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INTERNATIONAL STANDARD

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Railway applications – Fixed installations – Protection principles for AC and DC electric traction power supply systems

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Railway applications – Fixed installations – Protection principles for AC and DC electric traction power supply systems

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

RAILWAY APPLICATIONS – FIXED INSTALLATIONS – PROTECTION PRINCIPLES FOR AC AND DC ELECTRIC TRACTION POWER SUPPLY SYSTEMS

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IEC 63438 has been prepared by IEC technical committee 9: Electrical equipment and systems for railways. It is an International Standard.

EN 50633 (2016) has served as a basis for the elaboration of this document.

The text of this International Standard is based on the following documents:

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Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

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RAILWAY APPLICATIONS – FIXED INSTALLATIONS – PROTECTION PRINCIPLES FOR AC AND DC ELECTRIC TRACTION POWER SUPPLY SYSTEMS

1 Scope

This International Standard applies to the electrical protection system, provided for AC and DC electric traction power supply systems. It:

– establishes railway specific protection principles;

– describes the railway specific protection system functionality;

– specifies minimum functional requirements and informative examples of their application;

– establishes limitations of the protection system and the acceptability of residual risks;

– specifies principles for design verification.

This document is applicable to:

– railways;

– guided mass transport systems, such as tramways, elevated and underground railways, mountain railways, trolleybus systems, and magnetically levitated systems which use a contact line system.

This document can also be applied to electrified road traffic with a contact line, such as truck-trolley systems.

This document applies to new electric traction power supply systems and can be applied to changes of existing systems.

This document does not apply to:

– underground mine traction systems;

– cranes, transportable platforms and similar transportation equipment on rails, temporary structures (e.g. exhibition structures) in so far as these are not supplied directly or via transformers from the contact line system and are not endangered by the traction power supply system;

– suspended cable cars;

– funicular railways;

– magnetic levitated systems (without a contact line system);

– railways with an inductive power supply without contact system;

– railways with a buried contact system that is required to be energized only below the train to ensure safety.

This document does not cover:

– technical requirements for products, e.g. protection devices;

– rules for maintenance of protection systems.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61991:2019, *Railway applications – Rolling stock – Protective provisions against electrical hazards*

IEC 61992-1:2006, *Railway applications – Fixed installations – DC switchgear – Part 1: General*
IEC 61992-1:2006/AMD1:2014

IEC 61992-7-1:2006, *Railway applications – Fixed installations – DC switchgear – Part 7-1: Measurement, control and protection devices for specific use in d.c. traction systems – Application guide*

IEC 62128-1:2013, *Railway applications – Fixed installations – Electrical safety, earthing and the return circuit – Part 1: Protective provisions against electric shock*

IEC 62128-3:2013, *Railway applications – Fixed installations – Electrical safety, earthing and the return circuit – Part 3: Mutual interaction of a.c. and d.c. traction systems*

IEC 62590:2019, *Railway applications – Fixed installations – Electronic power converters for substations*

IEC 62313:2009, *Railway applications – Power supply and rolling stock – Technical criteria for the coordination between power supply (substation) and rolling stock*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1
contact line system
support system and contact line supplying electric energy to vehicles through current-collecting equipment

Note 1 to entry: The contact line system can comprise

– the contact line;
– masts and foundations;
– supports and any components registering the conductors,
– cross-spans or cables,
– tensioners,
– other along track conductors such as feeders, earth wires and return conductors when supported from the same masts as the contact line,
– conductors connected permanently to the contact line for supplying other electrical equipment such as lighting, signal operation, point control and point heating.

[SOURCE: IEC 60050-811:2017, 811-33-59]

3.2
electric traction power supply system
railway electrical distribution network used to provide energy for rolling stock

Note 1 to entry: The system includes:

– contact line systems;
– return circuit of electric traction power supply systems;
– electrical installations in power plants and substations, which are utilized solely for distribution of power directly to the contact line;
– electrical installations of switching stations.

[SOURCE: IEC 60050-811: 2017, 811-36-21, modified – "power supply" added in the term for enhancing clarity since electric traction is typically used for onboard power supply. Also, running rails of non-electrified lines in the vicinity of, and conductively connected to the running rails of an electric traction power supply system, and electrical installations which are supplied from contact lines either directly or via a transformer have been excluded from Note 1 to entry.]

3.3
traction substation <electric traction>
substation <electric traction>
substation, the main function of which is to supply an electric traction power supply system

Note 1 to entry: The synonym substation is used only when the context is clear

[SOURCE: IEC 60050-811:2017, 811-36-02]

3.4
switching station
traction switching station
installation from which electrical energy can be distributed to different feeding sections or from which different feeding sections can be switched on and off or can be interconnected

[SOURCE: IEC 60050-811:2017, 811-36-22]

3.5
feeding section
electrical section of the route fed by individual track feeder circuit-breakers within the area supplied by one or more substations

[SOURCE: IEC 60050-811:2017, 811-36-25]

3.6
electrical safety
freedom from risk that is not tolerable and which is caused by electricity

[SOURCE: IEC 60050-195:2021, 195-01-20]

3.7
electric shock
physiological effect resulting from an electric current passing through a human body or livestock

[SOURCE: IEC 60050-195:2021, 195-01-04]

3.8
return circuit
all conductors which form the intended path for the traction return current and the current under fault conditions

Note 1 to entry: The conductors can be for example:

- running rails;
- return conductor rails;
- return conductors;
- return cables.

[SOURCE: IEC 60050-811:2017, 811-35-01]

3.9
switchgear
switching devices and their combination with associated control, measuring, protective and regulating equipment, also assemblies of such devices and equipment with associated interconnections, accessories, enclosures and supporting structures, intended in principle for use in connection with generation, transmission, distribution and conversion of electric energy

[SOURCE: IEC 60050-441:1984, 441-11-02]

3.10
protection operating time
interval of time between the fault inception and the instant of initiation of the opening operation of a switching device, e.g. circuit-breaker

Note 1 to entry: This time includes measurement, communication and protection device operation.

3.11
opening time <of a mechanical switching device>
interval of time between the specified instant of initiation of the opening operation and the instant when the arcing contacts have separated in all poles

Note 1 to entry: The instant of initiation of the opening operation, i.e. the application of the opening command (e.g. energizing the release, etc.), is given in the relevant specifications.

[SOURCE: IEC 60050-441:1984, 441-17-36]

3.12
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

[SOURCE: IEC 60050-441:1984, 441-17-39]

3.13
fault clearance time
time interval between the fault inception and the fault clearance

Note 1 to entry: This time is the longest fault current interruption time of the associated circuit-breaker(s) for elimination of fault current on the faulty item of plant.

Note 2 to entry: Fault clearance time is the total of the protection operating time, the (mechanical) opening time and the arc extinction time. The latter two are included in break-time, IEC 60050-441–17–39.

[SOURCE: IEC 60050-448:1995, 448-13-15, modified – Note 2 to entry has been added.]

3.14
touch voltage <effective>
voltage between conductive parts when touched simultaneously by a human being or livestock

Note 1 to entry: The value of the touch voltage is influenced by the impedance of the human being or the livestock in electric contact with these conductive parts.

[SOURCE: IEC 60050-195:2021, 195-05-11]

3.15
fault condition
non intended condition caused by short-circuit, whilst the time duration is terminated by the correct function of the protection devices and circuit-breakers

Note 1 to entry: For the relevant fault duration the correct operation of protection devices and circuit-breakers is taken into account.

[SOURCE: IEC 62128-1:2013, 3.4.5, modified – "Whilst" added so as to link the sentence "The time duration …" with the rest of the definition.]

3.16
low resistance fault
fault condition where the resistance of the fault is sufficiently low that the fault current has a similar magnitude to that which would flow if the fault resistance were zero

Note 1 to entry: The resistance of the fault is typically dominated by the resistance of the power arc.

Note 2 to entry: In this definition, resistance will be understood as also being impedance for AC fault currents.

3.17
high resistance fault <for electric traction power supply system>
shunt fault with high resistance at the fault location, where the resistance of the fault is sufficiently high that the fault current has a substantially different magnitude to that which would flow with a low resistance fault

Note 1 to entry: In this definition, resistance will be understood as also being impedance for AC fault currents.

[SOURCE: IEC 60050-448:1995, 448-13-08, modified – Definition amended to enhance clarity for the application in electric traction power supply systems. Note 1 added.]

3.18
abnormal operating condition <for electric traction power supply system>
condition where the system operates beyond its intended capabilities such that damage or reduced life expectancy can be anticipated

3.19
short-circuit
accidentdal or intentional conductive path between two or more conductive parts forcing the electric potential differences between these conductive parts to be equal to or close to zero

[SOURCE: IEC 60050-151:2001, 151-12-04]

3.20
current collector
equipment fitted to a vehicle and intended to collect current from a contact wire or conductor rail

[SOURCE: IEC 60050-811:2017, 811-32-01]

3.21
protection
provisions for detecting faults or other abnormal operating conditions in a power system, for enabling fault clearance, for terminating abnormal operating conditions, and for initiating signals or indications

Note 1 to entry: The term "protection" is a generic term for protection equipment or protection systems.

Note 2 to entry: The term "protection" may be used to describe the protection of a complete power system or the protection of individual plant items in a power system e.g. transformer protection, line protection, generator protection.

Note 3 to entry: Protection does not include items of power system plant provided, for example, to limit overvoltages on the power system. However, it includes items provided to control the power system voltage or frequency deviations such as automatic reactor switching, load-shedding, etc.

[SOURCE: IEC 60050-448:1995, 448-11-01, modified – "abnormal condition" becomes "abnormal operating conditions".]

3.22
protection system
arrangement of one or more protection equipments, and other devices intended to perform one or more specified protection functions

Note 1 to entry: A protection system includes one or more protection equipment, intelligent electronic devices (IED), instrument transformer(s), wiring, tripping circuit(s), auxiliary supply(s) and, where provided, communication system(s). Depending upon the principle(s) of the protection system, it may include one end or all ends of the protected section and, possibly, automatic reclosing equipment.

Note 2 to entry: The circuit-breaker(s) are excluded.

Note 3 to entry: The circuit-breaker protection functions are included, e.g. direct overcurrent or falling voltage release of dc-circuit-breaker(s).

[SOURCE: IEC 60050-448:1995, 448-11-04, modified – Note 3 to entry added.]

3.23
protection equipment
equipment incorporating one or more protection relays and, if necessary, logic elements intended to perform one or more specified protection functions

Note 1 to entry: A protection equipment is part of a protection system.

[SOURCE: IEC 60050-448:1995, 448-11-03, modified – Example omitted.]

3.24
protection relay
measuring relay which, either solely or in combination with other relays, is a constituent of a protection equipment

[SOURCE IEC 60050-448:1995, 448-11-02]

3.25
protected section
part of a power system network, or circuit within a network, to which specified protection has been applied

Note 1 to entry: The protected section normally originates from a point of automatic disconnection to at least the next point of automatic disconnection or the end of the circuit.

Note 2 to entry: An electric traction power supply system is a form of power system network.

[SOURCE: IEC 60050-448:1995, 448-11-05, modified – Notes to entry added.]

3.26
selectivity of protection
ability of a protection to identify the faulty section and/or phase(s) of a power system

Note 1 to entry: The synonym selectivity is used only when the context is clear.

[SOURCE: IEC 60050-448:1995, 448-11-06, modified – Note 1 to entry added.]

3.27
reliability of protection
probability that a protection can perform a required function under given conditions for a given time interval

Note 1 to entry: The required function for protection is to operate when required to do so and not to operate when not required to do so.

[SOURCE: IEC 60050-448:1995, 448-12-05]

3.28
redundancy
in an item, existence of more than one means for performing a required function

[SOURCE: IEC 60050-448:1995, 448-12-08]

3.29
sensitivity <of protection>
minimum operating level (e.g. current, voltage, frequency, temperature) in a process that can be detected for the purpose of protection

EXAMPLE Sensitivity of a protection system can be expressed by minimum fault current or maximum fault impedance coverage.

