Selection of LV Switchgear and Protective Devices

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Excellence in Electrotechnical & Engineering Services

Application Guide

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1 Contents

2 Introduction

This application guidance is intended to provide readers with information regarding the design, selection and installation of LV switchgear and protective devices and to offer practical guidance to all, though due to the nature of the subject must make reference to other guidance documents and standards.

It is not intended to inform readers about the application and protection afforded by protective devices.

Furthermore it is not intended to override manufacturer's data, but is intended to support it when selecting and installing equipment and to offer sound advice and guidance when selecting low-voltage switchgear.
For the purpose of this application guide, low-voltage switchgear can be defined as:

> *A collection of components including but not limited to circuit breakers, switches, off load isolators, on load isolators, disconnectors, fuses, enclosures etc. i.e. all the accessories required to protect the LV system.*

The main functions of switchgear are:

- Electrical protection
- Electrical isolation of sections of an installation
- Local or remote switching

This guide will aim to cover the most important aspects to be considered when selecting and specifying low-voltage switchgear, a typical example of such is as shown on the cover page.

3 Standards

There are numerous British and European standards that are relevant when it comes to selecting and specifying low-voltage switchgear and protection systems.
BS EN 61439 series of standards specify the requirements for low-voltage switchgear and assemblies. The relevant parts of which are:

PD IEC/TR 61439-0:2013	*Low voltage switchgear and controlgear assemblies. Guidance to specifying assemblies*
BS EN 61439-1: 2011	*Low-voltage switchgear and controlgear assemblies. General rules*
BS EN 61439-2: 2011	*Low-voltage switchgear and controlgear assemblies. Power switchgear and controlgear assemblies*
BS EN 61439-3:2012	*Low-voltage switchgear and controlgear assemblies. Distribution boards intended to be operated by ordinary persons (DBO) (incorporating corrigenda September 2013 and December 2015)*
BS EN 61439-4:2013	*Low-voltage switchgear and controlgear assemblies. Particular requirements for assemblies for construction sites (ACS)*
BS EN 61439-5:2015	*Low-voltage switchgear and controlgear assemblies. Assemblies for power distribution in public networks*
BS EN 61439-6:2012	*Low-voltage switchgear and controlgear assemblies. Busbar trunking systems (busways)*

These documents have replaced the previous *BS EN 60439* series.

The *BS EN 60947* series of standards specify the functional units within the assemblies, these are:

BS EN 60947-1:2007	*Low-voltage switchgear and controlgear. General rules (+A2:2014) (incorporating corrigendum January 2014)*
BS EN 60947-2:2006	*Low-voltage switchgear and controlgear. Circuit-breakers (+A2:2013) (incorporating corrigendum November 2013)*
BS EN 60947-3:2009	*Low-voltage switchgear and controlgear. Switches, disconnectors, switch-disconnectors and fuse-combination units (+A2:2015) (incorporating +A2 2015)*
BS EN 60947-4-1:2010	*Low-voltage switchgear and controlgear. Contactors and motor-starters - Electromechanical contactors and motor-starters (+A1:2012)*
BS EN 60947-5-1:2004	*Low-voltage switchgear and controlgear. Control circuit devices and switching elements. Electromechanical control circuit devices (+A1:2009) (incorporating corrigendum November 2004)*
BS EN 60947-6-1:2005	*Low-voltage switchgear and controlgear. Multiple function equipment. Transfer switching equipment (+A1:2014)*

4 Definitions, Acronyms and Symbols

The following definitions are useful to appreciate when specifying low-voltage switchgear and protective devices.

4.1 Voltage

BS 7671 defines voltage ranges in Part 2, Definitions as:

Voltage, nominal - Voltage by which an installation (or part of an installation) is designated. The following ranges of nominal voltages (rms value for a.c.) are defined:

Extra-low - Not exceeding 50 V a.c. or 120 V ripple-free d.c. whether between conductors or to Earth.

Low- Exceeding extra-low voltage but not exceeding 1000 V a.c. or 1500 V d.c. between conductors, or 600 V a.c. or 900 V d.c. between conductors and Earth.

High - Normally exceeding low voltage.

4.2 Switch

Load switches, or switches, are mechanical switching devices capable of making, carrying and breaking currents under normal circuit conditions which may include specified operating overload conditions and also carrying for a specified time currents under specified abnormal circuit conditions such as those of short-circuit. *Short-circuit currents can be conducted (high short-circuit withstand capacity), but not be switched-off.*
For load switches the range of designs is similarly wide as for isolator switches, for example “normal” (load) switches, fuse-switches, circuit breakers.

4.3 Disconnector

The disconnector is a mechanical device that fulfils in the open position the requirements specified for the isolation function (*BS EN 60947-1*).
The key factor here is the opening distance. Isolation must be guaranteed from pole to pole and from input to output, whether this is by means of a visible isolation gap or by suitable design features within the device (mechanical interlocking mechanism).

It must also be equipped with an indicator device in relation to the position of the movable contacts. This position indicator must be linked in a secure, reliable way to the actuator, whereby the position indicator can also serve as actuator, provided that it can only display the position “Open” in the “OFF” position, when all moving contacts are in the “Open” position. This is to be verified by testing.
According to *BS EN 60947-3*, an isolator must only be able to make and break a circuit, if either a current of negligible size is switched on or off, or if during switching no noticeable voltage difference between the terminals of each pole occurs. The isolator function can be realized with a variety of devices such as for example in disconnectors, fuse-disconnectors, switch-disconnectors, fuse-switch disconnectors and circuit breakers with isolating function.

4.4 Switch-disconnector

Switch disconnectors combine the properties of (load) switches and disconnectors. In this case, too, there are a variety of designs such as “normal” switch disconnectors, fuse- switch-disconnectors and circuit breakers.

4.5 Circuit breaker

Circuit breakers are mechanical switching devices, 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 (*BS EN 60947-2*).
They thus also fulfil the requirements of (load) switches. Circuit breakers are often designed so that they can fulfil the requirements for disconnectors.

4.6 An Assembly

A combination of one or more low-voltage switching devices together with associated control, measuring, signalling, protective, regulating equipment, with all the internal electrical and mechanical interconnections and structural parts

4.7 Functional unit

Part of an assembly comprising all the electrical and mechanical elements including switching devices that contribute to the fulfilment of the same function Section

4.8 Busbar

Low-impedance conductor to which several electric circuits can be separately connected

4.9 Section

Constructional unit of an assembly between two successive vertical delineations

4.10 Sub-section

Constructional unit of an assembly between two successive horizontal or vertical delineations within a section

4.11 Compartment

Section or sub-section enclosed except for openings necessary for interconnection, control or ventilation

4.12 Enclosure

Housing affording the type and degree of protection suitable for the intended application

4.13 Partition

Part of the enclosure of a compartment separating it from other compartments

4.14 Barrier

Part providing protection against direct contact from any usual direction of access

4.15 Duty holder

A term referred to in the *Electricity at Work Regulations* to describe the person appointed to be responsible for the safety of the electrical installation, equipment and any work activities that are to be carried out

4.16 Impulse withstand voltage

Highest peak value of impulse voltage of prescribed form and polarity which does not cause breakdown of insulation under specified conditions

4.17 I^2t

A measure of the thermal energy, a current, in a period of time, seconds that is usually displayed as a curve and made up of current in amperes squared times time in seconds.

4.18 U_0

Nominal a.c. rms line voltage measure Line to Earth.

4.19 Graphical symbols

The symbols used on switches, disconnections and the like are often overlooked, though are vital when selecting and graphically illustrating the appropriate device needed. The International Electrotechnical Commission (IEC) aims to standardise the symbols used for electrical designs. At the time of writing *IEC 60617-7:1996*, 'Graphical symbols for diagrams. Switchgear, control gear and protective devices', has been withdrawn and not replaced with anything definitive.

Figure 1 below illustrates some potential symbols that can be used, though others may be acceptable:

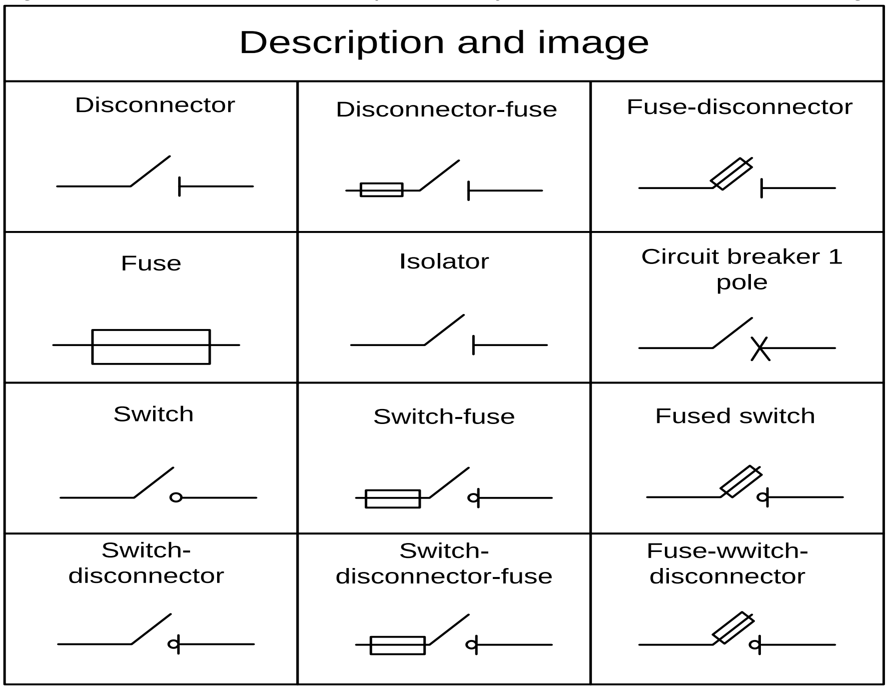


Figure 1 – Typical Graphical Symbols Used for Switchgear, controlgear and protective devices

4.20 Skilled, Instructed and Ordinary Persons

BS EN 61439-3, *part 1 – Scope*, restricts the rated current of the protective devices in distribution boards under the control of ordinary persons. These are limited to 250 A for incoming feeders and 125 A for outgoing feeders.

