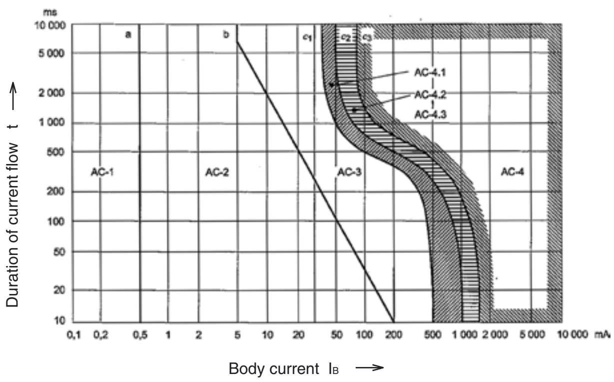


Fig. 6. 5 Effect of AC current (15Hz to 100Hz) on human body (IEC/TS60479-1)

The physiological effect in each zone is as follows.

Zone name	Range of zone	Physiological effect
AC-1	Below curve a	Normally imperceptible.
AC-2	Between curve a and curve b	Normally no harmful physiological effect.
AC-3	Between curve b and curve c_1	Normally, damage to organs not predicted. If the current continues for longer than 2 seconds, there is risk of muscular contraction or respiratory paralysis. Includes arterial fibrillation and temporary heart failure.
AC-4	Exceeding curve c_1	Increases with size and time. Possibility of pathophysiological effect such as hear failure, respiratory failure and severe burns.
AC-4.1	c_1 to c_2	In addition to effect of zone AC-3, possibility of ventricular fibrillation increases by 5%.
AC-4.2	c_2 to c_3	In addition to effect of zone AC-3, possibility of ventricular fibrillation increases by 50%.
AC-4.3	Exceeding curvec_3	In addition to effect of zone AC-3, possibility of ventricular fibrillation increases by more than 50%.

Curves c_1, c_2 and c_3 are the statistical evaluation of the result of animal experiments, and estimate the flow of current from the left hand to right foot.

6. 4 Types of ground fault protection

6. 4. 1 Comparison of ground fault protection methods

Table 6. 2

Protection method	Merits	Demerits
Earth leakage breaker method	◎The high-speed high-sensitivity type is extremely effective for electric shock protection. ◎The optimum sensitivity can be selected according to the working conditions and environment, scale of electrical circuit and importance, etc . ◎The current-operated type can protect all electrical circuits past the installation point. ◎Labor-saving as the electrical circuit insulation resistance measurement can be omitted, and the inspection cycle can be extended.	○If there is a ground fault accident, that circuit will be opened and the power will fail. ○Can be expensive if installed on each branch circuit to maintain the continuous power feed.
Protective grounding method	◎Economical if soil, where protective grounding is to be provided, has a low resistance value. ◎The contact voltage will not exceed the tolerable value. ◎Relatively high reliability in terms of chronological degradation.	○To limit the equipment's contact voltage to less than the tolerable value with the TT method, the protective grounding resistance value must be much less than the power side's grounding resistance value. However, since it is difficult to confirm the power side's grounding resistance value, the low resistance grounding work is difficult. Thus, this method is not practical for low voltages. ○The ground fault accident itself cannot be detected or removed, and thus, fires cannot be prevented.
Overcurrent breaker method	◎Highly reliable MCCB can swiftly and accurately remove ground fault accident circuits. ◎Cost feasible as the electrical circuit's metal pipes or building's steel frame can be used for the grounding dedicated wire.	○The tolerable contact voltage could be exceeded in the duration between generation of the ground fault accident to when MCCB functions and opens the circuit. ○Caution must be paid to the relation of the metal pipe and steel frame impedance and MCCB rated current.
Insulated transformer method (non-grounded)	◎With the secondary side non-grounded method, there is no contact voltage to the human body during a ground fault or when the live section is contacted. ◎There is no risk of power failure or fires caused by the ground fault accident.	○Can be hazardous if the ground fault accident is not detected and a double insulation breakdown occurs for a long time. ○If a high voltage is reached due to the effect of the induction, or if there is a ground fault in one wire, the voltage to ground for the other wires may become higher than the grounded type electrical circuit. This is not suitable for large capacity applications.
Earth leakage warning method	◎Economical if soil, where protective grounding is to be provided, has a low resistance value. ◎The contact voltage will not exceed the tolerable value. ◎Relatively high reliability in terms of chronological degradation.	○There is no self-protection function in respect to electric shocks. ○Not effective if the load electric device is not grounded. ○Not effective if there is no communicant or administrator when alarm is issued.

6. 4. 2 Ground fault protection method and application

The types of accidents that could occur in a ground fault accident can largely categorize into the three types shown in Table 6. 3. The main purpose must be understood when selecting the ground fault protection method and devices.

Table 6. 3 Types of damage caused by ground fault accidents

Type	Symptoms	Size of ground fault current
Electric shock	When a human body directly touches an electrical circuit or device's conductive section, or touches a frame onto which voltage is inducted due to degradation of motor insulation, etc., the current passes through the human body and a ground fault current flows.	Current that causes death is several 10mA or more.
Fire	When the insulation of the building where the wire passes through degrades and the ground fault current passes through the thin easily heated conductor, such as the metal truss, the conductor heats and can cause the building material to ignite.	Current that causes fires is several A or more.
Device burning	When the insulation of the electrical circuit or device is partially damaged and a large ground fault current flows, in most cases an arc occurs and burns the devices.	The current that causes arcs is several 10A or more.

(1) Electric shock damage protection

a. Contact state and tolerable contact voltage

If a ground fault occurs in the low-voltage electrical circuit, the contact voltage must be suppressed to the values shown in Table 6. 4 according to the human contact state.

① **Places where Class 1 contact state occurs**

If the human body is shocked in a swimming pool, measures against ventricular fibrillation current may lead to secondary accidents such as drowning. Thus, the tolerable current flowing through the human body (minimum involuntary current value) must be 5mA.

A double protection with the earth leakage breaking method and another method should be incorporated instead of just relying on the earth leakage breaking method.

A practical effect cannot be anticipated with the other ground fault protection methods.

② **Places where Class 2 contact state may occur**

The human resistance is set at 500Ω when the human body is extremely wet. In this case, the contact voltage must be 25A and the current/time product must be suppressed to within 50mA・s, and the current passing through the human body must be suppressed to the Koeppen tolerable limit of 50mA.

ELCB with a rated current sensitivity of 30mA and current/time product within 30mA・s (operating time 0.1 s or inverse time-delay type) must be used to provide protective grounding.

If the leakage current in the electrical circuit is large and it is difficult to use a high-sensitivity type, the device frame's grounding resistance value R_3 and rated current sensitivity must be selected with the following expression.

$$R_3 \leq \frac{25\ (V)}{\text{ELCB rated sensitivity current (A)}}\ (\Omega) \quad \cdots\cdots (1)$$

As shown in expression (1), even if the rated current sensitivity is not 30mA or less, if the protective grounding resistance value is suppressed, it may be possible to achieve a sufficient effect even with a 100mA or 200mA sensitivity product.

③ **Class 3 contact state**

In the normal state in which the hands and feet are not wet, the human resistance is set to be 1000Ω. To suppress the current passing through the human body to below Koeppen's tolerable limit of 50mA, then the contact resistance must be limited to 50V or less, or the current/time product must be suppressed to 50mA・s or less.

Use ELCB with a rated current sensitivity of 30mA or less and operating time within 0.1s, or one with inverse time-delay characteristics together with protective grounding.

If the leakage current in the electrical circuit is large and it is difficult to use a high-sensitivity type with rated current sensitivity of 30mA, etc., the same state as Class 2 contact can be attained by selecting the device frame grounding resistance value R_2 and rated current sensitivity that satisfies the following r relation.

$$R_3 \leq \frac{50\ (V)}{\text{ELCB rated sensitivity current (A)}}\ (\Omega) \quad \cdots\cdots (2)$$

③ **Class 4 contact state**

Normally, sections that will not contact human bodies do not require special electric shock protection. However, measures must be take for fire protection, etc.

Table 6. 4 Tolerable contact voltage (JEAG8101-1971)

Types of contact states		Tolerable contact voltage
Class 1	○Most of human body is submerged in eater.	2.5V or less
Class 2	○Human body is very wet. ○Part of metal electric device or system or structure is in constant contact with human body.	25V or less
Class 3	○Cases other than Class 1 or Class 2 where there is a high risk if contact voltage is applied in normal body state.	50V or less
Class 4	○Cases other than Class 1 or Class 2, where risk of contact voltage being applied in normal human body state is extremely low. ○When there is no risk of contact voltage being applied.	No limits

b. Application of various ground fault protection methods

Applications of the various ground fault protection methods for electric shock protection are shown in Table 6. 5. Even if ELCB is installed, there is a risk of electric shock accidents if two live places are touched.

Table 6. 5 Application of ground fault protection methods (JEAG8101-1971)

Protection method \ Contact state		Class 1	Class 2	Class 3	Class 4
Protective grounding	Tolerable contact voltage 25V	×	×	○	○
	Tolerable contact voltage 50V	×	×	○	○
	No limits	×	×	×	○
Overcurrent breaking		×	×	○	○
Earth leakage breaking	Current-operated type	○ (limited to high-speed high-sensitivity type)	○ (limited to high-speed high-sensitivity type)	○	○
Earth leakage alarm		×	×	○	○
Insulating transformer	Non-grounded type	×	○ (Working voltage on primary side 600V or less)	○	○
	Middle point grounded type	×	○ (Working voltage on secondary side 50V or less)	○ (Working voltage on secondary side 50V or less)	○

Remarks (1) ○ indicates that the protection method can be used independently in each contact state. × indicates that the independent use is not possible.

(2) The combination methods shown the same level as the minimum protection level.

(3) These applications do not apply to the double insulation structure load device.

(4) In the Class 1 or Class 2 contact state, if the current passing through the human body might be several mA such as when using a portable device, a protection method that operates at approx. 50mA is required.

(5) The types of contact states are shown in Table 6. 4.

(2) Earth leakage fire protection

Generally, fires caused by electrical leaks occur when the insulation sheath of the wire is damaged, and the electricity flows through the structure's metal body resulting in heating or spark discharge. In residential homes, it is essential to provide protection against earth leakage accidents caused when the metal truss contacts a stable or when the wire sheath is damaged in an earthquake, etc. If the ground fault occur is small, the risk of fires is small. However, if not repaired, the fault could develop and cause a fire. The size of the ground fault current that causes a fire differs according to various conditions, but is said to be several A.

The rated current sensitivity of ELCB is thought to have sufficient protection against fires when 1A or less.

The earth leakage alarm method is effective if it is in the constant monitor state. However, when using the protective grounding method or insulating transformer method, the ground fault current cannot be detected, and thus sufficient protection against earth leakage fires cannot be anticipated.

(3) Protection against arc ground fault damage

A well-known example of a fire that started with an arc ground fault is a large apartment fire in New York in 1964. The arc accident continued for an hour completely destroying a 480/277V distribution panel. The two 5000A bus wires were completely melted to the point of origin.

It took several days to recover the situation. Water, lighting and electric service to 10,000 people were stopped during that time.

There are many cases of arc accidents in load centers, distribution panels, bus wires, control centers and cables that resulted in serious damage.

Arc ground fault accidents cannot be prevented with just an overcurrent breaker. In other words, the arc short-circuit limits the short-circuit current with the arc resistor and prevents the overcurrent protector from functioning or taking a long time to function. Even in indirect arc accidents, there are cases when the overcurrent breaker does not function even through the damage is sequentially increases. Thus, an arc accident protection device is required in addition to the overcurrent breaker.

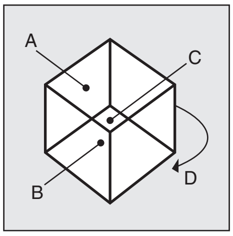
The arc ground fault current can extend over the range of several A to several 1000A, so protection using the earth leakage breaker method is the most appropriate.

6. 5 Types and features of ground fault protection devices and ground fault monitor dvevices

The ground fault protection device and ground fault monitor device for low-voltage electrical circuits must be selected carefully according to the purpose, cost efficiency and functions, etc. If an appropriate device is selected, optimum protection and monitoring can be provided for a long time. The features of the most commonly used main ground fault protection devices and ground fault monitoring devices are listed below. Refer to this table when selecting the devices.

Table 6. 6 Types and features of ground fault protection devices and ground fault monitor devices

	ELCB	Earth leakage relay	Ground fault relay	4E relay	Earth leakage fire alarm
Rated sensitivity current	Applicable from 15mA high sensitivity to several A. Also available as rated sensitivity current switching type for use according to electrical circuit state.	Applicable from 30mA high sensitivity to several A. Also available as rated sensitivity current switching type for high universality.	Typically available in 200, 400, 600mA switching type. 5-step switching from 100 to 600mA also available, but not available as high-sensitivity type.	100mA is standard.	Generally available in 100mA to 400mA. Some special products with low sensitivity (400 to 700mA) are available.
Operating time	Both high-speed and time-delay types are available enabling selective breaking.	In addition to high-speed and time-delay types, available in models for a wide range of applications such as automatic recovery types and selective coordination.	0.1 to 0.3 s at 130% of sensitivity current. 0.1 to 0.2 s at 400%. (JIS C4601 stipulation)	Only high-speed type.	Differs according to maker as there are no special stipulations.
Electrical Circuit breaking function	Equipped with capability to break load current and abnormal overcurrent, so capable of automatically breaking the accident circuit.	Earth leakage breaker itself does not have a main circuit breaking capability. However, a breaking circuit can be easily structured using the built-in contact.	Ground fault relay itself does not have a breaking capability, but equipped with built-in contact.	Same as earth leakage relay.	Typically, most do not have a breaking function. However, a breaking function can be provided.
External alarm function	Possible by incorporating earth leakage alarm (EAL) switch.	Optical or audio alarm can easily be created using built-in contact.	Some products have built-in alarm circuit in addition to built-in contact.	Same as earth leakage relay.	Equipped with device to sound 70 phons or more with Class 1 and 60 phons or more with Class 2 using audio device.
Overcurrent protection combination	Most products typically have short-circuit and overload protection functions, so three functions are covered with a single unit.	None	None	Protection corresponding to the load device possible as the overcurrent protection mechanism is electronic.	None
Energizing capacity	Mitsubishi's maximum frame is 1200A.	Mitsubishi's maximum frame is 3200A. Generally, a larger capacity than other devices can be manufactured.	Manufactured for the highest voltage. Available in 50 to 1000A class with zero-phase converter.	Typically available in 150A class. 1000A class available when specified.	Approximately available in 200A class or lower.
Handling Construction	Easy	Zero-phase converter and relay must be converted. A little more complicated than ELCB.	Same as earth leakage relay.	In addition to 3E relay, zero-phase converter must be mounted.	Same as earth leakage relay.
Overcurrent strength	Up to rated breaking current.	100,000A	40-times of more than rated primary current.	Overcurrent strength of zero-phase converter is 100,000A.	2,500A



7. Structure and Operation

7. 1 Earth leakage circuit breakers

7.1. 1 Outline of structure

ELCB consist of the following major parts.

- Switching mechanism that opens and closes the contacts
- Earth leakage tripping device which trips the circuit breaker according to short circuit current
- Earth leakage indication device which is interlocked with the overcurrent protection device and indicates that it has operated owing to ground fault
- Overcurrent trip device which trips the circuit breaker according to overload or ground fault current
- Arc extinguishing device which extinguishes arc generated when current is interrupted
- Terminals for connecting wires and conductors
- Contacts which open and close the circuit
- Test button for checking that the breaker operates upon occurrence of ground fault
- Molded case in which the above parts are contained compactly

Fig. 7. 1 shows an example of arrangement of the above parts.

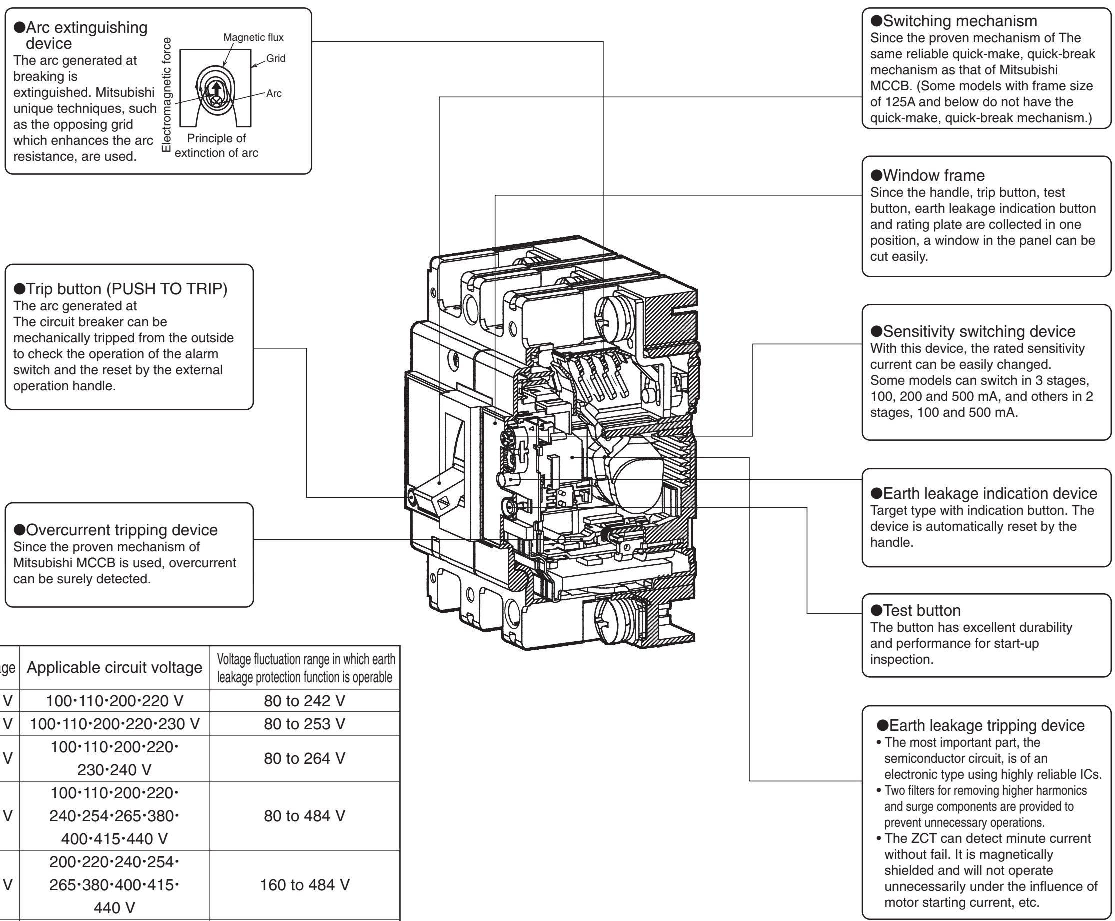
The earth leakage trip device is a current operation type device which detects directly the ground fault current and consists of a primary winding of each phase on the core, a zero-phase current transformer (hereinafter, referred to as ZCT) for detecting zero-phase current (ground fault current), an electronic circuit for amplifying the ZCT output and an electromagnetic device for tripping the circuit breaker.

The operating principle is explained below. See the input/output of ZCT on the circuit shown in Fig. 7. 2. If the circuit is sound, the magnetic fluxes generated by the forward current and return current cancel each other, and voltage is not induced on the secondary winding.

However, if a ground fault occurs, the forward current $\dot{I}_A$ is divided into current $\dot{I}_g$ which returns to the transformer through the earth and currents $\dot{I}_B$ and $\dot{I}_C$ which return through the ZCT. Therefore, the vector sum of the currents which pass through the ZCT is $\dot{I}_A + \dot{I}_B + \dot{I}_C = \dot{I}_g$, and a magnetic flux $\dot{I}_g$ depending on ϕg is generated on the core of ZCT, thereby inducing voltage on the secondary winding.

This signal enters the gate circuit of the thyristor on the electronic circuit to drive the thyristor, and the electromagnetic device connected with the thyristor in series operates to trip the circuit breaker.

In the case of 3-phase, if the circuit is sound even under unbalanced loading under which the currents of the phases are not equal to one another, the sum of currents of the phases is $\dot{I}_A + \dot{I}_B + \dot{I}_C = 0$, and ELCB will not malfunction. (Fig. 7. 3)



Rated voltage	Applicable circuit voltage	Voltage fluctuation range in which earth leakage protection function is operable
100-200 V	100•110•200•220 V	80 to 242 V
100-230 V	100•110•200•220•230 V	80 to 253 V
100-240 V	100•110•200•220•230•240 V	80 to 264 V
100-440 V	100•110•200•220•240•254•265•380•400•415•440 V	80 to 484 V
200-440 V	200•220•240•254•265•380•400•415•440 V	160 to 484 V
380-550 V	380•400•415•440•480•500•550 V	342 to 600 V

Fig. 7. 1 Construction of ELCB

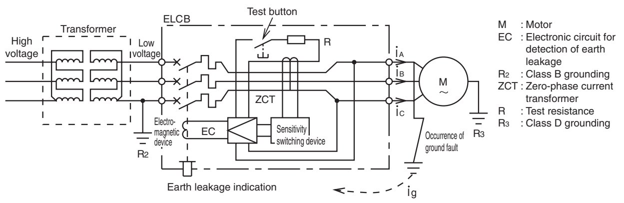


Fig. 7. 2 Circuit configuration of ELCB (TT system)

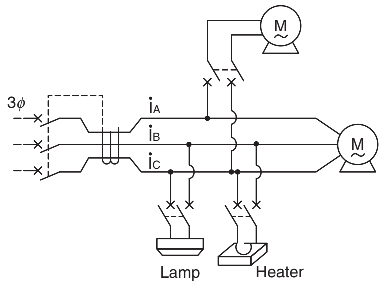


Fig. 7. 3 Unbalanced loads

7.1. 2 Earth leakage tripping device

(1) ZCT (zero-phase current transformer)

The ZCT is a current transformer for detecting minute ground fault current and shall be distinguished from general current transformers (CT). For the ZCT, mainly permalloy, a special material with high magnetic permeability, is used. It consists of a permalloy core, a primary conductor which feeds the main circuit current and a secondary winding on the core. The magnetic fluxes generated by the currents of the phases of the primary conductor are vector-synthesized by the core, and electromotive force is generated on the secondary winding by the magnetic flux according to the difference among the magnetic fluxes of the phases. Therefore, if the vector-synthesized current of the phases is 0, the magnetic fluxes cancel with one another in the core, and electromotive force is not generated on the secondary winding regardless of the magnitude of the primary current. On the other hand, if a ground fault occurs, the current balance among the phases is disturbed, the core is excited by the magnetic flux corresponding to the magnitude of the ground fault current, and electromotive force is generated on the secondary wiring.

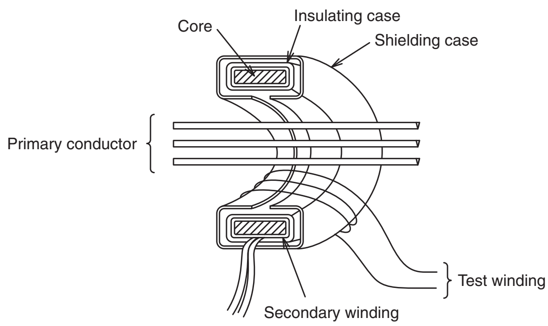


Fig. 7. 4 Structure of ZCT

(2) Electronic circuit

The circuit diagram is shown in Fig. 7. 5. The control power of almost all ELCB is 100 to 440VAC for facilitating selection, storage and maintenance. In addition, models with 100 to 200VAC, 100 to 230VAC, 200 to 415VAC and 200 to 440VAC and with fixed voltage of 100VAC are available.

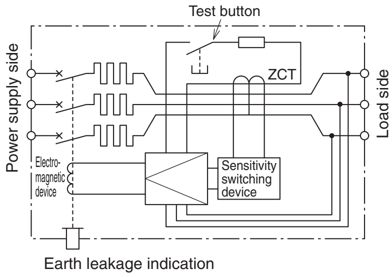


Fig. 7. 5 Internal connection diagrams

① Detection of ground fault on secondary side of inverter

As an example method of detecting the ground fault current on the inverter primary side and secondary side with ELCB installed on the inverter primary side, below is explained the method of detecting ground faults on the inverter secondary side where the waveform distortion is the largest.

a. Spectrum of leakage current on inverter secondary side

Fig. 7. 6 shows the spectrum (200V, Δ connection, one-line grounding, the same hereinafter) of ground fault current caused by the resistance on the inverter secondary side in the case of use of Mitsubishi inverter FR-Z220. The spectrum consists of commercial frequency, inverter operation frequency and carrier frequency components and their harmonic components. The spectrum contains commercial frequency and inverter operation frequency components at the same rate as that of the content of carrier frequency components.

Fig. 7. 7 shows the spectrum of ground fault current on the inverter secondary side including the leakage current caused by earth capacitance in the case of use of FR-Z220. This example simulates a case where the electric circuit on the inverter secondary side is long and its earth capacitance is large. Since the earth impedance caused by capacitance is inversely proportional to the frequency, the content of harmonic components in the carrier is higher compared to in Fig. 7. 6. This content increases in proportion to the earth capacitance and carrier frequency. The content of commercial frequency and inverter operation frequency components is identical to that in Fig. 7. 6.

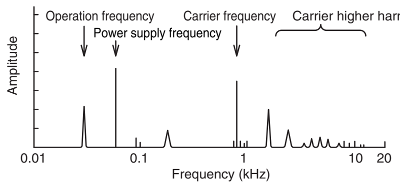


Fig. 7. 6 Spectrum of ground fault current (current caused by ground fault)

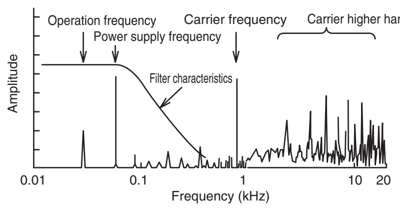


Fig. 7. 7 Spectrum of leakage current (by current caused by earth capacitance and ground fault current)

b. Concept of detection of ground fault on inverter secondary side

To detect ground fault on the inverter secondary side, it is necessary to reduce the influence of leakage current caused by earth capacitance on the secondary side. For this purpose, we used a method to remove the carrier frequency and harmonic content of the carrier which change depending on the earth capacitance and may cause unnecessary operations and unstable sensitivity current with a low pass filter. The filter characteristics are shown in Fig. 7. 7.

IEC 60479-2 presents the frequency characteristics of current value at which ventricular fibrillation is caused by the current passing the human body shown in Fig. 7. 8.

This curve shows that, at frequencies higher than 1kHz used as the inverter carrier frequency, the current value at which ventricular fibrillation occurs to expose the human body to hazardous situation is 14 times or more the value at 50/60 Hz and there is a low risk of electrical shock. Therefore, it is possible to realize stable detection of ground faults while ensuring the safety of human body against electrical shock by removing carrier frequency and the harmonic content of the carrier upon detection and detecting ground faults based only on the fundamental wave components. On inverters, the fundamental wave content is approx. 70% in the ground fault current. This percentage is less affected by the earth capacitance and is in proportion to the magnitude of ground fault current. Therefore, stable detection of ground faults can be realized by judging based on the fundamental wave content.

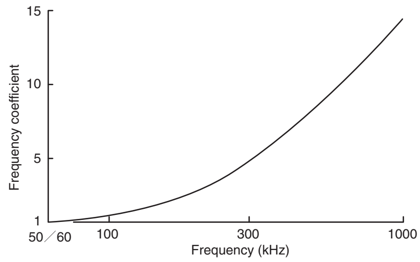


Fig. 7. 8 Current value at which ventricular fibrillation is caused by current passing human body (IEC 60479-2)

c. Structure and operation of ground fault detection circuit

As the low pass filter for removing carrier frequency and harmonic components of carrier, a digital filter was used. On ELCB applicable to higher harmonics and surge, signals from the ZCT are input to the input circuit and converted from analog to digital by the A/D converter. The digitalized signals are input to the low pass filter that is a digital filter. The digital filter is used because the filter provides sharp attenuation necessary for fundamental frequency components and carrier frequency (depending on the inverter type, approx. 800 Hz on low-frequency products) and filter characteristics without attenuating minute ZCT signals, and the filter constant for obtaining a low cutoff frequency can be set without influence on stability of ZCT and electronic circuit characteristics.

Fig. 7. 9 shows the structure of electronic circuit, and Fig. 7. 10 shows the digital filter block diagram. The ground fault current discriminating circuit detects the magnitude of ground fault current and the duration of signal. Fig. 7. 11 shows the function block diagram for explaining the operation. When the ground fault signal level exceeds the detection level, charging of the capacitor is started, and the occurrence of ground fault is detected after a lapse of a certain time. Therefore, relatively small surge current components which are leaked by the earth capacitance are removed. These circuits are contained in one chip as an IC for ELCB.

Fig. 7. 12 shows the effect of digital filter in detection of ground fault current. Comparing the waveforms before and after the digital filter, it is found that the fundamental wave components can be effectively extracted from the leakage current on the secondary side masked by the high frequency components. That is, not only on the primary side, but also on the secondary side, ground faults can be stably detected through the digital filter.

However, for a circuit containing harmonic components, the filter shall be used with load device leakage current distortion of 10kHz or less and at 3A or less because the zero-phase current transformer (ZCT) of the circuit breaker is overheated by iron loss. For circuit breakers with frame size of 800A and above, it is necessary to use the filter with load device leakage current distortion of 5kHz or less and at 3A or less.