3.30
main protection
protection expected to have priority in initiating fault clearance or an action to terminate an abnormal condition in a power system

Note 1 to entry: For a given item of plant, two or more main protections may be provided.

[SOURCE: IEC 60050-448:1995, 448-11-13]

3.31
backup protection
protection which is intended to operate when a system fault is not cleared, or abnormal condition not detected, in the required time because of failure or inability of other protection to operate or failure of the appropriate circuit-breaker(s) to trip

[SOURCE: IEC 60050-448:1995, 448-11-14, modified – Note to entry omitted.]

3.32
circuit local backup protection
backup protection where the input is either from those transducers which are used by the main protection or from transducers associated with the same primary circuit as the main protection

[SOURCE: IEC 60050-448:1995, 448-11-15 modified – "which is energised either from those instrument transformers which energize"" replaced with "where the input is either from those transducers which are used by". "instrument transformers" replaced with "a transducer" to make it more generic. Note to entry omitted.]

3.33
substation local backup protection
backup protection where the input is taken from a transducer located within the same substation as the corresponding main protection and not associated with the same primary circuit

Note 1 to entry: Substation local backup also extends to switching station local backup where appropriate.

[SOURCE: IEC 60050-448:1995, 448-11-16 modified – 'which is energized" replaced with "where the input is taken". "instrument transformers" replaced with "a transducer" to make it more generic. Note 1 to entry added.]

3.34
remote backup protection
backup protection located in a substation remote from that substation in which the corresponding main protection is located

[SOURCE: IEC 60050-448:1995, 448-11-17]

3.35
circuit-breaker failure protection
protection which is designed to clear a system fault by initiating tripping of other circuit-breaker(s) in the case of failure to trip of the appropriate circuit-breaker

[SOURCE: IEC 60050-448:1995, 448-11-18]

3.36
tripping
opening of a circuit-breaker by either manual or automatic control or by protective devices

[SOURCE: IEC 60050-448:1995, 448-11-31]

3.37
direct overcurrent release
overcurrent release directly energized by the current in the main circuit of a mechanical switching device

[SOURCE: IEC 60050-441:1984, 441-16-36]

3.38
indirect overcurrent release
overcurrent release energized by the current in the main circuit of a mechanical switching device through a current transformer or a shunt

[SOURCE: IEC 60050-441:1984, 441-16-37]

4 System to be protected

4.1 Description

The system to be protected within the scope of this document is the electric traction power supply system, within the limits set out in Figure 1. The electric traction power supply system comprises:

– infeed to traction power conversion;
– traction power conversion (e.g. converter, transformer);
– infeed to secondary distribution busbar (including bus coupler);
– infeed to power absorbing equipment (e.g. energy storage system or braking resistor unit);
– line feeder, traction power distribution to the contact line system;
– interconnecting feeders between secondary distribution busbars, e.g. between two substations or switching stations;
– switching station (including switching station feeder and bus coupler);
– autotransformers;
– contact line;
– return circuit.

Not every electric traction power supply system necessarily has all of the above mentioned parts.

NOTE 1 The operational responsibility of the above mentioned components can be split among different operators (owners). However, the protection principles described hereafter are valid for all installations.

The electric traction power supply system has interfaces to other parts of the railway system. These interfaces can include:

– infeed to the primary distribution busbar;
– rolling stock;
– electrical installations fed by the contact line system or busbar (e.g. auxiliary transformers).

Other subsystems or equipment, e.g. signalling and communication can be influenced by the electric traction power supply system but their protection is not within the scope of this document.

Transmission and distribution power lines which are in parallel to or in the railway boundary are not considered to be part of the electric traction power supply system. These are considered to be covered by the protection principles for general transmission and distribution systems.

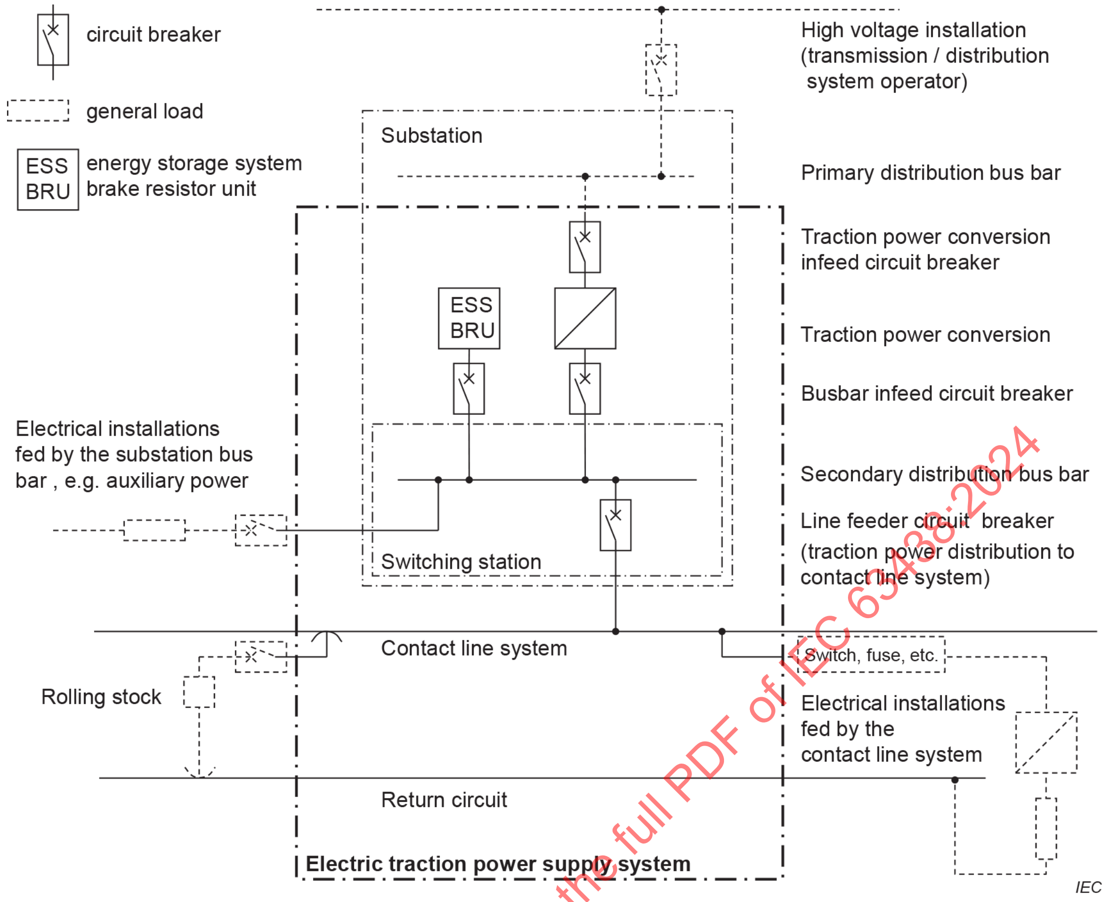


Figure 1 – Electric traction power supply system and its interfaces

NOTE 2 For DC systems the infeed to the secondary distribution busbar as shown in figure 1 can either be a circuit-breaker or a disconnector. See 6.3.2.

Figure 1 shows a traction substation, however it also applies to the relevant parts of a switching station, for example with a switching station feeder instead of a line feeder.

4.2 Interfaces

4.2.1 Infeed

The interface between the electric traction power supply system and the transmission / distribution system is the feeder circuit-breaker at the infeed to the traction power conversion. The upstream installations are considered to be covered by the protection principles for general transmission and distribution systems, taking into account the following aspects at the interface:

- protection coordination;
- communication;
- automatic reclosure;
- direction of power flow (consumption and regeneration).

4.2.2 Rolling stock

The interface between the electric traction power supply system and the electric rolling stock is the traction unit circuit-breaker.

For internal faults within a traction unit (i.e. faults occurring downstream of the traction unit circuit-breaker) the requirements of IEC 62313:2009, Table 5, apply.

Protection of electric rolling stock against faults downstream of the traction unit circuit-breaker is not the primary function of the protection system of the electric traction power supply system, however it can provide some degree of remote backup protection for such faults.

The protection in the traction substation shall be able to detect faults which include a maximum vehicle impedance as set out in IEC 61991.

NOTE According to IEC 62313 internal faults on electric rolling stock are preferably cleared by the circuit-breaker on the vehicle. The vehicle circuit-breaker is not intentionally delayed. The substation circuit-breaker is also tripped without intentional delay in the main protection, i.e. there is no selectivity between vehicle and substation other than by current magnitude. Even when considering the outage of one of these circuit-breakers the other provides limited backup protection. Due to their non-selectivity there is no intentional delay in the clearance time.

In case of vehicles with regenerative braking the requirements of IEC 62313:2009, Clause 12 normally apply. Accordingly compliant vehicles will not continue to regenerate if there is a loss of supply voltage or a contact line-rail/earth fault condition. In cases where rolling stock is not IEC 62313 compliant, the arrangements for protection in case of regenerative braking shall be agreed with the responsible entity.

4.2.3 Electrical installations fed by the electric traction power supply system

Electrical installations not directly related to traction power, for example auxiliary power supply, are not part of the electric traction power supply system, although they may be fed by the electric traction power supply system.

The interface between the electric traction power supply system and the electrical installations which are fed by the contact line is the disconnecting device between the connection to the contact line, i.e. overhead contact line or conductor rail, and the connection to the return circuit.

The interface of the electric traction power supply system to the electrical installations which are fed by the substation busbar is the disconnecting device between the substation busbar and the electrical installation where the downstream protection takes over.

The protection of the electric traction power supply system shall be coordinated with the protection of the electrical installation. However, detection of internal faults within the electrical installations fed by the electric traction power supply system is not the primary function of the electric traction power supply system's protection system.

5 General principles

5.1 Objectives

The function of the protection system is to provide protection in the event of fault conditions and abnormal operating conditions. This protection is provided by monitoring certain process values such as current, voltage, frequency and temperature and by the initiation of interventions, such as tripping of circuit-breakers.

The major objectives for protection systems are:

- continuation of service and performance of the electric traction power supply system and minimizing the disturbance to operations as far as practicable;
- limitation of the impact and damage to the affected equipment;
- avoidance of cascading effects and expanding to other network areas;
- minimization of arcing effects and energy released during faults;
- contribution to the protection of persons against indirect electric shock.

The main aims are to prevent and limit damage of equipment and additionally contribute to electrical safety in relation to indirect contact and secondary effects, e.g. arcing. Electrical safety of the electric traction power supply system shall be ensured by satisfying a wide range of requirements including those in IEC 62128-1 and IEC 62128-3.

It is not the objective of the protection system to prevent the risk of electric shock due to direct contact with live equipment. In case of a direct contact to live conductors, e.g. during maintenance activities, the predefined reaction will come too late. This risk is not mitigated by this document.

5.2 System requirements

5.2.1 General

The protection system's basic requirements are:

– reliability of protection;
– load discrimination;
– selectivity of protection;
– speed of operation;
– economic feasibility.

These requirements should be defined and balanced against the overall requirements of the electric traction power supply system.

Due to the geographical scope and the design of the electric traction power supply system it can be necessary to subdivide its protection into a number of discrete parts. This can include automatic disconnection by the protection system of all phases or individual phases. Protection is provided at each infeed point to each part.

While the protected section is defined in terms of the automatic disconnection points, it should be recognized that the protection measurement points can be located either side of each automatic disconnection point, i.e. inside or outside the protected section. This results in either a gap in detection, or otherwise a detection overlap with another protected section. This issue shall be taken into account in developing the protection concept documentation.

The protection systems of circuits fed by more than one source shall be coordinated.

