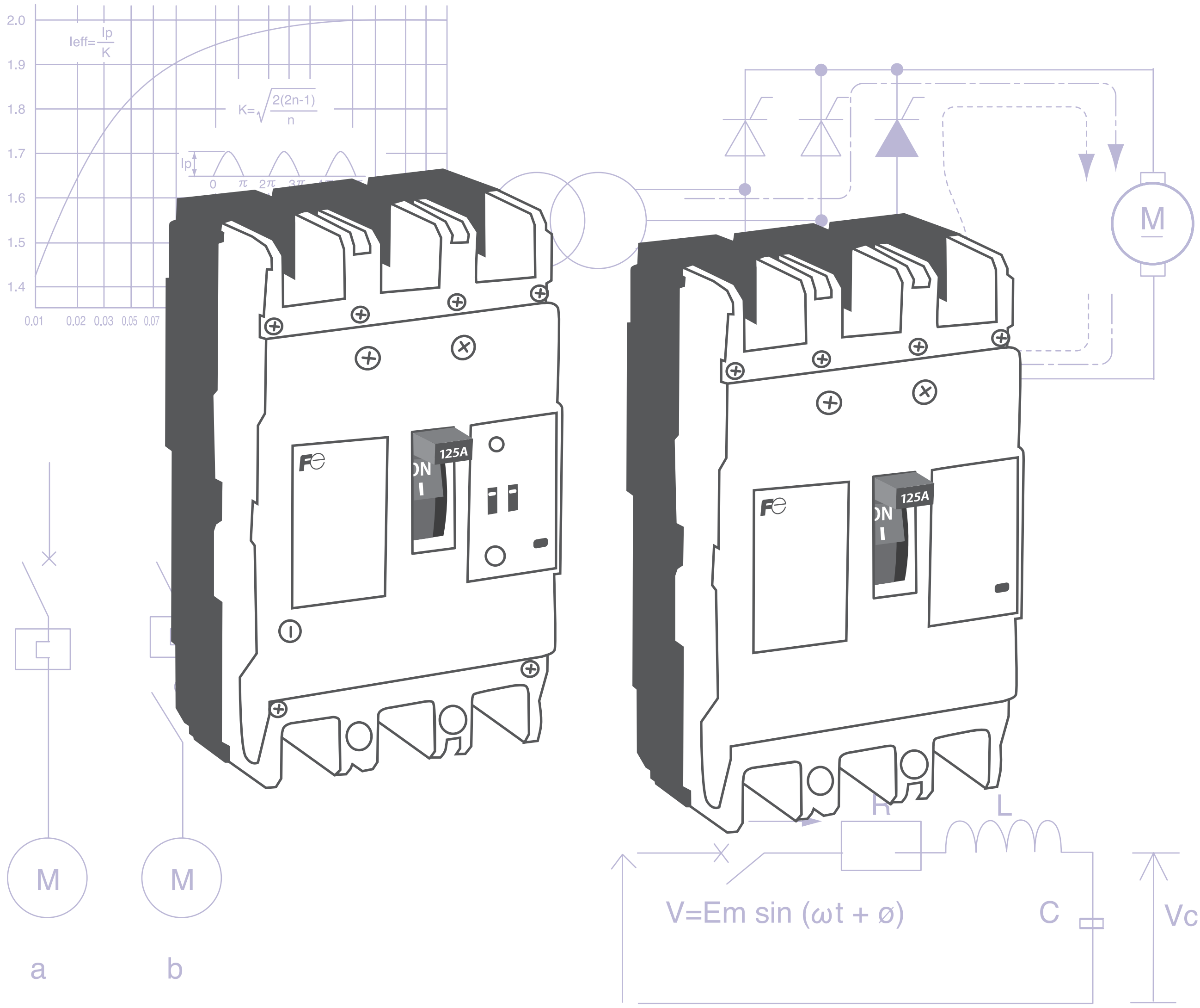
e-Front runners

Molded Case Circuit Breakers

Technical Information



Fuji Electric FA Components & Systems Co., Ltd.

EEH150b

CONTENTS

Introduction

FUJI has employed its comprehensive technical expertise to bring a complete range of models and features to its line of molded case circuit breakers (MCCBs), the mainstay for low-voltage overcurrent protection devices.

A more complete line of breakers is combined with better performance and greater economy to yield a wider selection of products than ever before. Now with superior applicability, operability and safety, MCCBs have firmly established their place in the world of overcurrent protection devices for low-voltage circuits.

In response to customer needs, this product line represents some of the safest and most economical protection systems available. This Technical Information contains the data that is needed for selecting the most appropriate FUJI MCCB.

It is provided to help you design superior equipment that is safe and cost efficient.

Chapter 1

Protecting low-voltage circuits

CONTENTS

1-1 Description

The most common faults occurring with low-voltage circuits are overcurrent (resulting from overload or short-circuit), ground faults, and phase-loss. A device that will protect equipment from these faults is therefore needed for reliable and economical operation. The following section describes low-voltage circuit faults along with measures to protect against them.

1-2 Overcurrent protection

1-2-1 Overcurrent fault

Overcurrent occurs when a circuit is exposed to current that is higher than the rated load current. It may be due to short circuiting in a circuit or to overloading that occurs when a motor overloads or the rotor locks. In either case, overcurrent can damage cables, and switching devices and load equipment connected to a faulty circuit, and can easily spread to other systems. Overcurrent protection devices are installed to protect cables and other devices connected to a faulty circuit while minimizing damage to systems beyond the circuit.

1-2-2 Overcurrent protection

(1) Overload protection

When overcurrent caused by motor overload or a locked rotor reaches as much as five times the motor rated current, it results in thermal damage. A circuit breaker is used to ensure quick tripping to protect the connected devices – the breaker having a lower operating characteristic curve than the heating characteristic curves of the motor winding and cable.

(2) Short-circuit protection

Since short-circuit current is caused by a short in a circuit, it tends to be fairly large. The actual amount is calculated from the power supply capacity, power supply voltage, and cable impedance to the shorting point. It can vary significantly with low-voltage circuits from near the rated load current to several hundred times the rated load current depending on the shorting point. This has prompted studies first to find circuit breakers with rated capacities that can handle massive short-circuit current, and second to look into materials that can protect against the electromagnetic forces generated by the short-circuit current peak value I_{sp} and the joule integral (I^2t) in circuits before the breaker cuts current off completely.

1-3 Phase-loss protection

1-3-1 Phase-loss fault

(1) Three-phase power supply circuit

A phase-loss fault occurs when there is a disconnection in one of the phase wires. If a motor continues running under those conditions, the result is an imbalance in the current flow to the motor windings that can generate enough heat to burn out the windings. This can develop eventually into a short-circuit or ground fault.
A phase-loss protection device protects the motor windings from burning and prevents the fault from developing into a wider problem.

1-3-2 Phase-loss burnout protection (three-phase circuit)

One way to prevent phase-loss from burning the motor or severely lowering its durability is to disconnect it from the circuit. For economic reasons, it is recommend that this be done using a manual motor starter (MMS) with phase-loss protection capability.

Chapter 2

Operating characteristics and performance

CONTENTS

2-1 Overcurrent tripping characteristics

2-1-1 Types of tripping

Overcurrent tripping in MCCBs occurs in three different ways depending on the amount of overcurrent. For line protection use in general, the breakers use an inverse-time delay trip and instantaneous trip (dual trip-element characteristic).
Some breakers use a short-time delay in addition to the inverse-time delay trip and the instantaneous trip mainly for selective trip coordination. This is particularly true with larger breakers (ternary trip-element characteristic).
Fig. 2-1 shows a dual trip-element characteristic curve while Fig. 2-2 shows a ternary trip-element characteristic curve.

(1) Inverse-time delay trip (long-time delay)

This type of tripping delays the tripping time of the breaker at a rate inversely proportional to the amount of overcurrent. It is available as either a thermal-magnetic type that uses ordinary bimetal elements or as a hydraulic-magnetic type that uses oil dashpot damping. The trip is also referred to as a long-time delay trip to distinguish it from the shorter tripping time of the short-time delay trip.

(2) Instantaneous trip

This trips the circuit breaker immediately when there is relatively significant overcurrent like short-circuit current.

Fig. 2-1 Dual trip-element characteristic

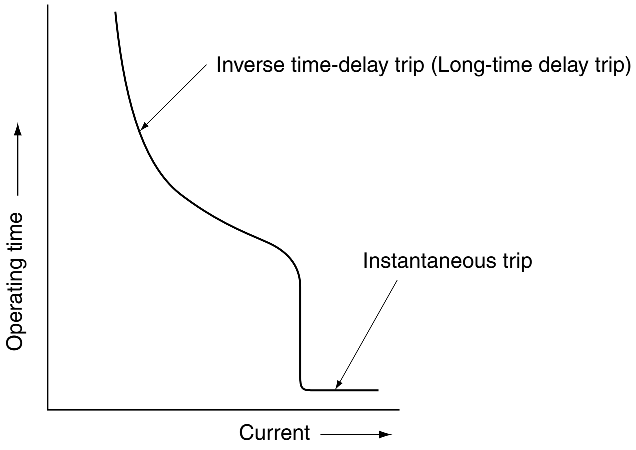
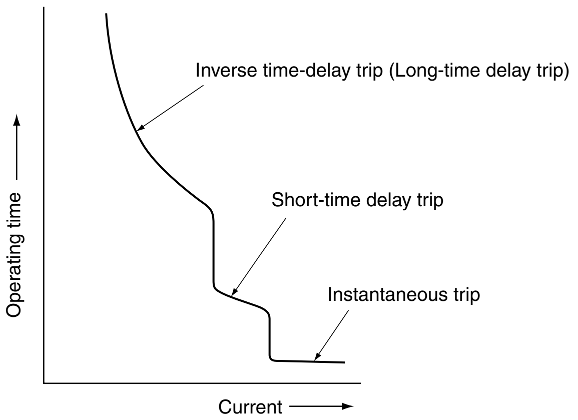


Fig. 2-2 Ternary trip-element characteristic



(3) Short-time delay trip

This type of tripping has a short-time delay to handle the selective trip coordination of low-voltage circuits.

2-1-2 Factors affecting overcurrent trip characteristics

There are basically three types of overcurrent tripping: thermal-magnetic, hydraulic-magnetic and solid-state. The effect of each varies with the principle involved.
Table 2-1 shows models organized by the type of trip device.

Table 2-1 Breaker trip devices

Trip device	MCCB type	ELCB type (Reference)
Thermal-magnetic	The following models not included.	The following models not included.
Hydraulic-magnetic	BW32AAG, BW32SAG BW50AAG, BW50EAG BW50SAG, BW50RAG BW63EAG, BW63SAG BW63RAG BW100AAG BW100EAG	EW32AAG, EW32EAG EW32SAG EW50AAG, EW50EAG EW50SAG, EW50RAG EW63EAG, EW63SAG EW63RAG EW100AAG EW100EAG

(1) Ambient temperature

If an MCCB is used at a temperature other than the reference ambient temperature at which its overcurrent trip characteristics are prescribed, the long-time delay trip characteristic changes. Therefore, the choice of MCCB must consider the cataloged temperature correction curve and overcurrent trip characteristics. As Table 2-2 shows, the effects of ambient temperature on the overcurrent trip characteristics of an MCCB vary according to the type of trip device.

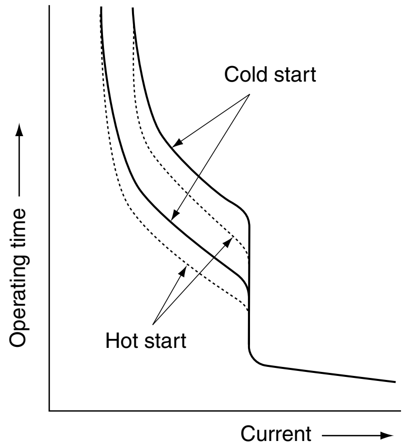
Table 2-2 Ambient temperature effects on overcurrent trip

Trip device	Effect of ambient temperature change
Thermal-magnetic	The minimum current for trip operation will decrease when the ambient temperature exceeds the reference ambient temperature, and vice versa. This means that a lower overcurrent makes the bimetal reach the operating temperature as the ambient temperature rises, because the bimetal's operating temperature is constant.
Hydraulic-magnetic	Although the minimum value of trip current remains unchanged, the operating time varies depending on the ambient temperature, as the viscosity of silicon fluid in the oil dashpot varies.

(2) Hot-start and cold-start

The cataloged characteristic curve that is called the cold-start characteristic represents the operating characteristic of an MCCB that has just been energized at the reference ambient temperature. The MCCB's operating characteristic appearing when overcurrent has just begun to flow after a long period of steady load current is called the hot-start characteristic.
In general, 50% or 75% of the rated load current is used as the steady state load current, and the associated operating characteristics are called the 50% or 75% hot-start characteristics. With both thermal-magnetic and hydraulic-magnetic type MCCBs, the hot-start operating time is shorter than the cold-start operating time as shown in Fig. 2-3.

Fig. 2-3 Hot and cold start characteristics



(3) Mounting angle

MCCBs are designed to be mounted in parallel with the vertical plate. Note that different mounting other than the standard position could alter the MCCB's operating characteristic (see Table 2-4). The effect of mounting angle on the overcurrent trip characteristic varies depending on the type of trip device as shown in Table 2-3.

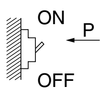
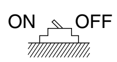
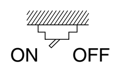
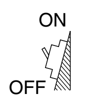
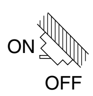
Table 2-3 Effect of mounting angle on overcurrent trip

Trip device	Effect of mounting angle
Thermal-magnetic	Although the heat radiation is slightly dependent on mounting angle, the operating characteristic is hardly affected by it. Therefore, the effect of mounting angle is negligible.
Hydraulic-magnetic	The gravity on the iron core in the cylinder varies depending on the mounting angle. The mounting angle, then, affects the operating characteristics. In general, a backward or forward tilt not exceeding the angle of 10° from the vertical plate has negligible effect. A larger angle than this needs the current rating correction as indicated in the Table 2-4.

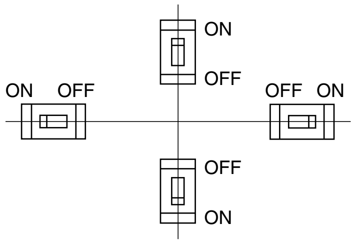
(4) Mounting angle effects

Special care must be taken regarding the mounting angle of MCCBs because the angle will affect their operating characteristics. In a hydraulic-magnetic type, for example, the operating current varies with the mounting angle because gravity affects the plunger in the oil dashpot.

Table 2-4 Current rating correction for hydraulic-magnetic MCCB by mounting angle

Mounting angle			Vertical *	Horizontal	Horizontal (upside down)	Slant 15° (backward)	Slant 45° (backward)	Slant 15° (forward)	Slant 45° (forward)
									
Rated current correction factor	MCCB	ELCB (Reference)							
	BW32AAG, BW32SAG BW50AAG, BW50EAG BW50SAG, BW50RAG BW63EAG, BW63SAG BW63RAG BW100AAG BW100EAG	EW32AAG, EW32EAG EW32SAG EW50AAG, EW50EAG EW50SAG, EW50RAG EW63EAG, EW63SAG EW63RAG EW100AAG EW100EAG	100%	85%	115%	95%	90%	105%	110%

Note: * A 100% rated current correction factor is maintained on a vertical line at any angle as shown in the figure below.



(5) Frequencies

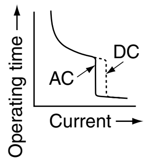
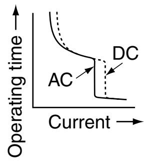
(a) Commercial frequencies (50Hz, 60Hz)

The characteristics of breakers are generally the same at 50 and 60Hz. In the following types equipped with current transformer-type trip devices, however, frequency must be specified because it actually affects characteristics: S1000, S1200.

(b) Direct current (DC)

If an MCCB designed for operation in an AC circuit were used in a DC circuit, its operating characteristics would change as shown in Table 2-5. Hence, an MCCB exclusively designed for operation in a DC circuit has to be used on this occasion.

Table 2-5 Operating characteristic changes for DC circuit application

Trip device	Inverse time-delay trip characteristic	Instantaneous trip characteristics	Operating characteristic curve
Thermal-magnetic	None	The instantaneous trip current is higher than that for an AC circuit. The rate of variation depends on the ampere-frame size, rated current and model. The trip current can be as high as 140% of the AC value.	
Hydraulic-magnetic	The minimum operating current at DC is about 110–140% of that for AC.		

(c) High frequency

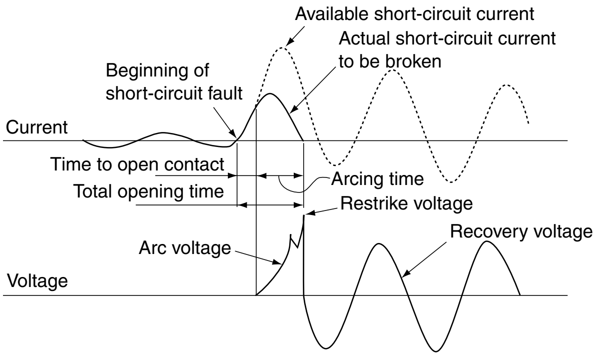
For operation at higher frequencies, such as 400 or 750Hz, the current rating of a thermal-magnetic MCCB has to be derated due to the heat generated by the skin effect in the conductors or the eddy current in the iron core. The rate of reduction slightly depends on the ampere-frame size and the rated current. The available current rating at 400Hz decreases to 70–80% of the rated current.
As the iron loss lowers the attractive force of the trip device, the instantaneous trip current will increase. Hydraulic-magnetic MCCBs cannot be used in a high-frequency circuit because the operating characteristics will change greatly due to the temperature rise of the moving iron core and the reduced attractive force by the high frequency.

2-2 Breaking performance

2-2-1 Short-circuit current breaking

Fig. 2-4 illustrates how a short-circuit current is broken.

Fig. 2-4 Short-circuit current breaking



When a short-circuit fault occurs and a short-circuit current flows, the instantaneous trip device is actuated to quickly open the contacts. An arc is generated between the contacts the moment the moving contact separates from the stationary contact.

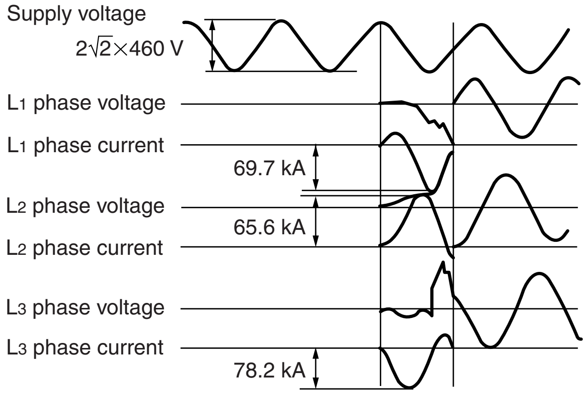
The rapid movement of the moving contact away from the stationary contact draws the arc rapidly across the arc horn and into the arc quencher. The arc lengthens as the distance between the contacts increases, until the electromotive force generated between the grid and arc current drives the arc deeply into the V-notches in the magnetic sheets composing the arc quencher's grid. The grid thus splits the arc into a series of shorter arcs. With the arc stretched and split up in this way, the resistance and the arc voltage increase due to the combined action of cooling by the grid, the rising pressure in the arc quencher, and the cathode effect. The arc is extinguished (quenched) when the arc voltage becomes larger than the supply voltage. At this time, a voltage equivalent to the supply voltage (recovery voltage) appears across the contacts. This condition is called completion of breaking.

In general, a circuit in which a large short-circuit current occurs has a low power factor. If the arc is quenched at the zero-crossing point of the short-circuit current, a circuit-constant, dependent oscillating transient voltage is superimposed on the recovery voltage that appears across the contacts. This voltage is called the restrike voltage and can cause rearcing between the contacts if the isolation between the contacts has not recovered sufficiently. To achieve complete breaking without rearcing, powerful arc-quenching action and sufficient contact spacing must be ensured quickly.

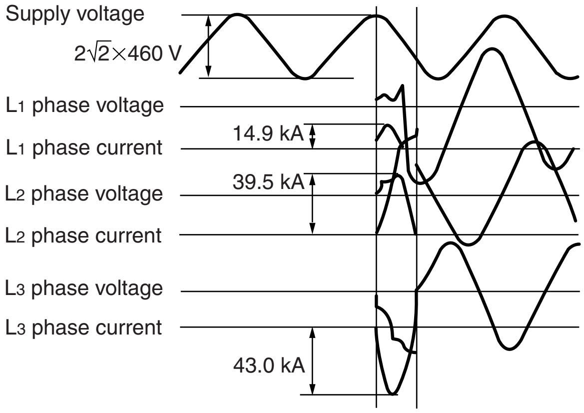
To achieve current-limiting breaking, current-limiting MCCBs use the electromotive force generated across two parallel conductors to quickly open the contacts without waiting for instantaneous trip, while increasing the arc voltage in an extremely short time. In DC circuits, the current does not fall to zero as in AC circuits. The arc voltage must be increased through a powerful arc quenching effect to suppress the current: arc quenching is complete when the supply of energy needed to maintain arcing is no longer available.

Fig. 2-5 shows the three-phase short-circuit current breaking test oscillograms.

Fig. 2-5 Three-phase short-circuit current breaking test oscillograms 460V AC, 3-phase



Non current-limiting type



Current-limiting type

2-2-2 Breaking characteristics

(1) Breaking performance

The characteristics that define MCCB breaking performance are the rated short-circuit breaking capacity, peak let-through current, and maximum let-through I^2t. The rated short-circuit breaking capacity is defined by the rated ultimate short-circuit breaking capacity (Icu), and the rated service short-circuit breaking capacity (Ics).

(2) Rated short-circuit breaking capacity

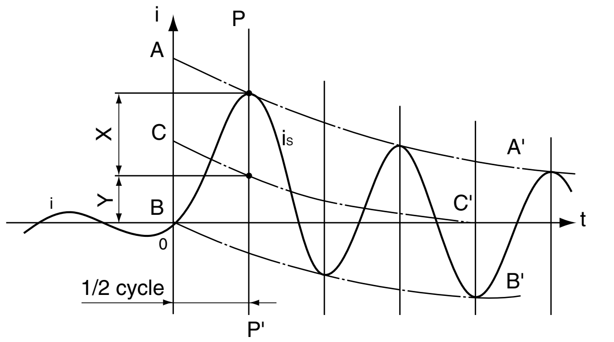
Fig. 2-6 is a typical oscillogram of a short-circuit current. In the figure, t=0 denotes the time the short-circuit fault occurred. The rated load current was flowing at the supply voltage before the short-circuit fault occurred. The current by several factors of ten flows after the occurrence of the short circuit. Because the load current immediately after the short-circuit fault contains a DC component, the current flow is asymmetrical with respect to the zero-current line, with the DC component being attenuated rapidly. The curve C-C' represents the DC component of the asymmetrical short-circuit current, and i_s indicates the current that would flow if a short circuit occurred. This current is called the available short-circuit current.

$$i_s = i_{AC} + i_{DC} = I_m \left[\sin(\omega t + ø - \varphi) - e^{-\frac{Rt}{L}} \sin(ø - \varphi)\right]$$

ø: Making phase angle
cosφ: Short-circuit power factor
The value of the above equation reaches its maximum when $(ø - \varphi) = \pm \frac{\pi}{2}$.

$$I_m = \frac{E_m}{\sqrt{R^2 + (\omega L)^2}}$$

Fig. 2-6 Short-circuit current oscillogram



i_s: Short-circuit current
C-C': Intermediate line between the envelopes A-A' and B-B'
P-P': 1/2 cycle after occurrence of short-circuit fault
X: AC component of short-circuit current
Y: DC component of short-circuit current

The rated breaking current of an MCCB is represented as $X/\sqrt{2}$, the effective value of the AC component 1/2 cycle after the occurrence of the short-circuit fault. For a three-phase circuit, the rated breaking current is represented the average of the three phases.
For DC circuits, the maximum available short-circuit current is used.

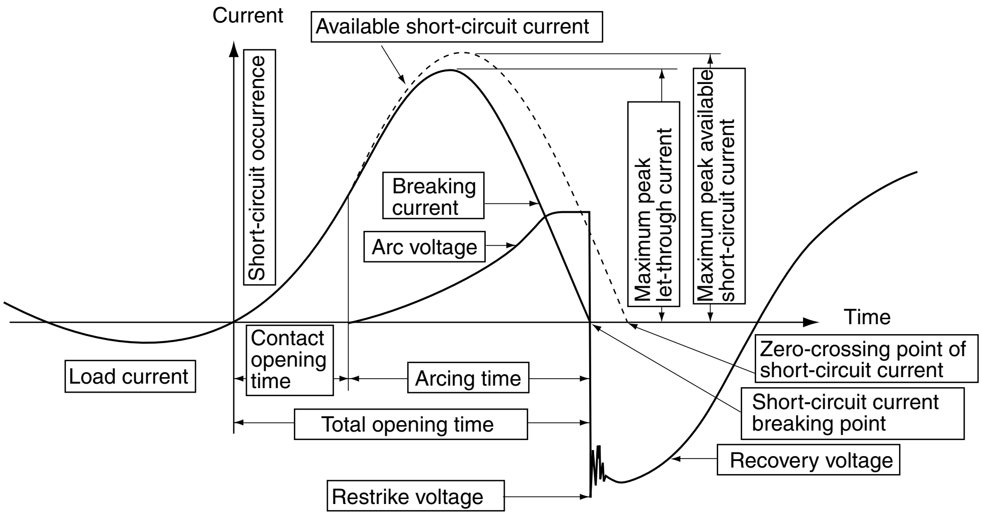
(3) Operating duty

Under conditions where the displayed rated breaking capacity is specified, breakers will break properly at an operating duty of "O" -t- "CO" for Icu and "O" -t- "CO" -t- "CO" for Ics (where t is three minutes or the time it takes to reset the breaker, whichever is longer). All this is done at the rated voltage and frequency. After the breaker trips, however, the rated current may or may not flow, but the breaking capacity, durability, let-through current and overload switching capacity will be diminished. Therefore, replace the breaker with a spare as quickly as possible. If current must be supplied with the same breaker, conduct a maintenance inspection that looks closely at the operating conditions prior to the breaker tripping, the amount of short-circuit current, as well as future operating conditions. Special attention must be paid to temperature rise as well.

(4) Breaking characteristics

When the magnitude of an overcurrent exceeds a certain limit, the instantaneous trip device is actuated to open the pole immediately. The minimum current that can actuate the instantaneous trip device is called the instantaneous trip current, which is expressed as a symmetrical effective value. With thermal-magnetic MCCBs, the instantaneous trip current setting is adjustable because their instantaneous trip device is installed separately from the inverse time-delay trip device. This eases coordination with other devices. Fig. 2-7 shows the progress of time after the start of short-circuit current flow until completion of breaking. The time interval between the occurrence of a short-circuit fault and the opening of the contacts is called the contact opening time. The time interval between completion of breaking and quenching of the arc generated by contact opening is called the arcing time. The sum of the contact opening time and the arcing time, or the period of time from the occurrence of a short-circuit fault to completion of breaking, is called the total opening time. Table 2-7 lists the contact opening times, arcing times, and total opening times of MCCBs at breaking of the rated breaking current.

Fig. 2-7 Current breaking process



(5) Maximum let-through current and maximum breaking I^2t

The current that would flow through a short circuit without a circuit breaker is called the available short-circuit current. It is the short-circuit current that is determined from the impedance map at circuit breaker selection, not the current that is actually interrupted by the circuit breaker. The current that actually flows through the circuit is smaller than the available short-circuit current. As the trip device in the circuit breaker is actuated to open the contact immediately on occurrence of a short circuit, the arc voltage is increased to inhibit current flow. This is equivalent in effect to having a variable resistor, called an arc resistor, connected in series in the circuit.

Current-limiting circuit breakers that take advantage of the magnetic repulsion force represent an application of this principle; current-limiting breaking is done before the short-circuit current reaches its peak value.

The maximum current that can flow through the circuit breaker is called the maximum let-through current, which is expressed as a peak value. The smaller the maximum let-through current, the less mechanical stress is imposed on the cable and load equipment. With a high short-circuit current having a low power factor, the transient peak value is more than twice the symmetrical effective value. In mechanical stress studies, therefore, a choice must be made between the current-limiting type and the non-current-limiting type, along with full allowance for electromotive force.

The squared product of the let-through current, or $\int_{t_1}^{t_2} i^2 dt$ from short-circuit occurrence time t_1 to completion of breaking time t_2, is called the maximum breaking I^2t. The smaller this value, the smaller the thermal effects on the cable and load equipment. Fig. 2-8 to 2-9 and Fig. 2-10 to 2-11 give the maximum let-through I^2t or maximum let-through current, and available short-circuit current of MCCBs.

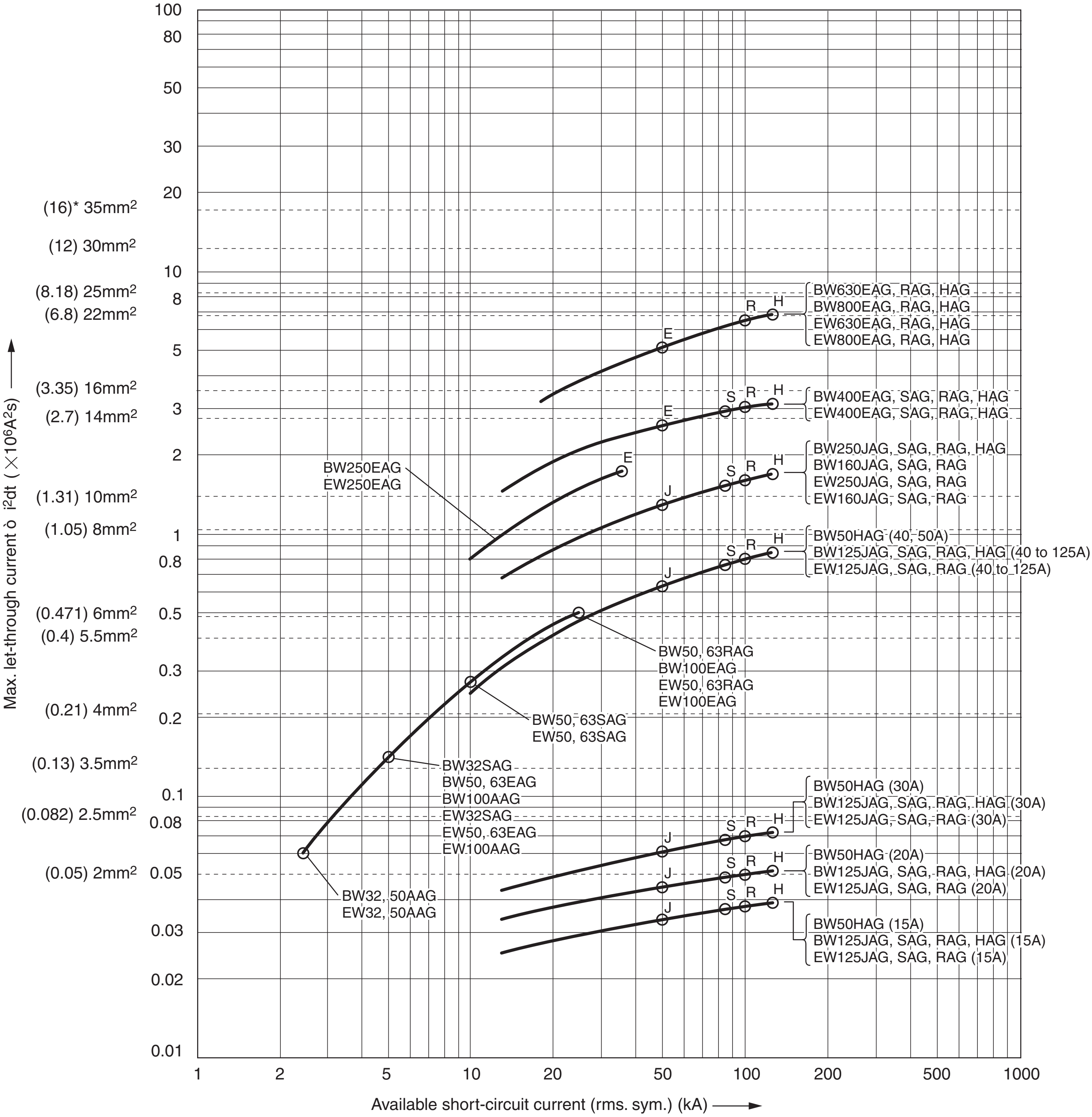
2-2-3 Arc space

When a short-circuit current is broken, an ionized gas is emitted from the breaker's line side exhaust vent and, because this gas is conductive, it could induce an interphase short circuit or ground fault if it bridges adjacent bare live parts or a bare live part and an adjacent grounded metallic surface. Because this is potentially hazardous, an arc space (insulation space) is required for safety.

Table 2-7 lists the arc spaces required for specific conditions. When wiring is done, live parts should be either taped or protected by insulating barriers in the ranges specified in Table 2-7 to allow for conditions that could be encountered while the MCCB is in service. Improved insulation may be needed outside the arc space depending on the service conditions of the MCCB.

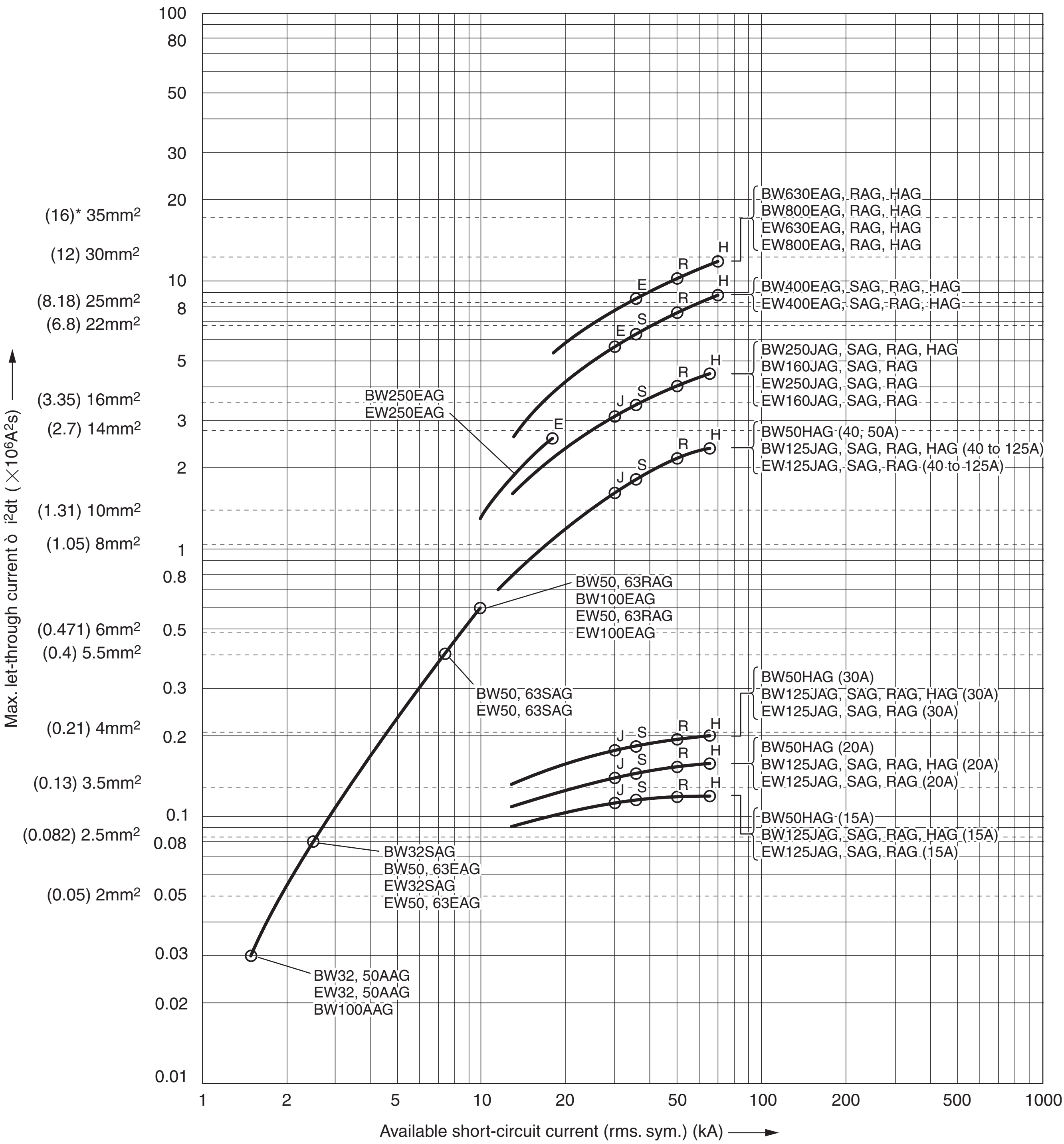
2-2 Breaking performance

Fig. 2-8 Max. let-through I²t 230V AC



Note: * The parentheses ( ) indicate approximate tolerances I²t for each wire gauge. (See Table 3-11, Chapter 3.)

Fig. 2-9 Max. let-through I²t 400V AC



Note: * The parentheses ( ) indicate approximate tolerances I²t for each wire gauge. (See Table 3-11, Chapter 3.)