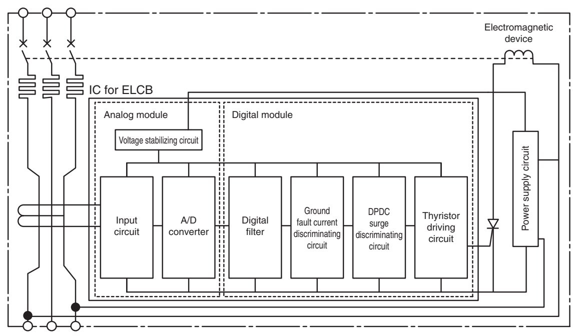


Fig. 7. 9 Structure of electronic circuit

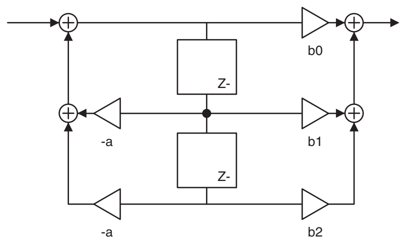


Fig. 7. 10 Block diagram of digital filter

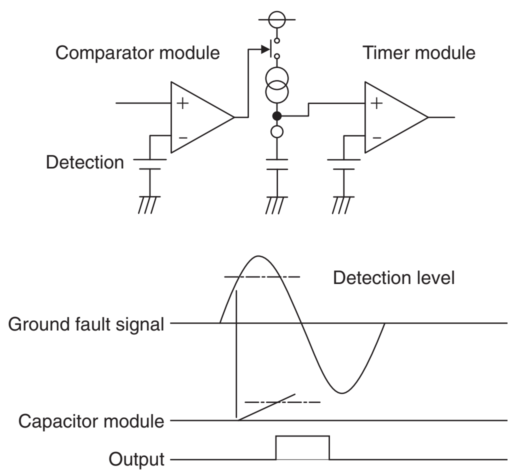


Fig. 7. 11 Function block diagram of ground fault current discriminating circuit

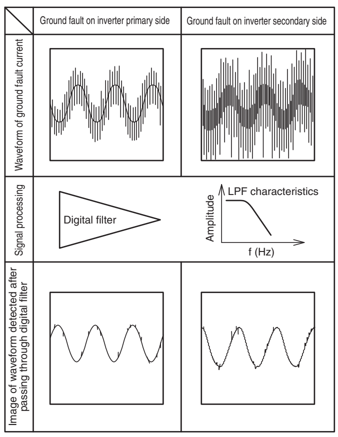


Fig. 7. 12 Effect of digital filter

② **Technique for prevention of unnecessary operations caused by surge**

As an example method of detectings the ground fault current on the ino higher harmonics and surge, signals from the ZCT are input to the input circuit and converted from analog to digital by the A/D converter. The digitalized signals are input to the low pass filter that is a digital filter. The digital filter is used because the filter provides sharp attenuation necessary for fundamental frequency components and carrier frequency (depending on the inverter type, approx. 800 Hz on low-frequency products) and filter characteristics without attenuating minute ZCT signals, and the filter constant for obtaining a low cutoff frequency can be set without influence on stability of ZCT and electronic circuit characteristics.

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Fig. 7. 12 shows the effect of digital filter in detection of ground fault current. Comparing the waveforms before and after the digital filter, it is found that the fundamental wave components can be effectively extracted from the leakage current on the secondary side masked by the high frequency components. That is, not only on the primary side, but also on the secondary side, ground faults can be stably detected through the digital filter.

However, for a circuit containing harmonic components, the filter shall be used with load device leakage current distortion of 10kHz or less and at 3A or less because the zero-phase current transformer (ZCT) of the circuit breaker is overheated by iron loss. For circuit breakers with frame size of 800A and above, it is necessary to use the filter with load device leakage current distortion of 5kHz or less and at 3A or less.

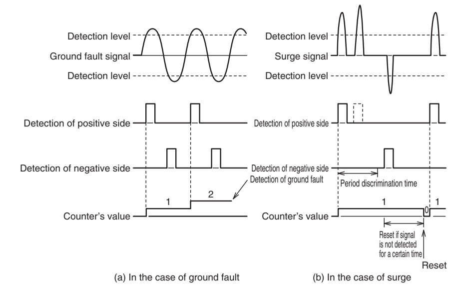


Fig. 7. 13 Operation of DPDC surge

Fig. 7. 14 shows the improvement of the performance to prevent unnecessary operations of ELCB applicable to higher harmonics and surge comparing with that of a conventional model. It was confirmed that no unnecessary operation was caused in any case of gap-less surge absorber and discharge gap type surge absorber.

According to the waveforms verified in Fig. 7. 14, the performance to prevent unnecessary operations is improved as stated below.

(1) Resistance to leakage current caused by surge: Three times or more as peak value

(2) Leakage electric power energy (I^2t) caused by surge: 100 times or more

Waveform of leakage current caused by surge	Electrical circuit to be protected	Occurrence of unnecessary operations	
		NV applicable to higher harmonics and surge	Conventional model
Earth leakage current Is; 150 A; 3 μs; Time	ELCB; C; Earth capacitance	○ No unnecessary operation	○ Unnecessary operation occurred.
Earth leakage current Is; 500 A; 20 μs; Time	ELCB; Gap-less surge absorber	○ No unnecessary operation	× Unnecessary operation occurred.
Earth leakage current Is; 28 A; 10 ms; Time	ELCB; Discharge gap surge absorber	○ No unnecessary operation	× Unnecessary operation occurred.

Fig. 7. 14 Performance to prevent unnecessary operations caused by surge

③ Improvement of leakage protection function by type A leakage characteristics

Recently, more machines are provided with inverters and servos to improve the performance and accuracy of drive control. Inverters and servos have rectifier circuits, and if the rectifier circuits go down, leakage current with half-wave rectified waveform or phase-controlled waveform may occur. To detect this leakage current and trip the circuit breakers to prevent electric shock and fire caused by earth leakage, type A (specified by IEC 60947-2) leakage protection characteristics for detection of half-wave rectified and half-wave phase controlled waveforms of leakage current shown in Fig. 7.15 must be provided. Then, we enlarged the leakage protection range by adding a function with the type A leakage characteristics to CE-marked and UL-listed circuit breakers with frame size of 250A and smaller (except some models).

Operation characteristics at ground fault current		
Ground fault waveform / Classification according to IEC 60947-2	AC ground fault	Half-wave rectified ground fault
Type A	○ Detectable	○ Detectable
Type AC	○ Detectable	× Not detectable

Note: Not applicable to complete DC ground faults

Fig. 7.15 Leakage detection characteristics

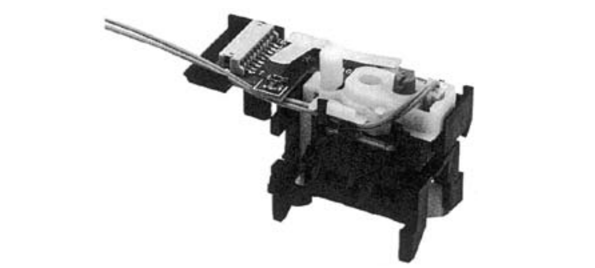


Fig. 7. 16 Example of electromagnetic device

7. 1. 3 Test device

Since electric shock may cause loss of life, it is necessary to check the operation of circuit breaker. The test device forms a ground fault simulation circuit as shown in Fig. 7. 17. Current is applied to the circuit by pressing the test button to make sure that the circuit breaker can operate surely upon occurrence of ground fault. All ELCB circuit breakers are provided with this test device.

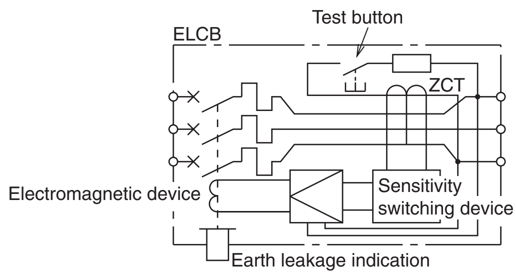


Fig. 7. 17 Circuit of test device

7. 1. 4 Earth leakage indication device

After ELCB operates owing to earth leakage, the earth leakage indication button shows that it has operated not owing to short circuit caused by overload. As shown in Fig. 7. 18, the earth leakage indication button is lower than the surface in the normal state and after the circuit breaker operates owing to overcurrent, but it is protruded when the circuit breaker operates owing to earth leakage.

The button is reset automatically by the handle.

The button will not be damaged even if it is pushed down accidentally. Furthermore, it is designed not to hinder operation owing to earth leakage even if it is pushed down for any reason.

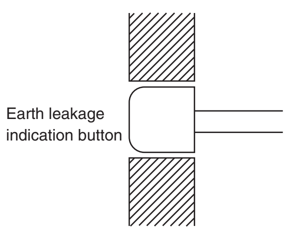
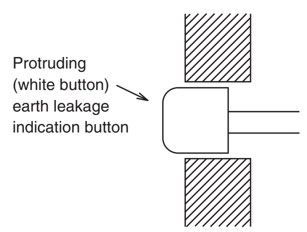
In normal state and after operation owing to overcurrent	After operation owing to earth leakage
	

Fig. 7. 18 Indication with earth leakage indication button

7. 1. 5 Trip button

Models with a trip button can be mechanically tripped by pressing this button.

With an alarm switch (AL), it is possible to check the operation of the alarm circuit for tripping owing to overcurrent and, if it has an operation handle, check that the circuit breaker has been reset by the operation handle.

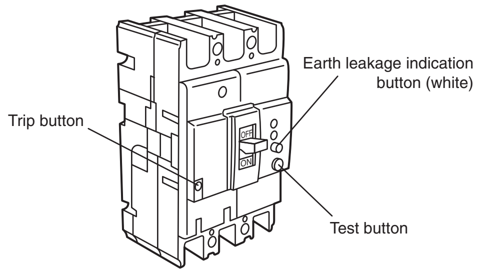


Fig. 7. 19 Example of button positions

7. 1. 6 Sensitivity switching device

With the sensitivity switching device, the rated sensitivity current can be easily and reliably switched.
Some models can switch in 3 stages, 100, 200 and 500mA, and others in 2 stages, 100 and 500mA.
JIS prescribes that a device which can switch the sensitivity between high (30mA or 15mA, operation within 0.1 s) and medium (50mA to 1000mA) levels should not be provided. ELCB of 100AF and smaller do not have this device. Fig. 7. 20 shows an example of the sensitivity switching device circuit.
The sensitivity can be switched by switching the adjusting resistances on the secondary size of the ZCT. The sensitivity on the high level is set by the adjusting resistance R_1, and the sensitivity on the low level is set by connecting the adjusting resistances R_2 and R_3 in series with the switching device. This system ensures safety against contact failure between R_2 and R_3 owing to nonconformity of the switching device because the sensitivity current is determined by R_3 and ELCB operates with high sensitivity.

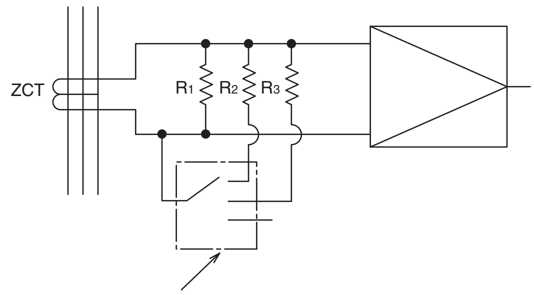


Fig. 7. 20 Example of sensitivity switching device circuit

7. 1. 7 Operating time switching device

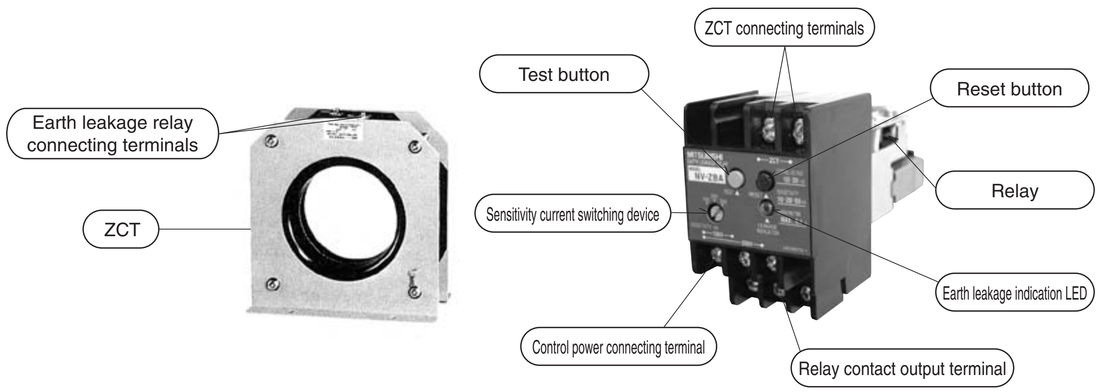
The time delay circuit breakers have an operating time switching device in addition to the sensitivity switching device, which can switch the operating time to three stages, 0.45, 1.0 and 2.0 s or to two stages, 0.3 and 0.8 s. With this device, a ground fault protection coordination system can be easily configured.

7. 1. 8 Others

The parts not stated in this section have the same structures as those of MCCB.

7. 2 Earth leakage relays

The major components of earth leakage relays include a ZCT, amplifier, built-in relay, test button, earth leakage indication device dsdssds



ZCT module (example: ZT100B)
Relay module (example: NV-ZBA)

Fig. 7. 21 Structure of earth leakage relay

7. 2. 1 Zero-phase current transformer (ZCT)

The ZCT is designed to detect the zero-phase current on a line and consists of a core made of a magnetic material with high magnetic permeability and a secondary winding on the core. In addition, it is provided with a shield case to prevent changes in sensitivity current under the influence of external magnetic field.

7.2.2 Amplifier

When ground fault current flows, electromotive force is generated on the secondary winding of ZCT. However, this electromotive force is very minute. The amplifier amplifies this minute signal and drives the built-in relay.

7.2.3 Built-in relay

The amplified signal level is compared by the comparison circuit in the amplifier, and, if the level is higher than the specified value, the coil of a small relay is excited. The relay has a built-in contact, which can retrieve an external signal when actuated. An alarm circuit or a breaking circuit can be configured with the aid of this contact.

7.2.4 Test button

The operation upon occurrence of earth leakage can be simulated and checked by pressing the test button. The button is intended to periodically check that the earth-leakage relay can operate correctly.

7.2.5 Earth leakage indication device

When the earth leakage relay operates owing to ground fault, this device indicates the operation. An electric (LED) type and a mechanical (button) type are available. On the electric device, the lamp lights up when the relay operates. On the mechanical device, the indication button protrudes over the cover surface.

7.2.6 Connecting terminals

On the separate type, the relay and ZCT modules are separated. Therefore, it is necessary to electrically connect them. They are provided with connecting terminals.

7.2.7 Structure of each model

Mitsubishi earth leakage relays are classified into the following 6 types according to function and into two types of combination, a compatible type in which any relay and ZCT can be combined and an incompatible type in which the relay and ZCT with the same product number should be combined although the ZCTs of both types have the same appearance. The relay modules vary depending on the function.

(1) NV-ZBA (small-size economical product)

This type has terminals for connecting the two terminals of ZCT to the ZCT terminals on the relay. The relay module has a sensitivity switching device, and the sensitivity can be switched in three stages. On the time delay type, not only the rated sensitivity current, but also the operating time can be switched in three stages.
When a ground fault occurs, the relay will operate according to the signal from the ZCT, the built-in small-size relay will be driven, the signal at the relay output terminal will be switched, and simultaneously the earth leakage indicator lamp (LED) will light up (self-holding type). If the ground fault has been removed, the relay will return to the initial state by pressing the reset button.
If the control power supply is connected to the load side of MCCB to break MCCB by the operation of the earth leakage relay, the reset operation is not required.

(2) NV-ZSA (general-purpose product)

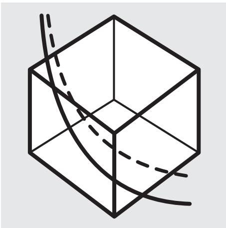
Like NV-ZBA, this type consists of ZCT and relay modules.
The releasing electromagnetic device in the relay module has been developed by Mitsubishi's unique technology. Since it is a mechanical self-holding device, it can be reset by pressing the reset button serving also for indication of earth leakage. Like NV-ZBA, this model is characterized by the indication of earth leakage left even if the control power is turned off after it operates owing to earth leakage. It cannot be reset by turning off the control power.

(3) NV-ZHA (applicable to higher harmonics and surge)

The fundamental operation and structure of this model are the same as those of NV-ZBA. This earth leakage relay is provided with ICs applicable to higher harmonics and surge having an active filter circuit and a DPDC surge discriminating circuit. It can detect ground faults on the inverter secondary side to improve the performance of prevention of unnecessary operations caused by surge.
This type complies with various standards (US UL Standard, Canada CSA Standard and European CE Marking).

(4) NV-ZLA (applicable to higher harmonics and surge)

The fundamental operation and structure of this model are the same as those of NV-ZSA. This earth leakage relay is provided with ICs applicable to higher harmonics and surge having an active filter circuit and a DPDC surge discriminating circuit. It can detect ground faults on the inverter secondary side to improve the performance of prevention of unnecessary operations caused by surge.
This type complies with various standards (US UL Standard, Canada CSA Standard and European CE Marking).
It can be used also on 480V circuits.



8. Characteristics and performance

8 Characteristics and performance

8. 1 Characteristics and types

ELCB are classified into the types shown in Table 8.1 according to the operating characteristics. Select the operating characteristics and sensitivity current depending on the purpose of use.

Table 8. 1 Classification of ELCB according to operating characteristics (IEC)

Operating characteristics		Rated sensitivity current		
Type	Operating time			
Fast-acting type	Within 0.04 sec. at current of 5 times the rated sensitivity current	6m A 10 30 100	300mA 500 1000	3A 10 30
Time delay type	Inertial non-operating time at current of twice the rated sensitivity current: 0.06 sec. – 0.1 sec. – 0.2 sec. – 0.3 sec. – 0.4 sec. – 0.5 sec. – 1 sec.	100mA 300 500 1000	3A 10 30	

8. 2 Impedance and power consumption

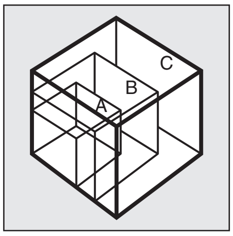
Table 8. 2 Impedance and power consumption of Mitsubishi ELCB Model

Model	Rated current (A)	Resistance R (mΩ)	Reactance X (mΩ)	Impedance Z (mΩ)	Powerconsumption Pw (W)
NV63-CV	5	105	14.5	106	9.88
	10	7.8	1.69	7.98	4.34
	15	5.6	1.59	5.82	5.78
	20	4.8	1.44	5.01	7.76
	30	3.9	1.20	4.08	12.5
	40	2.8	0.67	2.88	15.4
	50	2.1	0.46	2.15	17.8
	60	1.5	0.39	1.55	18.2
	63	1.49	0.35	1.53	19.7
NV125-CV	60	1.6	0.51	1.68	19.3
	75	1.15	0.31	1.19	21.4
	100	0.68	0.29	0.74	22.4
	125	0.64	0.23	0.68	32.0
NV250-CV	125	0.53	0.15	0.55	26.8
	150	0.51	0.14	0.53	36.4
	175	0.40	0.13	0.42	38.8
	200	0.33	0.12	0.35	41.6
	225	0.30	0.11	0.32	47.6
	250	0.28	0.11	0.30	54.5
NV400-CW	250	0.30	0.14	0.33	58.3
	300	0.22	0.15	0.26	61.4
	350	0.19	0.11	0.22	71.8
	400	0.16	0.11	0.19	78.8
NV630-CW	500	0.12	0.23	0.26	92.0
	600	0.10	0.38	0.39	110
	630	0.10	0.38	0.39	121.1
NV32-SV	5	105	14.5	106	9.88
	10	7.8	1.69	7.98	4.34
	15	5.6	1.59	5.82	5.78
	20	4.8	1.44	5.01	7.76
	30	3.9	1.20	4.08	12.5
	32	3.8	1.11	3.96	13.7
NV63-SV	5	137	16.6	138	12.3
	10	7.8	1.69	7.98	4.34
NV63-SV NV63-HV	15	5.6	1.59	5.82	5.78
	20	4.8	1.44	5.01	7.76
	30	3.9	1.20	4.08	12.5
	40	2.8	0.67	2.88	15.4
	50	2.1	0.46	2.15	17.8
	60	1.5	0.39	1.55	18.2
	63	1.49	0.35	1.53	19.7
NV125-SV NV125-HV	15	16.0	2.54	16.2	12.8
	20	9.0	1.41	9.11	12.8
	30	5.2	1.26	5.35	16.0
	40	2.5	0.64	2.58	14.0
	50	1.8	0.51	1.87	15.5
	60	1.6	0.51	1.68	19.3
NV125-SV NV125-HV	75	1.15	0.31	1.19	21.4
	100	0.68	0.29	0.74	22.4
	125	0.64	0.23	0.68	32.0
NV125-SEV	50	0.32	0.29	0.43	4.40
	60	0.32	0.29	0.43	5.46
	75	0.32	0.29	0.43	7.40
	100	0.32	0.29	0.43	11.6
	125	0.32	0.29	0.43	17.0
NV250-SV NV250-HV	125	0.53	0.15	0.55	26.8
	150	0.51	0.14	0.53	36.4
	175	0.40	0.13	0.42	38.8
	200	0.33	0.12	0.35	41.6
	225	0.30	0.11	0.32	47.6
	250	0.28	0.11	0.30	54.5
NV250-SEV	125-250	0.32	0.29	0.43	62.0
NV400-SW	250	0.31	0.25	0.40	60.1
	300	0.23	0.24	0.33	64.1
	350	0.19	0.26	0.32	71.8
	400	0.16	0.22	0.27	78.8
NV400-SEW NV400-HEW NV400-REW	200	0.10	0.31	0.32	14.0
	225	0.10	0.31	0.32	17.2
	250	0.10	0.31	0.32	20.8
	300	0.10	0.31	0.32	29.0
	350	0.10	0.31	0.32	38.8
	400	0.10	0.31	0.32	50.0
NV630-SW	500	0.1	0.38	0.39	92.0
	600	0.1	0.38	0.39	110
	630	0.1	0.38	0.39	121.1
NV630-SEW NV630-HEW	300	0.1	0.31	0.32	29.0
	350	0.1	0.31	0.32	38.8
	400	0.1	0.31	0.32	50.0
	500	0.1	0.31	0.32	77.0
	600	0.1	0.31	0.32	110.0
	630	0.1	0.31	0.32	121.1
NV800-SEW NV800-HEW	400	0.13	0.37	0.39	64.4
	450	0.13	0.37	0.39	80.9
	500	0.13	0.37	0.39	99.6
	600	0.13	0.37	0.39	142.4
	700	0.13	0.37	0.39	193.1
	800	0.13	0.37	0.39	251.6

Notes 1. Values at 50 Hz on front mounting type
2. For 60 Hz, multiply the reactance by 1.2.
3. There are differences depending on the connecting method and product.
4. The power consumption values of 3-pole products determined by the following formula are shown.

$Pw = I^2R \times 10^{-3} \times P + 2$ [W] P : Number of poles
2 : Power consumption of electronic circuit

Remark : 1J = 1W·s



9. Selection

9 Selection

9. 1 Before selecting rated current sensitivity

The most important factor for selection of ELCB is the rated current sensitivity. The rated current sensitivity should be determined examining various conditions of environment of use of electricity. However, also legal restrictions and measures against unnecessary operations should be taken into consideration. This section describes the factors to be examined in the selection.

9. 1. 1 Legally regulated places

Technical standards for electrical equipment, Labor Safety and Health Regulations and Interior Wiring Regulation specify the rated current sensitivity for some places. When installing ELCB in such a place, select the rated current sensitivity according to the regulations.

9. 1. 2 Selection for prevention of electric shock

For protection from electric shock, in principle, ELCB and protective grounding should be used, and the contact voltage should be reduced to low voltage. Therefore, if two bare live parts are touched even when ELCB is installed, the contact voltage caused by current passing the human body exceeds the allowable contact voltage regardless of protective grounding, and a shock hazard may be caused. ELCB is a device to provide protection against indirect contact described in IEC 60364-4-41. Protection against indirect contact can be provided by appropriately selecting ELCB rated current sensitivity based on the contact voltage and the resistance value of protective grounding. Generally, since the rated current sensitivity is not regulated, it is determined by the formulas (1) and (2) in 6. 4. 2. However, the rated current sensitivity should be selected from 15, 30, 100, 200 and 500mA, and the protective grounding resistance should be controlled to prevent the contact voltage from exceeding the allowable value.

9. 1. 3 Consideration of constant leakage current

From the viewpoint of protection coordination, it is necessary to confirm that unnecessary operations are not caused by constant leakage current originating from earth floating capacitance. Particularly, when selecting a high-sensitivity model, it is necessary to take measures, for example, reducing the wiring length and increasing the distance from the earth, to reduce the constant leakage current.

9. 1. 4 Procedures for selecting rated current sensitivity

The three factors, rated current sensitivity, protective grounding resistance value and constant leakage current on electric circuit, have a relationship with one another. From the viewpoint of electric shock protection, the relationship between rated current sensitivity and protective grounding resistance value is critical, and, from the viewpoint of prevention of unnecessary operations, the relationship between rated current sensitivity and leakage current cannot be ignored. Fig. 9. 1 shows the relationship among them.

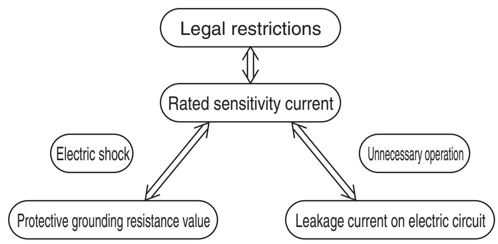


Fig. 9. 1

The factor to be defined first depends on various conditions. Generally, it is better to determine the relationship between rated current sensitivity and protective grounding and check for possibility of unnecessary operations caused by constant leakage current. It is not favorable, from the viewpoint of electric shock protection, to select a model with low rated current sensitivity for reasons of large leakage current on electric circuit except for unavoidable cases.

9. 2 Selection of rated current sensitivity

As a rule, the rated current sensitivity shall be selected based on the theories. However, since the theories contain many assumptions, it is necessary to select the rated current sensitivity referring to practical field data and experiences and observing the regulations if necessary. The actual selection procedures are described below.

9. 2. 1 Selection for electric shock protection

(1) The fundamental concept of prevention of risk of electric shock in the case of indirect contact is reduction of contact voltage value to reduce the passing current to the human body. Therefore, there is a close relationship between rated current sensitivity of ELCB and protective grounding resistance value of device.
If the allowable contact voltage (Table 6. 4 in 6. 4. 2 in "Outline of ELCB") is determined according to the

electrical environment conditions, the rated current sensitivity can be theoretically calculated by the following formula.

$$\text{Rated current sensitivity (mA)} \leq \frac{\text{allowable contact voltage (V)} \times 100}{\text{Protective grounding resistance value of casing of machines and devices } (\Omega)} \quad \cdots\cdots (1)$$

Actually, the protective grounding resistance value cannot be controlled finely. Therefore, the rated current sensitivity is selected from 30, 100, 200 and 500mA, and protective grounding work is performed to sufficiently meet the formula (1).

From the viewpoint of protection coordination, it is necessary to confirm that unnecessary operations are not caused by constant leakage current originating from earth floating capacitance. Particularly, when selecting a high-sensitivity model, it is necessary to take measures, for example, reducing the wiring length and increasing the distance from the earth, to reduce the constant leakage current.

Table 9. 2 Relationship between contact condition and rated current sensitivity

Item \ Contact condition	Class 1	Class 2	Class 3	Class 4
Degree of total danger	Highest	Very high	High	Low
Contact condition	• Most of human body is in water.	• Human body is considerably wetted. • Part of human body is constantly in contact with metallic electric device.	• Degree of danger is high if contact voltage is applied to human body in normal state in cases other than Class 1 and Class 2.	• Degree of danger is low even if contact voltage is applied in the state shown left. • There is no risk of application of contact voltage.
Fundamental concept	• Since the environment of application of contact voltage is severe, it is improper to specify the rated sensitivity current only based on individual elements, such as contact voltage and current passing human body. It is necessary to examine based on the product of current × time. • In underwater environment, a secondary accident may be caused by electric shock, and it is difficult to escape from the environment. Therefore, it is necessary to take measures to quickly and automatically break the electric circuit.	• The degree of danger in the case of application of contact voltage is the same as stated on the left because the human body resistance is regarded as identical to that in class 1 condition. • The difference from class 1 is that the affected range in class 2 is a point while that in class 1 is a surface. The environment of class 1 is underwater, and we cannot easily escape from it, but that of class 2 is the air, and we can easily escape from it.	• The degree of danger in the case of application of contact voltage ranges widely and, in some cases, may be close to the degree in class 2. • The difference from class 1 and class 2 is that no one is in constant contact with an electric circuit even if dielectric breakdown occurs on the circuit. • Since the human body is in the normal state, the human body resistance is relatively high. Therefore, generally, the contact voltage is allowed to be 50V or less, and a circuit breaker which gives an alarm or automatically breaks a circuit upon occurrence of dielectric breakdown may be used.	• If there is no possibility of contact of human bodies with a low-voltage electric circuit and the contact with the circuit is not so hazardous, it may be considered that the protection is primarily unnecessary. But, from the viewpoint of prevention of fire, practically, grounding work corresponding to class 3 work is required.
Electric circuits to be protected	• Electric circuits installed in bathtubs, swimming pools, water tanks, ponds and rice fields	• Water tanks, swimming pools and facilities around ponds and rice fields • In tunnels • When handling metallic electric devices and structures in constant contact with them • Electric circuits in houses and shops • Vending machines and freezing display cases	• General plants • Offices • Buildings and schools	• Electric circuits in locations where no one will touch the circuits • Electric circuits which do not require protective grounding (for example, electrical facilities installed in hidden areas in general places of houses, plants and offices or in high places)
Operating time	Fast-acting type or inverse time type	Fast-acting type or inverse time type	Fast-acting type or time delay type	Fast-acting type or time delay type
Allowable contact voltage	2.5V	25V	50V	Not specified

9. 2. 2 Selection based on leakage current

In many cases, there is some leakage current on electric circuits even if the insulation resistance is normal because earth floating capacitance exists between wire and earth. This leakage current can be approximately calculated if the wire type, wire size and circuit length from ELCB installation point to load device are determined. It is necessary to determine the rated current sensitivity to prevent unnecessary operations of ELCB owing to this leakage current.