EXAMPLE 1 An example for an electrical circuit is a feeding section. At the beginning of a feeding section a circuit-breaker with protection is provided at a substation. In case of a double end feeding system, the section is fed from two sources and protected by the protection and the circuit-breaker provided at each end of the section.

In certain cases, regenerating trains can influence the performance of the protection systems. The requirements for regenerative braking are defined in IEC 62313:2009, Clause 12.

For systems where regeneration is permitted, the required protection responses to a fault by the traction power supply protection system, and also by a train or other trackside regenerative system, shall be considered and agreed with the system designer / infrastructure manager taking into account the requirements of IEC 62313.

NOTE The design of protection systems for railways utilizing regenerative braking requires particular attention regarding any impact of regeneration on the normal performance of the protection system. An example is the effect of underreach due to regeneration, where regeneration current can mask the effects of faults to distance protection.

For certain situations a single universally valid predefined action of the protection might not exist. For such situations which require specific actions, the required response of the protection system shall be agreed with the responsible entity, e.g. Infrastructure Manager.

EXAMPLE 2 The decision to automatically disconnect power in tunnel sections and hence possibly strand trains and passengers depends on the overall operational safety concept.

5.2.2 Protection reliability methods

For the protection of an electric traction power supply system a single fault condition in the power circuits shall be detected and clearance initiated even when one single failure is present in the protection system.

In order to achieve this, one or more of the following basic reliability methods shall be applied, which are based on long-term service experience in electric traction power supply systems.

The methods and related protection functionalities at the different locations in the protection chain shall be defined and coordinated with the basic design of the electric traction power supply system.

However, these methods provide different degrees of redundancy and shall therefore be applied to the protection chain by taking into account the specific requirements specified in Clause 6.

Applicable protection reliability methods (Mx) are described in the following:

a) M1: Simultaneous independent redundancy:

   With this method another protection (main-2) is operating in parallel to and independent from the main protection (main-1).

   This shall comprise independent protection relays, and can also include independent:

   1) inputs including sensors, as described in 5.3 (optional);
   2) tripping releases (optional);
   3) trip circuits (optional);
   4) auxiliary supply (optional).

   Optional items are typically to be agreed between the relevant entities, e.g. system designer and infrastructure manager.

   Using a protection relay with different functionality can increase diversity, but consideration should be given to whether it will provide comparable performance.

   Generally parallel redundancy is required for high energy fault conditions only, where significant asset damage is possible or where there is an economic reason for standardization. This reliability method ensures the fastest clearance of a fault when the main-1 protection fails.

b) M2: Circuit local backup protection:

   With this method, redundancy to the main protection is provided by a circuit local backup protection (in accordance with 3.32). Backup protection acts only in case of a sustained fault condition, e.g. indicating the main protection could have failed to clear the fault condition.

   This shall comprise independent protection relays, and can also include independent:

   1) inputs including sensors, as described in 5.3 (optional);
   2) tripping releases (optional);
   3) trip circuits (optional);
   4) auxiliary supply (optional).

   Optional items are typically to be agreed between the relevant entities, e.g. system designer and infrastructure manager.

   NOTE 1 With this method normally an additional delay time is included when clearing the fault condition in case of failure of the main protection and consequently higher levels of let through energy can occur.

   When the main protection functionality is available, the backup protection shall not interfere with the main protection system operation.

   Generally, a protection device comprising the protection functions dedicated to the method M1 can also provide supplementing protection functions used for M2.

Using method M2 the circuit local backup protection may have a reduced set of functions compared to the main protection.

c) M3: Overlapping backup protection:

This method uses the functionality of the substation local backup or remote backup protection. The protection system is organized into different protected sections with the backup protection being provided by overlapping the reach of the adjacent section(s). The protection relays at the different levels in the chain of protection fulfill the main protection for their assigned protected section and shall cover adjacent protected sections as backup, which acts only in case of a sustained fault condition when the main protection in an adjacent section has failed to clear the fault condition.

In this protection architecture overlapping sections shall be arranged for selectivity, so that if a fault condition occurs and the main is functioning normally, although a number of protection equipments can detect the fault condition, only those relevant to the faulty section complete the tripping function. The backup protection resets on incomplete operation. This can require blocking or intertripping schemes.

NOTE 2 With this method an additional delay time is normally included when clearing the fault in case of failure of the main protection and consequently higher levels of let through energy can occur.

d) M4: Supervision:

This method provides a monitoring regime which assists with the detection of latent defects affecting the capability of the protection system. This can initiate interventions which reduce the probability of the protection system being required to act while a defect is present.

This can comprise, but is not limited to:

1) monitoring of vital functions;
2) trip circuit supervision;
3) auxiliary supply supervision;
4) sensor supervision e.g. current and voltage transformers.

Supervision of the protection system supports management of the electric traction power supply system according to the protection system reliability requirements. Depending on the operational requirements two different concepts may be applied:

a) supervision which automatically initiates a trip of the associated circuit-breaker, in case the main protection system is out of service and there is no backup protection covering the protected section; or
b) supervision of the main protection in a way that the operation personnel are made aware when it is out of service and can initiate corrective action, but which does not trip the associated circuit-breaker(s). For certain cases, operation of a section which is not fully covered by the backup protection when the main protection is out of service may be accepted for limited time period.

NOTE 3 The decision if concept B can be applied depends on the overall operations safety concept.

5.2.3 Load discrimination

The protection system shall be designed taking into consideration load discrimination and should remain stable under load conditions.

In some electric traction power supply systems, it can be difficult to discriminate between fault condition and load current conditions.

This is relevant for electric traction power supply systems due to the high power demand of the trains. In some situations the magnitude of the line currents in normal operation (load) can be comparable with the magnitude of the fault currents, for faults located in positions far from the the substations and characterized by high fault loop impedance.

EXAMPLE Example of instability: If a line feeder circuit-breaker trips unnecessary while the current collector(s) on trains momentarily bridge between adjacent electrical sections, this unnecessary trip can cause a high load current to be transferred between electrical sections and result in damage of the OCL (Overhead Contact Line) due to excessive arcing.

In order to reduce unnecessary tripping for load currents the following typical protection solutions may, where appropriate, be adopted:

- impedance protection or current rate of rise functions or inverse overcurrent protection and undervoltage intertripping for DC systems as described in IEC 61992-7-1;
- impedance angle or rate of rise functions for AC systems.

5.2.4 Speed of protection

Protection systems shall facilitate fast clearance of fault conditions within a tolerable time frame. The fault clearance may be initiated without or with intentional delay. The required time frame shall take into account the following aspects:

- Equipment protection, in terms of limiting thermal and mechanical stress within the tolerances for the system design. Main protection shall consider the short term withstand capacity of the protected equipment. Backup protection shall also minimize the risk of thermal and mechanical damage. The time characteristics during backup protection shall be stated in the protection concept document.
- Electrical safety in relation to indirect contact, in terms of maximum permissible time for touch voltage according to the return circuit and earthing design. According to IEC 62128-1 the assessment of the permissible touch voltage is based on the assumption of the correct operation of the protection devices and circuit-breakers.

  Precondition is that the electric traction power supply system and vehicles are adequately designed to meet the requirements in IEC 62128-1, IEC 62128-3 and IEC 61991 regarding touch voltage and thermal design of the return circuit and earthing installations.
- Limiting of the damage due to arcing at the location of the fault, in particular for overhead contact lines.
- System stability.

5.2.5 Selectivity of protection

The protection system shall be able to selectively identify and initiate automatic disconnection of the faulty section or the faulty equipment. The healthy part of the network shall not be permanently affected, i.e. normal operation is resumed at the end of the fault switching sequence.

For the backup protection reduced selectivity is permissible.

5.2.6 Economic feasibility

The economic feasibility of a protection system concerning the economic value of the protected equipment and the consequence of a fault condition not cleared or loss of supply due to unnecessary tripping on the other hand should be considered in the design of the protection system.

5.3 Description of the protection system

Based on the functional interpretation of 3.22, the protection system applied in an electric traction power supply system is the totality of the devices to fulfil the desired function, (see Figure 2 for an example). Accordingly, the protection system can comprise:

- protection devices (i.e. a single protection function, multifunctional relays or intelligent electronic devices);

NOTE 1 Intelligent electronic devices (IEDs) contain one or more processors capable of executing the behaviour of one or more logical nodes, specified in the IEC 61850 series for protection functions.

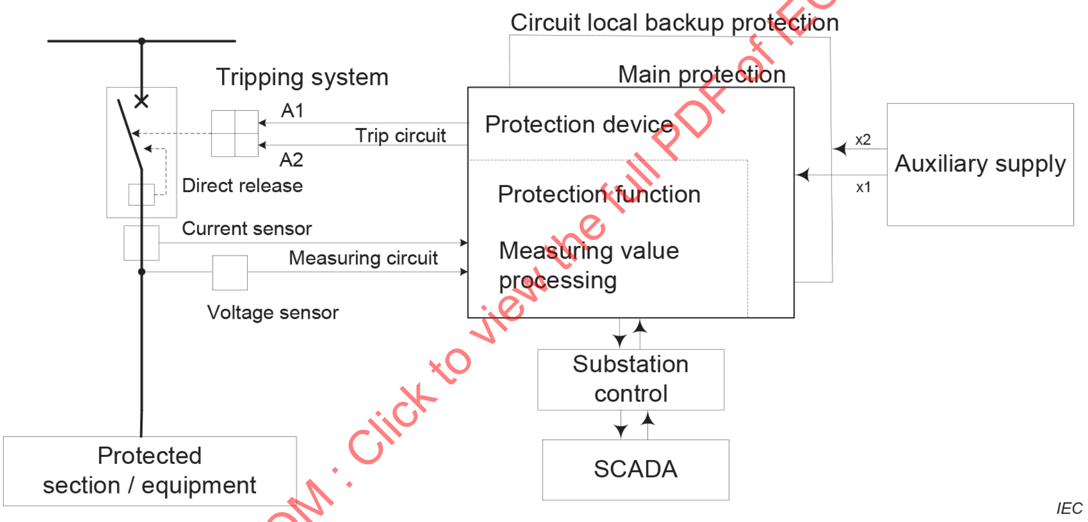
- sensors, e.g. instrument transformers, temperature sensors, position indicators;
- circuit-breaker protection functions, including tripping devices (release);
- self-supervision at device level;
- dedicated communication for protection;
- general communication for control purposes, e.g. substation control, SCADA (Supervisory Control and Data Acquisition);
- auxiliary supply.

NOTE 2 In this document the protection function of the circuit-breakers are regarded as part of the protection system. Product design properties and design specifications are covered in the relevant product standards for DC and AC switchgear, e.g. the IEC 61992 series and the IEC 62505 series.

NOTE 3 The typical auxiliary supply is DC (with local energy storage, e.g. battery).

NOTE 4 In some applications, the protection system can be combined with control system(s) to form an integrated protection and control scheme/arrangement. This could take the form of wide-area protection schemes with dedicated communications between substations, for example based on the IEC 61850 series.

NOTE 5 In some applications, other system can interact with the protection system, e.g. fire detection or emergency trip systems.



NOTE Connections from local backup protection to current and voltage measuring circuits, to tripping system and to substation control/SCADA are not shown for clarity.

Figure 2 – Example of a protection system

5.4 Fault and abnormal conditions

The protection system design shall take into account the following fault conditions:

a) low resistance fault between:

   1) any energized conductor and the traction return circuit or neutral;

   2) and where the traction return circuit is earthed, any energized conductor and the earthing system;

   3) two or more energized conductors with phase displacement or different polarities, e.g. AC lines with 60°, 120° or 180° phase displacement, or other specified phase displacement in the system design;

b) where reasonably practicable and within technical limits, high resistance fault between:

   1) any energized conductor and the earthing system, and in addition

   2) any energized conductor and the traction return circuit or neutral;

   3) two or more energized conductors.