2-2 Breaking performance

Fig. 2-10 Peak let-through current 230V AC

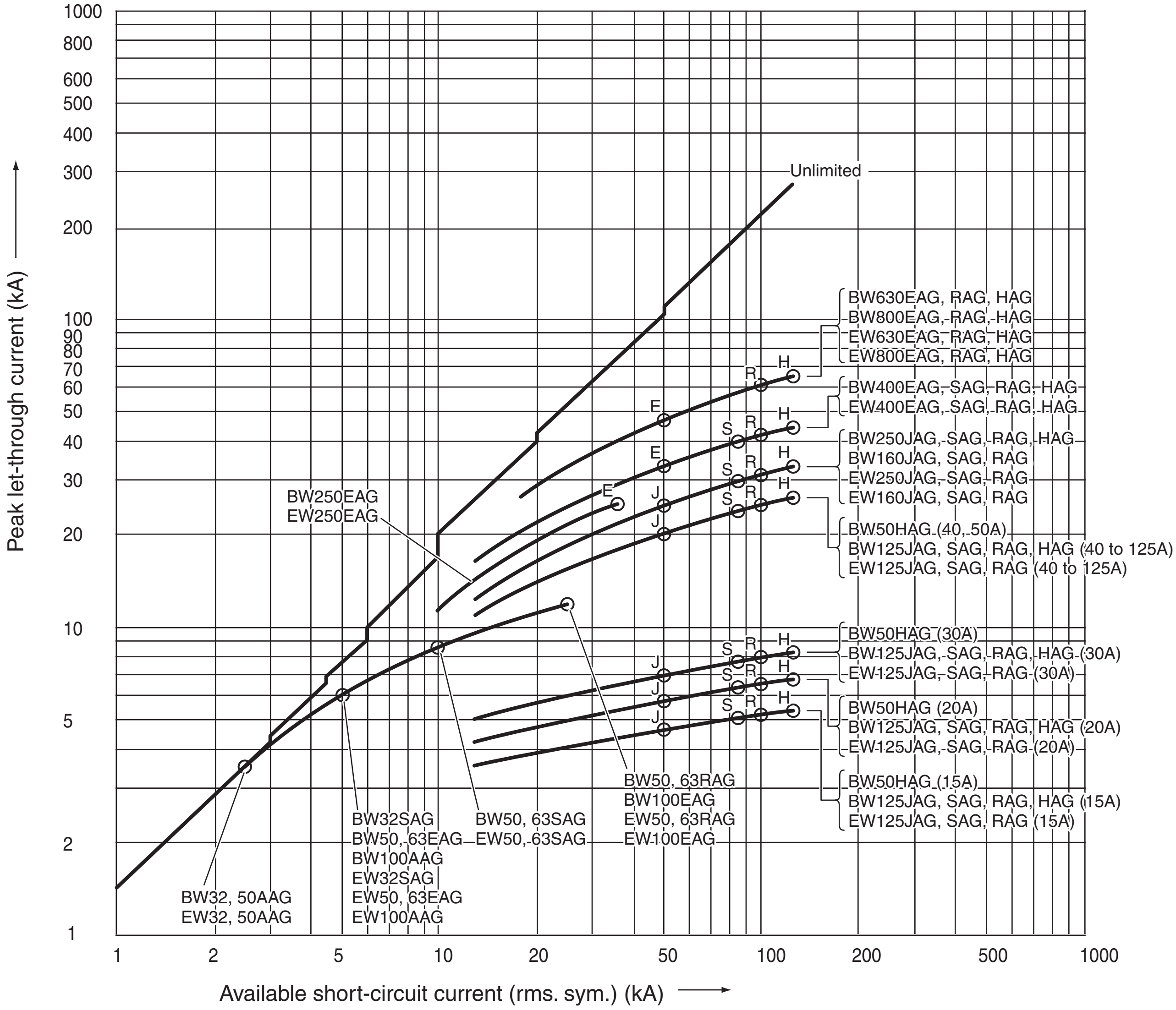
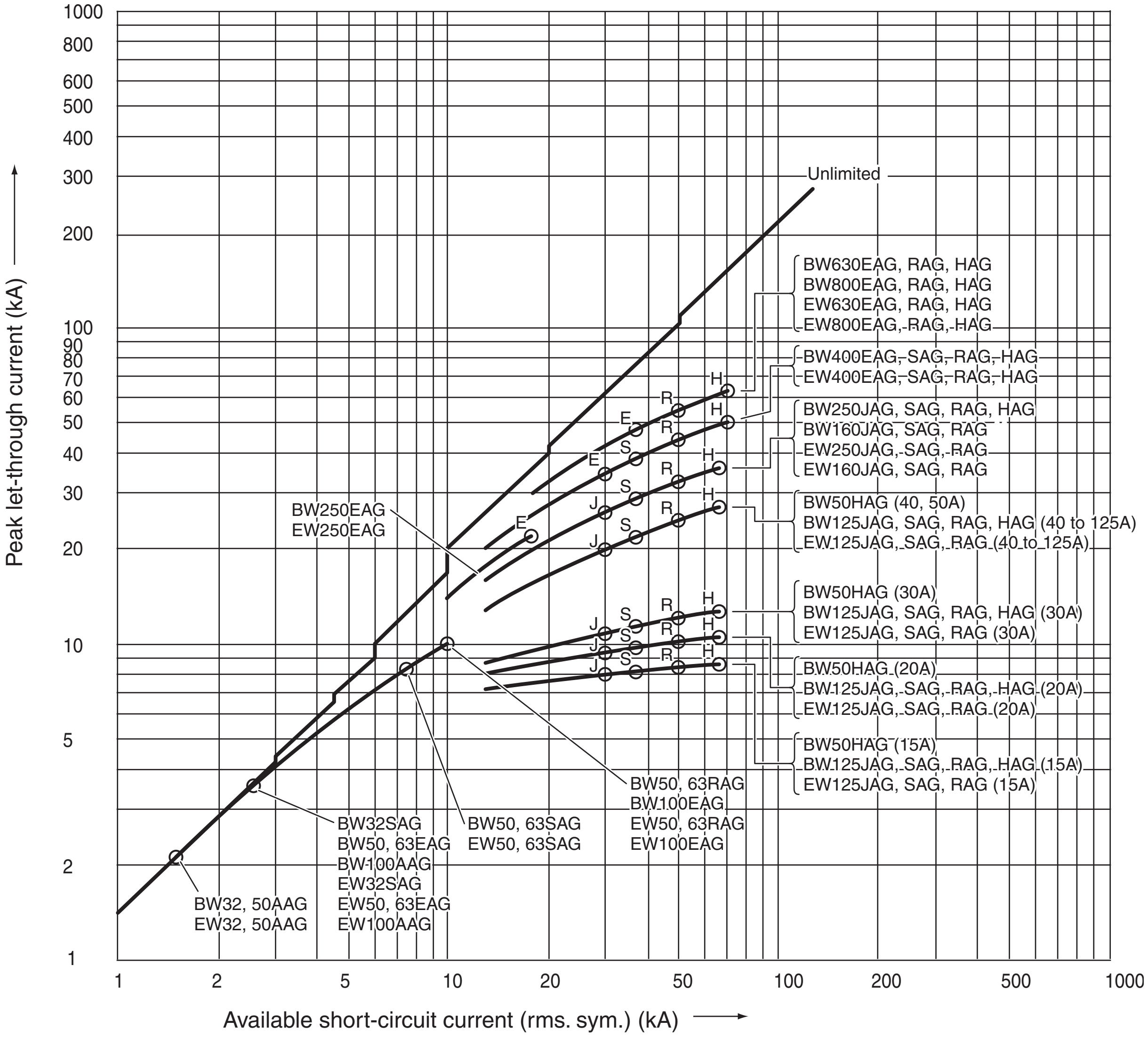
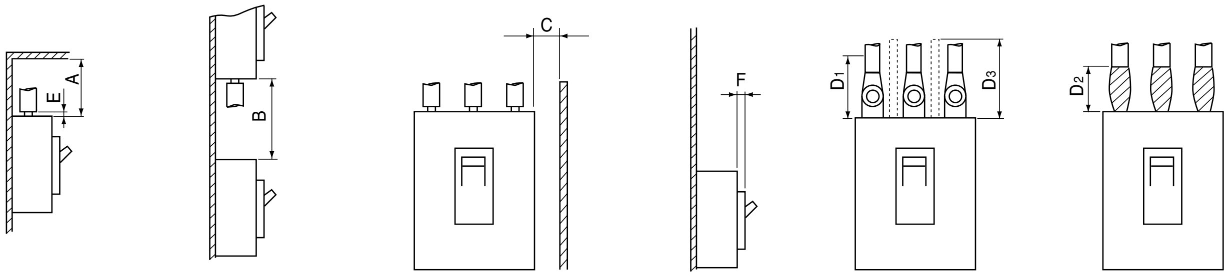


Fig. 2-11 Peak let-through current 400V AC



2-2 Breaking performance

Table 2-7 Arc space, mm



Frame size	MCCB basic type	ELCB basic type (reference)	Ceiling distance A		Vertical distance B		Side plate distance C		Front plate distance				Taping		Barrier
									Painted F		No painted F		Crimp type terminal lug	Bus-bar	
			440V	230V	440V	230V	440V	230V	440V	230V	440V	230V	D1	D2	D3
32A	BW32A	EW32A	–	10	–	10	–	10	–	0	–	0	Exposed live part dimension +20	10	10
		EW32E	10	10	30	10	20	15	0	0	0	0		30	30
	BW32S	EW32S	10	10	30	30	20	15	0	0	0	0		30	30
50A	BW50A	EW50A	–	10	–	10	–	10	–	0	–	0		10	10
	BW50E	EW50E	10	10	30	30	25	15	0	0	0	0		30	30
	BW50S	EW50S	30	10	40	40	25	15	0	0	0	5		30	30
	BW50R	EW50R	50	25	50	50	25	15	0	0	10	5		50	50
	BW50H		60	60	80	80	50	20	5	0	10	5		80	80
63A	BW63E	EW63E	10	10	30	30	25	15	0	0	0	0		30	30
	BW63S	EW63S	30	10	40	40	25	15	0	0	0	0		30	30
	BW63R	EW63R	50	25	50	50	25	15	0	0	10	5		50	50
100A	BW100A	EW100A	–	10	–	20	–	15	–	0	–	0		50	50
	BW100E	EW100E	50	25	50	50	25	15	0	0	10	5		50	50
125A	BW125J	EW125J	40	40	50	50	25	20	0	0	10	5		50	50
	BW125S	EW125S	40	40	60	60	25	20	5	0	10	5		50	50
	BW125R	EW125R	40	40	60	60	25	20	5	0	10	5		50	50
	BW125H		60	60	80	80	50	20	5	0	10	5		80	80
160A	BW160E	EW160E	40	40	50	50	50	15	0	0	10	5		80	80
	BW160J	EW160J	40	40	60	60	50	20	0	0	10	5		80	80
	BW160S	EW160S	40	40	80	80	50	20	5	0	10	10		80	80
	BW160R	EW160R	40	40	80	80	50	20	5	0	10	10		80	80
250A	BW250E	EW250E	40	40	50	50	50	15	0	0	10	5		80	80
	BW250J	EW250J	40	40	60	60	50	20	0	0	10	5		80	80
	BW250S	EW250S	40	40	80	80	50	20	5	0	10	10		80	80
	BW250R	EW250R	40	40	80	80	50	20	5	0	10	10		80	80
	BW250H		60	60	80	80	60	60	5	0	10	10		80	80
400A	BW400E	EW400E	100	80	100	80	50	20	0	0	10	5		100	100
	BW400S	EW400S	100	80	100	80	50	20	0	0	10	5		100	100
	BW400R	EW400R	100	80	100	80	80	40	5	0	20	10		100	100
	BW400H	EW400H	100	80	100	80	80	40	5	0	20	10		100	100
630A	BW630E	EW630E	100	80	100	80	80	40	0	0	10	5		100	100
	BW630R	EW630R	100	80	100	80	80	40	5	0	20	10		100	100
	BW630H	EW630H	120	100	120	100	80	40	5	0	20	10		120	120
800A	BW800E	EW800E	100	80	100	80	80	40	0	0	10	5		100	100
	BW800R	EW800R	100	80	100	80	80	40	5	0	20	10		100	100
	BW800H	EW800H	120	100	120	100	80	40	5	0	20	10		120	120
1000A	SA1000E	–	150	150	150	150	80	40	5	5	20	20		150	150
1200A	SA1200E	–	150	150	150	150	80	40	5	5	20	20		150	150
1600A	SA1600E	–	150	150	150	150	100	40	5	5	20	20		150	150

2-2-4 Reset time

The reset time is the time it takes the trip device in a breaker to return to its normal operating condition after breaking automatically. With thermal-magnetic types, the directly heated type used in small-frame products takes a minute or so to reset while the indirectly heated type takes slightly longer. The two types function virtually identically with significant current, such as with short-circuit current breaking. Hydraulic-magnetic type breakers, on the other hand, can be reset immediately after tripping. It takes the plunger a few minutes to return to its normal position, however, which means that trip characteristics will not be as specified for a short amount of time. The operating time is virtually the same with massive current, such as with instantaneous tripping, because the plunger hardly moves in those situations. Table 2-8 shows breaker reset times.

Table 2-8 Reset time

MCCB type	ELCB type(Reference)	Overcurrent trip device	Reset time (Minute)	
			With overload current tripping (200% of) current)	With short-circuit current (Icu) breaking
BW32AAG, SAG	EW32AAG, EAG, SAG	Hydoraulic-magnetic	Immediately	Immediately
BW50AAG,EAG, SAG, RAG	EW50AAG, EAG, SAG, RAG			
BW63EAG, SAG, RAG	EW63EAG, SAG, RAG			
BW100AAG, EAG	EW100AAG, EAG			
BW50HAG		Thermal-magnetic	1	2
BW125JAG, SAG, RAG, HAG	EW125JAG, SAG, RAG			
BW160EAG, JAG, SAG, RAG	EW160EAG, JAG, SAG, RAG			
BW250EAG, JAG, SAG, RAG, HAG	EW250EAG, JAG, SAG, RAG			
BW400EAG, SAG, RAG, HAG	EW400EAG, SAG, RAG, HAG	Thermal-magnetic	2	2
BW630EAG, RAG, HAG	EW630EAG, RAG, HAG			
BW800EAG, RAG, HAG	EW800EAG, RAG, HAG			
SA1003E, SA1004E	---	Solid state	Immediately	Immediately
SA1203E, SA1204E				
SA1603E, SA1604E				

2-3 Overload switching performance

Contacts should have no overt signs of damage, burn out, welding and other electrical or mechanical faults after an overload switching test is conducted in accordance with the stipulations (IEC 60947) in Table 2-9.

Table 2-9 Overload switching test conditions

Rated current (A)	Circuit condition				Operating system and No. of operations		Operations per hour
	Voltage	Current	Power factor/time constant	Frequency	Manual closing Manual opening	Manual closing Automatic opening	
100 or less	Max. operating voltage (Ue)	AC: 6 times the rated current (In), 150A min.	Power factor: 0.5	45 to 62Hz	9 Total: 12	3	120
More than 100, but 315 or less							120
More than 315, but 630 or less		DC: 2.5 times the rated current (In)	Time constant: 2.5ms				60

Notes:
- This test may be conducted on breakers rated above 630A.
- The trip device must be set at maximum if this test is conducted on breakers with adjustable trip devices.
- If the maximum current set for the short-circuit trip device in a breaker is lower than the test current, then the circuit must be broken automatically all 12 times required in the test.
- In each manual operating cycle, the breaker must close the circuit long enough to allow current to reach maximum levels. This must not take longer than 2 seconds however.

2-4 Performance with current at 100%

2-4-1 Temperature rise

At the rated current, the temperature of MCCBs and ELCBs (reference) should not rise above the values given in Table 2-10 at any specification.

Table 2-10 MCCB and ELCB temperature rise at the rated current

	Terminal	Handle	Cover top
IEC 60947-2 Table 7	80K	35K	50K
JISC 8201-2-1, JISC 8201-2-2	80K	35K	50K
UL 489 Table 40.1 (reference)	50K	60K	60K
UL 508 Table 40.1 (reference)	65K	–	–

2-4-2 Internal resistance and power consumption

The breakers used in AC circuits have the following losses.
1. Resistance loss in conductive parts and contacts
2. Iron loss induced in internal magnetic materials
The losses are so small at commercial frequencies that they can be ignored as is often done with resistance losses.
Table 2-11 shows average internal resistance per phase as well as power consumption at the rated current for MCCBs.

2-4 Performance with current at 100%

Table 2-11 MCCB internal resistance and power consumption

Type	Rated current (A)	Internal resistance (mΩ/phase)	Power consumption (W/3-phase)
BW32AAG BW32SAG	3	101.1	2.7
	5	39.3	2.9
	10	11.4	3.4
	15	5.8	3.9
	20	3.8	4.6
	30	2.3	6.2
	32	2.1	6.4
BW50AAG BW50EAG BW50SAG	5	39.3	2.9
	10	11.4	3.4
	15	5.8	3.9
	20	3.8	4.6
	30	2.3	6.2
	32	2.1	6.4
	40	1.7	8.2
	50	1.4	11.0
BW50RAG	10	10.9	3.3
	15	5.3	3.6
	20	3.3	4.0
	30	1.8	4.9
	32	1.7	5.2
	40	1.2	5.8
	50	1.0	7.5
BW50HAG	15	14.0	9.5
	20	11.8	14.2
	30	5.0	13.5
	40	2.7	13.0
	50	2.1	15.8
BW63EAG BW63SAG BW63RAG	60	0.9	9.7
	63	0.9	10.7
BW100AAG	60	0.9	9.7
	63	0.9	10.7
	75	0.7	11.8
	100	0.6	18.0
BW100EAG	50	1.0	7.5
	60	0.9	9.7
	63	0.9	10.7
	75	0.7	11.8
	100	0.6	18.0
BW125JAG BW125SAG BW125RAG BW125HAG	15	14.0	9.5
	20	11.8	14.2
	30	5.0	13.5
	40	2.7	13.0
	50	2.1	15.8
	60	1.5	16.2
	75	1.1	18.6
	100	0.8	24.0
	125	0.7	32.8

Type	Rated current (A)	Internal resistance (mΩ/phase)	Power consumption (W/3-phase)
BW160EAG BW160JAG BW160SAG BW160RAG	125	0.56	26.3
	150	0.49	33.1
	160	0.39	30.0
BW250EAG BW250JAG BW250SAG BW250RAG BW250HAG	175	0.39	35.8
	200	0.31	37.2
	225	0.24	36.5
	250	0.21	39.4
BW400EAG BW400SAG BW400RAG BW400HAG	250	0.25	47.0
	300	0.21	57.0
	350	0.19	70.0
	400	0.18	86.4
BW630EAG BW630RAG BW630HAG	500	0.117	88.0
	600	0.097	105.0
	630	0.097	116.0
BW800EAG BW800RAG BW800HAG	700	0.087	128.0
	800	0.070	134.0
SA1000E	500	0.04	30.0
	600	0.04	43.2
	700	0.04	58.8
	800	0.04	76.8
	900	0.04	97.2
	1000	0.04	120.0
SA1200E	600	0.04	43.2
	700	0.04	58.8
	800	0.04	76.8
	1000	0.04	120.0
	1200	0.04	172.8
SA1600E	800	0.022	42.2
	900	0.022	53.5
	1000	0.022	66.0
	1200	0.022	95.0
	1400	0.022	129.4
	1600	0.022	169.0

2-5 Durability

2-5-1 Switching durability

MCCBs do not require the high-frequency switching capability needed by magnetic motor starters because their primary purpose is to protect cables or equipment against overcurrents. Further, longer durability would detract from the economy of the MCCBs because they are furnished with a switch mechanism and a trip mechanism. IEC specifies the switching performance and durability requirements listed in Table 2-12.

2-5-2 Trip switching durability

There are two types MCCB trip action: trip actuated by the overcurrent trip device, and trip actuated by accessories such as a shunt trip or undervoltage trip device. Trip switching durability is defined as 10% of the total number of switching operations both with and without current as given in Table 2-12. This value, however, assumes mechanical switching, or the breaking of the rated current by a shunt trip device. If the trip is caused by an overcurrent, the durability is lowered depending on the magnitude of the overcurrent because of the resultant contact wear and arc quencher thermal damage. According to IEC 60947-2, trip switching durability is defined as the current and the number of switching operations for an overload test as given in Table 2-12.

Table 2-12 MCCB switching durability

Circuit conditions				Rated current (A)	Operations per hour *	No. of operations		
Voltage	Current	Power factor/ time constant	Frequency			With current	Without current	Total
Rated operating voltage (Ue)	Rated current (In)	Power factor: 0.8 Time constant: 2ms	45 to 62	100 or less	120	1500	8500	10000
				More than 100, but 315 or less	120	1000	7000	8000
				More than 315, but 630 or less	60	1000	4000	5000
				More than 630, but 2500 or less	20	500	2500	3000
				More than 2500	10	500	1500	2000

Notes: * An operating cycle constitutes one making and breaking. It should be closed for 1.5 to 2 seconds.
- The breaker must close the circuit long enough to allow current to reach maximum levels. This must not take longer than 2 seconds however.
- For breakers equipped with a shunt trip device or an undervoltage trip device, 5% of the total number of switching operations should be allocated at the beginning and the end of the test for operation with those tripping devices.

2-5-3 Rated ultimate short-circuit breaking performance

See Table 2-13.

The operating duty for breaking current corresponding to the rated ultimate short-circuit breaking capacity (Icu) of the MCCB can be broken twice with O-t-CO. However, CO after interval t was implemented in case you need to restart when it is not clear what caused the breaker to trip before you have eliminated the cause of the fault. This does not mean that the breaker can function for long after it has tripped, however, and you should replace it with a new one after short-circuit current breaking has occurred.

Table 2-13 Rated ultimate short-circuit breaking

	Circuit conditions	Number of breaks
Single-pole breaking *	Maximum rated operating voltage 25% of (Icu) rated ultimate short-circuit breaking capacity	O-t-CO at each pole: 1 time O:Breaker opens when a short-circuit occurs in a closed circuit. CO:Breaker closes and opens in a shorted circuit. t: Time interval between O and CO Three minutes or the time it takes to reset the MCCB, whichever is longer.
Single or three-phase breaking	Maximum rated operating voltage Rated ultimate short-circuit breaking capacity (Icu)	O-t-CO: 1 time

Note: * Applies to multi-circuit breakers in voltage phase grounding-type distribution systems.

2-5-4 Switching durability of accessories

As Table 2-14 indicates, MCCB accessories whose switching capability requires consideration can be grouped into two types: accessories that are actuated by the switching of the MCCB, and those that are actuated when the MCCB trips. Accessories of the former type require a switching durability equivalent to the associated MCCB. They provide the durability specified by the total number of switching operations both with and without current as given in Table 2-14.

Table 2-14 Switching durability of MCCB accessories

	Accessory actuated by switching of MCCB	Accessory actuated when the MCCB trips
Accessory built into the MCCB	Auxiliary switch (W)	Alarm switch (K) Shunt trip device (F) Undervoltage trip device (R)
External accessory	Operating handle (N, V) Motor operating mechanism (M)	
Durability	Total number of switching operations both with and without current as given in Table 2-12.	10% or more of the total number of switching operations both with and without current as given in Table 2-12.

2-6 Withstand voltage performance

2-6-1 Rated power frequency withstand voltage (IEC 60947-1, 2)

(1) Circuit breaker body

The breaker should function normally with 2000V applied for one minute at the following locations if it is rated at 300V or less, and with 2500V applied for one minute at the following locations if it is rated at more than 300V and 600V or less.

- Between terminals on the power supply side and the load side with the breaker in the open or tripped state.
- Between opposite polarity terminals with the breaker closed. (However, electronic components used for ground-fault detection and overvoltage protection elements must be electrically left open.)
- Between the live part and ground with the breaker open and closed.

(2) Breakers with non-electrically operated accessories

(a) Between accessory circuits and the breaker live part

The breaker should withstand the following voltages above the rated voltage applied to the control circuit for one minute.
60V or less: 1000V
More than 60V, but less than 600V:
(Rated voltage) × 2 + 1000V (1500V min.)

(b) Between accessory circuits and ground

The breaker should withstand (the rated voltage of the accessory × 2 + 1000V) applied for one minute. The 1000V are between contacts on the auxiliary switch.

(3) Electrically operated breakers

(a) Between electrically operated circuits and the live part of the breaker

The breaker should withstand (the rated voltage of the breaker × 2 + 1,000V) applied for one minute.

(b) Between electrically operated circuits and ground

The breaker should withstand (the rated voltage of the electrically operated device × 2 + 1000V) applied for one minute. The 1000V are on the operating motor.

2-6-2 Rated impulse withstand voltage (IEC 60947-1, 2)

Use the test circuit shown in Fig. 2-12 in order to check rated impulse withstand voltage performance. Apply the 1.2 × 50μs voltage waveform shown in Fig. 2-13 between the live part of the specimen and metal plate. Observe the waveform by memory scope to determine whether the MCCB passes or not. (See Fig. 2-14.)

Conduct the test on a new specimen. Use one that came with the accessory, such as an auxiliary switch (W), alarm switch (K), shunt trip device (F) or undervoltage trip device (R).
Fig. 2-14 shows the criteria for the test.

Fig. 2-12 Test circuit for rated impulse withstand voltage characteristics

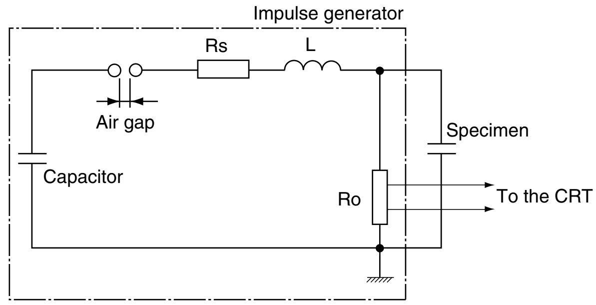


Fig. 2-13 Impulse voltage waveform

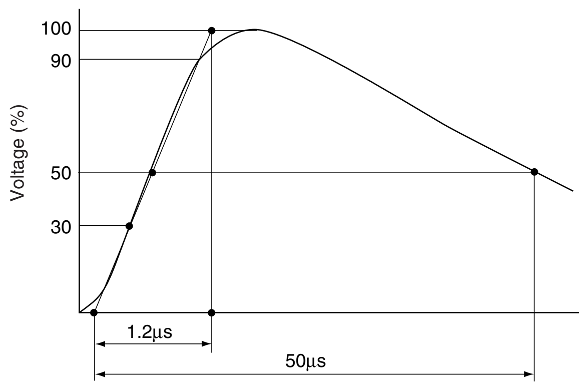
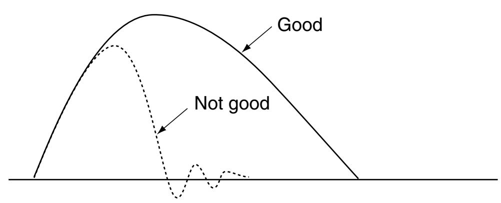


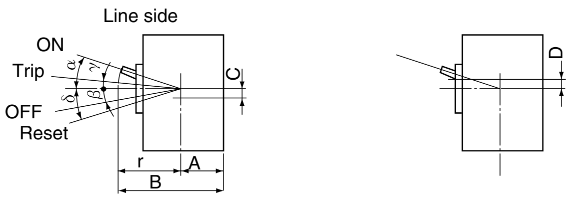
Fig. 2-14 Evaluating MCCBs by waveform observation



2-7 Handle operating force and angle

Table 2-15 shows the operating force and angle of handles by type of breaker.

Table 2-15 Handle operating force and angle



MCCB	ELCB (Reference)	Operating force (N·m)			Operating angle (°)				Dimensions (mm)				Rotating radius r (mm)
		OFF→ ON	ON→ OFF	Trip→ Reset	ON α	OFF β	Trip γ	Reset δ	A	B	C	D	
BW32AAG-2P BW32SAG-2P BW50AAG-2P BW50EAG-2P BW50SAG-2P BW50RAG-2P BW63EAG-2P BW63SAG-2P BW63RAG-2P BW100EAG-2P	EW32AAG-2P EW50AAG-2P	0.42	0.54	0.89	22	15	4	17.5	57	84	9.5	–	26.9
BW32AAG-3P BW32SAG-3P BW50AAG-3P BW50EAG-3P BW50SAG-3P BW50RAG-3P BW63EAG-3P BW63SAG-3P BW63RAG-3P BW100AAG-3P BW100EAG-3P	EW32AAG-3P EW32EAG-3P EW32SAG-3P EW50AAG-3P EW50EAG-3P EW50SAG-3P EW50RAG-3P EW63EAG-3P EW63SAG-3P EW63RAG-3P EW100AAG-3P EW100EAG-2P EW100EAG-3P	0.59	0.7	1.6	22	15	4	17.5	57	84	9.5	–	26.9
BW125JAG-2P		1.18	1.3	1.67	21	10	11	12.5	33.7	95	–	0.8	61.3
BW50HAG-3P BW125JAG-3P BW125SAG-2P,3P BW125RAG-2P,3P BW125HAG-3P	 EW125JAG-3P EW125SAG-3P EW125RAG-3P	1.72	1.9	2.45	21	10	11	12.5	33.7	95	–	0.8	61.3
BW125JAG-4P BW125SAG-4P BW125RAG-4P	EW125JAG-4P EW125SAG-4P EW125RAG-4P	2.35	2.6	3.35	21	10	11	12.5	33.7	95	–	0.8	61.3
BW160EAG-3P BW160JAG-2P,3P BW160RAG-2P,3P BW250EAG-3P BW250JAG-2P,3P BW250RAG-2P,3P BW250HAG-3P	EW160EAG-3P EW160JAG-3P EW160RAG-3P EW250EAG-3P EW250JAG-3P EW250RAG-3P	3.37	3.8	4.9	21	10	11	12.5	33.7	95	–	0.8	61.3
BW160JAG-4P BW160SAG-4P BW160RAG-4P BW250JAG-4P BW250SAG-4P BW250RAG-4P	EW160JAG-4P EW160SAG-4P EW160RAG-4P EW250JAG-4P EW250SAG-4P EW250RAG-4P	4.6	5.21	6.74	21	10	11	12.5	33.7	95	–	0.8	61.3
BW400EAG-2P,3P BW400SAG-2P,3P BW400RAG-2P,3P BW400HAG-2P,3P	EW400EAG-3P EW400SAG-3P EW400RAG-3P EW400HAG-3P	8	7.5	14	22	10.5	6.7	13.5	54.6	146	4.3	–	91.4
BW400RAG-4P BW400HAG-4P	EW400RAG-4P EW400HAG-4P	10.93	10.25	19.13	22	10.5	6.7	13.5	54.6	146	4.3	–	91.4
BW630EAG-3P BW630RAG-3P BW630HAG-3P BW800EAG-3P BW800RAG-3P BW800HAG-3P	EW630EAG-3P EW630RAG-3P EW630HAG-3P EW800EAG-3P EW800RAG-3P EW800HAG-3P	11	10	20	22	10.5	6.7	13.5	54.6	146	4.3	–	91.4
BW630RAG-4P BW630HAG-4P BW800RAG-4P BW800HAG-4P		15.03	13.67	27.33	22	10.5	6.7	13.5	54.6	146	4.3	–	91.4

Chapter 3

Selection and application

CONTENTS

3-1 Selection check points

When applying MCCBs to low-voltage circuits it is necessary to consider their short-circuit breaking capacities, rated voltages, rated currents, installation details, protection systems, wire sizes and type of load (motor, capacitor, mercury arc lamp, etc.)
Fig. 3-1 illustrates points to be considered when selecting MCCBs. These are listed in Table 3-1.

3-1-1 MCCB selection check points

(1) Power supply system
- Distribution system type/Network
- Power supply capacity/Transformer kVA
- Regulation
- AC or DC
- Frequency
- Line voltage/Rated voltage
- Circuits/Single-phase, 3-phase

(2) Location
- Environment conditions
- Ambient temperature

(3) Installation and connection
- Motor control center, distribution board
- Main or branch
- Front mounted, front connection
- Front mounted, rear connection
- Flush mounted
- Plug-in
- Draw-out
- Arc space clearance
- Mounting angle
- Termination

(4) Applications
- Line protection
- Motor protection
- Instantaneous trip
- Marine use
- Special purpose/Welder, capacitor, lights

(5) Short-circuit breaking capacity
- Fully-rated
- Selective trip
- Cascade (backup) trip

(6) Short-circuit current
- MCCB series
- Frame size

(7) Loads
- MCCB rated current
- Wire size, bus bars
- Current-time characteristics

(8) Characteristics
- Wire and load equipment
  Mechanical and allowable thermal characteristics
- Breaker
  Breaking characteristics
  Operation characteristics

(9) Operation
- Switching frequency/operating durability
- Operation method
  Remote – manual, motor driven
  External operating handle (V and N)

(10) Accessories
- Undervoltage trip
- Auxiliary switch
- Shunt trip
- Alarm switch
- Padlocking
- Terminal cover
- Mechanical interlock device
- Enclosure

Fig. 3-1 Check points for selection

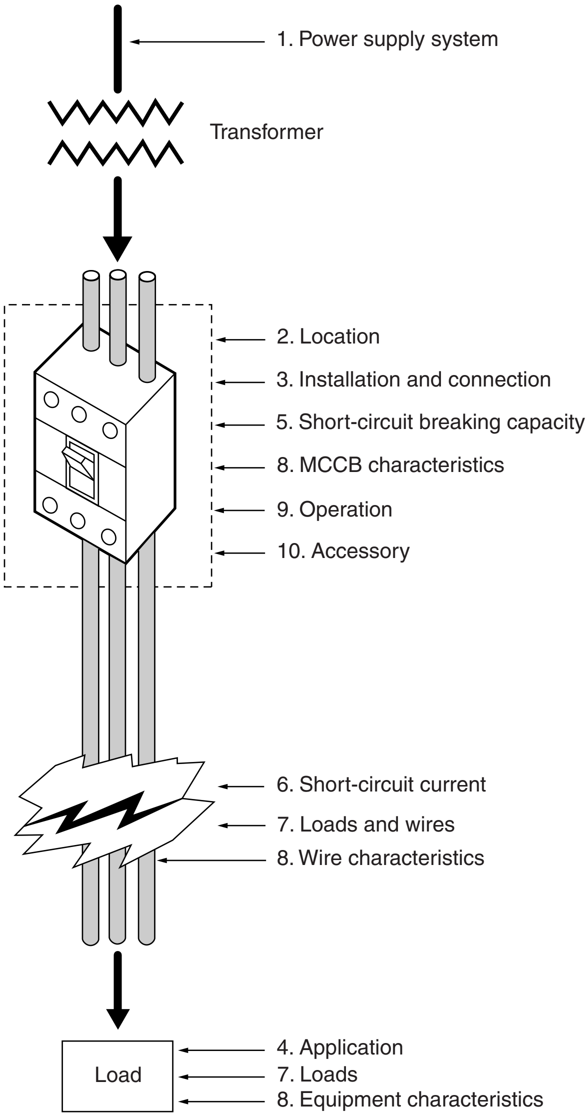


Table 3-1 Systematic MCCB selection

Check point	Check points for system designing	Check points for circuits and protective equipment	Check points for MCCBs	Specifications of MCCBs
Total load capacity	Power supply capacity Power supply system	Short-circuit current	Icu	Series Frame size
Load voltage	Power supply voltage (AC, DC, frequency)			Rated voltage (Ue)
	No. of circuit wires			No. of poles
Load current	Wire size	Wires and equipment connected in series • Mechanical allowable characteristics • Thermal allowable characteristics	Breaking characteristics Operating characteristics	Series Frame size Rated current (In)
Load types		Load current-time characteristics		
Installed location	Main circuit Branch circuit	Protected equipment types (Wires, loads)	Types by use	Line protection Motor protection Instantaneous trip type
Operation		Switching frequency Operating method (Remote, manual)	Operating durability Operating device Accessories	Motor driven (M) External operating handle (V, N) Shunt trip (F) Undervoltage trip (R) Auxiliary switch (W) Alarm switch (K)
Installation and connection		Switchboard construction	Installation and connection method	Front mounting, front connection Front mounting, rear connection (X) Plug-in (P)
Power supply reliability	Selective trip coordination	Line side or load side protective device • Breaking characteristics • Operating characteristics	Breaking characteristics Operating characteristics	Series Frame size Rated current (In)
Economical use	Cascade (back up) trip coordination Main MCCBs Branch MCCBs	Allowable characteristics of load side protective devices Operating characteristics of line side protective devices	Operating characteristics Allowable characteristics	

3-1-2 Selecting and MCCB ratings

(1) Rated ultimate short-circuit breaking capacity (Icu)

A breaker must be selected that has a rated ultimate short-circuit breaking capacity (Icu) higher than the short-circuit current that passes through it. The short-circuit current will vary with transformer capacity as well as with the impedance between the load and the MCCB.
Since a breaker should protect the load-end terminal and protect against failures that occur near that terminal, it should have a breaking capacity that is higher than the short-circuit current at the load-end terminal.

(2) Rated current

The rated current of an MCCB is the maximum current that can be continuously flowed through the MCCB without problems, and should be higher than the maximum load current expected in the circuit.
Select an MCCB with a rating that can carry a load current, including transient currents, such as motor starting current, and that can protect the cable and equipment from the overcurrent.

The load current must not exceed the derated current value when the MCCB is derated according to the following environmental factors.

1. Effects of ambient temperature
   MCCB performance conforms to the standard operating conditions stipulated in IEC 60947-2. (For further details, see Table 4-1.)
   When the ambient temperature exceeds standard operating conditions (–5 to 40°C), you must select an MCCB that allows less load current to pass through the breaker.
2. Difference between the nominal rated current of the load equipment and its actual value
3. Increase in the load current resulting from supply voltage variations
4. Frequency variations (including waveform distortion)
5. Other

(3) Rated frequency

MCCBs for AC application are rated for operation at both 50 and 60Hz. If these MCCBs are used in circuits having other frequencies, their operating performance, current carrying capability, or breaking characteristics may be altered, and prior verification is required. (Refer to page 75 3-12.)
When MCCBs are to be used for DC circuits, it is important to ensure that the MCCBs are marked with “Acceptable DC circuits.” (Refer to page 76 3-13.)

3-1-3 Overcurrent protection principle

Fig. 3-2 is a schematic diagram of a typical low-voltage distribution system. The aim of overcurrent protection is to safeguard the system against overcurrent faults, to ensure high power-feeding reliability, and to establish an economical protecting system.
In the overload or intermediate overcurrent region, the combination of a protective device and load equipment to be protected, such as motors including cables, must be determined carefully. Generally, the combination is determined by considering the protection characteristic curve of the protection device (MCCB) and the thermal damage characteristics of the equipment to be protected. As shown in Fig. 3-3, overcurrent protection is available in the region where the operating curve of the circuit breaker lies below the thermal damage characteristics of the equipment to be protected.

