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MOULDED CASE CIRCUIT BREAKERS
EARTH LEAKAGE CIRCUIT BREAKERS

TECHNICAL NOTES

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1. Outline of MCCB

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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
		30 or less	60	2	1 to 30	60	2
	Minimum operating current MCCB is 125% of rated current	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

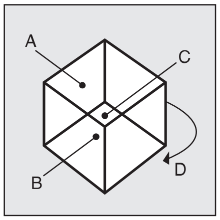
a. The MCCB opening time is small compared to the ACB, so cascade protection using MCCB and ACB combination is not recommended.

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

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

2. 3 Circuit breakers with ISTAC

2. 4 Electronic circuit breakers

2. 5 Measuring display unit breakers (MDU breakers)

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.

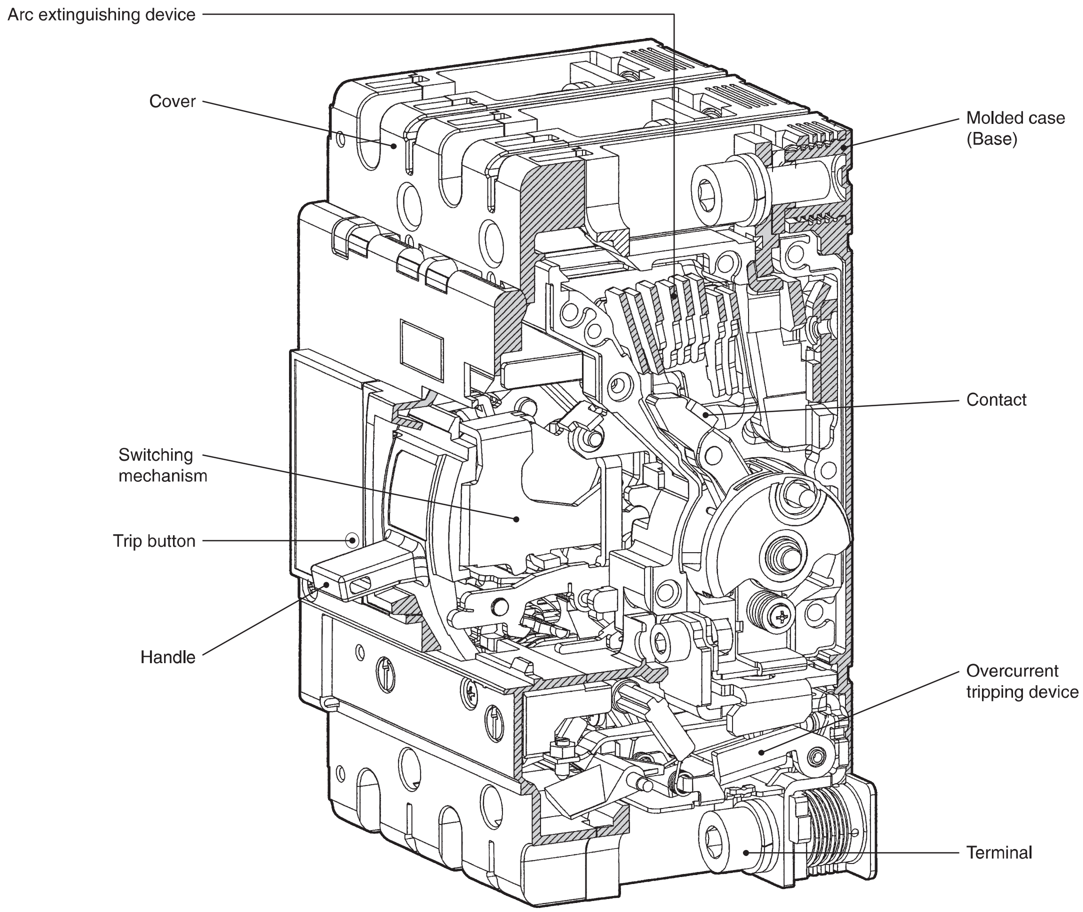


Fig. 2. 1 Construction of MCCB

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.

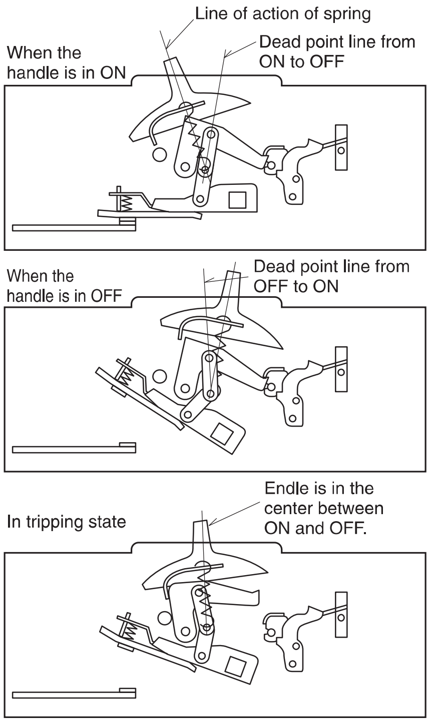


Fig. 2. 2 Switching mechanism

(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)

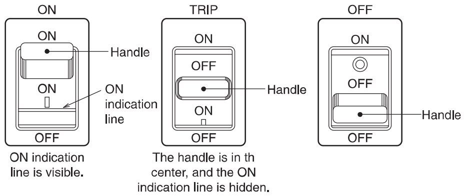


Fig. 2. 3 Positions of MCCB handle

(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.

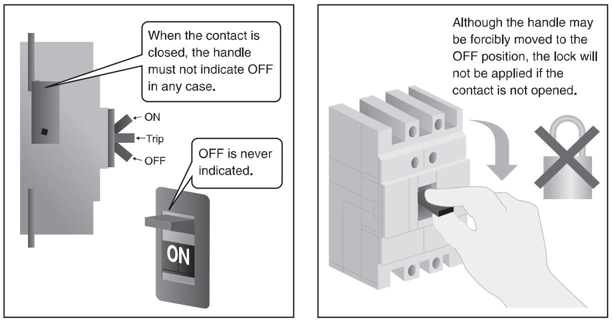


Fig. 2. 4 Isolation function

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.

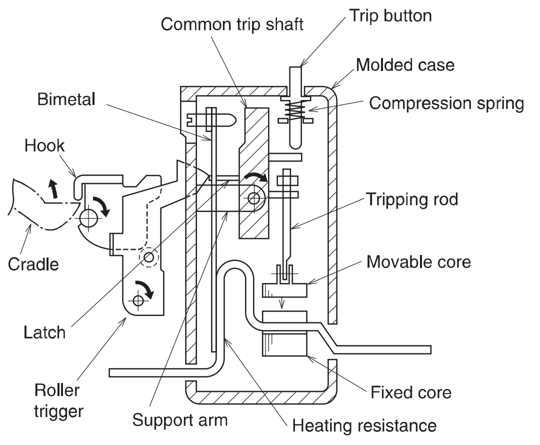
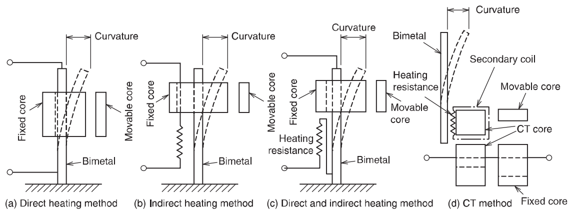


Fig. 2. 5 Structure of thermal magnetic type trip device

- — **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.



(a) Direct heating method (b) Indirect heating method (c) Direct and indirect heating method (d) CT method

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.

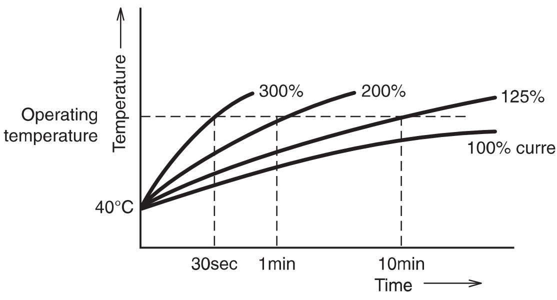


Fig. 2. 7. a Bimetal temperature-time characteristics

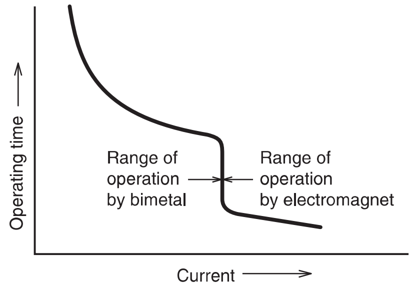


Fig. 2. 7. b Operating time-current characteristics

(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 is 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.

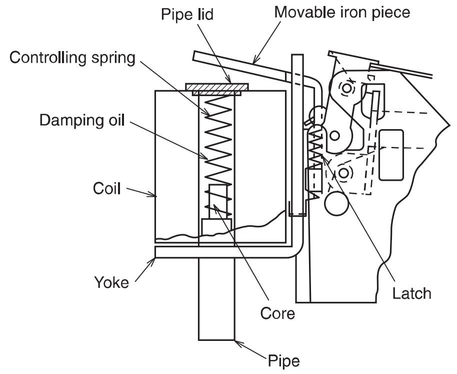


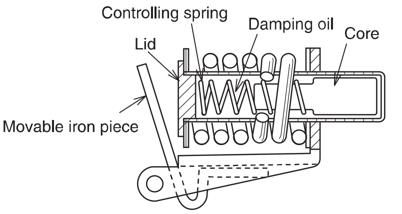
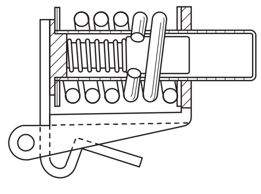
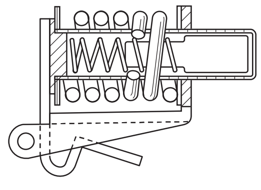
Fig. 2. 8 Hydraulic magnetic type

(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.

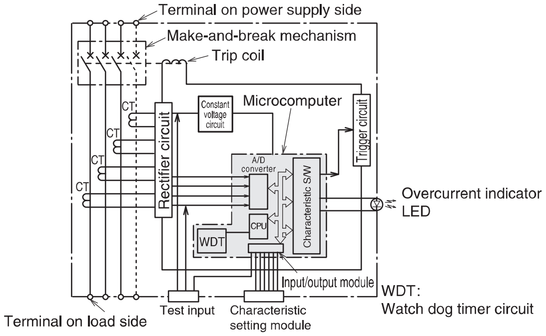
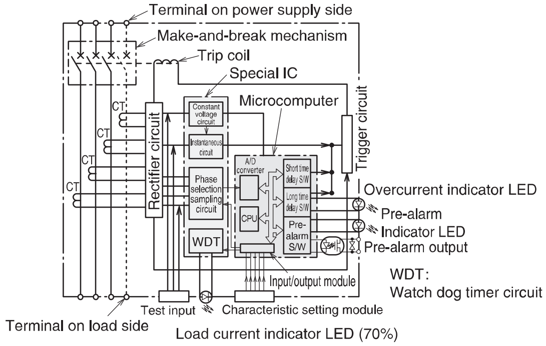
(3) Electronic trip relay (ETR)

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.

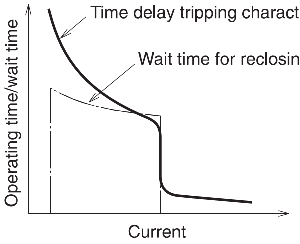
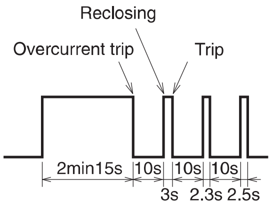
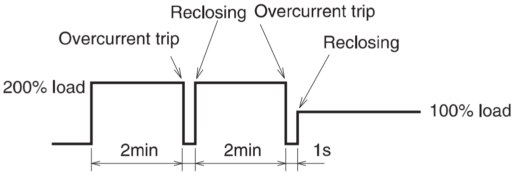
Table 2. 2