These restrictions do not apply where the equipment is accessed only by skilled or instructed persons, such as would be the norm in main LV switchrooms.

Should any low-voltage switchgear be designed for use by ordinary persons, then this aspect must be considered.

5 Forms of Separation

When specifying low-voltage switchgear, one of the most important elements to consider is the form of separation that is to be selected. Making the incorrect decision at this stage can result in the assembly being over specified or unsuitable for the purpose it is intended to fulfil.

5.1 What Are Forms of Separation?

In low-voltage switchgear, forms of separation refer to the separation of the bus bars, functional units and terminals of protective devices.
The basics forms are as follows:
Form 1 – No internal separation provided
Form 2 – Internal separation is provided between busbars and functional units
Form 3 – Internal separation is provided between busbars and functional units and separation of all functional units from each other
Form 4 - Internal separation is provided between busbars and functional units and separation of all functional units from each other. Incoming and outgoing terminals are also separated from each other.

The standard offers a variety of each Form, with the exception on Form 1.
Engineers should consider what functions will be needed to be carried out without complete and full isolation of the assembly. Table 1 below offers suggestions as to which Form is most suitable.

5.2 Why Are They Important?

To consider the appropriate form of separation is to consider the ability to undertake future work on the unit. The different forms will allow different sections of the assembly to be accessed without isolating the entire assembly in the future.

5.3 Electricity at Work Regulations 1989

One important element to consider when selecting and working on an assembly is regulation 14 of the *Electricity at Work Regulations* which states:

> *No person shall be engaged in any work activity on or so near any live conductor (other than one suitably covered with insulating material so as to prevent danger) that danger may arise unless –*
> *(a) it is unreasonable in all the circumstances for it to be dead; and*
> *(b) it is reasonable in all the circumstances for him to be at work on or near it while it is live; and*
> *(c) suitable precautions (including where necessary the provision of suitable protective equipment) are taken to prevent injury.*

This regulation effectively prohibits live working. Therefore selecting certain low-voltage switchgear will either help with this or hinder this.

5.4 Types of Separation – Detailed Information

Each of the aforementioned Forms offer different options in regard to separation and how the installation can be suitably maintained going forward. A summary of the characteristics of the four Forms is as follows:

5.4.1 Form 1

In a Form 1 system there is no separation provided. This should only be specified if the option to completely isolate the assembly is freely available.

5.4.2 Form 2

A Form 2 has the bus bars separated from the functional units and depending on if 2a or 2b has been selected the cable terminals may be separated from the bus bars but as the functional units are not separated from one another there is limited practical advantage over a Form 1 as the entire assembly needs to be isolated to safely work upon.

5.4.3 Form 3

With a Form 3 it may well permit some maintenance work to be carried out within the functional units. There is no requirement for the one circuit to be separated from the terminals of another.

5.4.4 Form 4

This Form provides many varieties and opportunities and is most likely the preferred choice of many specifiers. As Form 4 is split into 4a (3 types) and 4b (4 types) it is useful to consider the need and purpose of the installation in a logical manner.
The following table, taken from *BS EN 61439-2*, explains the Forms and differing types within them.

Table 1 - Table NA.1 taken from BS EN 61439-2 National Annex, regarding Forms of separation

Main criteria	Sub-criteria	Form	Type of construction	
No separation		Form 1		
Separation of busbars from the functional units	Terminals for external conductors not separated from busbars	Form 2a		
	Terminals for external conductors separated from busbars	Form 2b	Type 1	Busbar separation is achieved by insulated covering, e.g. sleeving, wrapping or coatings[1])
			Type 2	Busbar separation is by metallic or non-metallic rigid barriers or partitions
Separation of busbars from the functional units and separation of all functional units from one another Separation of the terminals for external conductors from the functional units, but not from each other	Terminals for external conductors not separated from busbars	Form 3a		
	Terminals for external conductors separated from busbars	Form 3b	Type 1	Busbar separation is achieved by insulated covering, e.g. sleeving, wrapping or coatings[1])
			Type 2	Busbar separation is by metallic or non-metallic rigid barriers or partitions
	Terminals for external conductors in the same compartment as the associated functional unit	Form 4a	Type 1	Busbar separation is achieved by insulated covering, e.g. sleeving, wrapping or coatings[1]) Cables may be glanded elsewhere
			Type 2	Busbar separation is by metallic or non-metallic rigid barriers or partitions Cables may be glanded elsewhere
			Type 3	Busbar separation is by metallic or non-metallic rigid barriers or partitions The termination for each functional unit has its own integral glanding facility
	Terminals for external conductors not in the same compartment as the associated functional unit, but in individual, separate, enclosed protected spaces or compartments	Form 4b	Type 4	Busbar separation is achieved by insulated covering, e.g. sleeving, wrapping or coatings[1]) Cables may be glanded elsewhere
			Type 5	Busbar separation is by metallic or non-metallic rigid barriers or partitions Terminals may be separated by insulated coverings1) and glanded in common cabling chamber(s)
			Type 6	All separation requirements are by metallic or non-metallic rigid barriers or partitions Cables are glanded in common cabling chamber(s)
			Type 7	All separation requirements are by metallic or non-metallic rigid barriers or partitions The termination for each functional unit has its own integral glanding facility

[1]) See Clause 8.4.2.2 of Part 1 in relation to protection against contact with live parts.
NOTE Conductors which are connected to a functional unit but where they are external to its compartment or enclosed protected space (e.g. control cables connected to a common marshalling compartment) are not considered to form part of the functional unit.

5.5 Other Considerations

When specifying low-voltage switchgear, in particularly the forms of separation, then ultimately the greater the degree of protection, the greater the cost. This can initially be seen as a barrier to selecting the more expensive options, however this should not be the case, as an appropriate selection can ensure that not only the does the installation provide safe working situations for those working on/near it, but it can also reduce down-time when inevitable maintenance is required.
Within an assembly it is permissible to have multiple Forms of separation between different functional units. This option could be available where a Form 4 assembly has a functional unit with a MCB distribution system in it.

As a rule of thumb, the higher the Form of separation, the larger and more costly the assembly will be. This will impact on the selection should space and budget be limited, but should never override safety.

5.6 Note on Forms of Separation

With regard to Form 4 switchboard assemblies it is often assumed that; the higher the type designation, the safer it is. Specifications often specify Form 4 Type 5 construction for switchboards. In a Type 5 construction, the terminations of the outgoing ways are ‘coppered out’ into the adjacent cable way, with rubberised shrouds placed over the cable terminations. In the author’s opinion, this is inherently dangerous as it exposes personnel required to work in the cable way to potentially bare terminals.
For this reason Form 4 Type 5 should be avoided and a combination assembly is preferred, being Form 4 Type 6 for larger outgoing ways (typically 630 A and above) and Form 4 Type 2 for smaller outgoing ways in the range 100 to 400 A.

6 Device selection

As outlined in Section 7 the various devices that can interrupt power, from a source to a load, have different functions and characteristics, therefore selecting the correct device for the right application is vital, in order to ensure that the circuit has appropriate protective device characteristics and suitable isolation, switching or protection.
Ignoring circuit breakers for now, as these will be covered later, it can be seen that there are 3 main terms to consider:

- Switch
- Disconnector
- Fuse

The characteristics of each of these are summarised in table 2 below:

Term	Features provided	Features not provided
Switch	Current rating Operational and insulation voltage Making and breaking of load and overload currents	Isolation Protection
Disconnector	Current rating Isolation Operation and insulation voltage	Protection Making and breaking capability
Fuse	Overload protection Short circuit protection	Switching

Table 2 – Characteristics of Switches, Disconnectors and Fuses

6.1 Isolation and Switching

BS 7671 recognises four types of isolation and switching:

1. Isolation
2. Switching off for mechanical maintenance
3. Emergency switching
4. Functional switching

Each has specific requirements suitable selection of the devices is imperative.

6.1.1 Isolation

Isolation is defined in *BS 7671 Part 2* as:

A function intended to cut off for reasons of safety the supply from all, or a discrete section, of the installation by separating the installation or section from every source of electrical energy.

6.1.2 Switching Off for Mechanical Maintenance

Switching off for mechanical maintenance is defined in *BS 7671 Part 2* as:

The replacement, refurbishment or cleaning, of lamps and non-electrical parts of equipment, plant and machinery.

6.1.3 Emergency Switching

Emergency Switching is defined in *BS 7671 Part 2* as:

An operation intended to remove, as quickly as possible, danger, which may have occurred unexpectedly.

BS 7671 regulation 537.4.1 makes reference to BS *EN 60204-1:2006+A1:2009* (Safety of machinery. electrical equipment of machines. General requirements). This standard gives guidelines on ‘Measures to minimise risk in the event of failure’ and ‘Recommendation for the use of switches having direct opening action’. This suggests it is good practice to have a device with a direct mechanical link, from the toggle to the contacts i.e. not a spring. When specifying equipment for this purpose, this specific element is worth considering.