The protection system design shall also take into account the following abnormal operating conditions:

c) system overload;

d) system over- and under-voltage;

e) system over- and under-frequency when specified, for example by the system designer or infrastructure manager;

f) abnormal condition of traction power supply equipment, e.g. rectifier open arm condition, switchgear low gas pressure;

g) circuit-breaker closure prevention (e.g. for bus coupler circuit-breaker, normally separating two busbars under out of phase condition) when specified, for example by the system designer or infrastructure manager.

The fault and abnormal conditions covered by the protection for each protected section shall be outlined in the protection concept, as described in 5.5.

NOTE Inter-system faults, e.g. between HV transmission system and electric traction power supply system, are not covered in this document.

5.5 Protection concept

For the electric traction power supply system to be protected, the design principles and requirements for the protection shall be defined in a protection concept, describing the protection architecture and redundancy philosophy. The protection concept should be elaborated as an integral part of the system design.

The protection concept shall describe the protection system for the relevant part of the electric traction power supply system, which also comprises the interface information as defined in 4.2 and considers the needs of any electrically connected network, independent of the owner or operating authority.

NOTE 1 Interfaces also include parts of the existing system which are not being changed.

The protection concept shall also describe arrangements for combined/integrated protection and control, where these are proposed.

For the protection concept, the normal switching status as well as defined outage or emergency conditions and corresponding switching status of the electric traction power supply system and its interfaces shall be considered. Concepts for individual subsections of a network are also possible, provided that all interfaces are defined unambiguously.

If the protection concept requirements are clearly identified in other design documents, these documents may be used instead of a dedicated protection concept document.

EXAMPLE 1 A design document for a new electrical section can reference company technical regulations or design frameworks which contain the required information for the protection design.

EXAMPLE 2 A general protection concept for the electric traction power supply system setting out standard parameters and required performance can be adopted as the protection concept of the subsequent individual electrical sections. In this case the individual section protection concepts only need to document deviations from the general protection concepts.

Generally the protection concept shall describe the following main subjects:

a) sections to be protected;

b) fault cases and abnormal conditions to be considered for different locations in the electric traction power supply system architecture;

c) maximum fault clearance times required by system design;

d) fault clearance characteristics achieved by the protection concept:
   1) protection operating time;
   2) break-time of the circuit-breaker;
   3) fault clearance times;

   NOTE 2 Maximum fault clearance times and maximum break-time of the circuit-breaker required by the system design are provided by the entity responsible for system integration and jointly agreed.
e) main protection and related protection device functions;
f) reliability methods (as generally described in 5.2.2 and in accordance with the requirements in Clause 6) and associated protection device functions;
g) selectivity requirements;
h) coordination and grading requirements;
i) protection coordination with interfacing systems (see 4.2).

The protection concept shall also include a statement addressed to the system integrator to advise that they need to establish implementation and maintenance requirements for the protection system. For example this can include processes for protection setting management, commissioning and ongoing maintenance.

The protection schemes given in informative Annex A, Figure A.1 to Figure A.6, may serve as examples which need to be adapted and modified according to the individual system requirements. They can be used as part of the protection concept.

An example of a protection concept for a 25 kV line feeder is presented in the informative Annex B. Additionally informative Annex C provides an example of a protection scheme for a 25 kV line section with automatic changeover section.

6 Specific requirements of different systems

6.1 General

The specific protection requirements for AC and DC systems are given in separate subclauses, due to differences in architecture and operation. Specific differences for AC systems are identified in the relevant subclauses.

In all cases the protection arrangements for individual stages of the electric traction power supply system (power conversion infeed; busbar infeed; line feeder, etc.) shall be coordinated and graded with each other in respect of both upstream and downstream directions.

The protection system shall take account of changes in the feeding configurations and provide a suitable protection concept for all configurations. This can require the use of multiple settings, and for modern numerical relays these can be pre-defined in multiple parameter sets or setting groups.

For all electric traction power supply systems, it is possible that a train can run into a faulted section during the fault, so that its current collector bridges an insulated overlap or section insulator. This can affect normal protection operation, and also can reenergize a fault which has been cleared. This scenario shall be taken into account within the development of the protection concept.

An informative overview of the reliability methods described in 6.2 and 6.3 is given in 6.4 and Table 1.

6.2 AC systems

6.2.1 Power conversion infeed

The protection of the power conversion infeed shall provide main protection for low resistance fault conditions in the protected section of the power conversion infeed. It can also provide protection against inadmissible thermal overloads of the power conversion infeed circuit. The main protection shall discriminate between low resistance fault conditions and maximum loads caused by train operation as described in 5.2.3.

When the power conversion unit has internal protection functions which can fulfil the function of main or backup protection these functions may be used.

EXAMPLE Some oil immersed traction transformers are equipped with Buchholz relay, oil temperature and level monitoring, possibly supplemented by winding temperature monitoring.

Reliability of the power conversion infeed protection shall be achieved by using at least one application of the following reliability methods, depending on the protection concept and taking into account the overall operation requirements:

- M1: simultaneous independent redundancy for high energy fault conditions in the power conversion feeder circuit, which can act also as a backup (M3) for the downstream protection;
- M2: circuit local backup protection, which can act also as a backup (M3) for the downstream protection;
- M3: overlapping backup protection by the upstream primary incoming feeder circuit protection which may be configured as remote backup protection;
- M4, concept A: supervision of main protection and tripping of associated circuit-breaker when main protection is out of service.

Additionally, the power conversion infeed circuit-breaker can be fitted with a circuit-breaker failure protection to initiate tripping of the upstream primary incoming feeder circuit-breaker(s) in the case of a failure to trip.

In cases where the fault condition can continue to be supplied from other sources, the protection scheme shall also initiate disconnection of the fault condition from these sources. When tripping the power conversion infeed circuit-breaker, the downstream circuit-breaker(s) can also be tripped, or disconnector(s) opened subsequently in order to separate the power conversion.

6.2.2 Busbar infeed

For AC systems different configurations for the busbar infeed circuit can be used, typically with either a circuit-breaker or a disconnector in the circuit. For AC 16,7 Hz systems the busbar infeed circuit is typically equipped with a circuit-breaker, either with a dedicated protection and/or included in a mass tripping scheme, e.g. busbar protection, frame leakage protection.

Depending on the configuration the following protection requirements shall apply:

a) Circuit-breaker with protection: The protection of the busbar infeed shall provide main protection for low impedance fault conditions in the busbar. It can additionally provide some backup protection (M3) for the downstream line protection. The main protection shall discriminate between fault conditions and maximum loads caused by train operation as described in 5.2.3. This protection can also provide protection against inadmissible thermal overloads of the power conversion infeed circuit.

   The reliability of this protection shall be increased by using at least one application of the following methods:

   - M2: circuit local backup protection;
   - M3: overlapping backup protection by the power conversion protection.

It can additionally be fitted with a circuit-breaker failure protection to initiate tripping of the upstream power conversion feeder circuit-breaker in the case of failure to trip.

b) Disconnector: The protection in conjunction with the circuit-breaker in the upstream power conversion feeder shall also act as the main protection for low impedance fault conditions in the busbar. In this case the reliability criteria of the upstream power conversion circuit apply.

Where the busbars are sectioned, e.g. with bus section circuit-breakers or disconnectors, the protection arrangements should also take into account the feeding configurations, i.e. with the bus sections connected or separated. Under some of these scenarios, the bus section circuit-breaker can be considered to be a supplementary infeed.

In cases where the fault condition can continue to be supplied from other sources, the protection scheme shall also initiate disconnection of the fault condition from these sources. For busbar faults it is normally the case that the faulted busbar section is disconnected from all other equipment.

The busbar protection requirements set out in this clause may also be applied to busbars at other locations, e.g. switching stations.

6.2.3 Line feeder

6.2.3.1 General

The protection of the line feeder circuit(s) shall provide main protection for low impedance fault conditions in the protected section of the contact line(s), as well as for thermal overloads.

The main protection shall discriminate between fault conditions and heavy loads caused by train operation as described in 5.2.3. Main protection can generally be provided by distance or overcurrent protection. Where impedance-based distance protection is employed, timed zones can be used to provide selectivity.

For AC systems the reliability of the line protection for the protected section shall be achieved by using at least one application of the following methods, depending on the protection concept and taking into account the overall operation requirements:

- M1: simultaneous independent redundancy;
- M2: circuit local backup protection able to cover the complete protected section;
- M2 limited reach, supported by M4: in case that the circuit local backup protection cannot cover the complete protected section a supervision of the main protection is required;
- M3: overlapping backup protection able to cover the complete protected section;
- M3 limited reach, supported by M4: in case that the next upstream feeder protection cannot cover the complete protected section a supervision of the main protection is required; in this case also additional protection functions integrated in the same device as the main protection may be used for supplementing redundancy;
- M4: supervision of main protection.

Additionally, a circuit-breaker failure protection can be implemented to initiate tripping of the upstream feeder circuit-breaker in the case of failure to trip.

In respect of protection for thermal overloads backup protection is not generally required.

Protected sections for AC systems can be defined for the feeding section of each single line or can consist of a number of parallel lines grouped in one protected section. For grouped protected sections selectivity between lines should be achieved by sequential switching after the initial fault clearance period.

Single protected sections (see Figure 3 for an example) shall be arranged to protect a line section between two circuit-breakers with protection or a single end section fed by one circuit-breaker and shall provide selectivity to adjacent line sections.

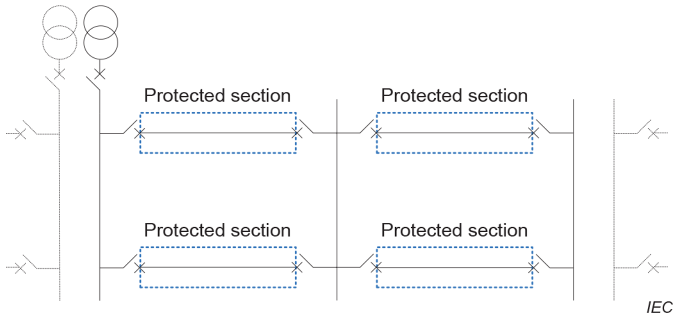


Figure 3 – Example for single protected line sections

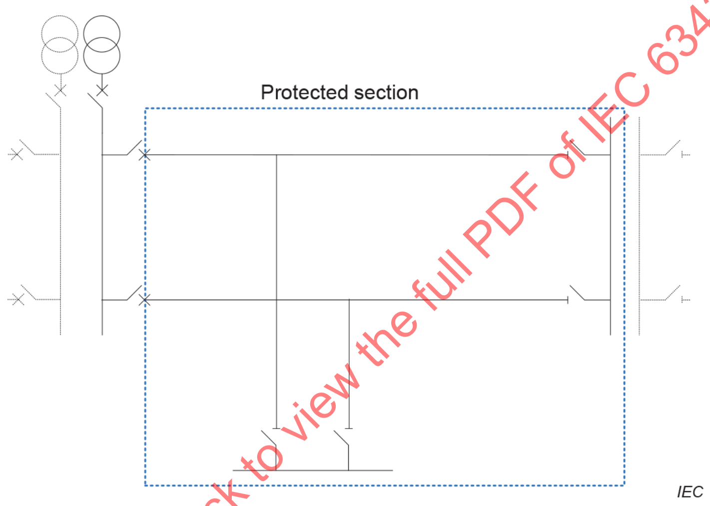


Figure 4 – Example for a grouped protected line section

For grouped protected sections (see Figure 4 for an example) the protection philosophy shall trip the full protected section for a fault condition on any line. Following the clearance of the fault (i.e. during the dead time) further switching operations should be used to isolate the sub-section containing the fault and restore supplies. This may be achieved through the use of auto-reclose, or by the use of wide-area protection schemes with communications links between substations within the grouped section.

