GUIDANCE NOTES
GD 02-2007

INTERNATIONAL SHIP CLASSIFICATION

GUIDELINES FOR SELECTIVE OVERCURRENT PROTECTION FOR ELECTRICAL SYSTEMS OF SHIPS

2007

CONTENTS

CHAPTER 1 GENERAL

1.1 General requirements

1.1.1 Over-current is a fault normally seen in the electrical installations on board, which may result in a ship's blackout situation, in loss of maneuverability or in even more serious consequences, such as collision or fire. Therefore, some specific provisions for over-current protection of electrical installations are given in ISC Rules. A requirement of principle is also given in ISC Rules for how to ensure the continuity of service for the supply to the healthy circuits of essential equipment during a fault in a circuit of ship's electrical systems, i.e., for achieving over-current selective protection for electrical systems.

1.1.2 In addition to the specific provisions for ship's over-current selective protection for electrical systems, requirements for the sensitivity of over-current protective devices that constitute the basis of over-current selective protection are given in the Guidelines. Other protections such as operating characteristics of undervoltage protection and reverse power protection are to be coordinated with the over-current selective protection requirements.

1.1.3 The Guidelines apply to ships with a main power station over 250 kVA in total capacity and, unless otherwise expressly specified in ISC Rules, may also apply to other ships.

1.1.4 Documents to be submitted for approval

For ships as specified in 1.1.3, an Analysis of Electrical Power System Protective Device Coordination is to be submitted for approval, which normally includes:

(1) Summary of over-current selective protection at each level of the electrical power system;

(2) Arrangement and the Tripping Characteristics Setting Tables of protective devices with regard to over-current selective protection;

(3) Analysis of protective device coordination in the electrical power system and time-current characteristic curves thereof (time-current characteristic curves of protective devices of each level are drawn on the same diagram).

1.2 Definitions

1.2.1 In addition to the definitions given in PART FOUR of ISC Rules for Classification of Sea-going Steel Ships, the following definitions apply to the Guidelines:

(1) Over-current

Current exceeding the rated current.

(2) Overload

Operating conditions in an electrically undamaged circuit which cause an over-current.

(3) Short-circuit

Accidental or intentional connection of two or more points of a circuit at different potentials under normal conditions through a negligible resistance or impedance.

(4) Over-current protective co-ordination of over-current protective device

Co-ordination of two or more over-current protective devices in series to ensure over-current discrimination (selectivity) and/or back-up protection.

(5) Over-current discrimination

Co-ordination of the operating characteristics of two or more over-current protective devices such that, on the incidence of over-currents within stated limits, the device intended to operate within these limits does so, while the other(s) does (do) not.

(6) Switching device

Device designed to make or break the current in one or more electrical circuit.

Note: A switching device may perform one or both of the operations.

(7) Mechanical switching device

Switching device designed to close and open one or more electrical circuits by means of separable contacts.

Note: Any mechanical switching device may be designated according to the medium in which its contacts open and close, e.g.: air, SF6, oil.

(8) Circuit breaker (mechanical)

A 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.

(9) Molded case circuit beaker

A circuit-breaker having a supporting housing of moulded insulating material forming an integral part of the circuit-breaker.

(10) 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.

Note: This definition does not imply dimensional standardization.

(11) Release (of a mechanical switching device)

A device, mechanically connected to a mechanical switching device, which releases the holding means and permits the opening or the closing of the switching device.

(12) Over-current relay or release

Relay or release which causes a mechanical switching device to open with or without time-delay when the current in the relay or release exceeds a predetermined value.

Note: This value can in some cases depend upon the rate-of-rise of current.

(13) Short-circuit release

An over-current release intended for protection against short circuits.

(14) Short-time short-circuit release

An over-current release intended to operate at the end of the short-time delay.

(15) Instantaneous relay or release

Relay or release which operates without any intentional time-delay.

(16) Definite time-delay relay or release

Over-current relay or release which operates with a definite time-delay which may be adjustable, but is independent of the value of the over-current.

(17) Inverse time-delay relay or release

Over-current relay or release which operates after a time-delay inversely dependent upon the value of the over-current.

Note: Such a relay or release may be designed so that the time-delay approaches a definite minimum value for high values of over-current.

(18) Shunt release

Release energized by a source of voltage.

Note: The source of voltage may be independent of the voltage of the main circuit.

(19) Operating current (of an over-current relay or release)

Value of current at and above which the relay or release will operate.

(20) Current setting (of an over- current overload relay or release)

Value of current of the main circuit to which the operating characteristics of the relay or release are referred and for which the relay or release is set.

Note: A relay or release may have more than one current setting, provided by an adjustment dial, interchangeable heaters, etc.

(21) Current setting range (of an over-current overload relay or release)

Range between the minimum and maximum values over which the current setting of the relay or release can be adjusted.

(22) Fuse

A device that by the fusing of one or more of its specially 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.

(23) Fuse-link

Part of a fuse including the fuse-element(s), intended to be replaced after the fuse has operated.

(24) 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. The fuse-link may comprise several fuse-elements in parallel.

(25) Indicator

Part of a fuse provided to indicate whether the fuse has operated.

(26) Striker

Mechanical device forming part of a fuse-link which, when the fuse operates, releases the energy required to cause operation of other apparatus or indicators or to provide interlocking.

(27) Pre-arcing time (of a fuse)

Interval of time between the beginning of a current large enough to cause a break in the fuse-element(s) and the instant when an arc is initiated.

(28) Arcing time (of a pole or fuse)

Interval of time between the instant of the initiation of the arc in a pole or a fuse and the instant of final arc extinction in that pole or that fuse.

(29) Arcing time (of multi pole 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.

(30) Opening time (of 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.

For circuit breakers:

- for a circuit breaker operating directly, the instant of initiation of the opening operation means the instant when the current increases to a degree big enough to cause the breaker to operate;
- for a circuit breaker operating by means of a auxiliary power supply, the instant of initiation of the opening operation means the instant when auxiliary power supply applies on the release.

Note: ① 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.

② For circuit breakers, Opening Time is usually referred to as Release Time. Strictly speaking, release time means the interval of time between the instant of initiation of the opening operation and the instant when the opening order becomes irreversible.

(31) 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.

Note: ① It is referred to as Full Break Time in the Guidelines to avoid ambiguity.
② For fuses, there is a term Operating Time which means the pre-arcing time plus arcing time and is actually identical with Break Time.

(32) Making capacity (of a switching device)

Value of prospective making current that a switching device is capable of making at a stated voltage under prescribed conditions of use and behavior.

Note: ① The voltage to be stated and the conditions to be prescribed are dealt with in the relevant product standard.
② For short-circuit making capacity, see (34).

(33) Breaking current (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.

Note: ① The voltage to be stated and the conditions to be prescribed are dealt with in the relevant product standard.
② For A.C., the current is expressed as the symmetrical r.m.s. value of the A.C. component.
③ For short-circuit breaking capacity, see (35).

(34) Short-circuit making capacity

Making capacity for which prescribed conditions include a short circuit at the terminals of the switching device.

(35) Short-circuit breaking capacity

Breaking capacity for which prescribed conditions include a short circuit at the terminals of the switching device

(36) Ultimate short - circuit breaking capacity

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.

(37) Service short-circuit breaking capacity

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.

(38) Short-time withstand current

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.

(39) Main bus-bar

Bus-bar directly supplied by main generator.

(40) Low-voltage main bus-bar

Bus-bar that is supplied by a transformer transforming a high-voltage main bus-bar directly supplied by main generator into a low-voltage, then directly supplies the auxiliary services which is necessary for ship’s normal operation and habitability without transforming.

(41) Sensitivity coefficient

Coefficient that indicates the sensitivity of protective devices. For over-current protective devices:
Sensitivity coefficient = calculated value of minimum metallic short-circuit current/set value of protective devices.

Note: “calculated value of minimum metallic short-circuit current” means the calculated short-circuit current value in the event of short circuit of the end protected circuit, when the electrical system is supplied by single smallest generator.

1.3 Symbols and codes

1.3.1 Symbols and codes are adopted in the Guidelines as follows:
Table 1.3.1 shows the list of symbols and codes adopted in the Guidelines.

Symbols and Codes **Table 1.3.1**

symbol or code	Characteristics or definition
U_e	Rated operational voltage
I_{n}①	Rated current
I_r	Current setting of overload release
I_{cn}	Rated short-circuit breaking capacity
I_{cm}	Rated short-circuit making capacity
I_{cu}	Rated ultimate short-circuit breaking capacity
I_{cs}	Rated service short-circuit breaking capacity
I_{cw}	Rated short-time withstand current
i_p	Peak short-circuit current (peak)
I_{ac}	Symmetrical short-circuit current
MCCB	Moulded case circuit breaker
MCB	Mini moulded case circuit breaker, e.g. moulded case circuit with moulded case less than 63 A
ACB	A circuit-breaker in which the contacts open and close in air at atmospheric pressure
LTD protection	Long time delay overload protection
STD protection	Short time delay short-circuit protection
INST protection	Instantaneous short-circuit protection
G protection	Ground fault protection
Note: ① Capital letter “I” is given in root-mean-square value.	

CHAPTER 2 APPLICATION OF NORMAL PROTECTIVE DEVICES

2.1   General requirements

Ships sailing at sea and rivers seem to moving towns in land. Similar to land-based electrical systems, various protective devices, such as instrument transformers, protective relays, fuses and circuit breakers, etc., are used for over-current protection of electrical systems in ships. According to ISC Rules, appropriate fuses or circuit breakers are to be provided for short-circuit and overload protection. Also, high-voltage generators and low-voltage generators having a capacity of 1500 kVA or above, are to be equipped with a suitable protective device or system which in the case of short-circuit in the generator or in the supply cable between the generator and its circuit breaker will de-excite the generator and open the circuit breaker.

As aforementioned, fuses and circuit breakers are the protective devices normally used in electrical systems of ships, moreover, differential protective relays are normally used for internal failure protection of generators, motors (e.g. electrical propulsion motors) and transformers of large capacity. This Chapter is a general introduction of the function, composition and characteristics of these protective devices and gives the requirements for how to choose them for over-current protection.

Fuses and circuit breakers can be classified into AC and DC, or high-voltage (over 1000 V for AC, over 1500 V for DC) and low-voltage. This Chapter concerns AC low-voltage fuses and breakers only.

Low-voltage fuses and breakers are manufactured based on the following standards:

IEC60947-2 (GB14048.2①) Low-voltage switchgear and control-gear - Part 2: Circuit-breakers

IEC60269-1(GB13539.1) Low-voltage fuses - Part 1: General requirements

IEC60269-2(GB13539.2) Low-voltage fuses - Part 2: Supplementary requirements for fuses for use by authorized persons (fuses mainly for industrial application)

IEC60269-2-1(GB13539.6) Low-voltage fuses - Part 2: Supplementary requirements for fuses for use by authorized persons (fuses mainly for industrial application) - Sections 1 to 5: Examples of standardized fuses

2.2   Circuit breaker

2.2.1   Functions

A circuit breaker is a 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.

Here, mechanical switching device means a switching device designed to close and open one or more electrical circuits by means of separable contacts. While semiconductor switching device is a switching device designed to make and/or break the current in an electrical circuit by means of the controlled conductivity of a semiconductor. Semiconductor switching devices are not used in electrical systems in ships.

Isolation and over-current protection are two basic functions of circuit breakers. Over-current protection is to be achieved by automatically tripping a circuit under protection, in case of a fault that the current in the circuit exceeding the tripping setting value of the circuit breaker.

2.2.2   Classification

(1)   Circuit-breakers may be classified A or B, according to their utilization category, as shown in Table 2.2.2.1.

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① This GB standard is equivalent to IEC60947-2. Ditto below.

Utilization category of circuit breakers **Table 2.2.2.1**

Utilization category	Application with respect to selectivity
A	Circuit-breakers not specifically intended for selectivity under short-circuit conditions with respect to other short-circuit protective devices in series on the load side, i.e. without an intentional short-time delay provided for selectivity under short-circuit conditions, and therefore without a short-time withstand current rating.
B	Circuit-breakers specifically intended for selectivity under short-circuit conditions with respect to other short-circuit protective devices in series on the load side, i.e. with an intentional short-time delay (which may be adjustable), provided for selectivity under short-circuit conditions. Such circuit-breakers have a short-time withstand current rating.

(2) According to the interrupting medium, for example:
– air-break;
– vacuum break;
– gas-break.
Normally marine low-voltage circuit breaker is interrupted by air, called Air Circuit Breaker.
(3) According to the design, for example:
– open construction (abbreviated as ACB in the Guidelines);
– moulded case (abbreviated as MCCB or MCB in the Guidelines).
(4) According to the method of controlling the operating mechanism, for example:
– dependent manual operation;
– independent manual operation;
– dependent power operation;
– independent power operation;
– stored energy operation.
(5) According to the suitability for isolation:
– suitable for isolation;
– not suitable for isolation.
(6) According to the method of installation, for example:
– fixed;
– plug-in;
– withdrawable.
(7) According to the degree of protection provided by the enclosure:
–degree 1;
–degree 2;
–degree 3;
–degree 4.

2.2.3 Components of circuit breakers

Low-voltage circuit breakers are mainly composed of the following parts: (see Figure 2.2.3)
(1) fixed and moving contacts;
(2) arc-dividing chamber;
(3) latching mechanism;
(4) over-current release and other releases(e.g. undervoltage release, etc.);
(5) terminals for incoming and outgoing circuits;
(6) operation handle linked to the latching mechanism;
(7) other electrical fittings, such as auxiliary contacts, electrical switch-on mechanism (except for that of small size), and indication and measuring components (normally from electronic releases).

Over-current release is the nerve center of a circuit breaker. On detection of abnormal current conditions, the latching mechanism will be unlatched by the over-current release and the circuit in fault will be cut. Currently there are two types of releases: thermal magnetic release and electronic release. Thermal magnetic release is a classic type, which is now only used in moulded case circuit breakers. It comprises two parts. One is a thermally-operated bi-metal strip which, in case of over-current, is deformed and unlatches the latching mechanism and then causes the circuit breaker to trip. The time interval between the start of heating to tripping of the circuit breaker may last as long as tens of seconds or even several minutes, so is called as Long Time Delay, LTD in abbreviation. The other is actually an electromagnet which acts in case of a strong over-current and causes the circuit breaker to quickly trip, so is called as Instantaneous, INST in abbreviation. Electronic releases are newly appeared in the recent decades as a result of the development of electronics and computer technology. Compared with thermal magnetic releases, an advantage with electronic releases is their protection capability. Electronic releases provide three protection levels①: LTD, STD and INST. Grounding protection may also be easily added where necessary. Settings are easy to be adjusted and electronic releases are less affected by temperatures. Owning to these advantages, more and more circuit breakers are fitted with electronic releases which facilitate the over-current selective protection of electrical systems in ships.

With the rapid development of computer technology in recent years, some circuit breakers are able to provide, in addition to protection, other functions including measurement (including power quality analysis), diagnosis, communication, control and monitoring.

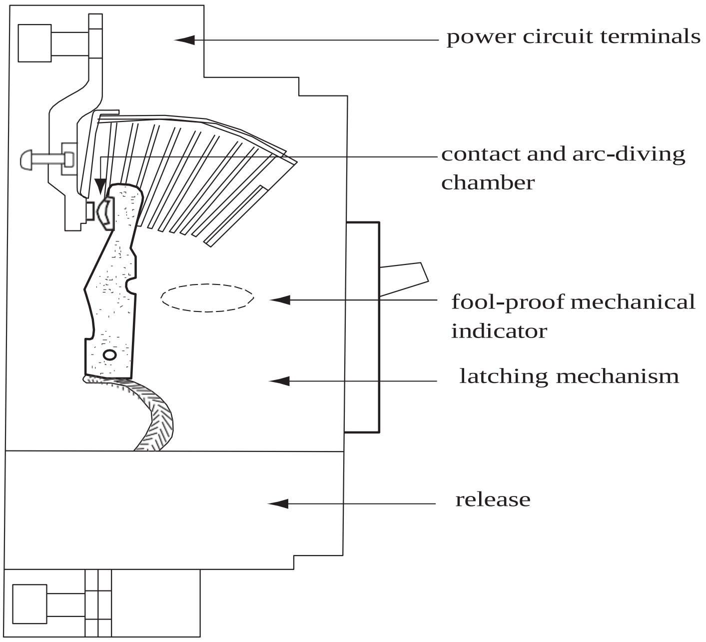

Figure 2.2.3 Main Parts of a Low-voltage Circuit Breaker

2.2.4 Characteristics

(1) Parameters

Rated operational voltage U_e

This is the voltage at which the circuit-breaker has been designed to operate, in normal (undisturbed) conditions.

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① Except for some certain products (e.g. NS MCCB below 800A as stated in 2.2.4(4)), a circuit breaker with two level protections: LTD and STD may be chosen according to practical situations.

Rated insulation voltage U_i

The rated insulation voltage of equipment is the value of voltage to which dielectric test voltage (normally more than $2U_i$) and creepage distances are referred. The highest value of the rated operational voltage is not to exceed the rated insulation voltage, i.e. $U_e \leqslant U_i$.

Rated current I_n

This is the maximum value of current that a circuit-breaker, fitted with a specified over-current tripping relay, can carry indefinitely at an ambient temperature stated by the manufacturer, without exceeding the specified temperature limits of the current carrying parts.

Frame-size rating

This is the maximum value of current that the highest over-current level tripping relay can be set when a tripping relay is fitted with different current level-setting ranges.

Overload trip-current setting I_r

Overload trips are generally adjustable. The trip-current setting I_r is the current above which the circuit-breaker will trip. It also represents the maximum current that the circuit-breaker can carry without tripping.

The thermal-trips are generally adjustable from 0.7 to 1.0 times I_n, but when electronic devices are used for this duty, the adjustment range is greater; typically 0.4 to 1 times I_n.

Short-circuit (instantaneous or short-time delay) trip-current setting I_i or I_{sd}

Short-circuit tripping relays (instantaneous or short-time delayed) are intended to trip the circuit-breaker rapidly on the occurrence of high values of fault current. Their tripping settings are I_i or I_{sd}. Table 2.2.4 shows the short-circuit tripping-current setting or setting range for the typical products of a company. For details of other products, see the product manual.

Short-circuit tripping-current setting for typical products of a company Table 2.2.4

Type of trips	STD	INST
Thermo magnetic	-	Fixed: I_i = 7 to $10I_n$
		Adjustable: - low setting: 2 to $5I_n$ - standard setting:5 to $10I_n$
Electronic	$1.5I_r \leqslant I_{sd} < 10I_r$	I_i = 12 to $15I_n$

(2) Time-current characteristic curves

A time-current characteristic curve shows the automatic break time related to the current. X-coordinate represents the current (I), Y-coordinate represents the time (t) and both are logarithmic coordinates. The time-current characteristic curves of circuit breakers, as shown in Figures 2.2.4a and Figure 2.2.4b. Due to fabrication errors and ambient temperature, the time-current characteristic curves are actually in the shape of a strip.

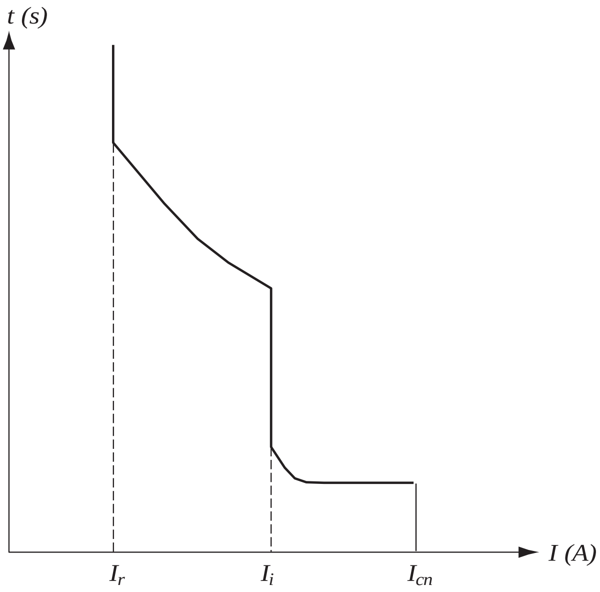

Figure 2.2.4a Time-current characteristic curve of a thermal magnetic circuit-breaker

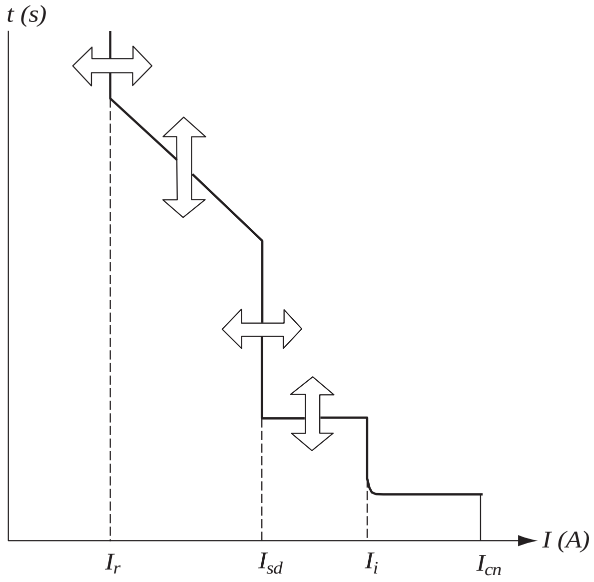

Figure 2.2.4b Time-current characteristic curve of an electronic circuit-breaker

Figure 2.2.4c shows the time-current characteristic curve of an ACB of an electric company, while Figure 2.2.4d shows the time-current characteristic curve of a MCCB of another electric company.