6.1.4 Functional Switching

Functional Switching is defined in *BS 7671 Part 2* as:

> *An operation intended to switch ON or OFF or vary the supply of electrical energy to all or part of an installation for normal operation purposes.*

6.2 Table 53.4 of *BS 7671*

BS 7671, table 53.4 provides useful information related to what can or cannot be used as an isolator and states the type of device and their operational use.
 (Note – the BS EN numbers within this table are not listed in the appendices of this guidance as cross references / source).
Table 53.4 of BS 7671 is reproduced in table 3 below:

Table 3 – (Table 53.4 of BS 7671 – Guidance on the selection of protective, isolation and switching devices)

Device	**Standard**	**Isolation(4)**	**Emergency switching(2)**	**Functional switching(5)**
Switching device	*BS EN 50428*	No	No	Yes
	BS EN 60669-1	No	Yes	Yes
	BS EN 60669-2-1	No	No	Yes
	BS EN 60669-2-2	No	Yes	Yes
	BS EN 60669-2-3	No	Yes	Yes
	BS EN 60669-2-4	Yes(3)	Yes	Yes
	BS EN 60947-3	Yes(1,3)	Yes	Yes
	BS EN 60947-5-1	No	Yes	Yes
Contactor	BS EN 60947-4-1	Yes(1,3)	Yes	Yes
	BS EN 61095	No	No	Yes
Circuit-breaker	BS EN 60898	Yes(3)	Yes	Yes
	BS EN 60947-2	Yes(1,3)	Yes	Yes
	BS EN 61009-1	Yes(3)	Yes	Yes
RCD	*BS EN 60947-2*	Yes(1,3)	Yes	Yes
	BS EN 61008-1	Yes(3)	Yes	Yes
	BS EN 61009-1	Yes(3)	Yes	Yes
Isolating switch	*BS EN 60669-2-4*	Yes(3)	Yes	Yes
	BS EN 60947-3	Yes(1,3)	Yes	Yes

Device	Standard	Isolation[4]	Emergency switching[2]	Functional switching[5]
Plug and socket-outlet (≤ 32 A)	*BS EN 60309*	Yes[3]	No	Yes
Plug and socket-outlet (> 32 A)	*BS EN 60309*	Yes[3]	No	No
Device for the connection of luminaire	*BS EN 61995-1*	Yes[3]	No	No
Control and protective switching device for equipment (CPS)	*BS EN 60947-6-1*	Yes[1,3]	Yes	Yes
	BS EN 60947-6-2	Yes[1,3]	Yes	Yes
Fuse	*BS 88 series*	Yes	No	No
Device with semiconductors	*BS EN 50428*	No	No	Yes
	BS EN 60669-2-1	No	No	Yes
Luminaire Supporting Coupler	*BS 6972*	Yes[3]	No	No
Plug and unswitched socket-outlet	*BS 1363-1*	Yes[3]	No	Yes
	BS 1363-2	Yes[3]	No	Yes
Plug and switched socket-outlet	*BS 1363-1*	Yes[3]	No	Yes
	BS 1363-2	Yes[3]	No	Yes
Plug and socket-outlet	*BS 5733*	Yes[3]	No	Yes
Switched fused connection unit	*BS 1363-4*	Yes[3]	Yes	Yes
Unswitched fused connection unit	*BS 1363-4*	Yes[3] (Removal of fuse link)	No	No
Fuse	*BS 1362*	Yes	No	No
Cooker Control Unit switch	*BS 4177*	Yes[3]	Yes	Yes

Yes = Function provided, No = Function not provided

[1] Function provided if the device is suitable and marked with the symbol for isolation (see *BS EN 60617* identity number S00288) 

[2] See Regulation 537.4.2.5.

[3] Device is suitable for on-load isolation, i.e. disconnection whilst carrying load current.

Device	Standard	Isolation[(4)]	Emergency switching[(2)]	Functional switching[(5)]
[(4)] In an installation forming part of a TT or IT system, isolation requires disconnection of all the live conductors. See Regulation 537.2.2.1.				
[5)]Circuit-breakers and RCDs are primarily circuit protective devices and, as such, they are not intended for frequent load switching. Infrequent switching of circuit-breakers on-load is admissible for the purposes of isolation or emergency switching. For a more frequent duty, the number of operations and load characteristics according to the manufacturer's instructions should be taken into account or an alternative device from those listed as suitable for functional switching in Table 53.4 should be employed.				
NOTE 1: An entry of (1,3) means that the device is suitable for on-load isolation only if it is marked with the symbol for **on-load** isolation				
NOTE 2: In the above table, the functions provided by the devices for isolation and switching are summarized, together with an indication of the relevant product standards.				

7 Enclosures

Enclosures are a vital element of any switchgear and protection system. Often the switchgear will be combined with an enclosure, though in many cases this will not be an option and a suitable separate enclosure should be sought to house the protection system.

7.1 Enclosure Materials

The typical materials used for electrical low-voltage enclosures are:

- Metal
- Glass Reinforced Polyester (GRP)
- Polycarbonate
- Polyester

Though more materials exist, it is vital that the appropriate enclosure is selected for the installation.

Where ferrous metallic enclosures are specified, consideration should be made to the mitigation of eddy currents where single core cables are passing through the enclosure.

7.2 Ingress Protection

The requirement for basic protection of any systems, product or installation will require an understanding of the International Protection codes. The general make up of this coding convention is summarised in figure 2 below and as further described:

	1st number	2nd number	Additional letter	Supplementary letter
IP	4	5	A	W

Figure 2 - IP code layout

First Numeral 0-6

Protection of persons and Resistance to solid objects

Second Numeral 0-8

Resistance to ingress of water

Additional Letter (Optional)

- A: up to the guard/stop face of 50 mm sphere
- B: up to the guard/stop face of test finger
- C: up to the guard/stop face of 2.5 mm x 100 mm probe
- D: up to the guard/stop face of 1.0 mm x 100 mm probe

Supplementary Letter (Optional)
For specific applications:

- H: High voltage equipment
- M: Moving or rotation equipment - *(Tested whilst in motion)*
- S: Moving or rotating equipment - *(Tested whilst at rest)*
- W: Weather conditions

'X' Letter

The letter 'X' is used in place of the first or second numeral or both by equipment manufacturers to indicate that tests are not applicable and have therefore not been conducted.
In specifications the letter 'X' is used in place of the first or second numeral to indicate that tests are not required.

E.g.: IP4X provides protection against the 1mm probe, but has not been tested for ingress of water.

Where products are to be installed outside or in environments where high levels of moisture are present, the IP rating should be maintained though all penetrations in the enclosure.

7.3 Pollution Degree

The pollution degree is the level of environmental conditions for which the assembly is intended to operate within. Four categories are defined in the *BS EN 61439-1* standard as follows:

- *Pollution degree 1: No pollution or only dry, non-conductive pollution occurs. The pollution has no influence.*
- *Pollution degree 2: Only non-conductive pollution occurs except that occasionally a temporary conductivity caused by condensation is to be expected.*
- *Pollution degree 3: Conductive pollution occurs, or dry, non-conductive pollution occurs which is expected to become conductive due to condensation.*
- *Pollution degree 4: Continuous conductivity occurs due to conductive dust, rain or other wet conditions.*

Unless otherwise stated, ASSEMBLIES for industrial applications are generally for use in pollution degree 3 environments. However, other pollution degrees may be considered to apply, depending upon particular applications or the micro-environment.

8 Accessibility for Installation and Future Maintenance

All equipment will require access for installation, testing and maintenance, the following should be considered when selecting or specifying LV switchgear.

8.1 Front Access or Rear Access

Panels and switchgear are often available as front or rear access, front access panels and switchgear are designed to be installed and terminated from the front of the unit. This usually involves having cable ways and routes between the units, therefore increasing the height and/or width of the unit. Front access panels can often be mounted against a wall.

Rear access panels and switchgear will have an accessible area at the back of the panel or switchgear. This increases the depth of the unit but often reduces the height/width.

The location and space around the unit will help to determine the appropriate selection.

8.2 Maintenance

Regularly LV switchgear and protective devices are installed in locations that do not allow suitable access for maintenance and alterations. Consideration should be given to the end user and any maintenance personnel who are likely to work on the system.

8.3 Thermal Imaging

Where the future use of thermal imaging is envisioned for non-invasive inspection, suitable provision in the enclosure should be made.

8.4 Accessibility to Operating and Maintenance Gangways

Section 729 of *BS 7671* specifies the requirements surrounding the operation and maintenance of switchgear and controlgear in areas such as gangways, where access is restricted to skilled and instructed persons.

9 Utilization Category

The term Utilization category (spelt with a ‘z’ in the standard) of equipment defines the intended application and is specified in the applicable *BS EN 60947-3* standard. It helps to define the characteristics and switching capability of the device i.e. if it can be switched on or off-load.

Table 4 below provides a short extract from table 3.2 of Guidance Note 2 by the IET summarising some of the more applicable categories for LV switchboards.

The designation of utilization categories should also be accompanied by the suffix A or B according to whether the device is intended for frequent or infrequent operation. The standard does not specify the definition of frequent or infrequent, this is left up to the manufacturer.