EXAMPLE 1 For an auto-reclose system of a grouped protected section as shown in Figure 4, the main functional stages of sequential switching in case of a fault condition are as follows:

1) short circuit occurs in one of the two lines;
2) the protection systems in the traction substation of both lines initiate a trip;
3) both line feeder circuit-breakers of the traction substation open and the two lines are de-energized;
4) after some seconds the under-voltage relays in the switching stations cause the opening of the related circuit-breakers or disconnectors to achieve the electrical separation of the two lines;
5) after a further delay of a few seconds (from the electrical separation of the two lines), the two line feeder circuit-breakers of the traction substation reclose;
6) the line feeder circuit-breaker connected to the faulty line opens again;
7) the line feeder circuit-breaker of the healthy line remains closed.

EXAMPLE 2 For a wide-area system as shown in Figure 4 the communication links between substations and switching stations can be provided using an IEC 61850 series substation automation system. Generally for this type of grouped protected section the main functional stages of sequential switching in case of a fault condition are as follows:

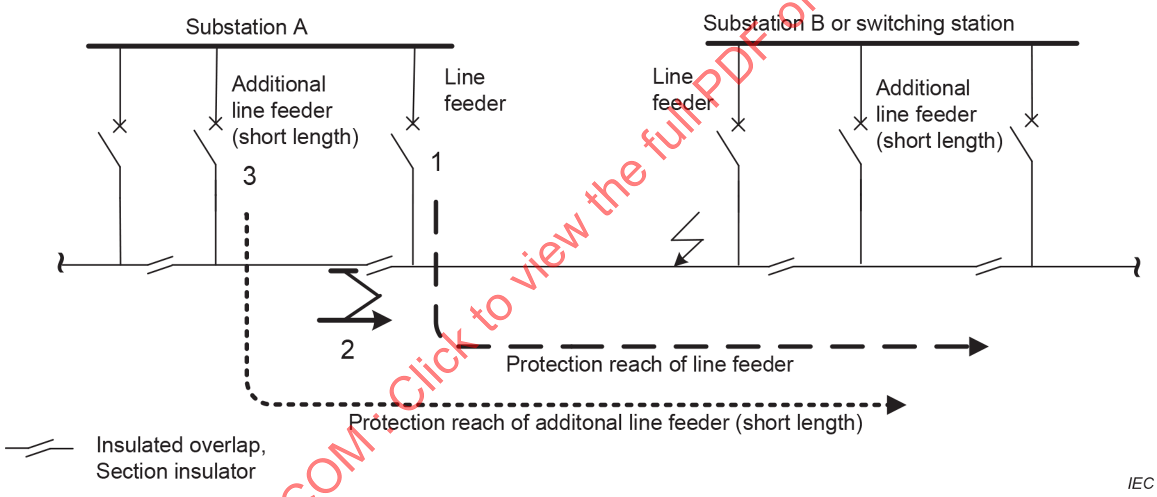
1) short circuit occurs in one of the two lines;
2) the protection systems in the traction substation of both lines initiate a trip;
3) both line feeder circuit-breakers of the traction substation open and the two lines are de-energized; healthy sub-sections are identified during the fault condition;

4) the intermediate switches on the faulted sub-sections open during the dead time; those on the healthy sub-sections are blocked from opening;
5) once the switching sequence completes, supplies are restored to the healthy sub-sections only.

6.2.3.2 AC 16,7 Hz – special conditions for line protection

AC 16,7 Hz systems are characterized by:

- meshed areas of the network, where the fault current can reach levels up to the maximum specified in IEC 62313;
- relatively long duration between successive zero crossings (30 ms);
- the need for very fast fault clearance in order to minimize the risk of equipment damage; in certain cases clearance of the fault is necessary within the first half-period; this can require specific protection functions and fast acting circuit-breakers;
- typically double end feeding sections, possibly in combination with T-feeding which may lead to impedance underreach;
- insulated overlaps and section insulators, which can be bridged by current collectors, causing re-energization of a faulty section by another feeder at the same busbar or at the next substation; this can require special protection settings and/or feeding arrangements as shown in Figure 5, where an additional line feeder is supplying a short section of the contact line.



Key

1 fault and trip of line feeder

2 bridging of section insulation by current collector and re-energization of faulty section

3 trip of the additional line feeder of the short section

NOTE The reactions of feeders of substation B are the same, but are not shown for clarity.

Figure 5 – Example for an extended protected section of an additional line feeder of a short section by bridged section insulation

6.2.4 Switching station feeder

If the feeders at sectioning and paralleling locations have dedicated protection equipment with main and backup protection configurations, the requirements of 6.2.3 shall apply.

NOTE Backup protections can be located in another switching station or substation (e.g. overlapping zones of impedance-based distance protection).

Alternatively these feeders may be configured to operate a switching sequence following the clearance of the fault to isolate the sub-section containing the fault and to restore supplies.

6.2.5 Autotransformer

The protection of the autotransformer, where dedicated circuit-breakers are installed, shall provide main protection for low impedance fault conditions. It should also cover inadmissible thermal overloads. Generally, in this case the protection in the line feeder can act as the remote backup protection (M3) of the Autotransformer.

Where autotransformers are connected by disconnectors or switch-disconnectors with insufficient switching capacity for clearing the fault, the protection shall initiate fault clearance by tripping non-dedicated circuit-breakers.

This can be by:

- remote detection and tripping of the line or switching station feeder; or
- local detection and intertripping of remote circuit-breakers.

In this case the reliability methods are inherently defined by those of the non-dedicated circuit-breakers protection.

In addition low current fault conditions can be cleared by local switch-disconnectors.

When the autotransformer has internal protection functions, these may be used in the protection concept.

EXAMPLE Some oil immersed traction transformers are equipped with Buchholz relay, oil temperature and level monitoring, possibly supplemented by winding temperature monitoring.

Depending on the importance and selectivity requirements with regard to the individual autotransformer stations, additional protection schemes which apply the reliability methods in 5.2.2 can be provided.

6.3 DC systems

6.3.1 Power conversion infeed

The protection of the AC power conversion infeed circuit-breaker shall provide main protection for low impedance fault conditions in the protected section of the power conversion infeed.

This protection shall also provide protection against inadmissible thermal overloads. Usually the power conversion feeder circuit-breaker is the only protection for the AC/DC converter in respect of thermal overload. Consequently, the protection of the power conversion feeder shall take into account the withstand capability and maximum fault clearance time as described in IEC 62590:2019.

NOTE According to IEC 62590:2019 the converter of a traction substation is designed to sustain a short circuit for at least 150 ms, unless agreed otherwise between purchaser and supplier.

The main protection shall discriminate between fault conditions and maximum loads caused by train operation as described in 5.2.3.

When the power conversion unit has internal protection functions which can supplement the function of main or backup protection these functions may be used.

EXAMPLE Some oil immersed traction transformers are equipped with Buchholz relay, oil temperature and level monitoring, possibly supplemented by winding temperature monitoring. Some dry type transformers are equipped with winding temperature monitoring. Some rectifiers are equipped with diode fuse protection and/or temperature monitoring. Some controlled converters can actively limit or interrupt their current flow and/or initiate disconnection.

Reliability of the power conversion infeed protection shall be achieved by using at least one application of the following reliability methods, depending on the protection concept and taking into account the overall operation requirements:

- M2: circuit local backup protection able to cover complete protected section;
- M3: overlapping backup protection by the upstream primary incoming feeder circuit protection which may be configured as substation local or remote backup protection;
- M3 limited reach, supported by M4: in cases where the upstream feeder protection cannot cover the complete protected section supervision of the main protection is required;
- M4 concept A: supervision of main protection and tripping of associated circuit-breaker when main protection is out of service.

Additionally the power conversion infeed circuit-breaker can be fitted with a circuit-breaker failure protection to initiate tripping of the upstream primary incoming feeder circuit-breaker(s) in the case of failure to trip.

In cases where the fault condition can continue to be supplied from other sources the protection scheme shall also initiate disconnection of the fault condition from these sources. When tripping the power conversion feeder circuit-breaker the downstream DC busbar feeder circuit-breaker should also be tripped or disconnector opened subsequently in order to separate the power conversion.

For special applications of power conversion units, e.g. line commutated inverters, the opening of the upstream and downstream breakers needs to be coordinated.

EXAMPLE Typically for line commutated inverters the DC side opens first and the AC side later with some delay in order to avoid commutation failure.

6.3.2 DC busbar infeed

For the DC busbar infeed different principle configurations can be used, typically with either a circuit-breaker or a disconnector in the circuit.

Depending on the configuration the following protection requirements shall apply:

- Circuit-breaker with protection: The protection shall provide main protection for low resistance fault conditions at the busbar. Additionally, it can provide some overlapping backup protection (M3) for the downstream line protection. The main protection shall discriminate between fault conditions and maximum loads caused by train operation as described in 5.2.3.

  The reliability of this protection shall be increased by the upstream protection acting as overlapping backup protection (M3). Additionally, it can be fitted with a circuit-breaker failure protection to initiate tripping of the upstream power conversion feeder circuit-breaker in the case of failure to trip.

  Due to the nature of the direct acting device generally used in the line feeder circuit-breaker, (e.g. direct overcurrent release), selectivity for high current faults on the line can be impossible.

  NOTE 1 Even if the line feeder protection has opened, the busbar feeder will open as well because a reset of the triggering of the protection function is not possible with a direct acting device.

  In case of internal faults in a converter a reverse current protection can be used to prevent reverse fault currents fed by the other converter(s) or from the lines.

  In case the busbar infeed circuit-breaker connects regenerative power absorbing equipment to the DC busbar the according protection of the circuit-breaker shall provide main protection for low impedance fault conditions in the regenerative power absorbing unit. For energy storage systems, the circuit-breaker protection shall also provide main protection for low resistance fault conditions at the busbar.

When the regenerative power absorbing equipment has internal protection functions which can supplement the function of main or backup protection these functions may be used.

When tripping the busbar feeder circuit-breaker the downstream line feeder circuit-breaker(s), in conjunction with any bus-section/bus-coupler circuit-breaker(s), can also be tripped in order to separate the busbar.

- Circuit-breaker without protection, or disconnector: The protection in conjunction with the circuit-breaker in the upstream power conversion feeder shall also act as the main protection for low resistance fault conditions in the busbar.

Examples for protection functions and characteristics that can be used and further details are described in IEC 61992-7-1.

NOTE 2 In IEC 61992-7-1 this feeder is referred to as "rectifier circuit-breaker" with functional designation (R).

If the busbars are sectioned, e.g. with bus section circuit-breakers or disconnectors, the protection arrangements should also take into account the possible feeding configurations, i.e. with the sections connected or separated. Under some of these scenarios, the bus section circuit-breaker can be considered to be a supplementary infeed.

6.3.3 Line feeder

The protection of the line feeder circuit(s) shall provide main protection for low resistance fault conditions in the protected section of the contact line(s). This protection can also provide protection against inadmissible thermal overloads.

Depending on the line configuration, i.e. separation by means of switching stations with circuit-breakers and associated protection, one or more zones of protection can apply.

DC high speed current limiting circuit-breakers of class H according to IEC 61992-1 are generally fitted with a direct acting device, e.g. direct overcurrent release or direct acting falling voltage relay, which may be used as the main protection.

NOTE 1 IEC 61992-1 distinguishes between H-, V-, and S-breakers. Typically class H breakers are used in DC line feeder protection.

The main protection shall discriminate between fault conditions in its protected section and large load currents caused by train operation as described in 5.2.3.

For DC systems the reliability of the line protection for the protected section shall be achieved using at least one application of the following methods, depending on the protection concept and taking into account the overall operation requirements:

- M1: simultaneous independent redundancy;

  EXAMPLE The direct overcurrent release of a DC high-speed circuit-breaker providing coverage for the full extent of the protected section can be defined to ensure reliability classification M1 for the indirect overcurrent release which is providing the main protection.