	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

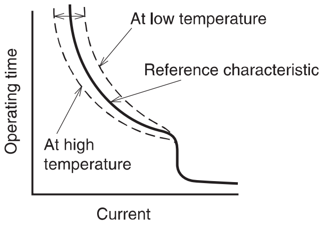
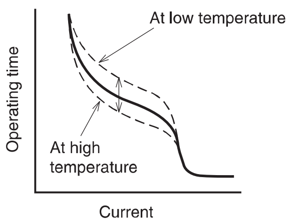
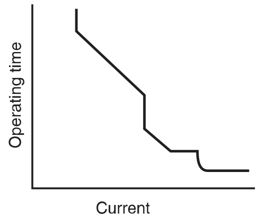
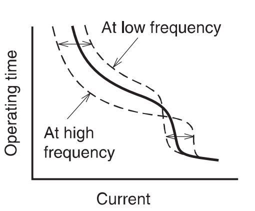
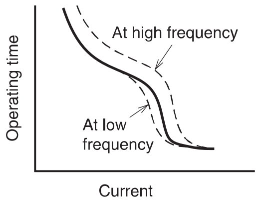
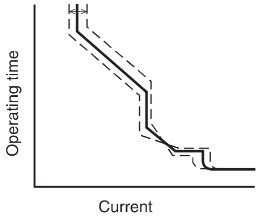
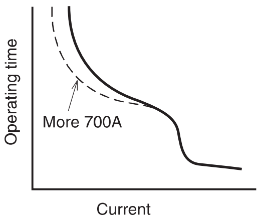
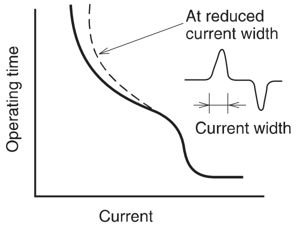
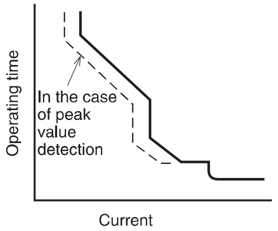
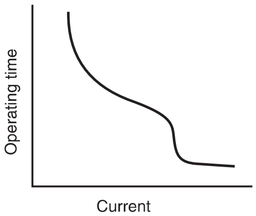
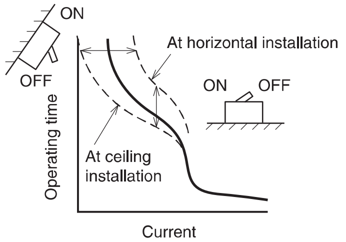
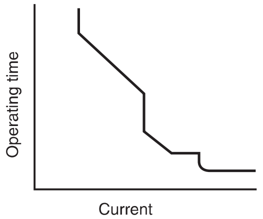
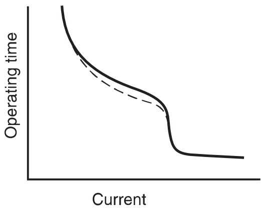
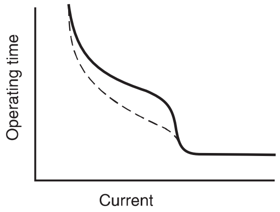
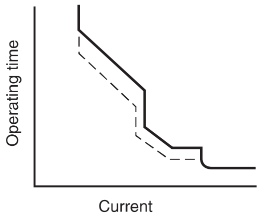
(a) Reclosing after overcurrent tripping

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

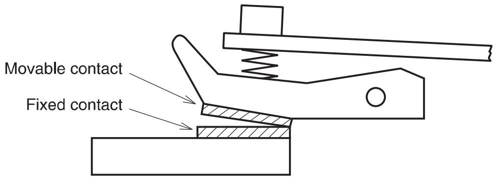
Table 2. 4 Thermal magnetic, hydraulic magnetic and electronic types

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.

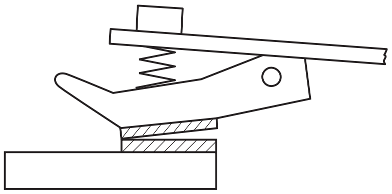
2. 1. 4 Contacts

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.



(a) In ON state



(b) Moment of contact and opening

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.

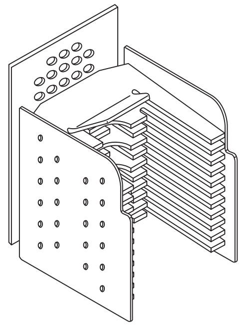


Fig. 2. 10 Arc extinguishing device

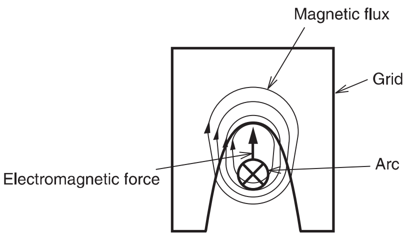


Fig. 2. 11 Principle of de-ion arc extinguishing device

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.

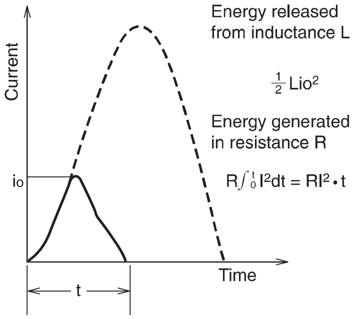


Fig. 2. 12 Current-limiting breaking

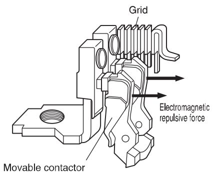
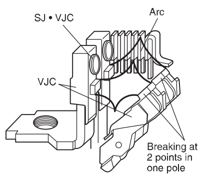
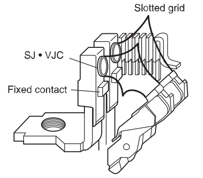
2. 2 Ultra current-limiting circuit breakers (U class)

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.

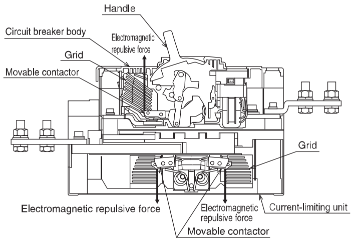
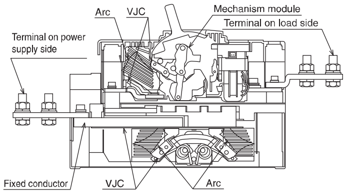
- NF125-UV, NF250-UV

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.

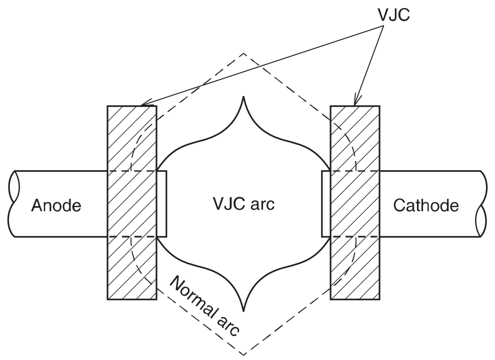


Fig. 2. 13 Difference in arc with and without VJC

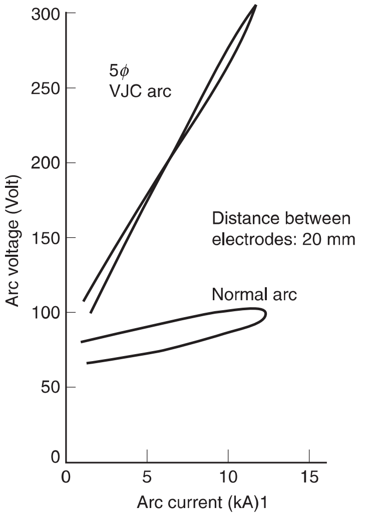


Fig. 2. 14 Difference in arc voltage with and without VJC

ISTAC technology

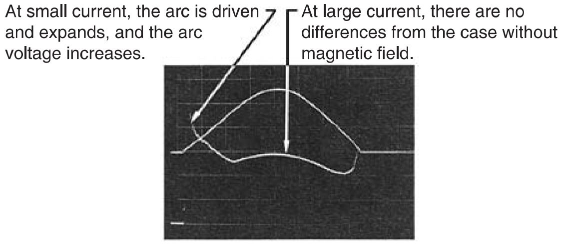
The ISTAC consists of a mover for accelerating the startup of current-limiting effect for further improvement of current-limiting performance, a high driving force structure for arc and a new insulating material for enhancing the insulation performance at breaking.

ISTAC current paths

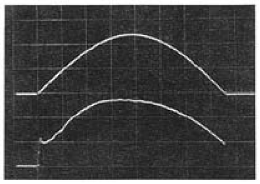
If the current-limiting effect occurs sooner at breaking, current limiting is started at lower current, and, as the result of this, the passing current peak value can be reduced. For this purpose, it is important to open the mover earlier at the start of breaking to expand the arc longer. As shown in 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.



(a) When a magnetic field is applied to drive the arc (magnetic flux density B = 1.1T)



(b) Without magnetic field

Upper waveform: current 4.5 kA/div Lower waveform: current 54 V/div
Abscissa: Time (1 ms/div)

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

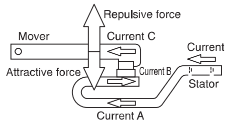


Fig. 2. 16 Conventional system with U-turn stator

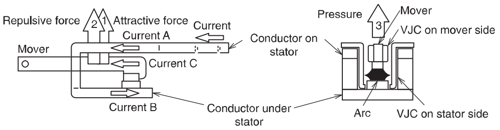


Fig. 2. 17 Structure of ISTAC

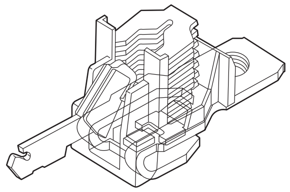


Fig. 2. 18 ISTAC slotted structure

• Current-limiting characteristic diagrams (415 VAC)

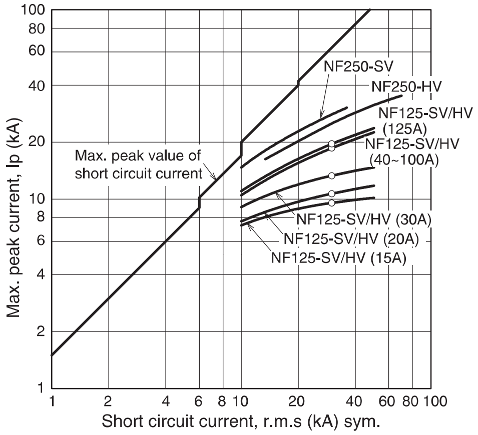


Fig. 2. 19 Passing current peak value characteristics of models NF125-SV/HV and NF250-SV/HV

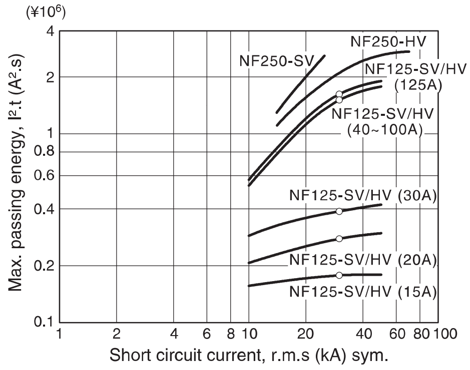


Fig. 2. 20 Passing I^2.t characteristics of models NF125-SV/HV and NF250-SV/HV

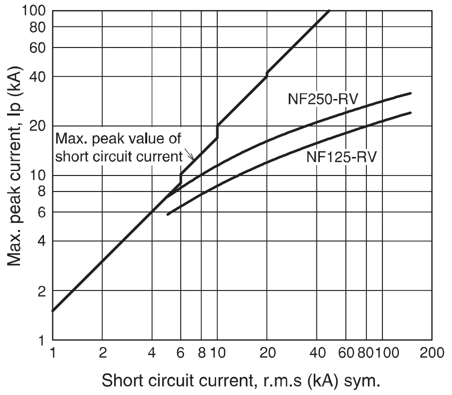


Fig. 2. 21 Passing current peak value characteristics of models NF125-RV and NF250-RV

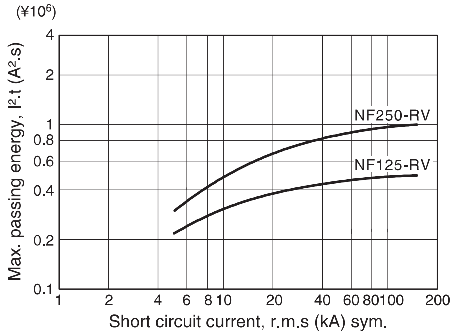


Fig. 2. 22 Passing I^2.t characteristics of models NF125-RV and NF250-RV

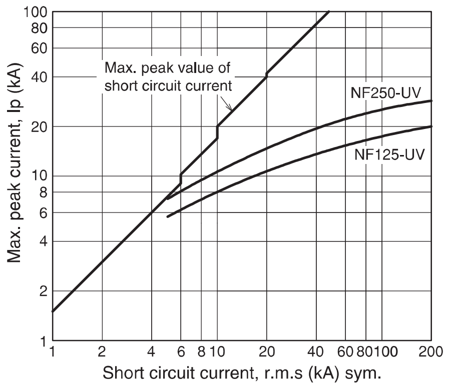


Fig. 2. 23 Passing current peak value characteristics of models NF125-UV and NF250-UV

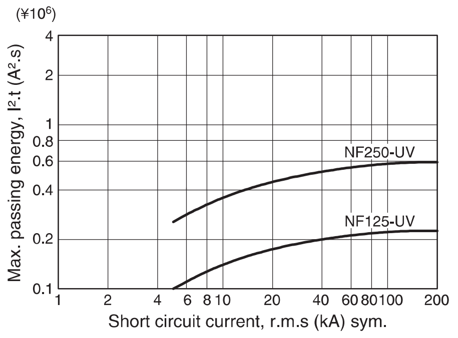


Fig. 2. 24 Passing I^2.t characteristics of models NF125-UV and NF250-UV

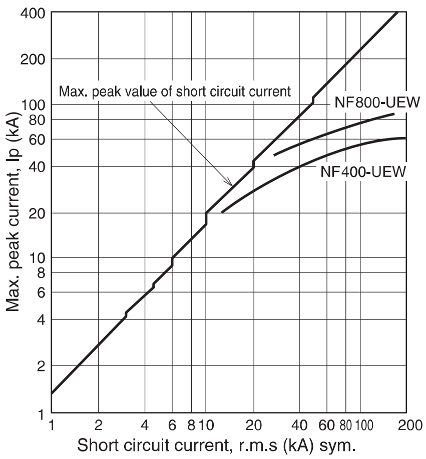


Fig. 2. 25 Passing current peak value characteristics of models NF400-UEW and NF800-UEW

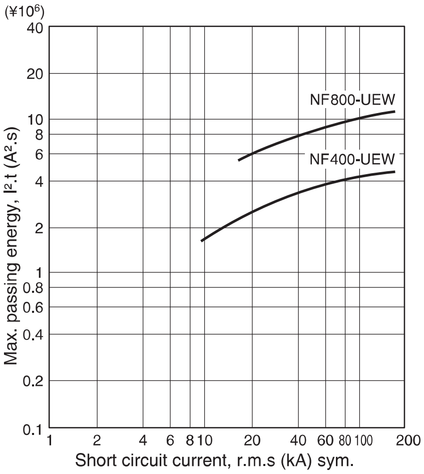


Fig. 2. 26 Passing I^2.t characteristics of models NF400-UEW and NF800-UEW

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.