Table 4 - Utilization Category (Extract from IET GN 2 table 3.2)

Nature of current	**Category**	**Typical applications**	**Relevant BS EN Product Standard**
a.c.	AC-20	Connecting and disconnecting under no-load conditions	*60947-3*
	AC-21	Switching or resistive loads, including moderate overloads	
	AC-22	Switching of mixed resistive and inductive loads, including moderate overloads	
	AC-23	Switching of motor loads or other highly inductive loads	

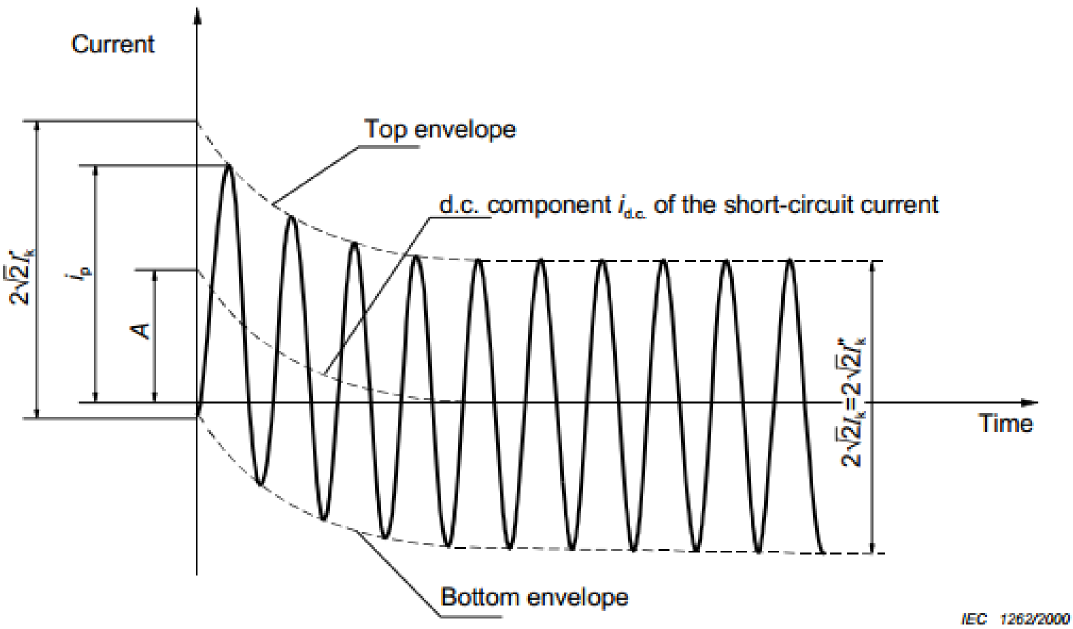
Typical guidance will be that for main LV switchboards, an AC-22 device will generally suffice, unless it is known that there are likely to be heavy inductive loads present.

10 Fault Rating

The fault rating of a low-voltage assembly is a consequence of the current experienced and the time which it lasts. The rated short-time withstand current (**I_{cw}**) is the r.m.s. of the short circuit current that can be carried before damage occurs.

This data is generally available on the assembly, or by contacting the manufacturer.

Typically the peak withstand current (**I_{pk}**) will also be displayed. The **I_{pk}** occurs at the inception of the 3 phase fault but rapidly decays, as illustrated in figure3 below. As such, this is generally not regarded in the selection process.



I_k'' = initial symmetrical short-circuit current

i_p = peak short-circuit current

I_k = steady-state short-circuit current

$i_{d.c.}$ = d.c. component of short-circuit current

A = initial value of the d.c. component $i_{d.c.}$

Figure 3 - Short-circuit current of a far-from-generator short circuit with constant a.c. component (taken from *BS EN 60909-0: 2001* Short-circuit currents in three-phase a.c. systems)

BS EN 60947-2 specifies the following definitions when it comes to fault current levels expected at a switchboard or circuit breaker:

> ***I_{cu}*** *- 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*

> ***I_{cs}*** *- 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*

I_{cw} - *rated short-time withstand current - The rated short-time withstand current of a circuit-breaker is the value of short-time withstand current assigned*

I_{cm} - *short-circuit breaking (or making) capacity - a breaking (or making) capacity for which the prescribed conditions include a short circuit*

10.1 Determining the Fault Current

The assembly should be capable of handling the maximum fault current expected. This can be determined from enquiry to the supply authority (where the supply is given at LV) or from the transformer manufacturer (where the LV supply is from a transformer).

Calculating the required capacity of transformer is based on the following equation:

$$kVA = \frac{V\ x\ I\ x\ \sqrt{3}}{1000}$$

Where:

- kVA is the required capacity of a transformer
- V is the line to line voltage
- I is the full load current
- $\sqrt{3}$ is due to the presence of 3 phase

Transposing this equation to calculate full load current, we get:

$$\mathrm{I} = \frac{1000 \text{ x kVA}}{\text{V x} \sqrt{3}}$$

As an example for a 1000 kVA transformer:

$$\frac{1000 \text{ x } 1000}{415 \text{ x } 1.732} = 1443 \text{ A}$$

Once the full load current is obtained, the approximate prospective fault current at the LV switchgear can be determined by:

$$\text{Fault current} = \frac{\text{Full load current}}{\text{Per unit voltage impedance}}$$

If we assume a 1000 kVA transformer with 5% impedance, then the maximum approximate fault current in amperes will be:

$$\frac{1443}{0.05} = 28{,}860$$

Rounding up, therefore, a maximum fault current of 29 kA is present. This equation has not taken into account any impedance within the cables, from the transformer terminals to the incomer, which will reduce the fault current.

The foregoing equations are approximations with no consideration of loads, and therefore have some margin of safety built into them, for additional information on these and other equations see *BS EN 60909-0:2001*; *IEC 60909-0:2001 'Short-circuit currents in three-phase a.c. systems. Calculation of currents'*; and *PD CLC/TR 50480:2011 'Determination of cross-sectional area of conductors and selection of protective devices'.*

10.2 Rated Short-time Withstand Current (I_{cw})

BS EN 60947-1 defines this as:

The rated short-time withstand current shall be equal to or higher than the prospective r.m.s. value of the short-circuit current (I_{cp}) at each point of connection to the supply.

Different values of I_{cw} for different durations (e.g. 0,2 s; 1 s; 3 s) may be assigned to an LV assembly, or switchboard with the time applied being depend on the use. If the low-voltage switchgear has adequate protection (a main incoming circuit breaker) a 1 second time can be applied, whereas if the only protection is on the primary side of the HV transformer (as might be the case in a DNO owned LV Feeder pillar) then a 3 second time would be applicable.

To calculate this disconnection time, the fault level on the LV busbar needs to be calculated.

Further information on this can be obtained in ECA Application Guide ***AG 03/2016/1*** - Earthing of Industrial / Commercial Secondary HV / LV Substations and Main Earthing Systems.
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11 Protective Devices

When selecting the appropriate protective device there are many to choose from. The following section of this application guide specifies some relevant information in terms of low-voltage switch gear selection.

11.1 Characteristics of a Miniature Circuit Breaker

Miniature circuit breakers (or MCBs are they are often referred to) are possibly the most common form of protective devices used in electrical installations. Their use and characteristics are well known and familiar to most professionals.

11.2 Moulded Case Circuit Breakers (MCCBs)

Moulded Case Circuit Breakers (MCCBs) or circuit breakers are commonly used for sub-main distributing loads in switchgear. The variety and sizes available mean that they can be used in many circumstances where other forms of devices would be unsuitable. Advances in the intelligence of these devices enable building owners to monitor loads remotely and manage energy use better.

Some useful terms associated with circuit breakers are below.

Rated operational voltage (U_e)

The voltage at which the circuit-breaker has been designed to operate under normal conditions.

Rated current (I_n)

This is the maximum current that the circuit breaker can maintain, at ambient temperature, without exceeding the ratings of the current carry parts of the device.

Frame size rating

If the circuit breaker can be fitted with varying sizes and ratings of overcurrent units, the frame size rating is a figure corresponding to the maximum current setting and physical size the unit can adequately accept. Typical frame sizes of MCCBs are: 100; 125; 250; 400; 630; 800; 1000 and 1250 A. In many applications, with long sub-main cables and therefore volt drop, it is common that the size of the sub-main cable cannot be easily terminated to the device, if it were selected for overcurrent rating alone. An example might be a 200A rated circuit with a 185 mm2 4 core sub-main cable. In this case it would be prudent to specify a 400 A frame size with a 200 A trip unit.

Overload relay trip-current setting (I_{rth} or I_r)

Circuit breakers are commonly equipped with removable parts, such as interchangeable overcurrent-trip relays. The trip relays are often adjustable with the trip-current setting (I_r or I_{rth}) setting a value above which, the circuit breaker will rupture. Details on the amount of adjustment available can be found from the manufacturer.

Short-circuit relay trip-current setting (I_m)

Short-circuit tripping relays (instantaneous or slightly time-delayed) are intended to trip the circuit-breaker rapidly on the occurrence of high values of fault current. Smaller devices have fixed values where larger devices can often have adjustable values of I_m.

Rated short-circuit breaking capacity (I_{cu} or I_{cn})

The short-circuit current-breaking rating of a circuit breaker is the maximum value of current that the circuit breaker is capable of breaking without being damaged. The rated value (I_{cu}) for industrial CBs and (I_{cn}) for domestic-type CBs is normally given in kA and is often referred to as the ultimate breaking capacity.

Category (A or B) and rated short-time withstand current (I_{cw})

There are two categories of LV industrial switchgear within *BS EN 60947-2*, section 4.4; A and B.