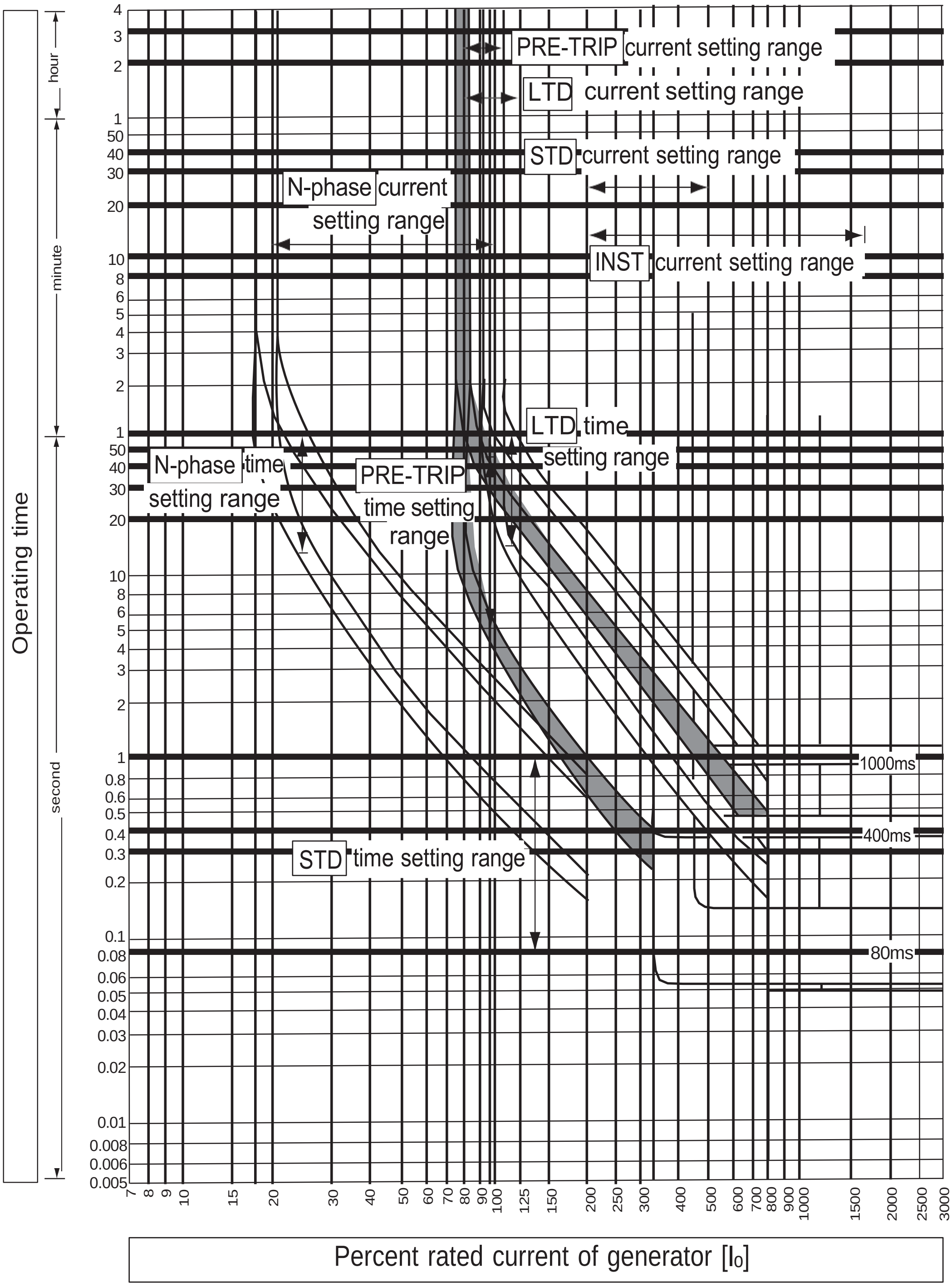

Figure 2.2.4c Time-current characteristic curve of an ACB for generator protection

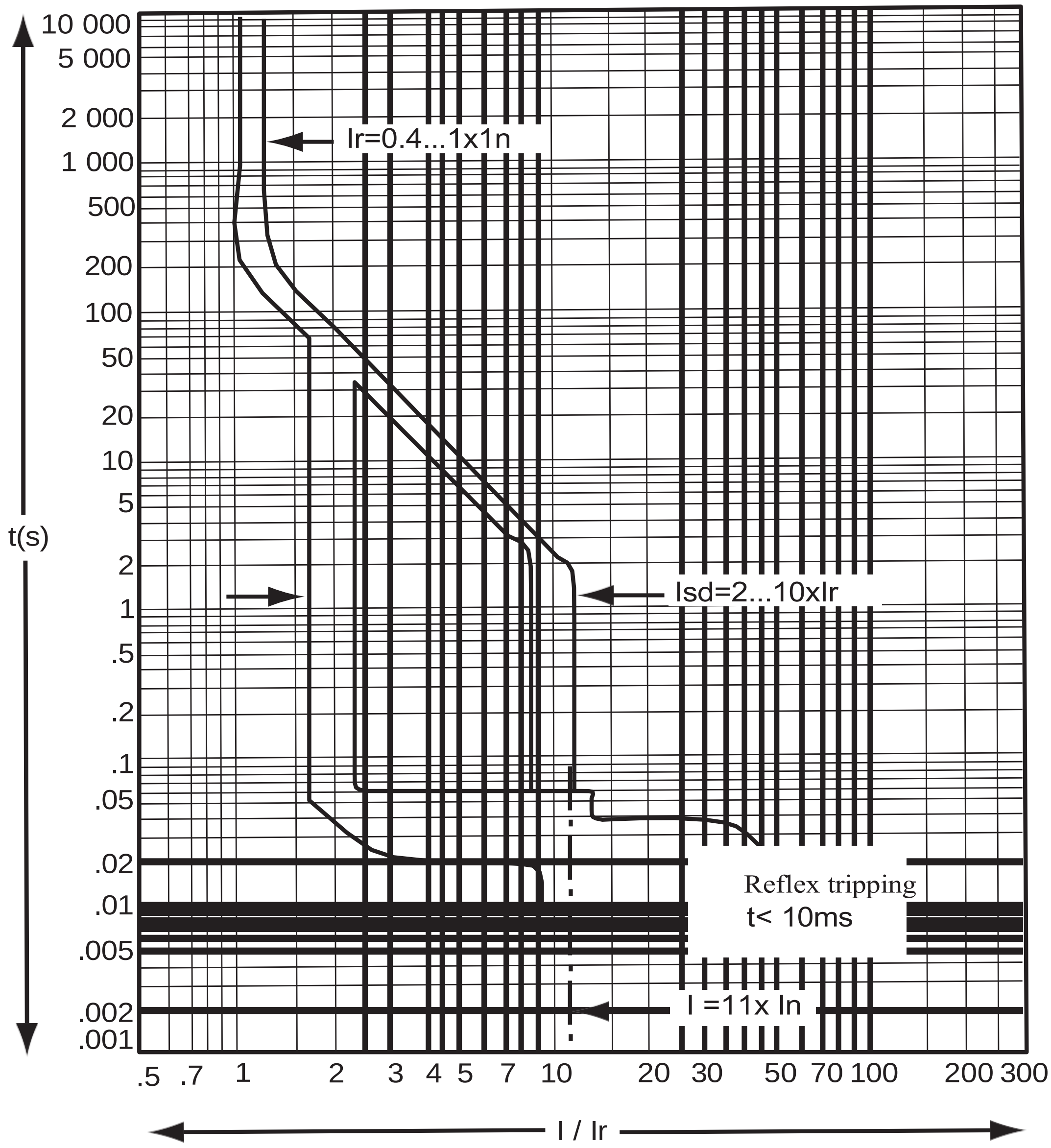

Figure 2.2.4d Time-current characteristic curve of a MCCB

(3) Current limitation

A current limiting circuit breaker is designed in such a way that electromagnetic repulsion force induced by short-circuit current causes the fast opening of contacts (e.g. 3 to 5 ms), preventing the short-circuit current from reaching its otherwise attainable peak value. In this way the passage of the maximum prospective short-circuit current is prevented by permitting only a limited amount of current to flow, as shown in Figure 2.2.4e.

The use of current-limiting circuit breakers affords numerous advantages: better conservation of electrical installations and cables, reduction of thermal effects, mechanical effects and electromagnetic-interference effects, and less influence on measuring instruments and telecommunication systems, etc.

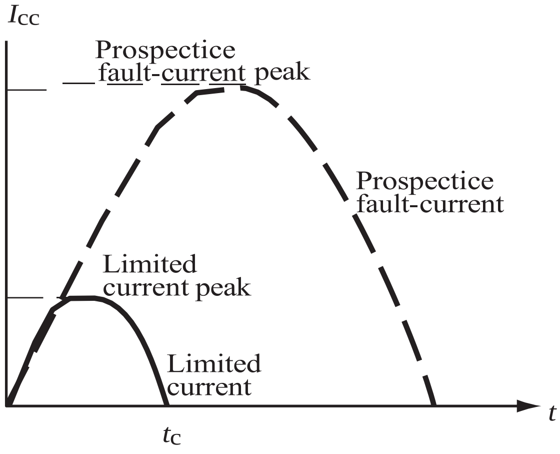

Figure 2.2.4e Prospective and actual currents

(4) Reflex tripping

There is a type of MCCB with a unique double rotary contact system, which performs better in limiting current and breaks very high fault currents by means of reflex tripping. In this way short-circuit selective protection can be achieved. See for details in 3.1.2(4) of the Guidelines.

2.2.5 Choice of circuit breakers

As aforementioned, circuit breakers are used for overload protection and short-circuit protection. Choice of circuit breakers is clearly specified in ISC Rules. See for details in 2.5.3 to 2.5.5 of PART FOUR of ISC Rules for Classification of Sea-going Steel Ships.
Here special attention is to be paid to the ratings.

(1) Rated service short-circuit breaking capacity I_{cs}

The rated service short-circuit breaking capacity of instantaneous circuit breakers for relevant circuits of essential services is not to be less than the maximum prospective short-circuit current at the point of installation. For the A.C. systems, the rated service short-circuit breaking capacity is not to be less than the maximum prospective symmetrical short-circuit current (root-mean-square value) at the point of installation.
I_{cs} and I_{cu} differ in that:
Firstly, the operation sequences in short-circuit breaking capacity test are different. For I_{cs} the sequence is O — t — CO — t — CO, while for Icu is O — t — CO.

Note: “O” represents a breaking operation; “CO” represents a making operation followed, after the appropriate opening time, by a breaking operation; “t” represents the time interval between two successive short-circuit operations which is to be 3 min or equal to the resetting time of the circuit-breaker, whichever is longer.

Secondly, they differ in the ability to carry rated operational current after test.
Obviously, a circuit breaker satisfying I_{cs} is more reliable than the one satisfying I_{cu}. It is reasonable that I_{cs} is used for assessing circuit breakers for the circuits of essential services which requires continuous power supply. Presently many MCCBs can make $I_{cs} = 100\% I_{cu}$.

(2) When short-circuit power factor is less than circuit breaker test power factor

For circuit breakers that are arranged near generators, it may happen that the power factor of the circuit breaker is greater than that of the prospective short circuit current. ISC Rules require that "when the power factor of the circuit breaker is greater than that of the prospective short circuit current, the circuit breaker is to be chosen with regard to its short circuit making capacity (I_{cm}) or after conversion of the rated short circuit breaking capacity of circuit breakers, according to Appendix B to Appendix 1 of PART FOUR". This can be achieved by choosing a circuit breaker the rated short-circuit making capacity of which is not less than the maximum peak value of the prospective short-circuit current i_p at the point of installation. Therefore, by obtaining a satisfactory rated short-circuit making capacity; the rated short-circuit breaking capacity will accordingly meet the requirement. If there is only the rated short-circuit breaking capacity in the product manual, the rated short-circuit making capacity may be obtained from the formula below, with the value of "n" as shown in Table 2.2.5:

Short-circuit making capacity = n × short-circuit breaking capacity.

Ratio n between short-circuit making capacity and short-circuit breaking capacity and related power factor①　　Table 2.2.5

Rated short-circuit breaking capacity I_{cn} kA r.m.s.	Power factor	Minimum value required for n
$I_{cn} \leqslant 3$	0.9	1.42
$3 < I_{cn} \leqslant 4.5$	0.8	1.47
$4.5 < I_{cn} \leqslant 6$	0.7	1.5
$6 < I_{cn} \leqslant 10$	0.5	1.7
$10 < I_{cn} \leqslant 20$	0.3	2.0
$20 < I_{cn} \leqslant 50$	0.25	2.1
$50 < I_{cn}$	0.2	2.2

(3) Rated short-time withstand current I_{cw} of a circuit breaker

To achieve short-circuit selective protection, circuit breakers with STD are often used, the rated short-time withstanding current (I_{cw}) of which is not to be less than the maximum prospective short-circuit current at the contact open instant at the point of installation, where:

① "contact open instant" means the setting time of STD. For example, if the STD time of a circuit breaker for generator protection is set as 0.4s, then its Icw is to be verified in terms of the maximum prospective symmetrical short-circuit current at main bus-bar at 0.4s;

② how to obtain the value of short-circuit current at this instant. The above 0.4s is the time interval counted after the occurrence of a short-circuit fault occurred, at which the generator is regarded as already being in a steady-state short-circuit condition. The steady-state short-circuit current may be taken as 3 times the value of the rated current of the generator, if no exact value is given.

Similarly for a circuit breaker installed at the main bus-bar or near to the main bus-bar where the circuit impedance is relatively smaller (e.g. at 25% of generator steady-state impedance), if the STD time is not less than 0.15 s, the short-circuit current may be estimated based on the steady-state short-circuit current of the generator; if the STD time is at about 0.1 s, I_{cw} can be verified by calculating the symmetrical short-circuit current at 0.1s at the installation point according to Appendix 1 to PART Four of ISC Rules for Classification of Sea-going Steel Ships;

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① From IEC 60947-2(2006), and data in lines 1 and 2 are from the old version of IEC 60947-2.

③ according to the standards referred to in 2.1, preferred values of the short-time delay associated with the circuit breaker and rated short-time withstand current are to be: 0.05 – 0.1 – 0.25 – 0.5 – 1 s. Normally 0.5 s and 1.0 s, sometimes 0.3 s, are specified by manufactures for products and are without corrective coefficients, but the real I_{cw} for MCCBs used in electrical systems of ships is much smaller, which makes it difficult to choose suitable MCCBs. Therefore, in the event that the real STD time in electrical systems of ships is less than the product given value, such as, the setting time of STD on board is 0.1 s, while the setting value for Icw given by the manufacturer is 0.3 s, 0.5 s or 1.0 s, then Icw for the circuit breaker may be verified, considering the arrangement of main generators, by calculating the short-circuit current fed by all generators which may operate in parallel (not connected in parallel) under maximum power required.

2.3 Fuse

2.3.1 Fuse and its operation principle

As aforementioned, fuse is also an over-current protective device normally used in electrical systems in ships. It is also a mechanical switching device that by the fusing of one or more of its specially 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.

Operation Principle: fuse-elements made of well designed fusible alloys are connected in series in the circuit, which have normal temperature and do not melt during normal current flow. But in case of overload or over-current, the temperature will increase till the fuse-elements melt. Fusing speed (or time) depends on the value of fault current; the higher the value, the shorter the breaking time.

2.3.2 Components of fuse and related parameters

A fuse is basically made up of fuse-base (or fuse-mount), fuse-link (with fuse-element) and terminals. Additionally it may be provided with fittings including striker and fuse indicator.

Parameters for fuse-link are rated voltage, rated current and fuse-element rated current. Parameters for fuse-base are rated voltage and rated current.

2.3.3 Time-current characteristics

Two types of time-current characteristics are: the pre-arcing or operating time-current characteristics as a function of prospective current under specified operation conditions, and the time-current zone covered by the minimum and maximum pre-arcing time-current characteristics.

Figure 2.3.3 shows the time-current zone of a certain type of fuse.

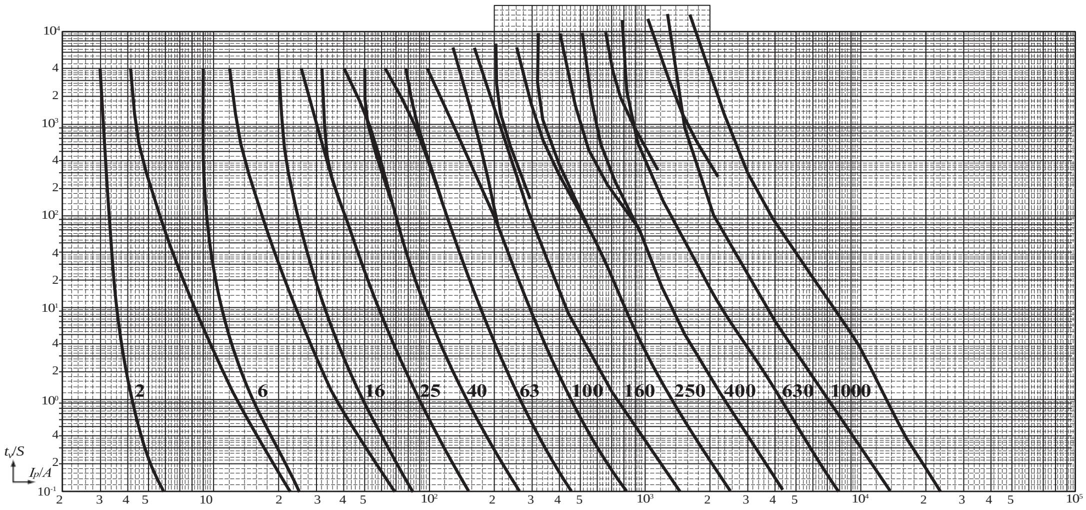


Figure 2.3.3 Time-current zone of a fuse

2.3.4 Application of fuses in ships

As aforementioned, it is clearly prescribed in ISC Rules that “adequate fuses or circuit breakers are to be deployed to provide short-circuit protection and overload protection”. In the mid- and late-20th century, fuses are widely applied in the electrical systems of ships in Western Europe due to their extraordinary advantage in over-current protection. However, fuses have drawbacks in overload protection and cause the increase of work load of the person in charge, while circuit-breakers are improved in their protection capability due to the development of modern technology of circuit-breaker manufacturing. Therefore, fuses are only used, especially in China, in emergency light circuits, extra-low voltage circuits, and additionally in control and instrument circuits.

In view of the above, circuit-breakers are mainly used in all levels of electrical distribution systems for the purpose of Chapter 3 of the Guidelines, and fuses are only used in special cases.

2.4 Differential relay

2.4.1 Operation principle

Short circuit, over-current and overload protection in ship electrical systems are all achieved by breaking the fault circuit or equipment which incurred a fault current. It is difficult to identify which level of the circuit the fault comes from due to the specialty of electrical power network in ships, but to ensure the reliable operation, the area where an accident happens is to be clearly located, and a protective device is required to operate quickly and reliably at the occurrence of a fault to its removal. In a differential protection scheme, it can be accurately identified whether a fault develops inside or outside of the protected zone by detecting all terminals from the protected equipment (such as generator stator winding terminal). Where the fault develops inside of the protected zone, the differential relay acts instantaneously to remove the fault; where the fault develops outside of the protected zone, the differential relay will never act. In this way, quick and selective protection is achieved. The principle of the differential protection lies in detecting and comparing currents amplitude and phases of all terminals. Take Figure 2.4.1 for example, it is assumed that there are n terminals from the protected equipment and the current flows through all the terminals are positive, then:

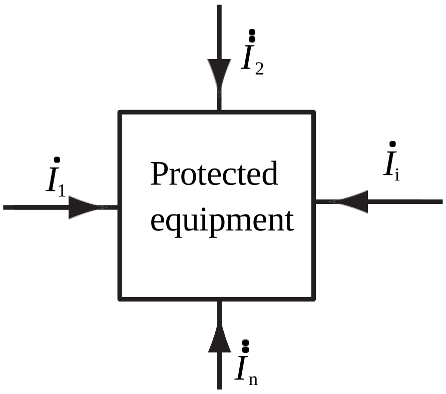


Figure 2.4.1 Principle of differential protection

No fault occurs inside the protected equipment (i.e. the equipment is in normal operation or a fault occurs outside):

$$\sum_{i=1}^{n} \dot{I}_i = 0$$

i.e. the sum of the currents flowing into the equipment equals to that of the currents flowing out of the equipment.