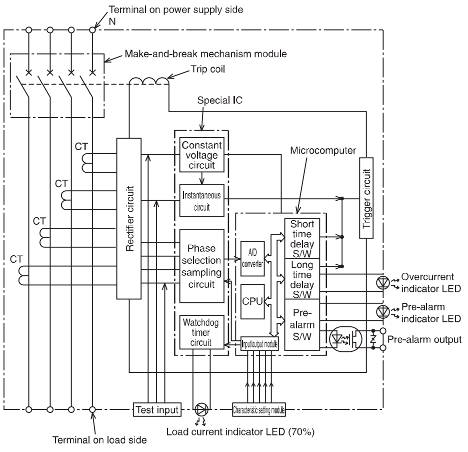


Fig. 2. 27 Circuit diagram of electronic overcurrent trip device

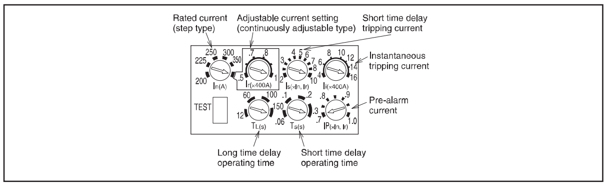


Fig. 2. 28 Adjustment module

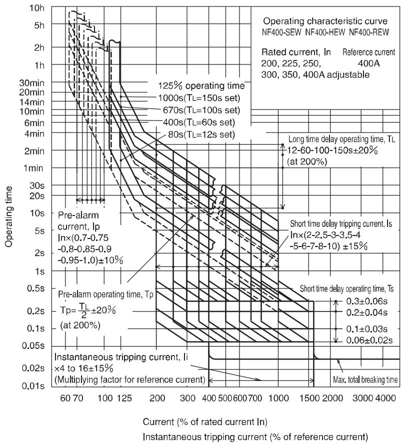


Fig. 2. 29 Example of operating characteristic curves

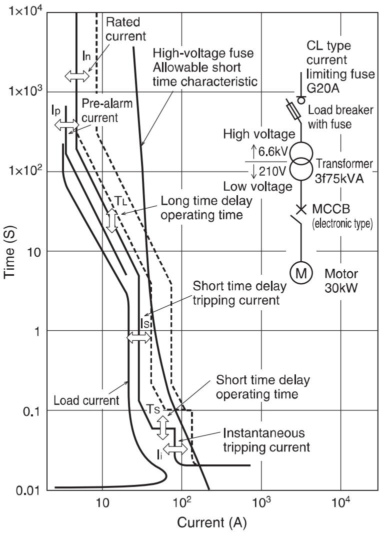


Fig. 2. 30 Overload protection coordination diagram

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.

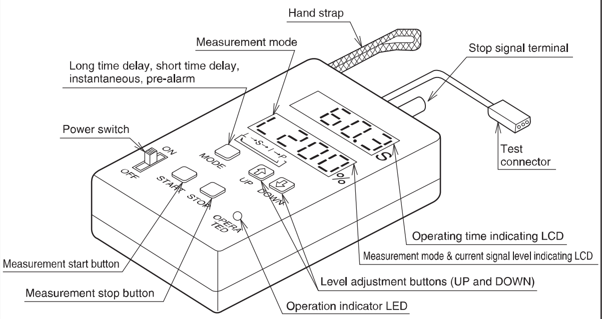


Fig. 2. 31 Appearance of portable tester Y-250

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.

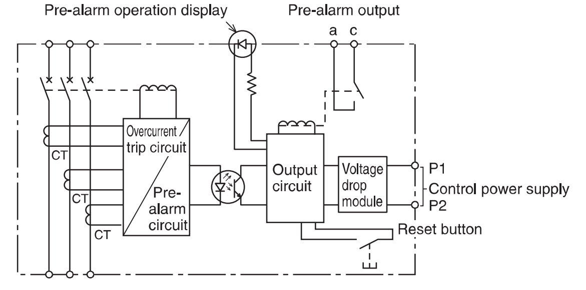
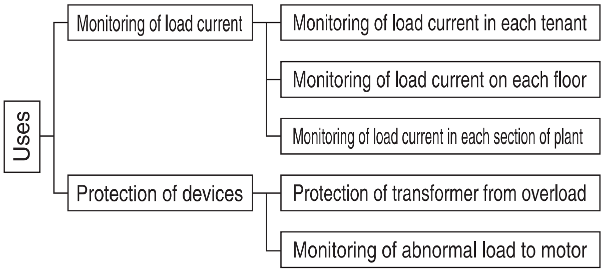


Fig. 2. 32 Example of internal connection diagram of pre-alarm

(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.

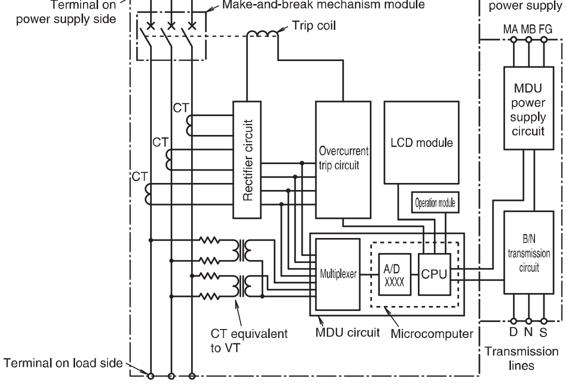


Fig. 2. 33 MDU block diagram

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

Applicable model Item		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)

Applicable model Item		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.

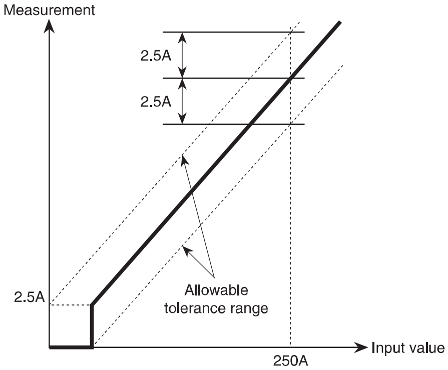


Fig. 2. 34 Measurement accuracy

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)

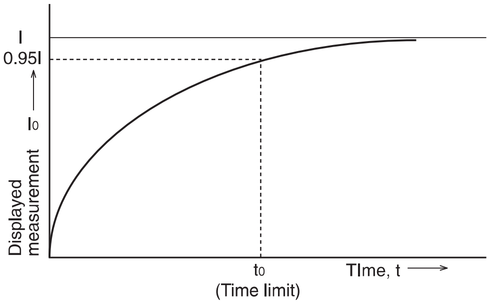


Fig. 2. 35 Demand characteristics

(c) Appearance and installation of MDU

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

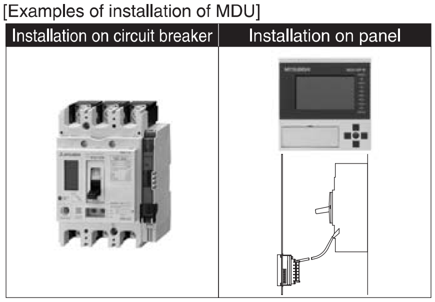
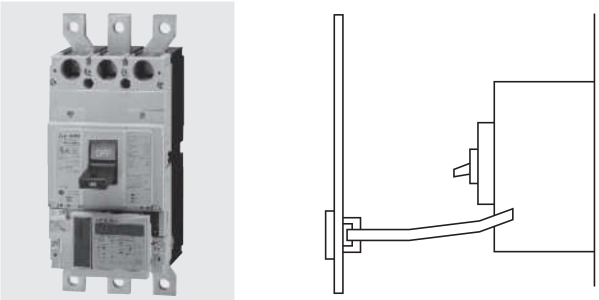


Fig. 2. 36 NF250-SEV with MDU 3P



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

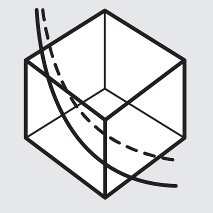
Since a VT is connected between the poles on the load side of the circuit breaker, the withstand voltage between the poles on the load side cannot be measured. (Items marked with × in Table 2. 10)

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. 1 Operating characteristics

3. 2 Changes in operating characteristics

3. 4 Operating characteristics depending on special waveforms

3. 7 Insulation 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.

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 × $\frac{107}{100}$) at an ambient temperature of 25°C and 190% (200 × $\frac{95}{100}$) 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.)

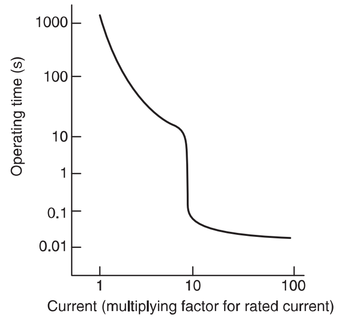


Fig. 3. 1 Example of operating characteristic

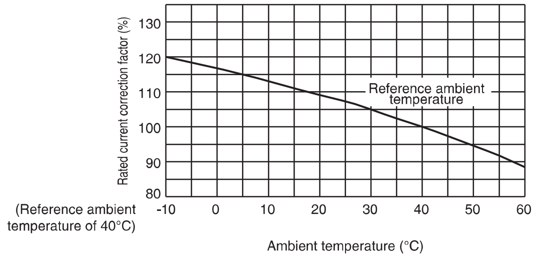


Fig. 3. 2. 1 Example of temperature correction curve

(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.

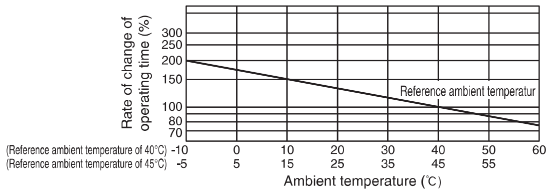


Fig. 3. 2. 2 Example of temperature characteristic curve

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).

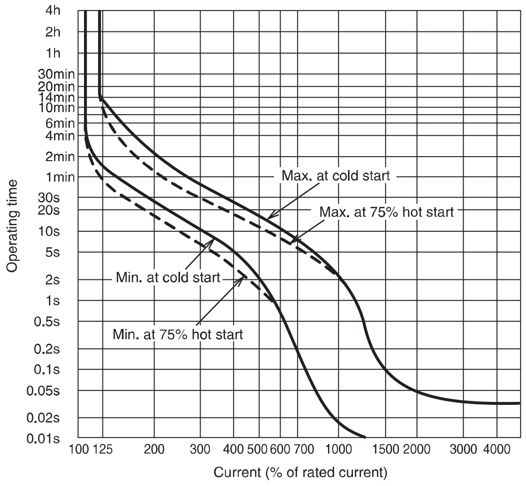


Fig. 3. 3 Examples of hot start operating characteristic curves

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).

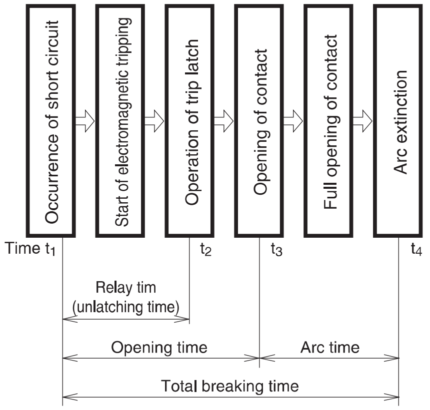


Fig. 3. 4 Instantaneous operation time

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.

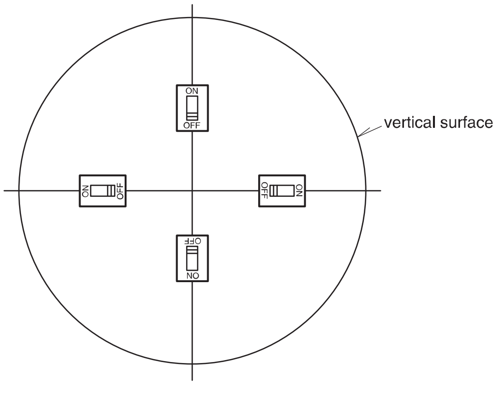


Fig. 3. 5 Installation postures in which the operating characteristics of hydraulic magnetic MCCB can be assured

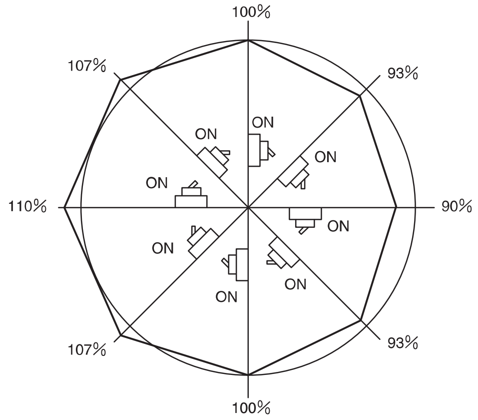
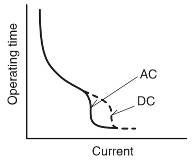
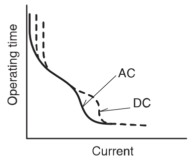


Fig. 3. 6 Changes in rated current due to changes in angle of installation of hydraulic magnetic MCCB

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.