(1) Total leakage current on Δ connection 3-phase 3W 200V electric circuit

① Calculation of leakage current from wire
Determine the length of electric circuit, wire type and size on the load side of ELCB, and calculate the leakage current from Attached Tables 4 to 8 in Appendix 10.

② Calculation of leakage current from motor
Determine the motor capacity and the number of motors, and calculate the leakage current using the value shown in the "leakage current at start" column in Attached Table 11 in Appendix 10 for the number of motors to be simultaneously started (generally, 10% of total number of motors are selected starting from that with the largest capacity) or in the "leakage current during operation" column for other motors.
Leakage current from almost all machines, such as air conditioners and machine tools, using motors, may be calculated based on the motor capacity.

③ Leakage current from fluorescent lamp
When lamp is installed directly on steel frame (also when metallic fittings are used): 0.1mA/unit
When lamp is installed on wood or concrete: 0.002mA/unit

(2) Calculation of leakage current on electric circuits by other wiring methods
Determine the leakage current by multiplying the leakage current value obtained in 9. 2. 2 (1) "Total leakage current on Δ connection 3-phase 3W 200V electric circuit" by the multiplying factor shown in Table 9. 3.

Table 9. 3 Table of conversion of leakage current

Kind of electric circuit	Multiplying factor
Single-phase 100V circuit	0.3
Single-phase 3 wire 200V circuit	0.3
3-phase 400V circuit (star connection)	0.7

(3) Inrush current on capacitive circuit
To prevent unnecessary operations, it is important to examine not only the constant leakage current caused by earth floating capacitance of the line, but also the transient leakage current caused by switching surge generated when switches (Magnetic Contactors, MCCBs, etc.) are opened and closed. As an example, the ratio of steady-state value to transient value for a circuit shown in Fig. 9. 2 is determined.

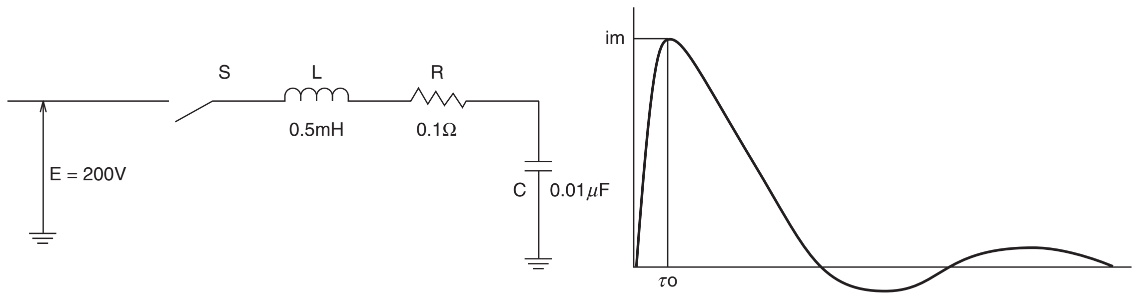


Fig. 9. 2 CapacitormAking current

im and τo in Fig. 9. 2 (b) are obtained by the following formulas.

$$im = \frac{\sqrt{2}\,E}{\sqrt{\frac{L}{C}}}\ \varepsilon - \frac{R}{\sqrt{(4L/C)-R^2}}\ \arctan \frac{\sqrt{(4L/C)-R^2}}{R} \quad \text{Formula (2)}$$

$$\tau o = \frac{2L}{\sqrt{4L/C-R^2}}\ \arctan \frac{\sqrt{\frac{4L}{C}-R^2}}{R} \quad \text{Formula (3)}$$

Assign the values shown in Fig. 9. 2 (a) to these formulas, and the following results can be obtained.

im = 1.26A τo = 3.5μS

Since the steady-state leakage current Ig in Fig. 9. 2 (a) is R $<< \frac{1}{\omega c}$ $\omega L << \frac{1}{\omega c}$,

$$Ig = \frac{E}{\sqrt{R^2 + (\omega L - \frac{1}{\omega c})^2}} \fallingdotseq \omega CE = 0.754\text{mA} \quad \text{Formula (4)}$$

im/Ig = 1670.

Since current of 1670 times the steady-state current flows to a circuit, it is necessary to examine whether or not ELCB will operate at this pulse current.

As is evident from this example, on a capacitance circuit, even if the constant leakage current is 0.754mA, current of 1670 times (1.26A) the steady-state leakage current may flow in a transient state depending on conditions. The resistance to the transient current varies depending on the manufacture and product. Mitsubishi circuit breakers with rated current sensitivity of 30mA will not operate if the capacitance is lower than the earth floating capacitance (= 0.04μF, 200V). In this case, the constant leakage current Ig is equal to $\sqrt{3}$ ωCE = 5.2mA (60Hz) on a 3-phase 200V Δ connectionn circuit, and unnecessary operations will not occur at a leakage current of 5.2mA or less. However, it is generally desirable that the leakage current is less than 1/10 of the rated current sensitivity to allow some margin.

(4) Selection of rated current sensitivity

After determining the constant leakage current by the above method and further examining the transient inrush current, finally determine the rated current sensitivity.

Table 9. 4 shows the relationship between constant leakage current (the insulation resistance to the earth is generally negligible, and the capacitance has a larger influence) and rated current sensitivity.

Table 9. 4 Selection of rated current sensitivity based on leakage current

Rated current sensitivity	Leakage current on electric circuit	
	200/400V circuit	100V circuit
15mA	1.5mA or less	3mA or less
30mA	3mA or less	6mA or less
100mA	10mA or less	20mA or less
200mA	20mA or less	40mA or less
500mA	50mA or less	100mA or less
1000mA	100mA or less	200mA or less

(5) Example of calculation and selection of leakage current

a. Conditions

① Steel-framed single story plant

② 3-phase 3W 200V Δ connection electric circuit

③ Electric devices

Machine tools (motor capacity of 0.75kW or less): 30 units

2.2kW compressor: 2 units

220W fluorescent lamp: 30 pcs.

④ Wiring with 600V vinyl-coated $14mm^2$ wire, circuit length 50m, $2mm^2$ × 100m, 1.6ϕ × 1km

⑤ One ELCB installed onmAin circuit

b. Leakage current

As shown in Table 9. 6, the total leakage current is approx. 13mA.

Table 9. 5 Leakage current

Electrical machine	Number of units	Leakage current per unit (mA)	Leakage current (mA)	Remarks
Compressor, 2.2kW	2	0.79	1.58	Value at start shown in Attached Table 11 in Appendix 10
Machine tool, 0.75kW	2	0.35	0.70	
Machine tool, 0.75kW	28	0.12	3.36	Value during operation shown in Attached Table 11 in Appendix 10
Fluorescent lamp	30	0.1	3.00	Value in the case of installation with fittings shown in 9. 2. 2 (1) ③
Electric wire, $14mm^2$	50m	22.1/km	1.11	Wiring with vinyl tube along steel frame according to Attached Table 8 in Appendix 10. For $2mm^2$ wire, the value for $5.5mm^2$ wire in the table is used.
Electric wire, $2mm^2$	100m	19.9/km	1.99	
Electric wire, $14mm^2$	1km	1.29/km	1.29	Wiring at a distance of 10cm from steel frame according to Attached Table 7 in Appendix 10, value for $5.5mm^2$ wire
Total			13.03	

c. Rated current sensitivity

The rated current sensitivity is 200mA from Table 9. 3.

In this case, the use of one ELCB with a sensitivity of 30mA on the main circuit is insufficient. It is necessary to install one circuit breaker on each of the power circuits of compressors and machine tools and lighting circuits.

9. 3 Analysis of unnecessary operations

While the operations of ELCB caused by the intended faults, such as earth leakage, electric shock and ground fault, are considered to be normal operations, the operations caused by other factors, such as surge and induction, are unnecessary operations (nuisance operations or nuisance trips). Many users may think that ELCB operates without reasons and causes troubles. This section analyzes the unnecessary operations of ELCB and describes the correct selection of ELCB.

9. 3. 1 Classification of ELCB operations

The operations are classified as shown below.

- Operations
  - Normal operations
    - (1) Operations owing to earth leakage, electric shock and ground fault
  - Unnecessary operations
    - Caused by ELCB
      - (2) Failure of earth leakage circuit breaker
      - (3) Improper sensitivity current (too sensitive)
    - Caused by circuits, etc.
      - (4) Surge
      - (5) Circulating current
      - (6) Induction
      - (7) Improper connection
      - (8) Improper grounding
      - (9) Influence of ground fault of branch circuit
      - (10) Overload or short circuit
      - (11) Environmental conditions (vibration, impact, etc.)
      - (12) Carrier phone
      - (13) Radio wave
      - (14) Inverter
      - (15) Others (operation of surge absorber, etc.)

9. 3. 2 Details of operations

(1) Normal operations

The normal operations of ELCB refer to the intended operations of ELCB. The major causes of the operations are shown below.

a. Deterioration of machine insulation
   Mainly, machines, such as washing machines, using water and machines, such as presses, receiving high impact.

b. Deterioration of wiring insulation
   Mainly, joints and terminals of temporary electric circuits.

c. Nonconforming work
   Ground fault caused by cables damaged during work and disconnection.

d. Careless handling
   Electric shock caused by submerging and ground fault caused by surge and drop of foreign substances.

(2) Defects of ELCB

Some parts of circuit breakers may be deteriorated and corroded to cause troubles, but the earth leakage detection module causes less defects. Wear of the electromagnet switching mechanism may cause unstable switching. Mitsubishi ELCB have sufficiently improved durability and can be used without concern for these problems. Besides these defects, circuit breakers with low equilibrium characteristics may operate at the start of motor. If the characteristics of the ZCT used in ELCB are inferior or the magnetic shield effect for the ZCT is low, the equilibrium characteristics of the ZCT are deteriorated by the influence of the residual current, and the circuit breaker may operate improperly because electromotive force is generated on the secondary winding of ZCT when the motor starting current (several times the full-load current) flows in the samemAnner as when an apparent ground fault occurs. As the bus-bar current increases, the absolute value of residual current becomes larger. Therefore, it is necessary to pay attention to the influence of residual current on a circuit with large load current. Care must be taken for circuits with unshielded ZCTs.

The residual current characteristics of ZCT vary depending on the coremAterial, conductor position and winding. It is not allowed that the circuit breakers on general circuits are operated incorrectly by the ZCTs. If a low-quality core is used or the ZCT shielding effect is insufficient, malfunction may be caused. For the ZCTs of Mitsubishi ELCB circuit breakers, high-quality Ni-based permalloy having good residual magnetic characteristics is used, and the outer surfaces of ZCTs are covered with a high-quality material having good magnetic characteristics for hydraulic magnetic shielding. Therefore, the influence of residual current on them can be minimized, and they will not malfunction. When unbalanced current occurs on a load, theoretically, ELCB will not operate. However, if a ZCT with low residual current characteristics is used, malfunction may be caused. malfunction at the start of motor or under unbalanced loading is caused owing to improper equilibrium characteristics of ZCT which are based on the residual current characteristics. It is necessary to use the product of a reliable manufacture.

(3) Improper current sensitivity

When the current sensitivity of ELCB is too high for the normal leakage current of a circuit, ELCB operates unnecessarily. This trouble is caused by improper selection of current sensitivity.

In most cases, circuit leakage current is caused by earth floating capacitance of electric wire. However, some electric furnaces and sheathed heaters decrease in insulation resistance at high temperatures although they have sufficient insulation resistance at low temperatures, and it may take time to reveal the cause of the operation.

In addition to the leakage current in the steady state, the transient leakage current at the switching or start may activate ELCB. The transient leakage at the start is caused through the capacitance to the winding frame because the potential distribution on the winding at the start differs from that during operation.

(4) Operation caused by surge

For the surge caused by secondary shift of induced lightning in distribution line, fig. 9. 3 shows a circuit for test for non-operation at lightning impulse.

When a circuit is affected by induced lightning surge, high voltage is applied to the distribution device through the electric line. At this time, the electronic parts of ELCB may malfunction to trip ELCB or may be damaged to disable ELCB. ELCB for service entrance may be influenced by this high voltage. Special care must be taken for this influence.

The magnitude and frequency of surge voltage carried by the induced lightning significantly vary depending on the region also in Japan. Statistically, in most cases, the surge voltage is 5kV or less. Although large induced lightning surges corresponding to 6 to 7kV have been recorded several times a year, it is generally allowed to think the surge voltage is about 5kV. Mitsubishi ELCB use electronic parts which have sufficient characteristics to cope with such phenomena. However, in many cases, as shown in Fig. 9. 4, the switching surge generated when the circuit is opened or closed by the inductive load switch S is not a single pulse unlike induced lightning surge, but a continuous pulse. Since the non-operating performance for continuous pulse is different from that for single pulse, it is necessary to improve the performance for continuous pulse. Mitsubishi ELCB have sufficient non-operating performance for continuous pulse and can be used reliably. However, it may be helpful to be well acquainted with this property.

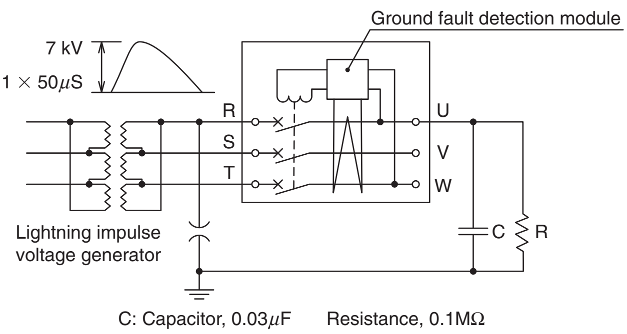


Fig. 9. 3 Test circuit for non-operation at lightning impulse

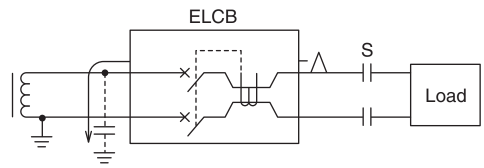


Fig. 9. 4 Switching surge

① The switching surge is not always caused when the current of inductive load is large. It occurs rather easier when the load current is low, 1 to 2A, and the load inductance is large. Attention must be paid to magnetic coil loads, such as magnetic switch coil current.

② The magnitude and repetition of surge depend on the performance of the switch S shown in Fig. 9. 4.
If the switch S causes chattering or a vacuum switch having too high breaking performance is used, surge is easily generated. Therefore, as the switch S, a device with less chattering and high current cutting performance is favorable. General magnetic relays are regarded as relatively useful.

③ To prevent switching surge, it is effective to add an arc reduction device, such as C or R, between the contacts of switch S or install a surge absorber on the load side.

Since the distribution line and load device have capacitance to the earth (earth floating capacitance), the charge current flowing through the earth floating capacitance may instantaneously increase when switches are closed under adverse conditions with non-simultaneous operations of contacts upon closing of switches and the above-mentioned surge voltage, and, if the charge current exceeds the rated non-operating current value, ELCB may operate. Electric circuits have various degrees of capacitance to the earth, but zero-phase current is not generated in the steady state if the capacities of the phases are well-balanced. However, switching surge is caused owing to contact chattering, the voltage phase will be disturbed, high-frequency voltage will occur, the impedance by the earth floating capacitance will decrease, and excessive charge current will flow, and, as the result, electromotive force will be generated on the ZCT secondary winding to activate ELCB. Therefore, a filter is provided on the ZCT secondary side to prevent the thyristor from responding to extremely short-time output of ZCT secondary winding owing to the surge voltage, and a surge absorbing circuit is installed to protect the electronic components against excessive leakage and large ground fault current. Most of Mitsubishi MCCB are provided with DPDC surge discriminating circuits for discriminating the ground fault current and the transient leakage current caused by surge to improve the performance to prevent unnecessary operations and will not malfunction on general circuits.

(5) Operation caused by loop circuit (circulating current)

As on parallel circuits connected on the load side as shown in Fig. 9. 5, the branch currents of each phase at the right and left branches are not always equal to each other. For example, when the current of phase A is divided into 11A and 9A, current of 1A is continuously flowing in this loop. This circulating current causes ELCB to operate. Therefore, use of two ELCB in parallel must be avoided. If earth leakage is detected on the ground wire of each transformer in the case of parallel operation of two transformers as shown in Fig. 9. 6, circulating current will flow through the ground wire owing to unequal division of current, thereby causing ELCB to operate. As a method to avoid this, the circuit may be configured as shown in Fig. 9. 6 (B).

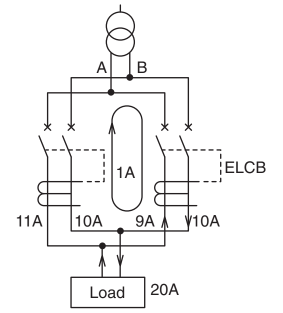


Fig. 9.5 Parallel circuit

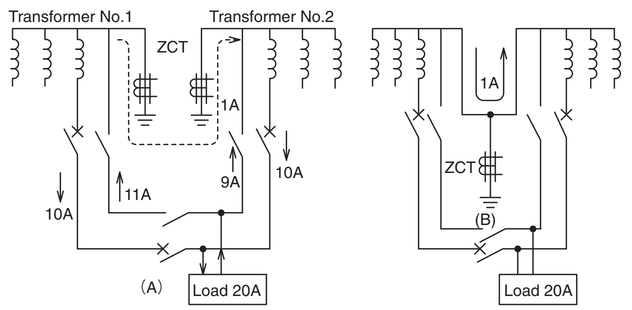


Fig. 9. 6 Parallel operation of transformers

(6) Operation caused by induction

A circuit contains a loop circuit as stated in (5) is easily affected by induction. That is, if the loop shown in Fig. 9. 5 is considered to be a loop antenna, the ZCT primary winding is connected to the antenna and easily generates induction. As an example, assume tha t the loop area is $1m^2$, and a 200A heavy current source is located at a distance of 5m (see Fig. 9. 7). When the circumference of a circle with a radius of 5m is the magnetic path length, the magnetic field strength H (AT/m) is:

$$H = \frac{AT}{2\pi R} = \frac{200}{31.4} = 6.37 \quad AT/m$$

Then, when $\mu = \frac{1}{800000}$,

$B = \mu H = 8 \times 10^{-6} Wb/m^2$ is the average magnetic flux density. The loop area is $S = 1\ m^2$, the total magnetic flux ϕ is:

$$\phi = BS = 8 \times 10^{-6} Wb.$$

The induced voltage E is $E = 4.44\ fN\phi$. However, since f = 60Hz and N = 1,

$$E = 2.12 \times 10^{-3}\ V.$$

Since the resistance R of 38-mm^2 wire 4m long is $R \fallingdotseq 1.92 \times 10^{-3} \Omega$, the circulating current I flowing in the loop is:

$$I' = \frac{E}{R} = 1.1A$$

This value is sufficient to activate ELCB with current sensitivity of up to 500mA. Actually, since the power supply is not isolated only in one direction, the influence of induction will be lower than the above calculation result. For example, when a single-phase power supply is used and other phases are at a distance of 5.2m from the power supply, the circulating current I' is $\frac{0.2}{5.2}$ of the above value:

$$I' = 0.04A.$$

This value is sufficient to activate ELCB with current sensitivity of 30mA.

As stated above, loop circuits are unfavorable from the viewpoint of induction. It is desirable to avoid such circuits.

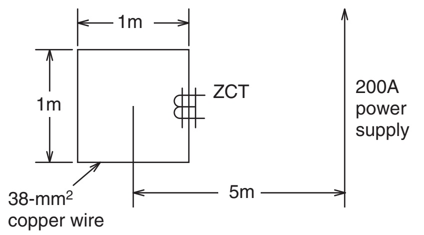


Fig. 9. 7 Loop antenna

If a ZCT is installed on the solid line in the figure when a common ground wire is used as shown in Fig. 9. 8, the primary conductor of the ZCT forms a loop. To avoid this, it is desirable to install the ZCT on the dashed line.

Induction can be caused also on the input circuit of an earth leakage relay. Therefore, the lead wires between the relay and ZCT must be twisted.

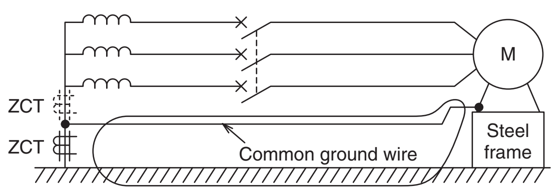


Fig. 9. 8 Detection of ground fault by ground wire

(7) Operation caused by improper connection

Simple errors, such as failure in passing the neutral line to the ZCT in Fig. 9. 9, can occur. In the case of Fig. 9. 9, ELCB will operate owing to single-phase load current.

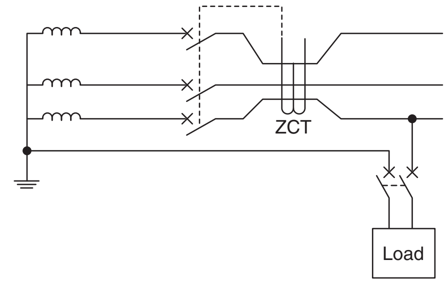


Fig. 9. 9 Improper connection of 3-phase 4-wire circuit

The TN-S system has the same circuit configuration as shown above. Care must be taken when using the system.
To the contrary, if a line not to be passed through the ZCT is passed through the ZCT, the circuit breaker may not operate when earth leakage occurs (see Fig. 9. 10). Therefore, do not pass the common ground wire through the ZCT.
The TN-C system corresponds to this.

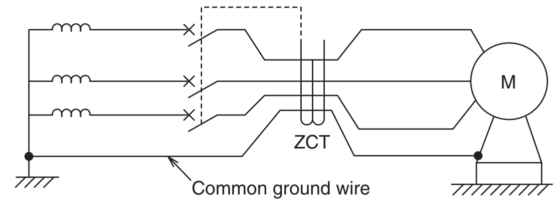


Fig. 9. 10 Improper connection of common ground wire

If grounding work has been performed for the metallic conduit or metallic shield of cable on the power supply side of the ZCT position as shown in Fig. 9. 11, ELCB may not normally operate when leakage occurs in the metallic conduit.
In this case, move the ground wire to the load side of the ZCT, or install the ZCT in a place other than the metallic conduit. If this is difficult, it is necessary to remove the metallic parts from the area of installation of the ZCT or take other proper measures.
If grounding is provided in two places, on the power supply side and the load side, in Fig. 9. 11, a loop as the primary conductor of ZCT is formed by the metallic conduit, ground wires and earth, and the circuit breaker may malfunction owing to the induction stated in (6).

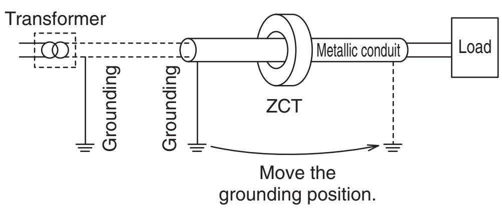


Fig. 9. 11 Grounding for metallic conduit

(8) Operation caused by improper grounding

The wire of a single-phase grounding delta circuit as shown in Fig. 9. 12 should not be grounded also on the load side.
In Fig. 9. 12, part of the load current is divided to I'_T by the voltage drop of the electric circuit on the grounding side, and ELCB is operated. (In addition, in Fig. 9. 12, the circuit breaker may not operate even if current leaks from the motor.)

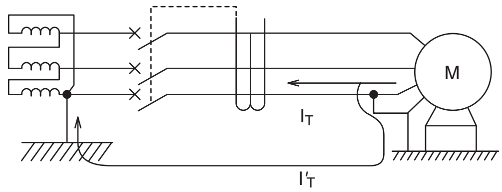


Fig. 9. 12 Improper double grounding

When the purchased power-private power line is switched, the neutral line must be switched simultaneously. If the line is not switched simultaneously as shown with the dashed line in Fig. 9. 13, the neutral line return current IN will be divided into IN and I'N shown in the figure, and ELCB on this circuit will operate.

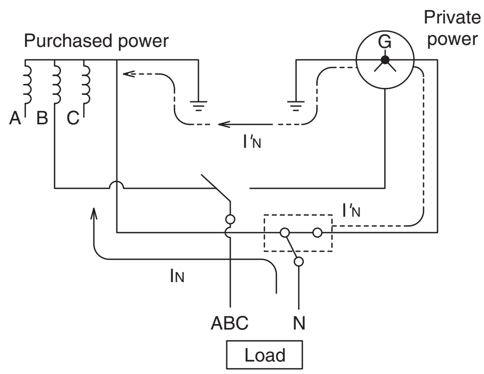


Fig. 9. 13 Simultaneous switching of neutral line

On machines (electronic calculators, numerically-controlled machine tools, etc.) using electronic circuits, filters are often used as measures against noise on the electronic circuits.
If a line filter is used as shown in Fig. 9. 14, current flows as shown with the dashed line to activate ELCB. To avoid this, an insulating transformer should be used in the power supply unit of the electronic machine.
On home-use audio equipment of auto transformer or transformer-less type, part of the return current I^2 leaks through the chassis earth as shown in Fig. 9. 15 to activate ELCB.

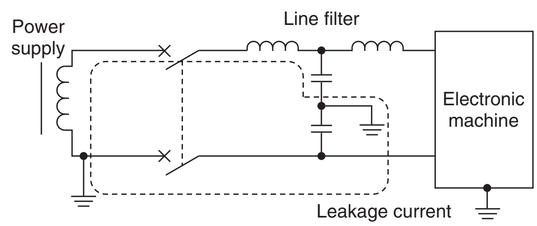


Fig. 9. 14 Line filter

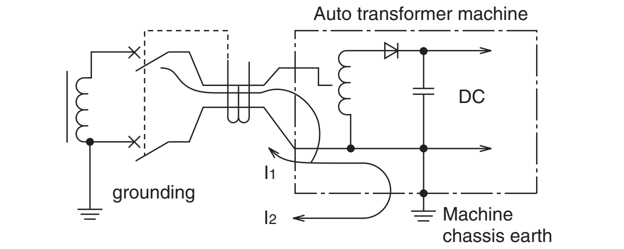


Fig. 9. 15 Chassis earth of transformer-less machine

On a system using a ZCT to detect zero-phase current for detection of ground fault, care must be taken for connection of neutral line. The neutral line on a single-phase 3-wire or 3-phase 4-wire circuit must pass through the ZCT without fail. In addition, the neutral line must be insulated from the earth, and the neutral line of each system must be electrically independent. When a ZCT is installed at each of the branches A and B in Fig. 9. 16, it is necessary to configure the circuit so that the neutral lines are not electrically connsected directly or indirectly through the earth. If they are connected correctly, the current at the branch A is $i_{1a} + i_{1b} + i_{1c} + i_{1N} = 0$, and that at the branch B is $i_{2a} + i_{2b} + i_{2c} + i_{2N} = 0$. No electromotive force occurs in each ZCT, and the ZCT will detect ground fault current when ground fault occurs.

However, if the neutral lines at the branches A and B are connected through the earth, $i_{1a} + i_{1b} + i_{1c} + i_{1N} = i_{2a} + i_{2b} + i_{2c} + i_{2N} = i_{0N}$ unless they are in full balance, and the ZCTs will detect current of i_{0N} and operate even when ground fault current does not flow.

As stated above, for detection of ground fault, if the connection of neutral lines is improper, troubles can occur. Therefore, wiring work for ground fault detection shall be performed more carefully compared to that without ground fault detection.

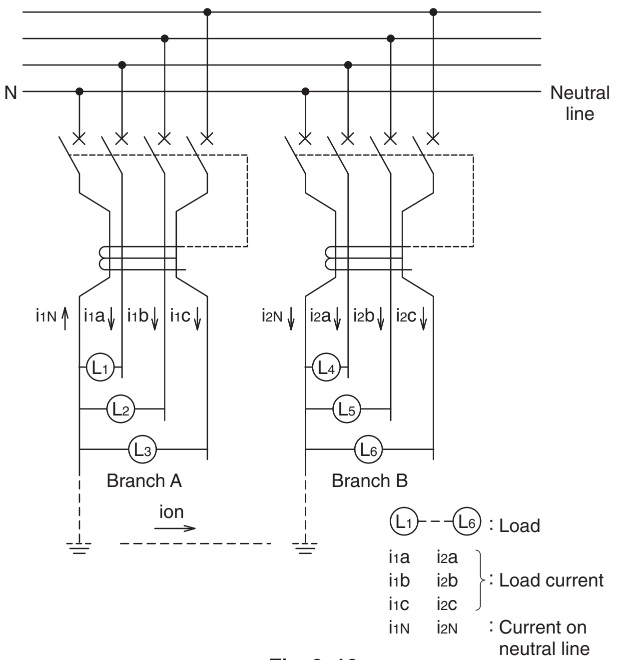


Fig. 9. 16

(9) Operation of sound circuit upon occurrence of ground fault of branch circuit

Circuits may be configured as shown in Fig. 9. 17, and ELCB not only on the ground fault circuit, but also on the sound circuit may operate. This can be prevented by using ELCB with current sensitivity appropriate to the leakage current caused by earth capacitance.