A short circuit fault occurs inside the protected equipment, and the short circuit point becomes a new terminal:

$$\sum_{i=1}^{n} \dot{I}_i = \dot{I}_d$$

where: $\dot{I}_d$ —— short-circuit current at the short circuit point

Currents in the main circuits must go through current transformers before into the differential relay. Assuming the current transformer ratio is n_{CT}, sum of the secondary currents in the current transformers is:

$$\sum_{i=1}^{n} \dot{I}_i \Big/ n_{CT} \geqslant 0$$

The magnetizing inrush currents in individual terminals are varied due to different working states of iron cores and different sectional length of secondary side connecting wires of current transformers at each terminal. This difference in magnetizing inrush currents then results in non-balance currents in a steady state and transient non-balance currents in case of an outside fault.

Where a short circuit occurs inside the protected equipment, sum of the secondary currents in the current transformers is:

$$\sum_{i=1}^{n} \dot{I}_i \Big/ n_{CT} = \dot{I}_d \Big/ n_{CT}$$

Normally the value $\dot{I}_d$ is so big that the differential relay can sensitively and quickly act.

2.4.2 Percentage differential relay

As aforementioned, $\sum \dot{I} / n_{CT} \neq 0$ in the case of an outside short-circuit, and there exist steady-state non-balance currents and transient-state non-balance currents. To prevent mal-operation, we can set an operating current that is greater than the non-balance current, but by this means sensitivity of the relay will be reduced in case of an inside short-circuit protection. Percentage differential relays are normally employed for protection of generators and transformers.

As shown in Figure 2.4.2, a percentage differential relay for protection of generators consists of two parts: operating part and restraining part.

In a differential circuit the operating part is connected to a reactor T_1, which has a winding W_{T1} on the left side (with winding turns as W_{T1}). The differential current $\dot{I}_{T1}$ flows through the winding with the ampere turns as $\dot{I}_{T1} W_{T1}$, which is for activating the relay.

In a secondary circuit the restraining part is connected to a reactor T_2, which comprises two primary windings: W_{T21} and W_{T22} (with winding turns as W_{T21} and W_{T22} respectively). Currents $\dot{I}'_{T2}$ and $\dot{I}''_{T2}$ flow through the two windings. As shown in Figure 2.4.2, the primary ampere turns of T_2 are $\dot{I}'_2 W_{T21} - \dot{I}''_2 W_{T22}$, which is for restraining the relay.

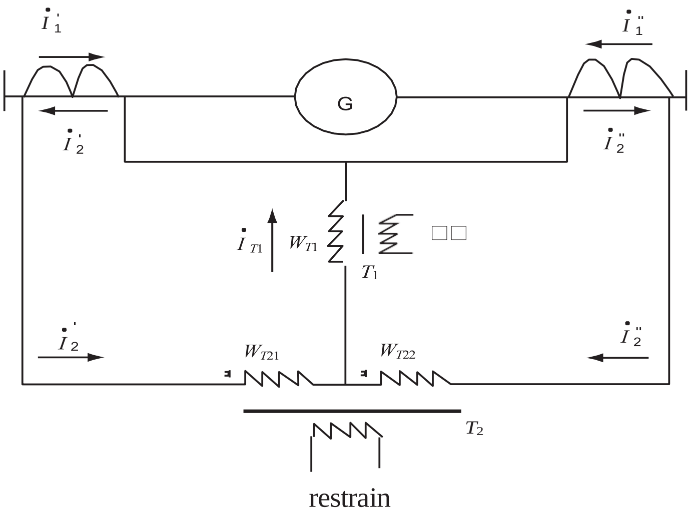


Figure 2.4.2 Percentage differential relay for Generator - Schematic

In case of a fault occurring inside or outside of the generator:

(1) A short-circuit occurs outside of the generator,

$$\dot{I}_{T1} = \dot{I}_2' + \dot{I}_2'' = \dot{I}_{in} \big/ n_{CT}$$

where: $\dot{I}_{in}$ —— short-circuit current inside the protected equipment

then, ampere turns of the operating part are $W_{T1}(\dot{I}_2' + \dot{I}_2'') = W_{T1}\dot{I}_{in} \big/ n_{CT}$;

ampere turns of the restraining part are $\dot{I}'_2 W_{T21} - \dot{I}''_2 W_{T22}$.

If $W_{T21} = W_{T22} = 0.5W_{T1}$,

then ampere turns of the restraining part equal to $0.5W_{T1}(\dot{I}_2' - \dot{I}_2'')$.

Here the value of ampere turns of the operating part is far greater than that of the restraining part, so the differential relay operates well and the operating current is proportional to the short-circuit current inside the protected equipment.

(2) A short-circuit occurs outside of the generator,

if $\dot{I}_1'' = -\dot{I}_1'$, then $\dot{I}_2'' \approx -\dot{I}_2'$,

then ampere turns of the operating part are $W_{T1}\dot{I}_{T1} = W_{T1}(\dot{I}_2' + \dot{I}_2'') \approx 0$.

and ampere turns of the restraining part are

$$0.5W_{T1}(\dot{I}_2' - \dot{I}_2'') = 0.5W_{T1} \times 2\dot{I}_2' = W_{T1}\dot{I}_2' = W_{T1}\dot{I}_{out} \big/ n_{CT}.$$

where: $\dot{I}_{out}$ —— short-circuit current outside of the protected equipment

Obviously the value of ampere turns of the restraining part are far greater than that of the operating part, so the differential relay does not act. Also the restraining current is proportional to the short-circuit current outside of the protected equipment. This operational mechanism is called percentage restraint.

2.4.3 Choice of current transformers for differential relays

Operation of a differential relay has relevance to the properties of the current transformers used, of which the nonlinear iron core (saturation) has special relevance. During the whole transient state of an outside short-circuit it is impossible that an iron core always works in the linear zone, but its is possible to limit the errors caused by nonlinearity within the permitted range (normally not more than 10％) by means of various methods.

Manufacturers of differential relays are responsible for guarantee the properties of current transformers in practice.

2.4.4 Choice and setting of differential relays

(1) Differential protection of generators

① Differential protection without restraint

The minimum operating current $I_{G.\min}$ of the differential relay is to be greater than the maximum non-balance current $I_{unb.\max}$ in an outside short-circuit, i.e.

$$I_{G.\min} > I_{unb.\max}$$

Iunb.max may be obtained from the following formula:

$$I_{unb.\max} = K_{B1} K_{B2} K_{B3} K_{\Delta} I_{out.\max} / n_{CT}$$

where: $I_{out.\max}$ —— maximum outside short-circuit (symmetrical short-circuit current);

K_{B1} —— reliable coefficient, normally $K_{B1} \approx 1.3$;

K_{B2} —— direct current component, normally $K_{B2} \approx 1 \sim 1.4$;

K_{B3} —— isomorphic coefficient of current transformers at both sides, $K_{B3} = 0.5$;

K_{Δ} —— error coefficient of current transformer secondary loaded impedance, $K_{\Delta} \approx 0.1$.

② Differential protection with restraint

The minimum operating current $I_{G.\min}$ of a differential relay is to be greater than the maximum non-balance current of the generator in normal operation. In practice, $I_{G.\min}$ can be obtained from the following formula:

$$I_{G.\min} = (0.1 \sim 0.3)\, I_{nG} / n_{CT}$$

where: n_{CT} —— current transformer ratio;

I_{nG} —— generator rated current.

③ Differential protection sensitivity coefficient

Considering the difficult in analyzing the excitation system of a generator during single-unit operation and synchronous operation in parallel, differential protection sensitivity coefficient K_n may be obtained from the following formula:

$$K_n = I_{K2} /(n_{CT} I_{G.\max})$$

where: I_{K2} —— generator short-circuit current during two-phase operation;

$I_{G.\max}$ —— maximum operating current of a differential relay.

Value of K_n is not to be less than 2.

(2) Differential protection of transformers

Transformers of large capacity may be differentially protected if needed by the system protection, and percentage differential relays are recommended.

The minimum operating current $I_{T.\min}$ of the differential relay may be obtained from the following formula:

$$I_{T.\min} = (0.1 \sim 1) I_{nT} / n_{CT}$$

where: I_{nT} —— transformer rated current

Normally check of the sensitivity is not required.

CHAPTER 3 SELECTIVE OVERCURRENT PROTECTION IN ELECTRICAL SYSTEMS

3.1 General requirements

3.1.1 Selective overload protection and selective short-circuit protection

Selective over-current protection in an electrical system comprises selective overload protection and selective short-circuit protection. In the electrical systems in ships, rating of the protection devices at a upstream feeder are normally several times that downstream, except for extremely large loads such as thrusters of a capacity matching that of one or more main generators for which provisions are needed for guaranteeing a safe power supply. Practice shows that selective overload protection may be achieved by means of circuit-breakers provided that ratio of the rated current of over-current release upstream to that downstream is more than 1.6, or by means of fuses provided that the rated current of the fuse upstream is more than two times that downstream. Selective overload protection may also be provided by other protective devices. In view of the above-mentioned, only selective short-circuit protection is discussed below.

3.1.2 Selective short-circuit protection

(1) General

According to ISC rules, the following are to be complied with for achieving a selective short-circuit protection:

① except for duplicate essential services which have automatic changing functions and are supplied by different distribution boards, short-circuit protection of all the circuits connecting essential services (i.e. the whole length of the circuits connecting the source of power supply to the essential services) is to be of a selective nature. Among them, selective protection for circuits connecting the primary essential services are to be completely achieved, and selective protection for circuits connecting the secondary essential services are at least to be partially achieved;

② where a selective protection is ensured, the fault circuit is to be broken as soon as possible to reduce damage to the electrical system and the hazard of fire;

③ the precondition to ensure a reliable selective short-circuit protection is that protection devices at all levels of circuits can act with adequate sensitivity, with a sensitivity coefficient not less than 1.3. Therefore, where the power is supplied by a single set of smallest generator, the short-circuit current is to be calculated at the end of the protected circuits connecting essential services, such as for stern lights, anchor lights and bow emergency lights, for check of the protection sensitivity.

(2) Characteristics of short-circuit currents in ship electrical systems

It is known that the largest ship currently in the world is not more than 350 m in length, and most of the electrical equipment are arranged in the engine room and accommodation space. Compared with land-based electrical systems of 15 kV and below, electrical systems in ships are relatively simple, within limited area and with shorter circuits (most of the electrical equipment are close to the generator). Another characteristic of electrical systems in ships is that the main source of power supply is made up by several (normally three) sets of generators which of medium or small capacity. The number of sets changes with conditions of a ship.

Based on the aforementioned, currents caused by a short-circuit fault in electrical systems in ships are, compared with a land-based electrical system of 15 kV or below, characterized by the following three items:

① Short-circuit current relatively big in value

Where supplied by the source of power of an adequate capacity, a short-circuit current is much greater in value than the rating of the protection device at the feeder, except for a short-circuit occurring at a distance from the generator. For example, a CO_2 refrigeration compressor of a ship is directly supplied by a low-voltage main bus-bar (400 V), for which the rating of the release of the protective circuit-breaker is 16A, while the calculated value of the peak short-circuit current i_p (peak value) at the outgoing terminal is 112.4822 kA, near to 5000 times the rating of the release. Another example is a rudder frequency converter at a distance from the low-voltage main bus-bar. Where supplied by the main source of power via an emergency distribution board, the calculated value of i_p (peak value) is 21.5849 kA, which is 61 times the rating of the release of the circuit-breaker.

② Short-circuit current at the same fault point in different conditions varied except for at a distance from the generator

For the purpose of clarity, we choose some typical points from four ship types, for each point possible short-circuit currents in different conditions are calculated. The calculated ratio of the maximum symmetrical short-circuit current $I_{ac\ max}$ (when supplied by all generators connected in parallel) to the minimum symmetrical short-circuit current $I_{ac\ min}$ (when supplied by a single smallest generator) are shown in Table 3.1.2(2)a.

Electrical system short-circuit current change at the same fault point Table 3.1.2(2)a

Position of short-circuit point	A train ferry	A product oil tanker	A bulk carrier	A multi-purpose cargo ship
	4 x 2880 kW ②	3 x 750 kW	2x440 kW + 1x312 kW	3 x 292 kW
	$I_{ac\ max}/I_{ac\ min}$	$I_{ac\ max}/I_{ac\ min}$	$I_{ac\ max}/I_{ac\ min}$	$I_{ac\ max}/I_{ac\ min}$
Main bus-bar (6600 V)	3.67	-③	-	-
Main bus-bar or low-voltage main bus-bar	2.06	3.19	3.44	2.55
Emergency bus-bar	1.71	1.65	2.51	-
Terminals of other power units	No. 10 combination starting box 1.91	Steering power unit 1.28	Emergency fire pump 1.21	Main engine lubricating pump 1.56
Main lighting bus-bar	1.07	1.15	1.37	1.21
Emergency lighting bus-bar	1.04	1.07	1.21	-
Navigation light control box	1.00	-	1.02	-
Bow lighting distribution board	-	1.01	-	1.001
Stern light or fore anchor light	1.00	1.00	1.00	1.001
Forecastle light	-	1.002	1.002	1.001

Notes: ① All data are calculated in case of power supplied by the main source.
② Installed capacity of the main generator of the ship. The same below.
Ⓒ "-" in this table means that this item is unavailable for the ship or short-circuit current at this point is not calculated.

Attention is to be drawn to the term “at a distance”, which is more than a geometrical distance. More specifically, it means that the impedance of power supply in the short circuit (i.e. impedance of the generator or equivalent generator) takes up only a small portion of the total impedance (i.e. sum of the impedance of connecting cable in the circuit and the impedance of power supply), for example, 10%, or even less. Obviously, in this case change of the power supply (one or more generators) has little influence on the short-circuit current in electrical systems.

Ratio of $I_{ac\,max}$ to $I_{ac\,min}$ at the same fault point as shown in Table 3.1.2(2) clearly indicates that:

a. In the area from main bus-bar or low-voltage main bus-bar and their vicinity (e.g. large power units inside engine room) to emergency switchboard which is at a height of four decks from the main switchboard or low-voltage main switchboard, the ratio reaches 1.5 or more. For some ship, the ratio at main bus-bar or low-voltage main bus-bar exceeds 3.

b. At main lighting bus-bar and emergency lighting bus-bar, the circuit impedance (transformers are taken as circuit impedance for calculation of short-circuit current) increases due to a transformer of smaller capacity, for example of 150 kVA and below. Therefore, this ratio drops abruptly to below 1.30 and continues to decrease gradually with the increase of the distance between the main and emergency lighting bus-bars and the generator, till to 1.0, and its short-circuit current also decreases greatly, which resembles a land-based electrical system of 15 kV and below.

③ Little difference between the value of short-circuit current in a protective device upstream and that downstream

This is because electrical systems in ships are within limited area and with shorter circuits, and most of the electrical equipment are located in the engine room and accommodation space. Calculation of short-circuit currents at several typical positions are shown in Table 3.1.2(2)b.

Short-circuit currents calculation at typical positions Table 3.1.2(2)b

Ship type	A multi-purpose cargo ship		A product oil tanker		A bulk carrier	
Position	Main bus-bar	Main engine Lubricating pump	Main bus-bar	No.3 distribution board	Main bus-bar	Emergency bus-bar
Short-circuit current I_{ac} (kA)	4.014	3.13	10.87	9.74	6.35	5.47

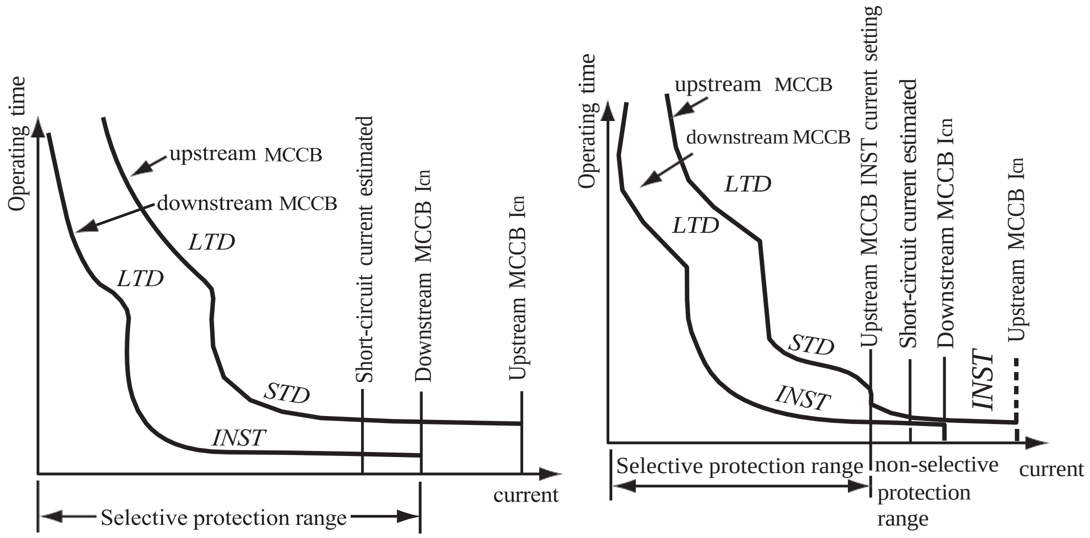
(3) Selective short-circuit protection according to the time principle

Based on the analysis of characteristics of short-circuit currents of electrical systems of ships, and considering short-circuit protection properties of circuit-breakers widely used in ships (see 2.2 of Chapter 2), we can come to the conclusion that a selective short-circuit protection is to be achieved by delaying the break time of protective device close to the power supply (i.e. time principle), except for the areas where reflex tripping or cascade protection may be employed, some certain circuits such as circuits connecting the main bus-bar and individual generators, and the areas at a distance from generators. For electrical systems in ships which are not complicated, this time-delaying scheme is really reliable and simple in design and construction. Under this circumstance, a selective short-circuit protection will be achieved provided:

① among all switching devices for short-circuit protection (hereinafter referred to as short-circuit protective device), the rated service short-circuit breaking capacity of circuit breakers with instantaneous trip unit for relevant circuits of essential services is to be higher than the maximum prospective short-circuit current at the point of installation. The rated short-time withstanding current of short time delay circuit breakers with short time delay trip unit is to be higher than the maximum prospective short-circuit current at the point of installation at the instant when the arcing contacts have separated;

② break (fuse) time of any upstream protective device is to be longer than that of the protective device at the downstream circuit. For example, if both the upstream and downstream fuses are of the same type and made by the same manufacturer, the upstream fuse rating is to be two times or more the downstream fuse rating. Where circuit breakers are used, the breaker at an upstream circuit normally provides specified-time STD protection, and its resettable time is higher than the full break time of the breaker downstream to it. The time-current characteristic curve of two-level protection devices, drawn in the same sheet, should not be close to or intersect with each other, as shown in Figure 3.1.2(3).
It is to be noted that the resettable time for STD protection by circuit breakers is to be taken into account in reviewing documents related to electrical system protection coordination analysis;

③ during the period of time for breaking fault circuits based on discrimination, elements including short-circuit protective devices, bus-bars, isolating switches, terminals and cables are all to have good thermal stability.



a) complete selective protection achieved　　b) partial selective protection achieved

Figure 3.1.2(3) How selective protection is achieved

(4) Selective short-circuit protection achieved by reflex tripping

As described in 2.2.4(4) of the Guidelines, there is a type of MCCB with a unique double rotary contacts system (see Figure 3.1.2(4)a), which performs better in limiting current. When the short-circuit current is 25 times the frame size or more, the double rotary contacts open to limit currents, meanwhile, strong air pressure produced by special composite material on the rotary contacts causes the MCCB to fast trip. With the change of short-circuit current, the tripping time changes in an inverse-time curve, and the greater the frame size, the longer the tripping time, provided the short current is unchanged, as shown in Figure 3.1.2(4)b. According to the test, a total discrimination can be achieved between the two levels provided the upstream frame size is two times that the downstream frame size or more, and the short-circuit current is 25 times the frame size or more.