Category A

Circuit breakers with no intentional short-time delay

Category B

Circuit breakers that, in order to discriminate with other devices in series, can be selectively adjusted; i.e. with an intentional short-time delay

Rated short-circuit making capacity (I_{cm})

The rated short-circuit making capacity of a circuit-breaker is the value of short-circuit making capacity assigned to that circuit-breaker by the manufacturer for the rated operational voltage, at rated frequency and at a specified power factor for a.c., or time constant for d.c.
In a.c. systems this instantaneous peak value is related to I_{cu} (the rated breaking current) by the factor **k**, which is dependant on the power factor (cos ϕ) of the short-circuit current loop

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

The rated breaking capacity (ultimate breaking capacity) offers the maximum level of fault current the device can safely handle, though in reality the chances of these extreme faults occurring are quite slim. More likely the fault that occurs will be much lower than the maximum ultimate breaking capacity.

I_{cs} is the value of rated short-circuit breaking capacity assigned to the device by the manufacturer as a percentage of I_{cu}. I_{cs} shall be at least equal to 25 % of I_{cu}.

11.3 Adjustable MCCBs

Many MCCBs have a variety of adjustments and settings that can be applied, to assist in providing protective device 'selectivity' throughout the installation and a typical MCCB is illustrated in figure 4 below:

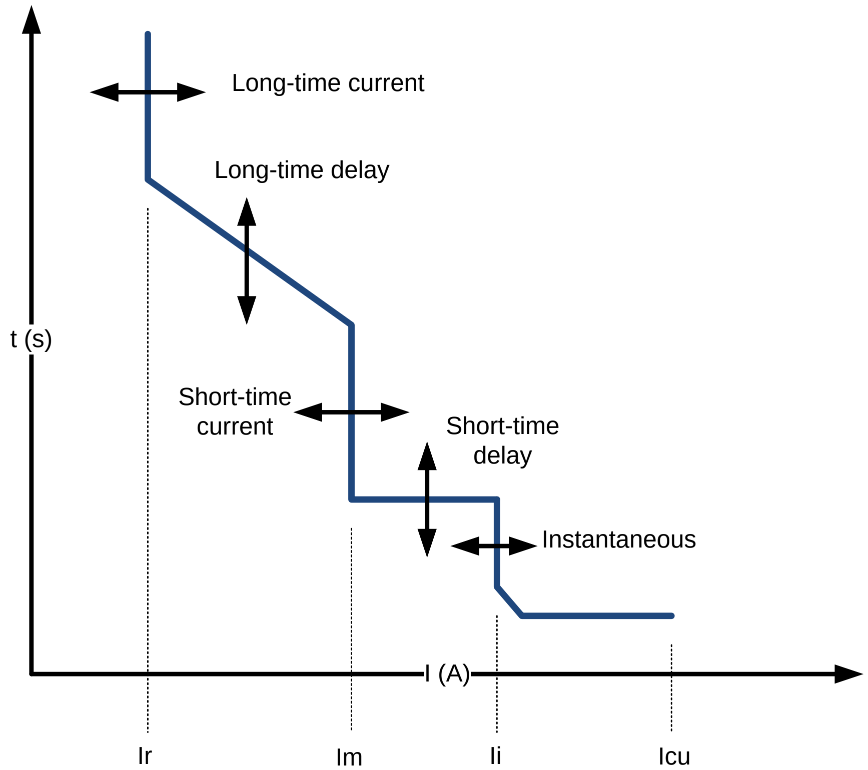


Figure 4 - Tripping current ranges of low voltage MCCBs

Ir	Overload (thermal or long-delay) relay trip-current setting
Im	Short-circuit (magnetic or short-delay) relay trip-current setting
Ii	Short-circuit instantaneous relay trip-current setting
Icu	Breaking capacity

Moulded case circuit breakers are often found in installations where the maximum prospective short-circuit currents are potentially very large. Many manufacturers now produce MCCBs with capacities in excess of 100 kA.

Where the downstream protective device is a fuse, many adjustable circuit breakers will need to have an I^2t on/off function (sometimes referred to as in/out).

I^2t 'On', results in an inverse-time delay characteristic that most closely parallels time/current characteristics of fuses.

I^2t 'Off', results in a constant delay characteristic that coordinates best with thermal-magnetic and electronic trip circuit breakers.

11.4 Air Circuit Breakers (ACBs)

Air Circuit Breakers (ACBs) are often used at the origin of larger installations due to their rating and ability to withstand high levels of faults.

One consideration when selecting ACBs is the option of fixed or withdrawable type. Fixed ACBs are generally less expensive than the withdrawable variety but offer additional challenges when it comes to maintenance and safe isolation. A withdrawable ACB will not require isolation of the upstream protective device as there is no need to access terminals or connections.

The withdrawable ACB will often require much more space within the low-voltage switchgear and in front of it and may require additional control or auxiliary wiring.

With either type, adequate working space should be provided and manufacturers' dimensions and recommendations closely followed and adhered to.

11.5 Protection Modules

Where protection of offered by an ACB, this is usually incorporated in a separate protection module. These modules are usually plugged into the ACB and eliminate the need for external protection systems.

11.6 Motor Protection Circuit Breakers (MPCB)

As their name implies, these circuit breakers are specifically designed for protection of motors, compressors and other such motive power loads.

Similar to a typical MCCB, these devices offer additional protection against motor overload and phase loss in balanced 3 phase systems.

11.7 Contactors

Contactors are solenoid operated switching devices, usually remotely operated, that are designed to undertake repeated cycles of operation.

BS EN 60947-4-1:2010+A1:2012 (Contactors and motor-starters - Electromechanical contactors and motor-starters) gives specific information about these devices.

11.8 Fuses

There are primarily two classes of low-voltage cartridge fuses, domestic and industrial applications. In domestic (or small scale commercial installations) the typical classification is the gG type, whereas in industrial installations, gM or aM are more often seen.

The first letter indicates the breaking range where:

g	full-range breaking-capacity fuse-link
a	partial-range breaking-capacity fuse-link

The second letter indicates the utilisation category. For example, a gG indicates fuse-links with a full-range breaking capacity for general purpose where a gM indicates fuse-links with a full-range breaking capacity for the protection of motor circuits.

Typically people refer to these as '*BS 88* fuses' or 'HRC fuses', though this standard is now withdrawn and has been replaced with the *BS HD 60269* series of documents for low voltage fuses.

11.9 Earth Fault Protection

Earth fault protection is offered in two main ways, these are discussed in the following section.

11.9.1 Restricted Earth Fault Protection (REF)

The windings of many Delta / Star (D/Y) HV / LV transformers have their secondary (the LV side) protected against earth fault by restricted earth fault protection (REF).

Under normal operation the sum of currents in the current transformers (CTs) to the neutral current transformer (NCT) will equal 0 A. Should an earth fault exist, an amount of current will bypass the CT, showing a difference, measuring this imbalance shows a fault exists and it can then be easily cleared. The fault detection zone is confined to the area between the CTs, hence the term 'restricted' and this is illustrated in figure 5 below:

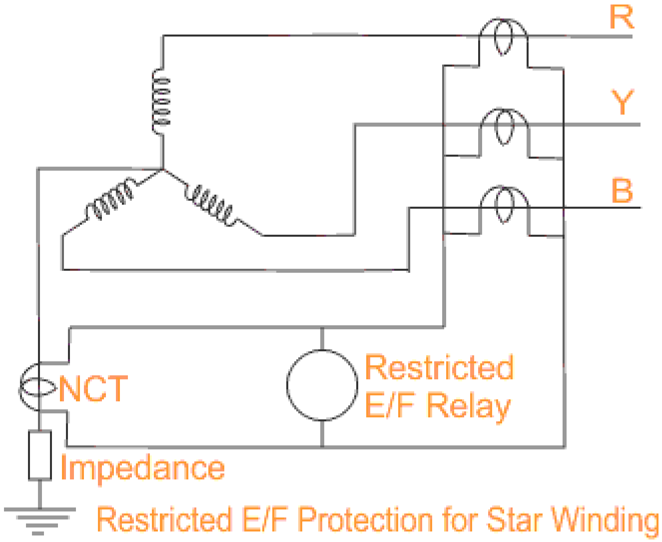


Figure 5 - Restricted earth fault relay protection schematic

As the isolation has to be undertaken by the HV device, before specifying REF protection it is essential to ensure that the HV protective device and circuit breaker on the primary side of the transformer is capable of remote tripping.

11.9.2 Unrestricted Earth Fault Protection

This method of protection is usually seen downstream of the incoming devices and is often an option on MCCBs.

It can be difficult to coordinate the protection and to achieve electrical discrimination as the setting on the circuit breaker is usually a percentage of the nominal current. If the setting of a 2000 A device was put to 20 % (400 A) and the downstream fuse was rated at 1000 A, then an earth fault in excess of 400 A will operate the upstream circuit breaker.

12 Back-up Protection

Typically installations and low voltage switchgear are designed to accommodate the fault currents at that given point in a particular location, however in some cases the fault current will be higher than the kA rating of the device(s).
One method to rectify this is to change the device to something more appropriate; i.e. by increasing the kA rating.

Another option is to consider the use of back-up protection. The principle behind back-up protection, or ‘cascading’ as it is sometimes called, is that the upstream device protects the downstream device by limiting the value of short-circuit energy let-through to a value that the downstream device can adequately cope with. An adequately designed system based on back-up protection can save time, space and money by reducing the possible fault currents seen at low-voltage switchgear further in the installation.

Back-up protection is best performed with manufacturer-supplied data; the easiest way to do this is using the same manufacturer throughout an installation and obtaining their data for individual devices. This allows the designer to select downstream devices with lower ratings than the initial calculations suggest, with lower ratings often resulting in less expensive devices.

Regulation 536.1 of *BS 7671* makes reference to back-up protection.

13 Discrimination

Electrical discrimination should be afforded between all protective devices. *BS 7671 section 536* does not specify the level at which discrimination should be set, merely that it should be present. The following section offers guidance on how discrimination can be best achieved.