(10) Operation owing to overload or short circuit

It is normal that circuit breakers with overload and short circuit elements operate upon occurrence of short circuit. Most of ELCB are designed both for these factors, and you may forget that they can operate upon occurrence of overload or short circuit.

Furthermore, since the equilibrium characteristics of ELCB are restricted, even those for ground fault may operate at large overload or short circuit. However, in this case, you will notice such a large overload or short circuit.

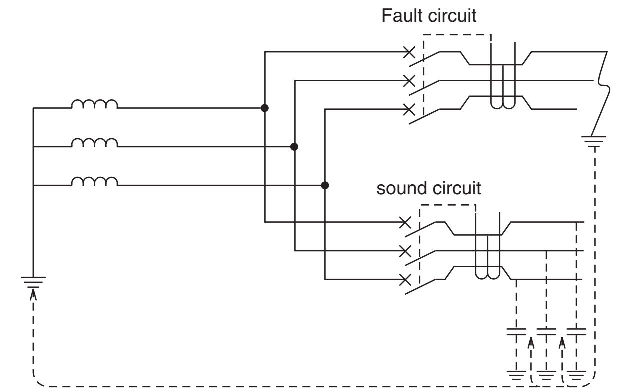


Fig. 9. 17 Operation on sound circuit owing to earth capacitance

(11) Environmental conditions, such as vibration, impact and high temperature

The influence of these conditions on ELCB can be considered to be almost identical to that on MCCB. Although the heat resistance of electronic circuits is often regarded as unreliable, Mitsubishi ELCB have a sufficient margin for the rating of parts and use parts which can withstand high temperatures and is containing temperature compensation circuits to stably operate at various ambient temperatures.

(12) Operation caused by carrier phone

If ELCB is installed on an electric circuit where a carrier phone unit for communication through power line is installed, ELCB may malfunction.

Since the carrier phone unit is a unit which forcibly inserts high frequency signals (normally, 50 KHz to 400 KHz) between electric circuit and earth as shown in Fig. 9. 18, ELCB detects the high frequency signals as leakage current andmAlfunctions.

Whether or not ELCB malfunctions depends on the magnitude of high frequency signal and the high frequency characteristics and rated current sensitivity of ELCB.

To prevent this malfunction, it is effective to use ELCB whose current sensitivity for high frequency current has been intentionally reduced. For determination of the specifications, consult us.

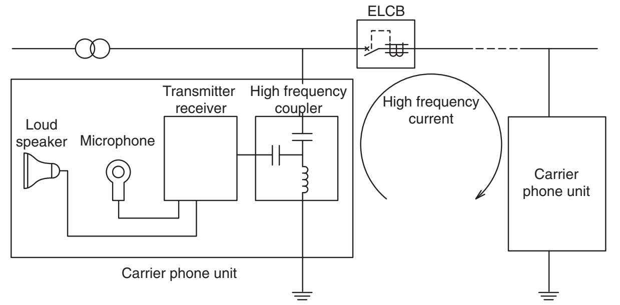


Fig. 9. 18 Example of installation of carrier phone unit

(13) Operation caused by radio wave

In the case where there is a large-output broadcasting station, taxi radio station or amateur radio station near a circuit with ELCB, ELCB may operate unnecessarily if the strength of radio wave, frequency, weather, landform and wiring method adversely affect them. Particularly, when signals from a portable transceiver are received near ELCB, high magnetic field strength is generated, and unnecessary operation can be easily caused.

Generally, portable transceivers are used in frequency bands of 27/28MHz, 50/60MHz, 150MHz, 400MHz and 90MHz, and their output is about 0.5 to 5W. Mitsubishi ELCB have been confirmed to cause no unnecessary operations when various commercially available transceivers with output of 5W transmit signals at a distance of 1m from ELCB. If it is expected that a stronger magnetic field will be generated, house ELCB in an iron box, and ground the box. The unnecessary operations can be prevented by installing a capacitor of hundreds to thousands pF as shown in Fig. 9. 19.

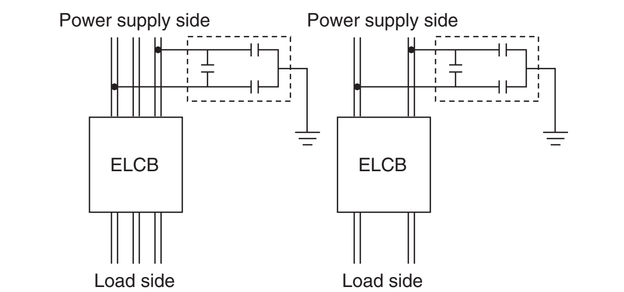


Fig. 9. 19 Installation of capacitor for prevention of unnecessary operations

(14) Operation caused by inverter

Since these high frequency components are constantly carried by the earth floating capacitance, ELCB may operate unnecessarily when the earth floating capacitance is increased. (Fig. 9. 20)

Therefore, when using a general ELCB on an inverter circuit, it is necessary to select one with current sensitivity lower than usual to prevent unnecessary operations.

To ensure high-sensitivity detection of ground fault on an inverter circuit and realize stable detection of ground fault on the primary and secondary sides of the inverter, it is suitable to use ELCB applicable to higher harmonics and surge which is hardly affected by high frequency components so that it can be used for inverter.

ELCB shall be installed on the inverter primary side. Never install it on the secondary side.

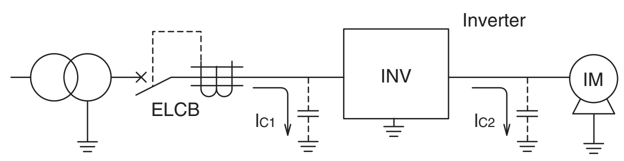


Fig. 9. 20 Circuit with inverter

(15) Others

As the electronics technologies are increasingly applied to load devices, in many cases, surge absorbers are installed in the devices or on the electric circuits to protect the devices from surge. The surge absorbers connected to the earth, which discharge surge to the earth, generate large transient leakage current although for a short time and may cause unnecessary operations of ELCB (Fig. 9. 21).

Most of ELCB are provided with DPDC surge discriminating circuits for discriminating ground fault current caused by faults, such as insulation failure, and the transient leakage current caused by surge to improve the performance to prevent unnecessary operations even if surge absorbers are installed between them and the earth.

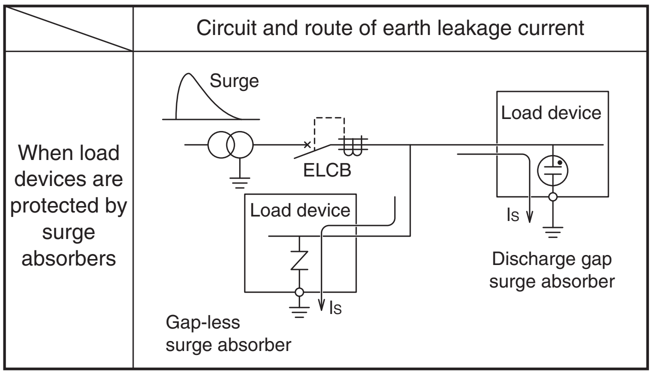


Fig. 9. 21 Transient leakage current caused by surge absorbers

9. 3. 3 Summary of unnecessary operations

The unnecessary operations of ELCB are described above. We have taken all possible measures against unnecessary operations caused by ELCB. Therefore, they will not cause any problem under normal working conditions. Almost all unnecessary operations are caused by factors of circuits. Most of unnecessary operations can be prevented by taking special care when wiring and connecting ELCB and selecting their installation locations and current sensitivity.

It is desirable to carefully examine the earth floating capacitance to the earth and the rated current sensitivity at the stage of design.

9. 4 Protection from arcing ground fault

9. 4. 1 Actual condition of arcing ground fault

General ground faults are caused by contact of electric circuits or electrical equipment with the earth at a resistance value lower than the normal insulation resistance value and include faults caused by electric shock and earth leakage and ground fault, and the ground fault current ranges from several mA to thousands A depending on the earth voltage and ground impedance. For prevention of these ground faults, high speed type ELCB or earth leakage relays are used at branches, and a time delay type ELCB or earth leakage relay is used on the main line for coordination of operating time. This method is gradually coming into use. The method ensures protection from general ground faults and limits damage to the faulty parts, and the damage is relatively minimal.

To the contrary, upon occurrence of arcing ground fault, an electric circuit or device is connected with the earth through arc, the fault current value is restricted to about 30% of the 3-phase short circuit current owing to arc voltage drop and earth resistance. Therefore, on a circuit using only general circuit breakers, the arcing ground fault current does not reach the instantaneous tripping area of any circuit breaker, and the arc may be kept for a long time. When a time delay type ELCB is used, since its operating time is long, the arc is kept during the operating time. If arcing ground fault continues, the electric circuit and device will be significantly damaged by a large amount of thermal energy generated by the arc, and other sound devices may be affected because the arc point moves. The best-known accident caused by arcing ground fault is the fire accident of a large apartment house in New York. In this accident, arcing ground fault continued for 1 hour on a 480/277V distribution circuit, the distribution board is burned out, and the 5000A bus bar burned out to the starting point. As the result of this, the lifts, lamps and feed pumps were stopped, and approx. 10,000 residents of the apartment house were forced to live rough, and several days were taken to restore the facilities. As stated above, when arcing ground fault continues, unlike in the case of general ground fault, electric circuits and devices are considerably damaged, and there is a possibility of damage to other devices.

9. 4. 2 Damage to electric circuits and devices by arc

(1) Arc energy and damage to devices

The scale of arcing ground fault is indicated not only by the ground fault current value, but also by the arc energy determined by the ground fault current, arc voltage and sustaining cycle and can be determined by the following formula.

$$Pa = \frac{Ig \times Ea \times t}{1000} \quad \cdots\cdots (1)$$

Where, Pa : arc energy [kW-cycle]
Ig : Ground fault current RMS value [A]
Ea : Arc voltage [V]
t : Sustaining cycle of arc [cycle]

Table 9. 7 shows the arc energy obtained by the above formula and the degree of damage to devices determined according to the results of various tests.

The limit of arc energy is 2000kW-cycle.

Table 9. 7 Arc energy and damage to devices

Arc energy	Degree of damage to devices
100kW-cycle	Spots and traces of smoke are left on device mounting panel, but there is no real damage.
2,000kW-cycle	The mounting panel is melted but not holed. The conductor exposed surfaces are not fused. The device insulated parts are spoiled by arc, but the insulation can be restored by cleaning. It is necessary to limit the arc energy to this level.
10,000kW-cycle	The metallic fittings and conductor exposed surfaces are considerably melted and damaged by arc, but the arc is within the box and does not spread to other boxes or panels. The box or panel where the arc occurred loses its functions.
20,000kW-cycle	The arc cannot be contained within the box or panel, damages the case and spreads to adjacent boxes or panels.

(2) Minimum sustaining current of arcing ground fault

The minimum sustaining current of arcing ground fault is up to about 350A although it significantly changes depending on the gap, pole arrangement at arc point and shape. If the sustaining current lowers below this value, the arc will become unstable and spontaneously disappear.

(3) Transition from arcing ground fault to phase-to-phase arcing short circuit

In most cases of normal metallic panels, if arcing ground fault does not spontaneously disappear, arcing ground fault changes to phase-to-phase arcing short circuit. The transition time varies significantly from several ms to hundreds ms depending on the device layout, gap and arcing ground fault current. Fig. 9. 22 shows the oscillogram in a case of transition from arcing ground fault to phase-to-phase arcing short circuit. In this case, the ground fault arc energy is 215kW-cycle, and the phase-to-phase arc energy is 2250kW-cycle. The damage caused by the phase-to-phase arc is larger.

According to the above, it is found that:

○ The arcing ground fault can occur on electric circuits on which ground fault current of 350A or more flows.

○ It is necessary that electric circuits must be broken quickly while the arc energy is within 2000kW-cycle.

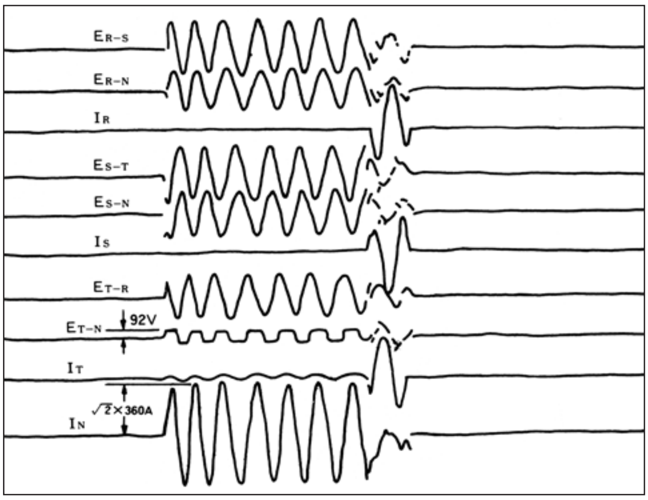


Fig. 9. 22 Example of MCCB breakng for phase to phase arcshort circuit caused by arc ground fault

9. 5 Ground fault protection coordination

Since the ground fault current changes from several mA to thousands A, the selective protection coordination shall be examined in the remarkably wide range.

When a selective breaking system is used, coordination cannot be achieved only based on the difference in rated current sensitivity.

Fig. 9.23 shows the operating characteristics of ELCB by single lines. Selective coordination between ELCB1 with sensitivity of 30mA and high-order ELCB2 with sensitivity of 200mA can be achieved at a ground fault current of 150mA or less. But, at a ground fault current exceeding 150mA, there is a strong possibility that both ELCB1 and ELCB2 will operate because they are high speed circuit breakers with operating time of 0.1 sec or less. Therefore, the selectivity shall be examined in consideration of the rated current sensitivity and operating time.

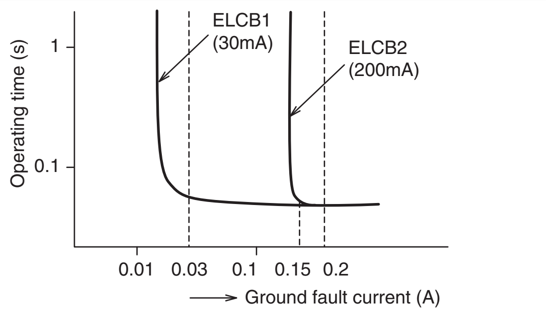


Fig. 9. 23 Operating characteristics of high speed MCCB

9.5.1 Ground fault protection coordination by time delay circuit breakers

In many cases of prevention of electric shock and ground fault at terminals, circuit breakers with high sensitivity (30mA or so) having the highest protection effect are used. For long systems, since faults between transformer and branches can occur, MCCB are often used also on the main lines for protection between them. In such a case, if selective coordination is not achieved on the whole circuit, the high-order ELCB will operate upon occurrence of ground fault, other sound circuits will be broken, and power supply cannot be continued. Therefore, it is necessary to examine the coordination.

Fig. 9. 24 shows an example of a coordination system using time delay circuit breakers, and Fig. 9. 25 shows the coordination diagram of ELCB1, ELCB2, ELCB3 and ELCB4 on the system shown in Fig. 9. 24. If a ground fault of several A occurs at the point A, ELCB4, which is a high speed circuit breaker, will operate within 0.1 sec. The high-order ELCB3 which is a time delay circuit breaker with operating time of 0.3 sec has a longer operating time than the total breaking time of ELCB4 at the branch. Therefore, selective trip can be ensured ly. On time delay circuit breakers, the inertial non-operating time is shown. The circuit breakers will not operate within the time even if ground fault current is flowing. The minimum value of the time is 0.1 sec. Therefore, coordination between the time delay and high speed types can be easily obtained as in this case.

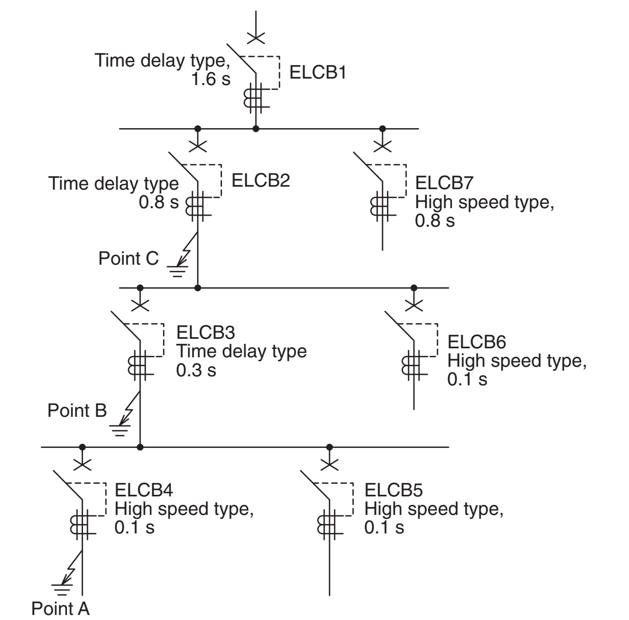


Fig. 9. 24 Example of coordination system with time delay circuit breakers

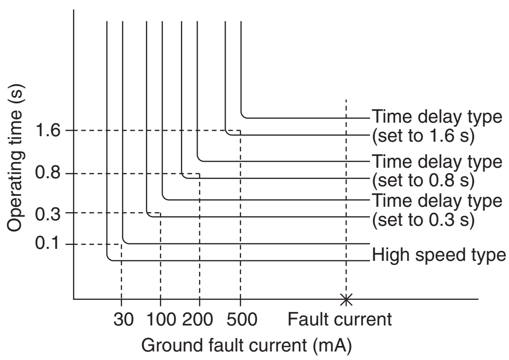


Fig. 9. 25 Coordination characteristics of time delay circuit breakers

Similarly, since the inertial non-operating time of ELCB1 and ELCB2 is longer than the total breaking time of ELCB4, ELCB3, ELCB2 and ELCB1 will not operate upon occurrence of fault.
When a fault occurs at the point B, since the inertial non-operating time of ELCB2 and ELCB1 is longer than the total breaking time of ELCB3, coordination between ELCB3 and ELCB2 and ELCB1 can be achieved, and power supply to ELCB6 can be continued.
Also when a fault occurs at the point C, coordination between ELCB2 and ELCB1 can be achieved, and power supply to ELCB7 can be continued.

9. 6 Application to concrete electric circuits

9. 6. 1 Branch circuits

Branch circuits are closest to devices and operators and, therefore, involve a high risk of electric hazard. Except for special cases, the use of high-sensitivity circuit breakers (30mA or so) is desirable. For outlets in western style bathrooms, vending machines, machines using midnight power and mobile and portable motor-driven machines, high-sensitivity high speed circuit breakers should be used.
Generally, since branch circuits are shorter and have lower earth floating capacitance, the risk of unnecessary operations is low even if high-sensitivity circuit breakers are used. However, if the earth floating capacitance is increased, it is better to reduce the constant leakage current through improvement of branch wiring method and use high-sensitivity circuit breakers.
Under some conditions, it is difficult to use high-sensitivity circuit breakers. In such a case, as stated in 9. 2. 2 “Selection for electric shock protection for general equipment,” use medium sensitivity circuit breakers with sensitivity of 100mA, 200mA or 500mA reducing the class D grounding resistance value to prevent the voltage from exceeding the allowable contact voltage.

9. 6. 2 Main circuits

ELCB installed on main circuits shall be capable of providing selective coordination with ELCB on branch lines and protecting the electric circuits from ground fault of the main lines. The most common and simplest method is to use medium sensitivity time delay ELCB, and this method is economical.
Note that since the rated non-operating current of ELCB is 50% of the rated current sensitivity, the rated current sensitivity of ELCB for branch exceeds the rated non-operating current of ELCB for main line if the rated current sensitivity of ELCB for branch is too close to that of ELCB for main line, and selectivity cannot be obtained. Therefore, the current sensitivity of branch and that of main line shall be different desirably by 2.5 times.
Table 9. 8 shows the relationship between rated current sensitivity of ELCB for branch circuit and that for main circuit.

Table 9. 8 Relationship between rated current sensitivity of ELCB for branch circuit and that for main circuit

Rated current sensitivity of ELCB for branch	Rated current sensitivity of ELCB for main line
15 · 30	100 · 200 · 500
100 · 200	500 · 1000
500	1000

9. 6. 3 Detection of ground fault by ground wire

One of the methods for protecting the whole electric circuit from ground fault is detection of ground fault by ground wire. As shown in Fig. 9. 26, only the ground wire of power supply is passed through the ZCT. When the circuit is broken, it is protected by the earth leakage relay combined with MCCB with SHT.

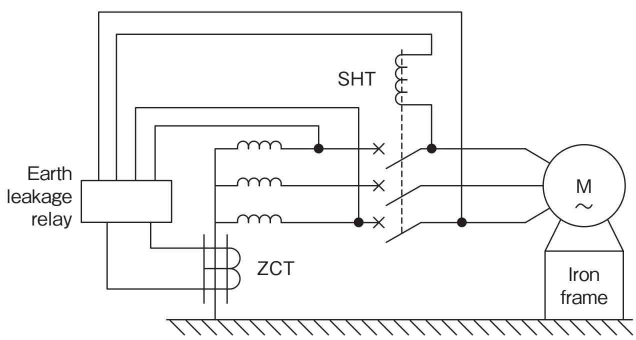


Fig. 9. 26 Ground fault protection by ground wire

9. 6. 4 Arc welder circuits

In many cases, an arc welder is moved in a working site during use. Therefore, there is a possibility that the workers may touch the insulated wires or movable cables on the primary side. In such a case, it is desirable to install ELCB.
Therefore, ELCB are used in many cases. ELCB for arc welders must not malfunction with an instantaneous transient phenomenon at the start of arc welding.
Therefore, some manufacturers separate the circuit breakers for arc welders from others. Mitsubishi ELCB of

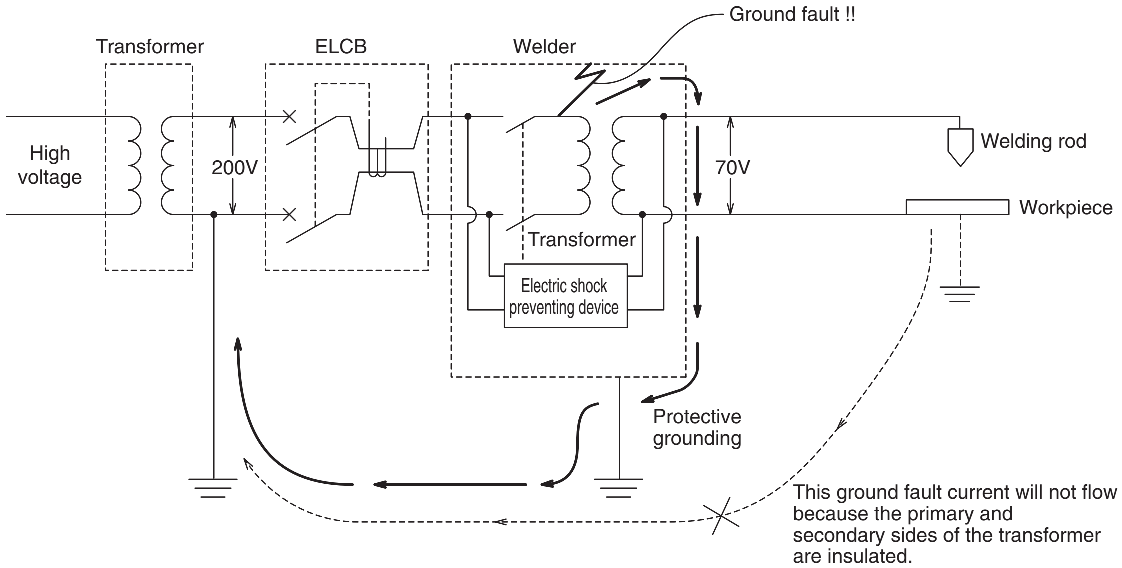


Fig. 9. 27 Arc welder circuit

standard type can be used for arc welders.

There are various kinds of welders, including arc welders and resistance welders. On welder electric circuits, as shown in Fig. 9. 27, the low-voltage circuit (primary circuit of welder transformer) is grounded, and the load circuit of the welder (secondary circuit of welder transformer) is insulated from the primary side.

When ELCB is installed on this low-voltage circuit, ELCB can protect only the range to the primary side of the welder transformer from electric shock and cannot protect the secondary circuit because the circuit is insulated from the primary side. For example, if insulation breakage occurs between the primary winding of the welder transformer and outer case, the “welder transformer → outer case → protective ground wire → earth → electric circuit ground wire → transformer” circuit will be formed as shown in Fig. 9. 27, and ground fault current will flow to operate ELCB.

However, even if the welding rod or workpiece is connected to the earth, ground fault current will not flow to the electric circuit ground wire because the primary side and secondary side of the welder transformer are insulated.

Therefore, it is unnecessary to take into consideration the leakage current which will be generated if the workpiece is connected to the earth, and ELCB rated current sensitivity of 30mA is allowed.

However, when one ELCB is installed for tens of welders or the wire between ELCB and welder is remarkably long, it may be desirable to install ELCB with medium sensitivity (200 or 500mA) in consideration of the earth floating capacitance.

The secondary circuit of the arc welder transformer has a voltage of about 70V while welding is suspended and can cause electric shock. Therefore, measures against electric shock must be taken for the circuit. To prevent the electric shock, an electric shock preventive device should be installed. The electric shock preventive device keeps open the primary side of the welder transformer while welding is suspended. Therefore, there is no possibility of electric shock on the secondary side. During welding, the voltage between welding rod and workpiece is reduced to several V, and there is no risk of electric shock.

✦Points for selection

(1) Operation with overcurrent trip element

The instantaneous tripping current value must be set larger than the transient inrush current value of welder.

The transient inrush current values of commercially available welders are 8 to 9 times.

(2) Operation with earth leakage trip element

Voltage may be generated on the secondary side of ZCT by the transient inrush current of welder, and a phenomenon similar to ground fault may occur.

Mitsubishi MCCB have excellent resistance to such transient phenomenon (equilibrium characteristics), and even the standard models will not malfunction.

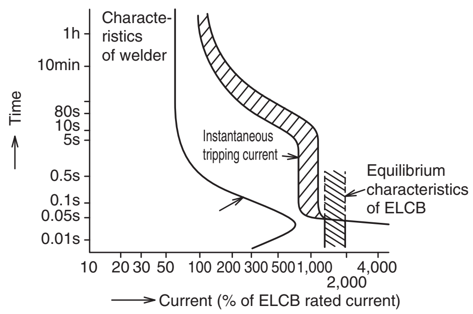


Fig. 9. 28 Overcurrent tripping characteristics of ELCB

(3) Rated current

Generally, calculate the rated current by the following formula in consideration of the use at the maximum output.

$$I_{ELCB} \geq K \times \frac{P}{E} \times 10^3$$

I_{ELCB} : Rated current of ELCB (A)

P : Rated input o f welder (kVA)

E : Rated voltage of welder (V)

K : Constant for use at max. output, normally 1.2 or so

(4) Rated current sensitivity

Since the major purpose is protection from electric shock, it is recommended to select a circuit breaker with rated current sensitivity of 30mA. However, when the electric circuit is remarkably long, determine the rated current sensitivity carefully because a circuit breaker may malfunction owing to the earth floating capacitance sf the electric circuit.

In this case, calculate the current sensitivity by the following formula.

$$I_{\Delta N} \geq K (L \times Ig_1 + n \times Ig_2)$$

$I_{\Delta N}$: Rated current sensitivity of ELCB (mA)

K : Safety factor for ingress of switching surge, normally 10 o r so

km) … According to Attached Tables 4 to 8 in Appendix 10

n : Number of welders

I_{g2} : Leakage current per welder (mA) (1 because the current is 1mA or less and negligible in the case of normal use)

9. 6. 5 Resistance welder circuits

Resistance welders are classified into several types according to voltage and capacity. All resistance welders used at 400VAC shall be provided with ELCB, and those used at 200VAC shall be provided with ELCB if they are water-cooled and may be exposed to moisture. In the case where workers may touch insulated wires or movable cables of welders, ELCB shall be installed on the welders used at 200VAC and 400VAC.

Fig. 9. 29 shows an example of a resistance welder circuit. Also on this circuit, ELCB can protect only the range to the primary side of the welder transformer from electric shock and cannot protect the secondary circuit. However, the voltage on the secondary side is normally 8V or so, and there is no possibility of electrocution at this voltage. (It is said that voltage of 25V or less is safe even in a sweating state.)

Mitsubishi ELCB (NV225-WEP and NV400-WEP) have built-in timers and can protect circuits even from abnormal weld flow.

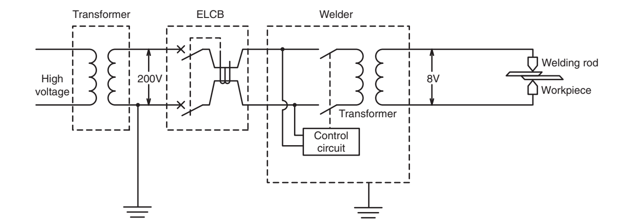


Fig. 9. 29 Resistance welder circuit

When welding is started, the timer detects the welder current and starts counting the time. If the welder current continues to flow after a lapse of the welding time set on the timer (continuous arc-through or abnormal weld flow), the built-in contact in the timer will close, the tripping coil will be excited, and the circuit breaker will automatically trip. In the case of normal weld flow, the welder current will be stopped within the welding time set on the timer, and the timer will be reset (the maximum reset time is 0.1 sec) and get ready for start of next welding.

The welding time shall be set on the timer somewhat longer than the welding time set on the welder control unit.