Fig. 3-2 Typical low-voltage distribution system

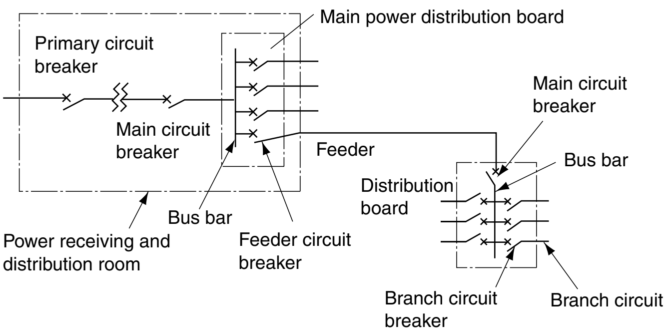
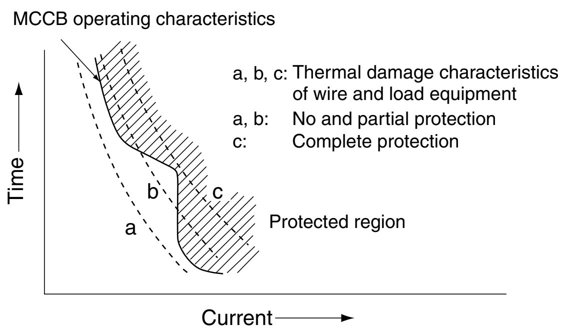


Fig. 3-3 Wiring and load protection using MCCBs (Overload and intermediate overcurrent region)



3-1-4 Protective coordination

When an overcurrent fault occurs, an overcurrent (overload current or short-circuit current) flows from the power source to the fault point. In this situation it is essential to not only safeguard the system against the fault current but ensure system reliability and economics while keeping other systems least affected by the fault. A scheme of overcurrent protection encompassing all of these considerations is called overcurrent protective coordination.

Generally, overcurrent protective coordination allows for the following (Table 3-2):

- Coordination between the protective device and protected equipment
- Selective trip coordination between protective devices
- Cascade (backup) trip coordination between protective devices

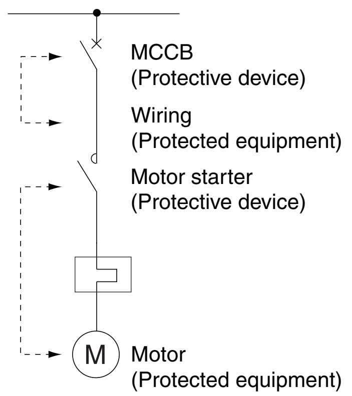
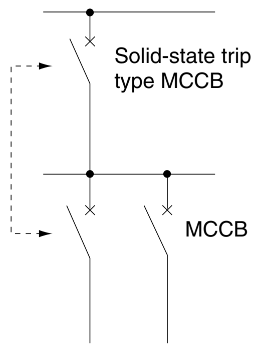
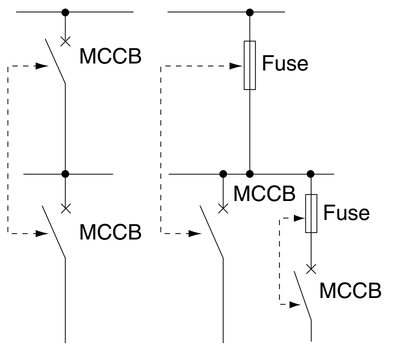
(1) Methods of coordination

It is important that the operating characteristics of the protective device (such as a circuit breaker or fuse) span the whole overcurrent range to safeguard the cable and load equipment. Reviews of both the overload current (overcurrent closer to the rated current) and the short-circuit current region are required.

Factors for consideration to ensure positive overcurrent protection should include:

- Short-circuit current at the point at which an MCCB is to be installed
- Damage characteristics of the wire in the overload region
- Allowable current and allowable I^2t value of the wire at the short-circuit time
- Current-time characteristics in the MCCB overload region
- Rated short-circuit breaking capacity of the MCCB
- Max. breaking I^2t value at the time of MCCB breaking
- Freedom from MCCB malfunctioning caused by ambient conditions, starting characteristics of the load equipment, etc.

Table 3-2 Low-voltage overcurrent protective coordination

Kind of coordination	Coordination between the protective device and equipment to be protected	Coordination between protective devices	
		Selective trip coordination	Cascade (backup) trip coordination
Objective	Protecting equipment	Improved power supply reliability	Economical protective coordination
Description	A protective device protects the wiring and load equipment against thermal and mechanical damage due to overcurrents.	Protective devices on the line side and the load side working in coordination prevent the short-circuit fault from extending from the fault circuit to other cables and also minimize the scope of power failure.	An economical circuit breaker with a small-short-circuit breaking capacity is used, with the short-circuit breaking of short-circuit currents higher than the rated short-circuit breaking capacity being undertaken by protective devices connected in series on the source line side.
Coordination condition	• Safe breaking of fault currents • Protection of wiring and load equipment against thermal or mechanical damage.	The load side protection device completes current breaking over the entire fault current range before the line side protection device is tripped, or before starting irreversible trip operation.	If a short-circuit current higher than the Icu of the load side protection device flows, line side protection devices connected in series break the current, protecting the load side protection device against expected thermal and mechanical damages.
Protective device state	Single or combined	Combined	Combined
Typical system (indicating the relationship of coordination)			

The breaker away from the shorting point on the power supply side must trip whenever short-circuit current occurs, but it must protect equipment from the thermal and mechanical stresses generated as short-circuit current passes through the circuit as well. This means the current peak value i_{pb} and the let-through current $\int i_b^2 dt$ at the time of MCCB breaking must be below the allowable current peak value i_{pa} of the protected equipment as well as the $\int i_a^2 dt$ in the breaking characteristics of the overcurrent protective device. In short, the following must be true.

$$i_{pa} > i_{pb}, \quad \int i_a^2 dt > \int i_b^2 dt$$

This point is especially important because breakers with relatively low rated currents and higher short-circuit braking capacity are used more offen in today's branch circuits.

Overcurrent protection method:
An overcurrent breaker operates on the principle that one protective device alone will cut off short-circuit current passing through it. This is called a fully-rated system. When a single protective device is insufficient, then another breaker is installed at the power supply side. This is called a cascade (backup) system, and it is often used to take advantage of more economical breaking method.
In an effort to ensure a more reliable power supply, only the breaker on the power supply side that is closest to the fault point will trip when a short-circuit fault occurs at a branching circuit such as a distribution system terminal. The operating times must be coordinated between the breakers as a result so they will not track the breaker on the power supply side. This is known as selective trip coordination as opposed to the fully-rated system. (Table 3-3)

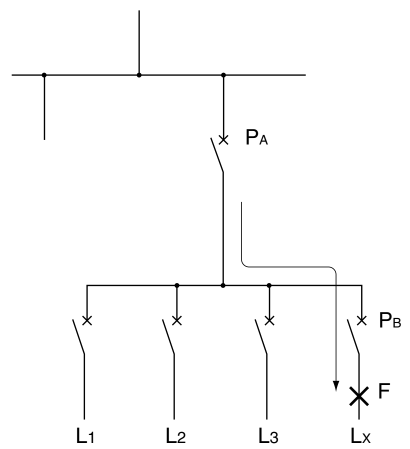
Table 3-3 Low-voltage overcurrent protection systems

Protection system		Purpose	Features	Protective device
Fully-rated system	Selective tripping	• Cuts off overcurrent. • Thermally and mechanically protects wiring and load equipment across the entire overcurrent range.	Improves the system's power feeding reliability.	Combination
	Non-selective tripping		–	Single or combination
Cascade (backup) system	Non-selective tripping		Provides an economical protection system.	Combination

(2) Selective trip coordination

In the main circuit of facilities having a large power receiving capacity or in systems containing an important load, selective trip coordination should be used to provide improved power feeding reliability.
Selective trip coordination between protection devices ensure that only the protection device located closest to a fault point trips, and the line side protection devices remain closed.
In Fig. 3-4, for example, when a short-circuit fault occurs at point F, only protection device P_B is tripped. Line side protection device P_A is not unactuated thus allowing an uninterrupted supply of power to the normal circuits L_1, L_2, and L_3.
The device system configuration for selective trip coordination must be such that the load side protection device completes the breaking of the fault current over the entire overcurrent range before the line side protection device is tripped, or before starting irreversible trip operation.
This condition must be met in both the overload current and the short-circuit current regions.
Selective trip coordination should be designed based on the overall system, but it is more commonly used in critical circuits or on key lines near the power supply. It is particularly important to coordinate between take-off circuit breakers and branch MCCBs in spot network systems. It ensures the take-off line will not be cut off when there is a terminal system failure.

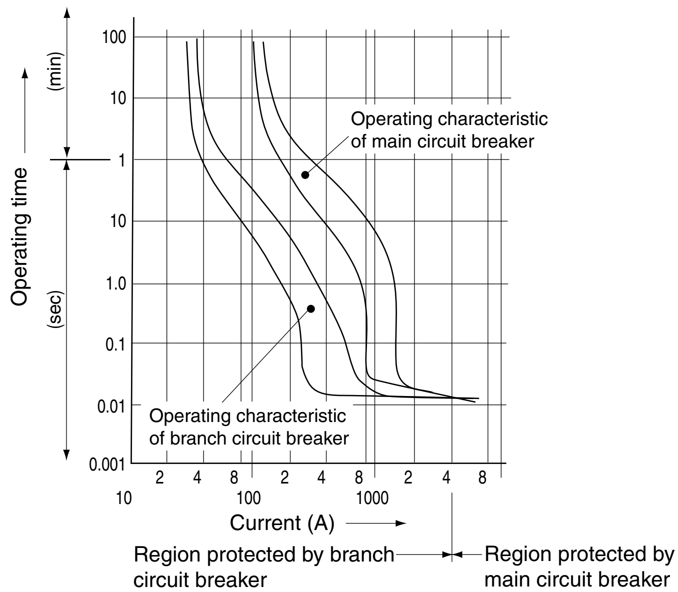
Fig. 3-4 Low-voltage power receiving system



(3) Cascade (backup) trip coordination

Selective trip coordination requires that each protective device have a sufficient short-circuit breaking capacity (fully-rated system). A fully-rated system, however, would not be economical to implement in large-capacity low-voltage systems. An economic solution is cascade (backup) trip coordination.
In cascade (backup) trip coordination, if a short-circuit current higher than the rated short-circuit breaking capacity of the load side protection device flows, the line side protection devices connected in series break the current to protect the load side protection device against thermal or mechanical damage.
Either a current-limiting fuse or current-limiting circuit breaker is used as the line side protection device.
Fig. 3-5 shows typical cascade trip coordination with a distribution board circuit breaker backed up by a current-limiting fuse.
The cascade (backup) system combines non-selective tripping systems for short-circuit current tripping, but short-circuit failures that actually require backup occur only once every few years. Because the initial cost of installing the system is high, however, an economical protective system designed using backup coordination is a more sensible approach for general circuits.

Fig. 3-5 Cascade trip coordination



3-2 Cascade trip applications

3-2-1 Conditions for cascade (backup) trip coordination

A cascade (backup) system established between overcurrent circuit breakers can yield a very economical system as described in 3-1-4.
When the main circuit breaker in a cascade (backup) system has sufficient breaking capacity and trips quickly in the event of a short-circuit fault, it can minimize the amount of energy passing through the branch MCCB. This depends on the following conditions, however, which the main breaker alone or a branch MCCB connected in series with the main breaker must satisfy:

(a) The peak let-through current must be kept below the allowable mechanical strength limit of the branch MCCB.
$I_{PL} < I_{PA}$

(b) The let-through I^2t must be kept below the allowable thermal strength limit of the branch MCCB.
$\int i_L^2 dt < \int i_A^2 dt$

(c) The arc energy generated in the branch breaker must be kept below allowable limits for the branch MCCB.
$\int e_L i_L dt < \int e_A i_A dt$

where

I_{PL}: Peak let-through current (A)
$\int i_L^2 dt$: Let-through I^2t (A^2s)
$\int e_L i_L dt$: Arc energy generated in the branch MCCB
I_{PA}: Allowable through current peak value for the branch MCCB
$\int i_A^2 dt$: Allowable I^2t for the branch MCCB
$\int e_A i_A dt$: Allowable arc energy for the branch MCCB

Condition (a) shows the effect the backup breaker has on controlling current and it suggests that current-limiting coordination of breakers is easier.

Condition (b) suggests that coordination is easier at each current level as the time the current is on gets shorter. The main breaker must trip at high speed in this case.

Condition (c) suggests that coordination is easier with less arc energy passing through the branch MCCB

The amount of arc energy present with a short circuit is determined by the short-circuit capacity of the system. If the amount of arc energy present when the backup MCCB trips is $\int e_S i_S dt$, it yields the following equation.

$$\int e_S i_S dt + \int e_L i_L dt = C \text{ (a constant)}$$

It follows that $\int e_S i_S dt$ should be as high as possible for easier coordination. This suggests that a system with backup MCCBs that have a faster contact opening time and higher arc voltage is better. It also suggests that either a current-limiting fuse or current-limiting circuit breaker is most appropriate for backup coordination.

3-2-2 Criteria for cascade (backup) trip coordination

Various breaker-based breaker-breaker or breaker-fuse combinations suitable for backup have been reported. However, testing and other standards are not well defined for backup protection at this point. Protective equipment combinations will have to be defined through uniform testing methods and criteria in order to ensure proper backup protection with minimal confusion.
Appendix A of IEC60947-2 stipulates protection coordination standards for cascade (backup) systems. Table 3-4 shows criteria from that appendix.

Table 3-4 Criteria for cascade (backup) systems (Appendix A of IEC60947-2)

Item	Items tested after the shorting test	Criteria
1	Withstand voltage and insulation resistance	Good
2	Contact welding	Not welded
3	250% current tripping	Good

Tables 3-5 (a) and (b) show MCCB combination used for cascade (backup) coordination.

Table 3-5 (a) Summary of combinations used for cascade (backup) coordination

230V AC

Branch circuit breaker		Main circuit breaker model	BW 100 EAG	BW 125 JAG	BW 125 RAG	BW 125 JAG	BW 160 EAG BW 250 EAG	BW 160 JAG BW 250 JAG	BW 160 RAG BW 250 RAG	BW 250 HAG	BW 400 EAG	BW 400 SAG	BW 400 RAG	BW 400 HAG	BW 630 EAG	BW 630 RAG	BW 630 HAG	BW 800 EAG	BW 800 RAG	BW 800 HAG
			EW 100 EAG	EW 125 JAG	EW 125 RAG	EW 125 JAG	EW 160 EAG EW 250 EAG	EW 160 JAG EW 250 JAG	EW 160 RAG EW 250 RAG	EW 250 HAG	EW 400 EAG	EW 400 SAG	EW 400 RAG	EW 400 HAG	EW 630 EAG	EW 630 RAG	EW 630 HAG	EW 800 EAG	EW 800 RAG	EW 800 HAG
MCCB	ELCB (reference)	Icu (kA) sym	25	50	100	125	36	50	100	125	50	85	100	125	50	100	125	50	100	125
BW32AAG	EW32AAG	2.5	5	10	10	10	5	7.5	7.5	7.5	–	–	–	–	–	–	–	–	–	–
	EW32EAG	2.5	5	10	10	10	5	7.5	7.5	7.5	–	–	–	–	–	–	–	–	–	–
BW32SAG	EW32SAG	5	22	50	60	60	10	30	30	30	–	–	–	–	–	–	–	–	–	–
BW50AAG	EW50AAG	2.5	5	10	10	10	5	7.5	7.5	7.5	–	–	–	–	–	–	–	–	–	–
BW50EAG BW63EAG	EW50EAG EW63EAG	5	22	50	60	60	10	30	30	30	–	–	–	–	–	–	–	–	–	–
BW50SAG BW63SAG	EW50SAG EW63SAG	10	22	50	60	60	10	30	30	30	–	–	–	–	–	–	–	–	–	–
BW50RAG BW63RAG	EW50RAG EW63RAG	25	–	50	85	85	36	50	50	50	35	50	50	50	42	50	50	42	50	50
BW100AAG	EW100AAG	5	22	50	60	60	10	30	30	30	–	–	–	–	–	–	–	–	–	–
BW100EAG	EW100EAG	25	–	50	85	85	36	50	50	50	35	50	50	50	35	50	50	35	50	50
BW125JAG	EW125JAG	50	–	–	100	100	–	50	100	100	50	85	85	85	50	85	85	50	85	85
BW125RAG	EW125RAG	100	–	–	–	–	–	–	100	100	–	–	100	125	–	100	125	–	100	125
BW160EAG BW250EAG	EW160EAG EW250EAG	36	–	–	–	–	–	50	60	60	42	50	50	50	42	42	50	42	50	50
BW160JAG BW250JAG	EW160JAG EW250JAG	50	–	–	–	–	–	–	100	100	50	85	85	85	50	85	85	50	85	85
BW160RAG BW250RAG	EW160RAG EW250RAG	100	–	–	–	–	–	–	–	–	–	–	100	125	–	100	125	–	100	125
BW400EAG	EW400EAG	50	–	–	–	–	–	–	–	–	–	85	85	100	50	85	85	50	85	85
BW400SAG	EW400SAG	85	–	–	–	–	–	–	–	–	–	–	100	125	–	100	125	–	100	125
BW400RAG	EW400RAG	100	–	–	–	–	–	–	–	–	–	–	–	125	–	100	125	–	100	125
BW630EAG	EW630EAG	50	–	–	–	–	–	–	–	–	–	–	–	–	–	85	100	50	85	100
BW630RAG	EW630RAG	100	–	–	–	–	–	–	–	–	–	–	–	–	–	–	125	–	100	125

3-2 Cascade trip applications

Table 3-5 (b) Summary of combinations used for cascade (backup) coordination

400V AC

Branch circuit breaker		Main circuit breaker model	BW 100 EAG	BW 125 JAG	BW 125 RAG	BW 125 JAG	BW 160 EAG BW 250 EAG	BW 160 JAG BW 250 JAG	BW 160 RAG BW 250 RAG	BW 250 HAG	BW 400 EAG	BW 400 SAG	BW 400 RAG	BW 400 HAG	BW 630 EAG	BW 630 RAG	BW 630 HAG	BW 800 EAG	BW 800 RAG	BW 800 HAG
			EW 100 EAG	EW 125 JAG	EW 125 RAG	EW 125 JAG	EW 160 EAG EW 250 EAG	EW 160 JAG EW 250 JAG	EW 160 RAG EW 250 RAG	EW 250 HAG	EW 400 EAG	EW 400 SAG	EW 400 RAG	EW 400 HAG	EW 630 EAG	EW 630 RAG	EW 630 HAG	EW 800 EAG	EW 800 RAG	EW 800 HAG
MCCB	ELCB (reference)	Icu (kA) sym	10	30	50	65	18	30	50	65	30	36	50	70	36	50	70	36	50	70
BW32SAG	EW32SAG	2.5	10	10	15	15	10	10	10	10	–	–	–	–	–	–	–	–	–	–
BW50EAG BW63EAG	EW50EAG EW63EAG	2.5	10	10	15	15	10	10	10	10	–	–	–	–	–	–	–	–	–	–
BW50SAG BW63SAG	EW50SAG EW63SAG	7.5	10	10	15	15	10	10	10	10	–	–	–	–	–	–	–	–	–	–
BW50RAG BW63RAG	EW50RAG EW63RAG	10	–	25	42	42	15	25	30	30	20	20	20	20	14	14	14	14	14	14
BW100EAG	EW100EAG	10	–	25	42	42	18	25	30	30	14	14	14	14	14	14	14	14	14	14
BW125JAG	EW125JAG	30	–	–	50	50	–	30	50	50	30	36	36	65	36	36	65	36	36	65
BW125RAG	EW125RAG	50	–	–	–	–	–	–	–	–	–	–	50	70	–	50	70	–	50	70
BW160EAG BW250EAG	EW160EAG EW250EAG	18	–	–	–	–	–	25	30	30	30	30	30	42	18	25	25	18	25	25
BW160JAG BW250JAG	EW160JAG EW250JAG	30	–	–	–	–	–	–	–	–	30	36	36	65	36	36	65	36	36	65
BW160RAG BW250RAG	EW160RAG EW250RAG	50	–	–	–	–	–	–	–	–	–	–	50	70	–	50	70	–	50	70
BW400EAG	EW400EAG	30	–	–	–	–	–	–	–	–	–	30	35	65	30	35	65	30	35	65
BW400SAG	EW400SAG	36	–	–	–	–	–	–	–	–	–	–	50	70	36	50	70	36	50	70
BW400RAG	EW400RAG	50	–	–	–	–	–	–	–	–	–	–	–	70	–	50	70	–	50	70
BW630EAG	EW630EAG	36	–	–	–	–	–	–	–	–	–	–	–	–	–	42	65	36	42	65
BW630RAG	EW630RAG	50	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	50	70

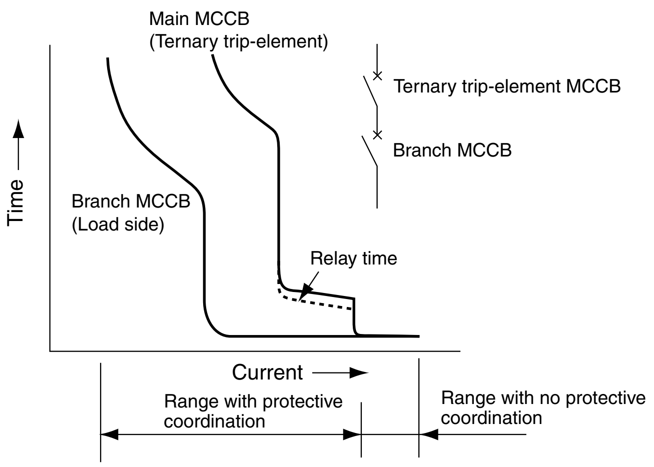
3-3 Selective trip applications

3-3-1 Selective trip coordination of breakers

Selective tripping is coordinated between the breaker on the power supply side and the one on the load side by setting the maximum breaking time for the branch breaker on the load side below the relay time characteristics of the breaker on the power supply side. However, it may not be possible to coordinate selective tripping in some instances because the breaker on the power supply side may have instantaneous characteristics as well. (See Fig. 3-6.)

When a breaker with ternary trip-element characteristics having a short-time delay trip element is used on the power supply side, selective trip coordination is much better than with general-used breakers because the allowable short-time delay is between 0.1 and 0.5 second.
Tables 3-6 (a), (b), (c), and (d) show possible breaker combinations used in selective trip coordination. Coordination is much better if current-limiting breakers are used on the load side because of their current limiting capabilities.

Fig. 3-6 Selective tripping characteristic, MCCB – MCCB



3-3 Selective trip applications

Table 3-6 (a) Selective trip coordination

Selective trip current: 230V AC

(shaded) : Tripping possible over entire range [unit: kA]

Main circuit breaker	Type			**SA225E**	**SA400E**	**H400E**	**SA600E**	**H603E**
	Protective characteristics			Ternary trip-element (long-time delay, short-time delay, instantaneous)				
	In (A)			125–225	200–400	200–400	300–600	300–600
	Icu (kA) (sym)			85	85	100	85	100
Branch circuit breaker	MCCB	ELCB (reference)	Icu (kA)	Icu (kA) For selective trip coordination				
	BW32AAG BW50AAG	EW32AAG EW50AAG	2.5	2.4	2.5	2.5	2.5	2.5
		EW32EAG	2.5	2.4	2.5	2.5	2.5	2.5
	BW50EAG BW63EAG	EW50EAG EW63EAG	5	2.4	3.8	3.8	5.0	5.0
	BW100AAG	EW100AAG	5	2.4	3.8	3.8	5.0	5.0
	BW100EAG	EW100EAG	25	2.4	3.8	3.8	6.0	6.0
	BW160EAG BW250EAG	EW160EAG EW250EAG	36	–	3.8	3.8	6.0	6.0
	BW400EAG	EW400EAG	50	–	–	–	6.0	6.0
	BW630EAG	EW630EAG	50	–	–	–	–	–
	BW800EAG	EW800EAG	50	–	–	–	–	–
	BW32SAG	EW32SAG	5	2.4	3.8	3.8	5.0	5.0
	BW50SAG BW63SAG	EW50SAG EW63SAG	10	2.4	3.8	3.8	6.0	6.0
	BW125JAG	EW125JAG	50	2.4	3.8	3.8	6.0	6.0
	BW160JAG BW250JAG	EW160JAG EW250JAG	50	–	3.8	3.8	6.0	6.0
	BW400SAG	EW400SAG	85	–	–	–	6.0	6.0
	BW50RAG BW63RAG	EW50RAG EW63RAG	25	2.4	3.8	3.8	6.0	6.0
	BW125RAG	EW125RAG	100	2.4	3.8	3.8	6.0	6.0
	BW160RAG BW250RAG	EW160RAG EW250RAG	100	–	3.8	3.8	6.0	6.0
	BW400RAG	EW400RAG	100	–	–	–	6.0	6.0
	BW630RAG	EW630RAG	100	–	–	–	–	–
	BW800RAG	EW800RAG	100	–	–	–	–	–
	BW50HAG	EW50HAG	125	2.4	3.8	3.8	6.0	6.0
	BW125HAG	EW125HAG	125	2.4	3.8	3.8	6.0	6.0
	BW250HAG	EW250HAG	125	–	3.8	3.8	6.0	6.0
	BW400HAG	EW400HAG	125	–	–	–	6.0	6.0
	BW630HAG	EW630HAG	125	–	–	–	–	–
	BW800HAG	EW800HAG	125	–	–	–	–	–

Note: The main circuit breakers are solid-state trip type MCCBs and ELCBs.
Contact FUJI for further information

Selective trip current: 230V AC (Continued)

: Tripping possible over entire range [unit: kA]

				SA800E	H800E	SA1200E	SA1600E	SA2000E	SA2500E
Main circuit breaker	Type			SA800E	H800E	SA1200E	SA1600E	SA2000E	SA2500E
	Protective characteristics			Ternary trip-element (long-time delay, short-time delay, instantaneous)					
	In (A)			400–800	400–800	600–1200	800–1600	1000–2000	1200–2500
	Icu (kA) (sym)			85	100	100	130	130	130
Branch circuit breaker	MCCB	ELCB (reference)	Icu (kA)	Icu (kA) For selective trip coordination					
	BW32AAG BW50AAG	EW32AAG EW50AAG	2.5	2.5	2.5	2.5	2.5	2.5	2.5
		EW32EAG	2.5	2.5	2.5	2.5	2.5	2.5	2.5
	BW50EAG BW63EAG	EW50EAG EW63EAG	5	5.0	5.0	5.0	5.0	5.0	5.0
	BW100AAG	EW100AAG	5	5.0	5.0	5.0	5.0	5.0	5.0
	BW100EAG	EW100EAG	25	7.7	7.7	12.0	15.4	19.2	24.0
	BW160EAG BW250EAG	EW160EAG EW250EAG	36	7.7	7.7	12.0	15.4	19.2	24.0
	BW400EAG	EW400EAG	50	7.7	7.7	12.0	15.4	19.2	24.0
	BW630EAG	EW630EAG	50	7.7	7.7	12.0	15.4	19.2	24.0
	BW800EAG	EW800EAG	50	–	–	12.0	15.4	19.2	24.0
	BW32SAG	EW32SAG	5	5.0	5.0	5.0	5.0	5.0	5.0
	BW50SAG BW63SAG	EW50SAG EW63SAG	10	7.7	7.7	10.0	10.0	110.0	10.0
	BW125JAG	EW125JAG	50	7.7	7.7	12.0	15.4	19.2	24.0
	BW160JAG BW250JAG	EW160JAG EW250JAG	50	7.7	7.7	12.0	15.4	19.2	24.0
	BW400SAG	EW400SAG	85	7.7	7.7	12.0	15.4	19.2	24.0
	BW50RAG BW63RAG	EW50RAG EW63RAG	25	7.7	7.7	12.0	15.4	19.2	24.0
	BW125RAG	EW125RAG	100	7.7	7.7	12.0	15.4	19.2	24.0
	BW160RAG BW250RAG	EW160RAG EW250RAG	100	7.7	7.7	12.0	15.4	19.2	24.0
	BW400RAG	EW400RAG	100	7.7	7.7	12.0	15.4	19.2	24.0
	BW630RAG	EW630RAG	100	7.7	7.7	12.0	15.4	19.2	24.0
	BW800RAG	EW800RAG	100	–	–	12.0	15.4	19.2	24.0
	BW50HAG	EW50HAG	125	7.7	7.7	12.0	15.4	19.2	24.0
	BW125HAG	EW125HAG	125	7.7	7.7	12.0	15.4	19.2	24.0
	BW250HAG	EW250HAG	125	7.7	7.7	12.0	15.4	19.2	24.0
	BW400HAG	EW400HAG	125	7.7	7.7	12.0	15.4	19.2	24.0
	BW630HAG	EW630HAG	125	7.7	7.7	12.0	15.4	19.2	24.0
	BW800HAG	EW800HAG	125	–	–	12.0	15.4	19.2	24.0

Note: The main circuit breakers are solid-state trip type MCCBs and ELCBs.
Contact FUJI for further information

Table 3-6 (b) Selective trip coordination

Selective trip current: 400V AC

: Tripping possible over entire range [unit: kA]

Main circuit breaker	Type			**SA225E**	**SA400E**	**H400E**	**SA600E**	**H603E**
	Protective characteristics			Ternary trip-element (long-time delay, short-time delay, instantaneous)				
	In (A)			125–225	200–400	200–400	300–600	300–600
	Icu (kA) (sym)			50	50	65	50	65
Branch circuit breaker	MCCB	ELCB (reference)	Icu (kA)	Icu (kA) For selective trip coordination				
	BW32AAG BW50AAG		1.5	1.5	1.5	1.5	21.5	1.5
		EW32EAG	1.5	1.5	1.5	1.5	1.5	1.5
	BW50EAG BW63EAG	EW50EAG EW63EAG	2.5	2.4	2.5	2.5	2.5	2.5
	BW100EAG	EW100EAG	10	2.4	3.8	3.8	6.0	6.0
	BW160EAG BW250EAG	EW160EAG EW250EAG	18	2.4	3.8	3.8	6.0	6.0
	BW400EAG	EW400EAG	30	–	–	–	6.0	6.0
	BW630EAG	EW630EAG	36	–	–	–	–	–
	BW800EAG	EW800EAG	36	–	–	–	–	–
	BW32SAG	EW32SAG	2.5	2.4	2.5	2.5	2.5	2.5
	BW50SAG BW63SAG	EW50SAG EW63SAG	7.5	2.4	3.8	3.8	5.8	5.8
	BW125JAG	EW125JAG	30	2.4	3.8	3.8	5.8	5.8
	BW160JAG BW250JAG	EW160JAG EW250JAG	30	2.4	3.8	3.8	5.8	5.8
	BW400SAG	EW400SAG	36	–	–	–	5.8	5.8
	BW50RAG BW63RAG	EW50RAG EW63RAG	10	2.4	3.8	3.8	5.8	5.8
	BW125RAG	EW125RAG	50	2.4	3.8	3.8	5.8	5.8
	BW160RAG BW250RAG	EW160RAG EW250RAG	50	2.4	3.8	3.8	5.8	5.8
	BW400RAG	EW400RAG	50	–	–	–	5.8	5.8
	BW630RAG	EW630RAG	50	–	–	–	–	–
	BW800RAG	EW800RAG	50	–	–	–	–	–
	BW50HAG	EW50HAG	65	2.4	3.8	3.8	5.8	5.8
	BW125HAG	EW125HAG	65	2.4	3.8	3.8	5.8	5.8
	BW250HAG	EW250HAG	65	2.4	3.8	3.8	5.8	5.8
	BW400HAG	EW400HAG	70	–	–	–	5.8	5.8
	BW630HAG	EW630HAG	70	–	–	–	–	–
	BW800HAG	EW800HAG	70	–	–	–	–	–

Note: The main circuit breakers are solid-state trip type MCCBs and ELCBs.
Contact FUJI for further information

Selective trip current: 400V AC (Continued)

(shaded) : Tripping possible over entire range [unit: kA]

Main circuit breaker	Type			**SA800E**	**H800E**	**SA1200E**	**SA1600E**	**SA2000E**	**SA2500E**
	Protective characteristics			Ternary trip-element (long-time delay, short-time delay, instantaneous)					
	In (A)			400–800	400–800	600–1200	800–1600	1000–2000	1200–2500
	Icu (kA) (sym)			50	65	65	85	85	85
Branch circuit breaker	MCCB	ELCB (reference)	Icu (kA)	Icu (kA) For selective trip coordination					
	BW32AAG BW50AAG		1.5	1.5	1.5	1.5	1.5	1.5	1.5
		EW32EAG	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	BW50EAG BW63EAG	EW50EAG EW63EAG	2.5	2.5	2.5	2.5	2.5	2.5	2.5
	BW100EAG	EW100EAG	10	7.7	7.7	10.0	10.0	10.0	10.0
	BW160EAG BW250EAG	EW160EAG EW250EAG	18	7.7	7.7	12.0	15.4	18.0	18.0
	BW400EAG	EW400EAG	30	7.7	7.7	12.0	15.4	19.2	24.0
	BW630EAG	EW630EAG	36	7.7	7.7	12.0	15.4	19.2	24.0
	BW800EAG	EW800EAG	36	–	–	12.0	15.4	19.2	24.0
	BW32SAG	EW32SAG	2.5	2.5	2.5	2.5	2.5	2.5	2.5
	BW50SAG BW63SAG	EW50SAG EW63SAG	7.5	7.5	7.5	7.5	7.5	7.5	7.5
	BW125JAG	EW125JAG	30	7.7	7.7	12.0	15.4	19.2	24.0
	BW160JAG BW250JAG	EW160JAG EW250JAG	30	7.7	7.7	12.0	15.4	19.2	24.0
	BW400SAG	EW400SAG	36	7.7	7.7	12.0	15.4	19.2	24.0
	BW50RAG BW63RAG	EW50RAG EW63RAG	10	7.7	7.7	10.0	10.0	10.0	10.0
	BW125RAG	EW125RAG	50	7.7	7.7	12.0	15.4	19.2	24.0
	BW160RAG BW250RAG	EW160RAG EW250RAG	50	7.7	7.7	12.0	15.4	19.2	24.0
	BW400RAG	EW400RAG	50	7.7	7.7	12.0	15.4	19.2	24.0
	BW630RAG	EW630RAG	50	7.7	7.7	12.0	15.4	19.2	24.0
	BW800RAG	EW800RAG	50	–	–	12.0	15.4	19.2	24.0
	BW50HAG	EW50HAG	65	7.7	7.7	10.0	10.0	19.2	24.0
	BW125HAG	EW125HAG	65	7.7	7.7	12.0	15.4	19.2	24.0
	BW250HAG	EW250HAG	65	7.7	7.7	12.0	15.4	19.2	24.0
	BW400HAG	EW400HAG	70	7.7	7.7	12.0	15.4	19.2	24.0
	BW630HAG	EW630HAG	70	7.7	7.7	12.0	15.4	19.2	24.0
	BW800HAG	EW800HAG	70	–	–	12.0	15.4	19.2	24.0

Note: The main circuit breakers are solid-state trip type MCCBs and ELCBs.
Contact FUJI for further information

3-3-2 Selective trip coordination between MCCBs and high-voltage side protective devices

(1) Coordination between MCCBs and power fuses

In type PF·S high-voltage power receiving facilities like those shown in Fig. 3-7, power fuses (PF) are often used as protective devices. Power fuses are also used to protect the primary circuit of a transformer as shown in Fig. 3-8.
In these types of facility, selective trip coordination must be maintained between the PF and the MCCB installed on the transformer secondary circuit. Without selective trip coordination between the PF and the MCCB, faults occurring on the load side of the MCCB will trip the PF, causing a total system shutdown.
To establish selective trip coordination between the PF and MCCB, the following condition must be satisfied: when the allowable current-time characteristic curve of the PF is superimposed on the operating characteristic curve of the MCCB as shown in Fig. 3-9 (by converting the current of the PF to the low voltage side, or the current of the MCCB to the high-voltage side), these curves do not cross.
Fig. 3-9 shows the operating characteristics of the MCCB converted to the high-voltage side (transformer primary side). Conversion to the high-voltage side is done by dividing the current in the operating characteristic curve of the MCCB by the voltage ratio of the transformer. (50, if 20kV/400V)
Conversion to the low-voltage side is done by multiplying the current value in the allowable current time characteristic curve of the PF by the same voltage ratio.
Because the maximum rated current of a PF is limited by the conditions stated below, to achieve selective trip coordination, it is necessary to reduce the current rating of the MCCB, or to select an MCCB with an adjustable instantaneous trip current feature.

(a) Conditions for selecting PF current rating:

- Selective tripping can be coordinated with upstream power fuse protective devices.
- A short-circuit current 25 times higher than the transformer current rating can be interrupted within 2 seconds to protect the transformer. Sometimes, an MCCB may be substituted for the PF to provide this function.
- Degradation of the PF due to transformer excitation inrush current can be prevented.

Table 3-7 lists the applicable combinations of FUJI MCCBs and FUJI high-voltage current-limiting fuses from the standpoint of selective trip coordination.

Fig. 3-7 PF·S high-voltage power receiving facility

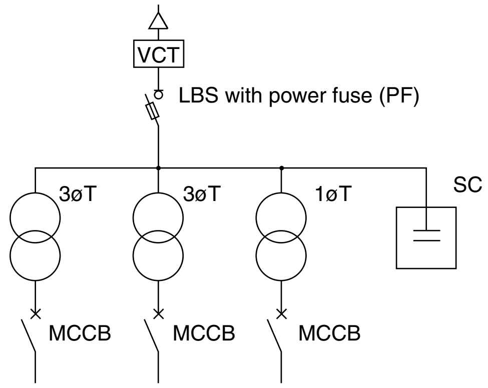


Fig. 3-8 PF high-voltage power receiving facility

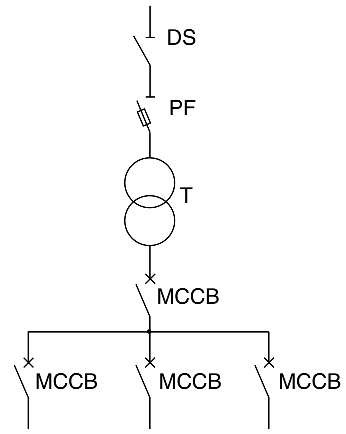
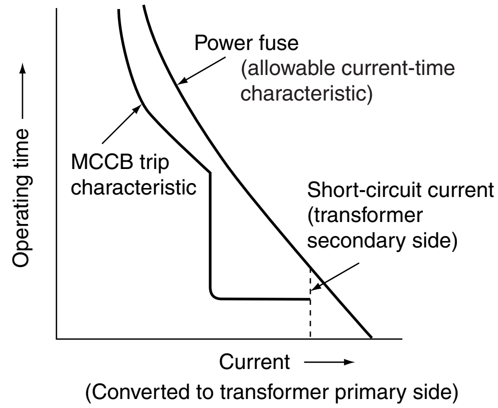


Fig. 3-9 MCCB – PF selective trip coordination



3-3-3 Selective trip coordination with a high-voltage fuse

This section describes selective trip coordination for a transformer primary-side high-voltage fuse and a secondary-side molded case circuit breaker or earth leakage circuit breaker. The applicable range, however, is within the short-circuit current determined by the transformer capacity and percentage of impedance for the breaking capacity of the molded case circuit breaker or earth leakage circuit breaker. (Use caution for the ranges marked with an asterisk (*).) This gives the secondary short-circuit current that is assumed to have an impedance percentage of 4% of the transformer depending on the conditions of short-circuit current calculation.