13.1 Fuses

One method of achieving discrimination when fuses are employed is using the 2:1 rule whereby the upstream device is 2 times higher rated or more than the downstream device, as can be seen in Figure 6:

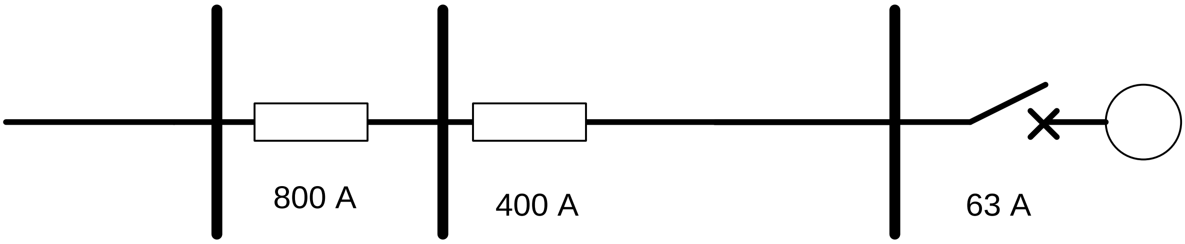


Figure 1 - Electrical discrimination

Coordinating fuses is a relatively simple process as long as a figure for pre-arcing and total operating I^2t is available. The pre-arcing value is related to the amount of energy needed to make the fuse element melt, the total operating value is the total energy needed to rupture the device.

Essentially discrimination shall be achieved if the pre-arcing value of the upstream device exceeds the total operating value of the downstream device.

The example shown in Figure 7 below suggests that discrimination cannot be achieved between a 100 A and an 80 A fuse but is achieved between a 125 A and an 80 A device.

These figures are purely indicative and accurate information should be sought from the device manufacturer.

It is important to stress that discrimination is different from back-up protection and the two must not be confused.

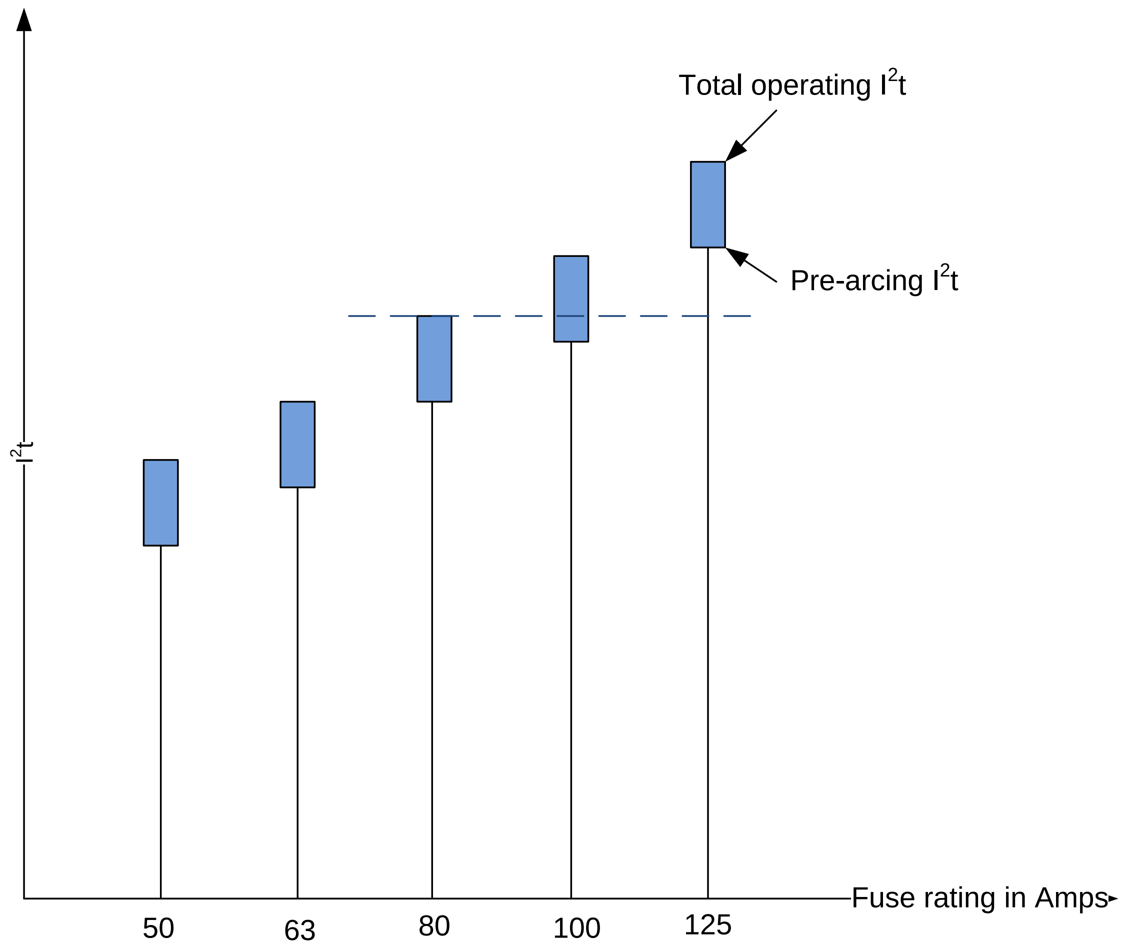


Figure 7 - Example pre-arcing and total operating I^2t values of fuses

13.2 Circuit Breakers

Unlike fuses, discrimination between circuit breakers is often harder to achieve. Use of software to model the device characteristics is advised (providing the technical details are up to date). If the installation is using the same protective device manufacturer throughout, this information should be readily available from the manufacturer. Figure 8 shows two different moulded case circuit breakers achieving discrimination in the computer software ‘design genie’, this is an electrical design software package that can be purchased from via ECA.

The 2:1 ratio should be suitable for the thermal tripping mechanism but it does not apply to the electromagnetic instantaneous trip mechanism.

One way to ensure discrimination is to plot the characteristics of the two devices (or more) on a sheet of log-log graph paper to see how much discrimination is offered.

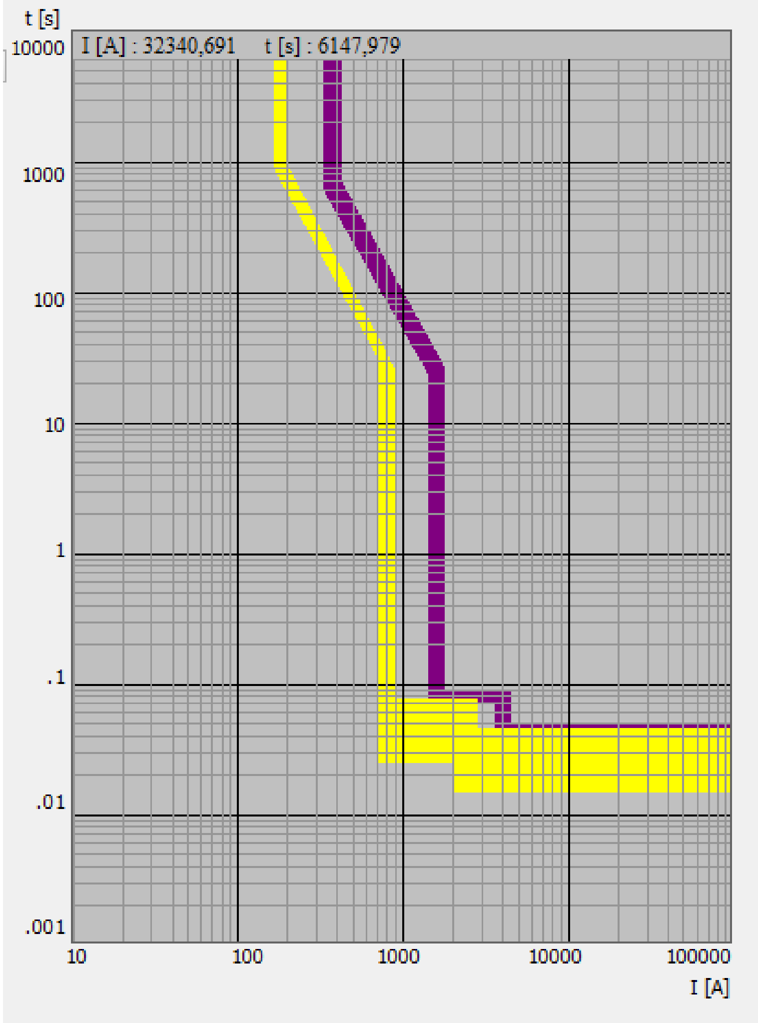


Figure 8 - Two different moulded case circuit breakers modelled in 'designgenie' to obtain a discrimination analysis

13.3 Discrimination Between HV and LV

Discrimination between the HV and LV switchgear is not always essential, especially if the transformer is feeding an individual installation, as tripping the HV device will not necessarily cause any additional issues with the LV system. It may be worth considering discrimination for the following reasons:

- It can help determine the location of the fault
- It can prevent unnecessary tripping of the HV circuit (useful where the client does not have access to the substation)
- HV switchgear is often built to *ENATS 41-26* and is often only rated for 5 fault disconnections, therefore each fault will reduce the life of the HV switch by 20 percent
- Even should the client have access and control over the HV switchgear, it is often much more convenient to restore low-voltage devices

14 Switches

14.1 3 Pole Versus 4 pole Switching

Generally both incoming and outgoing devices within the LV switchboard shall comprise 3 pole switching with a removable neutral link, though there are some exceptions to this, such as:

- On TT and IT systems the isolation device at the origin of the installation is required to be 4 pole. This device will usually be the incoming device at the LV switchboard
- Where stand-by generators are installed, the Distribution Network Operator (DNO) may require 4 pole isolation. This is particularly the case when the supply transformer serves more than one user

On installations where a stand-by generator and a UPS system are installed, considerations need to be given to ensure that the installation's neutral remains referenced to earth when both the generator incomer and mains incomer are open. This situation will occur immediately after mains failure / opening of the mains incomer, and will continue during the time the generator is running up to speed until the generator incomer closes.