When earth leakage occurs, the ZCT will detect the leakage, the tripping coil will be excited through the leakage detector, and the circuit breaker will trip. At a welder circuit a large inrush current will flow owing to the transient phenomenon at the start of welding, and the ZCT may detects it as earth leakage and cause malfunction (the magnitude of inrush current at which the circuit breaker does not malfunction is indicated as the RMS value referred to as an equilibrium characteristic). Mitsubishi ELCB have an equilibrium characteristic improved by reinforced magnetic shield and will not malfunction.

When short circuit occurs, the instantaneous trip device will function, and instantaneously the circuit breaker will trip automatically.

✦Points for selection

(1) Selection of rated flowing current

The rated flowing current is 225A or 400A. Select the current based on the thermally equivalent current of the welder primary current. Actually, the welder primary current varies depending on the welding conditions, such as the material and thickness of workpiece. However, the welder primary current determined based on the current value obtained from the rated capacity of welder can be used without problem. Since the rated capacity of welder is prescribed as input at a service factor of 50%, the thermally equivalent current Ie can be obtained by the following formula.

$$Ie = \frac{P}{V} \times \sqrt{\beta}$$

Where, P is the rated capacity of welder, V is the rated voltage of welder, and β is the service factor and expressed by the formula β = weld time/weld cycle.

For example, when the rated capacity is 100kVA and the rated voltage is 415V:

$$Ie = \frac{100 \times 10^3}{415} \times \sqrt{0.5} = 170A.$$

The rated flowing current is determined by allowing a margin of about 15% for this value in consideration of supply voltage fluctuation. Therefore, 170A × 1.15 = 19A, and a circuit breaker with rated flowing current of 225A should be selected.

Table 9. 9 Table of selection of rated flowing current

Rating of resistance welder		ELCB rated flowing current (A)
Rated voltage (V)	Rated capacity (kVA)	
200	50 or less	225
	Over 50 to 100	400
415	100 or less	225
	Over 100 to 200	400

Table 9. 9 shows the relationship between welder rated capacity and rated flowing current of ELCB determined by the above calculation formulas.

(2) Selection of rated current sensitivity

The standard current sensitivity of ELCB for inverter welders is 30mA.

If the electric circuit between ELCB and welder is increased, ELCB may malfunction under the influence of earth floating capacitance. It is necessary to install ELCB in such a way that the circuit length is less than the value shown in Table 9. 10. For cases where the circuit length is longer and circuit breakers with sensitivity of 30mA cannot be used, 100mA, 200mA and 500mA circuit breakers are available as special models.

Table 9. 10 Rated current sensitivity and maximum electric circuit length (m)

Rated voltage	Applicable wire size mm^2	For wiring with 600V vinyl coated wire (1V)						For wiring with chloroprene cabtyre cable (2RNCT)		
		Wiring work with vinyl tube			Wiring work with metallic conduit					
		30mA	(200mA)	(500mA)	30mA	(200mA)	(500mA)	30mA	(200mA)	(500mA)
200	38	125m	1250m	3100m	25m	250m	630m	45m	450m	1100
	60	100	1000	2500	20	200	500	37	370	910
	100	90	900	2300	18	180	440	36	360	890
415	100	78	780	1990	15	150	380	31	310	770
	150	70	700	1750	14	140	355	26	260	650
	200	68	680	1710	13	130	340	28	280	710

(3) Setting of instantaneous tripping current

The instantaneous tripping current must be determined in consideration of the maximum input current of welder and the inrush current at the start of welding. The maximum input current can be obtained from the standard maximum input of welder, but, when the welder secondary side is completely shorted, the maximum input current will be higher by about 30% than the current value determined from the standard maximum input. Therefore, the instantaneous tripping current Iinst in consideration of the inrush current at the start of welding can be determined by the following formula.

$$Iinst > \frac{Pmax}{V} \times 1.3 \times K$$

Where, Pmax is the standard maximum input of welder, V is the rated voltage of welder, and K is the margin ratio for inrush current and 1 to 1.5 for models with synchronous peak control, 1.4 to 3 for models without synchronous peak control and 2 to 6 for models with asynchronous soft start. Table 9. 11 shows examples of selection of instantaneous tripping current determined by the above formula.

Table 9. 11 Examples of selection of instantaneous tripping current

Welder specifications			ELCB rated flowing current (A)	Instantaneous tripping current (A)		
Rated voltage (V)	Rated capacity (kVA)	Standard max. input (kVA)		With synchronous peak control K = 1.0	Without synchronous peak control K = 1.4	With asynchronous soft start K = 2
200	35 50 70 100	69 144 144 240	225 225 400 400	900 2250 2400 4400	1200 2250 2400 4400	2250 3000 4400 4400
415	35 50 70 100 120 150 200	69 144 144 240 295 455 875	225 225 225 225 400 400 400	900 900 900 1200 1200 2400 4400	900 1200 1200 2250 2400 4400 6000	900 1200 1200 2250 2400 4400 6000

Note: In the above table, the instantaneous tripping current values determined based on inverter welder specifications are shown. When selecting the instantaneous tripping current, it is necessary to ensure the coordination so that the surge current capacity of control element (thyristor stack) is not exceeded.

9. 6. 6 Inverter circuits

(1) Influence of higher harmonics and countermeasures

Higher harmonics can be caused by CVCF units with thyristors and transistors used as computer power supply units, various rectifiers and VVVF units for motor control for meeting the recent trend toward energy conservation.

These units are used to make AC power using the semiconductor switching function. In this process, a current chopping phenomenon occurs, and wide-range higher harmonics and high frequency noises are generated. Below is described the influence of higher harmonics and high frequency noises on ELCB and proper selection of ELCB for the VVVF inverters which are widely used as a major method for motor control.

(2) Selection of ELCB

①Selection of rated current

Since the harmonic content is very high on inverter circuits, select the rated current to ensure the following relationship between ELCB rated current I_{ELCB} and load current I.

$I_{ELCB} \geq 1.4 \times I$

②Selection of rated current sensitivity

When a motor is driven by an inverter, the output voltage of the inverter contains harmonic components, and leakage current is constantly generated by the earth floating capacitance of the electric circuit from the inverter to the motor and the floating capacitance between the motor winding and core. Although the leakage current value varies depending on the wire type, wire thickness, length of wire from ELCB to inverter and wire from inverter to motor and inverter output frequency, calculate the approximate value of leakage current based on the values in the case of commercial power supply (50Hz or 60Hz).

1) Leakage current from wire

Determine the length of electric circuit from ELCB to inverter input terminal and the wire type and size, and calculate the leakage current according to Attached Tables 4 to 8 in Appendix 10. (Use the values at the commercial frequency. Ignore the high-frequency components.)

Determine the length of electric circuit from inverter output terminal to motor and the wire type and size, and calculate the leakage current according to Attached Tables 4 to 8 in Appendix 10. Then, multiply the calculated value by K_2 in consideration of high-frequency components. (Average multiplying factor K_2 depending on inverter output frequency)

2) Leakage current from motor

Determine the motor capacity and the number of motors, and calculate the total leakage current using the leakage current value during operation shown in Attached Table 11 in Appendix 10. Then, multiply the calculated value by K_2 in consideration of harmonic content. (Average multiplying factor K_2 depending on inverter output frequency)

3) When radio noise filters for inverter (FR-BIF) are used, take into consideration leakage current of approx. 4mA per filter.

● Selection of rated current sensitivity

Determine the constant leakage current by the method stated as above, and set the rated current sensitivity to 10 times or more the constant leakage current in consideration of transient inrush current.

According to the above, the following formula (1) for selection of rated current sensitivity can be obtained.

Rated current sensitivity $I\Delta n \times K_1 [Igc_1 + Ign + K_2 (Igc_2 + Igm)]$ (mA) ··· (Formula 1)

Igc_1 : Constant leakage current from electric circuit between ELCB and inverter (mA)

Igc_2 : Constant leakage current from electric circuit between inverter and motor (mA)

Igm : Constant leakage current from motor (mA)

Ign : Leakage current from noise filter from inverter input side (mA)

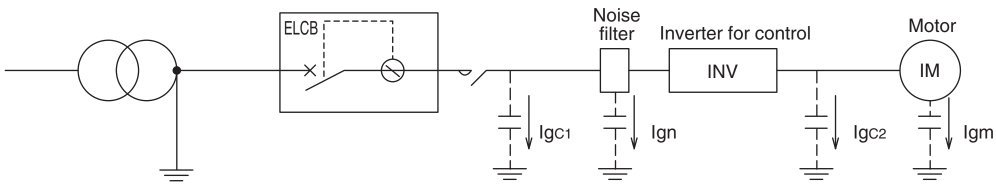
Ig : Total leakage current

K_1 : Constant for transient inrush current, 10

K_2 : Constant for harmonic content

Remarks (1) Models applicable to higher harmonics and surge can detect ground faults on the inverter secondary side at a working frequency of 120Hz or less. In the case of star connection neutral grounding, the current sensitivity to ground fault on the inverter secondary side is reduced, the protective grounding of load device shall be class C grounding (10Ω or less).

(2) ELCB shall be installed on the imerter primary side (power supply side).



9. 7 Ground fault protection for non-grounded circuits

The non-grounded system is used in plants where power failure must be prevented for operation. Particularly, in many petrochemical plants, where explosive gas may catch fire owing to ground fault current and serious accidents may be caused, this system is used to reduce the ground fault current.
On non-grounded circuits, the ground fault current is remarkably low even if one line falls down on the earth, and the current cannot be easily detected. Therefore, note that the protection effect of ELCB may not be expected only by installing it.

9. 7. 1 Circuit insulation detector (MEGMONITOR)

Mitsubishi circuit insulation detector, MEGMONITOR, has an excellent feature that enables constant monitoring of circuit without necessity of power interruption because it can monitor the whole electric circuit in the live state with low-voltage small current and detect deterioration of insulation of circuit to the earth. Article 40 of interpretation for Guide Book of Electrical Equipment requires installation of ground fault circuit breakers on non-grounded circuits. In the past, appropriate devices for ground fault protection were not available, and the protection was provided by grounding capacitors and installing ELCB. However, to normally actuate ELCB, the capacitor capacity should be considerably increased. This can generate sparks upon occurrence of ground fault and is unfavorable for the purpose of non-grounded circuits.

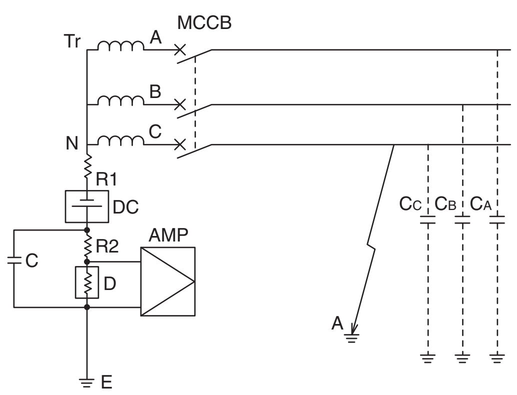


Fig. 9. 31 Explanation of operation

MEGMONITOR can detect insulation deterioration corresponding to ground fault current of several mA and is suitable for detection of ground faults on non-grounded circuits. A ground fault circuit breaker can be easily configured by combining it with breakers. The operation is explained based on Fig. 9. 31. As an AC content, charging current flows through the earth capacitances (C_A, C_B and C_C) on the circuit from the system power supply (commercial frequency) by the transformer (Tr). The signal detector (D) of the amplifier and the capacitor C are connected in series so that the signal by this current does not enter the amplifier (AMP). Therefore, the current flowing to the earth capacitances (C_A, C_B and C_C) is bypassed to the capacitor (C) to avoid giving input signals to the amplifier (AMP), and the AC signal is not amplified.
The DC content biases the lines of the phases (A, B and C) through the windings of the transformer (Tr) from the DC power supply (DC) installed in the device. If the insulation of the circuit is higher than a certain value (normal), the DC does not leak to the outside of the circuit, and DC current does not flow into the detector.
As stated above, since this device is biased by DC, charging current flows to the capacitances (C_A, C_B and C_C) only just after MCCB are closed even if the circuit is long and the earth capacitances (C_A, C_B and C_C) are large. After this, it will stabilize, and DC will not flow. Therefore, even on a long circuit, it will not be affected by the earth capacitances (C_A, C_B and C_C).
Against transient inrush current generated when MCCB is closed, a special circuit for prohibiting operation is provided to prevent malfunction. Then, if the insulation at the point A of T phase has deteriorated and the insulation to the earth is degraded, DC current from the DC power supply will flow to the resistor (R2), grounding point (E), fault point (A), transformer neutral point (N) and resistor (R1). After the completion of charging of the capacitor (C) connected in series with the detector (D), all DC current will flow to the detector (D), the signal of the detector (D) will be amplified by the amplifier (AMP), and insulation deterioration will be detected.
With this device, insignificant decrease of circuit insulation to 400kΩ or less can be detected. The sensitivity can be switched in 6 stages, 10 – 20 – 50 – 100 – 200 – 400k.

9. 7. 2 Method by combining grounded capacitors and ELCB

Capacitors are connected to the secondary side of non-grounded insulating transformer, the neutral point is grounded, and, when one-line ground occurs, ELCB detects the ground fault and protects the circuit.

(1) 3-phase 3-wire

Non-grounded insulating transformers are generally Δconnected. The relationship between grounded capacitor capacity and ground fault current in this case is shown below.

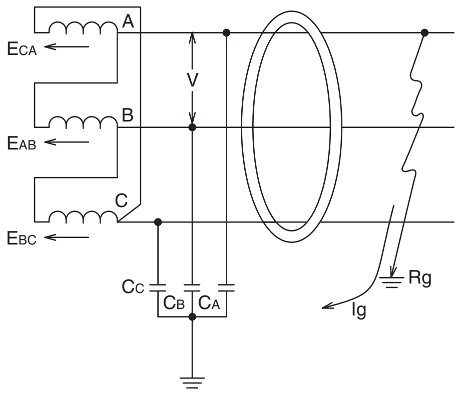


Fig. 9. 32

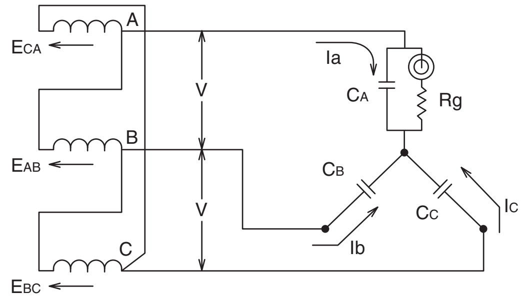


Fig. 9. 33

In Fig. 9. 32, the capacitors with capacitances C_A, C_B and C_C are star-connected, and the neutral point is grounded. This circuit is redrawn in Fig. 9. 33 to make it easier to understand the connection. In the normal state, the capacitors are a star-connected load consisting of capacitors when viewed from the power supply side, but, when a ground fault occurs, the resistance Rg (including the fault resistance of device, earth resistance of device and grounded resistance of capacitor) of the ground fault circuit is considered to be connected in series with the ground fault capacitor C_A of phase A, and the current flowing to Rg is detected by the ZCT. On condition that the capacitor capacities of the phases are identical and $C_A = C_B = C_C = C$, the relationship between capacitor capacity C and ground fault current Ig can be determined by the following formulas.

$$Ig = \frac{\sqrt{3}\,V}{\sqrt{(3Rg)^2 + \left(\frac{1}{\omega C}\right)^2}} \text{ (A)} \cdots\cdots (1)$$

$$\therefore \quad C = \frac{1}{\sqrt{3}\,\omega\sqrt{\left(\frac{V}{Ig}\right)^2 - 3Rg^2}} \text{ (F)} \cdots\cdots (2)$$

Therefore, the required capacitor capacity C can be obtained from the formula (2) by determining the maximum detected ground fault current, the current sensitivity, and estimating the ground fault resistance Rg.

<Example>

Determine the capacitor capacity required to protect the circuit from ground fault with ELCB by grounding the capacitors as shown in Fig. 9. 34.

The line voltage is 440V, frequency is 60Hz, and the total resistance Rg of the ground fault circuit is 150Ω.

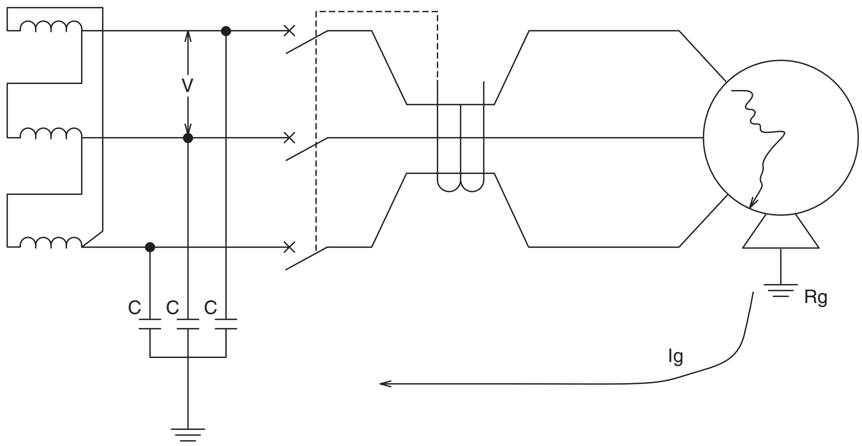


Fig. 9. 34

● Calculation method

At first, determine the maximum limit of ground fault current (related to the current sensitivity). The current should be about twice the rated current sensitivity of ELCB to be used.

In this example, assume that ELCB with sensitivity of 200mA is used, and the ground fault current is 0.5A.

From the formula (2),

$$C = \frac{1}{\sqrt{3}\,\omega\sqrt{\left(\frac{V}{Ig}\right)^2 - 3Rg^2}}$$

$$= \frac{1}{\sqrt{3} \times 2\pi \cdot 60\sqrt{\left(\frac{440}{0.5}\right)^2 - 3 \times 150^2}} = 1.82\mu F \quad \cdots\cdots (3)$$

Therefore, if the capacitor capacity in Fig. 9. 34 is 1.8μF (actually, a capacitor with standard capacity of 2μF is used), current of 0.5A will flow when the grounded circuit resistance reduces to 150Ω, and the current sensitivity of 500mA is allowable. However, actually, the sensitivity is set to 200mA with a little margin for more reliable operation. If a high-sensitivity circuit breaker is used, ground fault current can be detected even when the grounded circuit resistance is high. For example, when ELCB with sensitivity of 30mA is used, Rg can be determined by the formula (2) as shown below.

$$Rg = \frac{1}{3}\sqrt{\left(\frac{\sqrt{3}\,V}{Ig}\right)^2 - \left(\frac{1}{\omega C}\right)^2}$$

$$= \frac{1}{3}\sqrt{\left(\frac{\sqrt{3} \times 440}{0.03}\right)^2 - \left(\frac{1}{2\pi \times 60 \times 2 \times 10^{-6}}\right)^2}$$

$$\fallingdotseq 8500W \quad \cdots\cdots (4)$$

That is, when the grounded circuit resistance reduces to 8500Ω, ELCB operates and protects the circuit. This offers the advantage of detection of ground fault at an early stage at which the degree of fault is minor. After the capacitor capacity is determined, it is necessary to select a capacitor having a withstand voltage (rated voltage) appropriate to the circuit voltage. Although the voltage applied to the capacitor is $V/\sqrt{3}$ in the normal state, use a capacitor having two times higher withstand voltage to allow a margin. Since $44/\sqrt{3} \times 2 \fallingdotseq 509$, use a 2-$\mu$F capacitor having the standard voltage of 600V.

(2) Single-phase 2-wire, neutral point grounding

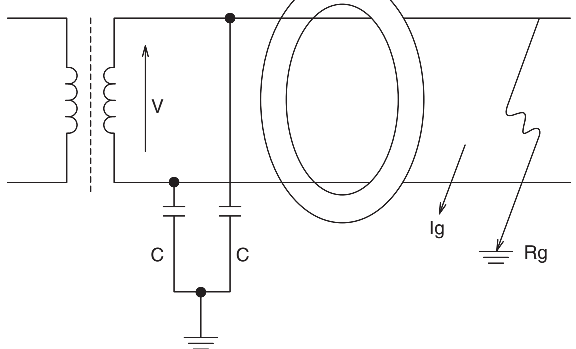


Fig. 9. 35

$$Ig = \frac{V}{\sqrt{\left(\frac{1}{\omega C}\right)^2 + (2Rg)^2}} \text{ (A)} \quad \cdots\cdots (5)$$

$$\therefore \quad C = \frac{1}{\omega\sqrt{\left(\frac{V}{Ig}\right)^2 - (2Rg)^2}} \text{ (F)} \quad \cdots\cdots (6)$$

From the formula (6), the required capacitor capacity can be obtained.

(3) 3-phase 3-wire (star connection)

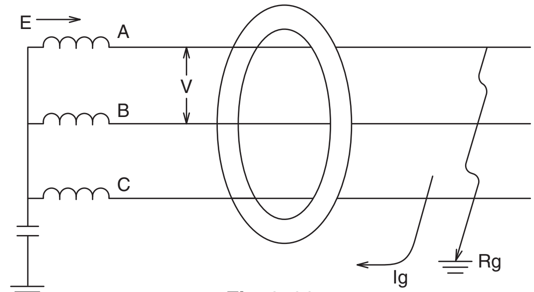


Fig. 9. 36

In the case of 3-phase, when the line voltage is V,

$$Ig = \frac{V/\sqrt{3}}{\sqrt{Rg^2 + \left(\frac{1}{\omega C}\right)^2}} \text{ (A)} \quad \cdots\cdots (7)$$

$$C = \frac{1}{\omega\sqrt{\left(\frac{V}{\sqrt{3}\,Ig}\right)^2 - Rg^2}} \text{ (F)} \quad \cdots\cdots (8)$$

From the formula (8), the required capacitor capacity can be obtained.

(4) Simplified calculation formula of capacitor capacitance

If the ground fault resistance Rg is negligible, the capacitor capacitance can be determined by the following simplified calculation formula.

In the case of 3-phase 3-wire (Δ connection)

$$C \geq \frac{I_{\Delta N}(1 + a)\,3 \times 10^3}{\sqrt{3}\,\omega \times 2\pi fV} \quad \cdots\cdots (9)$$

In the case of single-phase 2-wire

$$C \geq \frac{I_{\Delta N}\,(1 + a) \times 10^3}{2\pi fV} \quad \cdots\cdots (10)$$

C	: Capacitance of 1 phase of capacitor	(μF)
$I_{\Delta N}$	: Rated current sensitivity of ELCB	(mA)
V	: Line voltage	(V)
f	: Frequency	(Hz)
a	: Safety factor (1.0 to 1.5) … Normally, 1.0	

● Quick chart of capacitor grounded capacity on non-grounded electric circuit for the purpose of detection of earth leakage

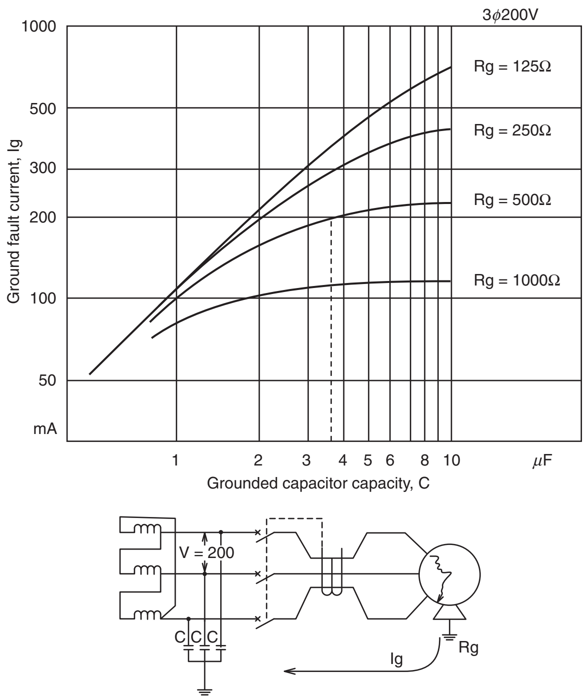


Fig. 9. 37-1

$$Ig = \frac{\sqrt{3}\,V}{\sqrt{(3Rg)^2 + \left(\frac{1}{\omega C}\right)^2}} \text{ (A)}$$

$$\therefore\ C = \frac{1}{\sqrt{3}\,\omega\sqrt{\left(\frac{V}{Ig}\right)^2 - 3Rg^2}} \text{ (F)}$$

Example: To obtain a ground fault current of 200mA at ground fault resistance of 500Ω, the capacitor capacity shall be 3.5μF.
(The ground fault current shall be at least twice the rated current sensitivity.)

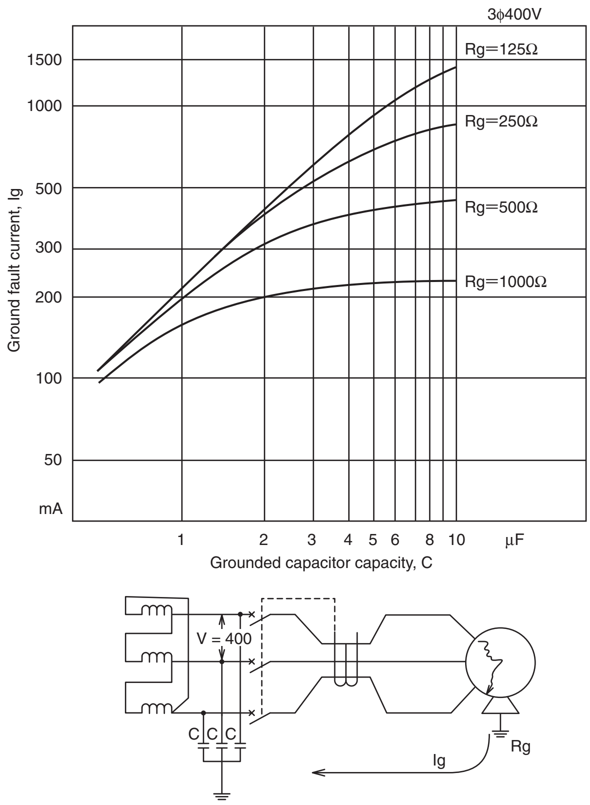


Fig. 9. 37-2

$$Ig = \frac{\sqrt{3}\,V}{\sqrt{(3Rg)^2 + \left(\frac{1}{\omega C}\right)^2}} \text{ (A)}$$

$$\therefore\ C = \frac{1}{\sqrt{3}\,\omega\sqrt{\left(\frac{V}{Ig}\right)^2 - 3Rg^2}} \text{ (F)}$$

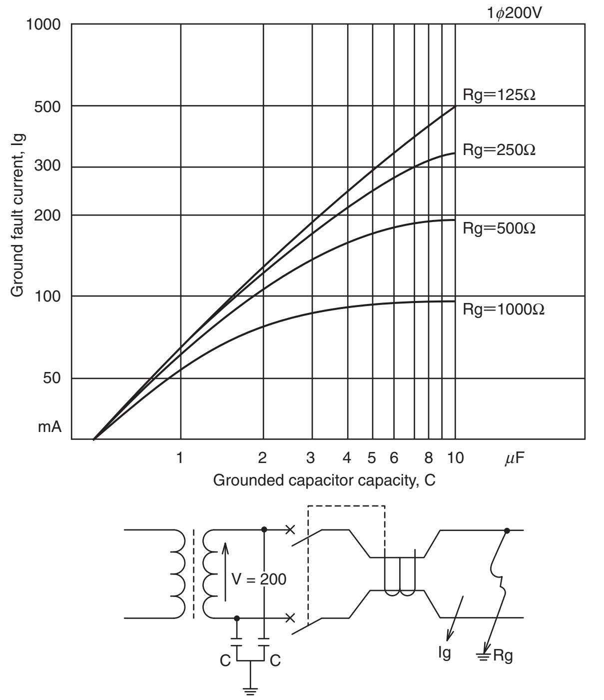


Fig. 9. 37-3

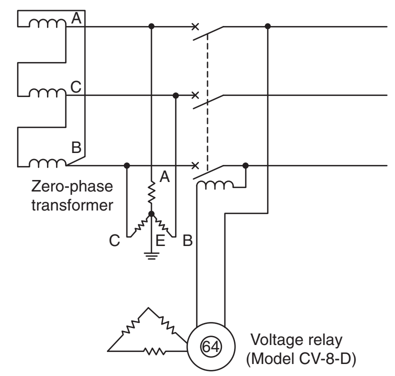


Fig. 9. 38

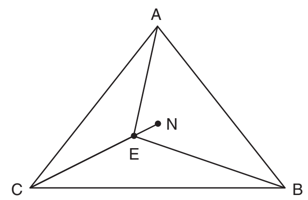


Fig. 9. 39

$$Ig = \frac{V}{\sqrt{\left(\frac{1}{\omega C}\right)^2 + (2Rg)^2}} \quad (A)$$

$$\therefore \quad C = \frac{1}{\omega\sqrt{\left(\frac{V}{Ig}\right)^2 - (2Rg)^2}} \quad (F)$$

9. 7. 3 Method by grounding transformer

This method is designed to detect zero-phase voltage and break the circuit owing to ground fault. When the devices are connected as shown in Fig. 9. 38, the voltage applied to the primary winding is $\overrightarrow{EA} + \overrightarrow{EB} + \overrightarrow{EC}$, and the corresponding voltage is induced to each phase of the secondary delta winding. The voltage applied to ⑭ is the vectorial sum of the voltages of the phases, $\overrightarrow{EA} + \overrightarrow{EB} + \overrightarrow{EC}$.