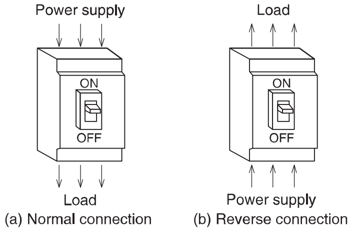
Since heat generation is increased by iron loss, at about 400 Hz, on MCCB with the maximum rated current in a frame size, the continuously applicable current reduces to approx. 80% of the rated current, and, on MCCB with the rated current of about 1/2 of the frame capacity, the current reduces to 90%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



(a) Normal connection
(b) Reverse connection

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.

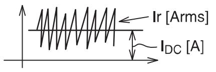
Table 3. 3. 1 Influence of higher harmonics from the viewpoint of operation principle

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
		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. 2 **Selective tripping method**

4. 3 **Cascade breaking method**

4. 4 **Coordination with wires**

4. 5 **Coordination of MCCB and magnetic switch**

4. 6 **Coordination of MCCB and motor**

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

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.

- Protection coordination
  - Voltage coordination [Overvoltage category]
  - Current coordination
    - Rated current
    - Overcurrent coordination
      - Overload current coordination
      - Short-circuit current coordination
    - Ground fault current coordination

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.

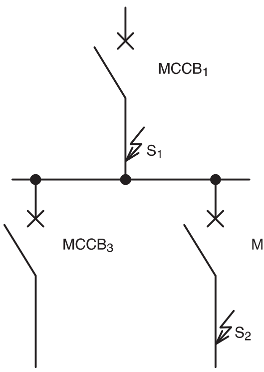


Fig. 4. 1 Selective tripping method

(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.

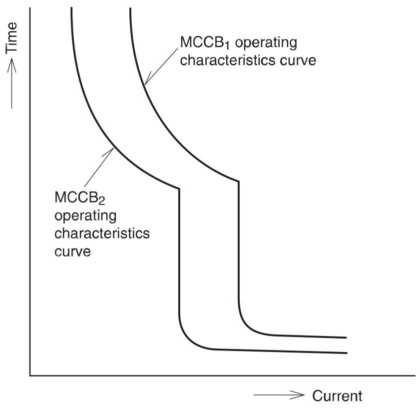


Fig. 4. 2 Operating coordination

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.

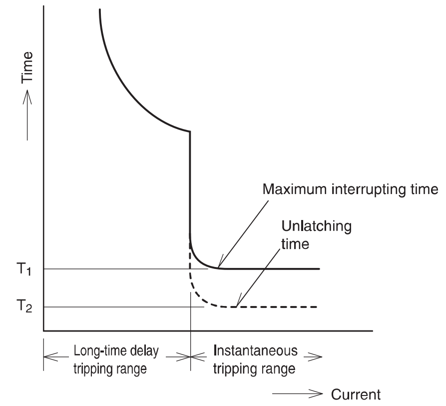


Fig. 4. 3 MCCB unlatching time

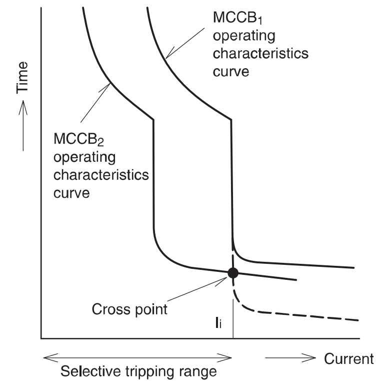


Fig. 4. 4 Selective tripping range for normal MCCB

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.

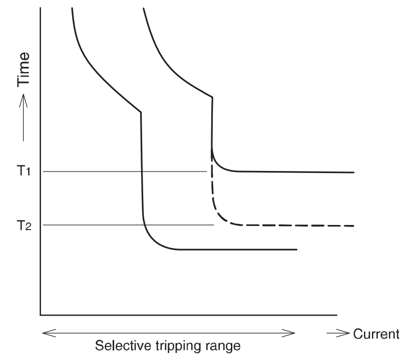


Fig. 4. 5 Selective tripping range for normal MCCB

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.

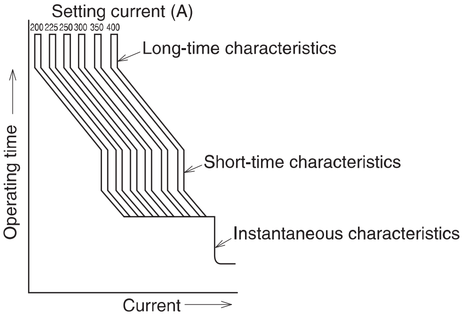


Fig. 4. 6 Electronic MCCB adjustable characteristics

(Example of NF400-SEW)

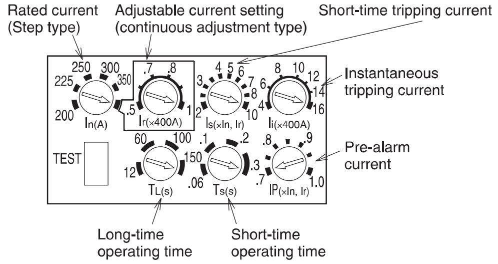


Fig. 4. 7 Electronic type MCCB characteristics setting section

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.

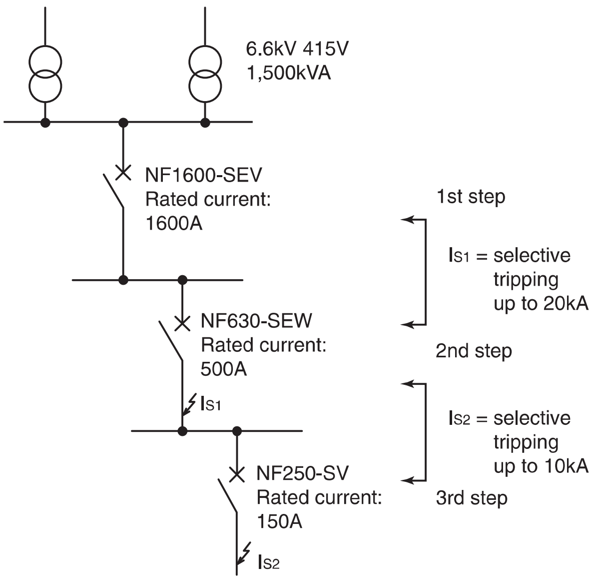


Fig. 4. 8 Example of system

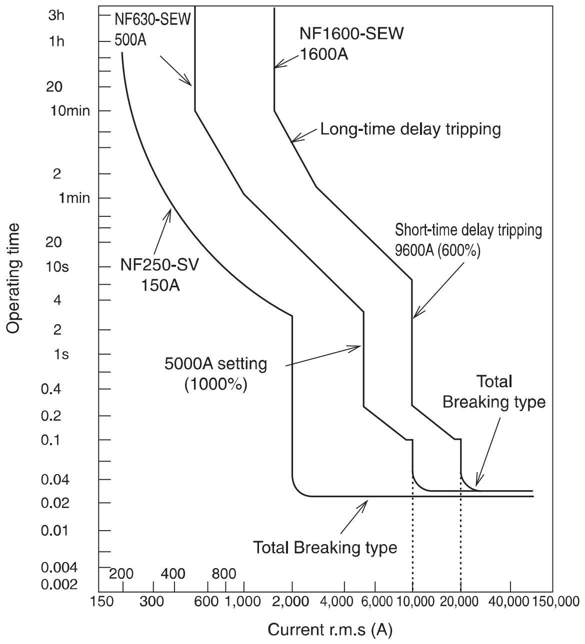


Fig. 4. 9 Coordination characteristics between MCCB using system example (Fig. 4. 8)

(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.

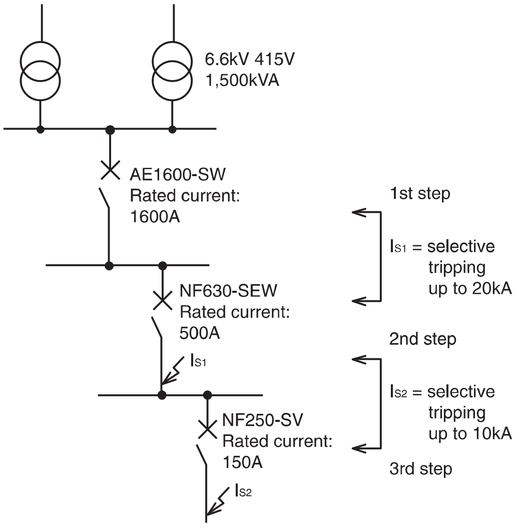


Fig. 4. 10 Example of system

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.

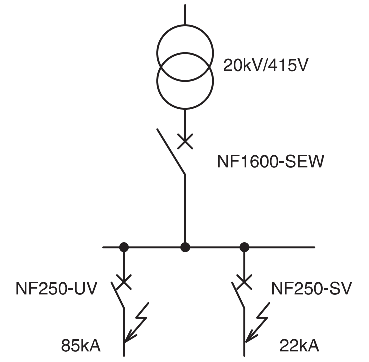


Fig. 4. 11 Case using current limiting breaker for branch circuit

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).

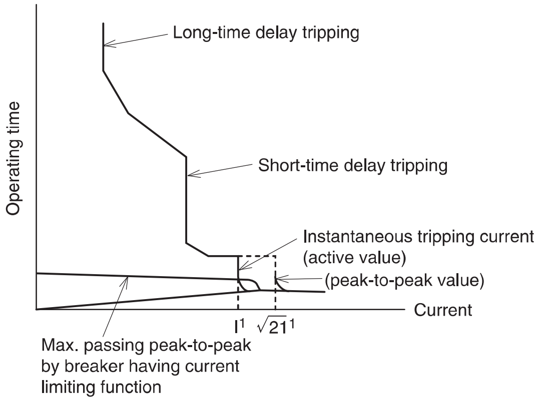


Fig. 4. 12 Current limiting breaker and selective tripping

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.

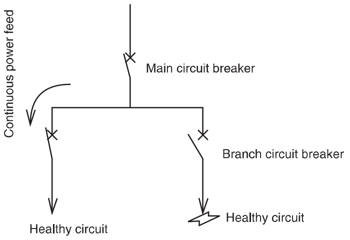


Table 4. 1 Selective tripping combination table

440VAC (IEC 60947-2)

sym.kA

Branch breaker		Main breaker Rated ultimate short-circuit breaking capacity of each breaker	Circuit breaker												
			NF125-SEV	NF125-HEV	NF250-SEV	NF250-HEV	NF400-SEV	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

Branch breaker		Main breaker Rated ultimate short-circuit breaking capacity of each breaker	Circuit breaker												
			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.

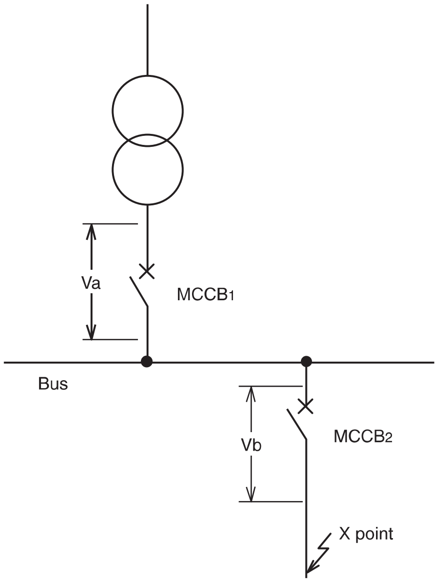
Each maker has announced combinations of this cascade tripping method by combining two breakers and data to backup the operation. MCCB wiring path is applied according to this combination. Cascade breaking is also prescribed in Interpretation 37 of the Electrical Installations Technical Standards.

4. 3. 1 Combination of cascade breaking type breakers

(1) Combination of MCCB units

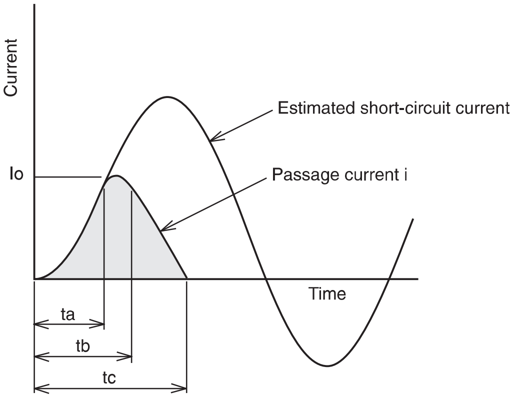
Focusing on the fact that MCCB opening time is extremely fast, the arc generated at $MCCB_2$ contact and the arc generated at $MCCB_1$ contact are superimposed on the short-circuit current generated at the X point short-circuit accident in Fig. 4. 13. These two cooperate to trip the circuit. This reduction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



Va : $MCCB_1$ arc voltage
Vb : $MCCB_2$ arc voltage

Fig. 4. 13 Cascade Breaking



ta : $MCCB_1$ opening time
tb : $MCCB_2$ opening time
tc : Total Breaking time

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.