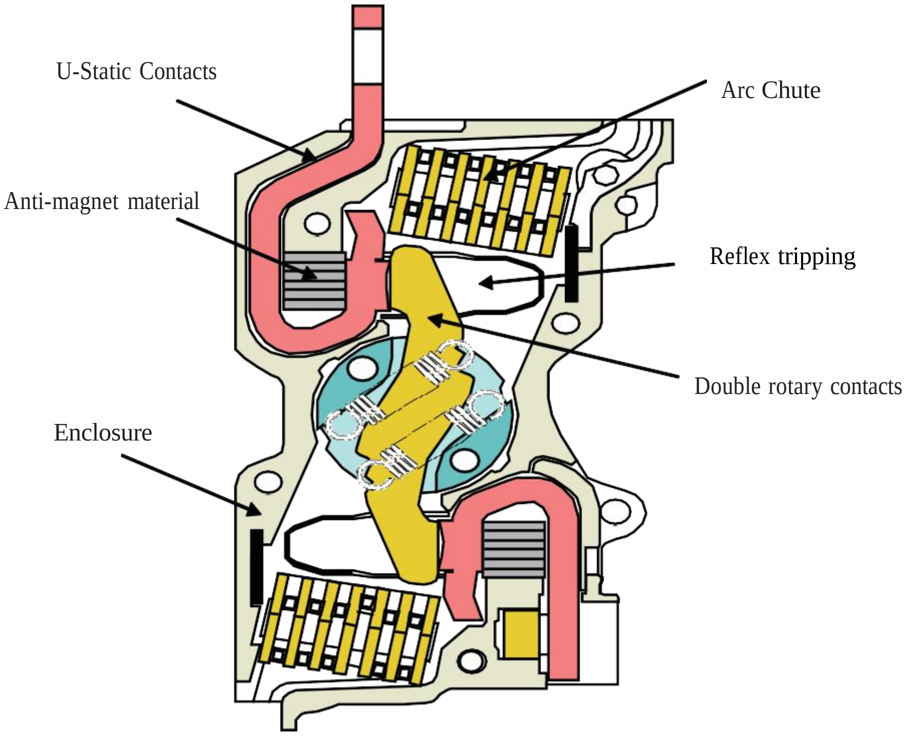


Figure 3.1.2(4)a A unique double rotary contacts system

Application of reflex tripping approach is limited because only the MCCBs from 100 A to 630 A are able to achieve reflex tripping.

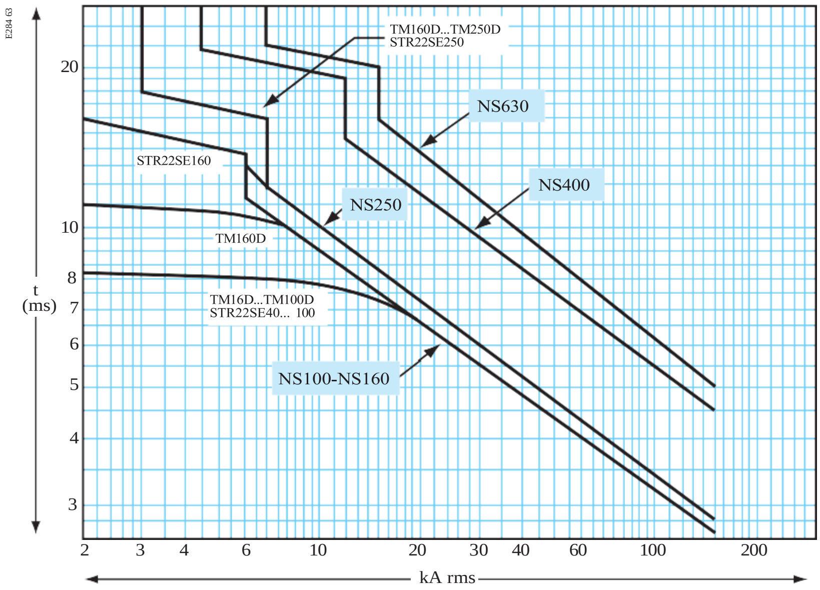


Figure 3.1.2(4)b A circuit breaker time-current characteristic curve in reflex tripping zone

The way to achieve selective short-circuit protection is elaborated as follows, starting form generators.

3.2 Selective short-circuit protection among main generators and between main generators and their downstream devices①

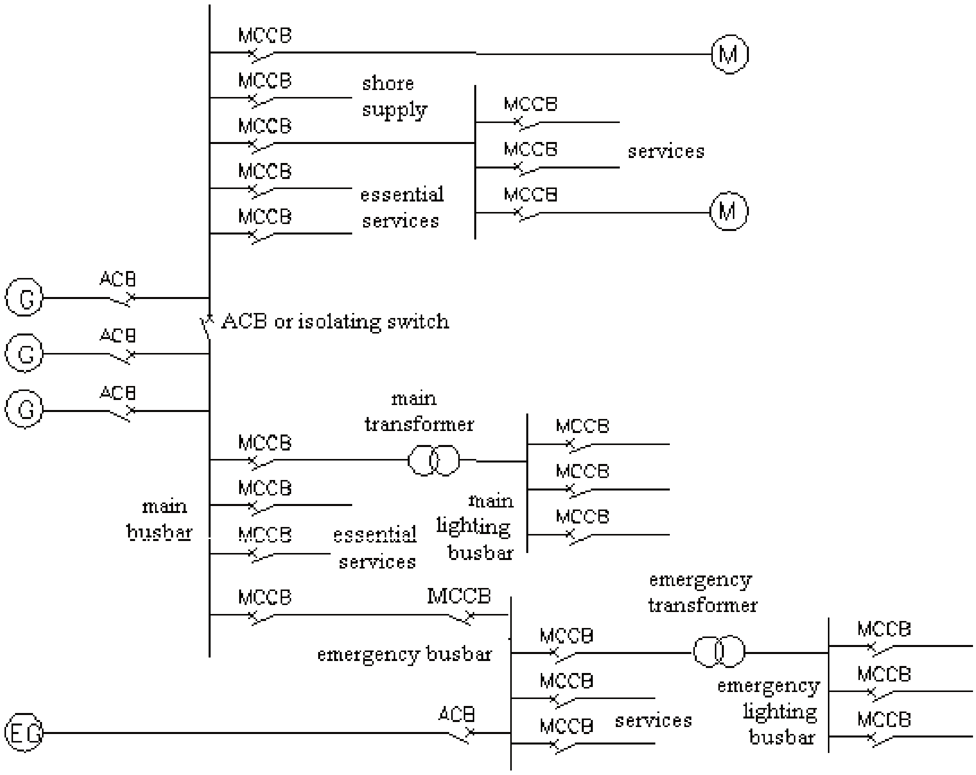
3.2.1 Among main generators

For the purpose of clarity, a schematic of a typical ship electrical system (single line) is given in Figure 3.2.1.

As aforementioned, there may be occasions in ships when several main generators operate in parallel. It is specified in ISC Rules that in case of three generators or more connected in parallel, selective short-circuit protection is to be achieved among them by either of the two ways:

(1) INST protection by circuit breakers

Where a short-circuit fault evolves between any of the generators (or inside the generator) in parallel and its protective circuit breaker, in circuit breakers protecting the non-fault generators there come only short-circuit currents sent by the non-fault generators, while in the circuit breaker of the fault generator there come not only short-circuit currents from all the other generators, but that from all the operating motors. Therefore selective protection can be achieved only when power is supplied by three generators or more connected in parallel.



where: G - main generator EG - emergency generator M - motor
ACB - air circuit breaker MCCB - moulded case circuit breaker

Figure 3.2.1 An electrical system onboard - schematic

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① "Among main generators and between main generators and their downstream devices" means among main generator circuit breakers, and between main generator circuit breakers and all protective devices downstream to them in electrical systems.

The following are to be satisfied for INST protection setting:

① circuit breakers do not operate when a short circuit occurs at main bus-bar or at a distance from main bus-bar;

② when a short circuit occurs between a generator and its circuit breaker, the circuit breaker protecting this fault generator acts instantaneously, while circuit breakers protecting non-fault generators do not operate;

③ where the requirements of ② have been complied with, current transformer magnetic saturation, operation errors and impedance at the fault point are to be taken into consideration, and an efficient action is to be ensured.

Based on the above, INST protection current setting I_i is calculated as follows:

$$I_i = (1.2 \sim 1.3) i_{pg} \big/ \sqrt{2}$$

where: i_{pg} —— maximum peak short-circuit current.

(2) Protection by an instantaneous or short time delaying (e.g. 50 ms) differential relay

Differential relays are employed for protection of generators in case of an inside fault (see for details 2.1 of the Guidelines), which may also provide selective protection between generators. For generators already having differential relays for inside fault protection, the aforementioned circuit breakers for INST protection are not necessary.

Principle of differential protective relays is described in 2.4 of the Guidelines.

3.2.2 Between main generators and their downstream devices

In normal electrical systems in ships, downstream to main generators there are main bus tie breaker(if provided with over-current release), and protective devices located at feeders from main bus-bars, emergency bus-bars (if fitted), electrical distribution boards(group starter panels), main lighting bus-bars, and emergency lighting bus-bars, which provide multi-levels of protection. Where power is supplied by a public power station which also supplies electrical propulsion units or where there is an A.C. high-voltage electrical system, two or three more levels of protection are to be added as there is a transformer transforming high voltage to 400 V. (see Appendix A).

Compared to the downstream protection, protection of main generators is of top priority, which affects continuous power supply of a ship. For this purpose, it is clearly prescribed in ISC Rules that except for generators less than 50 kW (or kVA) and not arranged to operate in parallel, for which fuses are used for protection, generators are to be STD protected against short circuit by circuit breakers, and “for over-current in excess of 50% but less than the steady short-circuit current of the generator, instantaneous tripping after a short-time delay is to be coordinated with the discriminative protection of the system”.

The following are to be taken into consideration in setting the STD current and time:

(1) generator steady short-circuit current. According to China national standards and ISC Rules, steady short-circuit current of an A.C. generator is to be at least three times its rated current. The STD current setting is to be determined according to the minimum possible steady short-circuit current, i.e., three times the rated current of the generator;

(2) maloperation is not allowed during starting of motors of large capacity;

(3) operation error in STD protection is normally taken as 15%;

(4) backup protection for the downstream devices.

From a comprehensive consideration, it is recommended that the pick-up current for STD protection be set at 200% to 250% of the rated current of generator. Setting of the delay time is to be coordinated with the downstream protective devices (i.e. to comply with 3.1.2(3)② of the Guidelines). Normally the delay time is not to be longer than 0.6 s (0.2 s for D.C. generators);

3.3 Selective short-circuit protection between main bus-bar and emergency bus-bar, between main bus-bar and its downstream devices, and between emergency bus-bar and its downstream devices①

3.3.1 Between main bus-bar and emergency bus-bar and protection devices for services supplied from emergency bus-bar

Where power is supplied by the main source of power, an emergency bus-bar supplies primary essential services including fire pumps, other extinguishing agent pumps, navigation aids and internal safety communication equipment, for which selective short-circuit protection is to be achieved completely.

The feeder connecting main bus-bar and emergency bus-bar (hereinafter referred to as MSB-ESB feeder) may be protected by the circuit breaker with STD against short circuit, and if a main bus-bar tie breaker with over-current release is provided, STD are to be used (INST protection may be chosen provided requirements for a complete selective short-circuit protection are satisfied). Four coefficients are to be considered in setting STD current and time the same way as that described in 3.2.2 for these circuit breakers are close to generators.

STD current setting of the main bus-bar tie breaker is, in principle, the same as current setting of a single generator connected to the main bar. However, if the main power station has four or more generators connecting in parallel, the current setting is to be determined according to the number of generators actually put into operation, which prevents maloperation or non-operation in normal conditions. Its STD time is to be less than that of the circuit breaker of the generator connected to it, and to be coordinated with that of the downstream circuit breaker, namely, to comply with the requirements of 3.1.2(3)② of the Guidelines.

It is recommended that STD current setting of the MSB-ESB feeder be taken as four to six times the LTD current setting I_r (or the rated release current), but not be higher than single generator steady short-circuit current setting. The setting value of delay time is to be coordinated with the generator circuit breaker and the upstream main bus tie breaker (if provided with over-current release) upstream, with the emergency power supply and lighting transformer downstream, and with protective devices downstream to the emergency power supply and lighting transformer. 3.1.2(3)② of the Guidelines is to be satisfied.

According to ISC Rules, the MSB-ESB feeder is to be disconnected automatically from the emergency distribution board upon failure of the main source of power. Therefore, a MCCB is normally fitted at one end of the feeder to which the emergency bus-bar is connected. This MCCB is only for breaking the circuit and does not provide over-current protection. However, if over-current protection is provided, this protection is to be selective and between the MCCB of feeder at the main bus-bar end and all downstream protective devices, provided main power supply is not affected.

3.3.2 Between main bus-bar and electrical distribution board (or group starter panel) and between distribution board and their feeders' devices

If an electrical distribution board (or group starter panel) supplies essential services which cannot automatically change over to other services and continue to work in case of failure, selective protection is to be provided to the same requirements as described in 3.3.1.

3.4 Selective short-circuit protection between primary sides of power and lighting transformers and lighting bus-bars

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① "Between main bus-bar and emergency bus-bar" means between main bus feeder protective devices and emergency feeder protective devices. The same hereinafter.

3.4.1 Between primary sides of main power and lighting transformers and main lighting bus-bar

It is required by ISC Rules that short-circuit protection of power and lighting transformers is to be provided at their primary circuits. As a transformer supplies the essential services including navigation lights, navigation aids, signals and lighting system, it is necessary to provide selective short-circuit protection for its primary and secondary circuits by means of any of the four alternatives①.

(1) MCCB used in transformer primary side, providing LTD protection against overload and STD protection against short current

In this alternative, the MCCB only includes LTD and STD function, and should not include INST function. Magnetizing inrush current incurred by connecting the transformer under no load conditions is to be taken into account in setting STD protection. It is known from related information that the magnetizing inrush current is about 20 to 25 times the rated current at 0.01s, but it drops quickly with the time. The current setting may be taken as 6 to 10 times the rated current of transformer. The setting time is normally not less than 0.1s, and is to be coordinated with its upstream STD protection (normally for generators) and its downstream MCCB short-circuit protection. Requirements of 3.1.2(3)② of the Guidelines are to be complied with.

This alternative is simple and reliable. The rated current is normally 200 A or lesser because power and lighting transformers used in ships are normally of small capacity. There is a strict requirement for rated short-time withstanding current of the MCCB as it is located at main bus-bar. Limited by manufacturing techniques of MCCBs, it is difficult to find a suitable type of MCCB for a main generator in a ship with the total capacity of 1000 kW and over. However, for a large power transformer with capacity of 500 kVA and over it is a good choice (see Appendix A).

(2) Three-section MCCB used at transformer primary side for short-circuit and overload protection

Recently an electrical company has introduced a type of MCCB which has high instantaneous value and aims to provide three sections of protection for power and lighting transformers. It provides LTD protection against overload and STD and INST protection against short circuit, of which INST protection is provided by fixed magnetic release with high instantaneous value.

Compared with the above (1), the difference is that this alternative includes an additional INST protection obviously. Therefore, the INST protection is to satisfy the following requirements provided STD is set in compliance with the above (1), so as to achieve a complete selective short-circuit protection between this MCCB and its downstream MCCB.

① $I_i > i_{inrush} / \sqrt{2}$

where: I_i —— MCCB instantaneous value (root-mean-square value);
i_{inrush} —— magnetizing inrush current at transformer primary side (peak value).

② $I_i > 1.2\left(U_{n2}/U_{n1}\right) \cdot i_{plb} / \sqrt{2}$

where: U_{n1} —— rated voltage of transformer primary side;
U_{n2} —— rated voltage at transformer secondary side;
i_{plb} —— max. peak short-circuit current of main or emergency lighting bus-bar.

③ $I_i \leqslant I_{cw}$

where: I_{cw} —— MCCB rated short-time withstand current.

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① Other feasible alternatives may also be accepted.

It is to be noted that where a MCCB with thermal magnetic release is fitted at transformer primary side providing only LTD and INST protection, a completed selective protection cannot be achieved between primary side and the lighting bus-bar, though the manufacturer may accept orders for products of high instantaneous value.

(3) MCCBs with reflex tripping feature used at both transformer primary and secondary sides

As described in 3.1.2(4), MCCBs with reflex tripping feature used at both primary and secondary sides can provide selective short-circuit protection for both sides, provided:

① symmetrical short-circuit current at transformer secondary side is 25 times greater than the frame size current of its MCCB;

② ratio of MCCB frame size current at transformer primary side to that at the secondary side is more than 2.

The following are to be considered in determining the MCCB frame size current at the primary side:

a. no maloperation of the MCCB under the magnetizing inrush current incurred by connecting the transformer under no load conditions;

b. no INST protection acted when a short-circuit fault occurs at main or emergency lighting bus-bar.

(4) Transformer primary side protected by fuse against short circuit and only LTD protection is provided by the MCCB against overload

This is an economical alternative. It is specified in ISC Rules that “The primary windings of power and lighting transformers are to be protected against short-circuit and overload by multi-pole circuit-breakers or fuses.” The problem is how to choose a suitable fuse to achieve short-circuit protection for transformers, also the following two problems are to be solved:

① How to avoid magnetizing inrush currents incurred by connecting the transformer under no load conditions

Fuses fitted with aM-type fuse-links (for protecting motor circuits) or gG-type fuse-links that can withstand motor starting current are to be chosen. Rating of fuse-links may be raised as they are used for short-circuit protection only, which may be, according to the known information, taken as 130% to 150% of the protected transformer rated current, and may also, where necessary, be 180% of the protected transformer rated current provided the requirements of ② below are complied with.

② How to coordinate fusing of the upstream and downstream protective devices

Normally the upstream protective device is a main generator ACB with STD, which allows maximum 0.3 s to 0.4 s for its adjacent downstream device to achieve protection. Where the downstream protective device is a transformer MCCB, INST function is normally chosen; where it is a transformer fuse, the requirements of 3.1.2(3)② are to be complied with. In this way, coordination between the up and downstream protective devices are achieved.

Besides, some lighting may be lost or some important equipment including navigation aids are not operable due to melting of a single or several fuse(s). In case of this situation, it is necessary to give an indication (some fuses have this function) or/and alarm to the operating personnel for repairing timely.

To sum up, this is an economical and reliable solution for power and lighting transformers of smaller capacity (e.g. of 40 kVA and below).

3.4.2 Between primary circuits of emergency power and lighting transformers and emergency lighting bus-bar

During normal service, emergency power and lighting transformers, powered by the main source of power, are required to be in operation, and therefore selective protection is also needed between primary circuits of emergency power and lighting transformers and emergency lighting bus-bar. This is similar to the protection between primary sides of main power and lighting transformers and main lighting bus-bar. The difference is that there is an additional protection of feeders between main bus-bar and emergency bus-bar, and emergency power and lighting transformers are of smaller capacity. Therefore, the four alternatives for protection coordination given by 3.4.1 of the Guidelines are all acceptable, and are compared as follows:

① where the alternative 3.4.1(1) is applied, it is more difficult to choose a suitable type of circuit-breaker at transformer primary circuits;

② alternatives 3.4.1(2) and 3.4.1(3) are both better ones, provided the requirements for achieving respectively such alternatives are complied with;

③ where the transformer is of smaller capacity, alternative 3.4.1(4) is feasible.

3.5 Selective short-circuit protection between main or emergency lighting bus-bar and its adjacent downstream devices

Up to now, only the protection between main or emergency lighting bus-bar and main or emergency lighting distribution board or between main or emergency lighting bus-bar and distribution boards of other services are left unmentioned. It has been concluded from the analysis of features of short-circuit currents in an electrical system that short-circuit current change of this part is similar to the land-based electrical system of 15 kV and below. Therefore, information on protection coordination given by circuit-breaker manufacturers are applicable, but it is to be noted that individual protective devices are to be so set that sensitivity of the devices are maintained with a sensitivity coefficient normally not less than 1.3.

3.6 Selective short-circuit protection between emergency generator and its downstream devices

3.6.1 Between emergency generator and its downstream devices

Selective short-circuit protection is also necessary in the case of power supplied by the emergency generator. Primarily, there is protection between emergency generator and emergency bus-bar, which is similar to that between main generators and their downstream devices which are specified in 3.2.2 of the Guidelines, except for the difference that there are less levels. Starting from the emergency generator, there are protective devices at feeders from, in sequence, emergency bus-bar, emergency lighting bus-bar, emergency lighting distribution board or distribution board for other equipment.

Therefore, the STD current of emergency generator may be set according to the same requirements for generator circuit breakers. The STD time may be taken as about 0.3 s, depending on the practical situation, and coordination with the downstream protective devices is to be taken into account.

INST protection is not to be provided by the circuit breaker protecting emergency generator①.

3.6.2 Between primary circuits of emergency power and lighting transformers and emergency lighting bus-bar

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① Unless the INST setting value of the circuit breaker satisfies the following:

$$I_i > 1.2 i_{pgE} \big/ \sqrt{2}$$

where: I_i —— circuit breaker instantaneous current;

i_{pgE} ——max. peak short-circuit current at emergency generator end, i.e., instantaneous protection cannot be achieved.