- M2: circuit local backup protection able to cover the complete protected section;
- M2 limited reach:
  1) supported by M3: in case that the circuit local backup protection cannot cover the complete protection section, intertripping of the circuit-breaker of the respective adjacent feeder is required; or
  2) supported by M4: in case that the circuit local backup protection cannot cover the complete protected section, a supervision of the main protection according to 5.2.2 is required; additionally a circuit-breaker failure protection may be implemented to initiate tripping of the upstream feeder circuit-breaker in the case of failure to trip;

- M3 limited reach, supported by M4: in cases where the next upstream feeder protection cannot cover the complete protected section, supervision of the main protection shall be provided; additionally a circuit-breaker failure protection may be implemented to initiate tripping of the upstream feeder circuit-breaker in the case of failure to trip.

In respect of protection for thermal overloads, backup protection is not generally required.

Examples for protection functions and characteristics that can be used and further details are described in IEC 61992-7-1.

NOTE 2 In IEC 61992-7-1 this feeder is referred to as "Line circuit-breaker" with functional designation (L).

6.3.4 Switching station feeder

If the feeders of sectioning and paralleling locations have dedicated protection equipment with main and backup protection configurations, the requirements of 6.3.3 shall apply.

Alternatively, these feeders can be configured to operate a switching sequence following the clearance of the fault to isolate the sub-section containing the fault and restore supplies.

6.3.5 Frame leakage protection

In DC substations normally the DC switchgear and the rectifier cubicle are insulated from earth. Insulation fault conditions within the DC switchgear and rectifier cubicle are detected by a frame fault detection, using a current detection device or a high impedance voltage detection device, as described in IEC 61992-7-1.

In case of an insulation failure inside the DC switchgear or rectifier cubicle the frame leakage detection shall initiate the opening of all downstream and upstream breakers. In cases where the fault condition can be continued to be supplied from other sources the protection scheme shall also initiate disconnection of the fault condition from these sources. Therefore an intertripping scheme can be required.

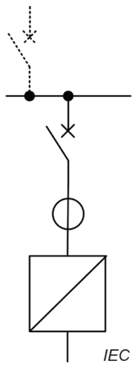
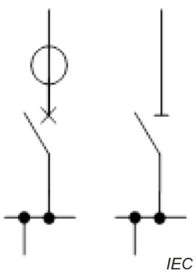
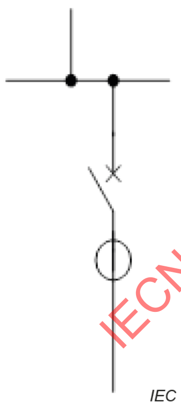
The frame leakage protection can provide some backup protection (M3) for the power conversion feeder and partly for the busbar feeder.

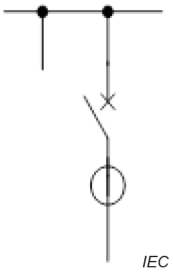
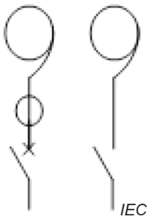
6.4 Overview of protection reliability methods

Table 1 provides an informative overview of the methods to increase reliability of the protection for electric traction power supply systems that are described in 6.2 and 6.3, depending on the system configuration and based on the general principles described in 5.2.

The informative Annex A provides examples with protection schemes illustrating an application of the given principles.

Table 1 – Overview of reliability methods

Location of protection [a]	**Options for reliability methods: [b] (Subclause 5.2.2)**
Power Conversion infeed  	General: transformer internal protection and/or converter internal protection AC systems, Subclause 6.2.1 M1: simultaneous independent redundancy M2: circuit local backup protection M3: overlapping backup protection by upstream incoming feeder protection M4, concept A: supervision of main protection DC systems, Subclause 6.3.1: M2: circuit local backup protection M3: overlapping backup protection by primary incoming feeder protection M3 limited reach, supported by M4: upstream protection together with supervision of main protection M4, concept A: supervision of main protection
Busbar infeed  	AC systems with circuit-breaker, Subclause 6.2.2: M2: circuit local backup protection M3: overlapping backup protection by power conversion protection DC systems with circuit-breaker, Subclause 6.3.2: M3: overlapping backup protection by power conversion feeder protection AC and DC systems with disconnector[c]: busbar fault protection by upstream power conversion feeder
Line Feeder  	AC systems, Subclause 6.2.3: M1: simultaneous independent redundancy M2: circuit local backup protection M2: limited reach, supported by M4: circuit local backup protection together with supervision of main protection M3: overlapping backup protection able to cover the complete protected section M3: limited reach, supported by M4: next upstream protection together with supervision of main protection M4: supervision of main protection DC systems, Subclause 6.3.3: M1: simultaneous independent redundancy M2: circuit local backup protection M2: limited, supported by M3: circuit local backup protection together with intertripping of adjacent feeder M2: limited, supported by M4: circuit local backup protection together with supervision of main protection M3: limited, supported by M4: next upstream protection together with supervision of main protection

Location of protection [a]	Options for reliability methods: [b] (Subclause 5.2.2)
Switching station feeder 	AC systems, Subclause 6.2.4: For circuit-breaker with dedicated protection see requirements of line feeder. DC systems, Subclause 6.3.4: For circuit-breaker with dedicated protection see methods for line feeder (DC systems).
Autotransformer 	General transformer internal protection AC systems with CB, Subclause 6.2.5: M3: overlapping backup protection by line feeder protection AC systems with disconnector, Subclause 6.2.5: Reliability methods for the non-dedicated circuit-breakers (see line or switching station feeders)

[a] The arrangement of the equipment is illustrative only.

[b] All options that are described in 6.2 and 6.3.

[c] This typically does not apply for 16,7 Hz systems.

7 Limitations and residual risks

In general, the protection system monitors parameters such as voltages and currents in terms of amplitude, phase, rate of rise, frequency, etc., depending on the application. If one of the process parameters is out of the intended range the protection will initiate a predefined action. Not all fault conditions can be detected by the protection systems. Limitations of protection systems and generic residual risks are given in Table 2.

Table 2 – Limitations of protection systems and generic residual risks

Limitations of protection systems	Residual risks
Certain fault conditions with high fault impedance occur infrequently and cannot be detected where the voltage and current remain within the permissible range for the intended operation of the system.	The consequences of undetected fault conditions, e.g. dissipation of energy caused by high resistance faults can be accepted in terms of damage of equipment. Also, experience shows that injuries of persons caused by undetected faults of this nature are rare events for electric traction power supply systems which comply with the relevant standards, e.g. the IEC 62128 series.
A finite time duration between occurrence of a fault and the successful completion of the predefined action to terminate the fault current is inevitable.	The time duration between the occurrence of a fault and the predefined action including back up protection is an accepted time at risk.
Where a single universally valid predefined action of the protection does not exist, according to 5.2.1, the required response of the protection system is agreed with the responsible entity, e.g. Infrastructure Manager.	In this case the residual risk for the protection system can be accepted.

Limitations of protection systems	Residual risks
The concept of supplementing redundancy in the architecture of the protection system has certain limitations, e.g. in terms of time, location or special operation cases, selectivity, etc.	It may be accepted that backup protection has reduced sensitivity, reduced selectivity and/or longer reaction time and can result in certain parameters exceeding the permissible range of the system design, e.g. higher let-through energy and longer time duration for touch voltage.
Bridging of electrical sections by the current collector of a train can influence the performance of the protection system. EXAMPLE 1 If a train enters a faulted section through an insulated overlap or section insulator, the fault will be re-energized through the overlap or section insulator to create an extended section. Protection of this extended section is then dependent on the line feeder protection of the adjacent section from which the train runs into the faulted section. For this example, the risk is that a fault of the extended section which is not cleared will result in a fault arc which continues after the train leaves the overlap section or section insulator, which can result in overhead line damage. The probability of a train running into the faulted section is dependent upon the nature of the line and traffic, and hence there is no single solution to be adopted in this case. EXAMPLE 2 In the event of trains bridging an insulated section and in the same moment occurrence of a fault in the respective electrical section the detection of a fault can be influenced, see 6.2.3.2. This is considered to be a very low probability event.	This residual risk for the protection system can be accepted where agreed with the responsible entity. NOTE The residual risk is based upon the probability and severity of the event. If the residual risk is low no additional protection provisions are envisaged. In other cases additional provisions can be needed.

Under the precondition that the requirements given in this document, as well as in applicable system and equipment standards, e.g. the IEC 62128 series and IEC 61936-1 (for earthing requirements) are met and the limitations are considered in the operational concept respectively, the residual risks of the protection system in Table 2 are accepted.

8 Design verification

Verification shall be carried out by design review, checking the compliance of the protection concept with the mandatory requirements specified in this document.

NOTE Other verification and validation activities associated with later stages of implementing the concept are outside the scope of this document, but are envisaged, e.g. testing and commissioning.

Annex A
(informative)

Examples of protection schemes

A.1 General

This informative annex gives a few examples for protection schemes, based on the requirements in this document. These examples can provide a basis for a scheme, but they need to be modified according to the individual system requirements.

A.2 Description of the structure of the protection scheme examples

According to the architecture of the electrical traction system, shown in the single line diagrams in Figure A.1, Figure A.2, Figure A.3, Figure A.4, Figure A.5 and Figure A.6, an example of the protection functions is defined for each protected section (e.g. busbar feeder protection).

The protection functions and reliability methods are structured in a matrix. The columns show the main protection and reliability method for the specified fault and abnormal conditions. In each row, corresponding to one protected section, the protection devices and their functions are shown.

The functional blocks, describing the main protection and reliability method with corresponding protection functions, shown in the same colour are integrated in the same device.

For each protection function inputs, e.g. measurement transformers, and outputs, for example trip signal, are set out, as well as the maximum allowable times.

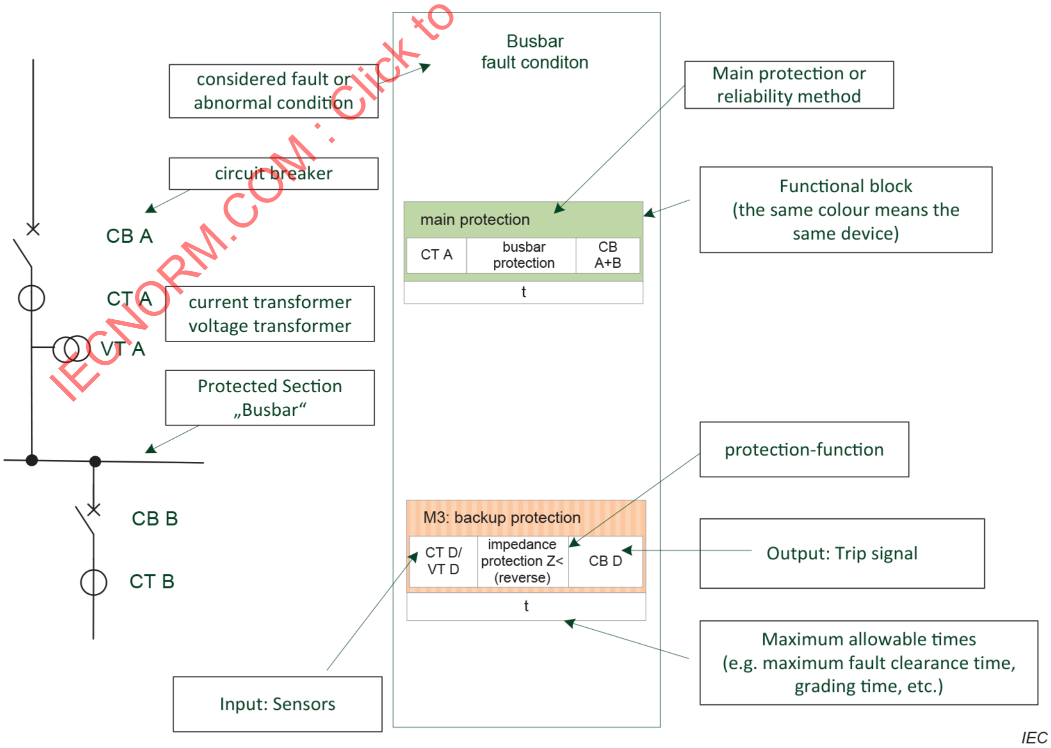


Figure A.1 – Key for protection scheme, example of protected section 'busbar'