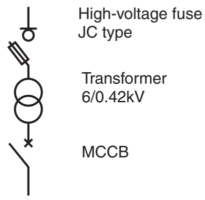


Table 3-7 (a) Selective trip coordination between MCCB and 6kV power fuse

- 3ø 6kV/400V

		Capacity (kVA)	100	200	300	500	750	1000
		Secondary current (A)	137	275	412	687	1031	1375
		Secondary short-circuit current (kA)	3.4	6.9	10.3	17.2	25.8	34.4
		JC type power fuse rated current (A)	20	30	50	60	75	100
MCCB type	**MCCB breaking capacity (kA)**	**MCCB rated current (A)**						
BW32AAG	1.5	(3), 5 to 32	*	*	*	*	*	*
BW50AAG		5 to 50	*	*	*	*	*	*
BW32SAG	2.5	3, 5 to 32	*	*	*	*	*	*
BW50EAG		5 to 50	*	*	*	*	*	*
BW63EAG		60, 63	*	*	*	*	*	*
BW50SAG	7.5	5 to 32			*	*	*	*
BW63SAG		60, 63			*	*	*	*
BW50RAG	10	10 to 50			*	*	*	*
BW63RAG		60, 63			*	*	*	*
BW100EAG		50, 60, 63, 75, 100			*	*	*	*
BW125JAG	30	15 to 75						*
BW125RAG	50							
BW125JAG	30	100 to 125						
BW125RAG	50							
BW160EAG	18	125					*	*
BW160JAG	30							*
BW160RAG	50							
BW160EAG BW250EAG	18	150 to 250					*	*
BW160JAG BW250JAG	30							*
BW160RAG BW250RAG	50							
BW400EAG	30	250						*
BW400SAG	36							
BW400RAG	50							
BW400HAG	70							
BW400EAG	30	300						
BW400SAG	36							
BW400RAG	50							
BW400HAG	70							
BW400EAG	30	350, 400						*
BW400SAG	36							
BW400RAG	50							
BW400HAG	70							
BW630EAG	36	500, 600, 630						
BW630RAG	50							
BW630HAG	70							
BW800EAG	36	700, 800						
BW800RAG	50							
BW800HAG	70							

Range that may exceed the allowable time-current range of the fuse

Note: For the number of poles, enter 2 or 3 in the parentheses, 3 or 4 in the square brackets, and 2, 3, or 4 in the curly brackets. For example, BW50AAG-3P030 is the model number of a three-pole, 30-A molded case circuit breaker. A rated current of 3A applies only to molded case circuit breakers.

Table 3-7 (b) Selective trip coordination between MCCB and 24kV power fuse

	Transformer	Capacity (kVA)		50	75	100	125	160	200	250	315	400	500	630	800	1,000	1,250	1,600	2,000
		Primary current (A)		1.5	2.2	2.9	3.6	4.7	5.8	7.3	9.2	11.6	14.5	18.2	23.1	29	36	46.5	58
		Secondary current (A)		72	108	144	180	230	290	360	455	576	720	910	1,160	1,440	1,800	2,300	2,890
		% impedance (%)		4	4	4	4	4	4	4	4	4	4	4	5	5	5	5	5
		Primary short-circuit current when the secondary side of the transformer shorts (A)		36	54	72	90	115	145	180	228	288	360	455	464	576	720	920	1,156
		Secondary short-circuit current (kA)		1.8	2.7	3.6	4.5	5.8	7.3	9.0	11.4	14.4	18.0	22.8	23.2	28.8	36.0	46.0	57.8
	Primary PF.	Rated current DIN/VDE 0670 Part 402(A)		6	6	10	10	16	16	25	25	32	40	50	63	63	80	80	80
Series	MCCB type	Breaking capacity Icu/Ics (kA) 400V IEC 60947-2	MCCB Rated current (A)																
AAG	BW32	1.5/1	3, 5, 10, 15, 20 30, 32	Note 3															
	BW50	1.5/1	5, 10, 15, 20, 30 32, 40, 50	Note 3															
	BW100	1.5/1	60, 63, 75, 100	Note 3															
EAG	BW50	2.5/2	5, 10, 15, 20, 30 32, 40, 50	Note 4	Note 3														
	BW63	2.5/2	60, 63	Note 4	Note 3														
	BW100	10/5	50, 60, 63, 75 100	Note 4							Note 3								
	BW160	18/9	125	Note 1		Note 4								Note 3					
			150, 160	Note 1				Note 4						Note 3					
	BW250	18/9	175, 200	Note 1				Note 4						Note 3					
			225, 250	Note 1						Note 4				Note 3					
	BW400	30/15	250	Note 1						Note 4							Note 3		
			300, 350	Note 1								Note 4					Note 3		
			400	Note 1									Note 4				Note 3		
	BW630	36/18	500, 600, 630	Note 1											Note 4			Note 3	
	BW800	36/18	700	Note 1											Note 4			Note 3	
			800	Note 1													Note 4	Note 3	
JAG	BW125	30/15	15, 20, 30, 40, 50 60	Note 4													Note 3		
			75, 100, 125	Note 1		Note 4											Note 3		
	BW160	30/15	125	Note 1		Note 4											Note 3		
			150, 160	Note 1				Note 4									Note 3		
	BW250	30/15	175, 200	Note 1				Note 4									Note 3		
			225, 250	Note 1						Note 4							Note 3		
SAG	BW32	2.5/2	3, 5, 10, 15, 20 30, 32	Note 4	Note 3														
	BW50	7.5/4	5, 10, 15, 20, 30 32, 40, 50	Note 4						Note 3									
	BW63	7.5/4	60, 63	Note 4						Note 3									
	BW125	36/18	15, 20, 30, 40, 50 60	Note 4														Note 3	
			75, 100, 125	Note 1		Note 4												Note 3	
	BW160	36/18	125	Note 1		Note 4												Note 3	
			150, 160	Note 1				Note 4										Note 3	
	BW250	36/18	175, 200	Note 1				Note 4										Note 3	
			225, 250	Note 1						Note 4								Note 3	
	BW400	36/18	250	Note 1						Note 4								Note 3	
			300, 350	Note 1								Note 4						Note 3	
			400	Note 1									Note 4					Note 3	

- Note 1 Selective trip coordination is not available.
- Note 2 Selective trip coordination is available. (Instantaneous trip current must be adjusted for coordination.)
- Note 3 Selective trip coordination is available. Make sure however that the short-circuit current where the MCCB is installed is less than its breaking capacity.
- Note 4 Selective trip coordination is available.

Table 3-7 (b) Selective trip coordination between MCCB and 24kV power fuse (Continued)

	Transformer	Capacity (kVA)		50	75	100	125	160	200	250	315	400	500	630	800	1,000	1,250	1,600	2,000
		Primary current (A)		1.5	2.2	2.9	3.6	4.7	5.8	7.3	9.2	11.6	14.5	18.2	23.1	29	36	46.5	58
		Secondary current (A)		72	108	144	180	230	290	360	455	576	720	910	1,160	1,440	1,800	2,300	2,890
		% impedance (%)		4	4	4	4	4	4	4	4	4	4	4	5	5	5	5	5
		Primary short-circuit current when the secondary side of the transformer shorts (A)		36	54	72	90	115	145	180	228	288	360	455	464	576	720	920	1,156
		Secondary short-circuit current (kA)		1.8	2.7	3.6	4.5	5.8	7.3	9.0	11.4	14.4	18.0	22.8	23.2	28.8	36.0	46.0	57.8
	Primary PF.	Rated current DIN/VDE 0670 Part 402(A)		6	6	10	10	16	16	25	25	32	40	50	63	63	80	80	80
Series	MCCB type	Breaking capacity Icu/Ics (kA) 400V IEC 60947-2	MCCB Rated current (A)																
RAG	**BW50**	10/5	10, 15, 20, 30, 32 40, 50	Note 4							Note 3								
	BW63	10/5	60, 63	Note 4							Note 3								
	BW125	50/25	15, 20, 30, 40, 50 60	Note 4															Note 3
			75, 100, 125	Note 1		Note 4													Note 3
	BW160	50/25	125	Note 1		Note 4													Note 3
			150, 160	Note 1				Note 4											Note 3
	BW250	50/25	175, 200	Note 1				Note 4											Note 3
			225, 250	Note 1						Note 4									Note 3
	BW400	50/25	250	Note 1						Note 4									Note 3
			300, 350	Note 1								Note 4							Note 3
			400	Note 1									Note 4						Note 3
	BW630	50/25	500, 600, 630	Note 1											Note 4				Note 3
	BW800	50/25	700	Note 1											Note 4				Note 3
			800	Note 1													Note 4		Note 3
HAG	**BW50**	65/17	15, 20, 30, 32, 40 50	Note 4															
	BW125	65/17	15, 20, 30, 40, 50 60	Note 4															
			75, 100, 125	Note 1		Note 4													
	BW250	65/17	125	Note 1		Note 4													
			150, 160, 175 200	Note 1				Note 4											
			225, 250	Note 1						Note 4									
	BW400	70/35	250	Note 1						Note 4									
			300, 350	Note 1								Note 4							
			400	Note 1									Note 4						
	BW630	70/35	500, 600, 630	Note 1											Note 4				
	BW800	70/35	700	Note 1											Note 4				
			800	Note 1													Note 4		

Note 1 Selective trip coordination is not available.
Note 2 Selective trip coordination is available. (Instantaneous trip current must be adjusted for coordination.)
Note 3 Selective trip coordination is available. Make sure however that the short-circuit current where the MCCB is installed is less than its breaking capacity.
Note 4 Selective trip coordination is available.

3-4 Wiring protection

3-4-1 Description

Wiring must be protected against the heat generated by overcurrents. When a circuit fault occurs, the overload or short-circuit current flowing into the fault point generates heat in the wire to raise the wire temperature. While the wire temperature is below the allowable temperature of the wire, the protective device must interrupt the overcurrent to protect the wire.
The allowable temperature of the wire depends on the material of the wire insulation. The highest temperature that the insulation can tolerate is designated the allowable temperature of the wire.
Since the temperature rise in the wire associated with heat can be translated into a current-time characteristic, a comparison of this characteristic with the current interrupting characteristic of circuit breakers will help determine the amount of protection. Protection in the overload region can be generally discussed with reference to a current-time characteristic diagram (see Fig. 3-3); protection in the short-circuit region is discussed in numeric terms with no allowance made for heat radiation. Either way, the basic idea is to interrupt the overcurrent before the wire is heated above its allowable temperature.

3-4-2 Thermal characteristics of wire

The temperature rise of wires due to overcurrent depends on the let-through current and the continuous current carrying time. The relationship between the temperature rise and the allowable current is classified in three modes: continuous, short-time, and short-circuit.
The allowable temperature limits of PVC insulated wires typically used in low-voltage circuits are prescribed to be 70°C (continuous), 100°C (short-time), and 160°C (short-circuit), respectively.
Since heat radiation is negligible at the time of a short circuit, the short-circuit protection of the wiring can be determined by comparing the maximum breaking I^2t value of the protective device and the allowable I^2t value of the wire.

$$R_0\,(1+\alpha\theta)\,i^2dt=JMCd\theta$$

transforms as $i^2dt=\frac{S^2}{k^2}\times\frac{1}{\frac{1}{\alpha}+\theta}d\theta$, where $k^2=\frac{\alpha p}{JC\delta}$

and $i^2t=\int i^2dt=\frac{S^2}{k^2}\int_0^{\theta}\frac{1}{\frac{1}{\alpha}+\theta}d\theta=\frac{S^2}{k^2}\log_e\frac{\frac{1}{\alpha}+\theta}{\frac{1}{\alpha}+\theta_0}$

$$i^2t=5.05\log_e\frac{234+\theta}{234+\theta_0}\times10^4\times S^2$$

$$i^2t\approx1.4\times10^4S^2$$

Conductor temperature following a short circuit

$$\theta_1=\left(\frac{1}{\alpha}+\theta_0\right)e^{\frac{k^2}{S^2}i^2t}-\frac{1}{\alpha}$$

The following equation holds based solely on temperature rise.

$$\theta_1=\left(\frac{1}{\alpha}+\theta_0\right)\left\{e^{\frac{k^2}{S^2}i^2t}-1\right\}$$

where

- R_0: Conductor resistance (Ω/cm)
- α: Temperature coefficient of the conductor resistor, 4.27×10^{-3} (1/°C)
- θ: Conductor temperature due to short circuit, 160 (°C)
- θ_0: Conductor temperature before short circuit, 70 (°C)
- θ_1: Rise in conductor temperature (K)
- J: Mechanical equivalent of heat, 4.19 (J/cal)
- M: Conductor mass, 8.93 (g/cm³)
- C: Specific heat of the conductor, 0.092 (J/cm³°C)
- δ: Specific gravity of the conductor, 8.93 (g/cm³)
- p: Specific resistance of the conductor, 1.6×10^{-6} (Ω/cm)
- S: Conductor cross section (mm²)
- I^2t: Current squared time (A^2s)

The equation above suggests that temperature rise in the conductor (wire) is determined by the let-through I^2t.
Fig. 3-11 shows this relationship, while Table 3-9 (a) shows allowable I^2t when there is a short circuit.

Fig. 3-11 Temperature rise in PVC insulated conductors due to let-through I^2t

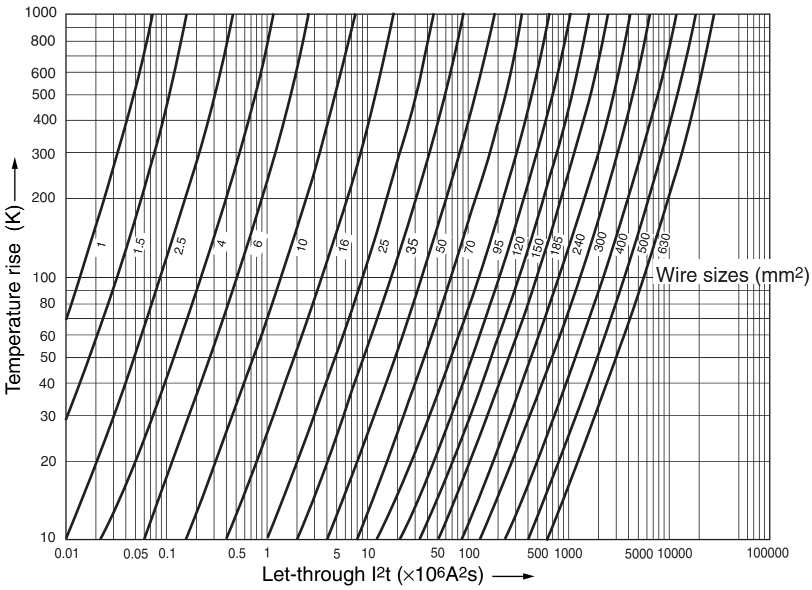


Table 3-9 (a) Current squared time $i^2t=5.05\ \log_e((234+\theta)/(234+\theta_0)\times S^2\times 10^4$

IEC wiring values			JIS wiring values (Reference)		
Wire cross section (S) (mm²)	Current squared time (×10⁶A²s)		Wire cross section (S) (mm²)	Current squared time (×10⁶A²s)	
	Starting at 70°C (i²t)	Starting at 30°C (i²t)		Starting at 60°C (i²t)	Starting at 30°C (i²t)
1	0.013	0.020	2	0.054	0.076
1.5	0.029	0.045	3.1	0.133	0.187
2.5	0.082	0.126	3.5	0.165	0.232
4	0.210	0.324	5.5	0.408	0.572
6	0.471	0.728	8	0.863	1.21
10	1.31	2.02	14	2.64	3.71
16	3.35	5.18	22	6.53	9.16
25	8.18	12.6	30	12.1	17.0
35	16.0	24.8	38	19.5	27.3
50	32.7	50.6	50	33.7	47.3
70	64.2	99.1	60	48.6	68.1
95	118	182	80	86.3	121
120	189	291	100	135	189
150	295	455	125	211	296
185	448	692	150	303	426
240	754	1165	200	539	757
300	1179	1820	250	843	1183
400	2095	3235	325	1425	1999
500	3274	5055	400	2158	3028
630	5198	8025	500	3372	4731

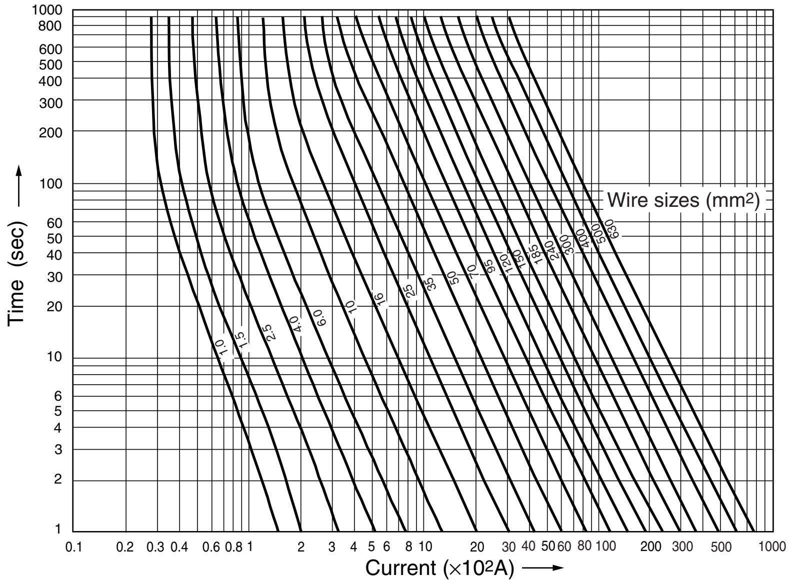
Table 3-9 (b) Conductor specifications

Resistor temperature coefficient	α $1/\alpha$	0.00427 (1/°C) 234 (°C)
Initial conductor temperature *	θ_0	IEC wiring: 70°C JIS wiring: 60°C
Ultimate conductor temperature *	θ	IEC wiring: 160°C JIS wiring: 150°C
Specific conductor resistance	ρ	0.0000016 (Ωcm)
Mechanical equivalent of heat	J	4.19 (J/cal)
Specific heat of the conductor	C	0.092 (J/cm³°C)
Specific gravity of the conductor	σ	8.93 (g/cm³)
	$K^2=\alpha\rho/JC\sigma$	1.985E–09

Note: * Ambient temperature: 30°C

The relationship of current to the rise in conductor temperature in the continuous and short-time regions makes heat dissipation too important to ignore, yet it varies with conditions like the type of installation. Although this is not impossible to calculate, it is not commonly done. IEC standards stipulate allowable current for insulated wiring in the continuous region using an ambient temperature of 30°C and a rise in conductor temperature of 40°C.
The IEEE uses a minimum of 20s for the short-time region where a conductor temperature as high as 100°C is allowable. This temperature is sustainable in the conductor because of the inverse time-delay trip time of the breaker. Fig. 3-12 shows current-time characteristics for 600V PVC-insulated wiring where conductor temperatures reach 100°C starting from no-load conditions at an ambient temperature for the wiring of 30°C.

Fig. 3-12 Current-time characteristics in which 600V PVC insulated conductors reach a temperature of 100°C (rise of 70°C)



3-4-3 Application of protective devices

(1) Principle

When an overcurrent fault occurs, a circuit breaker must be chosen that can interrupt an overcurrent before the wire is heated above its allowable temperature. The rated current of the circuit breaker thus must be lower than the allowable current of the wire. In the short-time region, the circuit breaker should exhibit operating characteristics below the allowable current-time characteristics of the wire as shown in Fig. 3-13. In the short-circuit region it is necessary to verify, by way of calculation, that the max. breaking I^2t value of the overcurrent protective device is lower than the allowable I^2t value of the wire.

(2) Wiring protection by MCCBs

The MCCB to be used for overcurrent protection of wiring can be selected by observing the principle in item (1). In the short-time region discussions, remember that the tripping characteristic curve of an MCCB may cross the allowable current characteristic curve of wire near the point of intersection of the inverse time-delay trip and instantaneous trip characteristics of the MCCB.
Table 3-10 shows the combinations of MCCBs and PVC wires available for protection in the short-time region. Protection for wires in the short-circuit region can be determined by reviewing the allowable I^2t value of the wire. Table 3-11 shows the max. breaking I^2t values of MCCBs at the time of short-circuit current breaking and the allowable I^2t values of wires needed to accomplish this determination.

Fig. 3-13 Protection coordination for wiring

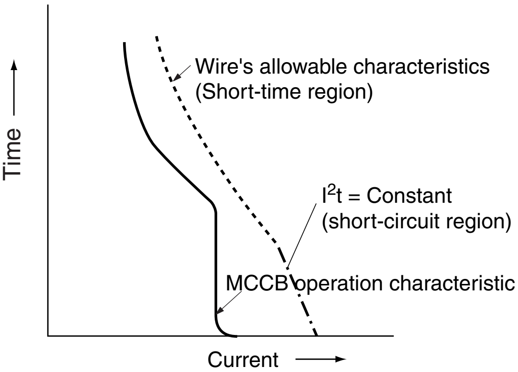


Table 3-10 MCCB protected wiring (up to the rated short-time range)

Wire size (mm^2)	Allowable current (A)		Allowable current considering MCCB trip characteristics (A)	MCCB rating (A)																					
	Open 3-wire	Duct 3-wire																							
	Amb. temp. 30°C Rise 40K		30°C→100°C	10	15	20	40	50	60	75	100	125	150	175	200	225	250	300	350	400	500	600	700	800	1000
1	14.5	10.2	12																						
1.5	18.5	13.0	18																						
2.5	25	18	27																						
4	34	24	40												Unprotected region										
6	43	30	52																						
10	60	42	68																						
16	80	56	98																						
25	101	71	123																						
35	126	88	154				Protected region																		
50	153	107	187																						
70	196	137	239																						
95	238	167	290																						
120	276	193	337																						
150	319	223	389																						
185	364	255	444																						
240	430	301	525																						
300	556	389	678																						
400	664	465	810																						
500	757	530	924																						
630	856	599	967																						

Table 3-11a PVC wiring protected by rated breaking capacity (for short circuits)

Notes: 1 Wiring selection consideration: I^2t of the wiring ≥ maximum I^2t of the MCCB (ELCB)
(Short-time wiring tempereture:160°C maximum, continuous region:70°C), and rated current of the wiring ≥ rated current of the MCCB (ELCB).
2 The let-through current(I^2t) is lower the MCCBs (ELCBs) in the table because short-circuit current can be limited by factors like wiring impedance in an actual circuit. This lowers thermal stress on the wiring.

MCCB	ELCB	Rated current (A)	230V MCCB (ELCB) Icu (kA)	Peak let-through current (kA: peak)	Max. let-through current I^2t ($\times10^6 \cdot A^2s$)	PVC cable (Note: 1) Permissible I^2t ($\times10^6 \cdot A^2s$)	Minimum wire size (mm^2)	Permissible current (A)
BW32AAG	**EW32AAG**	**3 (MCCB only), 5, 10, 15, 20, 30, 32**	2.5	3.5	0.06	0.082	2.5	18
BW50AAG	**EW50AAG**	**5, 10, 15, 20, 30, 32, 40, 50**	2.5	3.5	0.06	0.082	2.5	18
BW100AAG	**EW100AAG**	**60, 63, 75, 100**	5.0	6.0	0.145	0.21	4	24
	EW32EAG	**5, 10, 15, 20, 30, 32**	2.5	3.5	0.06	0.082	2.5	18
BW50EAG	**EW50EAG**	**5, 10, 15, 20, 30, 32, 40, 50**	5.0	6.0	0.145	0.21	4	24
BW63EAG	**EW63EAG**	**60, 63**	5.0	6.0	0.145	0.21	4	24
BW100EAG	**EW100EAG**	**50, 60, 63, 75, 100**	25	12.0	0.50	1.31	10	42
BW160EAG	**EW160EAG**	**125, 150, 160**	36	25.0	1.70	3.35	16	56
BW250EAG	**EW250EAG**	**175, 200, 225, 250**	36	25.0	1.70	3.35	16	56
BW400EAG	**EW400EAG**	**250, 300, 350, 400**	50	33.5	2.58	3.35	16	56
BW630EAG	**EW630EAG**	**500, 600, 630**	50	47.0	5.10	8.2	25	71
BW800EAG	**EW800EAG**	**700, 800**	50	47.0	5.10	8.2	25	71
BW125JAG	**EW125JAG**	**15**	50	4.65	0.033	0.082	2.5	18
		20	50	5.7	0.044	0.082	2.5	18
		30	50	6.95	0.06	0.082	2.5	18
		40, 50, 60, 75, 100, 125	50	20.0	0.62	1.31	10	42
BW160JAG	**EW160JAG**	**125, 150, 160**	50	24.5	1.28	1.31	10	42
BW250JAG	**EW250JAG**	**175, 200, 225, 250**	50	24.5	1.28	1.31	10	42
BW32SAG	**EW32**	**3, 5, 10, 15, 20, 30, 32**	5.0	6.0	0.145	0.21	4	24
BW50SAG	**EW50**	**5, 10, 15, 20, 30, 32, 40, 50**	10	8.5	0.27	0.471	6	30
BW63SAG	**EW63**	**60, 63**	10	8.5	0.27	0.471	6	30
BW125SAG	**EW125SAG**	**15**	85	5.035	0.036	0.082	2.5	18
		20	85	6.26	0.048	0.082	2.5	18
		30	85	7.685	0.067	0.082	2.5	18
		40, 50, 60, 75, 100, 125	85	23.5	0.746	1.31	10	42
BW160SAG	**EW160SAG**	**125, 150, 160**	85	29.5	1.504	3.35	16	56
BW250SAG	**EW250SAG**	**175, 200, 225, 250**	85	29.5	1.504	3.35	16	56
BW400SAG	**EW400SAG**	**250, 300, 350, 400**	85	40.0	2.65	3.35	16	56
BW50RAG	**EW50RAG**	**10, 15, 20, 30, 32, 40, 50**	25	12.0	0.50	1.31	10	42
BW63RAG	**EW63RAG**	**60, 63**	25	12.0	0.50	1.31	10	42
BW125RAG	**EW125RAG**	**15**	100	5.2	0.037	1.31	10	42
		20	100	6.5	0.05	1.31	10	42
		30	100	8.0	0.07	1.31	10	42
		40, 50, 60, 75, 100, 125	100	25.0	0.08	1.31	10	42
BW160RAG	**EW160RAG**	**125, 150, 160**	100	31.5	1.60	3.35	16	56
BW250RAG	**EW250RAG**	**175, 200, 225, 250**	100	31.5	1.60	3.35	16	56
BW400RAG	**EW400RAG**	**250, 300, 350, 400**	100	42.0	3.02	3.35	16	56
BW630RAG	**EW630RAG**	**500, 600, 630**	100	61.5	6.50	8.18	25	71
BW800RAG	**EW800RAG**	**700, 800**	100	61.5	6.50	8.18	25	71
BW50HAG		**15**	125	5.40	0.039	0.082	2.5	18
		20	125	6.8	0.051	0.082	2.5	18
		30	125	8.3	0.07	0.082	2.5	18
		40, 50	125	26.5	0.85	1.31	10	42
BW125HAG		**15**	125	5.40	0.039	0.082	2.5	18
		20	125	6.8	0.051	0.082	2.5	18
		30	125	8.3	0.07	0.082	2.5	18
		40, 50, 60, 75, 100, 125	125	26.5	0.85	1.31	10	42
BW250HAG		**125, 150, 160, 175, 200, 225, 250**	125	33.3	1.68	3.35	16	56
BW400HAG	**EW400HAG**	**250, 300, 350, 400**	125	45.0	3.10	3.35	16	56
BW630HAG	**EW630HAG**	**500, 600, 630**	125	66.5	6.8465	8.18	25	71
BW800HAG	**EW800HAG**	**700, 800**	125	66.5	6.8465	8.18	25	71

Table 3-11b PVC wiring protected by rated breaking capacity (for short circuits)

Notes: 1 Wiring selection consideration: I^2t of the wiring ≥ maximum I^2t of the MCCB (ELCB)
(Short-time wiring tempereture:160°C maximum, continuous region:70°C), and rated current of the wiring ≥ rated current of the MCCB (ELCB).

2 The let-through current(I^2t) is lower the MCCBs (ELCBs) in the table because short-circuit current can be limited by factors like wiring impedance in an actual circuit. This lowers thermal stress on the wiring.

MCCB	ELCB	Rated current (A)	440V MCCB (ELCB) Icu (kA)	440V MCCB (ELCB) Peak let-through current (kA: peak)	440V MCCB (ELCB) Max. let-through current I^2t ($\times 10^6 \cdot A^2s$)	PVC cable (Note: 1) Permissible I^2t ($\times 10^6 \cdot A^2s$)	PVC cable (Note: 1) Minimum wire size (mm^2)	PVC cable (Note: 1) Permissible current (A)
BW32AAG		**3, 5, 10, 15, 20, 30, 32**	1.5	2.1	0.03	0.082	2.5	18
BW50AAG		**5, 10, 15, 20, 30, 32, 40, 50**	1.5	2.1	0.03	0.082	2.5	18
BW100AAG		**60, 63, 75, 100**	1.5	2.1	0.03	0.082	2.5	18
BW50EAG	**EW50EAG**	**5, 10, 15, 20, 30, 32, 40, 50**	2.5	3.5	0.08	0.082	2.5	18
BW63EAG	**EW63EAG**	**60, 63**	2.5	3.5	0.08	0.082	2.5	18
BW100EAG	**EW100EAG**	**50, 60, 63, 75, 100**	10	10.0	0.60	1.31	10	42
BW160EAG	**EW160EAG**	**125, 150, 160**	18	22.0	2.60	3.35	16	56
BW250EAG	**EW250EAG**	**175, 200, 225, 250**	18	22.0	2.60	3.35	16	56
BW400EAG	**EW400EAG**	**250, 300, 350, 400**	30	35.0	5.70	8.18	25	71
BW630EAG	**EW630EAG**	**500, 600, 630**	36	47.0	8.75	16.0	35	88
BW800EAG	**EW800EAG**	**700, 800**	36	47.0	8.75	16.0	35	88
BW125JAG	**EW125JAG**	**15**	30	8.1	0.113	0.21	4	24
		20	30	9.5	0.140	0.21	4	24
		30	30	11.0	0.178	0.21	4	24
		40, 50, 60, 75, 100, 125	30	10.0	1.65	3.35	16	56
BW160JAG	**EW160JAG**	**125, 150, 160**	30	26.0	3.15	3.35	16	56
BW250JAG	**EW250JAG**	**175, 200, 225, 250**	30	26.0	3.15	3.35	16	56
BW32SAG	**EW32**	**3, 5, 10, 15, 20, 30, 32**	2.5	3.5	0.08	0.082	2.5	18
BW50SAG	**EW50**	**5, 10, 15, 20, 30, 32, 40, 50**	7.5	8.3	0.41	0.471	6	30
BW63SAG	**EW63**	**60, 63**	7.5	8.3	0.41	0.471	6	30
BW125SAG	**EW125SAG**	**15**	36	8.2	0.115	0.21	4	24
		20	36	9.65	0.145	0.21	4	24
		30	36	11.3	0.183	0.21	4	24
		40, 50, 60, 75, 100, 125	36	21.5	1.815	3.35	16	56
BW160SAG	**EW160SAG**	**125, 150, 160**	36	28.1	3.45	8.18	25	71
BW250SAG	**EW250SAG**	**175, 200, 225, 250**	36	28.1	3.45	8.18	25	71
BW400SAG	**EW400SAG**	**250, 300, 350, 400**	36	38.0	6.40	8.18	25	71
BW50RAG	**EW50RAG**	**10, 15, 20, 30, 32, 40, 50**	10	10.0	0.60	1.31	10	42
BW63RAG	**EW63RAG**	**60, 63**	10	10.0	0.60	1.31	10	42
BW125RAG	**EW125RAG**	**15**	50	8.5	0.120	1.31	10	42
		20	50	10.0	0.155	3.35	16	56
		30	50	12.0	0.195	3.35	16	56
		40, 50, 60, 75, 100, 125	50	25.0	2.20	3.35	16	56
BW160RAG	**EW160RAG**	**125, 150, 160**	50	33.0	4.15	8.18	25	71
BW250RAG	**EW250RAG**	**175, 200, 225, 250**	50	33.0	4.15	8.18	25	71
BW400RAG	**EW400RAG**	**250, 300, 350, 400**	50	44.0	7.70	8.18	25	71
BW630RAG	**EW630RAG**	**500, 600, 630**	50	54.5	10.30	16	35	88
BW800RAG	**EW800RAG**	**700, 800**	50	54.5	10.30	16	35	88
BW50HAG		**15**	65	8.55	0.121	0.21	4	24
		20	65	10.5	0.160	0.21	4	24
		30	65	12.6	0.20	0.21	4	24
		40, 50	65	27.3	2.40	3.35	16	56
BW125HAG		**15**	65	8.55	0.121	0.21	4	24
		20	65	10.5	0.160	0.21	4	24
		30	65	12.6	0.20	0.21	4	24
		40, 50, 60, 75, 100, 125	65	27.3	2.40	3.35	16	56
BW250HAG		**125, 150, 160, 175, 200, 225, 250**	65	36.2	4.50	8.18	25	71
BW400HAG	**EW400HAG**	**250, 300, 350, 400**	70	50.0	8.70	16	35	88
BW630HAG	**EW630HAG**	**500, 600, 630**	70	63.5	11.97	16	35	88
BW800HAG	**EW800HAG**	**700, 800**	70	63.5	11.97	16	35	88

3-5 Motor circuit applications

3-5-1 Description

Individual or tandem overcurrent protective devices are installed in motor circuits to provide the motor with overload and locked rotor protection and to provide the wiring with overcurrent protection. These protective devices must operate at or below current-time characteristics for the motor windings to reach the allowable temperature. Any of the combinations in Fig. 3-16 would provide adequate protection for actual motor circuits depending on the motor capacity, operating characteristics, frequency of operation, switching durability and short-circuit capacity.

(a) Motor protection MCCB only

(b) Motor protection MCCB plus magnetic contactor

(c) Magnetic motor starter plus line protection MCCB

(d) Magnetic motor starter plus instantaneous trip type MCCB

The MCCBs in (a) and (b) provide both overcurrent and short-circuit protection. With configurations (c) and (d), the motor starter provides overload protection while a line protection or instantaneous trip type MCCB provides short-circuit protection. Combination (d) acts as a single overcurrent circuit breaker for one panel.

(1) Motor starting current

Unlike the situation with loads like lamps, starting current and inrush current exceeding the full load current flow when motor circuits start up. Therefore, motor circuits need overcurrent protection devices that will not be tripped by these starting currents.

(a) Direct-on-line starters (Full voltage starting)

These are some of the problems to be solved when starting a squirrel-cage induction motor directly-on-line.

1) An asymmetrical current flows at the time the motor starts due to the symmetrical AC component and DC components. This causes the instantaneous trip mechanism to operate.
2) The inverse time-delay trip mechanism will operate due to the longer starting time.

The magnitude of the starting currents (symmetrical AC component) varies according to the type of motor, outputs, and the number of poles. However, overcurrents generally equal to 500% to 800% of the full load current will flow. For FUJI standard motors, approximately a 600% overload can be expected.

A few cycles immediately after starting the DC component will overlap.

The magnitude of the asymmetrical current can be obtained from the relations given in Fig. 3-14 and 3-15.

These two diagrams are used as follows. For instance, for a 55kW induction motor, the starting power factor $\cos\varphi$ will be 0.22. The effective value of α, including the DC component, is 1.23. Therefore, the asymmetrical currents can be expressed as follows.

Symmetrical starting current × 1.23 (effective value). In this example, assuming that the starting current's multiplication factor is 600%, the asymmetrical currents are approx. 750%. If the factor is 800% the latter is approx. 1000%.

The MCCB's instantaneous trip value will have to exceed this value. The starting period of a motor depends on the GD^2 of the load. Strictly speaking, this must be calculated for each motor. However, the starting period is generally less than 10 secs. Pump motors require a shorter starting time, while fans and blowers require a longer time to reach operating speed.

Fig. 3-14 Starting power factor example of induction motors

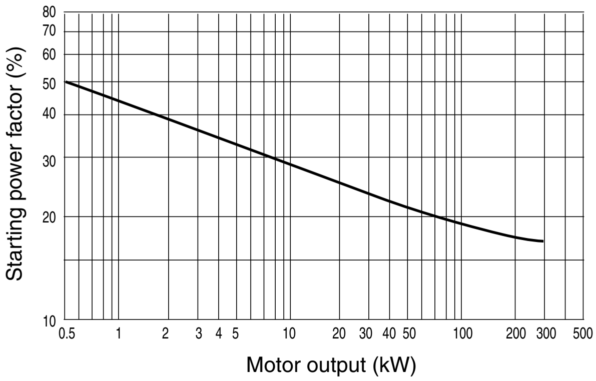
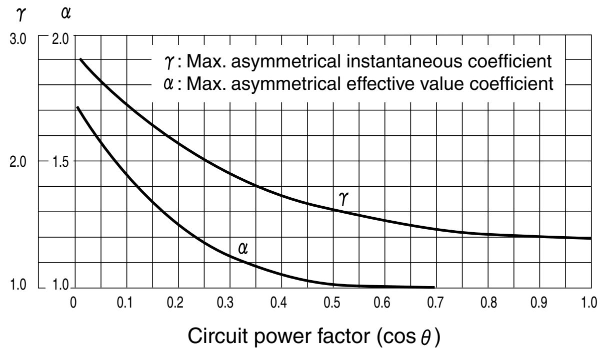


Fig. 3-15 DC component overlap ratio



(b) Star-delta starters

Although it takes little time to changeover from star to delta connection, the inrush current at this time is significant. This inrush current occurs when voltage higher than the power supply voltage ($1 + \frac{1}{\sqrt{3}} \approx 1.58$ times in the worst case scenario) is applied to the motor because of residual voltage generated in the motor stator winding and by the phase differential with the power supply voltage when a delta connection is performed.

The amount of inrush current in the worst case scenario is 1.1 to 1.3 times the starting current × 1.58, which is direct-on-line starting. If the starting current momentarily reaches 800% of the full load current, then the inrush current in the worst case scenario is 800% of the full load current × 1.3 × 1.58 ≈ 1700%. The instantaneous trip device in the MCCB may trip if its setting is exceeded for even a 1/2 cycle, so an MCCB must be selected where the instantaneous trip current is higher than the inrush current described above.