The consequences of the neutral becoming unreferenced, are that the voltage across each line and at the neutral point to earth will be determined by the load currents in each phase.

On unbalanced systems this will cause at least one of the phases to develop a higher voltage than if referenced to earth. In extreme cases this can approach the line voltage (i.e. 400 volts).

Use of 3 pole switching to one or more of the incomers, change-over contacts or bus switch can overcome the problem.

14.2 Bus Switches

Bus switches, or bus couplers, are often used where an installation has an inherent risk of loss of supply or where such a loss will be critical to the installation. In this case separate, two or more bus bars can be connected together to provide additional security against power loss.

ACBs are the common method of connected bus switches and can be provided with or without protection. Were no protection is provided; this is generally termed 'non-auto' operation.

15 Power Factor Correction (PFC) Equipment

Implementation of power factor correction (PFC) can have significant cost benefits on clients' installations. Power factor issues occur when the voltage and current sine wave are out of phase, most likely due to the use of inductive equipment.

The most common method to correct this imbalance is to employ the use of capacitors, often in the low-voltage switchgear. This can often reduce wasted space and reduce cabling costs.

However, on low-voltage switchgear with close coupled transformers, when capacitors are switched, the capacitor(s) and transformer(s) reactance's can cause resonance to occur, leading to overvoltages. These overvoltages can cause tremendous harm to capacitors and even cause them to fail, emitting dense smoke which can induce a flashover.

The preferred method, on packaged substations, to protect against this is to locate any PFC equipment away from the switchboard.

Two ways that can be adopted to minimise this are:

1 - Place impedance between the capacitors and the transformers.

Where the transformer is remote from the switchboard and / or the PFC unit is external from the switchboard, the transformer tails and / or the PFC cable add additional impedance.

2 - Use a pre-insert resistor to capacitor contactors.

These can be attached to contactors specifically designed for capacitor switching. At the time of switching, a resistor is placed in series with the load, and is then removed, reducing in-rush current.

16 Lightning Protection Systems (LPS) and Surge Protection Devices (SPD)

Many installations require the additional of LPSs and SPDs, these can be incorporated into the low-voltage switchgear to protect the building, the assembly and in many cases, to be connected to the main earth terminal.

16.1 LPS

Lighting protection systems should be designed and installed in accordance with the *BS EN 62305 2011* - Protection against lightning, series of standards. This standard is more relevant to the design of LPS and therefore will not be covered in this application guide in any detail.

Regulation 542.4.1 of *BS 7671* requires that the lightning protection system should be connected to the main earth terminal, though in some cases the requirements of *BS EN 62305* do contradict this. Additional advice from a suitably skilled lightning protections specialist should be sought.

Should the building require lighting protection, then a suitable risk assessment should be undertaken by a skilled and competent lightning engineer.

16.2 SPD

Recent changes to *BS 7671* have increased the awareness of many people to the availability of electrical surges and the protection thereof.

Should an installation be required to have an LPS, then surge protection will naturally follow, though the use of SPDs in an installation is not dependant on lightning protection alone. Inductive loads, such as lifts, motors etc. can cause surges to occur within the building and protection of sensitive equipment may be necessary.

It is also a requirement of BS 7671, *Regulation 443.2.4* that a risk assessment should be undertaken for any installation with regard to the need for SPDs which depends, in part, on the consequential levels of risks. The following are the different consequential levels of risks:

(i). *Consequences related to human life, e.g. safety services, medical equipment in hospitals*
(ii). *Consequences related to public services, e.g. loss of public services, information technology centres, museums*
(iii). *Consequences to commercial or industry activity, e.g. hotels, banks, industries, commercial markets, farms*
(iv). *Consequences to groups of individuals, e.g. large residential buildings, churches, offices, schools*
(v). *Consequences to individuals, e.g. small or medium residential buildings, small offices*

For levels of consequences (i) to (iii) protection against overvoltage should be provided.

In other words, for installations where (i) to (iii) exist, SPDs should be provided

Damage occurs when the surge exceeds the Impulse Withstand Voltage (**IWV**) of the electrical equipment installed. Switching on and off of inductive loads, examples previously listed, releases stored energy within them which can damage components and equipments. These type of surges are generally less severe than those from an atmospheric origin but are more regular and can have a large impact on the longevity of an installation.

An SPD is intended to limit any temporary overvoltage and safely divert it away from the equipment. If the increase in voltage lasts 2 nanoseconds or less it is referred to as a ‘spike’, if it lasts 3 or more nanoseconds it is referred to as a ‘surge’

BS 7671 2001 (the 16th edition) introduced section 443 – Protection against over-voltages of atmospheric origin. This was a new requirement at the time and has been amended over the years, though a new section, 534 – Devices for protection against overvoltage, has been inserted in recent years. In brief, 443 asks if SPDs are needed, if the answer is ‘yes, then 534 gives details on the requirements and what type of devices are to be used. Figure 9 below illustrates a typical SPD arrangement:

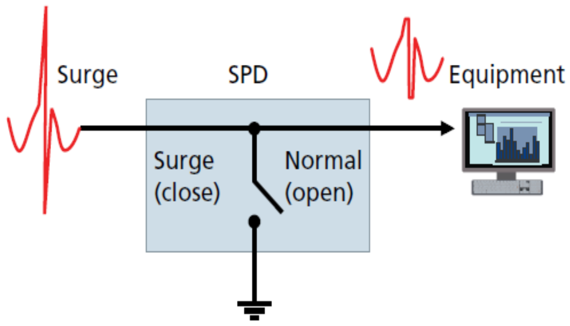


Figure 9 - Image of a SPD layout

SPDs fall into 3 types and these are detailed in table 5 and further illustrated in figure 10:

Type	Location	Protection
1	Placed at the origin of the installation (usually where there is a risk of direct lighting current)	Risk of direct strike to building, lightning protection system or overhead incoming
2	Located at the relevant distribution boards throughout the installation	Overvoltage and high currents at sub-board level, overstressing of insulation and the general installation
3	Fitted to pieces of electrical equipment	Overvoltage and high currents on items of equipment

Table 5 - SPD types and protection

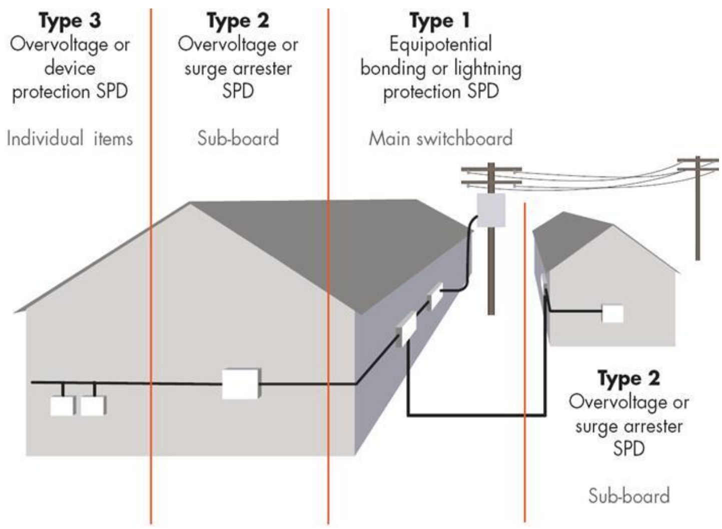


Figure 10 - Typical layout of SPDs (taken from the IET on site guide)

As can be seen, most scenarios relating to low-voltage switchgear that require SPDs will need a type 1 or type 2 to be incorporated.

Much like protective devices require discrimination, suitable consideration will need to be given to ensure SPDs offer suitable protection. A simple way to ensure this is to use devices from a single manufacturer.

One important element to consider in the design of any system incorporating SPDs at or near the origin is that the length of cable from the circuit, to the SPD and to the Main Earthing Terminal (MET) should be preferably less that 0.5 m but shall not exceed 1 m.

When specifying low-voltage switchgear it is important to consider the need to have and securely fit SPDs and to ensure that they are suitably selected throughout the installation.

As SPDs are generally not self re-setting, then it is likely that any SPD within the switchgear will need to have an external indicator to show that the unit is functioning correctly, or that maintenance will be required.

17 Labelling and Identification

Each element of the LV switchgear and protective device should be clearly labelled and identified. Rear access panels should have labelling duplicated on the front and back for clarity. Section 514 of *BS 7671* provides specific information about the requirements for labelling and identification of circuits and cables.

Regulation 514.10.1 refers to warning notices of voltage and requires that a danger notice be provided where a voltage greater than 230 V U_o is not likely to exist (line to earth). As most installations in the UK are at this level or below, rarely is a 'Danger 400 V' label required.

Clause 38.2.3.1 of *BS 9999: 2008 Code of practice for fire safety in the design, management and use of buildings*, requires that power supplies to life safety and fire protection equipment is clearly labelled to their purpose. Depending on how the isolating protective device is fed, additional warnings may be needed:

> *Additional warning labels should be provided, with their location and wording depending on whether the isolating protective device is fed from the live side or the dead side of the main isolating device*

Note – at the time of writing *BS 9999* is being updated.