Short-circuit protection in this regard has actually been described in 3.4.2 of the Guidelines, and the only difference is that power is supplied by main generators in 3.4.2 while here is supplied by an emergency generator. So it is only need to ensure the coordination between protective devices in the transformer primary circuits and the STD protection for emergency generators.

3.6.3 Between emergency lighting bus-bar and its adjacent downstream devices

Selective short-circuit protection in this regard is similar to that described in 3.5 of the Guidelines, which can be achieved by designing according to the information on protection coordination by circuit breaker manufacturers. Same as specified in 3.5 of the Guidelines, it is to be noted that protective devices are to be so set that sensitivity of the devices are maintained.

3.7 Ground fault current selective protection

Sometimes three-phase A.C. electrical systems with the neutral point being earthed are employed in ships, especially that of high voltage and the neutral point of that is connected to earth through a high impedance. In such a case, ground fault current may develop and its selective protection is to be considered. Normally circuit breakers with ground fault protection are fitted in relevant parts of the electrical systems for protection against ground fault current. Their current setting is to be determined according to the practical situations of the electrical systems. Their STD time is to be set according to the G protection setting range of the chosen circuit breaker and also according to the requirements of 3.1.2(3)② of the Guidelines.

Appendix A Electrical System Selective Over-current Protection Coordination Analysis Example 1

A.1 Brief introduction of the electrical system①

This example is based on the electrical system of a domestic train ferry, the system protection of which has been modified according to the requirements of the Guidelines.

The ship is propelled by A.C. electrical power system at voltage of 6600 V and is provided with public power station, which comprises of four sets of 6600 V/2880 kW generators. Power disposition in different conditions are:

for sea-going condition: four generators;
for arrival/departure condition: two generators;
for loading/unloading condition: one generator.

The ship is also equipped with two power transformers of AC6600/400 V, 3ϕ and 2200 kVA, and one emergency generator of AC400 V and 400 kW, supplying equipment up to 380 V onboard.

There are two high-voltage main distribution boards: No.1 and No.2 distribution boards, connected by a high-voltage circuit breaker providing STD protection. Low-voltage main bus-bar of 400 V is separated by a bus tie breaker without release.

Diagram of the electrical power system is shown in Figure A.1.

A.2 General

Maximum and minimum short-circuit currents that may occur at each level of protective devices provide the basis for coordination analysis of an electrical system. For the purpose of coordination analysis, fault points relating to this electrical system are calculated with the results listed in Table A.2.

Fault point short-circuit current value **Table A.2**

Fault point		Max. short-circuit current, in kA		Min. short-circuit current, in kA	
No.	Position	i_p	I_{ac}	i_p	I_{ac}
B	Main bus-bar(high-voltage)	20.65	7.29	5.52	1.99
C1	Low-voltage main bus-bar	112.48	50.90	58.90	24.66
C2	Emergency bus-bar	56.74	35.84	37.96	20.94
D2	Main lighting bus-bar	6.08 / 10.53①	4.05 / 7.02	5.78 / 10.02	3.80 / 6.59
D3	Emergency lighting bus-bar	4.17 / 7.22	2.84 / 4.92	4.03 / 6.98	2.72 / 4.72
F	Stern light(one of the navigation lights)	0.03 / 0.06	0.02 / 0.04	0.03 / 0.06	0.02 / 0.04
Note: ① Two data are given here: the former is the short-circuit current at transformer primary side, and the latter is the short-circuit current at transformer secondary side.					

Arrangements and settings of all levels of protective devices in the electrical system are shown in A.3. Coordination analysis and time-current characteristic curves of all levels of protective devices as well as sensitivity check of some short-circuit protective devices are given in A.4.

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① This part need not be covered when a complete set of electrical drawings required by ISC Rules are submitted for approval.

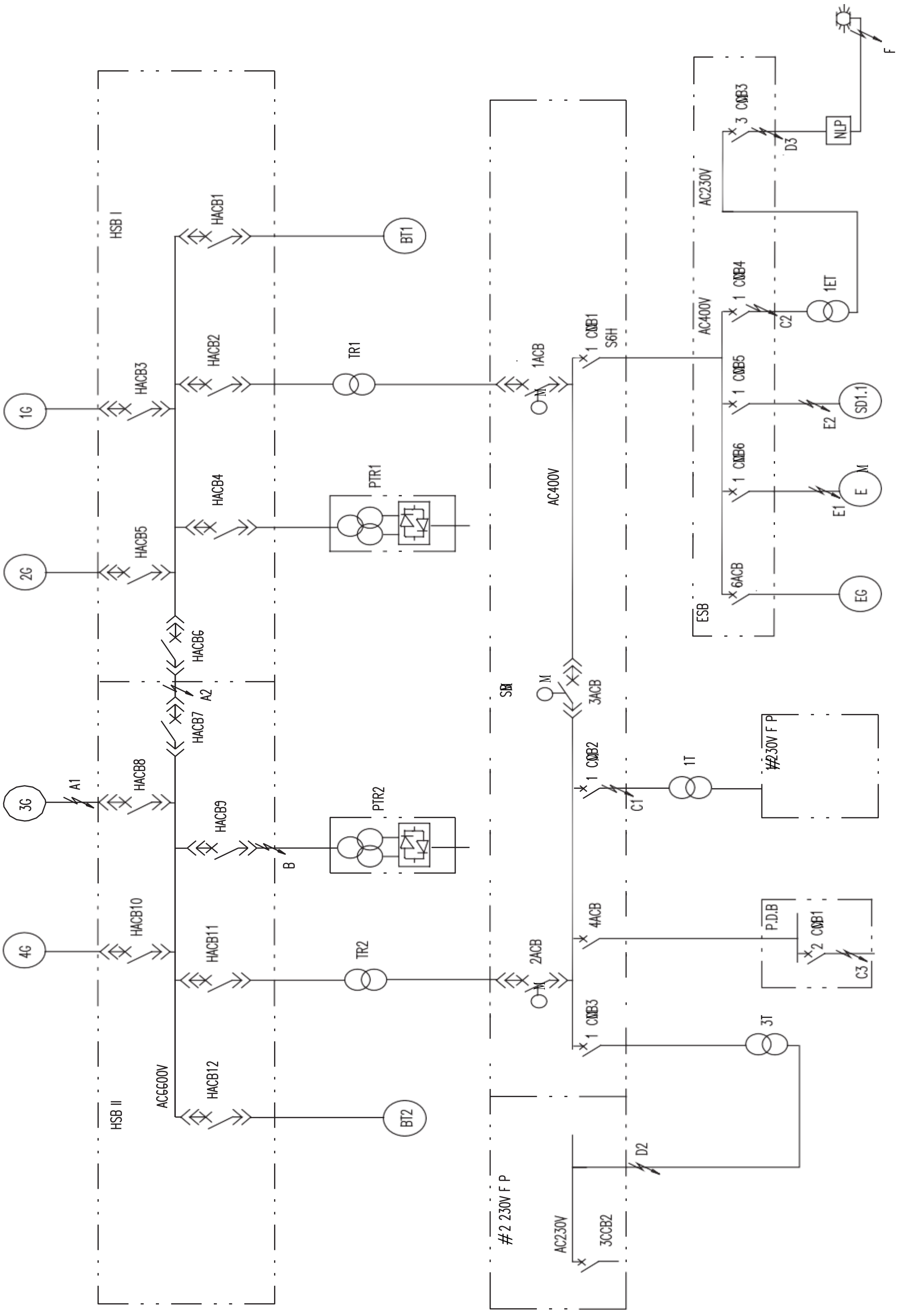

Figure A.1 Diagram of the Electrical System

A.3 Arrangements and settings of all levels of protective devices in the electrical system

Details are given in Table A.3a through Table A.3j.

Main generator circuit breaker and differential protective relay **Table A.3a**

Equipment/feeder			Protective device						Remarks
Code	Name	Rated value (A)	manufacturer/ type①	Frame size (A)	Release/current transformer rated current (A)	Protection type	Setting ranges	Set value	
1G 2G 3G 4G	No.1 generator No.2 generator No.3 generator No.4 generator	296	XXXX	1250		LTD	$I_r = 0.1 \sim 10I_n$	$I_r = 1.50\ I_n = 444\text{A}$	Only LTD and STD protection is provided by circuit breaker, and in case of a fault inside generator, differential relay will operate to cause instant release of circuit breaker.
							$t_r = 0.1 \sim 120\text{s}$	$t_r = 55\text{s}$	
						STD	$I_{sd} = 0.1 \sim 10\ I_n$	$I_{sd} = 2.5\ I_n = 740\text{A}$	
							$t_{sd} = 0.1 \sim 3.0\text{s}$	$t_{sd} = 0.6\text{s}$	
			XXXX	Differential protective relay		INST	$I_{INST} = (0.5 \sim 50)\%\ I_n$	$I_{INST} = 15\%\ I_n = 44\text{A}$	For protection against faults inside generators.

Circuit breaker connecting No.1 and No.2 high-voltage distribution boards **Table A.3b**

Equipment/feeder			Circuit breaker						Remarks
Code	Name	Rated value (A)	manufacturer/ type	Frame size (A)	Release/current transformer rated current (A)	Protection type	Setting ranges	Set value	
TB	Connecting circuit breaker	695	XXXX	1250		-	-	-	Only STD protection is provided by circuit breaker. I_{sd1} is set for operation of three or four generators. I_{sd2} is set for operation of one generator for No.1 and No.2 distribution board each.
							-	-	
						STD	$I_{sd} = 0.05 \sim 40\ I_n$	$I_{sd1} = 2.2I_n = 1529\text{A}$ $I_{sd2} = 1.1I_n = 765\text{A}$	
							$t_{sd} = 0.1 \sim 3.0\text{s}$	$t_{sd}\text{=0.4s}$	

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① Although manufacturer/type of protective device is indicated neither here nor in the following tables, it is to be indicated in drawings submitted for approval.

Bow thruster circuit breaker

Table A.3c

Equipment/feeder			Circuit breaker						Remarks
Code	Name	Rated value (A)	manufacturer/ type	Frame size (A)	Release/current transformer rated current (A)	Protection type	Setting ranges	Set value	
BT1	No.1 bow thruster	74	XXXX	1250		LTD	$I_r = 0.1 \sim 10 I_n$	$I_r = 1.85\ I_n = 137$A	INST protection is not provided by circuit breaker.
							$t_r = 0.1 \sim 120$s	$t_r = 99$s	
BT2	No.2 bow thruster					STD	$I_{sd} = 0.05 \sim 5\ I_n$	$I_{sd} = 3.0\ I_n = 222$A①	
							$t_{sd} = 0.1 \sim 3.0$s	$t_{sd} = 0.2$s①	

Note: ① During the starting process of thrusters motor, set value is automatically changed to: I_{sd}= 450A, t_{sd}= 3.0s.

Propulsion transformer primary side circuit breaker and differential protective relay

Table A.3d

Equipment/feeder			Protective device						Remarks
Code	Name	Rated value (A)	manufacturer/ type	Frame size (A)	Release/current transformer rated current (A)	Protection type	Setting ranges	Set value	
PTR1	No.1 propulsion transformer	455	XXXX	1250		LTD	$I_r = 0.1 \sim 10 I_n$	$I_r = 1.45 I_n = 660$A	Only LTD and STD protection is provided by circuit breaker, and in case of a fault inside transformer, differential relay will operate to cause instant release of circuit breaker.
							$t_r = 0.1 \sim 120$s	$t_r = 95$s	
						STD	$I_{sd} = 0.1 \sim 5\ I_n$	$I_{sd} = 2.2\ I_n = 1001$A	
							$t_{sd} = 0.1 \sim 3.0$s	$t_{sd} = 0.2$s	
PTR2	No.2 propulsion transformer		XXXX	Differential protective relay		INST	$I_{INST} = (0.5 \sim 50)\%\ I_n$	$I_{INST} = 20\%\ I_n = 91$A	For protection against faults inside transformers.

6600 V/400 V distribution transformer primary side circuit breaker and differential protective relay **Table A.3e**

Equipment/feeder			Protective device						Remarks
Code	Name	Rated value (A)	manufacturer/ type	Frame size (A)	Release/current transformer rated current (A)	Protection type	Setting ranges	Set value	
TR1 TR2	No.1transformer No.2 transformer	192	XXXX	1250		LTD	$I_r = 0.1 \sim 10I_n$	$I_r = 1.9I_n = 365A$	Only LTD and STD protection is provided by circuit breaker, and in case of a fault inside transformer, differential relay will operate to cause instant release of circuit breaker.
							$t_r = 0.1 \sim 120s$	$t_r = 101s$	
						STD	$I_{sd} = 0.1 \sim 5\ I_n$	$I_{sd} = 2.2\ I_n = 422A$①	
							$t_{sd} = 0.1 \sim 3.0s$	$t_{sd} = 0.3s$①	
			XXXX	Differential protective relay		INST	$I_{INST} = (0.5 \sim 50)\%\ I_n$	$I_{INST} = 20\%\ I_n = 38A$	For protection against faults inside transformers.
Note: ① Set value is automatically changed to I_{sd}= 850 A, t_{sd}= 0.75 s when magnetizing inrush current incurred by connecting the transformer under no load conditions is detected.									

Circuit breaker of feeder connecting main and emergency bus-bars **Table A.3f**

Equipment/feeder			Circuit breaker						Remarks
Code	Name	Rated value (A)	manufacturer/ type	Frame size (A)	Release/current transformer rated current (A)	Protection type	Setting ranges	Set value	
	feeder connecting main and emergency busbars	800	XXXX	1600	800	LTD	800~1000,…,1600	$I_r = 800A$	As here the requirement for I_{cw} is relatively higher, MCCB at a frame size of 1600A and with LTD and STD protection is selected.
							$t_r = 5,10,15,20,30s$	$t_r = 20s$ $(6I_r)$	
						STD	$I_{sd} = 2,4,6,8,10I_n$	$I_{sd} = 6.0\ I_n = 4800A$	
							$t_{sd} = 0.1,0.15,0.2,0.3s$	$t_{sd} = 0.2s$①	
Note: ① In such a case, MCCB resettable time is 180 ms and maximum full break time is 250 ms.									

Main lighting transformer primary side circuit breaker Table A.3g

Equipment/feeder			Circuit breaker						Remarks
Code	Name	Rated value (A)	manufacturer/ type	Frame size (A)	Release/current transformer rated current (A)	Protection type	Setting ranges	Set value	
3T	Main lighting transformer circuit breaker	180	XXXX	400	200	LTD	200,…,350,400A	I_r = 200A	This is a fixed-type MCCB with high instantaneous value which is suitable for transformer selective protection. As the requirement for I_{cs} is relatively higher here, MCCB at frame size of 400A is selected.
							t_r = 5,10,15,20,30s	t_r = 20s (6I_r)	
						STD	I_{sd} = 2,4,6,8,10I_n	I_{sd}=6.0I_n=1200A	
							t_{sd} = 0.1,0.15,…, 0.3s	t_{sd} = 0.1s①	
						INST	I_{INST} = 6.3kA	I_{INST} = 6.3kA	

Note: ① In such a case, MCCB resettable time is 80 ms and maximum full break time is 150 ms.

Emergency lighting transformer primary side circuit breaker Table A.3h

Equipment/feeder			Circuit breaker						Remarks
Code	Name	Rated value (A)	manufacturer/ type	Frame size (A)	Release/current transformer rated current (A)	Protection type	Setting ranges	Set value	
1ET	Emergency lighting transformer circuit breaker	144	XXXX	225	150	LTD	125,150,…,225	I_r = 150A	This is a fixed-type MCCB with high instantaneous value which is suitable for transformer selective protection.
							t_r = 5,10,15,20,30s	t_r = 20s (6I_r)	
						STD	I_{sd} = 2,4,6,8,10I_n	I_{sd}=6.0I_n=900A	
							t_{sd} = 0.1,0.15,…,0.3s	t_{sd} =0.1s①	
						INST	I_{INST} = 4.0kA	I_{INST} = 4.0kA	

Note: ① In such a case, MCCB resettable time is 80 ms and maximum full break time is 150 ms.

Circuit breaker at emergency bus-bar and main and emergency lighting bus-bar outgoing sides

Table A.3i

Equipment/feeder			Circuit breaker						Remarks
Code	Name	Rated value (A)	manufacturer/ type	Frame size (A)	Release/current transformer rated current (A)	Protection type	Setting ranges	Set value	
MLB ELB	Main lighting bus-bar Emergency lighting bus-bar	40	XXXX	100	40①	LTD	-	I_r= 40A	This is a MCCB with thermal magetic release.
							-	-	
						INST	Fixed	I_{INST} =600A±200A	

Note: ① MCCB used here has several grades of releases, but in this Table only the release of 40A is taken for example.

Emergency generator circuit breaker

Table A.3j

Equipment/feeder			Circuit breaker						Remarks
Code	Name	Rated value (A)	manufacturer/ type	Frame size (A)	Release/current transformer rated current (A)	Protection type	Setting ranges	Set value	
EG	Emergency generator	722	XXXX	800	722	LTD	I_r = (0.8-1.0-1.05)I_n	I_r = 1.0 I_n = 722A	This is an ACB with LTD and STD protection.
							t_r = 15,20,25,30,60s	t_r = 25s (1.2I_r)	
						STD	I_{sd} = 2,4,6,8,10I_n	I_{sd} = 2.0I_n=1450A	
							t_{sd} = 0.1,…,0.8s,	t_{sd} = 0.3s①	

Note: ① In such a case, MCCB resettable time is 275 ms and maximum full break time is 370 ms.

A.4 Coordination analysis and time-current characteristic curves of protective devices of each level in the electrical system

A.4.1 High-voltage part of 6600 V

A.4.1.1 Coordination analysis

It can be seen from Figure A.1 that a public power station includes two parts: high-voltage part and low-voltage part. The high-voltage part provides three levels of over-current protection for the low-voltage part, which starts from 6600 V main generator circuit breaker to circuit breaker connecting two high-voltage distribution boards, then to 6600 V/400 V distribution transformer primary side circuit breaker. They are all protected against over-current by ACBs with LTD and STD, in addition to main generators and distribution transformer protected against internal faults by differential instantaneous relay. Their operating current and setting values are given in Tables A.3a, A.3b and A.3e, which clearly indicate that starting from main generators, setting time of STD circuit breaker reduce gradually, and meet the requirements of 3.1.2(3)② of the Guidelines. Thus complete and selective protection for this part is achieved. Details are given in FigureA.4.1.2a which are time-current characteristic curves indicating coordination of respective circuit breakers.

Moreover, among main generator circuit breaker, circuit breaker connecting two high-voltage distribution boards and bow thruster circuit breaker, as well as among main generator circuit breaker, circuit breaker connecting two high-voltage distribution boards and propulsion transformer primary circuit breaker, over-current protection setting as well as operating current and setting values are listed in Tables A.3c and A.3d, which may meet the requirements of 3.1.2(3)② of the Guidelines. Therefore complete and selective protection for this part can be achieved. See for details in Figures A.4.1.2 b and A.4.1.2c which are time-current characteristic curves indicating coordination of respective circuit breakers.

Relays or releases which provide undervoltage protection, overvoltage protection, reverse power protection, phase sequence protection and low frequency protection for main generators are to operate after a time delay of at least 1 s. Undervoltage release for distribution transformer circuit breaker is to operate after a short-time delay based on coordination of selective protection.

Moreover, instantaneous differential relay for protection of main generator internal faults may also provide short-circuit selective protection for and among main generators.