From Fig. 9. 39,
$$\overrightarrow{NA} = \overrightarrow{EA} + \overrightarrow{NE}$$
$$\overrightarrow{NB} = \overrightarrow{EB} + \overrightarrow{NE}$$
$$\overrightarrow{NC} = \overrightarrow{EC} + \overrightarrow{NE}$$

The both sides of these formulas are added to obtain the following formula.

$$\overrightarrow{NA} + \overrightarrow{NB} + \overrightarrow{NC} = \overrightarrow{EA} + \overrightarrow{EB} + \overrightarrow{EC} + 3\overrightarrow{EN}$$

As is evidenced from Fig. 9. 39, N is the center of the triangle, and the left side is 0. Therefore,

$$\overrightarrow{EA} + \overrightarrow{EB} + \overrightarrow{EC} = -3\overrightarrow{NE} = 3\overrightarrow{EN}$$

Since $\overrightarrow{EN}$ is zero-phase voltage, three times larger zero-phase voltage appears in ⑭. This voltage is detected, and the voltage relay is operated to trip the circuit breaker to protect the circuit from ground fault.

9. 7. 4 Method by grounding detector

This method is similar to the method stated in (2) "grounding transformer." The degree of ground fault and the grounding phase can be defined by the indicator.

Fig. 9. 40 shows the connection diagram of model LM-11NGD grounding detector.

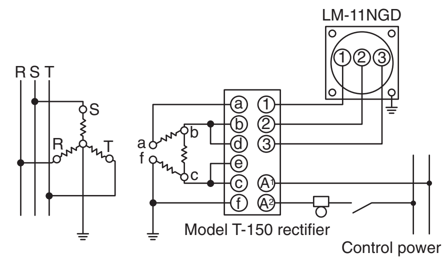


Fig. 9. 40

9. 8 Ground fault detection and protection at DC circuits

Usual MCCB are designed only for AC, and they can be used at DC circuits through DC ground fault detection relays.
Fig. 9. 41 shows the circuit diagram of a DC ground fault detection relay.
If a ground fault occurs at the ground fault resistance value Rg on the positive side, the potential at the point N will become higher than that at the point A, and current will flow to low-energy high-sensitivity DC moving coil element (D-5), thereby actuating the relay.
In the case of a ground fault on the negative side, current will flow from B to N.
In the case of a DC ground fault detection relay, the minimum working current of the element D-5 is ± 0.125mA.
The sensitivity can be adjusted with a variable resistor.

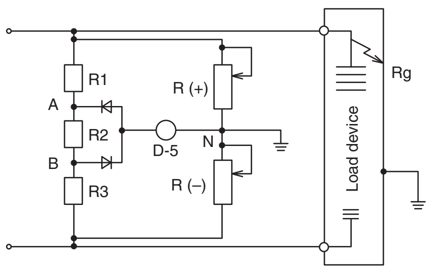
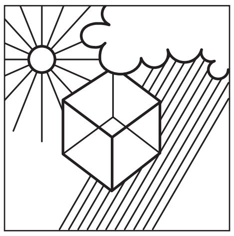


Fig. 9. 41



10. Environmental Characteristics

10 Environmental Characteristics

10. 1 Environmental characteristics

10. 1. 1 Atmospheric environment

Abnormal environments may adversely affect performance, service life, insulation and other aspects of MCCB quality. Where service conditions differ substantially from the specified range as below, derating of performance levels may result.

(1) Ambient temperature range –10°C~+40°C (Average temperature for 24 hours, however, shall not be higher than 35°C.)
(2) Relative humidity 85% max. with no dewing
(3) Altitude 2,000m max.
(4) Ambient No excessive water or oil vapour, smoke, dust, salt content, corrosive substance, vibration, and impact

Expected service life (MTTF) under the above conditions is 15 years.

10. 1. 2 High temperature application

To comply with relevant standards, all circuit breakers are calibrated at 40°C. If the circuit breaker is to be used in an environment where the ambient temperature is likely to exceed 40°C please apply the de-rating factor shown in table 10. 2.

For example: To select a circuit breaker for use on a system where the full load current is 70A in an ambient temperature at 50°C then from table 10. 2

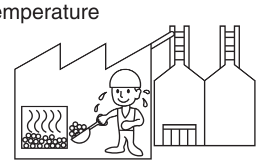
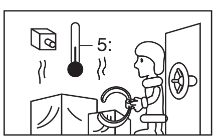
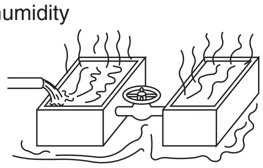
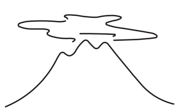
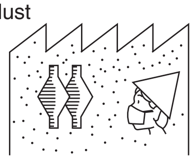
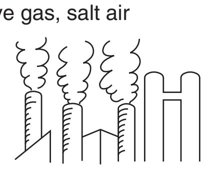
$$\frac{70A}{0.9} = 77.8A$$

Select a circuit breaker with a trip unit adjustable from 80-100A or fixed at 100A.

Table 10. 2 MCCB Derating

Ambient Temperature (°C)	Derating factor
50	0.9
55	0.8
60	0.7

Table 10. 1 Ambient environment for breaker

Environment	Trouble	Countermeasures
High temperature 	1. Nuisance tripping 2. Insulation deterioration	1. Reduce load current (derate). 2. Avoid ambients above 60˚C.
Low temperature 	1. Condensation and freezing 2. Low-temperature fragility in shipping (around –40˚C)	1. Install heater for defrosting and drying. 2. Ship tripped, or if not possible, OFF.
High humidity 	1. Insulation resistance loss 2. Corrosion	1. Use MCCB enclosure such as Type W. 2. Inspect frequently, or install high-corrosion-resistant MCCB.
High altitude 	1. Reduced temperature, otherwise no problem up to 2,000m	1. See “Low temperature”, above.
Dirt and dust 	1. Contact discontinuity 2. Impaired mechanism movement 3. Insulation resistance loss	1. Use Type I MCCB enclosure.
Corrosive gas, salt air 	1. Corrosion	1. Use Type W MCCB enclosure or install high-corrosion-resistant MCCB.

10. 1. 3 Low Temperature Application

In conditions where temperatures reach as low as –5°C special MCCB are usually required. Mitsubishi, however, have tested their standard MCCB to temperatures as low as –10°C without any detrimental effects.

For conditions where temperatures drop below –10°C special MCCB must be used.

If standard MCCB experience a sudden change from high temperature, high humidity conditions to low temperature conditions, there is a possibility of ice forming inside the mechanism. In such conditions we recommend that some form of heating be made available to prevent mal-operation.

In conditions of low temperature MCCB should be stored in either the tripped or OFF position.

Low Temperature MCCB

Special low temperature MCCB are available that can withstand conditions where temperatures fall to as low as –40°C. These special MCCB are available in sizes up to 1200A in the standard series and above 50A in the compact series.

10. 1. 4 High humidity

In conditions of high humidity the insulation resistance to earth will be reduced as will the electrical life.

For applications where the relative humidity exceeds 85% the MCCB must be specially prepared or special enclosures used. Special preparation includes plating all metal parts to avoid corrosion and special painting of insulating parts to avoid the build up of mildew.

There are two degrees of tropicalisation:

Treatment 1- painting of insulating material to avoid build up of mildew plus special plating of metal parts to avoid corrosion.

Treatment 2- painting of insulating material to avoid build up of mildew only.

10. 1. 5 Corrosive atmospheres

In the environment containing much corrosive gas, it is advisable to use MCCB of added corrosion resistive specifications.

For the breakers of added corrosionproof type, corrosion-proof plating is applied to the metal parts.

Where concentration of corrosive gas exceeds the level stated below, it is necessary to use MCCB of added corrosion resistive type being enclosed in a water-proof type enclosure or in any enclosure of protective structure.

Allowable containment for corrosive gas.

H_2S 0.01ppm SO_2 0.05ppm

NH_2 0.25ppm

10. 1. 6 Affection of altitude

When MCCB are used at altitudes exceeding 2000m above sea level, the effects of a drop in pressure and drop in temperature will affect the operating performance of the MCCB. At an altitude of 2200m, the air pressure will drop to 80% and it drops to 50% at 5500m, however interrupting capacity is unaffected. The derating factors that are applicable for high altitude applications are shown in table 10. 3. (According to ANSI C 37.29-1970)

Table 10. 3 Derating Factors for High Altitude Applications

Altitude	Rated current	Rated voltage
3000m	0.98	0.91
4000m	0.96	0.82
5000m	0.94	0.73
6000m	0.92	0.65

For example: NF800-SEW on 4000m

(1) Voltage

The rated operating voltage is AC690V. You should derate by $690 \times 0.82 = 565.8$V. It means that you can use this NF800-SEW up to AC565.8V rated voltage.

(2) Current

The rated current is 800A. You should derate by 800x0.96 = 768A. It means that you can use this NF800-SEW up to 768A rated current.

8.2Vibration-Withstand Characteristics

10. 2 The condition of test

1. Installation position and Direction of vibration
   - Every vertical and horizontal at vertical installed (as shown in Fig. 10. 1)
2. The position of MCCBs and vibration time
   Forty minutes in each position (ON, OFF and TRIP)
3. Vibration criteria
   - Frequency 10~100Hz
   - Vibration acceleration $22 m/s^2$
   - Period 10min./cycle

10. 2. 1 The result of test

The samples must show no damage and no change of operating characteristic (200% release), and must not be tripped or switched off by the vibration.

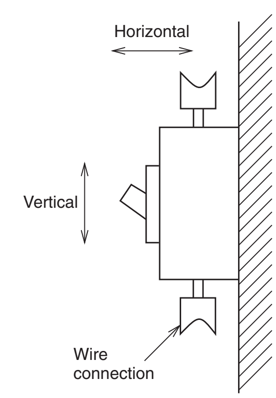


Fig. 10. 1 Applied Vibration

10. 3 Shock-withstand characteristics

10. 3. 1 The condition of test

(1) MCCB are drop-tested, as described in Fig. 10. 2.
The arrows show the drop direction.

(2) The samples are set to ON, with no current flowing.

10. 3. 2 The result of test

The samples must show no physical damage, and the switched condition must not be changed by the drop in any of the drop-attitudes tested.

The judgment of failure:

- A case the switched condition changed from ON to OFF
- A case the switched condition changed from ON to Trip
- A case the sample shows physical damage

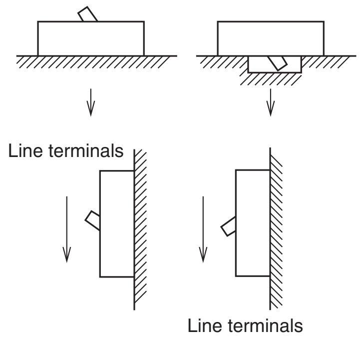


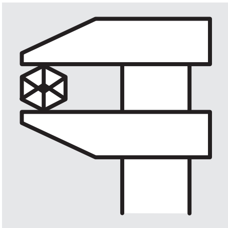
Fig. 10. 2 Drop-Test Attitudes

Table 10. 4 Shock-withstand characteristics of Mitsubishi MCCB

Series		Model						No tripped m/s2	No damage m/s^2
BH		BH-DN	BH-S	BH-PS	BH-D6	BH-D10	BH	147	
MB		MB30-CS						147	
MB		NF32-SV	NF63-CV	NF63-SV	NF63-SVF			196	
		NF125-SV	NF250-SV						
NF	S	NF32-SV	NF32-SVF	NF63-SV	NF63-HV	NF125-SV	NF125-HV		
		NF125-SEV	NF125-HEV	NF125-SGV	NF125-LGV	NF125-HGV	NF125-RGV		
		NF160-SGV	NF160-LGV	NF160-HGV	NF160-RGV	NF250-SV	NF250-HV		
		NF250-SEV	NF250-HEV	NF250-SGV	NF250-LGV	NF250-HGV	NF250-RGV		
		NF250-SEV with MDU	NF250-HEV with MDU	NF400-SW	NF400-SEW	NF400-HEW	NF400-REW	196	490
		NF400-SEP with MDU	NF400-HEP with MDU	NF630-SW	NF630-SEW	NF630-HEW	NF630-REW		
		NF600-SEP with MDU	NF600-HEP with MDU	NF800-SDW	NF800-SEW	NF800-HEW	NF800-REW		
		NF800-SEP with MDU	NF800-HEP with MDU	NF1000-SEW	NF1250-SEW	NF1250-SDW	NF1600-SEW		
		NF1600-SDW							
	C	NF30-CS						147	
		NF63-CV						196	
		NF125-CV	NF250-CV	NF400-CW	NF630-CW	NF800-CEW			
	U	NF125-UV	NF250-UV	NF400-UEW	NF800-UEW			196	

Table 10. 5 Shock-withstand characteristics of Mitsubishi ELCB

Model							No tripped m/s^2	No damage m/s^2
BV-D	BV-DN						196	490
NV32-SV	NV63-CV	NV63-SV	NV63-HV				196	490
NV125-CV	NV125-SV	NV125-HV	NV125-SEV	NV125-HEV	NV250-CV	NV250-SV	147	294
NV250-HV	NV250-SEV	NV250-HEV						
NV400-CW	NV400-SW	NV400-SEW	NV400-HEW	NV400-REW	NV630-CW	NV630-SW	147	294
NV630-SEW	NV630-HEW	NV800-SEW	NV800-HEW					



11. Standards

11 Standards

11. 1 International standards of circuit breakers

The main standards related to breakers and the usage methods are listed below.

11. 1. 1 Japanese standards

(1) Laws and regulations

- ◆ Ministerial ordinance setting technical standards concerning electrical facilities
- ◆ Interpretation of technical standards for electrical equipment
- ◆ Ministerial ordinance that establishes standards concerning technology for electrical appliances
- ◆ Labor Safety and Health Regulations

(2) JIS (Japan Industrial Standards)

- ◆ JIS C 8201-1 “Low-voltage switchgear and controlgear - Part 1: General rules”
- ◆ JIS C 8201-2-1 “Low-voltage switchgear and controlgear - Part 2-1: Circuit-breakers (wiring breaker and other breakers)”
- ◆ JIS C 8201-2-2 “Low-voltage switchgear and controlgear - Part 2-2: Circuit-breakers incorporating residual current protection
- ◆ JIS C 4610 “Circuit-breakers for equipment”
- ◆ JIS B 9960-1 “Safety of machinery - Electrical equipment of machines - Part 1: General requirements”

(3) Commercial standards

- ◆ JEAC 8001 “Indoor wiring regulations” (Japan Electrical Manufactures’ Association)
- ◆ Steel Boat Standards (Nippon Kaji Kyokai)

11. 1. 2 International standards - IEC standards

- ◆ IEC 60947-1 “Low-voltage switchgear and controlgear - Part 1: General rules”
- ◆ EC 60947-2 “Low-voltage switchgear and controlgear - Part 2: Circuit-breakers”
- ◆ IEC 60934 “Circuit-breakers for equipment (CBE)”
- ◆ IEC 60204-1 “Safety of machinery - Electrical equipment of machines - Part 1: General requirements”

11. 1. 3 European standards

(1) CE marking policy

These policies have been enforced to promote free distribution within the EEA district. Each product must comply with the corresponding EU Directive. The CE Mark indicates that the Directive is complied with. Product may not be sold in the European market without this Marking.

(2) EU directive

●**LVD directive (Low voltage directive)**

The low voltage directives are directives applied to devices designed to run at 50 to 1000VAC/75 to 1500VDC. There is no need to acquire a proof of model from a certifying agency (NB). Often, a self-declaration of compliance by the manufacturer is sufficient.

●**EMC directive (Electro-magnetic compatibility)**

This Directive stipulates that strong magnetic waves are not radiated outwards, and that the device is not affected by electromagnetic waves from an external source. Electronic breakers and leakage current breakers, etc., are subject to the evaluation test.

(3) EN standards - standardized as IEC standards

The optimum method to confirm that a product complies with the required safety requirements of the each EU Directive is to comply with the Standardized Standards. Most of the standardized standards are EN Standards.

- ◆ EN 60947-1 “Low-voltage switchgear and controlgear - Part 1: General rules” - EN 60947-2 “Low-voltage switchgear and controlgear - Part 2: Circuit-breakers” - EN 60934 “Circuit-breakers for equipment (CBE)”
- ◆ EN 60204-1 “Safety of machinery - Electrical equipment of machines - Part 1: General requirements”

(4) Third-party certification (TÜV Certification)

For many of Mitsubishi breakers, compliance with the EN Standards and safety are verified by the third-party certification agency TÜV Rheinland. (Refer to Section 11. 2 for the corresponding models.) When applying for TÜV verification as a machine system, inspection of the breaker will be excluded.

11. 1. 4 North American standards

(1) United States

- ◆ NFPA 70 “National Electrical Code”
- ◆ NFPA 79 “Electrical Standard for Industrial Machinery”
- ◆ UL 489 “Molded-Case Switches, and Circuit-Breaker Enclosures”
- ◆ UL 1053 “Standard for Ground-Fault Sensing and Relaying Equipment”
- ◆ UL 1077 “Standard for Supplementary Protectors for Use in Electrical Equipment”
- ◆ UL 508A “Standard for Industrial Control Panels”

(2) Canada

- ◆ CSA C22.2 No. 5 “Molded-Case Circuit Breakers, Molded-Case Switches and Circuit-Breaker Enclosures”
- ◆ CSA C22.2 No. 144 “Ground Fault Circuit Interrupters”
- ◆ CSA C22.2 No. 235 “Supplementary Protectors”

(3) Certification marks

Some of the Mitsubishi breaker models are certified with US UL Standards or Canadian CSA Standards by the certifying agency UL. (Refer to Section 11. 2 for the corresponding models.) The cULus or cURus marks indicate the certified model.

11. 1. 5 Chinese standards

(1) CCC policy

After China joined WTO in November 2001, the certification policy has been unified to CCC. There are 19 types and 132 products in the primary mandatory products subject to the CCC Certification policy. The Mitsubishi breaker has received CCC Certification as a low-voltage device. (Refer to Section 11.2 for the corresponding models.) The power distribution panel is subject to CCC, but the control panel (machine’s electric device) that complies with the GB 5226.1 compliance standards is not subject to CCC.

(2) GB standards

The GB standards (from Guojia BiaoZhun) are the basic standards applied in China.

The GB 14048 Series corresponds to the IEC 60947 Series.

- ◆ GB 14048.1 Low-voltage Switchgear and Controlgear General Rules
- ◆ GB 14048.2 Low-voltage Switchgear and Controlgear Low-voltage Circuit Breakers
- ◆ GB 17701 Circuit-breaker for equipment
- ◆ GB 5226.1 Electrical Safety of Machinery Electrical Equipment of Machines Part 1: General Requirements

11. 2 List of compatible standards

●Molded case circuit breakers and motor protection breakers

Specifications	Class	Applicable Models and Assignments	North American Safety Mark					Compulsory Mark		Third Party Mark	Classification Society (*1)
			UL Stgandards				CSA Standards	CCC	CE	TÜV Rheinland	NK
			USA				Canada	China	Europe	Germany	Japan
			RU	UL	c RU US	c UL US	SP	CCC	CE	TÜV Rheinland	
General	C	NF30-CS	–	–	–	–	–	●	●	●	●
		NF63-CV, NF125-CV	–	–	–	–	–	●	●(Self Declaration)	–	●
		NF250-CV	–	–	–	–	–	●	●	●	●
		NF400-CW, NF630-CW, NF800-CEW	–	–	–	–	–	●	●(Self Declaration)	–	●
	S	NF32-SV, NF63-SV, NF125-SV	–	–	–	–	–	●	●(Self Declaration)	–	●
		NF125-SEV	–	–	–	–	–	●	●(Self Declaration)	–	–
		NF250-SV	–	–	–	–	–	●	●	● (Except for 4P)	●
		NF125-SGV, NF160-SGV, NF250-SGV, NF250-SEV	–	–	–	–	–	●	●(Self Declaration)	–	–
		NF400-SW, NF630-SW NF400-SEW, NF630-SEW NF800-SEW, NF800-SDW	–	–	–	–	–	●	●(Self Declaration)	–	●
		NF1000-SEW, NF1250-SEW	–	–	–	–	–	●	●(Self Declaration)	–	●
		NF1600-SEW	–	–	–	–	–	●	●(Self Declaration)	–	–
		NF1250-SDW, NF1600-SDW	–	–	–	–	–	–	●(Self Declaration)	–	–
	L/H/R	NF63-HV	–	–	–	–	–	●	●(Self Declaration)	–	●
		NF125-HV	–	–	–	–	–	●	●(Self Declaration)	–	●
		NF125-HEV	–	–	–	–	–	●	●(Self Declaration)	–	–
		NF250-HV	–	–	–	–	–	●	●(Self Declaration)	–	●
		NF125-LGV, NF125-HGV, NF160-LGV, NF250-LGV, NF250-HGV, NF250-HEV, NF125-RGV, NF250-RGV	–	–	–	–	–	●	●(Self Declaration)	–	–
		NF400-HEW, NF400-REW NF630-HEW, NF630-REW NF800-HEW, NF800-REW	–	–	–	–	–	●	●(Self Declaration)	–	●
	U	NF125-UV	–	–	–	–	–	–	●(Self Declaration)	–	●
		NF250-UV, NF400-UEW	–	–	–	–	–	–	●(Self Declaration)	–	●
		NF800-UEW	–	–	–	–	–	–	●(Self Declaration)	–	–
	Motor Protection	NF32-SV MB, NF63-CV MB, NF63-SV MB, NF125-SV MB	–	–	–	–	–	●	●(Self Declaration)	–	●
		NF250-SV MB	–	–	–	–	–	●	●	●	●
UL	UL 489 Listed	NF50-SVFU, NF100-CVFU	–	–	–	●	–	●	●	●	–
		NF125-SVU, NF125-HVU	–	–	–	●	–	●	●	●	–
		NF225-CWU	–	–	–	●	–	●(Except for 250A)	●	●(Except for 250A)	–
		NF250-SVU, NF250-HVU	–	–	–	●	–	●	●	●	–
		NF-SKW, NF-SLW	–	–	–	●	–	–	●	●	–

Note *1 Except for 4 poles breaker.
Remark: 1. KC (Korea Certification) Mark and GOST-R (Russian Standards) approval products are prepared. Please inquire details.

●Earth leakage circuit breakers

Specifications	Class	Applicable Models and Assignments	North American Safety Mark					Compulsory Mark		Third Party Mark	Classification Society
			UL Stgandards				CSA Standards	CCC	CE	TÜV Rheinland	NK
			USA				Canada	China	Europe	Germany	Japan
CE and CCC	C	NV63-CV, NV125-CV	–	–	–	–	–	● (Except for 2P)	●(Self Declaration)	–	–
		NV250-CV	–	–	–	–	–	●	●	●	–
		NV400-CW, NV630-CW	–	–	–	–	–	●	●(Self Declaration)	–	–
	S	NV32-SV, NV63-SV	–	–	–	–	–	●	●(Self Declaration)	–	–
		NV125-SV	–	–	–	–	–	●	●(Self Declaration)	–	–
		NV250-SV	–	–	–	–	–	●	●	●	–
		NV125-SEV, NV250-SEV, NV400-SW, NV400-SEW, NV630-SW, NV630-SEW, NV800-SEW	–	–	–	–	–	●	●(Self Declaration)	–	–
	H/R	NV63-HV	–	–	–	–	–	●	●(Self Declaration)	–	–
		NV125-HV	–	–	–	–	–	●	●(Self Declaration)	–	–
		NV125-HEV, NV250-HV, NV250-HEV	–	–	–	–	–	●	●(Self Declaration)	–	–
		NV400-HEW, NV400-REW, NV630-HEW, NV800-HEW	–	–	–	–	–	–	–	–	–
UL	UL 489 Listed	NV50-SVFU, NV100-CVFU	–	–	–	●	–	●	●	●	–
		NV125-SVU, NV125-HVU	–	–	–	●	–	●	●	●	–
		NV250-SVU, NV250-HVU	–	–	–	●	–	●	●	●	–

Remark: 1. KC (Korea Certification) Mark and GOST-R (Russian Standards) approval products are prepared. Please inquire details.

●Miniature circuit breakers

Specifications	Class	Applicable Models	Compulsory Mark	
			CCC	CE
			China	Europe
IEC	BH	BH	–	–
		BH-P	–	–
		BH-S	–	–
		BH-PS	–	–
General	DIN	BH-D6	●	●(Self Declaration)
		BH-D10	●	●(Self Declaration)
		BH-DN	●	●(Self Declaration)
		BV-D	●	●(Self Declaration)
		BV-DN	●	●(Self Declaration)
		KB-D	●	●(Self Declaration)

●Circuit protectors

<table>
<tr><th rowspan="3">Specifications</th><th rowspan="3">Class</th><th rowspan="3">Applicable Models and Assignments</th><th colspan="5">North American Safety Mark</th><th colspan="2">Compulsory Mark</th><th>Third Party Mark</th><th>Classification Society</th></tr>
<tr><th colspan="4">UL Stgandards</th><th>CSA Standards</th><th>CCC</th><th>CE</th><th>TÜV Rheinland</th><th>NK</th></tr>
<tr><th colspan="4">USA</th><th>Canada</th><th>China</th><th>Europe</th><th>Germany</th><th>Japan</th></tr>
<tr><td>General</td><td>CP</td><td>CP30-BA</td><td>–</td><td>–</td><td>●</td><td>–</td><td>–</td><td>●</td><td>●(EN 60934)
●(EN 60947-2)
(Self-Declaration)</td><td>●(EN 60934)
–</td><td>–</td></tr>
</table>

Remark: 1. KC (Korea Certification) Mark and GOST-R (Russian Standards) approval products are prepared. Please inquire details.

●Air circuit breakers

<table>
<tr><th rowspan="3">Specifications</th><th rowspan="3">Class</th><th rowspan="3">Applicable Models</th><th rowspan="3">Assignments</th><th colspan="5">North American Safety Mark</th><th colspan="2">Compulsory Mark</th><th>Third Party Mark</th></tr>
<tr><th colspan="4">UL Stgandards</th><th>CSA Standards</th><th>CCC</th><th>CE</th><th>TÜV Rheinland</th></tr>
<tr><th colspan="4">USA</th><th>Canada</th><th>China</th><th>Europe</th><th>Germany</th></tr>
<tr><td rowspan="2">IEC</td><td>SW</td><td>AE630-SW, AE1000-SW
AE1250-SW, AE1600-SW
AE2000-SWA, AE2000-SW
AE2500-SW, AE3200-SW
AE4000-SWA, AE4000-SW
AE5000-SW, AE6300-SW</td><td>IEC 60947-2
or
JIS C 8201-2-1</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>●(Self Declaration)</td><td>–</td></tr>
<tr><td>SH</td><td>AE630-SH, AE1000-SH
AE1250-SH, AE1600-SH
AE2000-SH, AE2500-SH
AE3200-SH</td><td>IEC 60947-2</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>●(Self Declaration)</td><td>–</td></tr>
<tr><td rowspan="2">JEC</td><td>SW</td><td>AE630-SW, AE1000-SW
AE1250-SW, AE1600-SW
AE2000-SWA, AE2000-SW
AE2500-SW, AE3200-SW
AE4000-SWA, AE4000-SW
AE5000-SW, AE6300-SW</td><td rowspan="2">JEC 160</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>SH</td><td>AE630-SH, AE1000-SH
AE1250-SH, AE1600-SH
AE2000-SH, AE2500-SH
AE3200-SH</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>CCC</td><td>SW</td><td>AE630-SW, AE1000-SW
AE1250-SW, AE1600-SW
AE2000-SWA, AE2000-SW
AE2500-SW, AE3200-SW
AE4000-SWA, AE4000-SW
AE5000-SW, AE6300-SW</td><td>CCC</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>●</td><td>●(Self Declaration)</td><td>–</td></tr>
</table>

Note *1 Except for four poles breaker.
Remark: 1. GOST-R (Russian Standards) approval products are prepared. Please inquire details.

●Molded case circuit breakers, motor protection breakers, air circuit breakers, circuit protectors and miniature circuit breakers (classification society)

<table>
<tr><th rowspan="3">Specifications</th><th rowspan="3">Class</th><th rowspan="3">Applicable Models</th><th colspan="7">Classification societies (Note)</th></tr>
<tr><th>NK</th><th>LR</th><th>ABS</th><th>GL</th><th>BV</th><th>CCS</th><th>DNV</th></tr>
<tr><th>Japan</th><th>United Kingdam</th><th>USA</th><th>Germany</th><th>France</th><th>China</th><th>Norway</th></tr>
<tr><td rowspan="25">General</td><td rowspan="5">C</td><td>NF30-CS</td><td>●</td><td>●</td><td>●</td><td>–</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>NF63-CV, NF125-CV</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td><td>Scheduled to be certified</td><td>●</td></tr>
<tr><td>NF250-CV</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td><td>Scheduled to be certified</td><td>●</td></tr>
<tr><td>NF400-CW, NF630-CW</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td><td>–</td><td>–</td></tr>
<tr><td>NF800-CEW</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td><td>–</td><td>●</td></tr>
<tr><td rowspan="5">S</td><td>NF32-SV, NF63-SV, NF125-SV</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td><td>Scheduled to be certified</td><td>●</td></tr>
<tr><td>NF250-SV</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td><td>Scheduled to be certified</td><td>●</td></tr>
<tr><td rowspan="2">NF400-SW, NF630-SW
NF400-SEW, NF630-SEW
NF800-SEW</td><td rowspan="2">●</td><td rowspan="2">●</td><td rowspan="2">●</td><td rowspan="2">●</td><td rowspan="2">●</td><td rowspan="2">●</td><td>–</td></tr>
<tr><td>●</td></tr>
<tr><td>NF1000-SEW, NF1250-SEW</td><td>●</td><td>●</td><td>●</td><td>–</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td rowspan="4">H/R</td><td>NF63-HV, NF125-HV</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td><td>Scheduled to be certified</td><td>●</td></tr>
<tr><td>NF250-HV</td><td rowspan="3">●</td><td rowspan="3">●</td><td rowspan="3">●</td><td rowspan="3">●</td><td rowspan="3">●</td><td>Scheduled to be certified</td><td>●</td></tr>
<tr><td>NF400-HEW, NF400-REW</td><td>●
(HEW)</td><td rowspan="2">–</td></tr>
<tr><td>NF630-HEW, NF630-REW
NF800-HEW, NF800-REW</td><td>–</td></tr>
<tr><td rowspan="2">U</td><td rowspan="2">NF125-UV, NF250-UV
NF400-UEW, NF800-UEW</td><td rowspan="2">●</td><td rowspan="2">●</td><td rowspan="2">●</td><td rowspan="2">●</td><td rowspan="2">●</td><td>Scheduled to be certified</td><td>●</td></tr>
<tr><td>–</td><td>–</td></tr>
<tr><td>Motor Protection</td><td>NF32-SV MB, NF63-CV MB
NF63-SV MB, NF125-SV MB
NF250-SV MB</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td><td>Scheduled to be certified</td><td>●</td></tr>
<tr><td rowspan="2">AE</td><td>AE630-SW, AE1000-SW
AE1250-SW, AE1600-SW
AE2000-SWA, AE2000-SW
AE2500-SW, AE3200-SW
AE4000-SWA</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td></tr>
<tr><td>AE4000-SW, AE5000-SW, AE6300-SW</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td><td>–</td><td>–</td></tr>
<tr><td>CP</td><td>CP30-BA</td><td>●</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>BH</td><td>BH-P</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td><td>–</td><td>–</td></tr>
</table>

Remark: 1. Four poles breakers does not acquire Classification Society approval.