A.3 Protection scheme examples

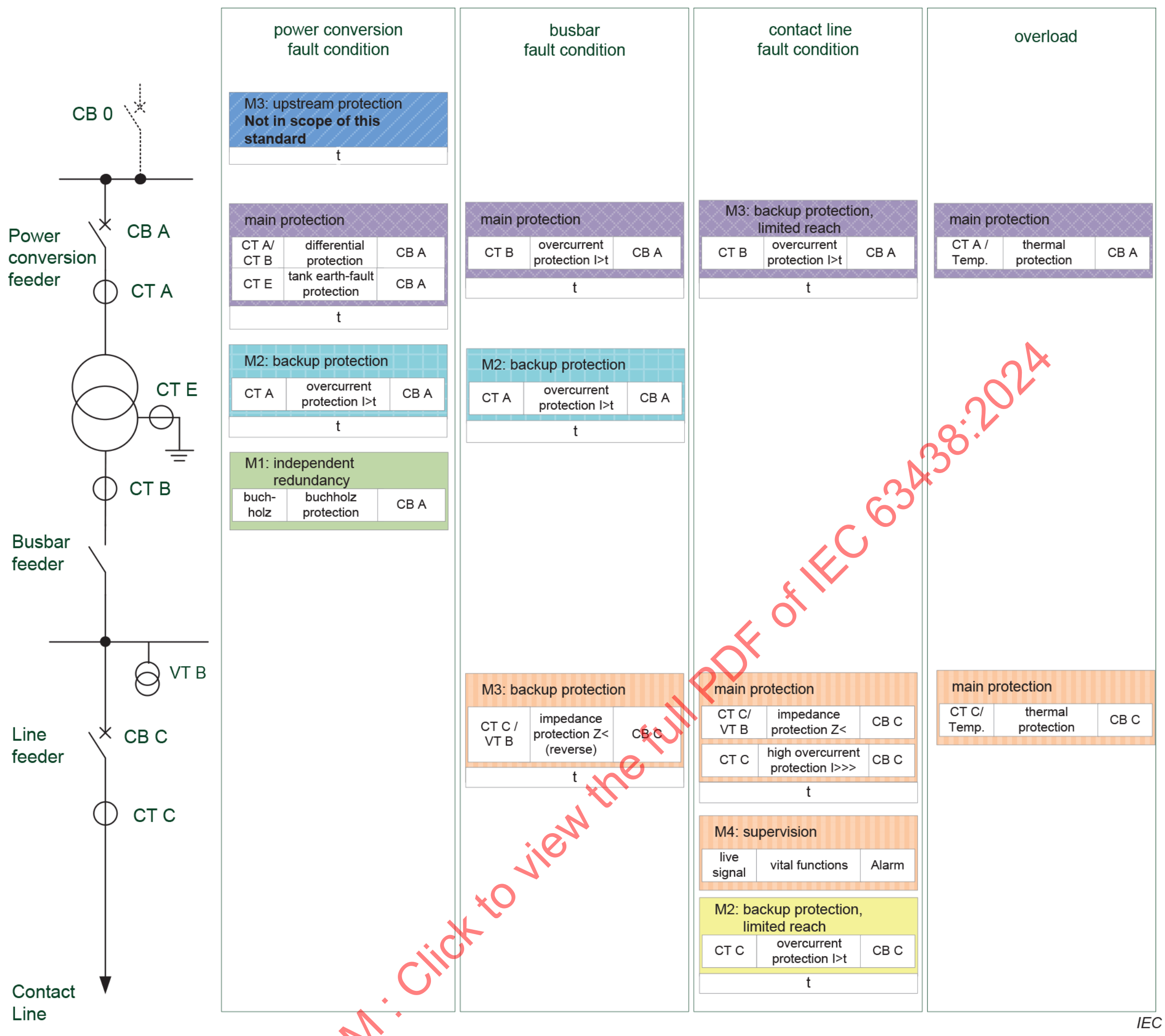


Figure A.2 – Example of a protection scheme for AC 50 Hz electric traction power supply systems without busbar infeed circuit-breaker

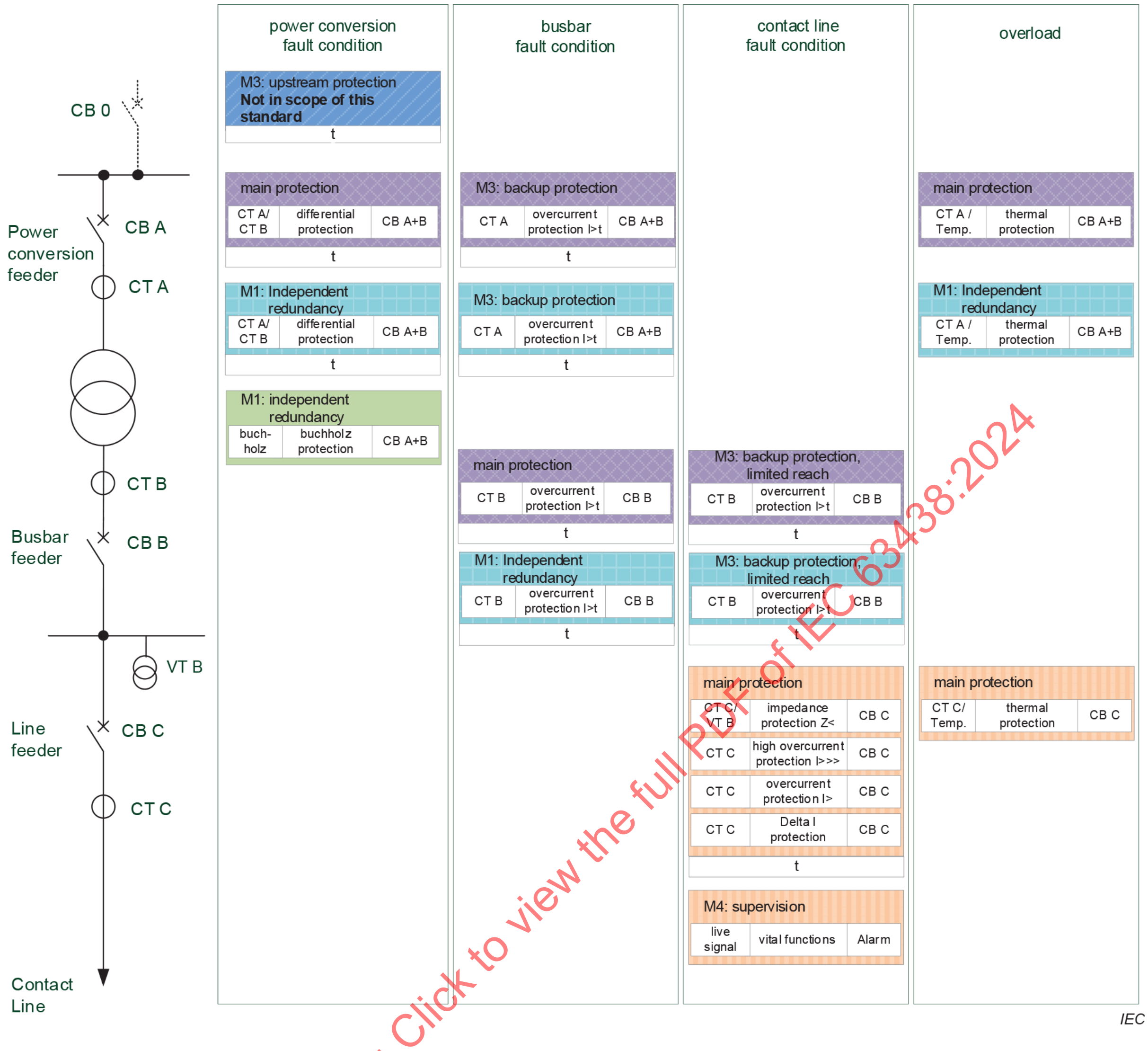


Figure A.3 – Example of a protection scheme for AC 50 Hz electric traction power supply systems with busbar infeed circuit-breaker