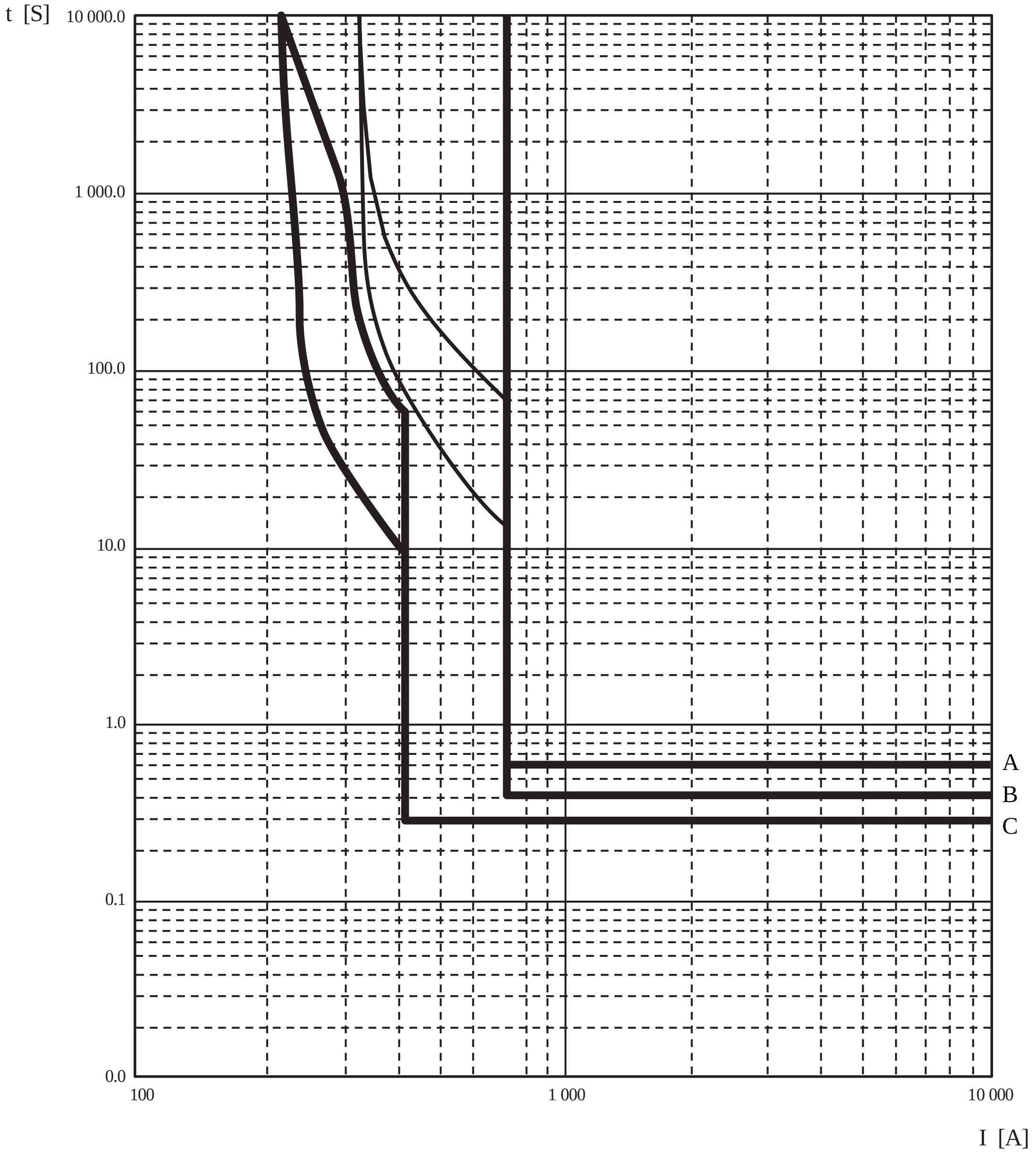
A.4.1.2 Time-current characteristic curves indicating coordination between protective devices of each level

Details are given in the following time-current characteristic curves:

Figure A.4.1.2a Time-current characteristic curves – coordination among main generator circuit breaker, circuit breaker connecting two high-voltage distribution boards, and distribution transformer primary side circuit breaker;

Figure A.4.1.2b Time-current characteristic curves – coordination between bow thruster circuit breaker and main generator circuit breaker;

Figure A.4.1.2c Time-current characteristic curves – coordination among main generator circuit breaker, circuit breaker connecting two high-voltage distribution boards, and propulsion transformer primary side circuit breaker.



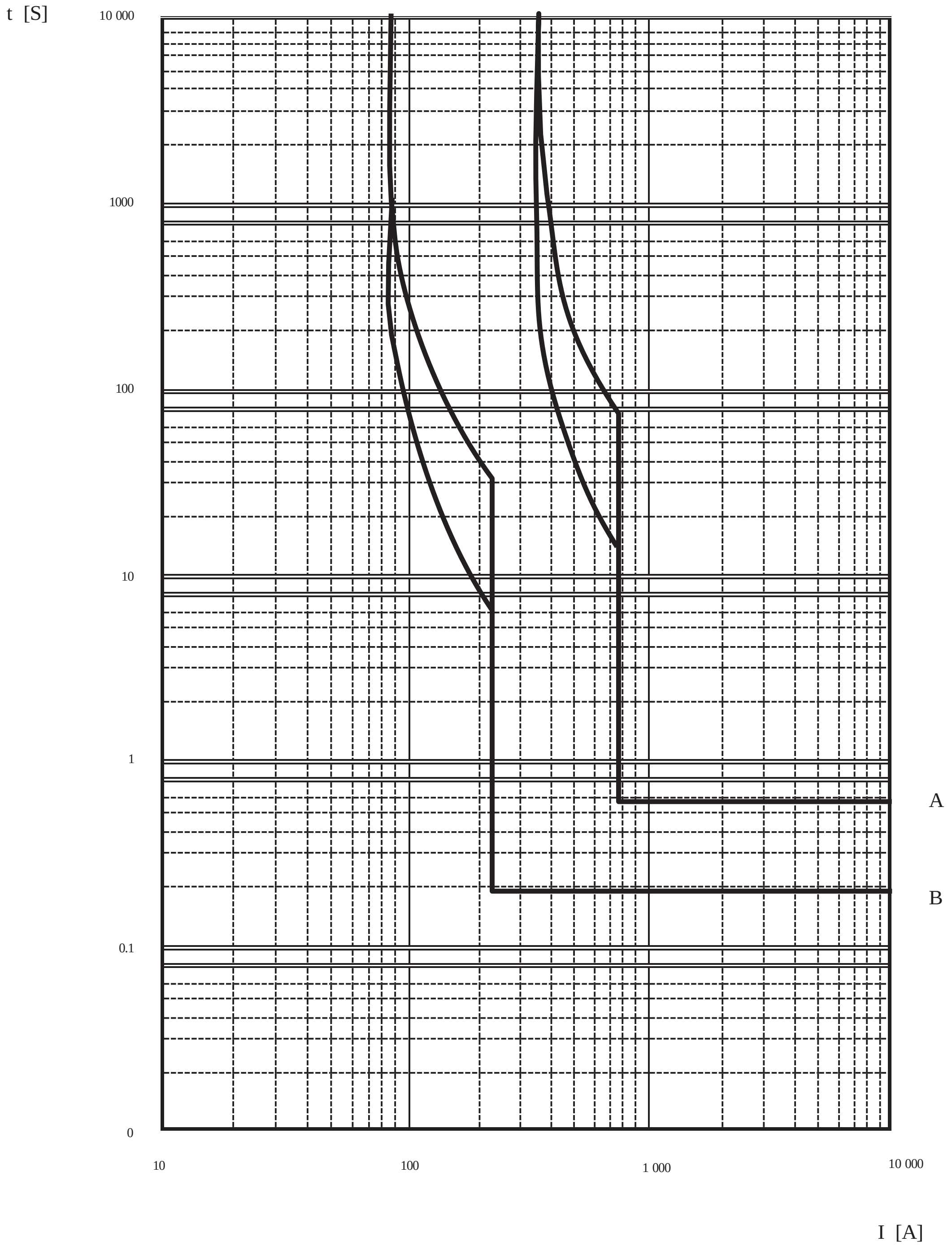
where: A - time-current characteristic curve of main generator circuit breaker;

B- time-current characteristic curve of circuit breaker connecting No.1 and No.2 high-voltage distribution boards;

C- time-current characteristic curve of 6600 V/400 V distribution transformer primary side circuit breaker.

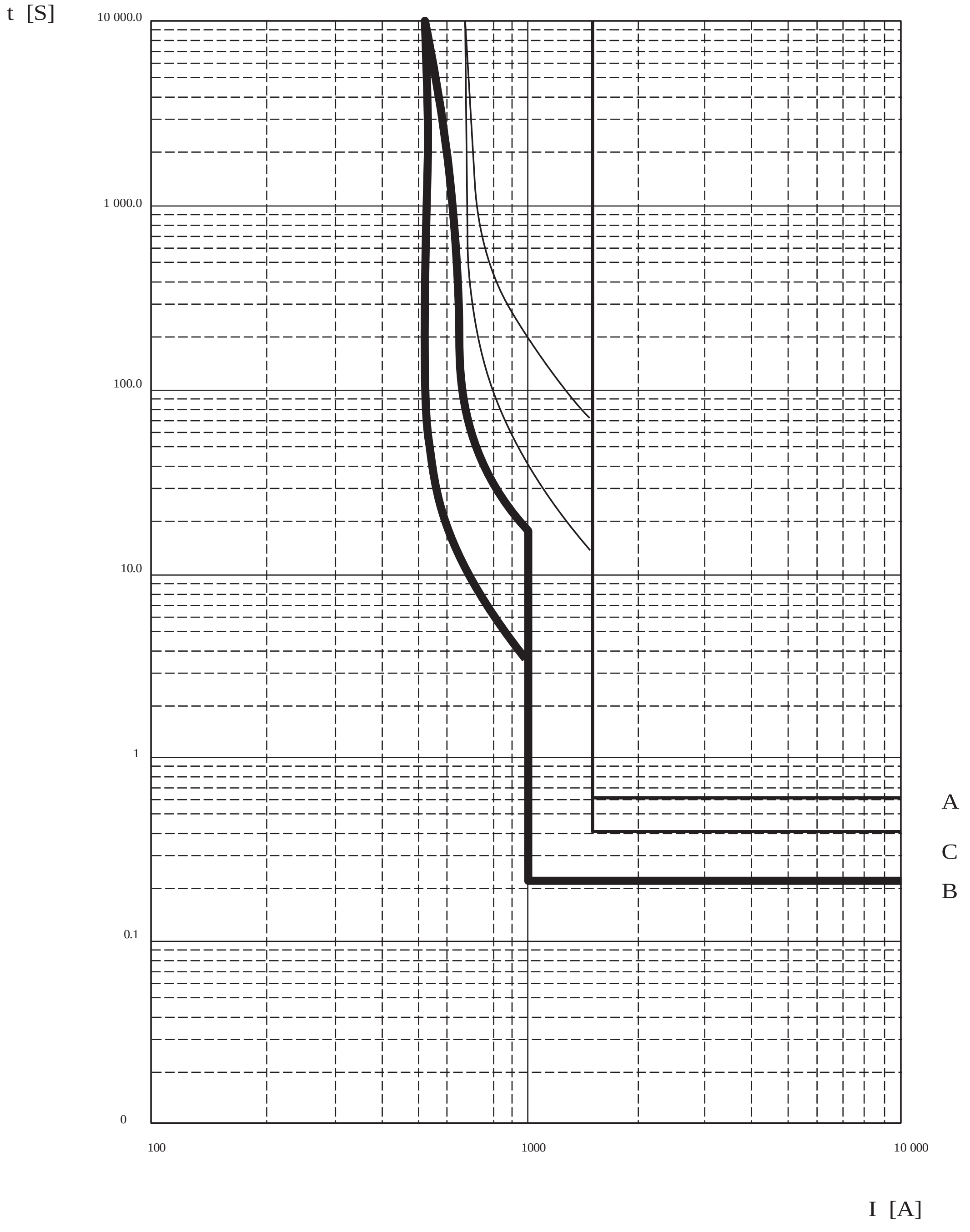
Figure A.4.1.2a

Time-current characteristic curves – coordination among main generator circuit breaker, circuit breaker connecting two high-voltage distribution boards, and distribution transformer primary side circuit breaker



where: A- time-current characteristic curve of main generator circuit breaker;
B- time-current characteristic curve of bow thruster circuit breaker.

Figure A.4.1.2b
Time-current characteristic curves – coordination between bow thruster circuit breaker and main generator circuit breaker



where: A- time-current characteristic curve of main generator circuit breaker;
B- time-current characteristic curve of propulsion transformer primary side circuit breaker;
C- time-current characteristic curve of circuit breaker connecting No.1 and No.2 high-voltage distribution boards.

Figure A.4.1.2c
Time-current characteristic curves – coordination among main generator circuit breaker, circuit breaker connecting two high-voltage distribution boards, and propulsion transformer primary side circuit breaker

A.4.2 400 V/230 V low-voltage part

A.4.2.1 Coordination analysis

(1) Over-current selective protection in terms of time principle

According to the requirements of ISC Rules and the Guidelines, selective over-current protection is achieved for the low-voltage part of 400 V/230 V of the electrical system according to time principle between:

① Distribution transformer primary side ACB and MSB-ESB feeder MCCB

As shown in Tables A.3e and A.3f, STD protection is adopted for both the circuit breakers against short-circuit, their setting time being 0.3 s for the former and 0.2 s for the latter, and the maximum full break time of the latter being 250 ms, while the resettable time of the former being 270 ms. Hence the complete and selective protection in-between is achieved.

② Distribution transformer primary side ACB, main lighting transformer primary side MCCB and main lighting transformer secondary side MCCB

Same as the above ①, but STD time of main lighting transformer primary side MCCB is set as 0.1 s, lesser than 0.3 s in the upstream. This MCCB operates instantaneously when the value of $1/\sqrt{2}\, i_p$ (i_p being peak short-circuit current flowing through the MCCB) equals the instantaneous value 6.3 kA. Hence complete and selective protection is achieved between the ACB and this MCCB.

Then we analyze the protection between the MCCBs at main lighting transformer primary side and secondary side respectively. It is shown in Table A.2 that the value of $1/\sqrt{2}\, i_p$ (i_p being peak short-circuit current flowing through MCCB secondary side) is 7.45 kA, which is converted to 4.20 kA at its primary side, so the MCCB at transformer primary side will not operate instantaneously (its instantaneous value being 6.3 kA), instead, it trips after a short time delay of 0.1 s. In this way, complete and selective protection is achieved between the two MCCBs.

③ MSB-ESB feeder MCCB, emergency lighting transformer primary side MCCB and emergency lighting transformer secondary side MCCB

Protection between MSB-ESB feeder MCCB and emergency lighting transformer primary side MCCB is similar to ②. The difference is that "distribution transformer primary side ACB" is replaced by "MSB-ESB feeder MCCB", and STD time of this MCCB is changed to 0.2 s, which satisfies the requirements of 3.1.2(3)② of the Guidelines.

As to protection between the MCCBs at emergency lighting transformer primary and secondary sides respectively, it is shown in Table A.2 that the value of $1/\sqrt{2}\, i_p$ (i_p being peak short-circuit current flowing through MCCB secondary side) is 5.11kA, which is converted to 2.95 kA at its primary side, so the MCCB at transformer primary side will not operate instantaneously (its instantaneous value being 4.0 kA), instead, it trips after a short time delay of 0.1 s. In this way, complete and selective protection is achieved between the two MCCBs.

④ Emergency generator ACB, emergency power and lighting transformer primary side MCCB and its secondary side MCCB

Same as the above the above ③, but the "MSB-ESB feeder MCCB" is replaced by "emergency generator ACB", and STD time of the ACB is changed to 0.3 s, which fully complies with 3.1.2(3)② of the Guidelines. Moreover, compared to ③, maximum short-circuit current flowing through emergency lighting transformer secondary side MCCB reduces about 21%, and therefore complete and selective protection is achieved between the two MCCBs at emergency lighting transformer primary side and secondary side in terms of time principle.

(2) Over-current selective protection according to the coordination specifications provided by manufacturer

As described in 3.1.2(2)②b of the Guidelines, over-current selective protection can be achieved between main and emergency lighting bus-bar distribution board MCCB and its adjacent downstream MCCB or MCB by setting according to the specifications given by manufacturers for coordination.

A.4.2.2 Sensitivity check of some short-circuit protective devices

According to the requirements of the Guidelines on protective device sensitivity, and considering that the ship is 200 m in length with its bridge at the bow while main and emergency distribution board at the stern, we select one of the navigation lights: stern light to check the sensitivity of its MCCB in case of short circuit. Its minimum two-phase symmetrical short-circuit current is calculated as follows:

$$I_{ac(2)} = 40\ \text{A} \times 0.866 = 35\ \text{A}$$

It is determined that instantaneous value of the MCCB protecting the feeder is $I_{INST} = 20$ A, and its sensitivity coefficient is 1.75, which complies with 3.1.2(1)③ of the Guidelines.

A.4.2.3 Time-current characteristic curves indicating coordination of circuit breakers of each level

Details are given in the following time-current characteristic curves:

Figure A.4.2.3a Time-current characteristic curves - coordination of 6600 V/400 V distribution transformer primary side ACB, main lighting transformer primary side MCCB and main lighting bus-bar distribution board MCCB;

FigureA.4.2.3b Time-current characteristic curves - coordination of 6600 V/400 V distribution board primary side MCCB, main and emergency bus-bar connecting feeder MCCB, emergency lighting transformer MCCB and emergency lighting bus-bar distribution board MCCB;

Figure A.4.2.3c Time-current characteristic curves - coordination of emergency generator ACB, emergency lighting transformer primary side MCCB and emergency lighting bus-bar distribution board MCCB.

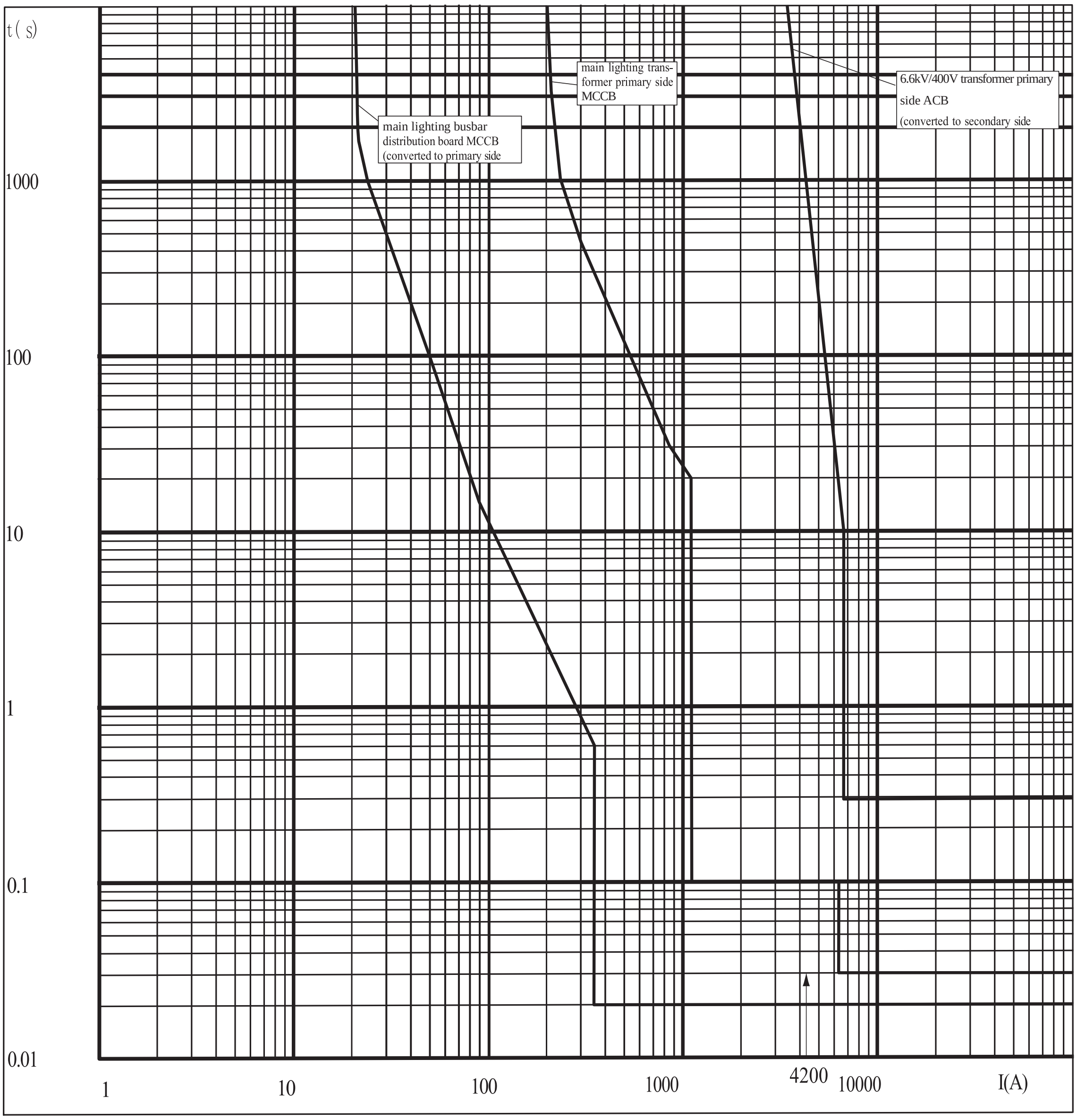
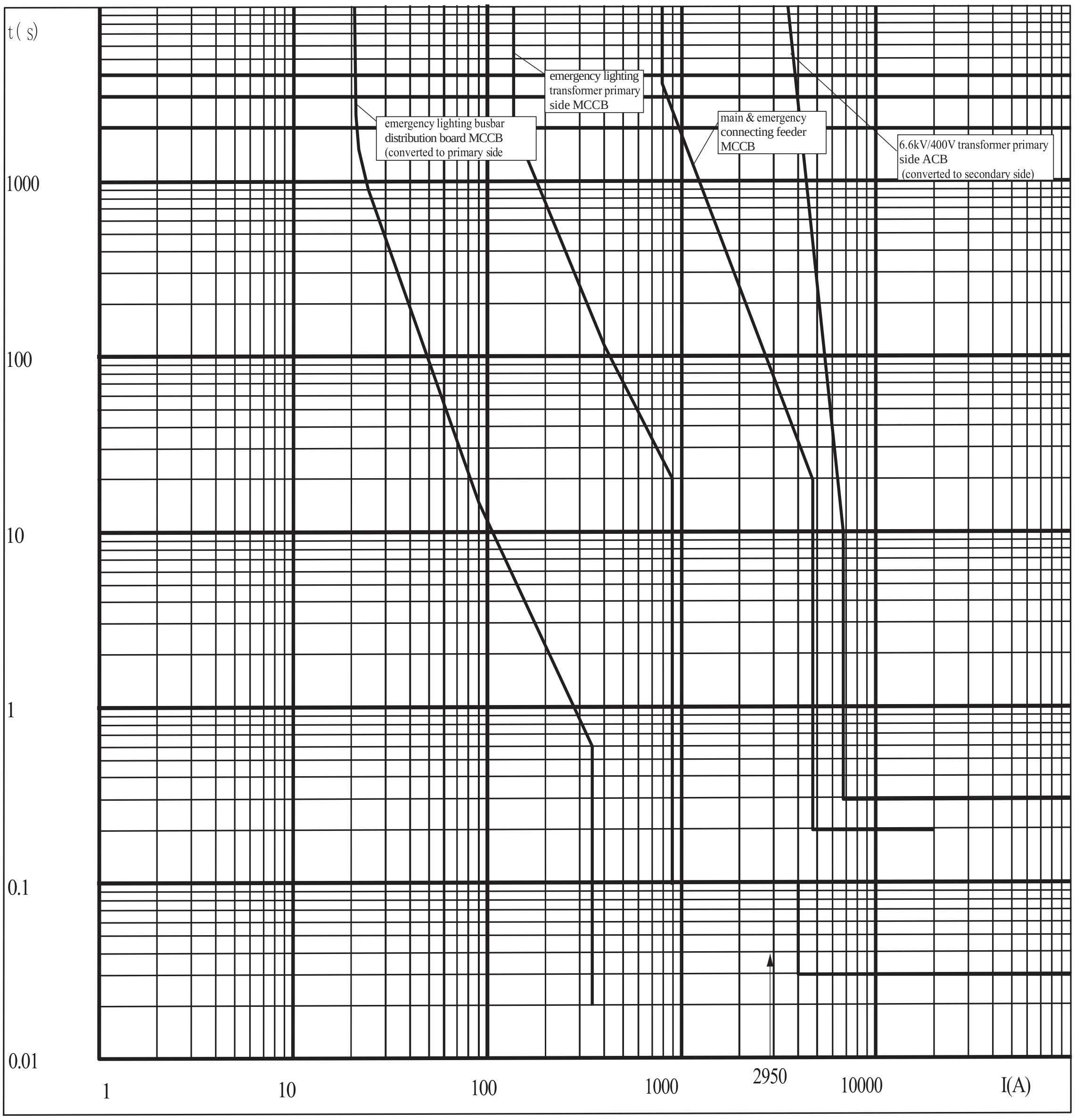