Standards MCCB & ELCB

11. 3 Comparison of international standards

11. 3. 1 MCCB

Standard	IEC 60947-2 EN 60947-2	JIS C 8201-2-1 Appendix 1	JIS C 8201-2-1 Appendix 2	
Name	Low-voltage switchgear and controlgear –Part 2: Circuit-breakers	Molded case circuit breakers	Molded case circuit breakers	
Scope	Rated voltage 1000VAC or less 1500VDC or less	Rated voltage 1000VAC or less 1500VDC or less Applies to electric installations constructed according to JIS C 0364 Series. Based on JIS C 3662-3 tolerable temperature 70°C insulation wire (PCV70°C reference insulation wire).	Rated voltage 1000VAC or less 1500VDC or less Applies to electric installations constructed according to conventional electrical installation regulations. Based on JIS C 3307 tolerable temperature 60°C insulation wire (PCV 60°C reference insulation wire).	
Rated current (In)	No stipulations The rated current (In) is the rated continuous current (Iu) (Refer to section 4. 3. 2. 4 of Part 1). It is equal to the thermal current (Ith).			
Rated insulation voltage (Ui)	No stipulations Unless specified, the maximum value of the rated working voltage (Ue) is Ui.	No stipulations Unless specified, the maximum value of the rated working voltage (Ue) is Ui.	No stipulations Unless specified, the maximum value of the rated working voltage (Ue) is Ui.	
Rated working voltage (Ue)	No stipulations Where, IEC 60038 stipulates the standard voltage for the AC system. 3ϕ3W or 3ϕ4W: 230/400, 400/690, 1000V 1ϕ3W: 120/240V	No stipulations	No stipulations	
Rated impulse withstand voltage (Uimp)	Peak value (kV) of 1.2/50μs waveform 0.33 0.5 0.8 1.5 2.5 4 6 8 12			
Rated control circuit voltage (Us)	Rated control circuit voltage (When different from main circuit voltage) / Operating voltage range % AC: 24-48-110-127-220-230 DC: 24-48-110-125-220-250 Operating voltage range: 85 to 110 For AC: rated frequency	Rated control circuit voltage (When different from main circuit voltage) AC: 24-48-100-110-127-200-220-230-240-415 DC: 24-48-100-110-125-200-220-250	Operating voltage range % 85 to 110 For AC: rated frequency	

Electric Appliance Safety Law Standards concerning technology for electrical appliances
Molded case circuit breakers
Rated voltage 100V or more 300V or less Rated current 100A or less
(1) Capacity of 15A or less (2) Capacity of 15A or more, 30A or less (3) Capacity of 30A or more, 50A or less (4) Capacity of more than 50A Note) The frame size is not stipulated.
No stipulations
(1) Capacity of 125V or less (2) Capacity of more than 125V
No stipulations
No stipulations

<table>
<tr><td>Standard</td><td>IEC 60947-2
EN 60947-2</td><td>JIS C 8201-2-1
Appendix 1</td><td colspan="2">JIS C 8201-2-1
Appendix 2</td></tr>
<tr><td>Name</td><td>Low-voltage switchgear and controlgear
–Part 2: Circuit-breakers</td><td>Molded case circuit breakers</td><td colspan="2">Molded case circuit breakers</td></tr>
<tr><td rowspan="2">Tripping voltage</td><td>Voltage tripping</td><td>Undervoltage tripping</td><td>Voltage tripping</td><td>Undervoltage tripping</td></tr>
<tr><td>Must trip at 70 to 110% of rated voltage.</td><td>Must trip at 70 to 35% of rated voltage; prevent closed circuit at 35% or less and create closed circuit at 85% or more.
Voltage upper limit at 110%.</td><td>Must trip at 85 to 110% (AC) or 75 to 110% (DC) of rated working voltage.</td><td>Must trip at 70 to 20% of rated voltage; prevent closed circuit at 35% or less and create closed circuit at 85% or more. Voltage upper limit at 110%.</td></tr>
<tr><td>Rated frequency</td><td>No stipulation</td><td>No stipulation</td><td colspan="2">No stipulation</td></tr>
<tr><td>No. of poles</td><td colspan="4">1 2 3 4 (with N pole)</td></tr>
<tr><td>Reference ambient temperature</td><td>30°C ± 2°C</td><td>30°C</td><td colspan="2">40°C</td></tr>
<tr><td>Rated tripping current (Icn)</td><td colspan="4">Icu (rated maximum short-circuit breaking capacity) is not stipulated.
Ics (rated service short-circuit breaking capacity) is expressed as a percentage of the %, and is 25, 50, 75 to 100%.
Indicated as a % display or a rounded up decimal value.
Lcw (rated short-time current) at a rated current of 2500A or less must be 12-times or 5kA the rated current, and at more than 2500A must be larger than 30kA.</td></tr>
<tr><td>Structure</td><td colspan="4">(1) Using the Glow Wire Testing method, the insulation material shall be verified to have a performance of 960°C (when holding the main circuit's energized section) or 650°C (when used in other sections).
(2) The energized section shall have the required strength and energizing capacity. The connector shall not be tightened via an insulator.
(3) The surface distance shall be stipulated by the rated insulation voltage (Ui), Pollution Degree and insulation material. The clearance distance shall be stipulated by the rated impulse voltage (Uimp).
(4) The operation panel's operation direction shall follow the IEC60447 stipulations.
(5) The ON/OFF position shall be clearly indicated. ON/OFF may be indicated with the IEC60417 symbols. (I, O)
(6) Required functions are added to products complying with Isolation stipulations. (Details omitted)
(7) Terminal screws shall not be used to fix other parts.
(8) Terminal symbols must be clear, not disappear easily, and must comply with IEC60447.
(9) Products with an N pole shall be indicated with an N. This pole shall not open faster or close slower than other poles.
The energizing capacity of the N pole shall be the same as other poles if the breaker capacity is 63A or lower. If the capacity is 63A or more, the energizing capacity shall be 50% or more of other poles and larger than 63A.
(10) Terminal strength
① Connection and removal shall be performed five times. The screw type terminal shall be tightened with the tightening torque given in IEC 60947-1 Table IV, or 110% of the manufacturer's specified torque, whichever is larger.
The strength shall be tightened with two terminals. A new conductor shall be used each time. The terminal shall not be damaged.
② A wire with the specified length (IEC 60947-1 Table V + 75mm) shall be tightened with the specified torque (IEC 60947-1 Table IV or manufacturer's designated value). A specified weight shall be attached to the wire at diameter 37.5mm, 10 ± 2rpm, swung 135 times. The wire must not dislocate or break. The pulling test shall be performed immediately with the specified load (IEC 60947-1 Table VI). The conductor shall not dislocate and the terminal shall not break.
(11) Draw type terminal structure (Details omitted)
(12) Stored energy type operation method (Details omitted)
(13) Mechanism
① The breaker must trip even if the closing device activates.
② There must be no damage even if the closing device activates when the breaker is ON.
③ The trip-free breaker must not maintain a closed contact when the tripping device activates.</td></tr>
</table>

Electric Appliance Safety Law Standards concerning technology for electrical appliances
Molded case circuit breakers
No stipulation
50/60Hz
1 2 3
40°C ± 2°C(25°C ± 2°C)
Symmetrical value Capacity of 1000A or less Capacity of 1000A or more 1500A or less Capacity of 1500A or more 2500A or less Capacity of 2500A or more 5000A or less Capacity of 5000A or more 7500A or less Capacity of 7500A or more 10000A or less Capacity of 10000A or more 15000A or less Capacity of 15000A or more 20000A or less Capacity of 20000A or more 25000A or less Capacity of 25000A or more 30000A or less Capacity exceeding 30000A
(1) If the rated current exceeds 20A, it must be possible to connect the wire without bending it into a ring. (2) When using a large round head flat screw, the area of the terminal fitting covered by the terminal screws head shall be larger than the area of the large head round flat screw's head. (3) If the product has two or more poles, it must be possible to switch each pole simultaneously (when there are three or more poles, the poles other than the grounding side poles). (4) Insulation distance If the rated current is 15A or more, the space distance shall be 4mm or more at the switch side. The surface distance must be 6mm or more (4mm at sections other than terminal section in breaker with a structure which the user cannot open the cover or outer housing). (5) The ventilation hole size shall not permit a 5mm diameter sphere to pass through it. (6) The breaker shall be a free tripping type. (7) The effective thread length of the terminal shall be 2 pitches or more if the nominal diameter is 8mm or less, and 50% of more of the nominal diameter if the nominal diameter is 8mm or more. Note that this shall not apply to a terminal with a nominal diameter of 8mm or more with a threaded section inside the terminal frame, and to which the following points do not apply. (a) The effective length of the total thread section is 25% or more of the nominal diameter, and the sum of the total thread section and partial thread section is 55% or more of the nominal diameter. (b) The terminal section's strength test is passed when repeated five times.

Standard	IEC 60947-2 EN 60947-2	JIS C 8201-2-1 Appendix 1	JIS C 8201-2-1 Appendix 2
Name	Low-voltage switchgear and controlgear –Part 2: Circuit-breakers	Molded case circuit breakers	Molded case circuit breakers
Size of terminal for wire connection	The maximum connectable wire shall be larger than the values given below. It shall be possible to tighten a terminal two sizes smaller than the sizes given in IEC 60947-1 Table I Wire sizes.		
Test wire	(see table below)		(see tables below)

Test wire (IEC 60947-2 / EN 60947-2, JIS C 8201-2-1 Appendix 1):

Test current		Conductor size mm^2
More than 0A	8A or less	1.0
8	12	1.5
12	15	2.5
15	20	2.5
20	25	4.0
25	32	6.0
32	50	10
50	65	16
65	85	25
85	100	35
100	115	35
115	130	50
130	150	50
150	175	70
175	200	95
200	225	95
225	250	120
250	275	150
275	300	185
300	350	185
350	400	240

Test wire (JIS C 8201-2-1 Appendix 2):

Rated current A	Wire	
	Single wire (diameter) mm	Strand wire (cross sectional area) mm^2
In ≦ 15	1.6	–
15 < In ≦ 20	2.0	–
20 < In ≦ 30	–	5.5
30 < In ≦ 40	–	8
40 < In ≦ 50(60)	–	14
50 < In ≦ 75	–	22
75 < In ≦ 113	–	38
113 < In ≦ 152	–	60
152 < In ≦ 208	–	100
208 < In ≦ 276	–	150
276 < In ≦ 328	–	200
328 < In ≦ 389	–	250
389 < In ≦ 455	–	2 X 100 or 325
455 < In ≦ 520	–	2 X 150 or 400
520 < In ≦ 600	–	2 X 200 or 500

Range of test current A		Conductor			
		Meter		MCM	
		No. of wires	Size mm^2	No. of wires	Size MCM
400	500	2	150	2	250
500	630	2	185	2	350
630	800	2	240	3	300

Electric Appliance Safety Law Standards concerning technology for electrical appliances
Molded case circuit breakers

Rated current A	Wire	
	Single wire (diameter mm)	Strand wire (nominal cross sectional area mm^2)
15 or less	1.6(2.0)	–
More than 15, less than 20	1.6 and 2.0 (2.0, 2.6 and 3.2)	2.0 and 5.5
More than 20, less than 30	20 and 2.6 (2.6 and 3.2)	3.5 and 8 (14.0)
More than 30, less than 50	–	8.0 and 14.0 (14.0 and 22.0)
More than 50, less than 60	–	8.0, 14.0 and 22.0 (14.0, 22.0 and 38.0)
More than 60, less than 75	–	14.0, 22.0 and 30.0 (14.0, 22.0 and 38.0)
More than 75	–	2.20, 30.0 and 38.0 (38.0, 50.0 and 60.0)

Values given in parentheses apply to wires with Aℓ or Aℓ-Cu markings.

Rated current A	Wire	
	Single wire (diameter mm)	Strand wire (nominal cross sectional area mm^2)
15 or less	1.6 (2.0)	–
More than 15, less than 20	2.0 (2.6)	–
More than 20, less than 30	(3.2)	5.5
More than 30, less than 40	–	8 (14.0)
More than 40, less than 60	–	14.0 (22.0)
More than 60, less than 75	–	22.0 (38.0)
More than 75	–	38.0 (60.0)

Standard	IEC 60947-2 EN 60947-2	JIS C 8201-2-1 Appendix 1	JIS C 8201-2-1 Appendix 2	
Name	Low-voltage switchgear and controlgear –Part 2: Circuit-breakers	Molded case circuit breakers	Molded case circuit breakers	
Overcurrent tripping test	(1) Long-time delay tripping At the reference ambient temperature, the breaker must not function when a current 1.05 times the rated current (non-operating current if it can be set) is passed for 2h (1h if rated current is 63A or less). When the current is immediately increased to 1.30 times, the breaker must trip within 2h (within 1h if rated current is 63A or less). If the breaker is not affected by the ambient temperature, the similar test shall be carried out at 30°C ± 2°C, 20°C ± 2°C or 40°C ± 2°C. Energize the three poles simultaneously, and perform a cold start. (2) Short-circuit protection tripping (a) Instantaneous tripping The breaker must not function for 0.2s at 80% of set current value. The breaker must function within 0.2s at 120% of set current value. (b) The short-time delay tripping must not function for a time 2-times the short-time delay tripping time set by the manufacturer at 80% of the rated current. At 120% of the set current value, the breaker must function within 2-fold the short-time delay tripping time set by the manufacturer. Two poles must be connected in series and tested. All possible combinations must be tested for the two poles. The test per pole must also be carried out thereafter. The tripping current shall be the value set by the manufacturer. (3) Additional test of short-time delay tripping (a) With a current that is 1.5 times the tripping current setting value, the tripping time for a 2-pole series must be measured and be within the range set by the manufacturer. All possible two-pole combinations must be tested. (b) Under the same conditions as (a), after passing a current 1.5 times the set value for the non-operating time set by the manufacturer, pass the rated current for 2-times the short-time delay tripping time. The breaker must not trip. (4) Instantaneous tripping for overload protection, short-time delay tripping (Details omitted) (5) The connected wire must have the size indicated in the Wire connection terminal column, and the length must be the length given in the Temperature rise test column. If the overcurrent tripping can be adjusted with the breaker, test with the maximum and minimum settings. Select the connected current from the setting In. The test voltage shall be an arbitrary value. (6) Sequence I, II Overcurrent tripping after temperature rise test Immediately after the temperature test, increase the rated current to 1.45 times. The breaker must function within 2 hours (within 1 hour for 63A or less). Connect all poles in series. A 3-phase current may be used. The voltage may be an arbitrary value. (7) Sequence III (a) The breaker must function within the time set by the manufacturer when a current double the rated current is passed to each pole. The voltage may be an arbitrary value. (b) Overcurrent tripping must occur after the Icu and withstand voltage test. The breaker must function within the time of the current 2 times set by the manufacturer when a current 2.5 times the rated current is passed to each pole.	Matters other than the following are the same as IEC. (2) Short-circuit protection tripping (a) Instantaneous tripping The breaker must not function for 0.2 at 80% of set current value. The breaker must function within 0.2s at 120% of set current value.	Matters other than the following are the same as Appendix 1. (1) Long-time delay tripping At the reference ambient temperature, the breaker must not function when a current 1.0 times the rated current (non-operating current if it can be set) is passed for 2h (1h if rated current is 50A or less). When the current is immediately increased to 1.25 times, the breaker must trip within 2h (within 1h if rated current is 50A or less). When a current 2.0 times the rated current is passed to each pole, the breaker must function within the specified operating time. If the breaker is not affected by the ambient temperature, the similar test shall be carried out at 30°C ± 2°C, 20°C ± 2°C or 40°C ± 2°C. Energize the three poles simultaneously, and perform a cold start. 200% Operating time (minutes) Within 2 (In ≦ 30A) Within 4 (30A < In ≦ 50A) Within 6 (50A < In ≦ 100A) Within 8 (100A < In ≦ 225A) Within 10 (225A < In ≦ 400A) Within 12 (400A < In ≦ 600A) Within 14 (600A < In ≦ 800A) Within 16 (800A < In ≦ 1000A) Within 18 (1000A < In ≦ 1200A) Within 20 (1200A < In ≦ 1600A) Within 22 (1600A < In ≦ 2000A) Within 24 (2000A < In)	
100% current test	No stipulation	No stipulation	Follows stipulations above	

	Electric Appliance Safety Law Standards concerning technology for electrical appliances
	Molded case circuit breakers

Rated current A	Operating time (min)	
	Current 200% of rated current	Current 125% of rated current
30 or less	Within 2	Within 60
More than 30, less than 50	Within 4	Within 60
More than 50	Within 6	Within 120

(1) Pass the 200% current to each pole.
(2) Pass the 125% current simultaneously to each pole.

The overcurrent tripping device must not function when a current equal to the rated current is passed until the temperature at each section stabilizes.

<table>
<tr><td>Standard</td><td>IEC 60947-2
EN 60947-2</td><td>JIS C 8201-2-1
Appendix 1</td><td>JIS C 8201-2-1
Appendix 2</td></tr>
<tr><td>Name</td><td>Low-voltage switchgear and controlgear
–Part 2: Circuit-breakers</td><td>Molded case circuit breakers</td><td>Molded case circuit breakers</td></tr>
<tr><td>Overload test</td><td>This test applies to a breaker with rated current of 630A or less.
The test circuit shall follow IEC 947-1 Figures 3 to 6.
The power capacity and copper fuse standards are the same as the conductivity durability test.
The test voltage shall be the maximum Ue.
The adjustable tripping setting shall be set to the maximum.
The test shall be performed 12 times in total. Nine times shall be manual switching, and three times shall be automatic breaking using the overcurrent tripping function.
The energizing time shall be the time that the current can sufficiently reach the specified value, but shall be within 2s.
The switching frequency shall be the same as the value given in the Durability column. The frequency can be lowered if the breaker cannot be reset.
The frequency shall be in the range of 45 to 62Hz.
<table>
<tr><td></td><td>AC</td><td>DC</td></tr>
<tr><td>Current</td><td>6In</td><td>2.5In</td></tr>
<tr><td>Voltage</td><td>1.05Ue max</td><td>1.05Ue</td></tr>
<tr><td>Power factor cosϕ</td><td>0.5</td><td>max</td></tr>
<tr><td>Time constant L/R (ms)</td><td>–</td><td>2.5</td></tr>
</table></td><td colspan="2">Matters other than those below shall be the same as IEC.
<table>
<tr><td></td><td>AC</td><td>DC</td></tr>
<tr><td>Current</td><td>6In</td><td>2.5In</td></tr>
<tr><td>Voltage</td><td>1.1Ue max</td><td>1.1Ue</td></tr>
<tr><td>Power factor cosϕ</td><td>0.5</td><td>max</td></tr>
<tr><td>Time constant L/R (ms)</td><td>–</td><td>2.5</td></tr>
</table></td></tr>
<tr><td>Overflow current test</td><td>No stipulation</td><td>When indicating the overflow performance with a rated working voltage of 100VAC or 110/220VAC and rated current of 50A or less, perform the following test. The breaker must not open automatically, and must not weld.
(1) Using a 100V, 200W incandescent light bulb as a reference, the number of lit bulbs to which the breaker’s rated current flows.
(2) Test voltage is 100 to 105V. The voltage drop when the bulb turns ON must be within 5%.
(3) The test shall be carried out for 2s. After the closing, the circuit shall be opened and cooled for 2 minutes. This process shall be repeated three times in succession.</td><td>When the rated working voltage is 100VAC or 110/220VAC and the rated current is 50A or less, perform the following test. The breaker must not function or weld when the incandescent light bulb turns ON at room temperature.
(1) Using a 100V, 200W incandescent light bulb as a reference, the number of lit bulbs to which the breaker’s rated current flows.
(2) Test voltage is 100 to 105V. The voltage drop when the bulb turns ON must be within 5%.
(3) The test shall be carried out for 2s. After the closing, the circuit shall be opened and cooled for 2 minutes. This process shall be repeated three times in succession.</td></tr>
</table>

	Electric Appliance Safety Law Standards concerning technology for electrical appliances
	Molded case circuit breakers
	When a current 6 times the rated current (150A if the rated current is 25A or less) is passed for 1 minute, the breaker must switch 35 times manually, and 15 times with the manual setting automatic tripping operation. The switching ratio is 4 times per minute. (1) The voltage drop shall be 15% or less when a current 6 times the rated current is passed. (2) Connect an insulated wire having the specified size to the test product and mount in the normal working state. Apply a voltage equivalent to the rated voltage. (3) The test circuit's power factor is 0.45 or more, 0.5 or less. (Note) If the breaker has individual tripping wires, automatic breaking must be tested for each pole.
	If the rated current is 50A or less, the breaker must not automatically break and the contact must not weld when the following test is performed. (1) Connect tungsten bulb having a rated voltage of 100V and rated power consumption of 200W to the load side of the test part (when using single-phase 3-wire type, connect to neutral wire on load side and voltage side wire of 1) so that the current in the ON state is approximately equal to the rated current. In this case, a bulb having a rated power consumption of 200W or less can be used within the required limit to adjust the current. (2) The no-load voltage of the power side terminal of the test part shall be 100V or more 105V or less. The voltage drop when the bulb turns ON shall be within 5%. (3) Turn the tungsten bulbs connected ON simultaneously, open the circuit after 2 second and allow the circuit to cool naturally for two minutes. Repeat this process three times in succession.

Standard	IEC 60947-2 EN 60947-2	JIS C 8201-2-1 Appendix 1	JIS C 8201-2-1 Appendix 2	
Name	Low-voltage switchgear and controlgear –Part 2: Circuit-breakers	Molded case circuit breakers	Molded case circuit breakers	
Temperature rise test	(see IEC 60947-2 / EN 60947-2 and JIS C 8201-2-1 Appendix 1 content below)		(see JIS C 8201-2-1 Appendix 2 content below)	

Temperature rise test — IEC 60947-2 / EN 60947-2, JIS C 8201-2-1 Appendix 1

Place		Temperature rise limit (K)
External insulated conductor connection terminal		80
Operation section	Metal	25
	Non-metal	35
Section accessible by worker	Metal	40
	Non-metal	50
Section normally inaccessible by worker	Metal	50
	Non-metal	60

Even insulators and parts that are not listed must not be damaged by a rise in temperature.

(1) Testing method

(a) The ambient temperature must be measured by at least two sensors.
Mount the sensors at a position at approx. 1m from the breaker and a height approx. half of the breaker mounting height. Protect the sensor from drafts and radiated heat.

(b) The ambient temperature must be within the range of +10 to +40°C, and must not fluctuate by 10K or more. If the temperature fluctuates by 3K or more, compensate the temperature rise value taking the thermal time constants into consideration.

(c) The electromagnetic coil's temperature shall follow the resistance method. T2 = R2/R1 (T1 + 234.5) - 234.5
The temperature rise shall follow the IEC 60216 or IEC 60085 stipulations.
T1: Temperature at start (°C) R1: Resistance at start (Ω)
T2: Temperature at saturation (°C) R2: Resistance at saturation temperature (Ω)

(d) A temperature rise fluctuation of within 1°C/hour shall be viewed as saturation. It shall not take more than 8h to achieve a saturated state.

(e) The breaker shall be mounted properly.

(f) The breaker's rated thermal current (Ith) shall be passed. Ith shall be the same as the breaker's rated current (In).
The voltage may be an arbitrary voltage.

(d) The DC breaker may be tested with an AC. the multi-pole breaker may be tested by passing a single-phase current to the series of all poles.

(h) With the 4-pole breaker having an N-pole:
① Test with the three voltage poles,
② Set the N pole in series with the adjacent pole, and use a single-phase current to test the N pole's Ith.

(i) When Ith = In is 400A or less
The connected wire shall follow the wire indicated in the Wire connection terminal column.
The minimum wiring length between terminals or to other terminals shall be 1m if the wire diameter is $35mm^2$ or less, and 2m if the diameter is $35mm^2$ or more.

(j) When Ith = In is more than 400A, 800A or less
The connected wire shall be a PVC wire or copper bar indicated in the Wire connection terminal column. A different copper bar with similar cross section area may also be used. The copper bar shall be painted black. When connecting several copper bars to one terminal, provide a space equivalent to the bar's thickness. When connecting multiple wires to one terminal, bundle the wires while providing a 10mm gap. The minimum conductor length between terminals and to other terminals shall be 2m. The length to the star point may be 1.2m.

(k) When Ith = In is more than 800A, 3150A or less
The connected copper bar is indicated in the Wire connection terminal column. A different copper bar with similar cross section area may also be used. When connecting a wire, the manufacturer's designations must be followed. The copper bar shall be painted black. When connecting several copper bars to one terminal, provide a space equivalent to the bar's thickness. The minimum length of the copper bar between the terminals and to other terminals shall be 3m. If the power terminal's temperature rise is not 5K lower than the copper bar length's interim value, the length may be 2m. The minimum length to the star point is 2m.

(l) When Ith = In exceeds 3150A, the test shall be decided by the manufacturer and user.

(m) The control circuit's temperature rise shall be tested by applying the rated voltage and rated current.
When testing an auxiliary or alarm switch, the voltage may be an arbitrary value.

(n) When using a 4-pole breaker, first the 3 voltage poles shall be tested. After that, the N pole and adjacent pole shall be tested with In if In is 63A or less, and with a current value decided by the manufacturer and user if In exceeds 63A.

(2) Temperature rise test after sequence II Ics
Only the terminal's temperature rise shall be measured. The result shall be 80K or less.
There is no need to test at the minimum In.

Temperature rise test — JIS C 8201-2-1 Appendix 2

Matters other than those below shall be the same as Appendix 1.

Place		Temperature rise limit (K)
External insulated conductor connection terminal		60
Operation section	Metal	25
	Non-metal	35
Section accessible by worker	Metal	40
	Non-metal	50
Section normally inaccessible by worker	Metal	50
	Non-metal	60

Electric Appliance Safety Law Standards concerning technology for electrical appliances		
Molded case circuit breakers		
Measurement position	Temperature rise	
	Thermoelectric pyrometer method	Resistance method
Switch contact section of a breaker with copper or copper alloy contact material, lump-type or a flat plate shape, and a butt contact mechanism	40	–
Switch contact section of a breaker with copper or copper alloy contact material, lump-type or a flat plate shape, and a sliding contact mechanism	45	–
Switch contact section of a breaker with silver or silver alloy contact material, lump-type or a flat plate shape, and a sliding contact mechanism	100	–
Terminal fitting	60	–
Class Y insulation coil	50	70
Class A insulation coil	65	85
Class E insulation coil	80	100
Class B insulation coil	90	110
Class F insulation coil	115	135
Class H insulation coil	140	160
Coil with bare wires wound in single layer	90	–
Coil with enameled wire wound in single layer	90	–
Coil with enabled wire wound in double layer	80	–
Selenium coil	45	–
Germanium coil	30	–
Silicon coil	105	–

Reference ambient temperature shall be 30°C.

Standard	IEC 60947-2 EN 60947-2	JIS C 8201-2-1 Appendix 1	JIS C 8201-2-1 Appendix 2
Name	Low-voltage switchgear and controlgear –Part 2: Circuit-breakers	Molded case circuit breakers	Molded case circuit breakers

Durability test

Rated current A	Switching frequency Times/hour	Number of switching times		
		Non-energized	Energized	Total
100 or less	120	8500	1500	10000
More than 100, 315 or less	120	7000	1000	8000
More than 315, 630 or less	60	4000	1000	5000
More than 630, 2500 or less	20	2500	500	3000
More than 2500	10	1500	500	2000

The switching frequency is the minimum value
The breaker must be energized with a closed circuit for a maximum of two seconds.