(2) Motor circuit protection by motor breaker

The overcurrent trip characteristics of a single MCCB may be used to protect the motor and the wiring at the same time. (See Fig. 3-17 a.)

Often the operating characteristics of an MCCB make it unsuitable in situations with long starting times or with significant current, like the inrush current generated by the changeover from star to delta connection. However, MCCBs are quite suitable for short (2s or less) starting times.

The need for frequent switching brings up other important considerations, such as connecting magnetic contractors in series. (See Fig. 3-17 b.) Fig. 3-16 shows the MCCB protection coordination curve. Table 3-12 (a) shows applicable breakers for 230V motors and Table 3-12 (b) shows breakers for 400V motors.

Fig. 3-16 Motor breaker protection coordination

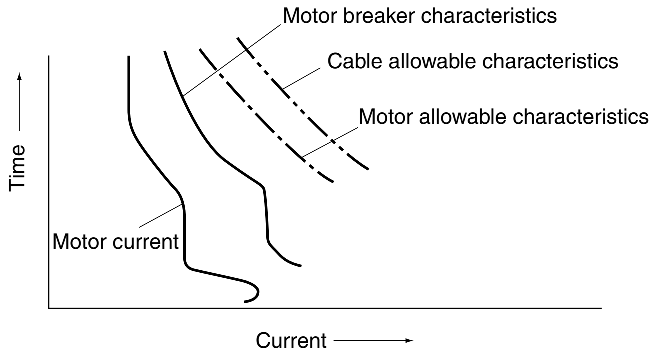


Fig. 3-17 Protective structure for motor circuits

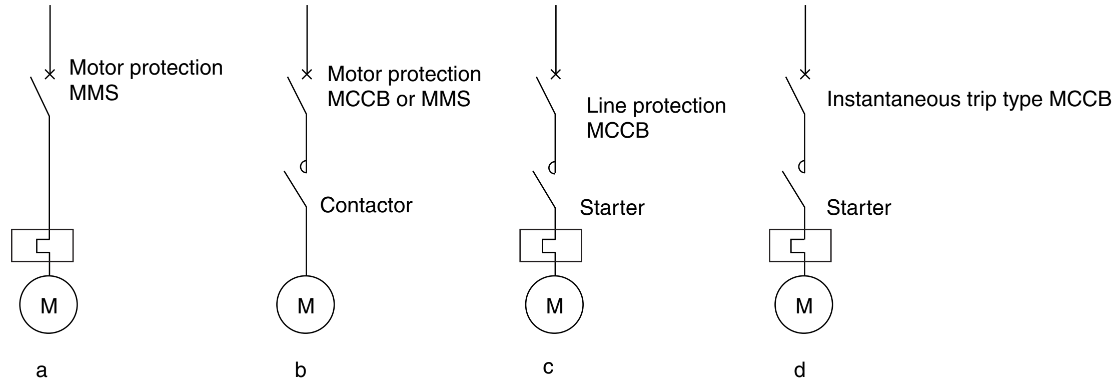


Table 3-12 Selection of manual motor starters (MMS)

(a) 230V AC

Combined magnetic contactor	Motor output (kW)	Motor rated current (A)	Motor rated current multiplying factor (A)×1.2	Manual motor starter rated current (A)	Manual motor starter Icu (kA)	
					50	100
SC-03	0.2	0.96	1.15	1.2	–	BM3RSB-☐
	0.4	1.65	1.98	2.3		BM3RHB-☐
	0.75	2.87	3.45	3.5		BM3VSB-☐
	1.5	5.2	6.3	7		BM3VHB-☐
	2.2	7.0	8.4	9		
SC-4-0	3.7	11.7	14.1	14	BM3RSB-☐	
SC-N1	5.5	17.4	20.9	21	BM3VSB-☐	BM3RHB-☐
SC-N2	7.5	23.1	27.7	28	BM3VSB-☐	BM3VHB-☐
SC-N2S	11	33.9	40.7	40		BM3VHB-☐
SC-N3	15	45.2	54.3	52		
SC-N4	18.5	54.8	65.8	65	–	–
SC-N5, N5A	22	67	80.4	80		
SC-N6	30	89.6	107.5	110	–	–
SC-N7	37	110.5	132.6	130		
SC-N8	45	132.2	158.7	150		
SC-N10	55	163.6	196.3	200		

Note: Motor full-load currents are based on FUJI's standard type totally-enclosed induction motors. Check the value of the full-load current before using.

(b) 400V AC

Combined magnetic contactor	Motor output (kW)	Motor rated current (A)	Motor rated current multiplying factor (A)×1.2	Manual motor starter rated current (A)	Manual motor starter Icu (kA)		
					25	50	100
SC-03	0.2	0.55	0.66	0.7	–	–	BM3RSB-□
	0.4	0.95	1.14	1.4			BM3RHB-□
	0.75	1.65	1.98	2			
	1.5	3	3.6	4			
	2.2	4.05	4.86	5		BM3RSB-□ BM3VSB-□	BM3VSB-□ BM3VHB-□
SC-0, 05	3.7	6.75	8.1	8	BM3RSB-□	BM3RHB-□	–
SC-4-0	5.5	10	12	12	BM3VSB-□	BM3VHB-□	
SC-4-1, 5-1	7.5	13.25	15.9	16			
SC-N1	11	19.5	23.4	24	BM3VSB-□	BM3VHB-□	
SC-N2	15	26	31.2	32			
SC-N2S	18.5	31.5	37.8	40	–	–	
SC-N2S	22	38.5	46.2	45			
SC-N3	30	51.5	61.8	60			
SC-N4	37	63.5	76.2	75			
SC-N5, N5A	45	76	91.2	90			
SC-N6	55	94	112.8	125			
SC-N7	75	128	153.6	150			
SC-N8	90	152	182.4	175			
SC-N10	110	185	222	225			

Note: Motor full-load currents are based on FUJI's standard type totally-enclosed induction motors. Check the value of the full-load current before using.

(3) Magnetic motor starter and MCCB motor circuit protection

These arrangements consist of a magnetic motor starter and line protection or instantaneous trip type of MCCB. The starter's thermal overload relay operates in the presence of sustained overload currents. The MCCB interrupts short-circuit currents. This is the most popular method.
For control centers where short-circuit currents are large, instantaneous trip type MCCBs are used. This is because standard MCCBs for line protection are provided with bimetal elements as tripping devices, which have limited overcurrent withstand values and which would cause damage due to overheating in the presence of short-circuit currents.
Fig. 3-18 gives an example of a protection coordination curve of a motor circuit.

When combining the MCCB with a magnetic motor starter, the fundamental rules for protection are as follows:

- The combined protection characteristics of 1 and 3 must operate before the motor and wire sustain damage.
- The MCCB does not trip from starting current or from current while the motor is running at the rated load.
- The MCCB must be able to interrupt short-circuit currents.
- In an overload condition, the starter operates before the MCCB.
- The MCCB operates when more current flows than the starter can interrupt. This protects the starter.

Even though the above requirements are satisfied and the MCCB interrupts, the heating element of the thermal overload relay can be damaged due to overheating caused by the magnetic force or the energy of the short-circuit currents.
This means that it is impossible for the MCCB to provide absolute protection for motor starters when short-circuit faults occur. It is therefore not realistic or economical to protect magnetic motor starters by means of MCCBs.
Therefore, magnetic motor starter protection is divided into two types by IEC 60947-4-1, with the prior understanding that the motor starter must be replaced or repaired after a short-circuit fault has occurred. Refer to Table 3-13.

Fig. 3-18 Protection coordination characteristics curve in motor circuits

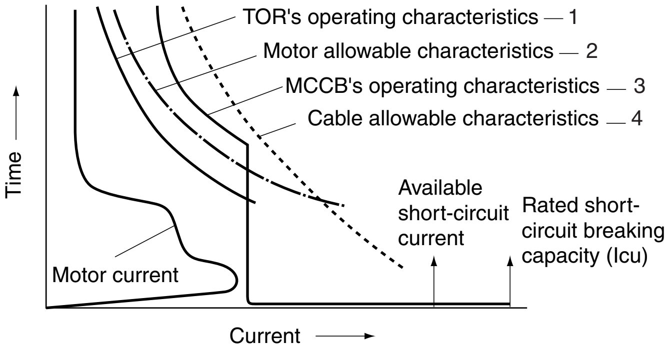


Table 3-13 Magnetic motor starter protection class (IEC 60947-4-1)

Type 1	Coordination requires that, under short-circuit conditions, the contactor or starter shall cause no danger to persons or installation and may not be suitable for further service without repair and replacement of parts.
Type 2	Coordination requires that, under short-circuit conditions, the contactor or starter shall cause no danger to persons or installation and shall be suitable for further use. The risk of contact welding is recognized, in which case the manufacturer shall indicate the measures to be taken as regards the maintenance of the equipment.

Table 3-14 Selection of line protection MCCB

(a) 230V AC 3-phase induction motor

Contactor type	Motor ratings		MCCB rated current (A)	Icu (kA)						
	Output (kW)	Current (A)		2.5	5	10	25	36	50	100
				MCCB type						
SC-03	0.2	1.3	1.4	BW32AAM-3P1P4	BW32SAM-3P1P4	BW50SAM-3P1P4				
	0.4	2.3	2.6	BW32AAM-3P2P6	BW32SAM-3P2P6	BW50SAM-3P2P6				
	0.75	3.6	4	BW32AAM-3P004	BW32SAM-3P004	BW50SAM-3P004				
	1.5	6.1	8	BW32AAM-3P008	BW32SAM-3P008	BW50SAM-3P008				
	2.2	9.2	10	BW32AAM-3P010	BW32SAM-3P010	BW50SAM-3P010	BW50RAM-3P010			
SC-4-0	3.7	1.5	16	BW32AAM-3P016	BW32SAM-3P016	BW50SAM-3P016	BW50RAM-3P016	BW125JAM-3P016		BW125RAM-3P016
SC-N1	5.5	22.5	24	BW32AAM-3P024	BW32SAM-3P024	BW50SAM-3P024	BW50RAM-3P024	BW125JAM-3P024		BW125RAM-3P024
SC-N2	7.5	29	32	BW32AAM-3P032	BW32SAM-3P032	BW50SAM-3P032	BW50RAM-3P032	BW125JAM-3P032		BW125RAM-3P032
SC-N2S	11	42	45	BW50EAM-3P045		BW50SAM-3P045	BW50RAM-3P045	BW125JAM-3P045		BW125RAM-3P045
SC-N3	15	55	60/63	BW63EAM-3P063		BW63SAM-3P063	BW100EAM-3P063	BW125JAM-3P063		BW125RAM-3P060
SC-N4	18.5	67	75	BW100EAM-3P075				BW125JAM-3P075		BW125RAM-3P075
SC-N5 SC-N5A	22	78	90	BW100EAM-3P090				BW125JAM-3P090		BW125RAM-3P090
SC-N6	30	107	125	BW250JAM-3P125 (Note: The maximum current for 125AF motors is 90A.)						BW250RAM-3P125
SC-N7	37	130	150	BW250EAM-3P150					BW250JAM-3P150	BW250RAM-3P150
SC-N8	45	156	175	BW250EAM-3P175					BW250JAM-3P175	BW250RAM-3P175
SC-N10	55	190	225	BW250EAM-3P225					BW250JAM-3P225	BW250RAM-3P225

Notes: 1 The model numbers to use for direct-on-line starters are given for electromagnetic contractors.
2 The model numbers for AC3-class electromagnetic contactors are given.
3 The catalog values are given for the rated motor current (catalog number MH123) for Fuji 3-phase totally enclosed fan-cooled models (4-pole, 400V/50Hz with feet).

3-5 Motor circuit applications

(b) 400V AC 3-phase induction motor

Contac-tor type	Motor ratings		MCCB (ELCB) rated current (A)	Icu (kA)						
	Output (kW)	Current (A)		1.5	2.5	7.5	10	18	30	50
				MCCB (ELCB) type						
SC-03	0.2	0.65	0.7		BW32SAM-3P0P7	BW50SAM-3P0P7				
	0.4	1.15	1.4	BW32AAM-3P1P4	BW32SAM-3P1P4	BW50SAM-3P1P4				
	0.75	1.8	2	BW32AAM-3P002	BW32SAM-3P002	BW50SAM-3P002				
	1.5	3.1	4	BW32AAM-3P004	BW32SAM-3P004	BW50SAM-3P004				
	2.2	4.6	5	BW32AAM-3P005	BW32SAM-3P005	BW50SAM-3P005				
SC-0 SC-05	3.7	7.5	8	BW32AAM-3P008	BW32SAM-3P008	BW50SAM-3P008				
SC-4-0	5.5	11.5	12	BW32AAM-3P012	BW32SAM-3P012	BW50SAM-3P012	BW50RAM-3P012			
SC-4-1 SC-5-1	7.5	14.5	16	BW32AAM-3P016	BW32SAM-3P016	BW50SAM-3P016	BW50RAM-3P016	BW125JAM-3P016		BW125RAM-3P016
SC-N1	11	21	24	BW32AAM-3P024	BW32SAM-3P024	BW50SAM-3P024	BW50RAM-3P024	BW125JAM-3P024		BW125RAM-3P024
SC-N2	15	27.5	32	BW32AAM-3P032	BW32SAM-3P032	BW50SAM-3P032	BW50RAM-3P032	BW125JAM-3P032		BW125RAM-3P032
SC-N2S	18.5	34	40	BW50EAM-3P040		BW50SAM-3P040	BW50RAM-3P040	BW125JAM-3P040		BW125RAM-3P040
SC-N2S	22	39	45	BW50EAM-3P045		BW50SAM-3P045	BW50RAM-3P045	BW125JAM-3P045		BW125RAM-3P045
SC-N3	30	54	60/63	BW63EAM-3P063		BW63SAM-3P063	BW100EAM-3P063	BW125JAM-3P060		BW125RAM-3P060
SC-N4	37	65	75	BW100EAM-3P075				BW125JAM-3P075		BW125RAM-3P075
SC-N5 SC-N5A	45	78	90	BW100EAM-3P090				BW125JAM-3P090		BW125RAM-3P090
SC-N6	55	95	125	BW250JAM-3P125 (Note: The maximum current for 125AF motors is 90A.)						BW250RAM-3P125
SC-N7	75	130	150	BW250EAM-3P150					BW250JAM-3P150	BW250RAM-3P150
SC-N8	90	155	175	BW250EAM-3P175					BW250JAM-3P175	BW250RAM-3P175
SC-N10	110	188	225	BW250EAM-3P225					BW250JAM-3P225	BW250RAM-3P225

Notes: 1 The model numbers to use for direct-on-line starters are given for electromagnetic contractors.
2 The model numbers for AC3-class electromagnetic contactors are given.
3 The catalog values are given for the rated motor current (catalog number MH123) for Fuji 3-phase totally enclosed fan-cooled models (4-pole, 400V/50Hz with feet).

3-6 Applications on the primary side of transformers

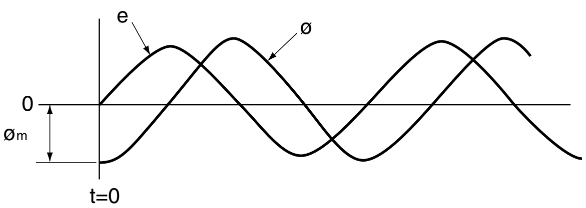
3-6-1 Inrush current for transformer excitation

The voltage **V** applied to the transformer in the normal condition is balanced by the voltage **e** induced by changes in the magnetic flux in the core. Only a slight exciting current is needed to generate the flux flows through the primary winding. The following relationship exists between the induced voltage **e**, the instantaneous value **ø** of the magnetic flux, and the primary winding **n**:

$$e=n\frac{d\phi}{dt}$$

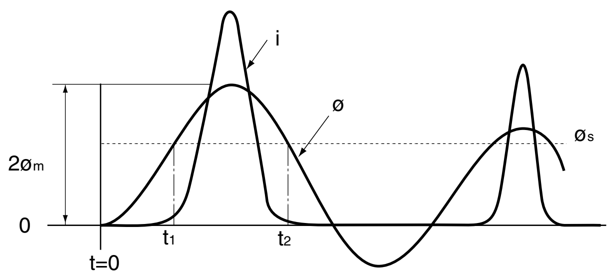
where $e = E_m \sin\omega t$ yields $\phi = -\phi_m \cos\omega t + C$. In a steady state (C = 0), the relationship is like that shown in Fig. 3-19.

Fig. 3-19 Relationship of induction voltage to magnetic flux in a steady-state transformer



Accordingly, assuming that excitation of the transformer is started at t=0, the magnetic flux ø must be 0 if the prior residual flux is 0. The flux exhibits ø as shown in Fig. 3-20, which is far above the core saturation flux ϕ_s of the transformer. However, as the magnetic flux ø is saturated to the value of ϕ_s for the period from t_1 to t_2, the induced voltage $e=n\frac{d\phi}{dt}$ is no longer balanced with the voltage V applied to the transformer, when a difference is created between the voltage V applied to the transformer and induced voltage e. As a result, inrush current i flows through the primary winding of the transformer (Fig. 3-20).

Fig. 3-20 Transformer excitation inrush current



When the transformer core has residual magnetic flux, then the amount of inrush current and the amount of saturation will increase by the amount of flux present. An MCCB is generally made near voltage phase π/2 to prevent excitation inrush current. With a three-phase transformer, however, it is done by making the MCCB near voltage phase 0 at some phase.
The magnitude of the inrush current for excitation is generally stated as an exciting inrush current multiplier (exciting inrush current first peak value relative to the transformer rated primary current peak value).
The exciting inrush current multiplier is a parameter of the transformer ratings and design. Generally, the lower the transformer capacity, the larger the exciting inrush current multiplier and the shorter the time constant.

3-6-2 Selecting an MCCB for transformer primary circuit

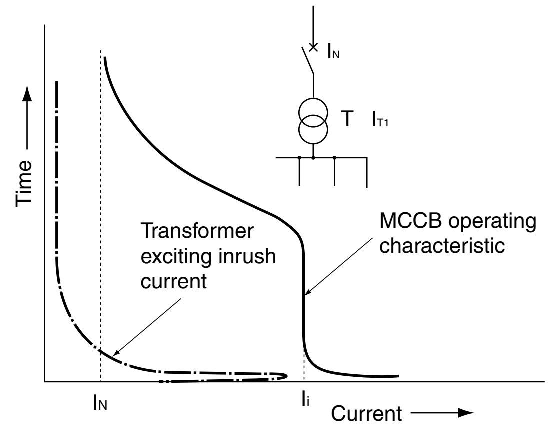
The MCCB to be selected must be capable of carrying the rated current safely in the normal condition, without malfunctioning with the inrush current for exciting the transformer.
More specifically, the MCCB is required to meet the following relation:

$$\sqrt{2}\times I_i > k\times I_{T1}$$

where
I_i: MCCB instantaneous trip current (effective value)
I_{T1}: Transformer rated primary current (A) (peak value)
k: Transformer exciting inrush current multiplier

This relation is illustrated in Fig. 3-21.

Fig. 3-21 Transformer exciting inrush current and MCCB operating characteristic



To select an MCCB for line protection, if the instantaneous trip current (Ii) is eight times the rated MCCB current (In), and the transformer exciting inrush current multiplier (k) is 20 (typical value for 100kVA class transformers), the following relation holds:

$$\sqrt{2}\times 8\times I_n > 20\times I_{T1}$$

This suggests that an MCCB with its rated current at least 1.8 times higher than the transformer rated primary current must be selected.
MCCBs designed for transformer primary circuits have their operating characteristics set up to meet the above conditions, and feature a rated current lower than that of an MCCB for line protection. Table 3-15 and 3-16 show single-phase transformer applications while Fig. 3-17 and 3-18 show three-phase transformer applications.

3-6-3 Transformer primary-side circuit selection

Selection is performed based on the exciting inrush current of the 440V terminals for a primary rated voltage of 400V to 440V (220V terminals for primary rated voltage of 200V to 220V) and 50Hz for a 50Hz/60Hz transformer.

Reason: The exciting inrush current decreases as the frequency rises. The current also decreases as the voltage decreases. Therefore, the breaker may operate incorrectly due to the large exciting inrush current if a voltage is applied without a load and the power supply voltage is higher than the rated terminal voltage at 50Hz.

Selection conditions: Exciting inrush current (Effective value conversion = Rated current x Peak exciting inrush current factor) < MCCB instantaneous tripping current (effective value at 0.01 s).

Table 3-15 Selecting MCCB for transformer primary circuit

Three-phase, 400-440V/210V Transformers

Transformer capacity (kVA)		**0.5**	**1.0**	**1.5**	**2.0**	**3.0**	**5.0**	**7.5**	**10**
In: Rated primary current (rms A)		0.656	1.312	1.968	2.624	3.936	6.561	9.841	13.122
Irush: Exciting inrush current (rms A)		15.418	30.836	46.254	61.672	92.507	154.179	231.268	308.358
Short-circuit current at 440V	1.5 (kA)	BW32AAG-3P003		BW32AAG-3P005		BW32AAG-3P010		BW50SAT-3P015	BW32SAT-3P020
	2.5 (kA)	BW32SAG-3P003		BW32SAG-3P005		BW32AAG-3P010		BW50SAT-3P015	BW32SAT-3P020
	7.5 (kA)			BW50SAG-3P005		BW50SAG-3P010		BW50SAT-3P015	BW50SAT-3P020
	10 (kA)					BW50RAG-3P010		BW50RAG-3P020	BW50RAG-3P040
	18 (kA)								BW125JAG-3P015
	30 (kA)								BW125JAG-3P015
	36 (kA)								BW125RAG-3P015
	50 (kA)								BW125RAG-3P015
	65 (kA)								BW50HAG-3P015

Transformer capacity (kVA)		**15**	**20**	**30**	**50**	**75**	**100**	**150**	**200**
In: Rated primary current (rms A)		19.682	26.243	39.365	65.608	98.412	131.216	216.506	288.675
Irush: Exciting inrush current (rms A)		462.536	616.715	708.566	1180.944	1771.416	2361.887	3897.114	5196.152
Short-circuit current at 440V	1.5 (kA)	BW32SAT-3P030	BW50SAT-3P040	BW100EAT-3P060	BW100EAT-3P090	BW250EAT-3P125	BW250EAT-3P150	BW250EAT-3P225	BW400EAT-3P350
	2.5 (kA)	BW32SAT-3P030	BW50SAT-3P040	BW100EAT-3P060	BW100EAT-3P090	BW250EAT-3P125	BW250EAT-3P150	BW250EAT-3P225	BW400EAT-3P350
	7.5 (kA)	BW32SAT-3P030	BW50SAT-3P040	BW100EAT-3P060	BW100EAT-3P090	BW250EAT-3P125	BW250EAT-3P150	BW250EAT-3P225	BW400EAT-3P350
	10 (kA)	BW50RAG-3P050	BW100EAG-3P060	BW100EAT-3P060	BW100EAT-3P090	BW250EAT-3P125	BW250EAT-3P150	BW250EAT-3P225	BW400EAT-3P350
	18 (kA)	BW125JAG-3P060		BW125JAT-3P060	BW125JAT-3P090	BW250EAT-3P125	BW250EAT-3P150	BW250EAT-3P225	BW400EAT-3P350
	30 (kA)	BW125JAG-3P060		BW125JAT-3P060	BW125JAT-3P090	BW250RAT-3P125	BW250RAT-3P150	BW250RAT-3P225	BW400EAT-3P350
	36 (kA)	BW125RAG-3P060		BW125RAG-3P100	BW250RAT-3P125	BW250RAT-3P125	BW250RAT-3P150	BW250RAT-3P225	BW400RAT-3P350
	50 (kA)	BW125RAG-3P060		BW125RAG-3P100	BW250RAT-3P125	BW250RAT-3P125	BW250RAT-3P150	BW250RAT-3P225	BW400RAT-3P350
	65 (kA)	BW125HAG-3P060		BW125HAG-3P100	BW250HAG-3P150	BW250HAG-3P225	BW400HAG-3P300	BW630HAG-3P500	---

Note: Peak inrush current used in calculations: 20kVA max.: 23.5 times the rated current, 20kVA min.: 18 times the rated current

Table 3-15 Selecting MCCB for transformer primary circuit
Three-phase, 200-220V/105V Transformers

Transformer capacity (kVA)		0.5	1.0	1.5	2.0	3.0	5.0	7.5	10
In: Rated primary current (rms A)		1.312	2.624	3.936	5.249	7.873	13.122	19.682	26.243
Irush: Exciting inrush current (rms A)		30.836	61.672	92.507	123.343	185.015	308.358	462.536	616.715
Short-circuit current at 220V	2.5 (kA)	BW32AAG-3P005		BW32AAG-3P010	BW32AAG-3P015	BW32SAT-3P015	BW32SAT-3P020	BW32SAT-3P030	BW50SAT-3P040
	5 (kA)	BW32SAG-3P005		BW32SAG-3P010	BW32SAG-3P015	BW32SAT-3P015	BW32SAT-3P020	BW32SAT-3P030	BW32SAT-3P040
	10 (kA)			BW50SAG-3P010	BW50SAG-3P015	BW50SAT-3P015	BW50SAT-3P020	BW50SAT-3P030	BW50SAT-3P040
	25 (kA)			BW50RAG-3P010	BW50RAG-3P015	BW50RAG-3P020	BW50RAG-3P040	BW50RAG-3P050	BW100EAG-3P060
	36 (kA)						BW125JAG-3P015	BW125JAG-3P060	BW125JAT-3P060
	50 (kA)						BW125JAG-3P015	BW125JAG-3P060	BW125JAT-3P060
	85 (kA)						BW125SAG-3P015	BW125SAG-3P060	BW125SAG-3P100
	100 (kA)						BW125RAG-3P015	BW125RAG-3P060	BW125RAG-3P100
	125 (kA)						BW50HAG-3P015	BW125HAG-3P060	BW125HAG-3P100

Transformer capacity (kVA)		15	20	30	50	75	100	150	200
In: Rated primary current (rms A)		39.365	52.486	78.730	131.216	196.824	262.432	393.648	524.864
Irush: Exciting inrush current (rms A)		925.073	1233.430	1417.132	2361.887	3542.831	4723.775	7085.662	9447.550
Short-circuit current at 220V	2.5 (kA)	BW50SAT-3P050	BW100EAT-3P075	BW100EAT-3P100	BW250EAT-3P150	BW400EAT-3P250	BW400EAT-3P300	---	---
	5 (kA)	BW50SAT-3P050	BW100EAT-3P075	BW100EAT-3P100	BW250EAT-3P150	BW400EAT-3P250	BW400EAT-3P300	---	---
	10 (kA)	BW50SAT-3P050	BW100EAT-3P075	BW100EAT-3P100	BW250EAT-3P150	BW400EAT-3P250	BW400EAT-3P300	---	---
	25 (kA)	BW100EAT-3P060	BW100EAT-3P075	BW100EAT-3P100	BW250EAT-3P150	BW400EAT-3P250	BW400EAT-3P300	---	---
	36 (kA)	BW125JAT-3P060	BW125JAT-3P075	BW125JAT-3P090	BW250EAT-3P150	BW400EAT-3P250	BW400EAT-3P300	---	---
	50 (kA)	BW125JAT-3P060	BW125JAT-3P075	BW125JAT-3P090	BW250RAT-3P150	BW400EAT-3P250	BW400EAT-3P300	---	---
	85 (kA)	BW160SAG-3P125		BW250RAT-3P125	BW250RAT-3P150	BW400RAT-3P250	BW400RAT-3P300	---	---
	100 (kA)	BW160RAG-3P125		BW250RAT-3P125	BW250RAT-3P150	BW400RAT-3P250	BW400RAT-3P300	---	---
	125 (kA)	BW250HAG-3P125	BW250HAG-3P175	BW400HAG-3P250	BW400HAG-3P300	BW630HAG-3P500	BW630HAG-3P600	---	---

Note: Peak inrush current used in calculations: 20kVA max.: 23.5 times the rated current, 20kVA min.: 18 times the rated current

3-6 Applications on the primary side of transformers

Table 3-15 Selecting MCCB for transformer primary circuit
Single-phase, 400-440V/210-105V Transformers

Transformer capacity (kVA)		0.5	1.0	1.5	2.0	3.0	5.0	7.5	10
In: Rated primary current (rms A)		1.136	2.273	3.409	4.545	6.818	11.364	17.045	22.727
Irush: Exciting inrush current (rms A)		28.409	56.818	85.227	113.636	170.455	284.091	426.136	568.182
Short-circuit current at 440V	1.5 (kA)	BW32AAG-2P003		BW32AAG-2P010	BW32AAG-2P015		BW32SAT-2P015		BW32SAT-2P030
	2.5 (kA)	BW32SAG-2P003		BW32RAG-2P010	BW32SAG-2P015		BW32SAT-2P015		BW32SAT-2P030
	7.5 (kA)			BW50SAG-2P010	BW50SAG-2P015		BW50SAT-2P015		BW50SAT-2P030
	10 (kA)				BW50RAG-2P015	BW50RAG-2P020	BW50RAG-2P030	BW50RAG-2P040	BW63RAG-2P060
	18 (kA)						BW125JAG-2P015	BW125JAG-2P060	BW125JAT-2P060
	30 (kA)						BW125JAG-2P015	BW125JAG-2P060	BW125JAT-2P060
	36 (kA)						BW125SAG-2P015	BW125SAG-2P060	BW125SAG-2P075
	50 (kA)						BW125RAG-2P015	BW125RAG-2P060	BW125RAG-2P075
	65 (kA)						BW125HAG-2P015	BW125HAG.3P060	BW125HAG-2P075

Transformer capacity (kVA)		15	20	30	50	75	100
In: Rated primary current (rms A)		34.091	45.455	68.182	113.636	170.455	227.273
Irush: Exciting inrush current (rms A)		852.273	1136.364	1704.545	2840.909	4261.364	5681.818
Short-circuit current at 440V	1.5 (kA)	BW50SAT-2P045	BW125JAT-2P060	BW125JAT-2P090	BW250EAT-2P175	BW400EAT-2P300	BW400EAT-2P400
	2.5 (kA)	BW50SAT-2P045	BW125JAT-2P060	BW125JAT-2P090	BW250EAT-2P175	BW400EAT-2P300	BW400EAT-2P400
	7.5 (kA)	BW50SAT-2P045	BW125JAT-2P060	BW125JAT-2P090	BW250EAT-2P175	BW400EAT-2P300	BW400EAT-2P400
	10 (kA)		BW125JAT-2P060	BW125JAT-2P090	BW250EAT-2P175	BW400EAT-2P300	BW400EAT-2P400
	18 (kA)		BW125JAT-2P060	BW125JAT-2P090	BW250EAT-2P175	BW400EAT-2P300	BW400EAT-2P400
	30 (kA)		BW125JAT-2P060	BW125JAT-2P090	BW250RAT-2P175	BW400EAT-2P300	BW400EAT-2P400
	36 (kA)	BW125SAG-2P125		BW125RAT-2P090	BW250RAT-2P175	BW400RAT-2P300	BW400RAT-2P400
	50 (kA)	BW125RAG-2P125		BW125RAT-2P090	BW250RAT-2P175	BW400RAT-2P300	BW400RAT-2P400
	65 (kA)	BW125HAG-2P125	BW250HAG-2P150	BW400HAG-2P250	BW400HAG-2P400	---	---

Note: A peak inrush current of 25 times the rated current is used in the calculations.

3-7 Welder circuit applications

3-7-1 Arc welders

MCCBs installed in arc welder circuits should not inadvertently trip due to the massive inrush current generated at ignition. Inadvertent tripping often occurs when inrush current instantly trips the overcurrent tripping element in the MCCB. Since the transient inrush current in arc welders is 8 to 9 times the primary current, an MCCB that can handle at least ten times the rated primary current without tripping should be selected for this kind of application.

3-7-2 Resistance welders

(1) Characteristics specific to resistance welder circuits

Resistance welders are characterized by intermittent operation with short switching intervals and also by switching in the primary circuit of the welder transformer. Consequently, the following points must be considered when selecting an MCCB:

(a) Thermal equivalent current

The current that flows through the welding circuit is repetitive with short periods as shown in Fig. 3-22. Since the MCCB operation or the temperature rise in the wire is determined by a thermal equivalent current, the current flowing during intermittent operation must be converted to a thermally equivalent continuous current.

(i) Thermal equivalent current Ia during period t (seconds)

Assuming that the current flowing time for resistance welding by the current I_L [A] is t_L (seconds) per point, and that resistance welding is conducted at one point per t (seconds), then the on-load factor α of the welder can be stated in an equation as:

$$\alpha = \frac{\text{Current flowing time}}{\text{Period}} = \frac{t_L}{t}$$

In this current flowing state, the amount of heat W generated by the total circuit resistance R per t (seconds) can be represented as

$$W = (I_L)^2 \cdot R \cdot t_L \text{ (joule)}$$

If this value is taken as the average amount of heat generated per *t* (seconds), then the equation derives as follows.

$$\begin{aligned}\frac{W}{t} &= (I_L)^2 \cdot R \cdot \frac{t_L}{t} \\ &= (I_L)^2 \cdot R \cdot \alpha \\ &= R(I_L\sqrt{\alpha})^2\end{aligned}$$

This means that the generated heat is equal to the amount of heat that would be generated upon continuous flow of the current $I_L\sqrt{\alpha}$ (A). Hence, the thermal equivalent current Ia at period t (seconds) can be stated as

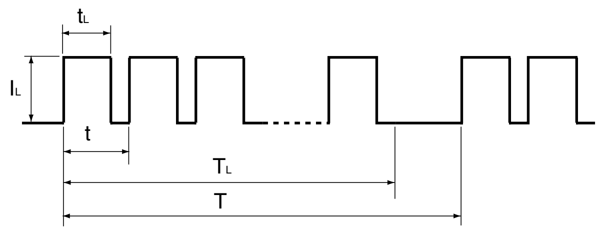
$$I_a = I_L\sqrt{\alpha} \text{ (A)}$$

(ii) Thermal equivalent current I_B at period T (seconds)

In Fig. 3-22, the thermal equivalent current I_B at period T_L (seconds) is similar to that at period t (seconds). At period T (seconds), however, the thermal equivalent current I_B can be represented as:

$$I_B = I_L\sqrt{\beta} \text{ (A)} \qquad \text{where, } \beta = n \cdot t_L/T, \quad n = T_L/t$$

Fig. 3-22 Typical intermittent operation



(b) Transient inrush current caused by switching transformer primary circuit

For resistance welders load switching is carried out in the primary circuit of the welder transformer. Consequently, a high transient inrush current may flow when the circuit is closed, as mentioned under "Selecting an MCCB for transformer primary circuit" (See page 57).
Whether or not inrush current flows depends on the type of switching control system used in resistance welders because inrush current is generated by the closed circuit phase or by residual magnetic flux in the transformer core. Switching is controlled using synchronous, semi-synchronous, or asynchronous systems.
Inrush current does not occur with synchronous control systems because they can control the current flow start phase and they can reverse the start polarity by the time the current flow ends.
Semi-synchronous control systems can control the current flow start phase, but cannot necessarily reverse the start polarity by the time the current flow ends. Inrush current may therefore occur here due to biased excitation of the core, but this is generally not a problem because these systems can adequately control the making phase.
Most semi-synchronous control systems today use thyristors for main current switching. With the anti-surge current capability of the thyristor as well, these systems take the half cycle at the start of the closed circuit phase and insert it just past the voltage phase $\pi/2$ to prevent inrush current.
Asynchronous control systems use a magnetic contactor for main current switching. Here, the closed circuit phase generates massive inrush current as high as 20 times the steady state current. This is why newer welders now use either synchronous or semi-synchronous control systems.

(2) Selecting MCCBs

(a) Basic rule

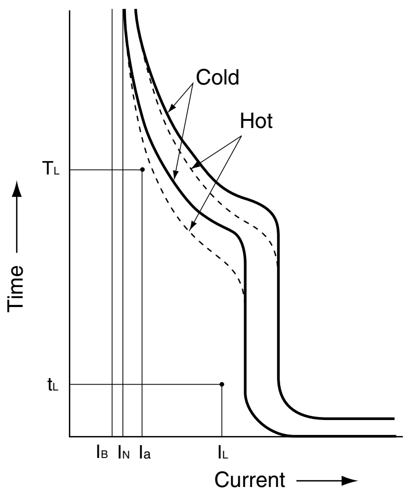
Assuming that the welder is used in the operating condition illustrated in Fig. 3-22, the MCCB to be used must meet the following requirements:

(i) The rated current (I_N) of the MCCB is higher than the thermal equivalent current I_B ($I_N > I_B$).
Allowing for possible supply voltage fluctuation, a margin of some 10% would be recommended.

(ii) The MCCB is not tripped by the primary input current. The MCCB's hot-start characteristic curves are positioned above the points (t_L, I_L) and (T_L, I_a) so that the currents I_L and I_a (A) would not cause the MCCB to malfunction (Fig. 3-23).

(iii) The MCCB is free from malfunction due to inrush current when the circuit is closed.

Fig. 3-23 Hot and cold MCCB operating characteristics



(b) Selecting MCCB based on welder ratings

If the operating conditions for the welder are not definite, the MCCB to be used should be selected by allowing for the maximum operating limits of the welder considering its ratings or specifications.
The rated capacity of a resistance welder is indicated in terms of a 50% on-load factor. Namely, the rated capacity is defined as an input load that would meet the temperature rise requirement when the welder is used with a 50% on-load factor.
If the welder is to be used with a current different from that available with a 50% on-load factor, it must be used with an on-load factor that would cause an equivalent temperature rise observed with a 50% on-load factor or lower.
The relationship between the primary input capacity and the allowable on-load factor can be stated in an equation as

$$\text{Allowable on-load factor} = \left(\frac{\text{Rated capacity}}{\text{Primary input capacity}}\right)^2 \times 50\%$$

This equation may be used to examine all possible combinations of the primary input capacity and the allowable on-load factor.

(i) Reviewing the thermal equivalent current

With an on-load factor of 100%, the thermal equivalent current can be stated in equation form as

$$\text{Thermal equivalent current} = \frac{\text{Rated capacity}}{\text{Rated voltage}} \times \sqrt{\frac{50}{100}}\ \text{(A)}$$

Hence, the rated current of the MCCB must be at least equal to this value.