Figure A.4.2.3a
Time-current characteristic curves - coordination of 6600 V/400 V distribution transformer primary side ACB, main lighting transformer primary side MCCB and main lighting bus-bar distribution board MCCB



FigureA.4.2.3b

Time-current characteristic curves - coordination of 6600V/400V distribution board primary side MCCB, main and emergency bus-bar connecting feeder MCCB, emergency lighting transformer MCCB and emergency lighting bus-bar distribution board MCCB

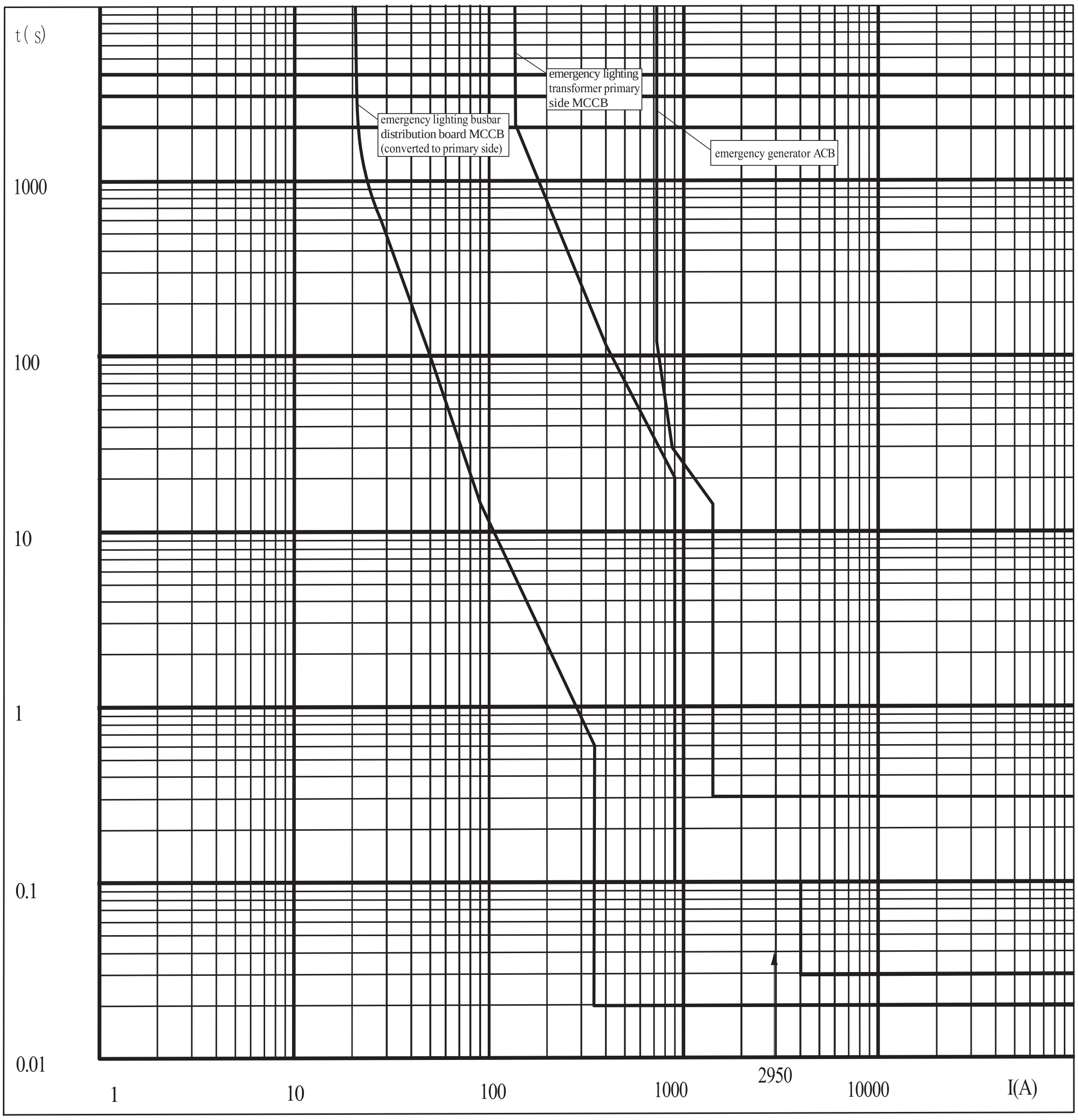


Figure A.4.2.3c
Time-current characteristic curves - coordination of emergency generator ACB, emergency lighting transformer primary side MCCB and emergency lighting bus-bar distribution board MCCB

Appendix B Electrical System Selective Over-current Protection Coordination Analysis Example 2

B.1 Brief introduction of the electrical system①

This example is based on the electrical system of a domestic bulk carrier, the protection system of which has been modified according to the requirements of the Guidelines.

The ship is propelled by A.C. electrical power at 400 V. Its main power is provided by two generators of 440 kW and one generator of 312 kW respectively. Power disposition in different conditions are:

for sea-going condition: one generator of 440 kW;
for arrival/departure condition: one generator of 440 kW and one of 312 kW;
for loading/ unloading condition: two generators of 440 kW;
for berthing condition: one generator of 312 kW.

Besides, one generator of 88 kW is provided as emergency power supply.

The main bus-bars are separated by a bus tie breaker without protection.

Diagram of the electrical power system is shown in Figure B.1.

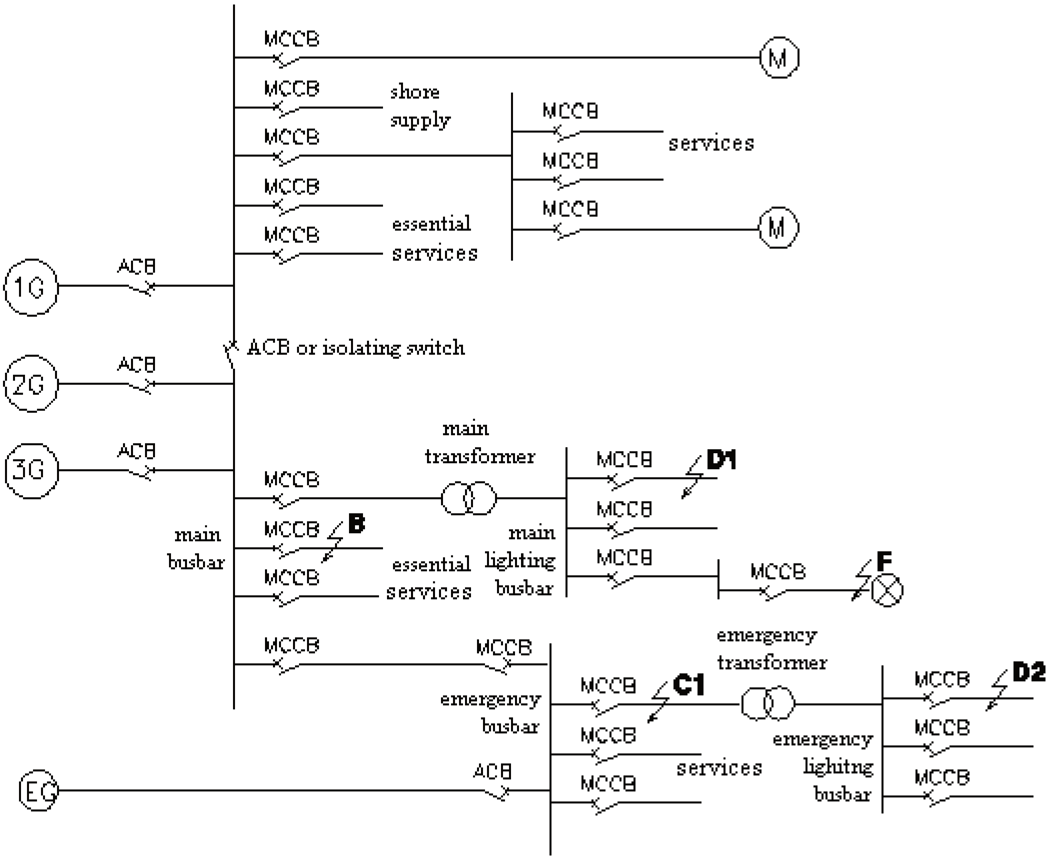


Figure B.1 Diagram of the Electrical System

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① This part need not be covered when a complete set of electrical drawings required by ISC Rules are submitted for approval.

B.2 General

Maximum and minimum short-circuit currents that may occur at protective devices of each level provide the basis for coordination analysis of an electrical system. For the purpose of coordination analysis, fault points relating to this electrical system are calculated with the results listed in Table B.2.

Fault point short-circuit current value **Table B.2**

Fault point		Max. short-circuit current (kA)		Supplied by one 440 kW generator (kA)		Supplied by emergency generator (kA)	
No	Position	i_p	I_{ac}	i_p	I_{ac}	i_p	I_{ac}
1G、3G①	Generator end	7.71②	2.91②	12.04	4.56		
B	Main bus-bar	38.10	14.92	15.95	6.35	-	-
C1	Emergency bus-bar	14.55	9.94	8.99	5.47	4.08	1.59
D1	Main lighting bus-bar	3.98③ 6.89	2.53 4.38	3.41 5.91	2.10 3.64	-	-
D2	Emergency lighting bus-bar	2.26 3.93	1.46 2.53	2.07 3.59	1.31 2.27	1.52 2.64	0.86 1.49
F	Forecastle light	0.069 0.119	0.049 0.084	0.069 0.119	0.049 0.084	0.058 0.101	0.041 0.071

Note: ① Short circuit current sent by single generator in the event of short circuit of main bus-bar.

② Short circuit current sent by 312 kW generator in the event of short circuit of main bus-bar.

③ Two data are given here: the former is short-circuit current at 400V/230V transformer primary side, and the latter is the short-circuit current at transformer secondary side.

Arrangements and settings of protective devices of each level in the electrical system are shown in B.3.

Coordination analysis and time-current characteristic curves of protective devices of each level as well as sensitivity check of some short-circuit protective devices are given in B.4.

B.3 Arrangements and settings of protective devices of each level in the electrical system

Details are given in Table B.3a through Table B.3g.

Main generator circuit breaker

Table B.3a

Equipment/feeder			Circuit breaker						Remarks
Code	Name	Rated value (A)	manufacturer/ type①	Frame size (A)	Release/current transformer rated current (A)	Protection type	Setting ranges	Set value	
1G 2G	No.1 generator No.2 generator	790A	XXXX	800	800	LTD	I_r = 0.4 ~1.0 I_n	I_r = 0.98 I_n = 784A②	where: STD protection is of time-defined type (I^2t OFF).
							t_r= 0.5 ~ 24 s (6I_r)	t_r = 1.0 s (6I_r)	
						STD	I_{sd} = 1.5 ~ 10 I_r	I_{sd} = 2.5 I_r = 1975A	
							t_{sd} = 0.1,0.2,0.3,0.4s	t_{sd} = 0.4s	
						INST	I_i = 2~15 I_n	I_i = 13 I_n =10.40kA	

Main generator circuit breaker

Table B.3b

Equipment/feeder			Circuit breaker						Remarks
Code	Name	Rated value (A)	manufacturer/ type	Frame size (A)	Release/current transformer rated current (A)	Protection type	Setting ranges	Set value	
3G	No.3 generator	530A	XXXX	630	630	LTD	I_r = 0.4 ~1.0I_n	I_r = 0.84 I_n = 530A	where: STD protection is of time-defined type(I^2t OFF).
							t_r = 0.5 ~24s(6I_r)	t_r = 1.0s(6I_r)	
						STD	I_{sd} = 1.5 ~ 10 I_r	I_{sd} = 2.5 I_r = 1330A	
							t_{sd} = 0.1,0.2,0.3,0.4s	t_{sd} =0.4s	
						INST	I_i = 2~15I_n	I_i = 11I_n =6.93kA	

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① Although manufacturer/type of protective device is indicated neither here nor in the following tables, it is to be indicated in drawings submitted for approval.

② According to Publication IEC 60947-2 and the manufacturer's specifications, the circuit breaker operates when the current exceeds 1.05 times the set value.

Circuit breaker of feeder connecting main and emergency bus-bars **Table B.3c**

Equipment/feeder			Circuit breaker						Remarks
Code	Name	Rated value (A)	manufacturer/ type	Frame size (A)	Release/current transformer rated current (A)	Protection type	Setting ranges	Set value	
	feeder connecting main and emergency bus-bars	250A	XXXX	630	630	LTD	$I_r = 0.4 \sim 1.0 I_n$	$I_r = 0.4\ I_n = 250\text{A}$	This circuit breaker has reflex tripping function. Electronic release is used.
							$t_r = 6 \sim 8\text{s}(6I_r)$	$t_r = 6\text{s}(6I_r)$	
						STD	$I_{sd} = 2 \sim 10\ I_r$	$I_{sd} = 4.0 I_r = 1000\text{A}$	
							$t_{sd} \leqslant 0.23\text{s}$	$t_{sd} = 0.2\text{s}$①	
						INST	$I_i = 1.5 \sim 11 I_n$	$I_i = 11 I_n = 4400\text{A}$	

Note: ① In such a case, MCCB maximum full break time is 230 ms and maximum resettable time is 140 ms.

Main lighting transformer circuit breaker **Table B.3d**

Equipment/feeder			Circuit breaker						Remarks
Code	Name	Rated value (A)	manufacturer/ type	Frame size (A)	Release/current transformer rated current (A)	Protection type	Setting ranges	Set value	
MT	Main lighting transformer	130	XXXX	250	250	LTD	$I_r = 0.4 \sim 1.0 I_n$	$I_r = 0.52\ I_n = 134\text{A}$	This circuit breaker has reflex tripping function. Electronic release is used.
							$t_r = 5 \sim 7.5\text{s}(6I_r)$	$t_r = 6\text{s}(6I_r)$	
						STD	$I_{sd} = 2 \sim 10\ I_r$	$I_{sd} = 8.0 I_r = 1072$ —A②	
							$t_{sd} = 0.05\text{s}$	$t_{sd} = 0.05$①s	
						INST	$I_i = 11 I_n$ (permanent)	$I_i = 11 I_n = 2750\text{A}$②	

Note: ① In such a case, MCCB maximum full break time is 60 ms and maximum resettable time is 40 ms.
② Value of the two items is to be set higher in order to avoid interference of transformer magnetizing inrush current.

Emergency lighting transformer circuit breaker **Table B.3e**

Equipment/feeder			Circuit breaker						Remarks
Code	Name	Rated value (A)	manufacturer/ type	Frame size (A)	Release/current transformer rated current (A)	Protection type	Setting ranges	Set value	
ET	Emergency lighting transformer	65	XXXX	250	160	LTD	$I_r = 0.4 \sim 1.0I_n$	$I_r = 0.41\ I_n = 64A$	This circuit breaker has reflex tripping function. Electronic release is used.
							$t_r = 5 \sim 7.5s(6I_r)$	$t_r = 6s(6I_r)$	
						STD	$I_{sd} = 2 \sim 10\ I_r$	$I_{sd} = 10.0I_r = 640A$②	
							$t_{sd} \leqslant 0.06$ s	$t_{sd} = 0.06$ s	
						INST	$I_i = 11I_n$ (permanent)	$I_i = 11I_n = 1760A$②	

Note: ① In such a case, MCCB maximum full break time is 60 ms and maximum resettable time is 40 ms.
② Value of the two items is to be set higher in order to avoid interference of transformer magnetizing inrush current.

Circuit breaker at emergency bus-bar and main and emergency lighting bus-bar outgoing sides **Table B.3f**

Equipment/feeder			Circuit breaker						Remarks
Code	Name	Rated value (A)	manufacturer/ type	Frame size (A)	Release/current transformer rated current (A)	Protection type	Setting ranges	Set value	
	emergency bus-bar and main and emergency lighting bus-bar outgoing sides	45	XXXX	100	50	LTD	$I_r = 0.8 \sim 1.0I_n$	$I_r = 0.9\ I_n = 45A$	This circuit breaker has reflex tripping function. Thermal-magnetic release is used.
						INST	$I_i = 500A$ (permanent)		

Note: ① MCCB used here has several grades of releases, but in this table only the release of 50 A is taken for example.

Emergency generator circuit breaker **Table B.3g**

Equipment/feeder			Circuit breaker						Remarks
Code	Name	Rated value (A)	manufacturer/ type	Frame size (A)	Release/current transformer rated current (A)	Protection type	Setting ranges	Set value	
EG	Emergency generator	158	XXXX	630	400	LTD	$I_r = 0.4 \sim 1.0 I_n$	$I_r = 0.4\ I_n = 160A$	where: STD protection is of time-defined type (I^2t OFF).
							$t_r = 0.5 \sim 24s(6I_r)$	$t_r = 1.0s(6I_r)$	
						STD	$I_{sd} = 1.5 \sim 10\ I_r$	$I_{sd} = 2.5\ I_r = 400A$	
							$t_{sd} = 0.1, 0.2, 0.3, 0.4s$	$t_{sd} = 0.3s$	
						INST		OFF	

B.4 Coordination analysis and time-current characteristic curves of protective devices of each level in the electrical system

B.4.1 Coordination analysis

B.4.1.1 Selective short-circuit protection among main generators and between main generator and its adjacent downstream protective device

(1) Selective short-circuit protection among main generators

This is achieved by INST function of the circuit breakers protecting main generators. Circuit breakers for 1G and 2G are set as 10.40 kA and that for 3G is 6.93 kA, all greater than 1.2 times the short-circuit current ($i_{pg}/\sqrt{2}$) of their respective generators, complying with 3.2.1(1) of the Guidelines. Hence, short-circuit selective protection of this part can be achieved.