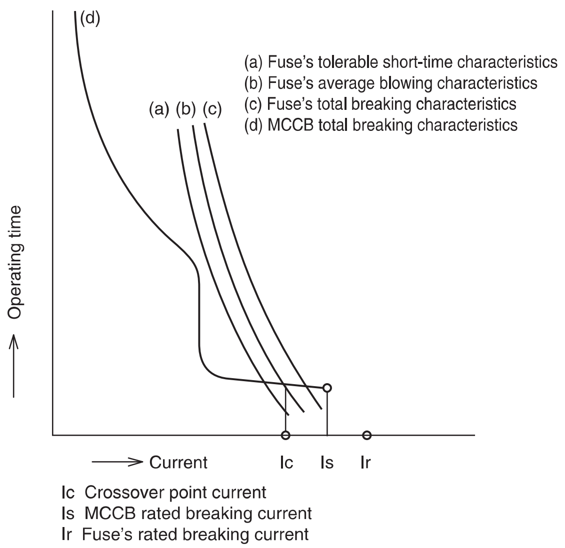


Fig. 4. 15 MCCB and fuse operation coordination

4. 3. 2 Table of cascade breaking capacity

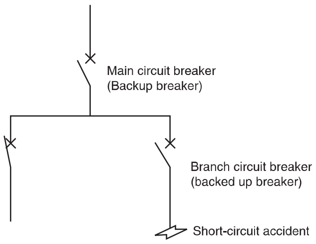


Table 4. 2
440 VAC (IEC 60947-2)

sym.kA

	Main breaker		NF-S • NV-S • NF-H • NV-H																							NF-C • NV-C				NF-R • NF-U					
	Rated ultimate short-circuit breaking capacity of each breaker		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
	Branch breaker	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

		Main breaker	NF-S • NV-S • NF-H • NV-H																							NF-C • NV-C				NF-R • NF-U					
	Rated ultimate short-circuit breaking capacity of each breaker		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
Branch breaker		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.

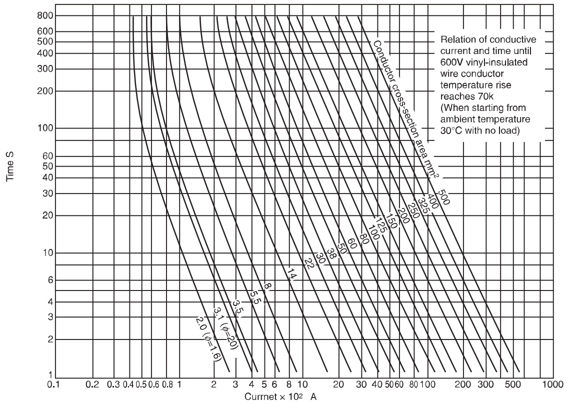


Fig. 4. 16 Current time characteristics for 600V vinyl-insulated wire conductor temperature 100°C to reach rise value 70K

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.

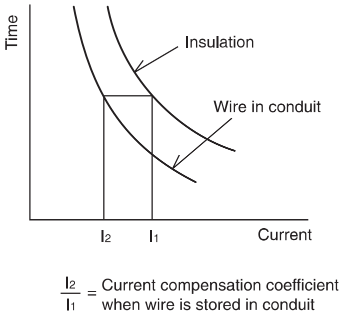


Fig. 4. 17 Compensation according to conduit

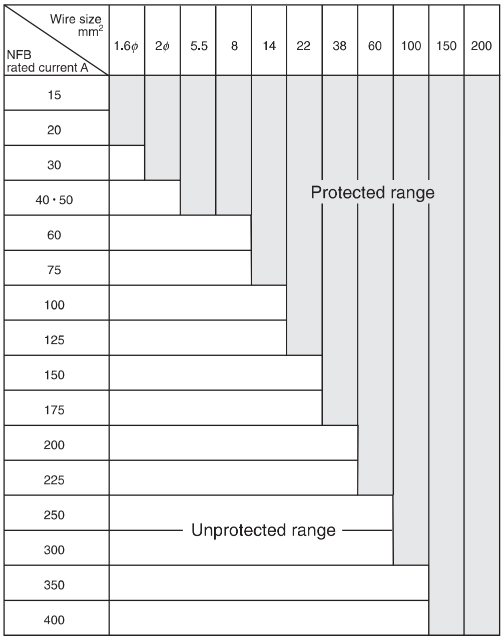


Fig. 4. 18 Coordination of 600V vinyl-insulated wire and MCCB

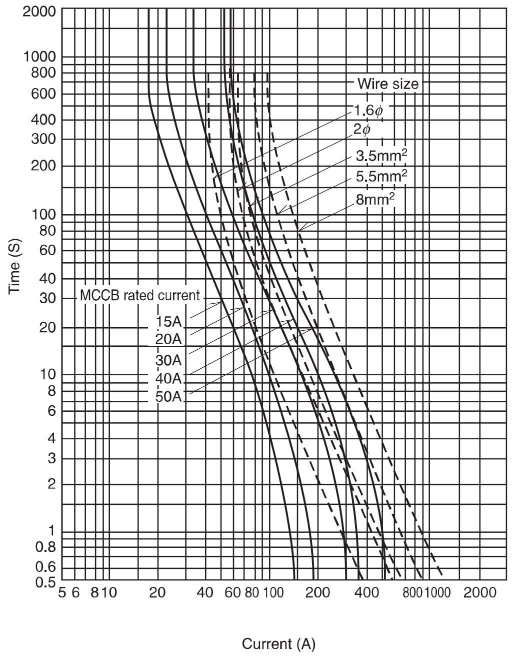


Fig. 4. 19 Coordination of 600V vinyl-insulated wire and MCCB 50A frame

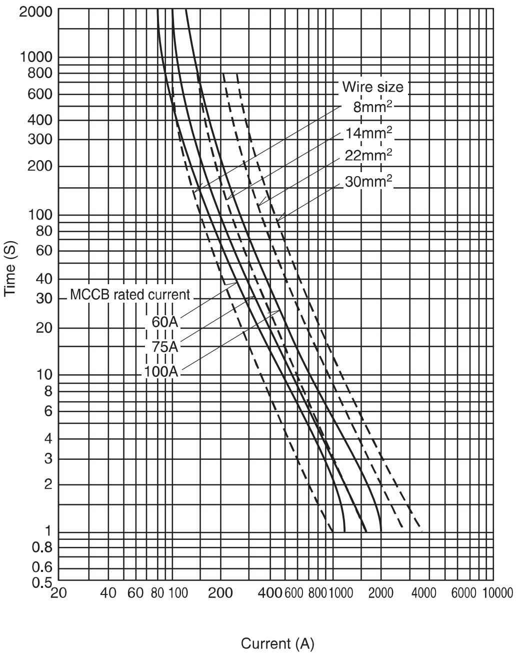


Fig. 4. 20 Coordination of 600V vinyl-insulated wire and MCCB 100A frame

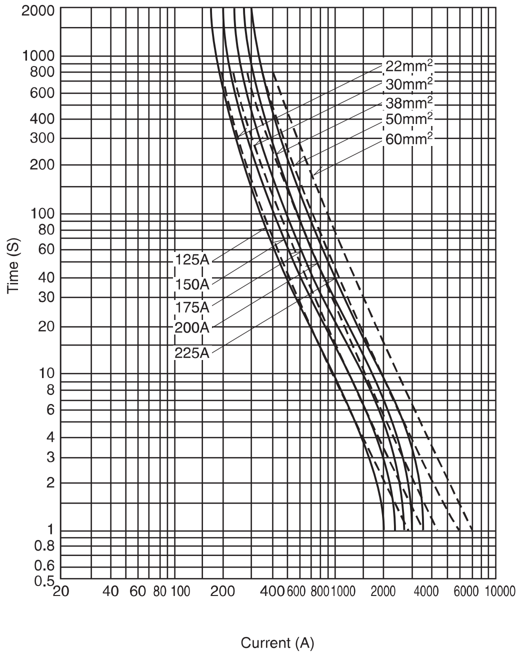


Fig. 4. 21 Coordination of 600V vinyl-insulated wire and MCCB 225A frame

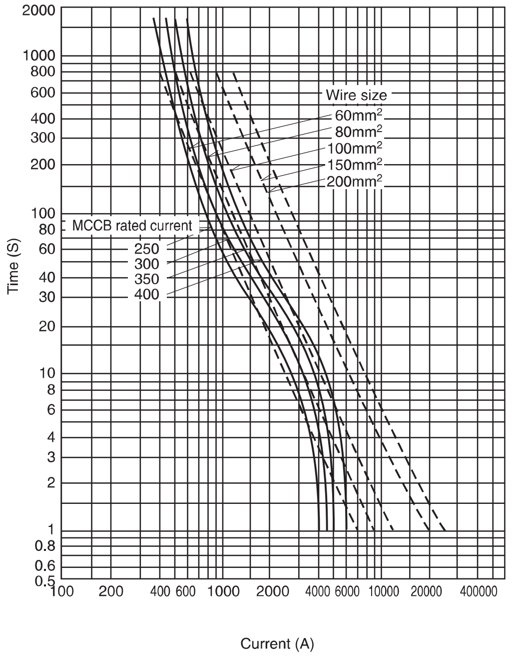


Fig. 4. 22 Coordination of 600V vinyl-insulated wire and MCCB 400A frame

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.

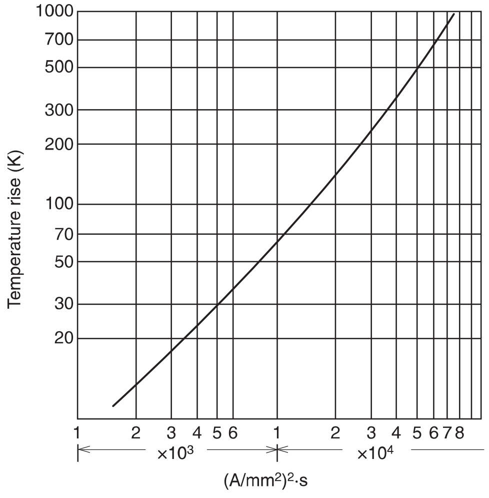


Fig. 4. 23 Conductor temperature rise caused by short-time overcurrent (copper)

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

Wire size mm^2 mm shown in ( )	Tolerable I^2t A^2·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·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·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 (∫i^2dt) 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 ∫i^2dt[*1] is:

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

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

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

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

Table 4. 7 shows the tolerable current (Is) when a half-cycle interruption is applied on a 14mm^2 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.

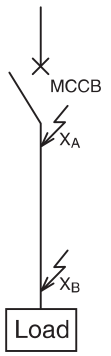


Fig. 4. 24 Wire protection and short-circuit point

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 (mm^2)	Rated breaking capacity (Sym. kA)	Minimum size (mm^2)
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:

$$F = 2 \times 10^{-7} \cdot \frac{i^2}{D}$$

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 $20\sqrt{C\,(d-C)}$ (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.

$$Fa = 2 \times 10^{-7} \cdot \frac{i^2 a}{D}$$

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.

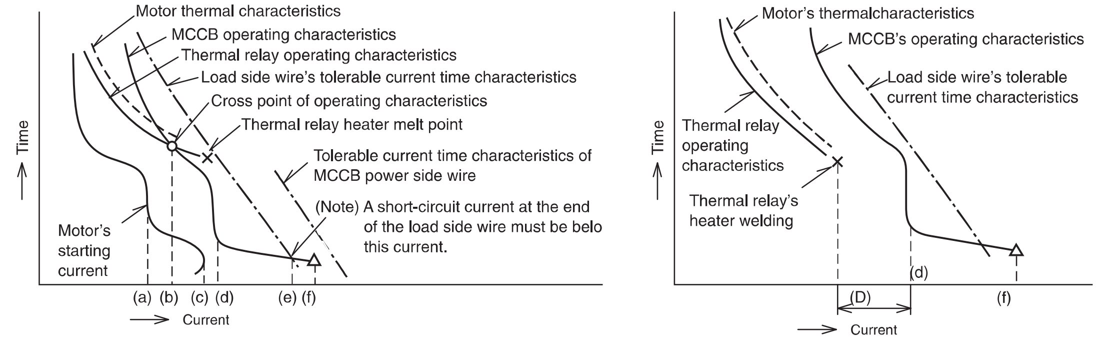
Of course, MCCB, magnetic contactor and thermal relay must satisfy the following conditions with their basic functions.

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.



(a): Motor's stationary starting current
(c): Motor's transient rush current
(d): MCCB instantaneous tripping current
(f): MCCB rated breaking capacity
(Short-circuit current at installation point)

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.

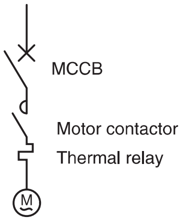
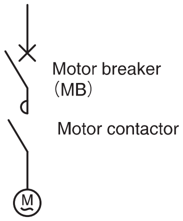
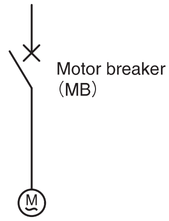
4. 6 Coordination of MCCB and motor

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.

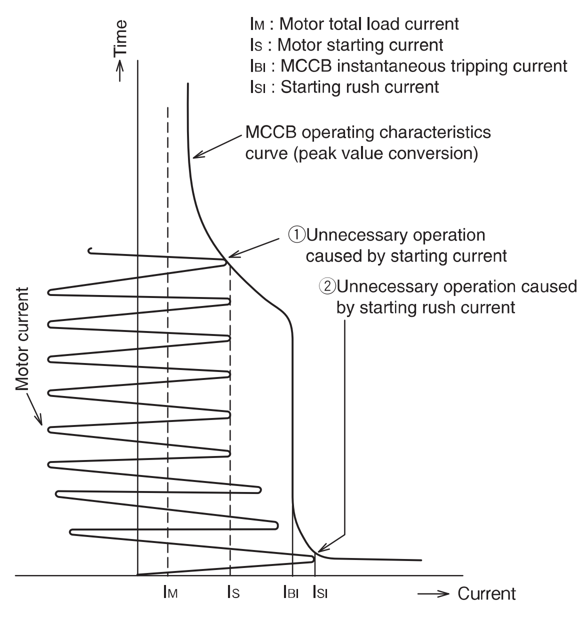


Fig. 4. 26 Coordination of motor and MCCB

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).