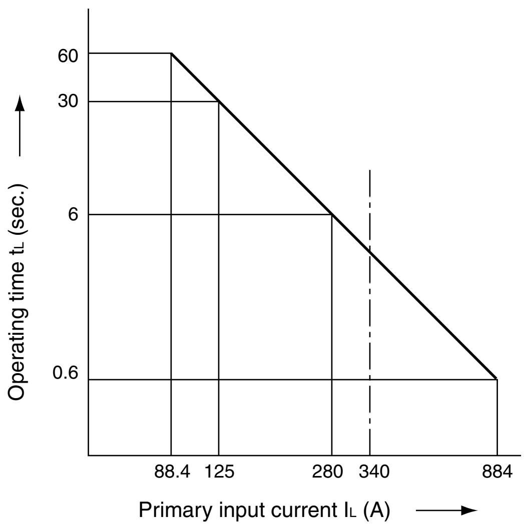
(ii) Reviewing the method to prevent malfunctioning associated with the primary input current

The first step in reviewing the primary input current-time characteristics of the resistance welder and the hot-start characteristic of the MCCB is setting the operating time (t_L) associated with the allowable on-load factor (α) of the welder. Assuming that the intermittent loading cycle is 1 minute and hence $t_L = 60 \cdot \alpha / 100$ (seconds), the relationship between the operating time (t_L) and the primary input current (I_L) must be represented.
Fig. 3-24 shows the relationship between the primary input current and allowable operating time for a single-phase 200V resistance welder rated at 25kVA.
Since the equation

$$\text{Primary input current} = \sqrt{\frac{50}{\text{On-load factor}}} \times \frac{\text{Rated capacity}}{\text{Rated voltage}}$$

is derived from the relationship presented above, the maximum operating limits of the welder can be calculated as follows:
125A for 50% on-load factor, (t_L = 30 seconds)
280A for 10% on-load factor, (t_L = 6 seconds)
884A for 1% on-load factor, (t_L = 0.6 seconds)

Fig. 3-24 Relationship between maximum primary input current and operating time



However, since the standard maximum input is prescribed for a resistance welder, even if the secondary circuit is fully shorted, the maximum short-circuit current is some 30% higher than the rated welding current (secondary current corresponding to the standard maximum input) at most. Consequently, allowance would be needed only for a value about 30% higher than the current corresponding to the standard maximum input.

Assuming a standard maximum input of 55kVA at 230V AC single-phase, I_L (max) is calculated as

$$I_L\ (\text{max}) = \frac{55000}{230} \times 1.3 \approx 310\ [\text{A}]$$

This result requires that the t_L–I_L curve shown in Fig. 3-24 be positioned below the hot-start characteristic curve of the MCCB in the range $I_L \leq 310$ (A). A general guideline for filling this requirement is to set the rated current of the MCCB at least 1.5 times higher than the thermal equivalent current calculated in (i).

(iii) Method to keep the MCCB free from malfunctioning caused by the inrush current when the circuit is closed.

With welders that use thyristors to permit closed circuit phase control, such as those operating in synchronous or semi-synchronous mode, the inrush current associated with the biased excitation of the transformer core would not be much of a problem. Rather, only the inrush current associated with the superposed DC component needs to be considered. Specifically, a choice should be made of an MCCB having its instantaneous tripping current at least two times the I_L (max) calculated in (ii).

Table 3-19 lists typical MCCBs that are selected to work with resistance welders that operate in synchronous or semi-synchronous mode, pursuant to the requirements given in (i) to (iii) above. Since, generally, the standard maximum input of a welder is some three times its rated capacity, and the instantaneous tripping current of an MCCB is eight times its rated current or higher, the following equation may be used to select an MCCB to work with welders that operate in synchronous or semi-synchronous mode:

$$I_N > 1.1 \times \left(\frac{\text{Rated capacity}}{\text{Rated voltage}}\right) \qquad I_N = \text{MCCB rated current}$$

$$\text{Assumption: } \left(\frac{\text{Max. input capacity}}{\text{Rated capacity}}\right) \leq 3$$

Table 3-19 Spot welder circuit motor breaker selection

Note: This table applies to models that can use a thyristor to perform phase control at startup for a synchronous or semi-synchronous system.

Resistance welder		**Single-phase, 200V Circuit short-circuit capacity (kA) (The short-circuit current at the service entrance must be less than the following values.)**				
Rated capacity example (kVA)	**Maximum input example (kVA)**	**5**	**25**	**36**	**50**	**100**
15	35	BW100AAG-2P100	BW100EAG-2P100	BW125JAG-2P100		
30	65	BW125JAG-2P125				BW125RAG-2P125
55	140	BW250EAG-2P225			BW250RAG-2P225	

Resistance welder		**Single-phase, 400V Circuit short-circuit capacity (kA) (The short-circuit current at the service entrance must be less than the following values.)**			
Rated capacity example (kVA)	**Maximum input example (kVA)**	**10**	**18**	**30**	**50**
15	35	BW50RAG-2P050	BW125JAG-2P050		BW125RAG-2P050
30	65	BW100EAG-2P100	BW125JAG-2P100		BW125RAG-2P100
55	140	BW125JAG-2P125			BW125RAG-2P125

3-8 Selecting an MCCB for capacitor circuit

3-8-1 Characteristics specific to capacitor circuits

Note the following points when considering MCCBs for capacitor circuits:

(1) Arc reignition due to recovery voltage

When a capacitor circuit shown in Fig. 3-25 is opened, it exhibits characteristics distinctly different from inductive loads due to the effects of residual electric charge in the capacitor.
In a single-phase circuit like that shown in Fig. 3-26, the capacitor voltage lags 90° behind the current, and a peak voltage exists across the capacitor terminals when the circuit is opened. The recovery voltage appearing between the switch contacts immediately after the circuit is opened is equal to the difference between the capacitor residual voltage and the supply voltage. Therefore, half a cycle after the circuit opens, the voltage between the switch contacts rises to twice the supply voltage or higher.
In a three-phase circuit, the recovery voltage appearing between the contacts in the first interrupted phase could rise as high as 2.5 times the supply voltage.
Unless the breaker contacts are fully open until half a cycle after the capacitor circuit opens, restrike of arc will occur. If the capacitor is discharged by damped oscillation at the oscillation frequency according to the inductance (L) and capacitance (C) of the circuit at re-ignition, then residual peak voltage will be left at the terminal again if the arc is quenched (current cuts off).
If restrike of arc is repeated, the voltage could continue to rise to the dielectric breakdown point of the capacitor.
Hence, fast-interrupting circuit breakers with quick-make, quick-break action are recommended for this type of circuit.

Fig. 3-25 Residual electric charge in the capacitor

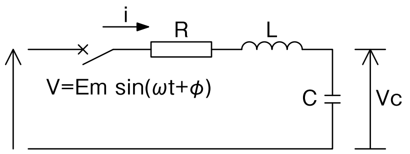
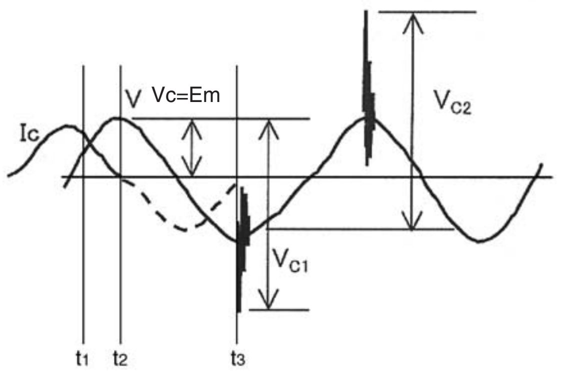


Fig. 3-26 Capacitor residual voltage



(2) Transient inrush current when a circuit closes

When a capacitor circuit like the one shown in Fig. 3-25 closes, the capacitor must be charged with an equivalent of the voltage applied the instant the circuit closed. This causes the circuit to be flooded with massive inrush current that has a steep slope like that shown in Fig. 3-27.
If the circuit closes now with peak supply voltage present, then the transient current at this time is expressed by the following equation.

If $i = (Em/L\beta)\varepsilon^{-\alpha t}\sin\beta t$ ······ (1)

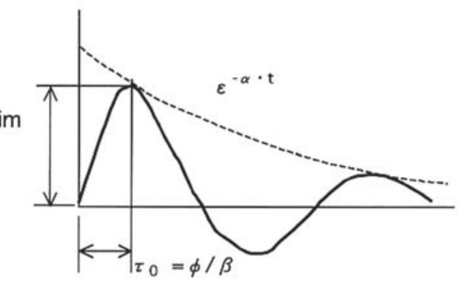
$\alpha = R/2L \qquad \gamma = \sqrt{4L/C-R^2}$

$\beta = \sqrt{(4L/C-R^2)}/2L, \quad \beta = \left(\sqrt{(1/LC-R^2/4L^2)}\right)$

which yields $\beta = \gamma/2L$

Generally $\beta > 0$ $(1/LC > R^2/4L^2)$ is true, and oscillating transient current flows at the natural frequency as shown below.

Fig. 3-27 Transient current when a capacitor circuit closes



Since the natural frequency at this time is as follows: $f = \omega/2\pi$, equation (1) yields $\omega = \beta$, and so

$f = \sqrt{1/(LC-R^2/4L^2)}/2\pi, \qquad f = \gamma/4\pi L$

Then equation (1) above yields the following equation.
$i = (2Em/\gamma)\varepsilon^{-tR/2L}\sin(\gamma/2L)t$ ....(2)
Maximum current at this time is expressed as follows:

$im = (Em/\sqrt{L/C})\varepsilon^{-R/\gamma\tan^{-}\gamma/R}$ ······ (3)

$im = (Em/\sqrt{L/C})\varepsilon^{-\alpha \cdot \varnothing/\beta}$ ······ (3)-1

The first wave peak τ_0 is expressed as follows:
$\tau_0 = (2L/\gamma)\tan^{-1}\gamma/R \qquad \tau_0 = \varnothing/\beta$ .....(4)
$\varnothing = \tan^{-1}\beta/\alpha$ (rad)
Since the time shown in equation (4) is very short, the voltage in equation (3) or (3)-1 is essentially V = Em.
Since $\varepsilon^{-\alpha\cdot\varnothing/\beta}$ is approximately 1, the peak transient inrush current is derived as follows from equation (3)-1.

$im \approx Em\sqrt{C/L}$ ······ (5)

(Here, Em is $\sqrt{2/3}$ times the line voltage in a three-phase circuit and is $\sqrt{2}$ times the line voltage in a single-phase circuit.)
The preceding equations prove that transient inrush current flowing to the capacitor is related to inductance (L), that is, it is related to the power supply capacity and the presence or absence of reactors connected in series with the capacitor.

If no reactors are connected in series with the capacitor, then the R, L, and C defined by the power supply transformer capacity, percentage impedance and capacitance will cause wild fluctuations in the inrush current factor (first wave peak/ effective rated capacitor current), oscillating frequency and damping constant. The amount of fluctuation is especially significant when it comes to selecting a rated current for the MCCB. This is why inserting reactors totaling up to 6% of the impedance into capacitor circuits is highly recommended for improving the power factor.
Series-connected reactors are needed because the inrush current from other capacitors is added to the current from the power supply if capacitors are inserted in parallel using multiple banks without reactors.

(3) Selecting an MCCB for phase advance capacitor circuits

Table 3-20 shows the rated current (In) for applicable MCCBs at various capacitances. Since the conditions for selecting MCCBs are aimed at preventing mistripping, first find the effective current (Ict), that is, the transient current plus the steady state current 0.01s after power is turned on. If that current (Ict) is less than 1/10 the instantaneous tripping current of the MCCB (10 times the rated current of the MCCB) or is more than 1.5 times the rated current of the capacitor (Icn), then use the main current approximating that value.

$In > k \times Ic$ $Ic > Ict/10$ or $Ic > Icn$

Icn: Capacitor rated current (effective value)

(Single phase: $Icn = \omega C \cdot V$, three-phase: $Icn = \omega C \cdot V/\sqrt{3}$)

In: MCCB rated current (effective value)

Ict: Inrush current 0.01s after power is turned ON (effective value)

Ic: Ict/10 or Icn min

k: 1.5 (margin coefficient for the allowable fluctuation error)

V: Line voltage (effective value)

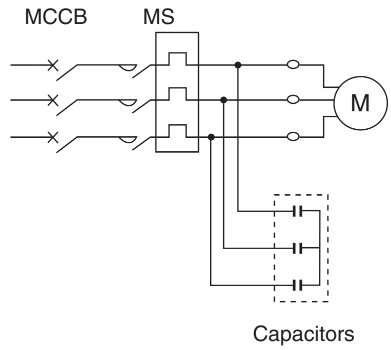
ω: $2\pi f$ (f: frequency (Hz) of the applicable circuit)

Notes:
- The value of 1.5 times is the sum of the maximum allowable current for the capacitor (1.3 times the rated current) and the allowable capacitance error plus 15%.
- The oscillating frequency of transient current is much higher than the fundamental harmonic. It ranges from several hundred hertz to several kilohertz with no series-connected reactors, or less than several hundred hertz (200 to 300Hz max.) regardless of the power supply capacity with reactors totaling 6% of the impedance connected in series.
- Transient current attenuation is relatively fast without reactors connected in series and is fairly slow with reactors connected in series.

(4) When capacitors are connected in parallel with individual motor circuits to improve the power factor (See Fig. 3-28.)

When selecting the rated current of an MCCB, choose one where startup inrush current-time characteristics for the motor will not cause the MCCB to malfunction. If capacitance less than 30% of the motor capacity is used here, then the rated current of the MCCB should be at least three times the rated current of the capacitor. This will prevent the MCCB from malfunctioning even without series-connected reactors because the capacitor is installed on the secondary side of the magnetic motor starter. Refer to the Technical Information for the magnetic motor starter for more details on available models and durability characteristics.

Fig. 3-28 Capacitors connected in parallel with the motor



3-8 Selecting an MCCB for capacitor circuit

Table 3-20 (1) MCCB rated current application examples for single-phase capacitor equipment capacity

Rated frequency (Hz)	Rated voltage (V)	Rated equipment capacity (kvar)	Rated current (A)	Capacitor rating		Series reactor 6%		MCCB rated current (A)
				(kvar)	(μF)	(kvar)	(mH)	
50	200	1.34	6.7	1.43	100	0.09	6.06	10
		2.67	13.4	2.84	200	0.17	3.04	20
		3.34	16.7	3.55	250	0.21	2.43	30
		4.01	20.1	4.27	300	0.26	2.03	30
		5	25.0	5.32	374	0.32	1.63	40
		10	50.0	10.64	748	0.64	0.81	75
		15	75.0	15.96	1,122	0.96	0.54	125
		20	100.0	21.28	1,496	1.28	0.41	150
		25	125.0	26.60	1,870	1.60	0.33	200
		30	150.0	31.91	2,244	1.91	0.27	225
		40	200.0	42.55	2,992	2.55	0.20	300
		50	250.0	53.19	3,740	3.19	0.16	400
		75	375.0	79.79	5,610	4.79	0.11	600
		100	500.0	106.38	7,480	6.38	0.08	800
		150	750.0	159.57	11,220	9.57	0.05	1200
		200	1000.0	212.77	14,961	12.77	0.04	1500
		300	1500.0	319.15	22,441	19.15	0.03	2500
	400	1.07	2.7	1.14	20	0.07	30.38	5
		1.60	4.0	1.70	30	0.10	20.32	10
		2.67	6.7	2.84	50	0.17	12.18	10
		4.01	10.0	4.27	75	0.26	8.11	15
		5	12.5	5.32	94	0.32	6.50	20
		10	25.0	10.64	187	0.64	3.25	40
		15	37.5	15.96	281	0.96	2.17	60
		20	50.0	21.28	374	1.28	1.63	75
		25	62.5	26.60	468	1.60	1.30	100
		30	75.0	31.91	561	1.91	1.08	125
		40	100.0	42.55	748	2.55	0.81	150
		50	125.0	53.19	935	3.19	0.65	200
		75	187.5	79.79	1,403	4.79	0.43	300
		100	250.0	106.38	1,870	6.38	0.33	400
		150	375.0	159.57	2,805	9.57	0.22	600
		200	500.0	212.77	3,740	12.77	0.16	800
		300	750.0	319.15	5,610	19.15	0.11	1200
60	220	0.97	4.4	1.03	50	0.06	12.17	10
		1.94	8.8	2.06	100	0.12	6.08	15
		2.91	13.2	3.10	150	0.19	4.06	20
		3.88	17.6	4.13	200	0.25	3.04	30
		5	22.7	5.32	258	0.32	2.36	40
		10	45.5	10.64	515	0.64	1.18	75
		15	68.2	15.96	773	0.96	0.79	125
		20	90.9	21.28	1,030	1.28	0.59	150
		25	113.6	26.60	1,288	1.60	0.47	200
		30	136.4	31.91	1,546	1.91	0.39	225
		40	181.8	42.55	2,061	2.55	0.30	300
		50	227.3	53.19	2,576	3.19	0.24	400
		75	340.9	79.79	3,864	4.79	0.16	600
		100	454.5	106.38	5,152	6.38	0.12	800
		150	681.8	159.57	7,728	9.57	0.08	1200
		200	909.1	212.77	10,303	12.77	0.06	1500
		300	1363.6	319.15	15,455	19.15	0.04	2500
	440	1.55	3.5	1.65	20	0.10	30.45	5
		2.33	5.3	2.48	30	0.15	20.26	10
		3.11	7.1	3.31	40	0.20	15.18	10
		3.88	8.8	4.13	50	0.25	12.17	15
		5	11.4	5.32	64	0.32	9.44	20
		10	22.7	10.64	129	0.64	4.72	40
		15	34.1	15.96	193	0.96	3.15	60
		20	45.5	21.28	258	1.28	2.36	75
		25	56.7	26.60	322	1.60	1.89	100
		30	68.2	31.91	386	1.91	1.57	125
		40	90.9	42.55	515	2.55	1.18	150
		50	113.6	53.19	644	3.19	0.94	175
		75	170.5	79.79	966	4.79	0.63	300
		100	227.3	106.38	1,288	6.38	0.47	350
		150	340.9	159.57	1,932	9.57	0.31	600
		200	454.5	212.77	2,576	12.77	0.24	700
		300	681.8	319.15	3,864	19.15	0.16	1000

Notes:
- The MCCB rated current should be approx. 150% of the capacitor rated current.
- The MCCB should have enough breaking capacity to cut off short-circuit current in the circuit.
- Use a magnetic contactor to switch multiple capacitor banks for automatic power factor regulation. Be sure to install series-connected reactors as well. Add up the total capacitance here to select the rated current for the main MCCB.
- As a rule, use series-connected reactors totaling 6% of the impedance.

Table 3-20 (2) MCCB rated current application examples for three-phase capacitor equipment capacity

Rated frequency (Hz)	Rated voltage (V)	Rated equipment capacity (kvar)	Rated current (A)	Capacitor rating		Series reactor 6%		MCCB rated current (A)
				(kvar)	(μF)	(kvar)	(mH)	
50	200	1.34	3.9	1.43	100	0.09	6.06	10
		2.67	7.7	2.84	200	0.17	3.04	15
		3.34	9.6	3.55	250	0.21	2.43	15
		4.01	11.6	4.27	300	0.26	2.03	20
		5	14.4	5.32	374	0.32	1.63	30
		10	28.9	10.64	748	0.64	0.81	50
		15	43.3	15.96	1,122	0.96	0.54	75
		20	57.7	21.28	1,496	1.28	0.41	100
		25	72.2	26.60	1,870	1.60	0.33	125
		30	86.6	31.91	2,244	1.91	0.27	150
		40	115.5	42.55	2,992	2.55	0.20	175
		50	144.3	53.19	3,740	3.19	0.16	225
		75	216.5	79.79	5,610	4.79	0.11	350
		100	288.7	106.38	7,480	6.38	0.08	500
		150	433.0	159.57	11,220	9.57	0.05	700
		200	577.4	212.77	14,961	12.77	0.04	900
		300	866.0	319.15	22,441	19.15	0.03	1400
	400	1.07	1.5	1.14	20	0.07	30.38	5
		1.60	2.3	1.70	30	0.10	20.32	5
		2.67	3.9	2.84	50	0.17	12.18	10
		4.01	5.8	4.27	75	0.26	8.11	10
		5	7.2	5.32	94	0.32	6.50	15
		10	14.4	10.64	187	0.64	3.25	30
		15	21.7	15.96	281	0.96	2.17	40
		20	28.9	21.28	374	1.28	1.63	50
		25	36.1	26.60	468	1.60	1.30	60
		30	43.3	31.91	561	1.91	1.08	75
		40	57.7	42.55	748	2.55	0.81	100
		50	72.2	53.19	935	3.19	0.65	125
		75	108.3	79.79	1,403	4.79	0.43	175
		100	144.3	106.38	1,870	6.38	0.33	225
		150	216.5	159.57	2,805	9.57	0.22	350
		200	288.7	212.77	3,740	12.77	0.16	500
		300	433.0	319.15	5,610	19.15	0.11	700
60	220	0.97	2.5	1.03	50	0.06	12.17	5
		1.94	5.1	2.06	100	0.12	6.08	10
		2.91	7.6	3.10	150	0.19	4.06	15
		3.88	10.2	4.13	200	0.25	3.04	20
		5	13.1	5.32	258	0.32	2.36	20
		10	26.2	10.64	515	0.64	1.18	40
		15	39.4	15.96	773	0.96	0.79	60
		20	52.5	21.28	1,030	1.28	0.59	100
		25	65.6	26.60	1,288	1.60	0.47	100
		30	78.7	31.91	1,546	1.91	0.39	125
		40	105.0	42.55	2,061	2.55	0.30	175
		50	131.2	53.19	2,576	3.19	0.24	200
		75	196.8	79.79	3,864	4.79	0.16	300
		100	262.4	106.38	5,152	6.38	0.12	400
		150	393.6	159.57	7,728	9.57	0.08	600
		200	524.9	212.77	10,303	12.77	0.06	800
		300	787.3	319.15	15,455	19.15	0.04	1200
	440	1.55	2.0	1.65	20	0.10	30.45	5
		2.33	3.1	2.48	30	0.15	20.26	5
		3.11	4.1	3.31	40	0.20	15.18	10
		3.88	5.1	4.13	50	0.25	12.17	10
		5	6.6	5.32	64	0.32	9.44	10
		10	13.1	10.64	129	0.64	4.72	20
		15	19.7	15.96	193	0.96	3.15	30
		20	26.2	21.28	258	1.28	2.36	40
		25	32.8	26.60	322	1.60	1.89	50
		30	39.4	31.91	386	1.91	1.57	60
		40	52.5	42.55	515	2.55	1.18	100
		50	65.6	53.19	644	3.19	0.94	100
		75	98.4	79.79	966	4.79	0.63	150
		100	131.2	106.38	1,288	6.38	0.47	200
		150	196.8	159.57	1,932	9.57	0.31	300
		200	262.4	212.77	2,576	12.77	0.24	400
		300	393.6	319.15	3,864	19.15	0.16	600

Notes:
- The MCCB rated current should be approx. 150% of the capacitor rated current.
- The MCCB should have enough breaking capacity to cut off short-circuit current in the circuit.
- Use a magnetic contactor to switch multiple capacitor banks for automatic power factor regulation. Be sure to install series-connected reactors as well. Add up the total capacitance here to select the rated current for the main MCCB.
- As a rule, use series-connected reactors totaling 6% of the impedance.

3-9 MCCBs for semiconductor circuit

Circuits containing semiconductor devices such as thyristors and diodes differ in the following respects:

- The current flowing through the MCCB depends on where the MCCB is installed in the circuit.
- The fault current depends on fault modes.
- The overcurrent capacity of semiconductor devices is lower than that of other electrical apparatus.

Allowance should be made for these characteristics when selecting an MCCB.

3-9-1 Faults and overcurrents in thyristor converters

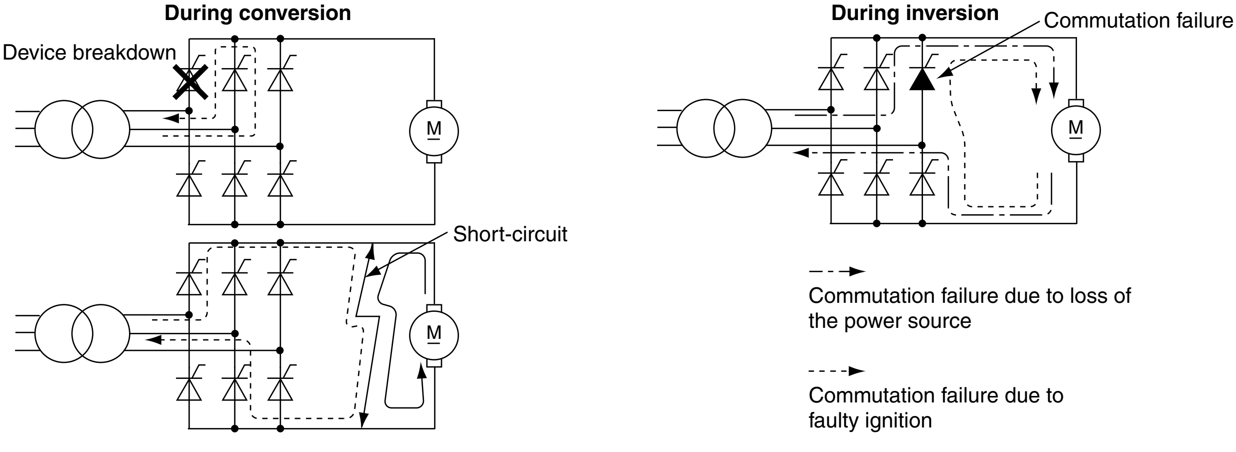
The possible causes of overcurrents in thyristor converters can be broadly classified into two categories: internal faults in the converters, and those external to the converters. Table 3-21 lists the typical possible causes of overcurrents in line-commutated thyristor converters and their associated conditions. Fig. 3-29 shows examples of the path of overcurrent flow.

Table 3-21 Possible causes of overcurrents in line-commutated thyristor converters

Causes of overcurrent			Overcurrent conditions	
Category	Phenomena	Possible cause	During conversion	During inversion
Internal faults	Misfiring	Thyristors fail to fire. Suspect a broken wire in the gate circuit or a fault in the controller.	Decreased output voltage. If some of the SCRs connected in parallel misfire, the remaining SCRs in that arm carry an overcurrent.	When all SCRs in one arm misfire, commutation fails, resulting in a short circuit on the DC side. If some SCRs in one arm misfire, the normal SCRs in that arm carry an overcurrent.
	Faulty ignition	SCRs fire when they should maintain forward blocking. Suspect an excessive forward voltage, excessive dv/dt, or gate noise.	If SCRs are connected in parallel, current concentrates in the SCRs that misfire, resulting in an overcurrent.	Commutation fails, resulting in a short circuit occurring on the DC side.
	Device breakdown	A short circuit has resulted from the loss of SCR forward blocking capability. Suspect an excessive junction temperature or overvoltage input.	A short circuit has occurred in the input AC source.	An AC interphase short circuit generated a backward current that caused a transition to commutation failure, resulting in a short circuit on the DC side.
External faults	Commutation failure	Suspect power failure or a broken wire in the power supply circuit.	With an inductive load, current flows through the arm that had been turned on until loss of the power source for a relatively long period of time raises junction temperature.	The loss of the commutating power source causes a commutation failure, resulting in a short circuit on the DC side.
	Short circuit in load side	Suspect a short circuit in the DC circuit or flashover in the DC motor.	A short circuit in the AC input source. The overcurrent flowing through the SCRs varies with the short-circuit point, or the presence or absence of a DC reactor.	Commutation fails as the AC voltage required for commutation is lost, but no overcurrent flows through the SCRs.

Table 3-21 and Fig. 3-29 show that, to protect normal devices, an overcurrent protection device must be installed, for each element (arm) in the conversion or on the AC side, for each element in an inversion or on the DC side.
The Ward-Leonard thyristor configuration in which the speed of the DC motor is controlled by thyristor phase control provides two modes: one in which the thyristor converter is run as a conversion (driving the DC motor), and one in which the thyristor converter is run as an inversion (regenerative braking of the DC motor). Installation of protective devices should be examined by considering possible failures in these two modes.

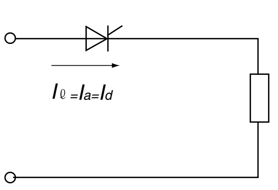
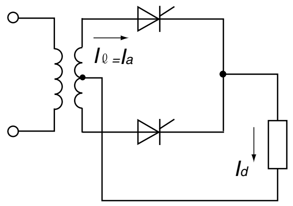
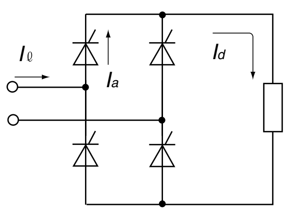
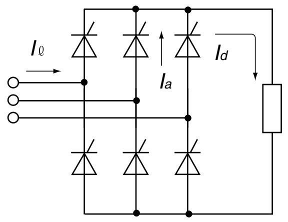
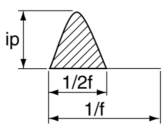
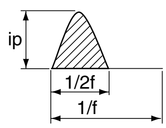
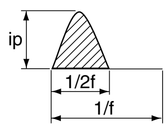
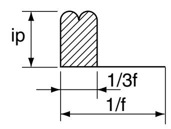
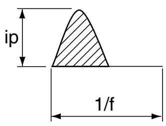
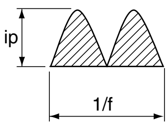
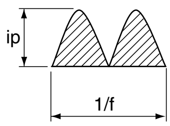
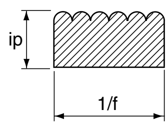
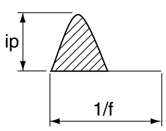
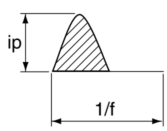
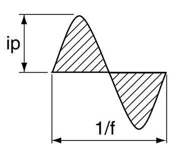
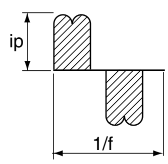
Fig. 3-29 Example of the path of overcurrent flow in thyristor converters



3-9-2 MCCB rated current

When an MCCB is used as a protective device, it is installed on either the AC or DC side. The current that flows through the MCCB may differ depending on the side in which it is installed. Remember this point when selecting an MCCB rated current rating.
With three-phase bridge circuits, installing an MCCB on the AC side may be more economical because an MCCB with a smaller current rating can be used in this setup. The type of failure may dictate, however, that the MCCB be installed on the DC side. Hence, the location of the MCCB should be determined with the importance of the load equipment and economy taken into consideration.
Table 3-22 indicates the circuit configurations and component current values of thyristor converters. Select an MCCB with a current rating higher than the effective circuit current, depending on its installation location. A 20% margin is recommended.

Table 3-22 Circuit configurations and component current of thyristor converters

Circuit configuration					
Element (arm)	Current waveform				
	Current Ia	Average: Ia (av) $\frac{1}{\pi}ip$ Effective: Ia (eff) $\frac{1}{2}ip$	Average: Ia (av) $\frac{1}{\pi}ip$ Effective: Ia (eff) $\frac{1}{2}ip$	Average: Ia (av) $\frac{1}{\pi}ip$ Effective: Ia (eff) $\frac{1}{2}ip$	Average: Ia (av) $\frac{1}{\pi}ip$ Effective: Ia (eff) $\sqrt{\frac{1}{6}+\frac{\sqrt{3}}{4\pi}}\,ip \approx 0.553ip$
DC side	Current waveform				
	Current Id	Average: Id (av) $\frac{1}{\pi}ip$ Effective: Id (eff) $\frac{1}{2}ip$	Average: Id (av) $\frac{2}{\pi}ip$ Effective: Id (eff) $\frac{1}{\sqrt{2}}ip$	Average: Id (av) $\frac{2}{\pi}ip$ Effective: Id (eff) $\frac{1}{\sqrt{2}}ip$	Average: Id (av) $\frac{3}{\pi}ip$ Effective: Id (eff) $\sqrt{\frac{3}{6}+\frac{3\sqrt{3}}{4\pi}}\,ip \approx 0.956ip$
AC side	Current waveform				
	Current Iℓ	Average: Iℓ (av) $\frac{1}{\pi}ip$ Effective: Iℓ (eff) $\frac{1}{2}ip$	Average: Iℓ (av) $\frac{1}{\pi}ip$ Effective: Iℓ (eff) $\frac{1}{2}ip$	Effective: Iℓ (eff) $\frac{1}{\sqrt{2}}ip$	Effective: Iℓ (eff) $\sqrt{\frac{2}{6}+\frac{2\sqrt{3}}{4\pi}}\,ip \approx 0.78ip$

Note: The loads are resistive, and the conduction angle of the device is 180°.

3-9-3 Protecting thyristors from overcurrent

The following methods are commonly used to protect semiconductor devices such as thyristors and diodes from overcurrent:

- Direct protection
  - Current-limiting fuses
  - Circuit breakers
  - Circuit protectors
  - High-speed DC circuit breakers
- Indirect protection
  - DC current limiting control
  - Gate control

These combinations can protect devices from all types of overcurrent, but they are a very costly method. It is best to achieve a balanced system that considers the importance of the equipment, the desired reliability, the cost performance, the potential faults and the probability of those faults when designing a protective system for semiconductor equipment. When devices must be fully protected in large-capacity replacement equipment (in which devices are expensive) and critical equipment, for example, it may be quite expensive, but the protective combination described above is sometimes needed for added assurance. In equipment where cost is critical on the other hand, every effort must be made to at least protect against the most likely faults.

(1) Protection in the overload current region

The overcurrent immunity of a thyristor, as represented in Fig. 3-30, is expressed with the period of time over which the thyristor can tolerate the peak value of positive half cycles of a sinusoidal current flowing through it.
The overload characteristics indicated by the solid lines suggest that the junction temperature remains within tolerable limits even when an overcurrent flows. The limit characteristic curves indicated by the dotted lines, generally known as allowable surge-on current limits, indicate limits of the thermal immunity of the device. Hence, the appropriate protective device to be selected must be capable of interrupting the current within the limits of time shown in Fig. 3-30. When making this selection, however, remember that the operating characteristics of MCCBs (including current-limiting fuses) are generally expressed using effective values of sinusoidal current, but in the case shown in Fig. 3-30, characteristics are expressed using the peak value of sinusoidal current.
It is therefore necessary to convert the overcurrent immunity characteristics expressed on the effective value base to compare with the characteristics of the protective device. Fig. 3-31 shows an example of a coefficient curve for converting to effective values.

Fig. 3-30 Overcurrent immunity characteristics of semiconductor devices

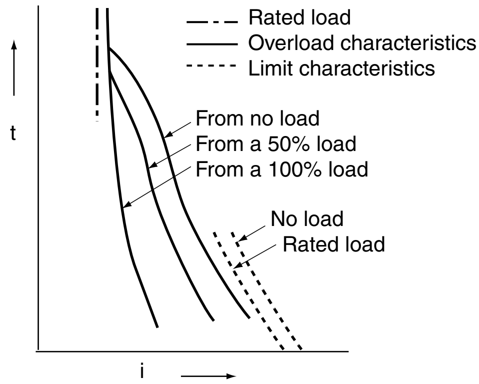
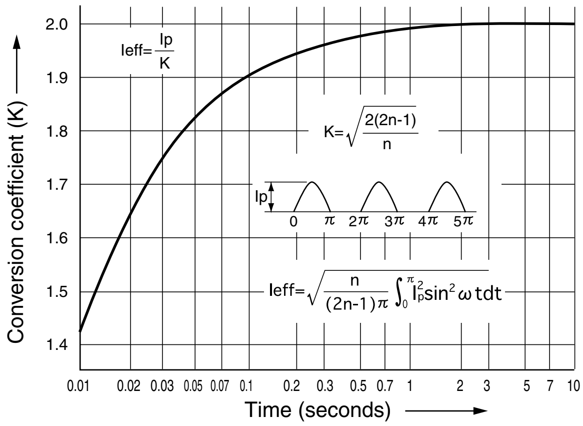


Fig. 3-31 Coefficient for converting to effective values



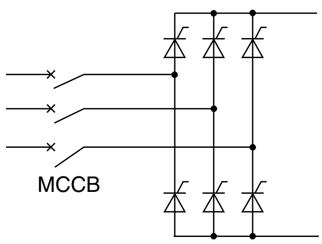
(2) Protection in the short-circuit region

If a short circuit in the load occurs during forward conversion (rectification) or if an arm short circuit results from device breakdown, the overcurrent must be interrupted in an extremely short period of time to protect the normal devices against the resulting large current.
In such a region, a protective device should be selected to meet the following relation with respect to the allowable limit value of I^2t of the devices:
Allowable I^2t of device > I^2t flowing through device when the protective device trips
Fuses for protecting semiconductors provide better current-limiting performance than MCCBs, that is, fuses are better suited for protecting thyristors against overcurrent caused by short circuits.

(3) Use of MCCBs on the AC side of thyristors

When MCCBs are installed on the AC side of a converter as shown in Fig. 3-32, their primary duty will be interrupting the fault current during forward conversion on rectification. From the standpoint of protection coordination with devices, instantaneous trip type MCCBs will be more suitable than MCCBs for line protection.
An instantaneous trip type circuit breaker is tripped within one cycle of any current exceeding its preset trip current Ii. Accordingly, if MCCB preset currents are specified as shown in (a) and (b) in Fig. 3-33, overcurrent protection is available in region B.
If the instantaneous trip characteristics of an MCCB are preset as indicated by 2 in (a), Fig. 3-33, an additional protective relay such as an overcurrent relay will be needed to provide protection in region A.
There will be no problem as long as the maximum current flowing through the circuit does not enter region C. Circuits in which fault currents are likely to flow in region C, however, would benefit by installation of reactors to suppress the fault current, or fuses for protecting semiconductors.

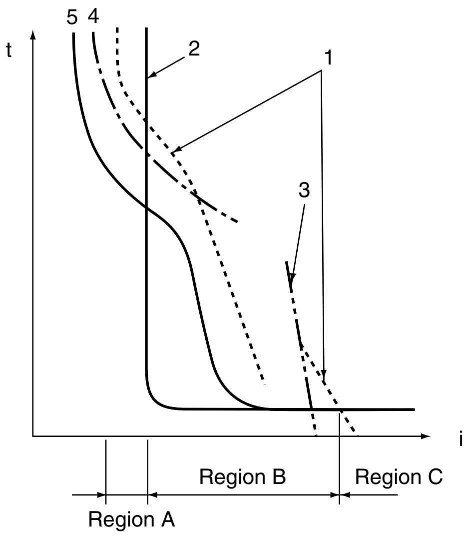
Fig. 3-32 MCCBs for AC applications



Any examination of the scheme of protection coordination between MCCBs and devices should allow conversion of the device overcurrent immunity into effective values for comparison. For example, in a three-phase bridge like that shown in Fig. 3-32, the currents through the MCCBs differ from that in devices and they must be compared on the same current base.