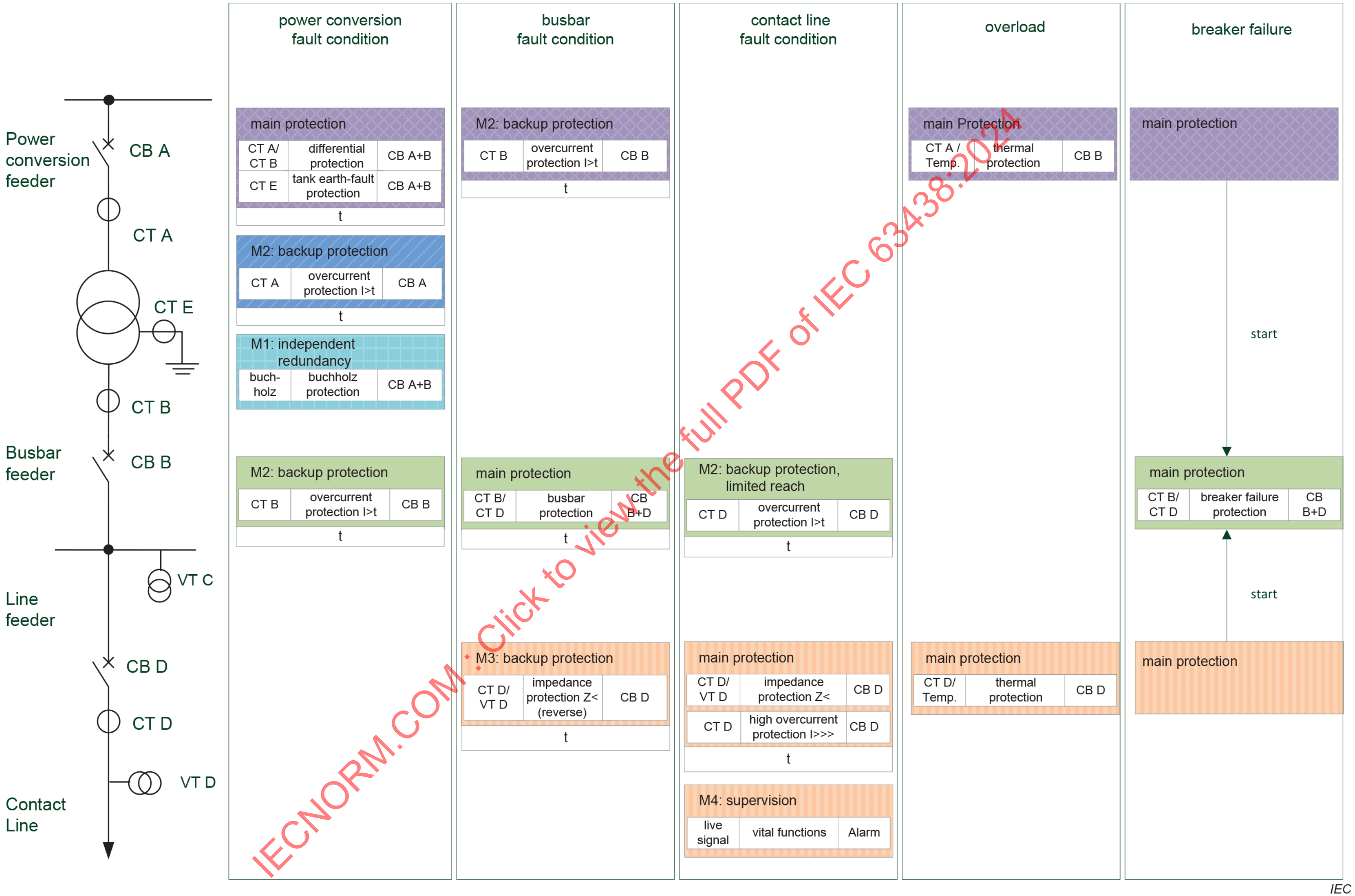
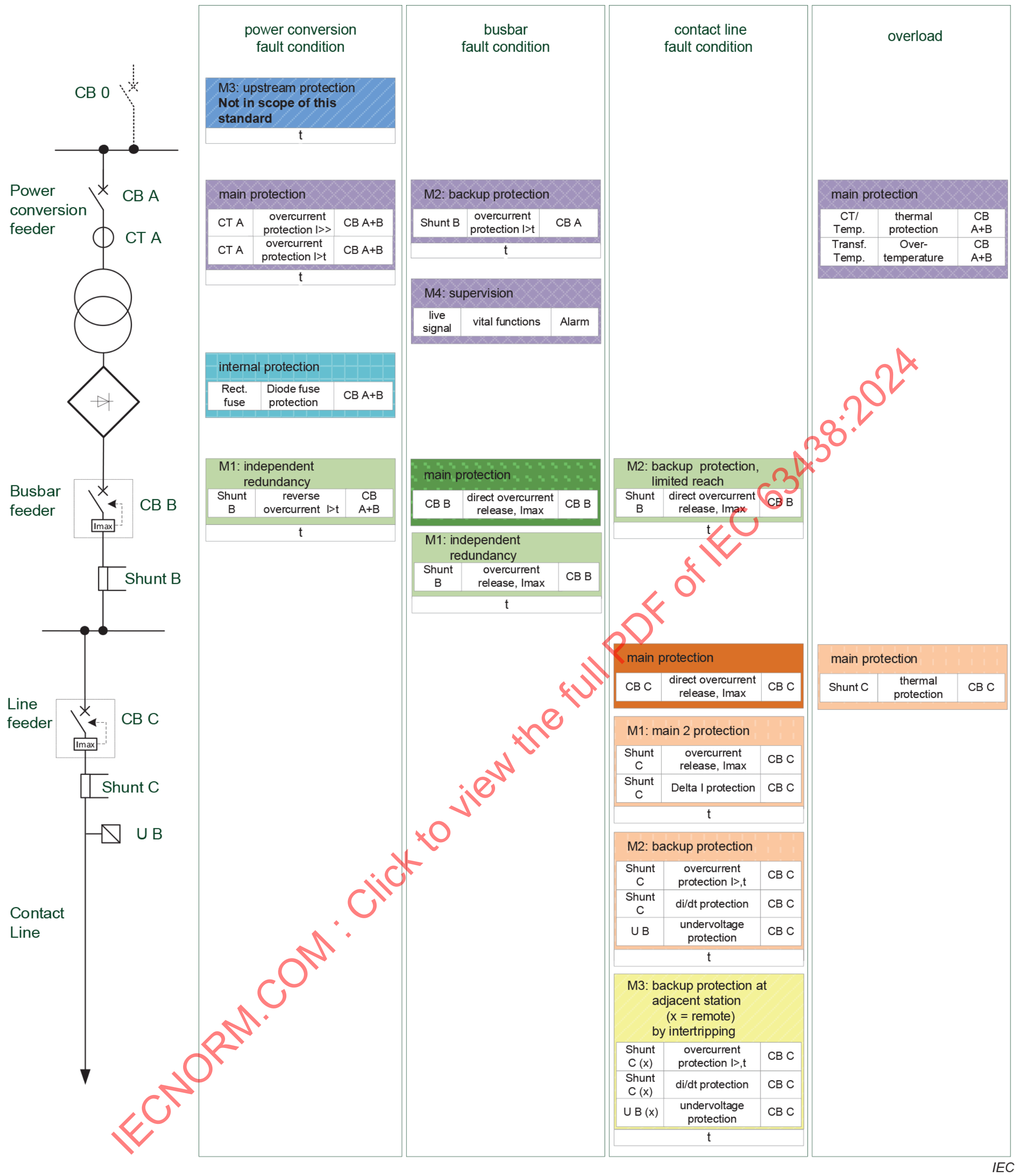
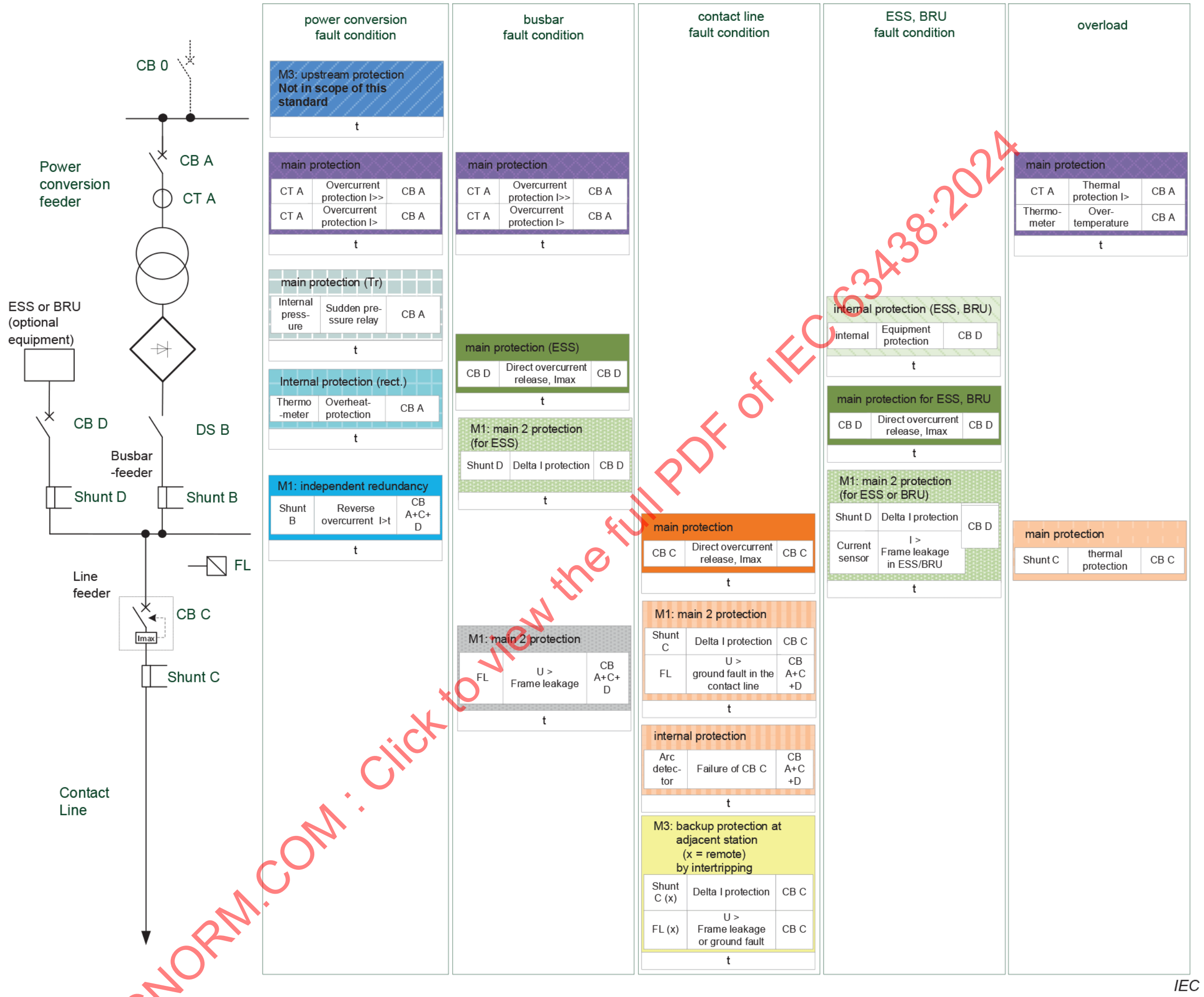


Figure A.4 – Example of a protection scheme for AC 16,7 Hz electric traction power supply systems with busbar infeed circuit-breaker



NOTE Shunt can be replaced by any other type of sensor, such as Hall sensors or optical fibre sensors

Figure A.5 – Example of a protection scheme for DC electric traction power supply systems with busbar infeed circuit-breaker



NOTE Shunt can be replaced by any other type of sensor, such as Hall sensors or optical fibre sensors

Figure A.6 – Example of a protection scheme for DC electric traction power supply systems with regenerative power absorbing equipment

Annex B
(informative)

Example of a protection concept for a 25 kV line section

B.1 Overview

This example of a protection concept is based on a 25 kV line feeder applied in a wide-area system of grouped protected section corresponding to the Example 2 given in 6.2.3.1. A functional scheme and concept may be developed for a conventional, hard-wired protection scheme using protection relays, or for a modern IEC 61850 series substation automation system. This example demonstrates application of a substation automation system approach, and hence the architecture and terminology are related to the application of the IEC 61850 series substation architecture.

The purpose of this annex is to serve as an example, outlining the basic contents of a protection concept. The detailed protection setting values and also the details of implementation requirements shown in this annex are not intended to be taken as best practice or recommendation, but as an implementation example. As set out in the normative text, these aspects and the detailed values are subject to be defined in the integrated process of system and protection design, which would follow the concept and hence are not discussed in this annex.

The text below is written from the perspective of a protection concept designer.

B.2 Protection concept

This protection concept sets out the principles of line feeder protection to be applied to the classic 25 kV line section given in Figure B.1, which incorporates a substation, three intermediate paralleling posts and a sectioning post. An IEC 61850 series intelligent electronic device (IED) is installed on each bay (A1, A2, A3, …, B4, B5), and the diagram shows the main protection functions for A1 and A2. The remaining functions are omitted here for clarity.

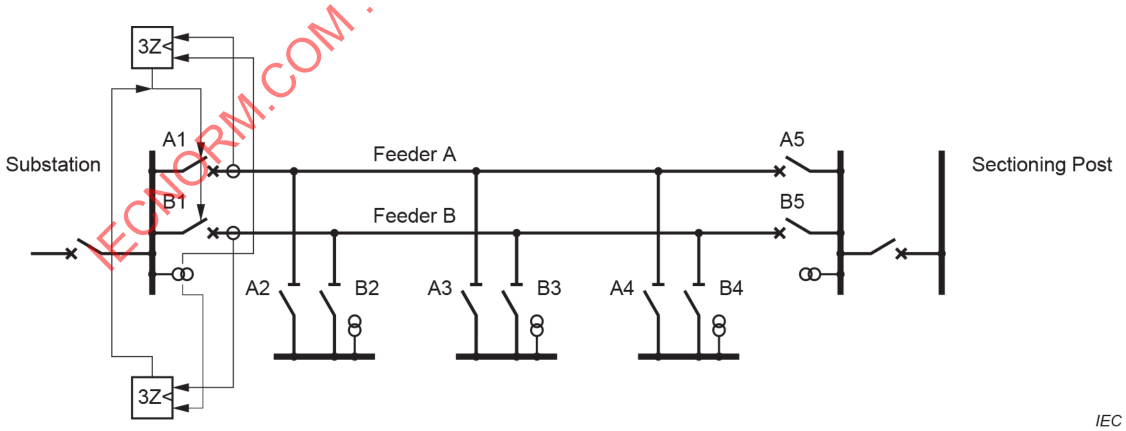


Figure B.1 – System single line diagram

The full section shown in Figure B.1 will be isolated as a grouped protection section, both track feeders being tripped and cleared following a fault by the boundary circuit-breakers (A1, B1, A5, B5). At the intermediate paralleling posts, the switches will remain closed during the fault. During the dead time, the intermediate switches on the faulted line will open, and then supplies will be restored to the healthy line.