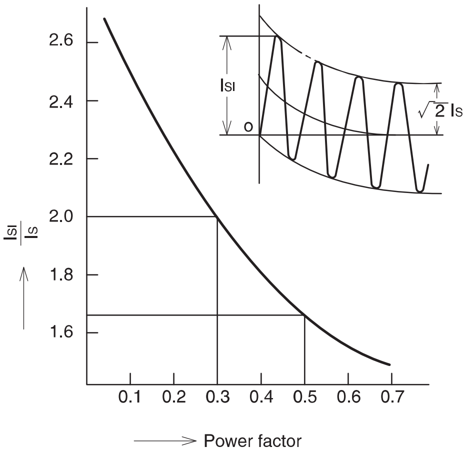


Fig. 4. 27

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

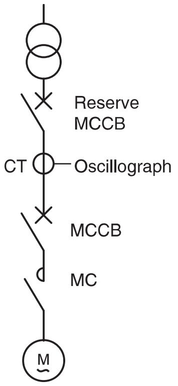
When items ① and ②) are considered, if the effect of the residual voltage and the increment of the starting current so that the slip = 2 is double, the starting rush current (peak value) will be 42-times (8×2.6×2) of the total load current (active value). (When power factor is 0.05.) Thus, MCCB instantaneous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

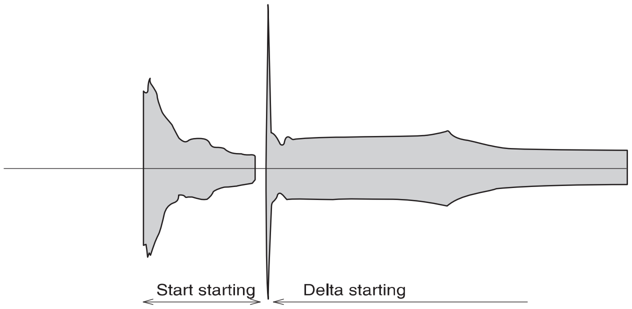


Measured rush current value

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

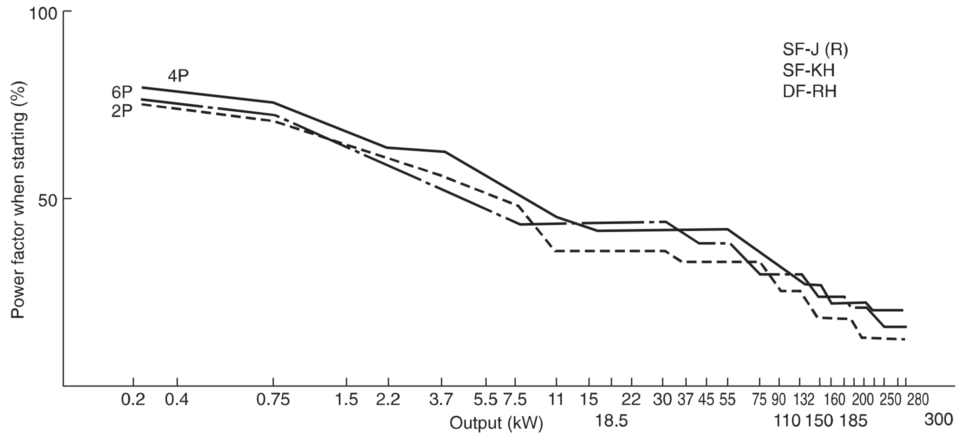


Fig. 4. 30 Example of power factor during motor starting

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.

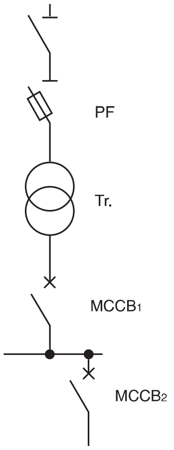


Fig. 4. 31 Coordination of PF and MCCB

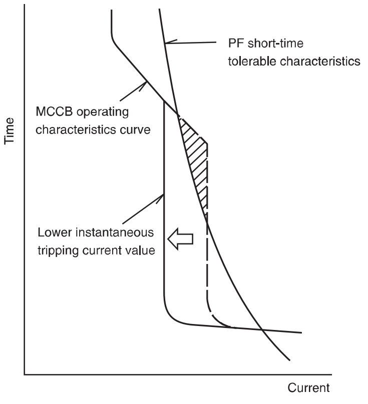


Fig. 4. 32 Advantages of using thermal adjustable type

4 Protection Coordination

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

CL rated current (A) / MCCB 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	60			△	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
NF125-SV	75			△	△	▨	▨	▨	Range in which coordination is attained						▨
NF125-HV	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

CL rated current (A) / MCCB 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	60			▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
NF125-SV	75			△	▨	▨	▨	▨	Range in which coordination is attained						
NF125-HV	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.

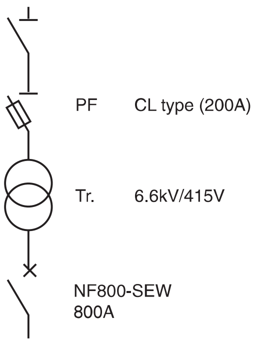


Fig. 4. 33 Example of PF and electronic MCCB coordination

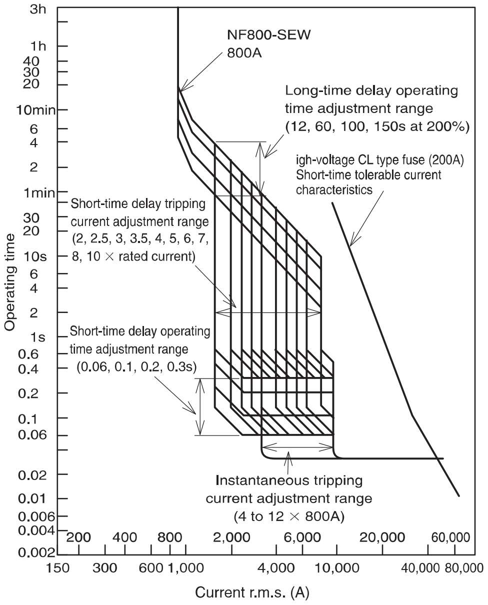


Fig. 4. 34 Example of PF and electronic MCCB coordination

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

CL rated current (A) / MCCB model 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.

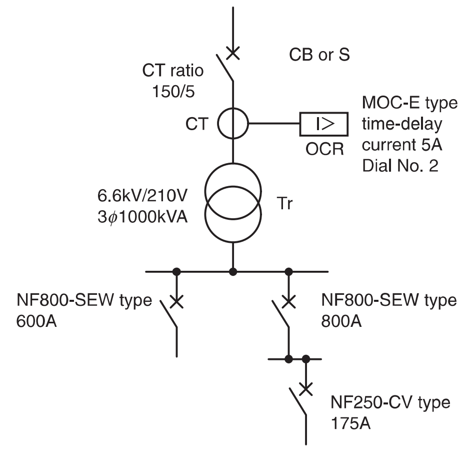


Fig. 4. 35 Coordination of electronic MCCB and high-voltage side OCR

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.

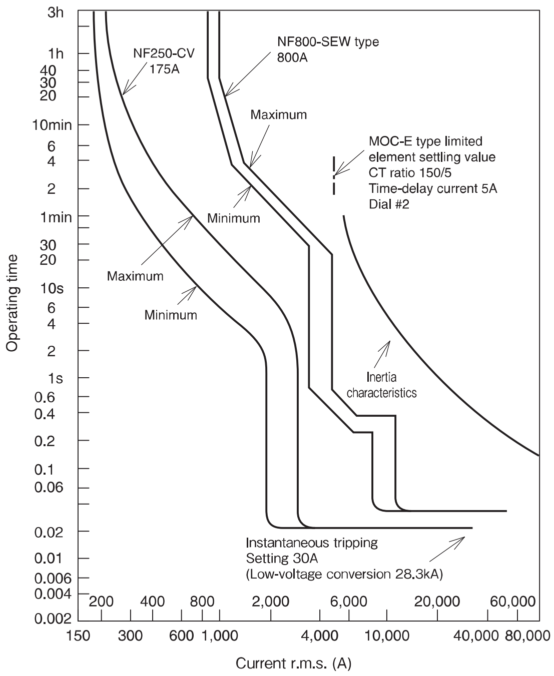


Fig. 4. 36 Example of coordination with high-voltage side OCR

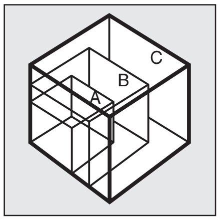
Table 4. 16 Coordination with electronic MCCB and high-voltage OCR (MOC-E type) 6.6kV/415V

	Tr capacity 3φ (kVA)	300	500	750	1000	1500	2000
MCCB model	Current (A) primary/secondary	26.2/ 394	43.7/ 656	65.6/ 984	87.5/ 1312	131.2/ 1968	175.0/ 2624
Rated current (A)	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

	Tr capacity 3φ (kVA)	300	500	750	1000	1500	2000
MCCB model	Current (A) primary/secondary	26.2/ 787	43.7/ 1312	65.6/ 1968	87.5/ 2624	131.2/ 3937	175.0/ 5429
Rated current (A)	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

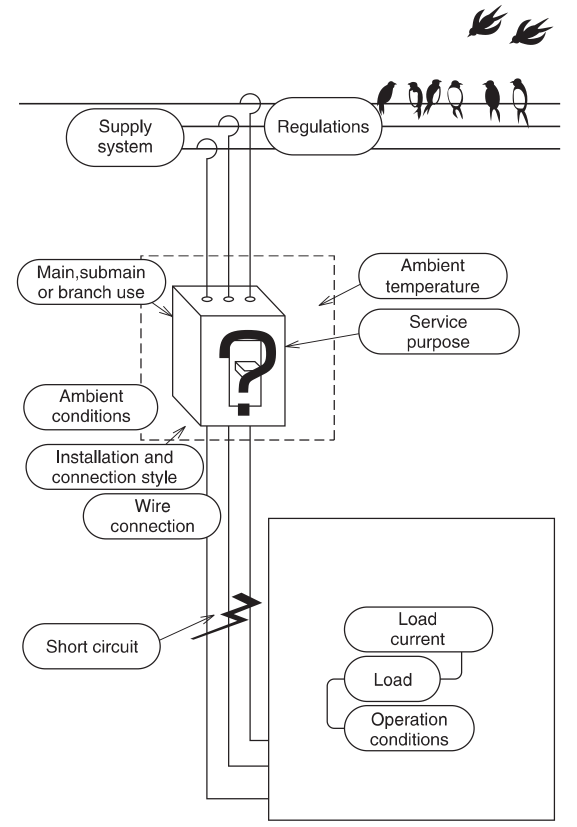


Fig. 5. 1 MCCB Selection Consideration

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.

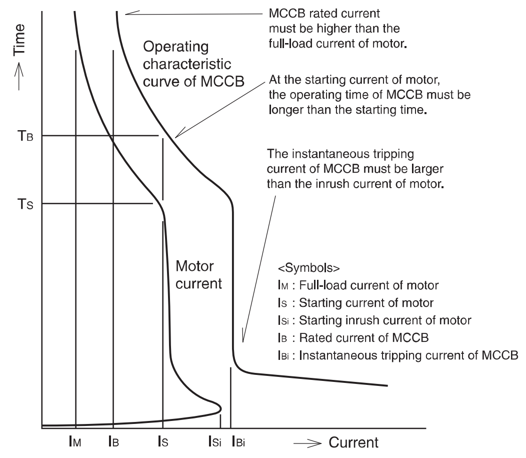


Fig. 5. 2 Characteristics of MCCB and motor

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.