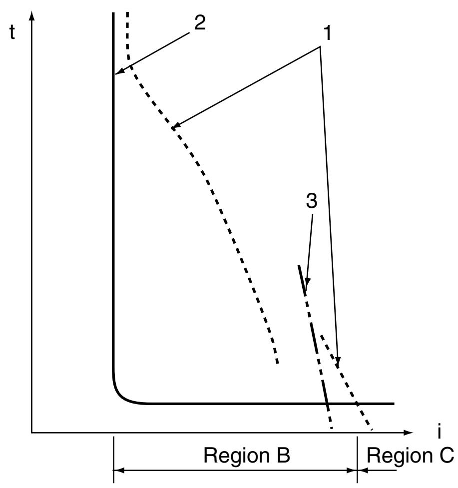
Fig. 3-33 Typical protection coordination curves

(a)



1. Thyristor overcurrent immunity characteristics
2. Instantaneous trip type circuit breaker operating characteristics
3. Semiconductor protection fuse operating characteristics
4. Overcurrent relay operating characteristics
5. Motor breaker operating characteristics

(b)

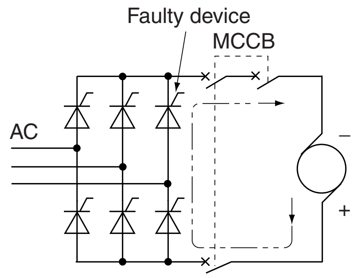


1. Thyristor overcurrent immunity characteristics
2. Instantaneous trip type circuit breaker operating characteristics
3. Semiconductor protection fuse operating characteristics

(4) Use of MCCBs on the DC side of thyristors

When MCCBs are installed on the DC side of a converter Fig. 3-34, their primary duty will be interrupting the fault current that flows through the circuit when commutation fails during inversion in a thyristor Ward-Leonard or similar configuration. Typically, an instantaneous trip type circuit breaker is used with the instantaneous trip current set to about two or three times its rating. The scheme of protection coordination is considered in terms of I^2t.

Fig. 3-34 Using an MCCB in a DC circuit



Since, in the circuit configuration shown in Fig. 3-34, the fault currents flowing through the MCCB and the devices are equal, it is necessary to meet the relation: allowable thyristor I^2t > MCCB maximum interrupting I^2t of the MCCB.

3-10 Protecting SSCs using MCCBs or MMSs

When an MCCB is used to protect a solid-state contactor (SSC), protection over the entire range of its overload region to the short-circuit region would be difficult to achieve with an MCCB alone. To ensure complete protection of the SSC with an MCCB, the MCCB should be combined with a thermal overload relay and current-limiting fuse, or any other appropriate protective device.

Solid-state contactor

3-10-1 For heater (resistive load) circuits

Table 3-23 lists recommended combinations of MCCBs and SSCs for heater control purposes. These combinations enable MCCBs to protect SSCs in region B, and current-limiting fuses to protect in region C (Fig. 3-33). The SSCs can thus be protected against short-circuit currents two times higher than the SSC's rated current and lower than the current-limiting fuse breaking capacity with MCCBs.

Table 3-23 Protecting SSCs for heater circuits using MCCB (short-circuit region)

Rated voltage	SSC type	MCCB		Fuse		
		Type	Icu (kA)	Type	I^2t (×10^3A^2S)	Icu (kA)
230V AC	SS03☐	**BW32SAQ-3P005**	5	CR2LS-10	0.04	100
	SS08☐	**BW32SAQ-3P010**	5	CR2LS-10	0.04	100
	SS20☐	**BW32SAQ-3P040**	5	CR2LS-30	0.35	100
	SS30☐	**BW32SAQ-3P060**	5	CR2LS-50	0.85	100
	SS40☐	**BW32SAQ-3P080**	10	CR2LS-70	2.3	100
	SS50☐	**BW63SAQ-3P120**	10	CR2LS-100	4.0	100
	SS80☐	**BW125JAQ-3P450**	50	CR2L-140	7.0	100
	SS120☐	**BW250JAQ-3P600**	50	CR2L-200	17	100
400V AC	SS30☐H	**BW32SAQ-3P060**	2.5	CR6L-50	1.8	100 *1
	SS50☐H	**BW63SAQ-3P120**	7.5	CR6L-100	7.0	100 *1
	SS80☐H	**BW125JAQ-3P450**	30	CR6L-200	30	100 *1
	SS120☐H	**BW250JAQ-3P600**	30	CR6L-200	30	100 *1

Notes:
- Indicates SSCs mounted on standard cooling fins.
- Use an BW125JAQ-3P450 for SS120☐ applications with through current at or below 100A.
- Use a two-pole MCCB in single-phase circuit SSC applications, or a three-pole MCCB in three-phase circuit SSC applications.

*1 Breaking capacity at 600V AC.

3-10-2 Motor circuits

Table 3-24 shows various combinations that are available for motor circuit SSC control. Fig. 3-33 shows that a manual motor starter (MMS) protects regions A and B while a current-limiting fuse protects region C. This combination can protect the SSC from anything from overloading to short-circuiting.

Table 3-24 Protecting SSCs for motor circuits using MMSs (overloading and short-circuiting)

Rated voltage	Motor capacity (kW)	SSC Type	Manual motor starter (MMS)		Fuse	
			Type	Breaking capacity (kA)	Type	Breaking capacity (kA) 250V AC
230V AC 3-phase	0.2	SS03☐	BMSRSB-1P6	100	CR2L(S)-10	100
	0.4	SS08☐	BM3RSB-2P5 *1	100	CR2L(S)-10	100
	0.75	SS20☐	BM3RSB-004	100	CR2L(S)-30	100
	1.5	SS30☐	BM3RSB-6P3	100	CR2L(S)-50	100
	2.2	SS40☐	BM3RSB-010	100	CR2L(S)-75	100
	3.7	SS50☐	BM3RSB-016	100	CR2L(S)-100	100
	5.5	SS80☐	BM3RSB-025	50	CR2L-140	100
	7.5	SS802	BM3RSB-032	50	CR2L-175	100
	7.5	SS120☐	BM3RSB-032	50	CR2L-175	100
400V AC 3-phase	1.5	SS30☐H	BM3RSB-004	100	CR6L-30	100 *2
	2.2	SS30☐H	BM3RSB-6P3	100	CR6L-50	100 *2
	3.7	SS30☐H	BM3RSB-010	100	CR6L-50	100 *2
	5.5	SS50☐H	BM3RSB-013	50	CR6L-75	100 *2
	7.5	SS50☐H	BM3RSB-016	50	CR6L-100	100 *2
	15	SS80☐H	BM3RSB-032	50	CR6L-200	100 *2
	15	SS120☐H	BM3RSB-032	50	CR6L-200	100 *2

Notes: Indicates SSCs mounted on standard cooling fins.
*1 Overload protection is not available in some regions.
*2 Breaking capacity at 600V AC.

3-11 Protecting inverter circuits using MCCBs

3-11-1 Inverter circuits

Inverters usually rely on internal overcurrent protection. Therefore, the MCCB must protect the system up to the power supply terminal for the main circuit and must not inadvertently trip while the inverter is operating normally.

Table 3-25 MCCB rated current

Rated voltage	Motor output (kW)	MCCB rated current (A)	
		With DC reactor	Without DC reactor
230V AC 3-phase	0.1	5	5
	0.2		
	0.4		
	0.75		10
	1.5	10	15
	2.2		20
	3.7	20	30
	5.5	30	50
	7.5	40	75
	11	50	100
	15	75	125
	18.5	100	150
	22		175
	30	150	200
	37	175	250
	45	200	300
	55	250	350
	75	350	–
	90	400	
	110	500	

Note: For the MCCB types, the rated current values recommended for 50°C or lower panel inside temperature are shown. Select an actual type according to the facility short-circuit interrupting capacity.

Rated voltage	Motor output (kW)	MCCB rated current (A)	
		With DC reactor	Without DC reactor
400V AC 3-phase	0.4	5	5
	0.75		
	1.5		10
	2.2		15
	3.7	10	20
	5.5	15	30
	7.5	20	40
	11	30	50
	15	40	60
	18.5		75
	22	50	100
	30	75	125
	37	100	
	45		150
	55	125	200
	75	175	–
	90	200	
	110	250	
	132	300	
	160	350	
	200	500	
	220		
	280	600	
	315	800	
	355		
	400	1000	
	450	1200	
	500		

Note: For the MCCB types, the rated current values recommended for 50°C or lower panel inside temperature are shown. Select an actual type according to the facility short-circuit interrupting capacity.

3-12 MCCBs for high frequency circuits

Hydraulic-magnetic type and solid-state trip type MCCBs cannot be used in 400Hz circuits because their characteristics would vary considerably.
Since the instantaneous trip current of standard thermal-magnetic MCCBs models (magnetic element) will increase by 1.5 to 2.5 times the cataloged value around 400Hz, circuit breakers specially designed for use in 400Hz circuits should be used (these models are available on request). Because high-current rating MCCB (400AF to 800AF) generate increased heat due to the skin effect, their load capacity must be derated 20% to 30%.

Table 3-26 lists some FUJI MCCBs recommended for use in 400Hz circuits.

Table 3-26 MCCBs for 400Hz circuits
Specify 400Hz when ordering an MCCB for a 400Hz circuit.

Frame size	Type	Icu (kA)		Rated current (A)
		400V AC	230V AC	
125AF	BW125JAG	30	50	15, 20, 30, 40, 50, 60, 75, 100, 125
	BW125RAG	50	100	
160AF	BW160EAG	18	30	125, 150, 160
	BW160JAG	30	50	
	BW160RAG	50	100	
250AF	BW250EAG	18	30	175, 200, 225, 250
	BW250JAG	30	50	
	BW250RAG	50	100	
400AF	BW400EAG	30	50	250, 300, 350, 400
	BW400SAG	36	85	
	BW400RAG	50	100	
630AF	BW630EAG	36	50	500, 600, 630
	BW630RAG	50	100	
800AF	BW800EAG	36	50	700, 800
	BW800RAG	50	100	

Note: *1 Use a load capacity 20 to 30% lower because of the skin effect.

3-13 MCCBs for DC circuit applications

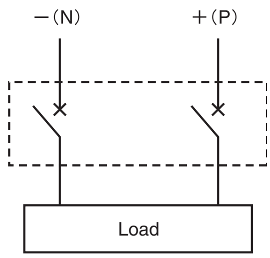
The operating characteristics of an MCCB adjusted for AC specifications will not be the same in a DC application, so use an MCCB adjusted specifically for DC specifications in those applications. (See Table 2-5 section 2-1, Chapter 2.)
Breaking is harder with DC current than with AC current at high voltages because there is no zero crossing point with DC current. Breaking is difficult using AC if the voltage is high because there is no zero point for DC. In normal use, the circuit voltage is 250V max., but application is possible up to 400V DC for a three-pole series connection and up to 600V DC for four poles, as shown in the figure. Special-order products are DC-only. Specify if required.

Table 3-27 MCCBs for 250V DC circuit applications

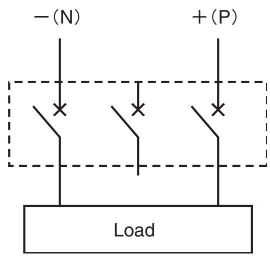
Tripping device	MCCB type	DC load application	Rated insulation voltage (V)	Rated breaking capacity [kA] Icu/Ics at 250 VDC
Hydraulic-magnetic	BW32SAG	Specially designed MCCB is required (standard type MCCB cannot be used). (Specified by "C2" at the end of the model number when ordering.)	250V DC	2.5/2
	BW50EAG			2.5/2
	BW63EAG			2.5/2
	BW50SAG			5/3
	BW63SAG			5/3
	BW50RAG			5/3
	BW63RAG			5/3
	BW100EAG			5/3
Thermal-magnetic	BW50HAG-3P	Standard type MCCB can be used.	250V DC	40/20
	BW125JAG			15/8
	BW125RAG			40/20
	BW125HAG-3P			40/20
	BW250EAG			10/5
	BW250JAG			20/10
	BW250RAG			30/15
	BW250HAG-3P			30/15
	BW400EAG			20/10
	BW400SAG			20/10
	BW400RAG			40/20
	BW400HAG			40/20
	BW630EAG-3P			20/10
	BW630RAG-3P			40/20
	BW630HAG-3P			40/20
	BW800EAG-3P			20/10
	BW800RAG-3P			40/20
	BW800HAG-3P			40/20
Instantaneous trip type	BW32SAQ	Specially designed MCCB is required (standard type MCCB cannot be used). (Specified by "C2" at the end of the model number when ordering.)	250V DC	2.5/2
	BW50SAQ			5/3
	BW63EAQ			2.5/2
	BW63SAQ			5/3
	BW125JAQ			15/8
	BW125RAQ			40/20
	BW250JAQ			20/10
	BW250RAQ			30/15
	BW400RAQ			40/20
	BW400HAQ			40/20
	BW630RAQ-3P			40/20
	BW630HAQ-3P			40/20
	BW800RAQ-3P			40/20
	BW800HAQ-3P			40/20
Disconnect switch	BW32SAS	Standard type MCCB can be used.	250V DC	
	BW50SAS			
	BW63SAS			
	BW100EAS			
	BW125JAS			
	BW125RAS			
	BW250EAS			
	BW250RAS			
	BW400EAS			
	BW400RAS			
	BW630EAS			
	BW630RAS			
	BW800EAS			

Note: There is no polarity.

2-pole model
Power supply (250V)



3-pole model
Power supply (250V)



Notes:
- The time constant is 10 s max.
- The instantaneous DC tripping current for AC/DC models is approximately 140% max. of the AC rating. Models with the same instantaneous tripping current as the operating characteristics curve given in a catalog or other documentation can be produced if "C2" is specified at the end of the model number. (DC-only models) Example: BW125JAG-2P100 C2

Table 3-28(1) MCCBs for 400 and 500V DC applications

Tripping device	MCCB type	DC load application	Rated insulation voltage (V)	Rated breaking capacity [kA] Icu/Ics at 250 VDC
Hydraulic-magnetic	BW32SAG-3P	Specially designed MCCB is required (standard type MCCB cannot be used). (Specified by “C4” at the end of the model number when ordering.)	400V DC	2.5
	BW50SAG-3P			5
	BW63SAG-3P			5
	BW100EAG-3P			5
Thermal-magnetic	BW125JAG-3P	Specially designed MCCB is required (standard type MCCB cannot be used). (Specified by “C5” at the end of the model number when ordering.)	500V DC	10
	BW125RAG-3P			20
	BW250JAG-3P			10
	BW250RAG-3P			20
	BW400EAG-3P	Standard type MCCB can be used.		20
	BW400SAG-3P			20
	BW400RAG-3P			40
	BW400HAG-3P			40
	BW630EAG-3P			20
	BW630RAG-3P			40
	BW630HAG-3P			40
	BW800EAG-3P			20
	BW800RAG-3P			40
	BW800HAG-3P			40
Disconnect switch	BW32SAS-3P32	Specially designed MCCB is required (standard type MCCB cannot be used). (Specified by “C4” at the end of the model number when ordering.)	400V DC	
	BW50SAS-3P50			
	BW63SAS-3P63			
	BW100EAS-3P100			
	BW125JAS-3P125	Specially designed MCCB is required (standard type MCCB cannot be used). (Specified by “C5” at the end of the model number when ordering.)	500V DC	
	BW125RAS-3P125			
	BW250EAS-3P250			
	BW250RAS-3P250			
	BW400EAS-3P400	Standard type MCCB can be used.		
	BW400RAS-3P400			
	BW630EAS-3P630			
	BW630RAS-3P630			
	BW800EAS-3P800			
	BW800RAS-3P800			

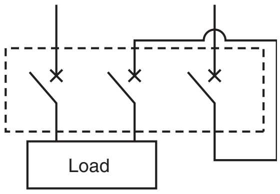
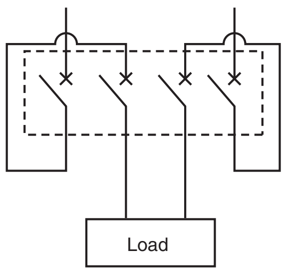


Table 3-28(2) MCCBs for 600V DC applications

Tripping method	Model number	Application to DC circuit	Rated insulation voltage (V)	Rated breaking capacity [kA] Icu/Ics at 250 VDC
Thermal-magnetic	BW125RAG-4P	Can be used with special-order products. Specified by “C6” at the end of the model number when ordering.	600V DC	25
	BW250JAG-4P			25
	BW250RAG-4P			40
	BW400RAG-4P	Can be used with standard products. (See notes 1 and 2.)		40
	BW400HAG-4P			40
	BW630RAG-4P			40
	BW630HAG-4P			40
	BW800RAG-4P			40
	BW800HAG-4P			40
Disconnect switch	BW125RAS-4P125	Can be used with special-order products. Specified by “C6” at the end of the model number when ordering.		
	BW250RAS-4P250			
	BW400RAS-4P400	Can be used with standard products. (See note 2.)		
	BW630RAS-4P630			
	BW800RAS-4P800			



Notes:
- The instantaneous DC tripping current for AC/DC models is approximately 140% max. of the AC rating. Models with the same instantaneous tripping current as the operating characteristics curve given in a catalog or other documentation can be produced if “C5” or “C6” is specified at the end of the model number. (DC-only models)
- Only 250V DC models are given for standard products. If 500V DC or 600V DC is required, specify “C5” (for 500V DC) and “C6” (for 600V DC) at the end of the model number. (DC-only models)

3-14 MCCBs for UPS applications

Select an MCCB with 1.2 times the UPS (uninterrupted power supply) output, and use an MCCB with the same capacity at the input side. Consider the following points when selecting an MCCB.

UPS overload withstand:
125% for 10 minutes
150% for 1 minute
With overcurrent (including short-circuit current) at the load side exceeding 160% of the operating current, the UPS will switch to a backup circuit without tripping the MCCB.

3-15 MCCBs for servo amplifier applications

Install an MCCB on the primary side of the servo amplifier for power supply switching and to prevent damage caused by short-circuit current.
Table 3-29 lists the types that are available for servo amplifier applications. Servo amplifiers are equipped with overcurrent (output side) and other protective functions.

Table 3-29 MCCBs for servo amplifiers (FALDIC-α and -β series)

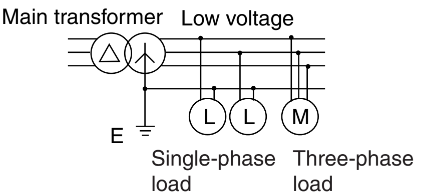
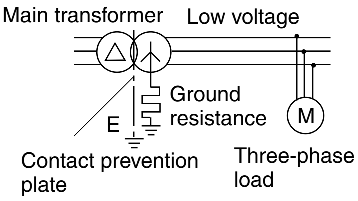
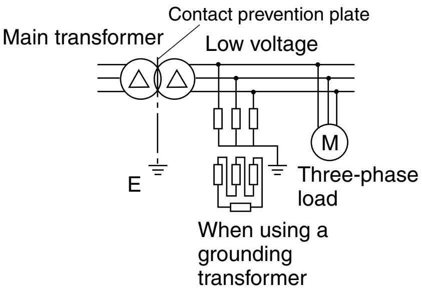
Input power supply	Output [kW]	FALDIC-α and -β series		FALDIC-β series		MCCB type	ELCB (reference) type
Three-phase 230V	0.05	Standard series	RYS500S3-□□□	Standard series 100V series	RYB500S3-VBC	**BW32AAG-3P003**	EW32SAG-3P003
	0.1		RYS101S3-□□□		RYB101S3-VBC		
	0.2		RYS201S3-□□□		RYB201S3-VBC	**BW32AAG-3P005**	EW32EAG-3P005
	0.4		RYS401S3-□□□		RYB401S3-VBC	**BW32AAG-3P010**	EW32EAG-3P010
	0.75		RYS751S3-□□□		RYB751S3-VBC	**BW50EAG-3P015**	EW50EAG-3P015
	1		RYS102S3-□□□			**BW50EAG-3P015**	EW50EAG-3P015
	1.5		RYS152S3-□□□				
	2		RYS202S3-□□□			**BW50EAG-3P030**	EW50EAG-3P030
	3		RYS302S3-□□□			**BW50EAG-3P040**	EW50EAG-3P040
	4		RYS402S3-□□□			**BW50EAG-3P050**	EW50EAG-3P050
	5		RYS502S3-□□□				
	0.5	Low-base speed series	RYS501A3-□□□			**BW50EAG-3P015**	EW50EAG-3P015
	1.5		RYS152A3-□□□				
	2.5		RYS252A3-□□□			**BW50EAG-3P040**	EW50EAG-3P040
	2.9	Medium capacity α- series	RYS292M3-□□□			**BW50EAG-3P040**	EW50EAG-3P040
	4		RYS402M3-□□□			**BW50EAG-3P050**	EW50EAG-3P050
	5.5		RYS552M3-□□□				
	7.5		RYS752M3-□□□			**BW100EAG-3P075**	EW100EAG-3P075
	11		RYS113M3-□□□			**BW100EAG-3P100**	EW100EAG-3P100
	15		RYS153M3-□□□			**BW125JAG-3P125**	EW125JAG-3P125

3-16 Ground fault protection in system applications

3-16-1 Grounding methods and ground fault protection in system applications

There are three possible grounding systems for low-voltage circuits: direct grounding, neutral point resistor grounding or no grounding at all.
Direct grounding systems are widely used in Europe and the United States. Unfortunately, direct grounding causes ground circuit impedance to drop and ground fault current to rise rather steeply when there is a ground fault, and the result is often a malfunction.
Table 3-30 provides an overall description of all grounding systems.

Table 3-30 Grounding systems for low-voltage circuits

Method	Description	Main circuit	Sample applications
Direct grounding *1	Direct grounding systems run a ground to a neutral point in order to minimize any increase in the electric potential to ground with mixed high and low voltage grounding. Since ground fault current on a single wire is rather large with direct grounding systems, it is much easier to detect ground faults, and any increase in the electric potential to ground is relatively small with a sound phase. This is quite helpful for system safety. There is also no real danger of abnormal voltage occurring due to resonance or intermittent grounding as is often the case with no grounding at all. As a rule, a faulty circuit is shut down as quickly as possible when a ground fault occurs.	Fig. a 	Used to reduce voltage to ground for safety in building wiring.
Resistor grounding (low to mid impedance grounding)	Ground fault current is significant with direct grounding, and no grounding systems may be to blame for circuit problems. However, low-voltage wiring systems tend to have low charging current to ground and the sensitivity of protective relays makes it hard to choose a feeder for ground faults in that case. The resistor grounding method shown in Fig. b then is a better choice for this application. Unfortunately, resistor grounding does not completely eliminate possible abnormal voltages or higher electric potential to ground even with appropriate phases if a ground fault occurs.	Fig. b 	Factory wiring Circuits shutting down immediately when a ground fault occurs very often shuts down operations in factories, so greater emphasis is being placed on suppressing ground fault current to prevent fires and explosions.
No grounding (high-impedance grounding) *2	A ground fault in a factory power supply instantly trips circuits that can shut down operations. No grounding is generally used in 3 to 6kV high-voltage wiring systems because ground fault current continues to flow here without high-speed tripping as long as the ground fault current is kept low enough to prevent damage to the equipment and to prevent the fault from becoming more widespread. Nearly all motors in a factory are 3-phase loads that do not normally require a neutral line, and even an ungrounded system like that shown in Fig. c can be used in a 400V wiring system. This makes it hard to detect ground faults, however, so steps must be taken to handle abnormal voltages when they occur.	Fig. c 	Factory wiring Circuits shutting down immediately when a ground fault occurs very often shuts down operations in factories, so greater emphasis is being placed on suppressing ground fault current to prevent fires and explosions.

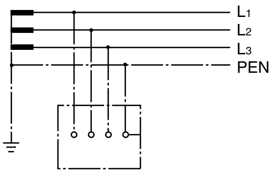
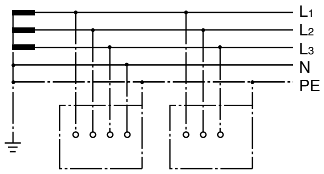
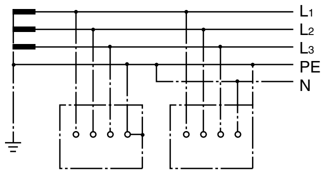
Notes: *1 The TN system is mainly used in Europe (except for France) while the TT system is mainly used in Japan and France for direct grounding. A TN system is grounded to one point. Here, all exposed conductive parts at the load side are grounded at one point through protective conductors. The neutral conductor and protective conductor are handled in one of the following ways.

- TN-S: The neutral conductor and protective conductor for the overall system are completely separate.
- TN-C: The neutral conductor and protective conductor functions for the overall system are combined into a single conductor.
- TN-C-S: The neutral conductor and protective conductor functions are combined into a single conductor in one part of a TN-S system.

Table 3-31 shows a comparison of various characteristics for grounding systems as well as precautions regarding their use.
A TT system is grounded to one point in the system. All exposed conductive parts at the load side are grounded to a ground electrode that is electrically separate from the ground terminal for the system.

*2 A system that uses no grounding is referred to as an IT system.

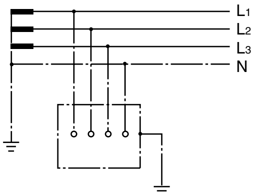
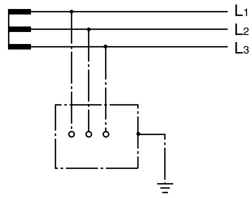
Table 3-31 Comparison of grounding system (TN, TT and IT systems) characteristics and precautions for their use

<table>
<tr><td rowspan="2">Comparison item</td><td colspan="3">Wiring system</td></tr>
<tr><td>TN-C</td><td>TN-S</td><td>TN-C-S</td></tr>
<tr><td>Circuit diagram</td><td>
</td><td>
</td><td>
</td></tr>
<tr><td>Features</td><td>• The neutral conductor and protective conductor functions for the overall system are combined into a single conductor.
• All exposed conductive parts of the equipment are connected to a PEN conductor.
• Calculate the fault loop impedance for shock protection and use an MCCB for system protection.
• Widely used in France, the UK, and the United States</td><td>• The neutral conductor and protective conductor for the overall wiring system are completely separate.
• The protective conductor (PE) is either a metal sheath on the supply cable for the equipment or a conductor completely separate from the system.
• All exposed conductive parts of the equipment are connected to the conductor through the main ground terminal on the equipment.</td><td>• The neutral conductor and protective conductor functions for part of the wiring system are combined into a single conductor.
• The most common configurations are the TN-C wiring system on the power supply side and a TN-S wiring system on the equipment side.
• All exposed conductive parts of the equipment are connected to a conductor through the main ground terminal and the neutral line terminal on the equipment, which are connected together.</td></tr>
<tr><td>Indirect contact protection standards</td><td colspan="3">From the phase conductor to the ground for the exposed parts of the load equipment: Contact voltage of 50V max.
Zero impedance short-circuiting from the phase conductor in the equipment to the protective conductor or exposed parts:
$U_0 \geq Ia \times Zs$ where U_0 is the nominal voltage to ground (effective AC value), Ia is the maximum breaking time from the following table as a function of U_0 or the current that causes the protective device to trip automatically within the conditional time setting of five seconds, and Zs is the fault loop impedance derived from the charging conductor from the power supply to the fault point and the protective conductor between the fault point and the power supply.
• Maximum breaking time for a TN system:
<table>
<tr><td>U_0 (V)</td><td>120</td><td>230</td><td>277</td><td>400</td><td>400 or higher</td></tr>
<tr><td>Maximum breaking time (s)</td><td>0.8</td><td>0.4</td><td>0.4</td><td>0.2</td><td>0.1</td></tr>
</table>
• Conditions for a maximum breaking time of 5 s: The maximum breaking time in the table above may be exceeded in branch circuits that supply power to stationary equipment only, but 5 s or less is the allowable breaking time. Supplemental conditions must be provided separately if other branch circuits that require the maximum breaking time given in the table are connected to those branch circuits.
MCCB
• With inverse time-delay characteristics, Ia is the current that can trip the MCCB automatically within 5 s.
• With instantaneous tripping characteristics, Ia is the smallest current that can trip the MCCB automatically.</td></tr>
<tr><td>Applicable protective device</td><td>• MCCB</td><td>• MCCB
• ELCB</td><td>• MCCB
• ELCB (applicable only in TN-S wiring circuits only)</td></tr>
<tr><td>Application (design) precautions</td><td>1. Use only MCCBs.
2. Calculate the fault loop impedance.
3. Ignore the fault point impedance between the phase conductor and the protective conductor.</td><td>1. Select a suitable ground fault protection device for the protection system.
2. Overcurrent breaking precautions: Same as TN-C items 2 and 3.</td><td>1. Select a suitable ground fault protection device for the protection system.
2. ELCBs can only be installed in certain locations.
3. Overcurrent breaking precautions: Same as TN-C items 2 and 3.</td></tr>
</table>

Note: The number of ground fault protection devices can be reduced once potential equalization work and fault loop impedance calculations are completed with TN systems, but never install low-voltage electrical equipment using both TN and TT systems together in the same location.

3-16 Ground fault protection in system applications

Continued

Comparison item	Wiring system	
	TT	IT
Circuit diagram		
Features	• All exposed conductive parts of the equipment are connected to a ground electrode that is completely separate from the power supply ground. • This system is the most commonly used in Japan.	• All exposed conductive parts of the equipment are connected to a ground electrode that is completely separate from the power supply ground. • The power supply is connected to ground through inserted ground impedance or is completely disconnected from ground. • This wiring system is widely used in Norway. In Japan, however, greater emphasis is placed on circuits that supply power without interruption rather than on those that shut down the power supply.
Indirect contact protection standards	$50V \geq Ia \times R_A$ R_A: Sum of the ground resistance and the protective conductor resistance connected to exposed conductive parts. Ia: Current that trips the MCCB automatically. (With an ELCB, Ia is the rated sensitivity current $I\Delta n$.) The MCCB is as follows. • With inverse time-delay characteristics, Ia is the current that can trip the MCCB automatically within 5 s. • With instantaneous tripping characteristics, Ia is the smallest current that can trip the MCCB automatically.	$50V \geq Id \times R_A$ R_A: Same as that on the left. Id: Ground fault current at the first occurrence of a ground fault where impedance between the phase conductor and exposed conductor parts can be ignored. It is derived from the leak current and total ground impedance of the electrical equipment. • Install an insulation monitoring device that indicates the first occurrence of a ground fault in order to maintain an uninterrupted power supply. • Power supply shutdown conditions following the first occurrence of a ground fault or with the second occurrence of a ground fault should be provided separately.
Applicable protective devices	• MCCB (only if R_A is very low however) • ELCB	• Insulation monitoring device • MCCB • ELCB
Application (design) precautions	1. Select a suitable ground fault protection device for the protection system. 2. Overcurrent breaking precautions: • The additional conditions outlined above must be provided separately. • Other precautions are the same as TN-C items 2 and 3.	1. Select a suitable ground fault protection device for the protection system. 2. The power supply can shut down automatically when a second ground fault occurs with overcurrent breaking. 3. $Id \geq I\Delta n$ when leak current breaking is used. Here, the power supply can shut down automatically when the first ground fault occurs.

Chapter 4

Environment and usage precautions

CONTENTS

4-1 Standard conditions

Because ambient conditions have a significant effect on the short-circuit and overload characteristics, durability, and insulating properties of circuit breakers, the conditions under which they are used must be clarified.
For reference, Table 4-1 lists the standard operating conditions for FUJI MCCB performance. If the ambient conditions under which a circuit breaker is to be used differ significantly from these standards, the circuit breaker's characteristics may differ considerably, and appropriate modification of usage criteria is necessary.

Table 4-1 Standard conditions for MCCBs (IEC 60947-1)

Ambient temperature	Operating	–5 to 40°C (the average temperature through 24-hour does not exceed 35°C)
	Storage or transport	–25 to 55°C or the temperature under 24-hour does not exceed 70°C
Relative humidity		85% max.
Altitude		2000m max.
Pollution degree		3

4-2 Application to special environments

4-2-1 High-temperature, high-humidity applications

(1) High temperature condition

The temperature of each component of an MCCB is the sum of the ambient temperature and the temperature rise in the component due to current flow in the MCCB. When the ambient temperature is higher than 40°C, the continuous carrying current should be derated to keep the temperature of MCCB internal insulators and other materials within standard. Thermal-magnetic type circuit breakers without a temperature compensation device tend to trip with currents below their rated current. It is recommended that the continuous carrying current be reduced to the current shown in Table 4-2.

Table 4-2 Current decrease due to ambient temperature

Ambient temperature (°C)	Decrease
50	90% max.
60	80% max.

(2) High humidity condition

MCCBs to be used in excessively humid locations should be housed in a moisture-proof cabinet, or thorough maintenance and inspection should be conducted to prevent loss of insulation properties or rusting of metallic mechanical parts. When an MCCB is housed in a moisture-proof enclosure, the temperature inside the enclosure is liable to change suddenly when the related equipment is powered up or shut down, and condensation may form. This problem can be averted by installing a heater inside the enclosure.

4-2-2 Cold climate applications

At –5°C or lower temperatures, MCCB metallic parts and insulators may become brittle and the viscosity of the lubricant used in its mechanical parts changes; therefore, provisions should be made to avoid low ambient temperatures, such as installing near a heater. Since the operating characteristics of a thermal-magnetic type MCCB are temperature dependent, the MCCB's relationship to the equipment it is to protect must be considered when choosing the appropriate current rating. Although the switching, trip, and short-circuit interruption characteristics are not adversely affected at –20°C, installation of a heater nearby is recommended to reduce adverse effects of low temperatures. When shipped, temperatures as low as –40°C present no problem, but the breakers should be shipped in the off or tripped state to minimize brittleness.

4-2-3 High altitude applications

Special care must be taken when using MCCBs at altitudes higher than 2000m because the lower air pressure (about 0.8atm at 2000m and about 0.5atm at 5500m) at higher altitudes reduces the cooling effect and dielectric strength of the air. When using MCCBs under these conditions, multiply the rated voltage and rated current by a correction factor from Table 4-3 as recommended by ANSI C37.13-1981. Observe the preceding precautions for cold climate applications as well because temperatures generally drop at higher altitudes.

Table 4-3 Rated voltage and rated current correction factors for high altitude

Altitude (m)	Rated voltage	Rated current
2000m max.	1.00	1.00
2600m max.	0.95	0.99
3900m max.	0.80	0.96

4-2-4 Application to special atmospheres

(1) Corrosive gas and salt

The contacts of MCCBs are generally made of silver or silver alloy that readily forms a sulfide film on contact with sulfurized gas. Although this may degrade the quality of the contacts, the film peels off easily so the problem is not significant, especially with frequent switching. Intentional switching may be required periodically when ordinary switching occurs infrequently. An MCCB designed for special atmospheres should be used in areas with high concentrations of sulfurized gas.

Table 4-4 Corrosive gas effects and protective measures

Gas type	Effect on metal	Effect on insulation materials	MCCB application	
Hydrogen sulfide gas (H_2S)	(1)Copper and copper alloy: A sulfide film develops that forms a high-resistance layer. Components that make actual physical contact as well as components that operate with high levels of mechanical stress, such as terminals, require anti-corrosion measures like surface treatment using Sn plating or clear coating with lacquer. (2)Silver and silver alloy: Although a sulfide film develops, it is not a problem here because the film peels off the contact with arcing or sliding action during switching. (3)No problems have been found with other metals.	No problems	Gas density (ppm) → 0 to 0.02 to 0.07 to 0.3 to Standard parts | *1 | Parts treated for anti-corrosion and (B) or (C) | Parts treated for anti-corrosion and (D) *2	Note: *1 Use parts treated for anti-corrosion. *2 Protective measures for equipment and control panels (A)Lower the humidity with equipment like a space heater to prevent condensation. (B)Use an activated charcoal filter to improve the environment. (C)Install the packing provided for the doors and seal the control panel floor as well as cable ports. (D)Use an air purging system.
Sulfurous acid gas (SO_2) Nitrous acid gas (NO_2)	High temperature and high humidity conditions that are particularly prone to condensation will accelerate corrosion. There is less chance of corrosion with humidity at 65% or lower.	No problems	0 to 0.04 to 0.5 to %RH ↑ 100 / 65 Above 65 %RH: *1 | Parts treated for anti-corrosion and (A+C) or (B) *2 Standard parts	
Chlorine gas (Cl_2)	Chlorine gas is far more corrosive than nitrous acid gas or sulfurous acid gas. Because it corrodes just about any metal, protective measures are critical for equipment and control panels.	Moisture absorbed by premixed polyester lowers its insulation resistance.	0 to 0.02 to 0.1 to Standard parts | *1 | Parts treated for anti-corrosion and (D) *2	

(2) Others

Table 4-5 shows special atmosphere problems and protective measures.

Table 4-5 Special environment problems and protective measures

Environment	Potential problems	Protective measures
Water vapor, water drops and oil vapor	• Metal corrosion • Moisture absorbed by insulation material • Lower insulation resistance	• Place in a waterproof casing (IP54). • Conduct periodic maintenance inspections
Dust	• Contact failure • Poor insulation	• Place in a dustproof casing (IP5X).
Flammable gas	• Explosive combustion	• Do not use in this environment.

4-3 Connection precautions

4-3-1 Reversed connection

The power supply side and the load side are indicated on the following products. The breaking capacity for power supply reverse connection is different than that for regular connection.

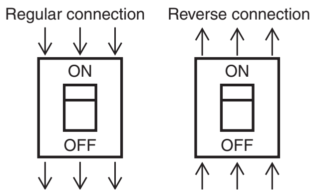


Table 4-8 Breaking capacity for MCCB connected in reverse

Model number	Reverse connection breaking capacity [kA] (JIS C 8201-2-1 Ann. 2)	
	200V	**400V**
BW32AAG	2.5	–
BW32SAG	5	2.5
BW50AAG	2.5	–
BW50EAG	5	2.5
BW50SAG	10	2.5
BW50RAG	15	2.5
BW63EAG	5	2.5
BW63SAG	10	2.5
BW63RAG	15	2.5
BW100AAG	5	–
BW100EAG	15	2.5

Note: Reverse connection is possible with standard products of 125AF or higher.

4-3-2 Tightening torque

Conductor connections should be tightened to the specified torque because loose connections may cause overheating or malfunctioning while overtightening may damage the screw or the molded plastic. Always use the appropriate screwdriver for the screw head.

Soldering must not be done when using a box-type terminal connection.