(2) Selective short-circuit protection between main generator and its adjacent downstream protective device according to time principle

① Between main generator ACB and MSB-ESB feeder MCCB

As shown in Tables B.3a, B.3b and B.3c, STD protection is adopted for both the circuit breakers against short-circuit, their setting time being 0.4 s for the former and 0.2 s for the latter, and the maximum full break time of the latter being 230 ms, while the resettable time of the former being 250 ms minimum. Hence the complete and selective protection in-between is achieved.

② Between main generator ACB and main lighting transformer primary side MCCB

Same as the above ①, but from Table B.3d, the maximum full break time of main lighting transformer primary side MCCB during STD operation is 60 ms. Hence complete and selective short-circuit protection is achieved.

(3) Coordination of main generator undervoltage protection and reverse power protection with selective short-circuit protection

Both main generator undervoltage release and reverse power relay are to operate after a time delay of at least 1 s of a fault occurred, in order to coordinate with the above selective short-circuit protection.

B.4.1.2 Protection between lighting transformer primary side MCCB and secondary side MCCB

(1) Between main lighting transformer primary side MCCB and secondary side MCCB

It is known from Table B.3d that main lighting transformer primary side MCCB has reflex tripping function and its frame size is 250 A, ratio of which to the secondary side frame size is greater than 2. Reflex tripping is achieved when short circuit current flowing through the secondary side MCCB reaches 2.5 kA or above. It is known from Figure B.4.3d that the MCCB fast trips in about 8 ms to break fault circuits and then achieve complete and selective short-circuit protection.

Where short-circuit current flowing through the secondary side MCCB is less than 2.5 kA, then that through the primary side MCCB is less than 1.44 kA, and the primary side MCCB will not operate instantaneously. However, as long as short-circuit current flowing through transformer secondary side MCCB exceeds 500A, this MCCB will operate instantaneously and fully break in about 8 ms. The greater the short-circuit current flowing through, the shorter the breaker time due to limiting current (see for details in Figure B.4.3d). Where secondary side MCCB protection fails, STD section of the primary side MCCB will operate as a backup, which breaks fault circuit in 60 ms.

(2) Between emergency lighting transformer primary side MCCB and its secondary side MCCB

Same as that of main lighting transformer in the above (1), reflex tripping will be achieved if short-circuit current is great and complete and selective short-circuit protection is achieved according to time principle if short-circuit current is smaller.

B.4.1.3 Protection between MSB-ESB feeder MCCB and downstream MCCBs

(1) Between MSB-ESB feeder MCCB and emergency bus-bar distribution board MCCB

As shown in Tables B.3c and B.3f, both MCCBs have reflex tripping function. Frame size of the feeder MCCB(630A) is 6.3 times that of the distribution board MCCB (100A). Short-circuit current at emergency bus-bar is over 5kA. Therefore, complete and selective short-circuit protection is achieved between the two MCCBs by means of reflex tripping.

(2) Between MSB-ESB feeder MCCB and emergency transformer primary side MCCB

As shown in Tables B.3c and B.3e, both MCCBs have reflex tripping function. Ratio of frame size of the upstream MCCB (630 A) to that of the adjacent downstream MCCB (250 A) is greater than 2, however, according to D2 in Table B.2, short-circuit current flowing through is less than 25 times 250A, so reflex tripping cannot be achieved. Instead, short-circuit selective protection is achieved between the two MCCBs in terms of time principle: maximum STD resettable time of the upstream MCCB (140 ms) is greater than full break time of the adjacent downstream MCCB (60 ms).

B.4.1.4 Among emergency generator ACB, emergency lighting transformer primary side MCCB and secondary side MCCB

Similar to the above B.4.1.3(2), the difference is that “main and emergency bus-bar connecting feeder MCCB ” is replaced by “emergency generator ACB” and STD time of the ACB is changed to 0.3 s, complying with the requirements of 3.1.2(3)② of the Guidelines.

Supplied by emergency generator, short-circuit current through emergency lighting transformer secondary side MCCB is relatively smaller than that in B.4.1.2(2). Complete and selective short-circuit protection is achieved between emergency lighting transformer primary side and secondary side MCCBs.

B.4.1.5 Between main and emergency lighting busbar distribution board MCCB and its adjacent downstream MCCB (or MCB)

As described in 3.1.2(2)②b of the Guidelines, over-current selective protection can be achieved between main and emergency lighting bus-bar distribution board MCCB and its adjacent downstream MCCB or MCB by setting according to the specifications for coordination given by manufacturers.

B.4.2 Sensitivity check of some short-circuit protective devices

According to the requirements of the Guidelines for protective device sensitivity, we select forecastle deck light to check the sensitivity of its MCCB in case of short circuit. Its minimum two-phase symmetrical short-circuit current is calculated as follows:

$$I_{ac(2)} = 84\text{ A} \times 0.866 = 72.74\text{ A}$$

It is determined that instantaneous value of the MCCB protecting the feeder is I_{INST} = 50 A, and its sensitivity coefficient is 1.45, which complies with 3.1.2(1)③ of the Guidelines.

B.4.3 Time-current characteristic curves indicating coordination of downstream and upstream circuit breakers

Details are given in the following time-current characteristic curves:

Figure B.4.3a Time-current characteristic curves - coordination of main generator ACB, main lighting transformer primary side MCCB and main lighting bus-bar distribution board MCCB;

Figure B.4.3b Time-current characteristic curves - coordination of main generator ACB, main and emergency bus-bar connecting feeder MCCB, emergency lighting transformer primary side MCCB, and emergency lighting bus-bar distribution board MCCB;

Figure B.4.3c Time-current characteristic curves - coordination of emergency generator ACB, emergency lighting transformer primary side MCCB and emergency lighting bus-bar distribution board MCCB;

Figure B.4.3d Time-current characteristic curves - coordination of XX series MCCB reflex tripping section

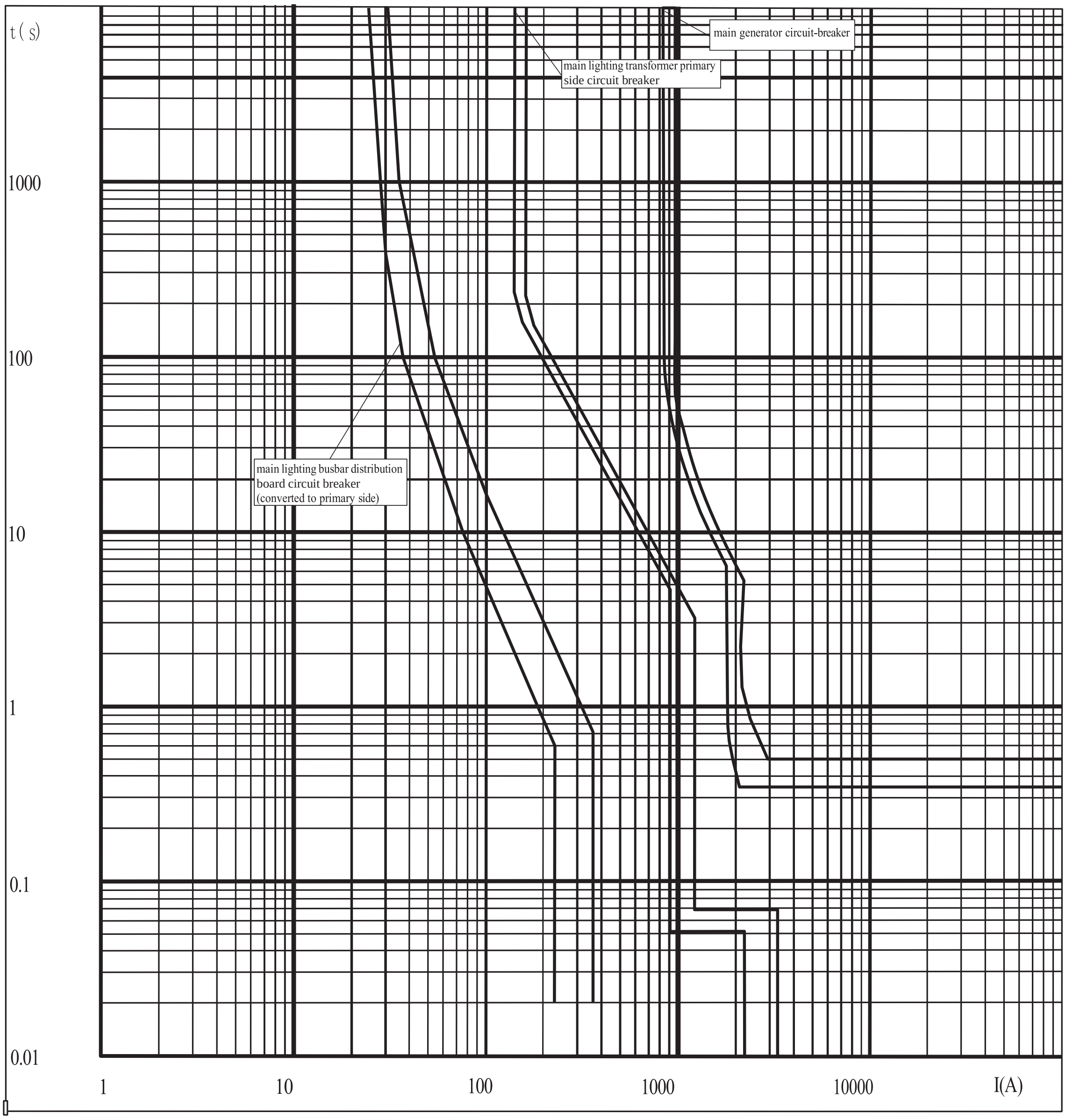

Figure B.4.3a

Time-current characteristic curves - coordination of main generator ACB, main lighting transformer primary side MCCB and main lighting bus-bar distribution board MCCB

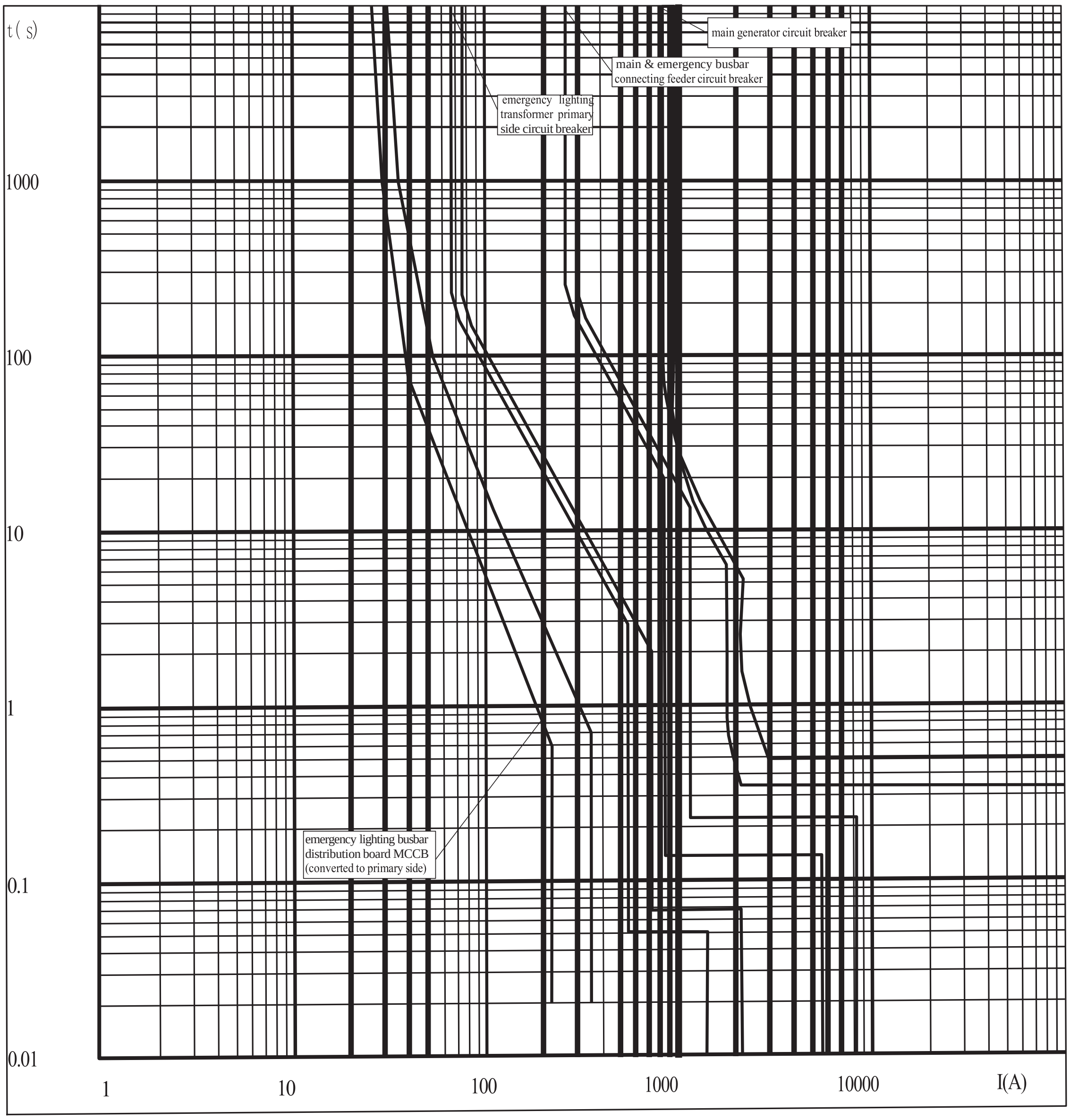

Figure B.4.3b
Time-current characteristic curves - coordination of main generator ACB, main and emergency bus-bar connecting feeder MCCB, emergency lighting transformer primary side MCCB, and emergency lighting bus-bar distribution board MCCB

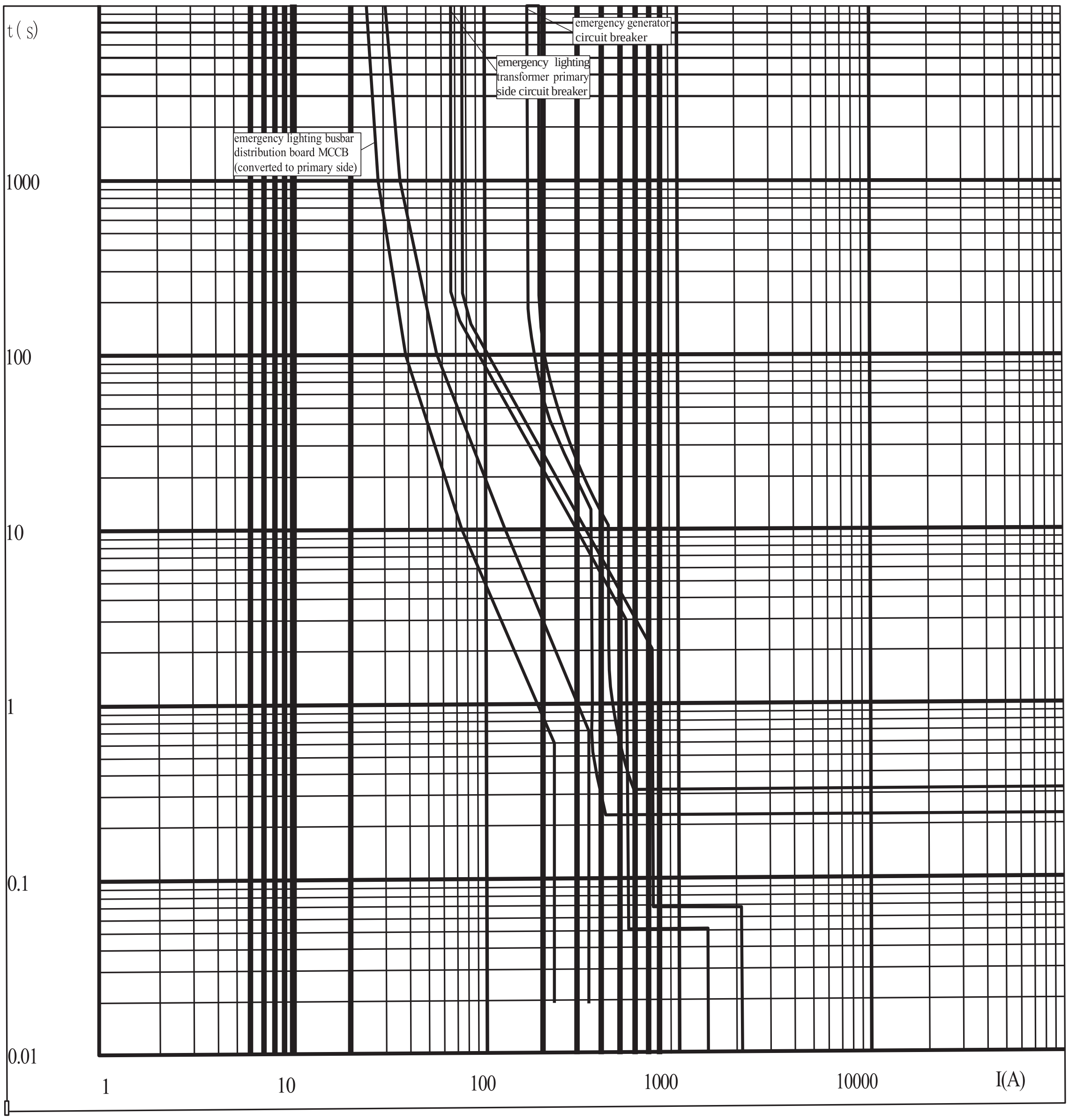

Figure B.4.3c

Time-current characteristic curves - coordination of emergency generator ACB, emergency lighting transformer primary side MCCB and emergency lighting bus-bar distribution board MCCB

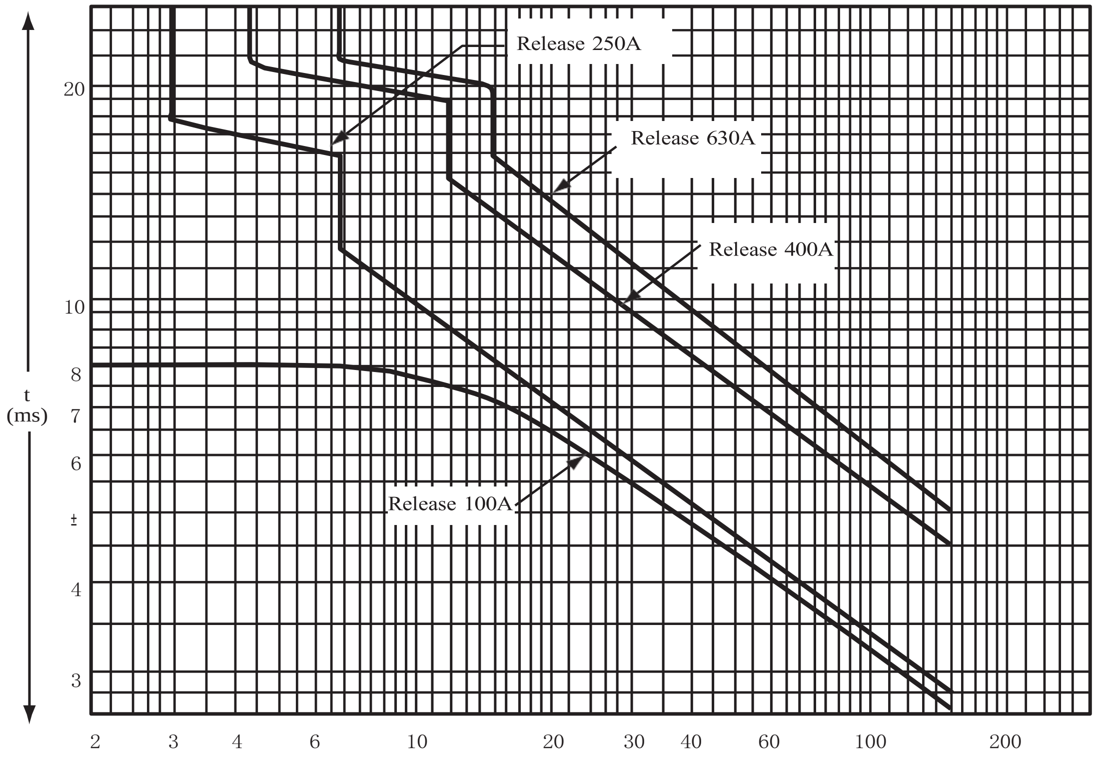

Figure B.4.3d
Time-current characteristic curves - coordination of XX series MCCB reflex tripping section