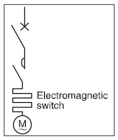


Table 5. 4 Selection of MCCB for motor branch circuit 200/220VAC for 3-phase induction motor

	For 4-pole motor		Electromagnetic contactor		Breaking capacity (kA) 230 V AC (Icu sym)																			
					2.5		7.5		15		25		30(*1)		50		85		100		150(*2)		200	
	Output (kW)	Full-load current (A)	Model	Heater nominal (A)	Model	Rating	Model	Rating	Model	Rating	Model	Rating	Model	Rating	Model	Rating	Model	Rating	Type name	Rating	Model	Rating	Model	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)
	0.2	1.2		1.3																				
	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)
	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)
	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)
	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
	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
	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
	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
	11	44	N50-N95	42									NF125-CV	75	NF125-SV	75			NF125-HV	75			NF125-UV	75
	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
	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
	11	44	—	42									NF125-CV	75	NF125-SV	75			NF125-HV	75			NF125-UV	75
	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
	22	85	N95-N150	82									NF250-CV	150			NF250-SV	150	NF250-HV	150			NF250-UV	150
	30	110	N125-N220	105									NF250-CV	175			NF250-SV	175	NF250-HV	175			NF250-UV	175
	37	130	N150-N220	125									NF250-CV	225			NF250-SV	225	NF250-HV	225			NF250-UV	225
	45	164	N180-N400	150											NF400-CW	350	NF400-SW	250	NF400-HEW	250	NF400-REW	250	NF400-UEW	250
	55	195	N220-N400	180											NF630-CW	500	NF400-SW	300	NF400-HEW	300	NF400-REW	300	NF400-UEW	300
	75	267	N300·N400·(N600)	250											NF630-CW	600	NF630-SW	500	NF400-HEW	400	NF400-REW	400	NF400-UEW	400
	90	320	N300·N400·(N600·N800)	330											NF800-CEW	600	NF630-SW	600	NF630-HEW	500	NF630-REW	500	NF800-UEW	500
	110	385	N300·N400·(N600·N800)	330											NF800-CEW	600	NF630-SEW	600	NF630-HEW	600	NF630-REW	600	NF800-UEW	600
	132	470	(N600·N800)	500																	NF1000-SEW	700		
	160	580	(N600·N800)	500																	NF1250-SEW	800		
	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

	For 4-pole motor		Electromagnetic contactor		Breaking capacity (kA) 415 V AC (Icu sym)																			
					1.5		2.5		7.5		10		25		30(*1)		50(*2)		70		150(*3)		200	
	Output (kW)	Full-load current (A)	Model	Heater nominal (A)	Model	Rating	Model	Rating	Model	Rating	Model	Rating	Model	Rating	Model	Rating	Model	Rating	Model	Rating	Model	Rating	Model	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)
	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)
	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)
	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)
	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)
	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
	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
	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
	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
	15	28	N35 • N50-N80	28			NF63-CV	60	NF63-SV	60	NF63-HV	60			NF125-SV	60	NF125-HV	60					NF125-UV	60
	18.5	34	N50-N95	35			NF63-CV	60	NF63-SV	60	NF125-CV	60			NF125-SV	60	NF125-HV	60					NF125-UV	60
	22	42	N50-N95	42							NF125-CV	75			NF125-SV	75	NF125-HV	75					NF125-UV	75
	30	55	N65-N125	54							NF125-CV	100			NF125-SV	100	NF125-HV	100					NF125-UV	100
	37	65	N80-N150	67							NF125-CV	100			NF125-SV	100	NF125-HV	100					NF125-UV	100
	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
	7.5	15	–	15			NF63-CV	40	NF63-SV	40	NF63-HV	40			NF125-SV	40	NF250-HV	40					NF125-UV	40
	11	22	–	22			NF63-CV	50	NF63-SV	50	NF63-HV	50			NF125-SV	50	NF250-HV	50					NF125-UV	50
	15	28	–	28			NF63-CV	60	NF63-SV	60	NF125-CV	60			NF125-SV	60	NF250-HV	60					NF125-UV	60
	18.5	34	–	35			NF63-CV	60	NF63-SV	60	NF125-CV	60			NF125-SV	60	NF250-HV	60					NF125-UV	60
	22	42	–	42							NF125-CV	75			NF125-SV	75	NF250-HV	75					NF125-UV	75
	30	55	–	54							NF125-CV	100			NF125-SV	100	NF250-HV	100					NF125-UV	100
	37	65	–	67							NF125-CV	100			NF125-SV	100	NF250-HV	100					NF125-UV	100
	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
	75	134	N150-N220	125									NF250-CV	225	NF250-SV	225			NF250-HV	225			NF250-UV	225
	90	160	N180-N400	150											NF250-SEV	225			NF250-HEV	225	NF400-REW	225	NF400-UEW	225
	110	192	N180-N400	180													NF400-SW	350	NF400-HEW	300	NF400-REW	300	NF400-UEW	300
	132	233	N220-N400	250													NF400-SW	400	NF400-HEW	400	NF400-REW	400	NF400-UEW	400
	160	290	N300 • N400 • (N600)	250													NF630-SW	500	NF630-HEW	500	NF630-REW	500	NF800-UEW	500
	200	360	N300 • N400 • (N600 • N800)	330													NF630-SW	600	NF630-HEW	600	NF630-REW	600	NF800-UEW	600
	220	389	N300 • N400 • (N600 • N800)	–													NF630-SW	600	NF630-HEW	600	NF630-REW	600	NF800-UEW	600
	250	430	(N600 • N800)	500													NF630-SEW	700	NF630-HEW	600	NF630-REW	600	NF800-UEW	700
	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	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

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

		For 4-pole motor		Electromagnetic contactor		Breaking capacity (kA) 415 V AC (Icu sym)																	
						2.5		5		7.5		10		25		30(*1)		50(*2)		70		125	
		Output (kW)	Full-load current (A)	Model	Heater nominal (A)	Model	Rating	Model	Rating	Model	Rating	Model	Rating	Model	Rating	Model	Rating	Model	Rating	Model	Rating	Model	Rating
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)				
		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)				
		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)				
		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)				
		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)				
		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				
		5.5	11	N18-N35	11	NV63-CV	30	NV32-SV	30	NV63-SV	30	NV63-HV	30			NV125-SV	30	NV125-HV	30				
		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				
		11	22	N25 • N35 • N50 • N65	22	NV63-CV	50			NV63-SV	50	NV63-HV	50			NV125-SV	50	NV125-HV	50				
		15	28	N35 • N50-N80	28	NV63-CV	60			NV63-SV	60	NV63-HV	60			NV125-SV	60	NV125-HV	60				
		18.5	34	N50-N95	35							NV125-CV	60			NV125-SV	60	NV125-HV	60				
		22	42	N50-N95	42							NV125-CV	75			NV125-SV	75	NV125-HV	75				
		30	55	N65-N125	54							NV125-CV	100			NV125-SV	100	NV125-HV	100				
		37	65	N80-N150	67							NV125-CV	100			NV125-SV	100	NV125-HV	100				
		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				
		7.5	15	–	15	NV63-CV	40			NV63-SV	40	NV63-HV	40			NV125-SV	40	NV125-HV	40				
		11	22	–	22	NV63-CV	50			NV63-SV	50	NV63-HV	50			NV125-SV	50	NV125-HV	50				
		15	28	–	28	NV63-CV	60			NV63-SV	60	NV125-CV	60			NV125-SV	60	NV125-HV	60				
		18.5	34	–	35							NV125-CV	60			NV125-SV	60	NV125-HV	60				
		22	42	–	42							NV125-CV	75			NV125-SV	75	NV125-HV	75				
		30	55	–	54							NV125-CV	100			NV125-SV	100	NV125-HV	100				
		37	65	–	67							NV125-CV	100			NV125-SV	100	NV125-HV	100				
		45	82	–	82									NV250-CV	150	NV250-SV	150			NV250-HV	150		
	Direct-to-line starting	55	96	N125-N220	105									NV250-CV	175	NV250-SV	175			NV250-HV	175		
		75	134	N150-N220	125									NV250-CV	225	NV250-SV	225			NV250-HV	225		
		90	160	N180-N400	150											NV250-SEW	225		225	NV250-HEW	225	NV400-REW	225
		110	192	N180-N400	180													NV400-SW	350	NV400-HEW	300	NV400-REW	300
		132	233	N220-N400	250													NV400-SW	400	NV400-HEW	400	NV400-REW	400
		160	290	N300 • N400 • (N600)	250													NV630-SEW	500	NV630-HEW	500		
		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.

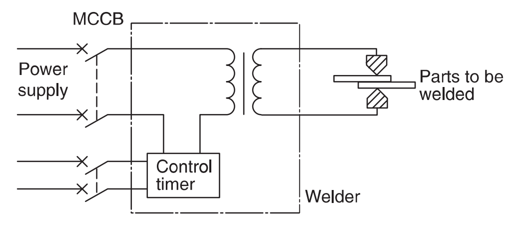


Fig. 5. 3 Spot welder circuit

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.

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

$$\left(\begin{array}{l} \text{where, } \beta \text{ is the duty cycle and obtained by} \\ \beta = \dfrac{\text{weld time}}{\text{period}} \end{array} \right)$$

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)

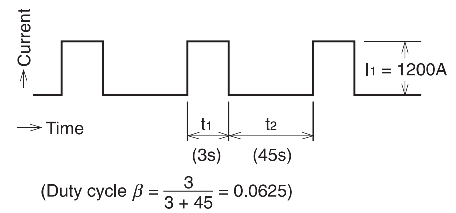


Fig. 5. 4. 1 Example of intermittent current

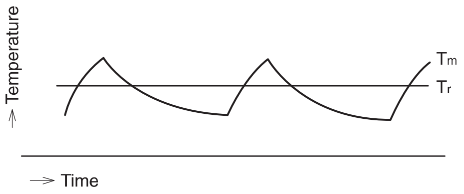


Fig. 5. 4. 2 Temperature rise due to intermittent current

The operating time of electronic MCCB is shorter than that of thermal magnetic MCCB. To select the rated current of electronic MCCB, reduce the weld 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:

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

MCCB rated current is just above the following value.

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

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:

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

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.

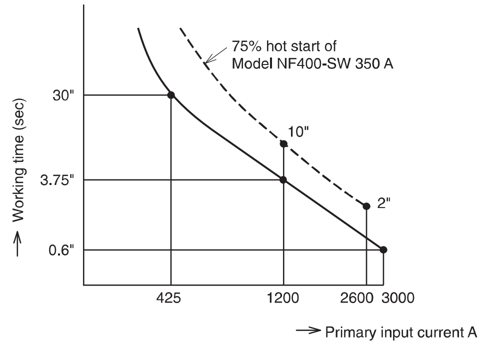


Fig. 5. 5 Working current and working time

(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,

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

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.

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

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			Single-phase, 400 V		
		Circuit breaker (magnetic-only)			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 2ϕm 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 2ϕm + ϕr 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.

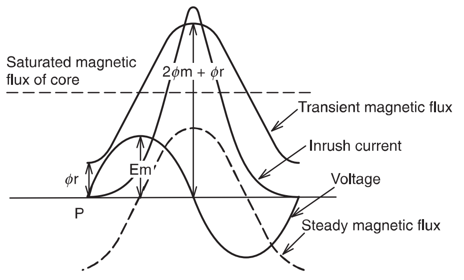


Fig. 5. 6 Magnetizing inrush current

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.

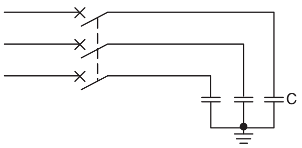


Fig. 5. 7 Example of capacitor circuit

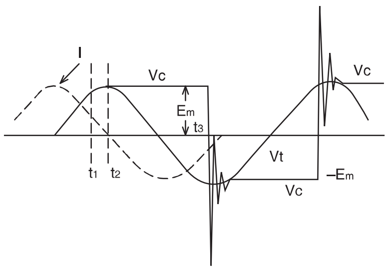


Fig. 5. 8 Breaking phenomenon of capacitor circuit

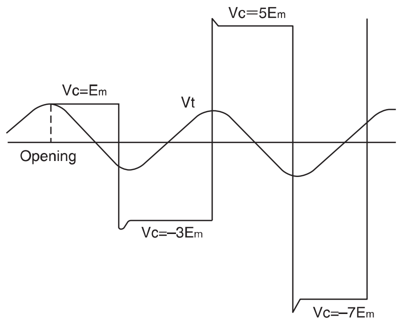


Fig. 5. 9 Example in the case of small capacitor capacity

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.

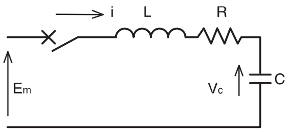


Fig. 5. 10. 1

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 $im \times 2\tau_0$.

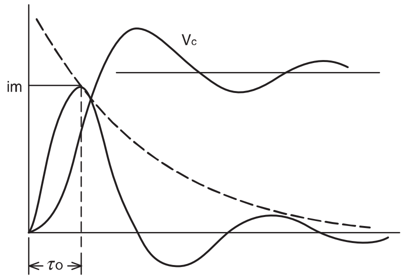


Fig. 5. 10. 2

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.

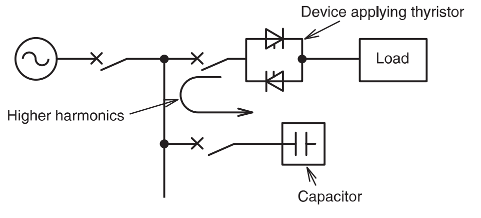


Fig. 5. 11 Higher harmonics source and capacitor circuit

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.

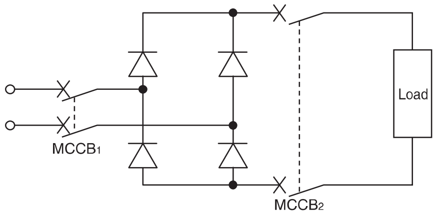


Fig. 5. 12 Example of installation of MCCB on thyristor circuit

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.

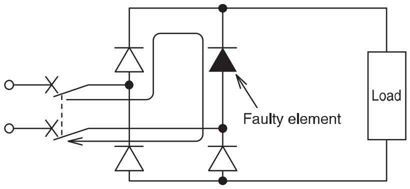


Fig. 5. 13 Example of element fault

(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.