(1) The test shall be performed at room temperature.
The voltage applied on the control circuit shall be measured at the terminal of the enclosed device.
The order for testing the overload, energizing durability and non-energizing durability is arbitrary.
(2) 10% of the total number of times in the non-energizing test shall be tripped with UVT or SHT. The applied voltage shall be the maximum operating voltage.
Half of the operation shall be performed at the start of the durability test, and the remaining half shall be performed when the test is finished.
When switching with an electric operation switch, apply the rated control voltage and test.
(3) Energizing durability test.
The test circuit shall follow IEC 60947-1 Figures 3 to 6.
The power capacity shall be more than 10 times the test current or 50kA, whichever is smaller.
A ϕ0.8mm, minimum 50mm long copper fuse shall be connected between the mounting plate and neutral point to detect accidents.
The accident current shall be 1500A ± 10%. A copper wire thinner than ϕ0.8 may be used. (Conditions omitted)
The rated current and rated working voltage (Ue) shall be switched.
The power factor shall be 0.8, the time constant shall be 2ms. The frequency shall be within the range of 45 to 62Hz.
When using adjustable tripping, the overcurrent setting shall be the maximum. The short-circuit setting shall be the minimum.
When switching with an electric operation switch, the rated control voltage shall be applied.

Standard	IEC 60947-2 EN 60947-2	JIS C 8201-2-1 Appendix 1	JIS C 8201-2-1 Appendix 2
Insulation resistance test	No stipulation	No stipulation	No stipulation

	Electric Appliance Safety Law Standards concerning technology for electrical appliances
	Molded case circuit breakers
	Apply a voltage equal to the rated voltage, and pass a current equal to the rated current. Switch 5000 times at a switching rate of 10 times per minute. The test circuit's power factor is 0.75 or more, 0.8 or less The test circuit's voltage drop is 2.5% of less

Measurement place	Insulation resistance (MΩ)
Between live section with different polarity (Excluding motor's live section and operating circuit with rated voltage of less than 100V. This also applies hereinafter in this table.). Between live sections with same polarity in open circuit state. Between live section and non-live metal section that could be grounded, or nonmetal section that could be touched by worker. Between live section and test metal plate. Between main circuit and operation circuit.	5
Between motor's live section, non-live section and metal. Between operating circuit with rated voltage less than 100V and nonmetal section that could be grounded, or nonmetal section that could be touched by worker. Between operation circuit with rated voltage less than 100V and test metal plate.	1

<table>
<tr><td>Standard</td><td>IEC 60947-2
EN 60947-2</td><td>JIS C 8201-2-1
Appendix 1</td><td>JIS C 8201-2-1
Appendix 2</td><td></td></tr>
<tr><td>Name</td><td>Low-voltage switchgear and controlgear
–Part 2: Circuit-breakers</td><td>Molded case circuit breakers</td><td>Molded case circuit breakers</td><td></td></tr>
<tr><td>Withstand voltage test</td><td colspan="2">(1) Impulse withstand voltage
The test voltage shall follow IEC 60947-1 Table 12.
If the breaker is equipped with an isolation function, the contact will be opened, and the voltage indicated in IEC 60947-1 Table 14 shall be applied.
If the spatial distance is larger than case A in IEC 60947-1 Table 13, the Uimp test may be omitted.
The surface distance must be larger than IEC 60947-1 Table 15. The material’s CTI value is stipulated by the working environment’s pollution degree.
If the breaker is equipped with an isolation function, the 1.1Ue test voltage shall be applied. The leakage current between the power and load shall be 0.5mA or less.
Cover the insulator’s operation handle with metal foil, and connect to a metal mounting plate.
A 1.2/50μs impulse waveform voltage shall be applied as a positive and negative voltage five times each at a minimum 1 second interval.
Voltage application position.
① Between main circuit and control circuit’s level section batch and mounting plate. Contact is ON, OFF, trip.
② Connect one pole of the main circuit, and the other poles in a batch to the mounting plate. Contact is ON, OFF, trip.
③ Between a control circuit that is not connected to the main circuit, and the main circuit, other control circuit and mounting plate.
④ Between the power terminal batch and load side terminal batch. Contact open.
(2) Voltage withstand test (high frequency voltage withstand test)
The withstand voltage test in the test sequence shall follow the sine wave voltage.
Mount on a metal plate. Cover the insulator’s operation handle with metal foil, and connect to a metal mounting plate.
If the breaker is equipped with a motor, instrument, snap switch or semiconductor device, etc., disconnect the connection during the test.
Voltage application position.
(a) Main circuit (Control circuit not connected to main circuit and auxiliary circuit are all connected to mounting plate)
① Breaker ON: Between batch of all live sections and mounting plate
Between each pole and batch of all other poles connected to mounting plate
② Breaker OFF, trip: Between batch of all live sections and mounting plate
Between power side terminal batch and load side terminal batch
(b) Control/auxiliary circuit (All live sections of main circuit connected to mounting plate)
① Between control/auxiliary circuit batch not connected to main circuit and mounting plate
② Between one enclosed device and other enclosed device
The voltage is applied for five sections. The test voltage shall be a sine wave with frequency between 45 and 62Hz. The current at the short-circuit shall be smaller than 0.2A.
Withstand voltage
Rated insulation voltage Ui (V) — Withstand voltage AC rms (V)
60 or less — 1000
More than 60, less than 300 — 1500
More than 300, less than 690 — 1890
More than 690, less than 800 — 2000
More than 800, less than 1000 — 2200
The test voltage of the control/auxiliary circuit not connected to main circuit shall be 1000V for Ui 60V, and 2Ui + 1000V at Ui 60V. The minimum value shall be 1500V.
(3) Sequence I Withstand voltage test after overload and energizing durability. Apply 2Ue. Note that minimum value is 1000V.
(4) Sequence II Withstand voltage test after Ics. Apply 2Ue. Note that the minimum value is 1000V.
(5) Sequence III Withstand voltage test after Ics. Apply 2Ue. Note that the minimum value is 1000V.</td><td>Matters other than the following shall be the same as Appendix 1.
(1) Impulse withstand voltage test

• When declaring Uimp.
Same as Appendix 1.

• When not declaring Uimp.
① Commercial frequency withstand voltage test.
Same as Appendix 1.
② Lightning impulse withstand voltage test
Apply a 1.2/50μs impulse waveform voltage 5kV three times each in positive and negative state, between the live section and non-live metal section.</td><td></td></tr>
</table>

Electric Appliance Safety Law Standards concerning technology for electrical appliances	
Molded case circuit breakers	
Rated voltage (V)	Test voltage (V)
30 or less	500
More than 60, 150 or less	1000
More than 150, 300 or less	1500
More than 300, 600 or less	2000
More than 600, 1000 or less	3000

(Remarks) If a double rating is provided, the higher rated voltage shall be used.

The breaker must withstand when the voltage listed above is continuously applied for one minute to the measurement position indicated for the insulation resistance test.

Standard	IEC 60947-2 EN 60947-2	JIS C 8201-2-1 Appendix 1	JIS C 8201-2-1 Appendix 2	
Name	Low-voltage switchgear and controlgear –Part 2: Circuit-breakers	Molded case circuit breakers	Molded case circuit breakers	
Short-circuit test	(1) Test conditions (a) Tolerable difference of each element Current +5 to 0% Voltage +5 to 0% Power factor 0 to −0.05 Time constant +25 to 0% Frequency ±5% (b) The recovery voltage must be 105% of rated working voltage (Ue). (c) If an electric operation device is provided, test by applying an 85% voltage. (d) If power side and load side terminal indications are provided, follow the indications. If there are no indications, follow the Standards. (e) The test circuit follows IEC 60947-1 Figure 9 to Figure 12. The section grounded during use, the wire mesh covering the breaker, and the box shall be connected to power's neutral point via a ϕ0.8mm min. 50mm long copper fuse for accident current detection. A resistor may be inserted so that the accident current is 1500A ± 10%. If a neutral point is created, regardless of the wiring method, the accident setting current and copper fuse may be smaller. (f) The connected wire size shall be the value given in the Wire connection terminal column. The wire length shall be 50cm on the power side and 25cm on the load side for a capacity breaker if In is 630A or smaller. (g) With a 4-pole breaker, the short-circuit breaking test for the N pole and adjacent pole shall be tested with the additional new part specimen. The applied voltage shall be Ue/. The test current shall be decided by the manufacturer in user, but shall not be smaller than 60% of ICU and ICW. (h) During the short-circuit breaking test, the copper fuse for detecting a short-circuit, ground fault or accident between the poles must not weld. (i) The tripping current is indicated as the average value for the 3-phase rms. The current for each phase must not fluctuate more than 10% from the average value. (j) The closing current is expressed as the maximum value for three phases. (k) The time during the breaking test is either 3 minutes or the reset time, whichever is longer. (2) Rated working short-circuit breaking test (Ics) The test specimen's rated working voltage (Ue), rated current (In), Ics, and number of test units shall follow IEC 60947-2 Table X. The test liability is O-t-CO-t-CO. If the breaker is equipped with a fuse, the fuse must be replaced each time it blows. (3) Rated maximum short-circuit breaking test (Icu) The test specimen's rated working voltage (Ue), rated current (In), Ics, and number of test units shall follow IEC 60947-2 Table X. The test liability is O-t-CO. (4) Details on the rated short-time withstand current (Icw), fuse built-in breaker short-circuit breaking test, and combination test (Icw = Ics, Icw = Ics = Icu) have been omitted.	Matters other than the following conditions are the same as IEC. (1) Test conditions (b) The recovery voltage shall be 110% of the rated working voltage (Ue). (2) Rated working short-circuit breaking test (ICs) This test sequence does not need to be applied for the time being.		

	Electric Appliance Safety Law Standards concerning technology for electrical appliances
	Molded case circuit breakers

(1) Short-circuit current AC element active value at 0.5 cycle after a voltage equal to the rated voltage is applied and a short-circuit is caused

(2) Circuit constant

Rated tripping current or rated cord protection current (A)	Short-circuit power factor
1500 or less	0.7 or more, 0.8 or less
1500 or more, 5000 or less	0.5 or more, 0.6 or less
More than 5000	0.3 or more, 0.4 or less

(3) Recovery voltage Must be equal to rated voltage. Test voltage must be applied for 0.2s or more after test unit opens.

(4) Short-circuit test The following test order shall apply.

(a) Connect a closed test unit serially to the open switch unit. The test unit must automatically trip the test circuit when the switch unit is closed.

(b) When 2min have passed from the automatic tripping (if more than two minutes is required for resetting, the minimum time required for resetting), close the test unit. The test circuit must automatically trip again.

(c) If there is only a single pole, perform test specified in (a) and (b) once on the single-phase test circuit. In this case, if the rated tripping current exceeds 10000A, perform the test with the test current set to 10000A. Then, switch the test unit, and perform with a test current equal to the rated tripping current.

(d) For a single-phase 2-wire 2-pole unit, use the following test.

a. If the rated tripping current is 10000A or less, perform the test specified in (a) and (b) once each on each pole (excluding pole with no overcurrent tripping element). Next, connect two poles in series, and perform the test specified in (a) and (b) once. If the rated tripping current exceeds 5000A at this time, the test current for each pole can be 5000A.

b. If the rated tripping current exceeds 10000A, perform the test specified in (a) and (b) once with a test current of 5000A for each pole (excluding pole that does not have overcurrent tripping element). Next, connect two poles in series, and perform the test specified in (a) and (b) with a test current of 10000A. Replace the test unit, and perform the test specified in (a) and (b) with a current equal to the rated tripping current.

(e) For the single-phase 3-wire type breaker, connect serially to the pole connected to the test unit's voltage side wire and pole connected to the neutral wire (neutral wire for wiring breaker with two poles and with individual tripping mechanism), and perform the test specified in (a) and (b) one time each. Next, in the single-phase 3-wire test circuit, connect serially to the pole connected to each voltage side wire of the test unit and perform the test specified in (a) and (b) once.

(f) The following test shall be performed for the 3-phase unit.

a. If the rated tripping current is 10000A or less, perform the test specified in (a) and (b) once each on each pole (excluding pole with no overcurrent tripping element). Next, with the 3-phase test circuit perform the test specified in (a) and (b) once. If the rated tripping current exceeds 5000A at this time, the test current for each pole can be 5000A.

b. If the rated tripping current is more than 10000A, perform the test specified in (a) and (b) once with a test current of 5000A on each pole (excluding pole with no overcurrent tripping element). Next, with the 3-phase test circuit perform the test specified in (a) and (b) once with a test current of 10000A. Replace the test unit, and perform the test specified in (a) and (b) on the 3-phase test circuit with a current equal to the rated tripping current.

Standard	IEC 60947-2 EN 60947-2	JIS C 8201-2-1 Appendix 1	JIS C 8201-2-1 Appendix 2	
Name	Low-voltage switchgear and controlgear –Part 2: Circuit-breakers	Molded case circuit breakers	Molded case circuit breakers	
Cord protection test	No stipulation	No stipulation	No stipulation	
Test order (model test) Whether to carry out each test item with the same test unit or a different test unit shall follow the Standards.	Sequence I (1) Overcurrent tripping (2) Withstand voltage (Uimp) (3) Mechanical switching durability Energizing switching durability (4) Overload (5) Withstand voltage (commercial frequency) (6) Temperature rise (7) Overcurrent tripping Sequence II (1) Rated working short-circuit breaking (o-co-co) (2) Withstand voltage (commercial frequency) (3) Temperature rise (4) Overcurrent tripping Sequence III (1) Overcurrent tripping (2) Rated maximum short-circuit breaking (o-co) (3) Withstand voltage (commercial frequency) (4) Overcurrent tripping		Sequence I (1) Overcurrent tripping (2) Withstand voltage (Uimp, commercial frequency, lightning impulse) (3) Overload (4) Withstand voltage (commercial frequency) (5) Overflow current (6) Temperature rise (7) Switching durability Sequence II Same as Appendix 1. Sequence III Same as Appendix 1.	

	Electric Appliance Safety Law Standards concerning technology for electrical appliances
	Molded case circuit breakers
	When the rated cord protection current is indicated, the breaker must automatically tripped at the (a) stipulation after two minutes have passed after the short-circuit test (if more than two minutes is required for resetting, the minimum time required for resetting). Reference If the rated cord protection circuit is indicated, the vinyl cord insulator must not fuse, and the vinyl cord's conductor must not melt.
	(1) Structure inspection (2) Overflow current (3) Overcurrent tripping (4) Overload (5) Switching performance (6) Overcurrent tripping (7) Temperature rise (8) Insulation performance (9) Short-circuit breaking (10) Cord protection

11. 3. 2 ELCB

<table>
<tr><td>Standard</td><td>IEC 60947-2 Annex B
EN 60947-2 Annex B</td><td>JIS C 8201-2-2
Appendix 1</td><td>JIS C 8201-2-2
Appendix 2</td><td></td></tr>
<tr><td>Name</td><td>Low-voltage switchgear and controlgear
–Part 2: Circuit-breakers</td><td>Earth leakage circuit breakers</td><td>Earth leakage circuit breakers</td><td></td></tr>
<tr><td>Scope</td><td colspan="4">Same as MCCB</td></tr>
<tr><td>Rated current (In)</td><td colspan="4">Same as MCCB</td></tr>
<tr><td>Rated insulation voltage (Ui)</td><td colspan="4">Same as MCCB</td></tr>
<tr><td>Rated working voltage (Ue)</td><td colspan="4">Same as MCCB</td></tr>
<tr><td>Rated impulse withstand voltage (Uimp)</td><td colspan="4">Same as MCCB</td></tr>
<tr><td>Rated control circuit voltage (Us)</td><td colspan="4">Same as MCCB</td></tr>
<tr><td>Rated sensitivity current (IΔn)</td><td>Recommended value 0.006, 0.01, 0.03, 0.1, 0.3, 0.5, 1, 3, 10, 30A</td><td colspan="2">Recommended value 0.005, 0.006, 0.01, 0.015, 0.03, 0.05, 0.1, 0.2, 0.3, 0.5, 1, 3, 5, 10, 20 or 30A</td><td></td></tr>
<tr><td>Rated non-operating current</td><td>Minimum value 0.5IΔn</td><td colspan="2">Minimum value 0.5IΔn</td><td></td></tr>
<tr><td>Operating characteristics</td><td>
<table>
<tr><td colspan="2">Leakage current</td><td>IΔn</td><td>2IΔn</td><td>5IΔn
10IΔn</td></tr>
<tr><td>Maximum operating time (Second)</td><td>Inverse time delay type</td><td>0.3</td><td>0.15</td><td>0.04</td></tr>
</table>
Time-delay type
The time-delay type's inertia dead time is stipulated with 2IΔn, and must be designated by the manufacturer.
The recommended inertia dead time at 2IΔn is 0.06sec., 0.1sec., 0.2sec., 0.3sec., 0.4sec., 0.5sec. and 1sec. The minimum inertia dead time is 0.06sec.
If the leakage breaker has an inertia dead time longer than 0.06 seconds, the manufacturer must indicate the maximum operating time at IΔn, 2IΔn, 4IΔn and 10IΔn.
Operating characteristics when inertial dead time is 0.06sec.
<table>
<tr><td>Leakage current</td><td>IΔn</td><td>2IΔn</td><td>5IΔn
10IΔn</td></tr>
<tr><td>Maximum operating time (Second)</td><td>0.5</td><td>0.2</td><td>0.15</td></tr>
</table>
</td><td colspan="2">
<table>
<tr><td colspan="2">Leakage current</td><td>IΔn</td><td>2IΔn</td><td>5IΔn
10IΔn</td></tr>
<tr><td rowspan="2">Maximum operating time (Second)</td><td>Inverse time delay type</td><td>0.3</td><td>0.15</td><td>0.04</td></tr>
<tr><td>High-speed type</td><td>0.1</td><td>-</td><td>-</td></tr>
</table>
Time delay type
Same as IEC
</td><td></td></tr>
<tr><td>Tripping voltage</td><td colspan="4">Same as MCCB</td></tr>
<tr><td>Rated frequency</td><td colspan="4">Same as MCCB</td></tr>
<tr><td>Number of poles</td><td colspan="4">Same as MCCB</td></tr>
<tr><td>Reference ambient temperature</td><td colspan="4">Same as MCCB</td></tr>
<tr><td>Rated tripping current (Icn)</td><td colspan="4">Same as MCCB</td></tr>
<tr><td>Structure</td><td colspan="3">MCCB details are added below.
(1) the testing device must not be the only way to open the circuit. This function must not be used to open the circuit.
(2) The color of the test unit's operation means must not be red or green. It should be a bright color.</td><td></td></tr>
<tr><td>Size of wire connection terminal</td><td colspan="4">Same as MCCB</td></tr>
<tr><td>Test wire</td><td colspan="4">Same as MCCB</td></tr>
</table>

	Electric Appliance Safety Law Standards concerning technology for electrical appliances
	Earth leakage circuit breakers
	(1) Capacity of 15mA or less (2) Capacity of more than 15mA, 30mA or less (3) Capacity of more than 30mA, 100mA or less (4) Capacity exceeding 100mA
	50% of rated sensitivity current
	1. After a voltage equal to the rated voltage is applied and a current equal to the rated current is passed, when a leakage current equal to 50% of the rated sensitivity current is superimposed on one pole of the test unit, the circuit must not open. In addition, the breaker must comply with the following matters. (a) The high-speed type breaker must open within 0.1 seconds when a leakage current equal to the rated sensitivity current is superimposed. (b) With the time-delay type, when a leakage current equal to the rated sensitivity current is imposed, it must open within the range of 50% (0.1sec. if less than 0.1sec.) and 150% (2sec. when more than 2sec.) of the rated operating time. (c) With the inverse time-delay type, the circuit must open within the range of more than 0.2sec. to 1sec. when a current equal to the rated sensitivity current is superimposed, within the range of more than 0.1sec. to 0.5sec. when a current equal to 140% of the rated sensitivity current is superimposed, and within 0.05sec. when a leakage current equal to 440% of the rated sensitivity current is superimposed. 2. After a voltage equal to the rated voltage is applied and the test unit is closed without connecting a load, when a leakage current is continuously applied on one pole of the test unit and increased from current equal to 50% of the rated sensitivity current in 30 seconds, the breaker must open before the current reaches a level equal to the rated sensitivity current. 3. After a voltage equal to the rated voltage is applied and the test unit is closed without connecting a load, when a 20A current is passed to one pole of the test unit, the high-speed type must open within 0.1sec., the time-delay type must open within the range of range of 50% (0.1sec. if less than 0.1sec.) and 150% (2sec. when more than 2sec.) of the rated operating time. The inverse time-delay type must open within 0.05sec.
	Same as MCCB

Standard	IEC 60947-2 Annex B EN 60947-2 Annex B	JIS C 8201-2-2 Appendix 1	JIS C 8201-2-2 Appendix 2
Name	Circuit breaker incorporating residual current protection (CBR)	Earth leakage circuit breakers	Earth leakage circuit breakers
Leakage current tripping test	85% of rated voltage 25°C, –5°C, no load The following test shall be performed on one pole. Each test shall be measured three times. ① The leakage current shall be started from 0.2IΔn or less, and gradually increased so that it reaches IΔn in approx. 30sec. The operating current shall be measured each time. ② The test circuit shall be set to the rated sensitivity current value IΔn, and shall be closed with the earth leakage breaker. The operating time shall be measured three times. ③ Set the test circuit's leakage current value IΔ for each, close switch S_2 and the leakage current shall be passed suddenly.		85% of rated voltage 25°C, –5°C, no load The following test shall be performed on one pole. Each test shall be measured three times. ① The leakage current shall be started from 0.2IΔn or less, and gradually increased so that it reaches IΔn in approx. 30sec. The operating current shall be measured each time. ② Set the test circuit's leakage current value IΔ for each, close switch S_2 and the leakage current shall be passed suddenly.
Equilibrium characteristics test (non-operating overcurrent test at single-phase load)	The test shall be performed with a single-phase load. 6In or 80% of the instantaneous tripping current setting maximum value, whichever is smaller. The sensitivity current adjustable type is set to the minimum setting. Power factor 0.5. The multi-phase equilibrium load test is not required.		
Testing of test device	① Apply a voltage 1.1 times the maximum rated voltage. Operate the test device 25 times at a 5 second interval. ② Operate the test device three times at a 5 second interval with a voltage 0.85 fold of the minimum rated voltage. ③ Apply a voltage 1.1 times the maximum rated voltage, and press the test device for five seconds.		
Overcurrent tripping test	Same as MCCB		
100% current test	Same as MCCB		
Overload test	Same as MCCB		
Overflow current test	Same as MCCB		
Temperature rise test	Same as MCCB		
Durability test	Same as MCCB		
Insulation resistance test	Same as MCCB		
Withstand voltage test	Same as MCCB		
Short-circuit test	Same as MCCB		
Cord protection test	Same as MCCB		
Environment test	Temperature and humidity cycle test Perform following IEC 60068-2-30. The number of cycles at the upper limit temperature 55 ± 2°C is as follows: 6 cycles when – IΔn > 1A 28 cycles when – IΔn ≤ 1A Set the test circuit leakage current to 1.25IΔn, open switch S_2, and the leakage current shall be passed suddenly.	Temperature and humidity cycle test Perform following IEC 60068-2-30. The number of cycles at the upper limit temperature 55 ± 2°C is as follows: 6 cycles when – IΔn > 1A 28 cycles when – IΔn ≤ 1A Set the test circuit leakage current to 1.25IΔn, open switch S_2, and the leakage current shall be passed suddenly.	
Heavy ground fault breaking test	No stipulation	No stipulation	No stipulation
Short-time current performance	No stipulation	No stipulation	No stipulation

	Electric Appliance Safety Law Standards concerning technology for electrical appliances
	Earth leakage circuit breakers
	No stipulation
	No stipulation
	① Apply a voltage equal to 80% of rated voltage and equal to 110%. Operate the test device ten times at a 10 second interval at each voltage level. ② Apply a voltage equal to the rated voltage, and operate the test device 1000 times at an interval of less than 10 seconds.
	No stipulation
	No stipulation
	No stipulation

Standard	IEC 60947-2 Annex B EN 60947-2 Annex B	JIS C 8201-2-2 Appendix 1	JIS C 8201-2-2 Appendix 2
Name	Circuit breaker incorporating residual current protection (CBR)	Earth leakage circuit breakers	Earth leakage circuit breakers
Lightning impulse withstand voltage test	Refer to impulse withstand voltage test given in the withstand voltage test section (same as MCCB).		
Lightning impulse non-operating test	No stipulation	No stipulation	Same as JIS C8371.
Aging test of electronic parts	No stipulation	No stipulation	No stipulation
Heat cycle test of wire connection terminal for main circuit	No stipulation	No stipulation	No stipulation
Radiated electromagnetic wave non-operating test	No stipulation	No stipulation	Follows immunity test.
High frequency current superimposed trip test	No stipulation	No stipulation	Follows immunity test.
High frequency current superimposed trip test	No stipulation	No stipulation	Follows immunity test.

Electric Appliance Safety Law Standards concerning technology for electrical appliances
Earth leakage circuit breakers
No stipulation
No stipulation
No stipulation
No stipulation
No stipulation
No stipulation
No stipulation

<table>
<tr><td>Standard</td><td>IEC 60947-2 Annex B
EN 60947-2 Annex B</td><td>JIS C 8201-2-2
Appendix 1</td><td>JIS C 8201-2-2
Appendix 2</td><td></td></tr>
<tr><td>Name</td><td>Circuit breaker incorporating residual current protection (CBR)</td><td>Earth leakage circuit breakers</td><td>Earth leakage circuit breakers</td><td></td></tr>
<tr><td>Immunity test</td><td colspan="2">The test follows Appendix J.
Electrostatic discharge
Radiated radio-frequency electromagnetic field
Electrical fast transient/burst
Surge
Conductive disturbance caused by radio-frequency</td><td>(1) Radiated electromagnetic wave non-operating test
In the circuit shown in Appendix 2 Fig. X.2, apply the rated voltage on the leakage breaker, and in the closed circuit state, apply the radiated electromagnetic waves for two seconds under the conditions given in the Table.
<table>
<tr><th>Frequency (MHz)</th><th>Strength of electric field around test unit</th></tr>
<tr><td>27</td><td>130dB (3.16V/m)</td></tr>
<tr><td>144</td><td>130dB (3.16V/m)</td></tr>
<tr><td>430</td><td>140dB (10V/m)</td></tr>
<tr><td>900</td><td>146dB (20V/m)</td></tr>
<tr><td colspan="2">Remarks 1μ mV/m shall equal 0dB.</td></tr>
</table>
(2) High frequency current superimposition tripping test
In the circuit shown in Appendix 2 Fig. X.3, apply the rated voltage with 50Hz or 60Hz frequency, and in the state with no load current passing, pass the commercial frequency current to one pole in the closed circuit state. Pass the high frequency current shown in the table to the other pole, and gradually increase the commercial frequency current. Measure the sensitivity current value when the leakage breaker functions.
<table>
<tr><th>I_{RF} frequency kHz</th><th>I_{RF} value</th></tr>
<tr><td>1</td><td>0.1 times the rated sensitivity current</td></tr>
<tr><td>3</td><td>0.26 times the rated sensitivity current</td></tr>
<tr><td>30</td><td>2.0 times the rated sensitivity current</td></tr>
<tr><td colspan="2">Remarks The maximum I_{RF} value shall be 2A.</td></tr>
</table>
(3) Higher harmonic current superimposition tripping test
In the circuit shown in Appendix 2 Fig. X.4, apply the rated voltage with 50Hz or 60Hz frequency, and in the state with no load current passing and circuit closed, superimpose the higher harmonic current to the forward phase and reverse phase so that the distortion rate is 10%. Gradually increase this current, and measure the sensitivity current where the leakage breaker functions. The higher harmonic current in this case shall be both the third-order and fifth-order higher harmonics.</td><td></td></tr>
<tr><td>Emission test</td><td colspan="2">The test follows Appendix J.
Conductive radio-frequency disturbance
Radiated radio-frequency disturbance</td><td>No stipulation</td><td></td></tr>
<tr><td>Test order (model test)

Whether to carry out each test item with the same test unit or a different test unit shall follow the Standards.</td><td colspan="2">Sequence I
(1) Overcurrent tripping
(2) Withstand voltage (Uimp)
(3) Mechanical switching durability
Energized switching durability
(4) Overload
(5) Withstand voltage (commercial frequency)
(6) Temperature rise
(7) Overcurrent tripping

Sequence II
(1) Rated working short-circuit breaking (o-co-co)
(2) Withstand voltage (commercial frequency)
(3) Temperature rise
(4) Overcurrent tripping

Sequence III
(1) Overcurrent tripping
(2) Rated maximum short-circuit breaking (o-co)
(3) Withstand voltage (commercial frequency)
(4) Overcurrent tripping

Additional sequence
(1) Operating characteristics
(2) Withstand voltage
(3) Test device
(4) Equilibrium characteristics
(5) Impulse wave non-operation
(6) DC superimposition
(7) Power voltage loss
(8) Open phase
(9) Heavy ground fault
(10) Environment
(11) Immunity
(12) Emission</td><td>Sequence I
(1) Overcurrent tripping
(2) Withstand voltage (Uimp, commercial frequency, lightning impulse)
(3) Overload
(4) Withstand voltage (commercial frequency)
(5) Overflow current
(6) Temperature rise
(7) Switching durability

Sequence II
Same as Appendix 1.

Sequence III
Same as Appendix 1.

Additional sequence
Same as Appendix 1.</td><td></td></tr>
</table>

	Electric Appliance Safety Law Standards concerning technology for electrical appliances
	Earth leakage circuit breakers
	No stipulation
	No stipulation
	(1) Structure inspection (2) Overflow current (3) Overcurrent tripping (4) Overload (5) Switching performance (6) Overcurrent tripping (7) Temperature rise (8) Insulation performance (9) Short-circuit breaking (10) Cord protection

MOULDED CASE CIRCUIT BREAKERS
EARTH LEAKAGE CIRCUIT BREAKERS

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