4-4 Malfunction due to transient inrush current

An MCCB may trip if the overcurrent detection device detects higher than normal transient current, like motor starting current or transformer exciting inrush current. One way to prevent this is to select an MCCB with instantaneous tripping characteristics higher than the motor starting current or transformer exciting inrush current.

Chapter 5

Maintenance inspections

CONTENTS

5-1 Faults and causes

Table 5-1 shows the appropriate countermeasure to take for faults that occur during MCCB operation.

Table 5-1 Troubleshooting

Type of fault	Fault status or location	Possible cause	Countermeasure
Abnormal heat	Abnormally high terminal temperature	• Loose terminal or conductor screw	Tighten the screw. *
	Burned insulation material in the terminal section	• Heat generated by excessive contact resistance • Loose terminal or conductor screw	Repair or replace with a new part. *
	Abnormally high molded case temperature (exceeding 70°C)	• Heat generated by excessive contact resistance	Replace with a new part. *
		• Significant higher harmonic current in the load current	Insert reactors to reduce the distortion factor or re-evaluate the rated current selection.
		• Heat generated in the solenoid coil (hydraulic-magnetic type) by high-frequency current (400Hz, etc.)	Re-evaluate the rated current selection or use a thermal-magnetic type. *
		• Loose internal screw	Replace with a new part. *
		• High current density caused by a broken braided wire (wire broken due to corrosive gas in the operating environment)	Use parts treated for anti-corrosion.
Faulty operation	Making fault	• The MCCB has not reset after tripping.	Reset the MCCB.
		• Voltage has been applied to a shunt trip device.	Inspect the wiring. *
	Reset fault	• The undervoltage trip device has not been energized.	Turn on the power supply.
		• The MCCB has not cooled sufficiently following an overcurrent trip.	Let the MCCB cool and then reset it.
		• The bimetal element has corroded or is otherwise deformed. • The number of trip operations has exceeded the durability of the MCCB. (The shunt trip device or undervoltage trip device tripped too many times.)	Replace with a new part. *
		• Faulty mechanism	
Breaker tripping	The breaker trips in a closed circuit with less than the rated current.	• The ambient temperature is abnormally high (40°C or higher).	Use ventilation or some other means to lower the ambient temperature.
		• Heat generated by a loose terminal screw (with thermal-magnetic type)	Tighten any loose screws. *
		• Heat generated inside the MCCB.	Replace with a new part. *
		• Shock and vibration	Take action like cushioning to reduce shock and vibration.
		• The load current has exceeded the rated current. (Example: The motor is running in overload, undervoltage or overvoltage conditions).	Re-evaluate the rated current selection.
	Starting current trips the MCCB	• Either motor starting current or transformer exciting inrush current trips the MCCB.	Change the instantaneous trip current setting or the rated current. *
		• Transient inrush current during the changeover from star to delta connection trips the MCCB.	
		• Inching operation instantly trips the MCCB.	
		• Capacitor inrush current (mercury lamp or phase advance capacitor), incandescent lamp inrush current, or fluorescent lamp starting current instantly trip the MCCB.	
		• Intermittent operation (spot welder or molding equipment)	See 3-7-2, Chapter 3.
		• High starting current causes an inverse time-delay trip. • A long starting time causes an inverse time-delay trip.	Change the rated current. *
		• Abnormal large current flows when the circuit closes. (Short in a load side circuit)	Inspect the circuit and eliminate the cause.
		• A layer insulation fault occurs in the motor.	Repair or replace the motor. *
		• A malfunction occurs because a control circuit in a shunt trip or undervoltage trip device is connected improperly.	Inspect wiring and repair the cables. *
Buzzing sound	Current flow is above the rated level.	• The solenoid coil in the MCCB operates because of a distorted current waveform (Inverter connected to the load).	Change the rated current. *

Note: * Do not inspect or take any other action until you are sure there is no voltage applied to the MCCB terminals.

Continued

Type of fault	Fault status or location	Possible cause	Countermeasure
Faulty operation due to overcurrent	Faulty operation at higher than the specified operating current	• Lack of coordination with an upstream current-limiting fuse, or with an upstream circuit breaker. • Ambient temperature is extremely low. • The ammeter gives an incorrect reading because of high-frequency current.	Re-evaluate coordination or change the selection. Check the current correction.
Accessory fault	Motor operating mechanism fault	• Improper control circuit cable connection causes faulty operation. • Improper control circuit cable connection causes operation to start and stop repeatedly. (Snake circuit formed by connecting the control signal circuit in parallel.)	Inspect and repair the cables. *
		• A drop in voltage due to insufficient capacity on the power supply circuit cable causes faulty operation. • Insufficient capacity of the control circuit power supply.	Use heavier gauge cable. Increase the power supply capacity (transformer capacity, etc.).
		• Make, run and reset do not work properly because the moving distance of the control mechanism is not properly adjusted.	Re-adjust the stroke. *
	Shunt trip device fault	• A drop in power supply voltage due to insufficient power capacity for the control circuit causes faulty operation. • A drop in power supply current due to insufficient power supply capacity causes faulty operation.	Increase the power supply capacity. *
		• Continuous excitation, an incorrect coil rating, and faulty coil anti-burnout contact operation or coil burnout due to welded contacts.	Replace the coil and replace the contacts with coil anti-burnout contacts. *
	Undervoltage trip device fault	• The MCCB does not trip due to residual magnetic flux and no voltage. • The MCCB does not trip due to an improperly moving stroke and no voltage.	Repair or replace with a new part. *
	Auxiliary switch and alarm switch fault	• Current exceeding the microswitch contact rating burns out the contacts or welds them together.	Replace the accessories and insert a control relay to reduce the load on internal switch contacts.
		• An improper microswitch moving stroke causes faulty operation.	Replace or repair the microswitch. *

5-2 Periodic inspections

5-2-1 Initial inspection

When newly installed equipment first goes into operation, there may be unexpected oversights or mistakes such that screws were not properly tightened or cable connections were incorrect. This is why the items shown in Tables 5-2 and 5-3 should be inspected before initial operation and again within the following month.

Table 5-2 Initial inspection and judgment criteria prior to the operation starting

Inspection item	Criteria	Countermeasures for defects
1. Inspect the area around the terminals to make sure no dust, fragments, pieces of wiring, screws, or other conductive foreign matter were left behind.	No foreign matter	Vacuum up foreign matter. Wipe the area with a dry cloth.
2. Inspect the MCCB case and cover to make sure there are no cracks or damage.	No cracks or damage	Replace the enclosure.
3. Inspect the connector to make sure the conductors are securely tightened.	Conductors are tightened to the specified torque	Tighten conductors to the specified torque.
4. Measure insulation resistance with a 500V DC megger.	5MΩ min.	Replace with a new part.

Note: Do not inspect until you are sure there is no voltage applied to the MCCB terminals.

Table 5-3 Inspection and judgment criteria within one month after the operation starting

Inspection item	Criteria	Countermeasure for defects
1. Loose conductor connectors?	Conductors tightened at the specified torque	Tighten conductors at the specified torque.
2. Inspect the area around the terminals to make sure no dust, fragments, pieces of wiring, screws, or other conductive foreign matter were left behind.	No noticeable dust, oil or conductive foreign matter	Vacuum up the foreign matter. Wipe the area with a dry cloth.
3. No abnormal temperature rise?	No discoloration of the terminal connectors or molded plastic due to excessive heat	Replace with a new part.

Note: Do not inspect until you are sure there is no voltage applied to the MCCB terminals.

5-2-2 Periodic inspections

No time-related durability performance criteria are determined for MCCBs. Durability performance can vary significantly with the operating environment, operating load, switching frequency, and the quality of periodic inspections and repairs. Proper operating conditions must be maintained at all times in order to ensure MCCB performance and to prevent unexpected failure. However, performance may decline for a number of reasons, including dust accumulation, loose screws, wear on mechanical parts due to excessive switching, or contact wear. This is why periodic inspections are important.
Table 5-4 shows inspection standards and Table 5-5 shows inspection procedures.

Table 5-4 Inspection standards

Conditions	Environment	Examples	Inspection interval	Remarks
Normal operating conditions	A location with a constant supply of clean and dry air	A dustproof, air-conditioned electrical equipment room	Once every two or three years Once a year for MCCBs installed more than ten years Once every six months for MCCBs installed more than 15 years	Use standard specification MCCBs. Set inspection intervals according to actual circumstances.
	An indoor location with minimal dust and no corrosive gases	Installed in a control panel in a separate electrical equipment room with no dustproofing or air conditioning, or inside an enclosure.	Once a year Once every six months for MCCBs installed more than 10 years Once a month for MCCBs installed more than 15 years	
Poor environment	A location with minimal dust containing nitrous acid gas, hydrogen sulfide gas, salt or high-temperature gases	Geothermal power generation equipment and sewage plants as well as paper, steel, and pulp plants	Once every six months Once a month for MCCBs installed for more than 5 years	Requires appropriate action. (See 4-2-4, Chapter 4.)
	A location where people could not stay for long periods, or a location with excessive dust or corrosive gas	Chemical factories, quarries, or mines	Once a month	Requires enclosing or other appropriate action.

Table 5-5 Inspection procedures

Inspection item	Procedure	Countermeasure
1. Presence or absence of dust or other contaminates	Inspect the surface of the MCCB and especially around the terminals on the power supply side to make sure no dust or oil has accumulated. Check to make sure that dust or other foreign matter has not bridged the gap provided to increase creepage distance.	Vacuum up any dust, and wipe the area down with a dry, lint-free cloth.
2. Exhaust gas outlet	Inspect the exhaust gas outlet for foreign matter like carbon or metal particles adhering near the outlet that may be evidence of overcurrent tripping.	Replace the MCCB if soot or metal particles are found. See items 6 and 7 in this table to decide whether to replace the MCCB when only a minute amount of soot or metal particles is found.
3. Discolored terminal	Inspect the terminal for evidence of an abnormal temperature rise or advanced damage due to corrosive gases like hydrogen sulfide gas.	Some discoloration of silver plating is not a problem. Replace the MCCB in case of advanced stages of discoloration or damage to the insulation due to an abnormal temperature rise.
4. Loose terminal screw	Check for loose terminal screws or cable tightening screws. Use standard tools for tightening.	Confirm the normal tightening torque for the screws and materials in advance, and never overtighten or undertighten screws.
5. Switching	Intentionally switch several times to prevent excessive wear due to grease hardening, and use the sliding action of contacts to stabilize contact resistance with a normally closed MCCB.	Repair MCCBs that do not switch smoothly.
6. Insulation resistance	Use a 500V DC megger to measure insulation resistance between the main poles as well as between live parts and ground. Remove all conductors prior to taking measurements.	Replace the MCCB if the megger reading is below 5MΩ.
7. Temperature rise	Check the following items through load current. (1)The temperature of the molded case should not exceed 70°C. (2)There should be no smoke or abnormal odors.	Replace the MCCB.

5-2-3 Inspection following overcurrent tripping

When an MCCB trips due to overcurrent, visually inspect it to see the extent of damage. Take action as prescribed in Table 5-6 to prevent malfunction or failure if the MCCB is to be used again.

Inspect the items in Table 5-7 and take the recommended action if the extent of MCCB damage due to overcurrent tripping is not clear or is as listed in Table 5-6.

Table 5-6 Extent of damage and recommended countermeasure

Extent of MCCB damage	Countermeasure
1. The area around the exhaust gas outlet is clean and no other foreign matter is visible.	The MCCB can be used again.
2. Black soot is visible in the area around the exhaust gas outlet.	See Table 5-7.
3. The exhaust gas outlet is noticeably dirty and soot is clearly visible on the handle.	Replace the MCCB.

Table 5-7 Inspection item and recommended countermeasure

Inspection item	Countermeasure
1. Measure insulation resistance with a 500V DC megger	• Insulation resistance is below 1MΩ: Replace the MCCB. • Insulation resistance is higher than 1MΩ but less than 5MΩ: Conduct a dielectric strength test (double the rated voltage for 1 minute). The MCCB can be used temporarily as long as test results indicate the voltage withstand level is within specified limits, but replace the MCCB as soon as possible. • Insulation resistance of at least 5MΩ: The MCCB can be reused.
2. Conduct periodic inspections	Take the recommended countermeasure described in Table 5-5 if there is a problem.

5-3 Replacement recommendations

An MCCB is generally thought to have exceeded its limit of durability when any of the following occurs.

- High failure rates and frequent losses due to power supply interruptions
- Declining performance that makes safe operation no longer sustainable
- Markedly higher maintenance costs due to deteriorating performance

The recommended replacement period makes systems more efficient by ensuring power supply reliability and more economical by replacing the MCCB before it reaches one of the three preceding conditions. This is true as long as the selected MCCB is the optimum choice (see Chapter 3) and is used under standard operating conditions (see 4-1, Chapter 4). The recommended period of replacement has no bearing on the stated durability or warranty period.
Exactly when an MCCB should be replaced cannot be defined in mere years because the replacement period will vary with the stress brought on by the operating environment and operating conditions.

5-3-1 Recommendations for MCCB deterioration diagnosis and replacement

Table 5-8 shows guidelines for the timing of MCCB deterioration diagnosis and replacement.

Table 5-8 Guidelines for the timing of MCCB deterioration diagnosis and replacement
(Technical Rep. 142, Standard of Japan Electrical Manufactures)

Environment		Example	Guidelines for the timing of deterioration diagnosis	Guidelines for the timing of MCCB replacement
Normal environment	A location with a constant supply of clean and dry air	A dustproof, air-conditioned electrical equipment room	10 years	15 years
	An indoor location with minimal dust and no corrosive gases	Installed in a control panel in a separate electrical equipment room with no dustproofing or air conditioning, or inside an enclosure.	7 years	13 years
Poor environment	A location with high humidity and minimal dust containing salt or gases like nitrous acid gas and hydrogen sulfide gas	Geothermal power generation equipment and sewage plants as well as paper, steel, and pulp plants	3 years	About 3 to 7 years
	A location where people could not stay for long periods, or a location with excessive dust or corrosive gas	Chemical factories, quarries, or mines	1 year	About 1 to 3 years

5-3-2 Recommended replacement guidelines based on switching durability

The number of switching operations determines the durability of an MCCB in frequent switching applications. MCCBs should be replaced before they exceed the value in any column in Table 5-9.

Table 5-9 Switching durability performance (IEC 60947-2)

Frame size	Number of switching operations			Number of trips by a shunt trip device or undervoltage trip device
	With current	Without current	Total	
100A max.	1500	8500	10000	10% of the total number of switching operations
300A	1000	7000	8000	
600A	1000	4000	5000	
800A	500	2500	3000	
1000A	500	2500	3000	
Over 1000A	500	2500	3000	

Chapter 6

Short-circuit current calculation

CONTENTS

6-1 Calculating short-circuit current

6-1-1 Calculation objective

The damage from a short-circuit fault in a system circuit must be kept to a minimum with power receiving equipment. This is why the short-circuit current generated when a fault occurs must be accurately calculated for all points in the system.

Purpose of short-circuit current calculations

1) To select the appropriate breaking capacity for overcurrent trip devices like MCCBs or fuses installed in the system.
2) To select the protective relay setting value that will ensure proper coordination at all points when a fault occurs.
3) To see how much short-circuit current the cables, disconnectors, current transformers and other series-connected devices can thermally and electrically withstand before the overcurrent trip device finally cuts off current.

6-1-2 Calculation formula

Short-circuit current is calculated from reference capacity and reference voltage impedance. When the various quantities needed in the calculation are expressed in percentages, then simply use Ohm's Law.

6-1-3 Calculating short-circuit current for three-phase circuits

• Step 1 Setting reference values

First set calculation references, and then select appropriate values for the references. The rated capacity of the transformer is generally used for the reference capacity.

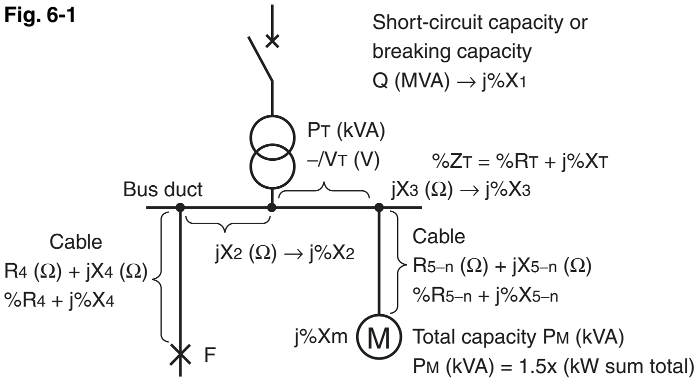
Reference capacity $P_B = P_T$ (kVA)
P_T = Transformer capacity
Reference voltage $V_B = V_T$ (V)
V_T = Line voltage

Reference current $I_B = I_T = \frac{P_T}{\sqrt{3}V_T} \times 10^3$ (A)

Reference impedance

$$Z_B = \frac{V_B^2}{P_B \times 10^3} = \frac{V_T^2}{P_T \times 10^3} \ (\Omega)$$

Fig. 6-1



• Step 2 Converting impedance values to reference values

(1) Reactance on the primary side of the transformer: %X1

The reactance can usually be obtained from the power company. If the reactance is not known, then it can be found by calculating back from the rated breaking capacity of the circuit breaker installed on the primary side of the transformer.

$$\%X_1 = \frac{P_B}{Q \times 10^3} \times 100 \ (\%)$$

Q = Short-circuit capacity on the primary side (MVA)

(2) Transformer impedance: %Zt

Transformer impedance is usually expressed as a percentage. If the transformer capacity is used for the reference capacity, then simply use $\%Z_T$. When the reference capacity and the transformer capacity are different, however, then convert them to a base reference capacity ($\%Z_t$) using the following formula.

$$\frac{P_T}{\%Z_T} = \frac{P_B}{\%Z_t} \quad \text{(Converting percentages into another capacity)}$$

When there is a single-phase transformer, treat it like a three-phase transformer, and set the impedance percentage at $\sqrt{3}/2$ times the obtained current value.

$$\%Z\ (3ø) = \frac{1}{2}\ \%Z\ (1ø)$$

Calculate three-phase short-circuit current using the formula above, and multiply the obtained current by $\sqrt{3}/2$.

(3) Motor reactance: %Xm

Motor capacity is generally expressed in kW, so convert the kW into kVA.
Conversion to kVA ≈ 1.5 × motor output (kW)
Use %Xm' = 25% to convert the motor capacity into a base reference capacity.

$$\frac{P_M}{\%X_m'} = \frac{P_B}{\%X_m}$$

(Formula for converting into another capacity)

(4) Bus duct and cable impedance

These are normally expressed by cross sections (rated current for the bus duct) and length.
Z_C = (Ohms per unit length) × (Length) (Ω)
Convert this value into a percentage.

$$\%Z_C = \frac{Z_C}{Z_B} \times 100\%$$

(If the value is given in ohms, convert it to a percentage.)

- **Step 3 Creating an impedance map**

Create an impedance map using the impedance calculated in step 2. Sources of short-circuit current like a power supply and motor constitute the same electric potential in an impedance map. Connect these sources together with an infinite busbar as shown in Fig. 6-2 and be very careful connecting impedance in series or in parallel between the busbar and fault point F when creating the impedance map.

- **Step 4 Unifying impedance**

Take the impedance map shown in Fig. 6-2 and use series-parallel calculations to unify all impedance as shown in Fig. 6-3.

$$\%Z = \%R + j\%X$$

$$\%Z = \sqrt{(\%R)^2 + (\%X)^2}$$

- **Step 5 Calculating effective values for symmetrical short-circuit current**

$I_F = (3ø) = I_F$ (rms) sym (3ø)

$$= \frac{P_B \times 10^3}{\sqrt{3}V_B\%Z} \times 100$$

$$= I_B \times \frac{100}{\%Z} \text{ [A]}$$

Fig. 6-2

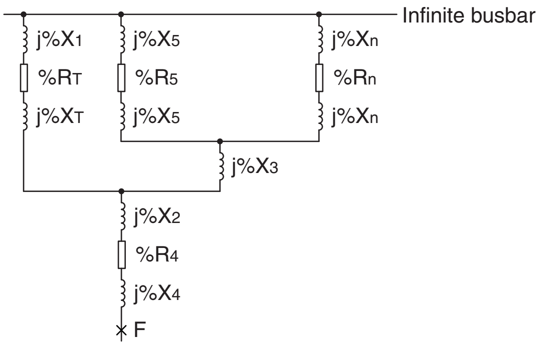
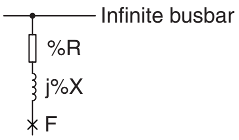


Fig. 6-3



6-1-4 Impedance examples

Table 6-1 Transformer impedance examples

Transformer capacity (kVA)	3-phase transformer											
	6.3kV/210V Oil immersed self-cooling			6.3kV/210V Cast-resin			20kV/420V Oil immersed self-cooling			20kV/420V Cast-resin		
	Impedance (%)			Impedance (%)			Impedance (%)			Impedance (%)		
	Z_T	R_T	X_T	Z_T	R_T	X_T	Z_T	R_T	X_T	Z_T	R_T	X_T
3												
5												
7.5												
10												
15												
20	2.3	2.1	0.9	3.0								
30	2.2	1.9	1.1	4.7	2.27	4.12						
50	2.1	1.8	1.1	4.7	1.94	4.28						
75	2.4	1.6	1.8	4.4	1.56	4.11						
100	2.4	1.6	1.8	4.5	1.5	4.24						
150	2.4	1.6	1.8	4.2	1.29	4.0						
200	2.5	1.5	2.0	4.5	1.17	4.35						
300	2.6	1.4	2.2	4.5	1.2	4.33						
500	3.0	1.3	2.7	4.8	0.8	4.69	5.0	1.56	4.76	6.0	1.0	5.92
750	5.3	1.5	5.1	6.0	0.8	5.95	5.0	1.40	4.80	6.0	0.9	5.93
1000	5.1	1.4	4.9	7.0	0.7	6.96	5.0	1.26	4.84	6.0	0.8	5.95
1500	5.6	1.3	5.4	7.0	0.6	6.97	5.0	1.2	5.37	7.0	0.75	6.96
2000	6.3	1.3	6.2	7.5	0.65	7.47	5.0	1.1	5.39	7.0	0.7	6.96

Table 6-2 Impedance of rubber and plastic-sheathed cables
Impedance of 600V, 3-core (CV, EV, PV, VV) round stranded cable at 50Hz

Nominal conductor cross section (mm^2)	CV cable			EV cable		
	R (90°C) (Ω/km)	X_L (Ω/km)	Z (Ω/km)	R (75°C) (Ω/km)	X_L (Ω/km)	Z (Ω/km)
2.0	12.5	0.0992	12.5	11.9	0.0992	11.9
3.5	6.78	0.0914	6.78	6.64	0.0914	6.64
5.5	4.51	0.0914	4.51	4.31	0.0914	4.31
8	3.14	0.0870	3.14	2.99	0.0870	2.99
14	1.76	0.0811	1.76	1.58	0.0811	1.58
22	1.10	0.0804	1.10	1.05	0.0804	1.05
38	0.653	0.0761	0.657	0.623	0.0761	0.628
60	0.408	0.0757	0.415	0.388	0.0757	0.395
100	0.242	0.0761	0.254	0.231	0.0751	0.243
150	0.159	0.0732	0.175	0.152	0.0732	0.169
200	0.126	0.0745	0.146	0.121	0.0745	0.142
250	0.100	0.0729	0.124	0.0962	0.0729	0.121
325	0.0808	0.0714	0.108	0.0775	0.0714	0.105

CV: Cross-linked polyethylene insulated power cable with vinyl sheath
EV: Polyethylene insulated power cable with vinyl sheath
PV: Ethylene propylene rubber insulated power cable with vinyl sheath
VV: Vinyl insulated power cable with vinyl sheath

Table 6-3 Cable impedance examples (600V vinyl cable)

Cable gauge	Reactance per meter of cable (Ω)			Resistance per meter of cable (Ω)
	Insulated wire or cable inside a steel tube or duct	Copper tube cable or vinyl tube cable with no duct	Indoor cable with insulator	
ø1.6mm	0.00020	0.00012	0.00031	0.0089
ø2mm				0.0056
ø3.2mm				0.0022
5.5mm²				0.0033
8mm²				0.0023
14mm²	0.00015	0.00010	0.00026	0.0013
22mm²				0.00082
30mm²				0.00062
38mm²				0.00048
50mm²	0.00013	0.00009	0.00022	0.00037
60mm²				0.00030
80mm²				0.00023
100mm²				0.00018
125mm²				0.00014
150mm²				0.00012
200mm²				0.00009
250mm²				0.00007
325mm²				0.00005

Notes:
- Add 20% reactance on the power supply side to find the value because reactance is 1.2 times higher at 60Hz.
- Use 1/2 or 1/3 the actual cable length to calculate reactance and resistance when using two or three cables connected in parallel.

Table 6-4 Bus bar and bus duct impedance examples (50Hz) Data: Furukawa Electric Co., Ltd.

Material	Rated current (A)	Regular bus duct			
		Conductor dimensions (mm)	Resistance (Ω/m)	Reactance X (Ω/m)	Impedance Z (Ω/m)
Aluminum (Al)	200	6 × 25	1.93×10^{-4}	1.25×10^{-4}	2.3×10^{-4}
	400	6 × 50	0.97×10^{-4}	0.909×10^{-4}	1.33×10^{-4}
	600	6 × 75	0.657×10^{-4}	0.72×10^{-4}	0.974×10^{-4}
	800	6 × 125	0.404×10^{-4}	0.516×10^{-4}	0.655×10^{-4}
	1000	6 × 150	0.343×10^{-4}	0.45×10^{-4}	0.566×10^{-4}
	1200	6 × 100 × 2	0.249×10^{-4}	0.882×10^{-4}	0.916×10^{-4}
	1500	6 × 125 × 2	0.201×10^{-4}	0.790×10^{-4}	0.815×10^{-4}
	2000	6 × 200 × 2	0.133×10^{-4}	0.588×10^{-4}	0.603×10^{-4}
Copper (Cu)	200	3 × 25	2.41×10^{-4}	1.312×10^{-4}	2.74×10^{-4}
	400	6 × 40	0.751×10^{-4}	1.02×10^{-4}	1.267×10^{-4}
	600	6 × 50	0.607×10^{-4}	0.91×10^{-4}	1.094×10^{-4}
	800	6 × 75	0.412×10^{-4}	0.72×10^{-4}	0.830×10^{-4}
	1000	6 × 100	0.315×10^{-4}	0.60×10^{-4}	0.678×10^{-4}
	1200	6 × 125	0.261×10^{-4}	0.511×10^{-4}	0.573×10^{-4}
	1500	6 × 150	0.221×10^{-4}	0.449×10^{-4}	0.500×10^{-4}
	2000	6 × 125 × 2	0.129×10^{-4}	0.79×10^{-4}	0.800×10^{-4}

Glossary

Alarm switch	An auxiliary switch which operates only upon the tripping of the circuit breaker with which it is associated.
Ambient air temperature	Temperature, determined under prescribed conditions, of the air surrounding the complete switching device or fuse.
Anti-pumping device	A device which prevents reclosing after a close-open operation as long as the device initiating closing is maintained in the position for closing.
Applied voltage (for a switching device)	Voltage which exists across the terminals of a pole as a switching device just before the making of the current. NOTE: This definition applies to a single-pole device. For a multipole device it is the phase-to-phase voltage across the supply terminals of the device.
Arcing contact	Arc contact on which the arc is intended to established.
Arcing time (of a multipole switching device)	Interval of time between the instant of the first initiation of an arc and the instant of final arc extinction in all poles.
Auxiliary contact	Contact included in an auxiliary circuit and mechanically operated by the switching device.
Auxiliary switch (of a mechanical switching device)	Switch containing one or more control and/or auxiliary contacts mechanically operated by a switching device.
Backup protection	Overcurrent coordination of two overcurrent protective devices in series where the protective device, generally but not necessarily on the supply side, effects the overcurrent protection with or without the assistance of the other protective device and prevents any excessive stress on the latter.
Breaking capacity (of a switching device or a fuse)	Value of prospective breaking current that a switching device or a fuse is capable of breaking at a stated voltage under prescribed conditions of use and behavior.
Breaking current (of a switching device or a fuse)	Current in a pole of a switching device or a fuse at the instant of initiation of the arc during a breaking process.
Break time	Interval of time between the beginning of the opening time of a mechanical switching device (or the pre-arcing time of a fuse) and the end of the arcing time.
Circuit breaker	Mechanical switching device, capable of making, carrying and breaking currents under normal circuit conditions and also making, carrying for a specified time and breaking currents under specified abnormal circuit conditions such as those of short-circuit.
Clearance	Distance between two conductive parts, along a string stretched the shortest way between these conductive parts.
Closing time	Interval of time between the initiation of the closing operation and the instant when the contacts touch in all poles.
Conditional short-circuit current (of a circuit or a switching device)	Prospective current that a circuit or a switching device, protected by a specified short-circuit protective device, can satisfactorily withstand for the total operating time of that device under specified conditions of use and behavior.
Conductive part	Part which is capable of conducting current although it may not necessarily be used for carrying service current.
Control circuit (of a switching device)	All the conductive parts (other than the main circuit) of a switching device which are included in a circuit used for the closing operation or opening operation, or both, of the device.

Glossary

Conventional free-air thermal current (Ith)	The conventional free-air thermal current is the maximum value of test current to be used for temperature-rise tests of unenclosed equipment in free-air. The value of the conventional free-air thermal current shall be at least equal to the maximum value of the rated operational current of the unenclosed equipment in eight-hour duty.
Conventional non-tripping current (of an overcurrent relay or release (trip device))	Specified value of current which the relay or release (trip device) can carry for a specified time (conventional time) without operating.
Conventional tripping current (of an overcurrent relay or release (trip device))	Specified value of current which causes the relay or release (trip device) to operate within a specified time (conventional time).
Creepage distance	Shortest distance along the surface of an insulating material between two conductive parts. NOTE: A joint between two pieces of insulating material is considered part of the surface.
Critical load current	Value of breaking current, within the range of service conditions, at which the arcing time is significantly extended.
Critical short-circuit current	Value of breaking current, less than the rated short-circuit breaking capacity, at which the arc energy is significantly higher than at the rated short-circuit breaking capacity.
Current-limiting circuit breaker	A circuit breaker with a break-time short enough to prevent the short-circuit current reaching its otherwise attainable peak value.
Cut-off current (Let-through current)	Maximum instantaneous value of current attained during the breaking operation of a switching device or a fuse. NOTE: This concept is of particular importance when the switching device or the fuse operates in such a manner that the prospective peak current of the circuit is not reached.
Disconnector	Mechanical switching device which, in the open position, complies with the requirements specified for the isolating function.
Exposed conductive part	Conductive part which can readily be touched and which is not normally alive, but which may become alive under fault conditions. NOTE: Typical exposed conductive parts are walls of enclosures, operating handles, etc.
Frame size	A term designating a group of circuit breakers, the external physical dimensions of which are common to a range of current ratings. Frame size is expressed in amperes corresponding to the highest current rating of the group. Within a frame size, the width may vary according to the number of poles.
Fuse	Device that, by the fusing of one or more of its specifically designed and proportioned components, opens the circuit in which it is inserted by breaking the current when this exceeds a given value for a sufficient time. The fuse comprises all the parts that form the complete device.
Fuse-element	Part of the fuse-link designed to melt under the action of current exceeding some definite value for a definite period of time.
Fuse-link	Part of a fuse (including the fuse-element(s)) intended to be replaced after the fuse has operated.
Impulse withstand voltage (U_{imp})	Highest peak value of an impulse voltage, of prescribed form and polarity, which does not cause breakdown under specified conditions of test.
Instantaneous relay or release (trip device)	Relay or release (trip device) which operates without any intentional time-delay.

Glossary

Inverse time-delay overcurrent relay or release (trip device)	An overcurrent relay or release (trip device) which operates after a time-delay inversely dependent upon the value of the overcurrent. NOTE: Such a relay or release (trip device) may be designed so that the time-delay approaches a definite minimum value for high values of overcurrent.
Isolating distance (of a pole of a mechanical switching device)	Clearance between open contacts meeting the safety requirements specified for disconnectors.
I^2t characteristic of a circuit breaker	Information (usually a curve) giving the maximum values of I^2t related to break time as a function of prospective current (r.m.s. symmetrical for AC) up to the maximum prospective current corresponding to the rated short-current breaking capacity and associated voltage.
Joule integral (I^2t)	Integral of the square of the current over a given time interval: $I^2t = \int i^2 dt$
Let-through current (= Cut-off current)	See "Cut-off current."
Live part	Conductor or conductive part intended to be energized in normal use, including a neutral conductor but, by convention, not a PEN conductor. NOTE: This term does not necessarily imply a risk of electric shock.
Magnetic overload relay or release (trip device)	Overload relay or release (trip device) depending for its operation on the force exerted by the current in the main circuit exciting the coil of an electromagnet. NOTE: Such a relay or release (trip device) usually has an inverse time-delay/current characteristic.
Main circuit (of a switching device)	All the conductive parts of a switching device included in the circuit which it is designed to close or open.
Main contact	Contact included in the main circuit of a mechanical switching device, intended to carry, in the closed position, the current of the main circuit.
Make time	Interval of time between the initiation of the closing operation and the instant when the current begins to flow in the main circuit.
Maximum prospective peak current (of an AC circuit)	Prospective peak current when initiation of the current takes place at the instant which leads to the highest possible value. NOTE: For a multipole device in a polyphase circuit, the maximum prospective peak current refers to one pole only.
Molded case circuit breaker	A circuit breaker having a supporting housing of molded insulating material forming an integral part of the circuit breaker.
Neutral conductor (symbol N)	Conductor connected to the neutral point of a system and capable of contributing to the transmission of electrical energy. NOTE: In some cases, the functions of the neutral conductor and the protective conductor may be combined under specified conditions in one and the same conductor referred to as the PEN conductor [Symbol PEN].
Opening time (of a mechanical switching device)	Interval of time between the specified instant of initiation of the opening operation and the instant when the arcing contacts have separated in all poles. NOTE: The instant of initiation of the opening operation, i.e. the application of the opening command (e.g. energizing the release), is given in the relevant product standard.
Overcurrent	Current exceeding the rated current.

Glossary

Overcurrent protective coordination	Coordination of two or more overcurrent protective devices in series to ensure overcurrent discrimination (selectivity) and/or backup protection.
Overcurrent relay or release (trip device)	Relay or release (trip device) which causes a mechanical switching device to open with or without time-delay when the current in the relay or release (trip device) exceeds a predetermined value. NOTE: This value can in some cases depend upon the rate-of-rise of current.
Overload	Operating conditions in an electrically undamaged circuit which cause an overcurrent.
Overload current	Overcurrent occurring in an electrically undamaged circuit.
Overload relay or release (trip device)	Overcurrent relay or release (trip device) intended for protection against overloads.
Pollution	Any condition of foreign matter, solid, liquid or gaseous (ionized gases), that may affect dielectric strength or surface resistivity.
Pollution degree (of environmental conditions)	Conventional number based on the amount of conductive or hygroscopic dust, ionized gas or salt and on the relative humidity and its frequency of occurrence, resulting in hygroscopic absorption or condensation of moisture leading to reduction in dielectric strength and/or surface resistivity.
Prospective breaking current (for a pole of a switching device or a fuse)	Prospective current evaluated at a time corresponding to the instant of the initiation of the breaking process.
Prospective making current (for a pole of a switching device)	Prospective current when initiated under specified conditions. NOTE: The specified conditions may relate to the method of initiation, e.g. by an ideal switching device, or to the instant of initiation, e.g., leading to the maximum prospective peak current.
Prospective peak current	Peak value of a prospective current during the transient period following initiation.
Prospective symmetrical current (of an AC circuit)	Prospective current when it is initiated at such an instant that no transient phenomenon follows the initiation.
Rated current (In)	For circuit breakers, the rated current is the rated uninterrupted current (Iu) and is equal to the conventional free-air thermal current (Ith).
Rated insulation voltage (Ui)	The insulation voltage of an equipment is the value of voltage to which dielectric tests and creepage distances are referred.
Rated operational voltage (Ue)	A rated operational voltage of an equipment is a value of voltage which, combined with a rated operational current, determines the application of the equipment and to which the relevant tests and the utilization categories are referred.
Rated uninterrupted current (Iu)	The rated uninterrupted current of an equipment is a value of current, stated by the manufacturer, which the equipment can carry in uninterrupted duty.
Selectivity limit current (Is)	The selectivity limit current is the current coordinate of the intersection between the total time-current characteristic of the protective device on the load side and the pre-arcing (for fuses), or tripping (for circuit breakers) time-current characteristic of the other protective device.
Service short-circuit breaking capacity (Ics)	A breaking capacity for which the prescribed conditions according to a specified test sequence include the capability of the circuit breaker to carry its rated current continuously.

Glossary

Short-circuit breaking capacity (Icn)	Breaking capacity for which prescribed conditions include a short-circuit at the terminals of the switching device.
Short-circuit current	Overcurrent resulting from a short-circuit due to a fault or an incorrect connection in an electric circuit.
Short-circuit making capacity (Icm)	Making capacity for which prescribed conditions include a short-circuit at the terminals of the switching device.
Short-circuit protective device (SCPD)	Device intended to protect a circuit or parts of a circuit against short-circuit currents by interrupting them.
Short-time delay	Any intentional delay in operation within the limits of the rated short-time withstand current.
Short-time withstand current (Icw)	Current that a circuit or a switching device in the closed position can carry during a specified short time under prescribed conditions of use and behavior.
Shunt release (trip device)	A release (trip device) energized by a source of voltage. NOTE: The source of voltage may be independent of the voltage of the main circuit.
Take-over current (I_B)	Current coordinate of the intersection between the time-current characteristics of two overcurrent protective devices.
Thermal overload relay or release (trip device)	Inverse time-delay overload relay or release (trip device) depending for its operation (including its time-delay) on the thermal action of the current flowing in the relay or release (trip device).
Time-current characteristic	Curve giving the time, e.g. pre-arcing time or operating time, as a function of the prospective current, under stated conditions of operation.
Tripping (operation)	Opening operation of a mechanical switching device initiated by a relay or release (trip device).
Ultimate short-circuit breaking capacity (Icu)	A breaking capacity for which the prescribed conditions according to a specified test sequence do not include the capability of the circuit breaker to carry its rated current continuously.
Undervoltage relay or release (trip device)	Relay or release (trip device) which permits a mechanical switching device to open or close, with or without time-delay, when the voltage across the terminals of the relay or release (trip device) falls below a predetermined value.
Working voltage	Highest r.m.s. value of the AC or DC voltage across any particular insulation which can occur when the equipment is supplied at rated voltage.

⚠ Safety Considerations

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