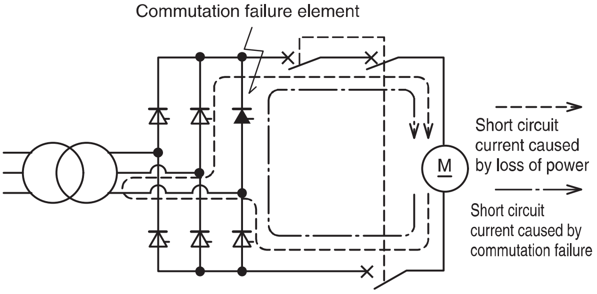


Fig. 5. 14 Faults on thyristor Leonard system

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:

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

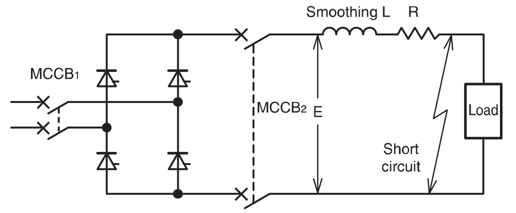
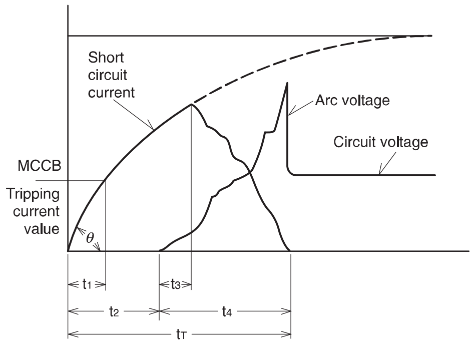


Fig. 5. 15 Short circuit

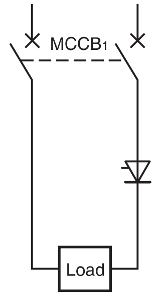
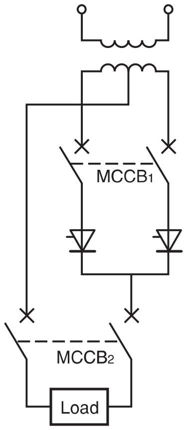
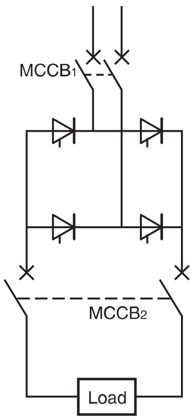
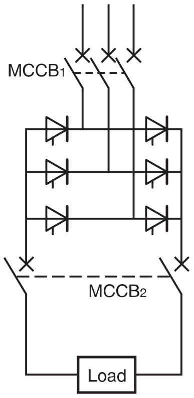
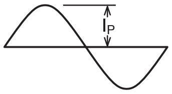
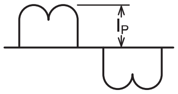
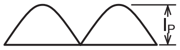
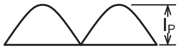
Since the magnitude of inductance on the line or for smoothing significantly affects $\frac{di}{dt}$, if there is a possibility of large short circuit current, it is effective to increase L and reduce the rate of current rise to break the circuit with MCCB before large current flows. Fig. 5. 16 shows this phenomenon on MCCB2.



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, IB (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 waveform				
	MCCB2	RMS current, IB (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 waveform				

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

When the passing $\int i^2dt$ of $MCCB_2$ 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 $MCCB_1$ is 1 cycle, $\int i^2dt$ applied to the thyristor is determined as shown below.

Circuits Ⅰ, Ⅱ and Ⅲ

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

Circuit Ⅳ

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

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 $MCCB_1$ is identical to the current flowing to the element on the circuits Ⅰ and Ⅱ, but the current flowing to $MCCB_1$ is twice the current flowing to the element on the circuits III and IV. Therefore, the passing $\int i^2dt$ of $MCCB_1$ 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 $MCCB_1$ 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 $MCCB_1$. For $MCCB_2$, 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.

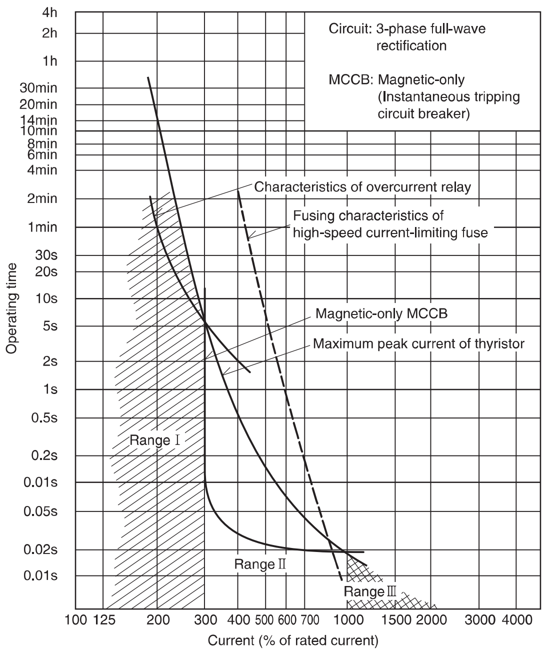


Fig. 5. 17 Protection coordination of thyristor by MCCB

(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)

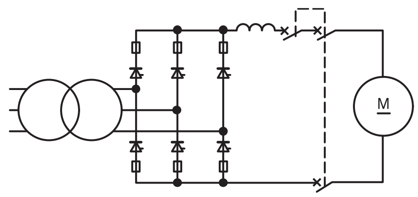
It is necessary to experimentally prove the condition. Table 5. 14 shows the selection of MCCB on the DC side of thyristor leonard system. Select MCCB according to the table.

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

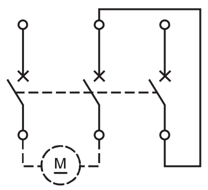
Breaker for protection of thyristor				Short circuit			Passing $I^2\cdot t$ ($\times10^4$) ($A^2\cdot s$)	Example of Mitsubishi thyristor which can be protected by breaker for protection of thyristor		
Model	Number of poles	Rated current A	Electromagnetic tripping current A	Voltage V	Current A	Time constant ms		Model	* Number of parallel thyristors	Allowable $I^2\cdot t$ ($\times10^4$) ($A^2\cdot s$)
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.

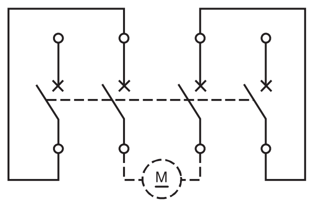
Remarks (1) The quick acting fuse shown in the figure interrupts the short circuit current which flows to the thyristor from the AC power supply when the thyristor is ruptured.



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.

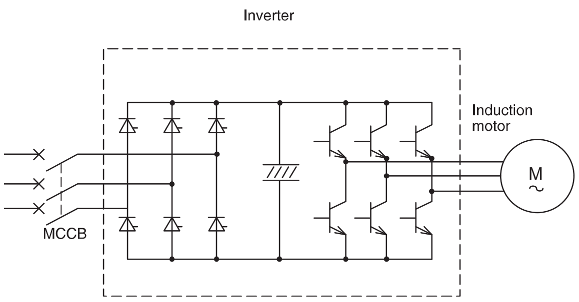


Fig. 5. 18 Example of use of MCCB on inverter circuit

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.

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

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

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

Note

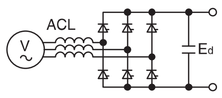
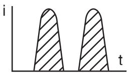
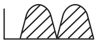
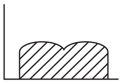
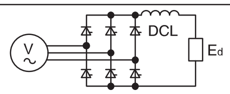
Note (1) Since hydraulic magnetic MCCB may considerably change in characteristics depending on waveform distortion, it is recommended to use thermal magnetic MCCB.

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

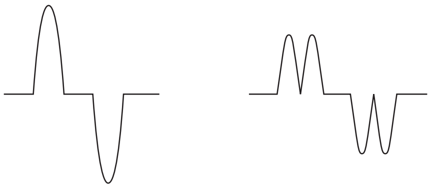
Harmonic order	Content of harmonic current (%)			
	PWM		PAM	
	Without ACL (standard)	With ACL for improvement of power factor	With standard ACL	With ACL for improvement of power factor
BASE	81.6	97.0	83.6	97.2
2	–	–	–	–
3	3.7	–	2.5	–
4	–	–	–	–
5	49.6	21.9	48.3	21.7
6	–	–	–	–
7	27.4	7.1	23.7	7.0
8	–	–	–	–
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

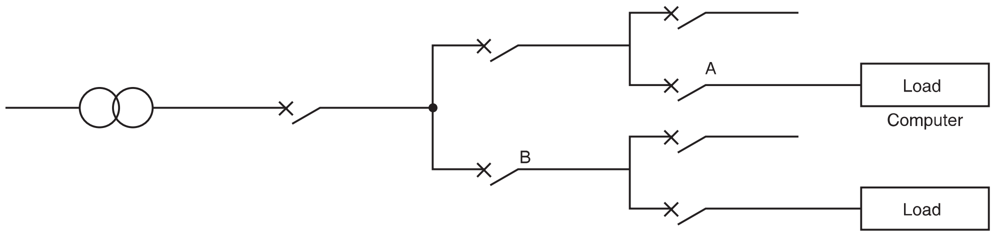


Fig. 5. 21 Measurement circuit

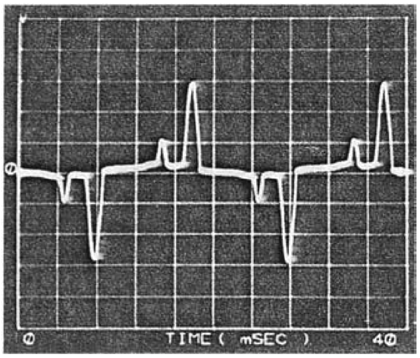


Fig. 5. 22 Current waveform at measurement point A

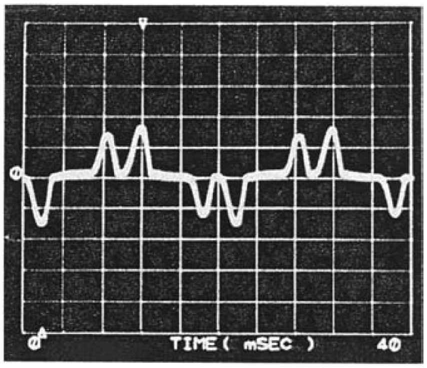


Fig. 5. 23 Current waveform at measurement point B

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.

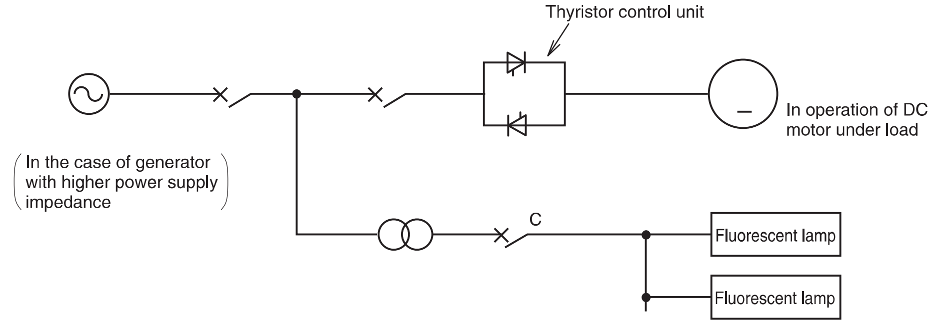


Fig. 5. 24 Measurement circuit

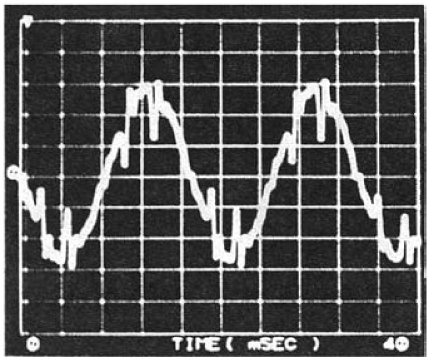


Fig. 5. 25 Voltage waveform at measurement point C

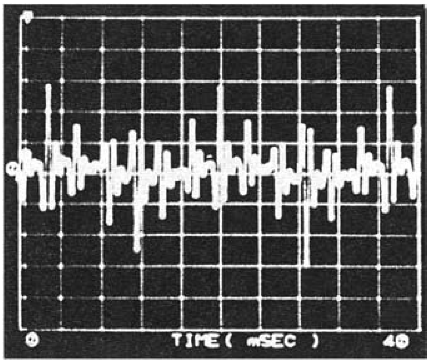


Fig. 5. 26 Current waveform at measurement point C

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

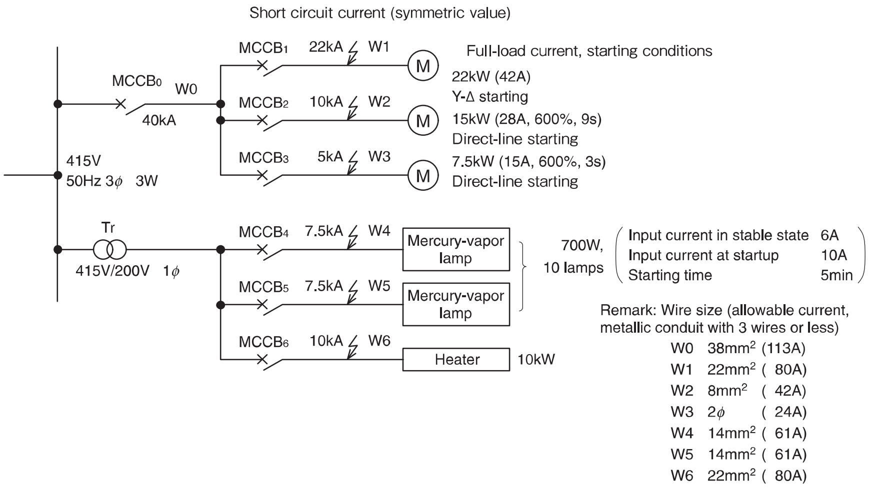


Fig. 5. 27 Example of selection

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 38mm^2 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 ↓ 8mm^2 (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 14mm^2.	Check • Wire and MCCB rating: MCCB 50A or lower because no motor is connected. Therefore, 14mm^2 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.