BS 5839-1: 2013 Fire detection and fire alarm systems for buildings – Part 1: Code of practice for design, installation, commissioning and maintenance of systems in non-domestic premises, provides specific information for supplies to fire alarm systems and their labelling.

17.1 BS EN 81346 Series

The BS EN 81346 - Industrial systems, installations and equipment and industrial product - Structuring principles and reference designations, series of standards specifies requirements for labelling of objects. This series of referencing provides each object i.e. a distribution board, a specific letter and number classification for identification. Though not widely adopted, certain contracts will require this method to be used when naming distribution equipment.

18 Electromagnetic Compatibility (EMC) Requirements

Electromagnetic compatibility requirements refer to, in general terms, the electromagnetic effects of one part of the system shall not interfere with another part of the system by causing electromagnetic interferences (EMI).

In the case of LV switchgear and protective device assemblies, fully meeting *BS EN 61439-2* and ensuring that all equipment meets the EMC requirements is the easiest route to presumption of compliance with the EMC Directive and *Regulations 331.1* and *332.2*.

Low voltage Assemblies marketed within the EU have to comply with all relevant Directives and be CE marked. For the majority of Assemblies this requires compliance with the Low Voltage and the EMC Directives.

Regulation 512.1.5 of BS 7671 introduced a new requirement in 2015 to place the onus on the designer of the installation to ensure that the fixed installation is in compliance with the EMC Directive 2004/108 and upon request should be able to provide documentation as required by the Directive.

Where installations are composed solely of CE-marked equipment in conformity with the EMC Directive, this meets the requirements of the EMC Directive. The designer should be able to provide the instructions and the maintenance documentation, as provided by the manufacturer, upon request.

A copy of the Electromagnetic Compatibility Regulations 2006 can be downloaded for free from:

http://www.legislation.gov.uk/uksi/2006/3418/pdfs/uksi_20063418_en.pdf

19 Thermal Effects

Where the low-voltage switchgear is to have multiple functional units and loads, the heat from the cables and busbars within the units can cause issues should it become excessive. Many manufacturers allow diversity factors for the number of outgoing circuits; this is called the rated diversity.

19.1 Rated Diversity

BS EN 61439-1 section, 5.4 gives a rated diversity of the assembly as:

> *The rated diversity factor is the per unit value of the rated current, assigned by the ASSEMBLY manufacturer, to which outgoing circuits of an ASSEMBLY can be continuously and simultaneously loaded taking into account the mutual thermal influences.*

Rated diversity factor can be stated:

- for groups of circuits;
- for the whole ASSEMBLY.

> *The rated diversity factor multiplied by the rated current of the circuits shall be equal to or higher than the assumed loading of the outgoing circuits. The assumed loading of outgoing circuits shall be addressed by the relevant ASSEMBLY standard.*

Careful discussions should take place with the manufacturer prior to specifying the equipment regarding the rated diversity factor. Should any doubt exist, a factor of 1 should be specified.

19.2 Cable Termination Temperatures

Typically cables are rated to operate at either 70 ^{O}C or 90 ^{O}C depending on their relevant British Standard. Often terminals to which power connections are attached are rated at 120 ^{O}C, though this should be confirmed with the manufacturer.

BS EN 60947-1 classifies ambient temperature as between 10 and 40 ^{O}C, should the sum of the cable and busbar heating loads take the functional unit beyond ambient, then calculations of overcurrent devices may have to be altered as effective tripping may not occur.

20 Cables

Typically, low-voltage switchgear will need to have multiple cables terminated into it, possibly bus bars too. Adequate provision should be made for the installation and maintenance of these supplies and feeds.

20.1 Cable Sizes

Before the low-voltage switchgear is specified, consideration of the number, size and type of cables is needed. This information should be made available to the manufacturer of the switchgear to ensure that suitable provision is provided. Also, if parallel cables are specified then this should be made clear.

Whilst this application guide does not consider the design of cables or their cross sectional area, it is important to carefully consider this prior to specifying the assembly. It is very easy to over-engineer the cables to allow for increased current carrying capacity or voltage drop but it should also be realised that this has an impact on cost, not just for the cable(s) but also for the assembly.

20.2 Cable Lugs and Pins

Where cables have been installed over long runs because of voltage drop issues, an oversized cross sectional area compared to the rating of the protective device is often found. This can have an impact on the ability to adequately terminate the cable to the protective device. In these instances suitable cable lugs or pins should be provided and installed, that have been tested to *BS EN 61238-1:2003 Compression and mechanical connectors for power cables for rated voltages up to 36 kV (Um = 42 kV). Test methods and requirements,* or similar standards.

Most connections should be torqued to appropriate levels with a suitable torque wrench. Manufacturers' instructions should be sought for the correct torque setting requirements.

20.3 Cable Supports

Where any cable is unsupported a potential for strain is placed on the terminations or the glands, this is also true where cables enter low-voltage switchgear. The cable supports should be adequate for the type and nature of the cable.

20.4 Glands

Where armoured or screened cables are connected into low-voltage switchgear, suitable glands should be provided and adequately installed. The glands are designed to offer mechanical support to the cables and also to provide a point of connection for the armouring to the low-voltage switchgear metalwork. In many cases these cables are connected into a removable gland plate which should be adequately connected to the main earth bar.

20.5 Eddy Currents in Single Core Cables

Where single core cables are used to enter metallic enclosures consideration should be made to minimise the impact of eddy currents. Although slotting of the containment is one method to reduce the heating impact of eddy currents, the preferred option would be to use a non-ferrous metal for the gland plate i.e. aluminium.

20.6 Identification

All cables should be suitably identified to allow easy maintenance to be undertaken. Where numerous armoured cables enter an assembly, it is advisory that suitable cable identifications are provided to the cables at the point of glanding and where they pass through the assembly.
Where multi-core cables are used, suitable cable identification ferrules are recommended at the point of termination.

21 Earthing & Bonding

Many low-voltage switchgear systems require their metallic structure to be connected to the earthing system. The connections should be made in accordance with *BS 7671* and meet manufacturers' requirements where relevant.

21.1 Earth Bars

The main earth bar shall be shall be adequate for the installation and should meet the minimum requirements of chapter 54 of *BS 7671*. Further guidance on this subject can be obtained from ECA Application Guide ***AG 03/2016/1 -*** Earthing of Industrial / Commercial Secondary HV / LV Substations and Main Earthing Systems.

21.2 Solid Versus Single-point Bonding

Where single-core sheathed or armoured cables are present with a steel armour protection, *BS 7430:2011+A1:2015 Code of practice for protective earthing of electrical installations 6.11.3* recommends that solid bonding be applied; i.e. the metallic sheath or armouring is connected to earth at both ends. Any induced voltages within the armouring will be reduced to relatively low levels and the armouring can be used as a protective conductor.

If solid bonding is not an option, single-point bonding can be implemented; i.e. connection of the sheath or armouring to earth at only one end of the cable. If this is the case, there will be an induced voltage present at the unearthed end of the cable armour, however, experience shows that the value of this voltage is unlikely to be greater than 50 V in all but the rare circumstances. (It would need in excess of 1000 A over 300 metres or more for the 'standing voltage' to become problematic).

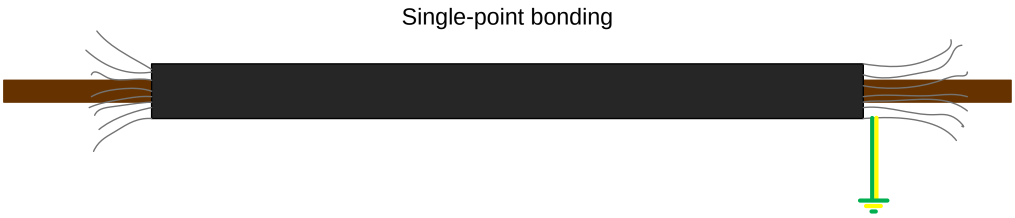


Figure 2 - Single-point bonding of single core armoured cable

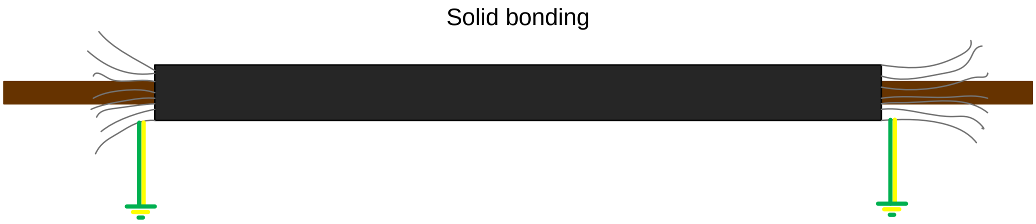


Figure 3 - Solid bonding of single core armoured cable

21.3 Bonding of Containment

Typically cables coming in to or out of the low-voltage switchgear are supported on, or in, some form of metallic containment. This containment is classed as an exposed conductive part and must therefore be bonded to the main earth terminal with an adequate cross-sectional-area bonding conductor.

22 Packaged Substations

A packaged substation typically has the HV / LV transformer close-coupled to the LV switchgear. Additionally, the HV switchgear may also be close-coupled to the transformer, or sited adjacent, the whole HV / LV assembly being contained in one room. Whilst packaged substations can be economically attractive there are a number of factors that need to be considered.

22.1 Segregation Between HV & LV

In should be acknowledged that the ‘switch room’ becomes both a High Voltage and Low Voltage ‘Closed Electrical Operating Environment’. Low Voltage Authorised Persons are likely to have different skills and training from those of a HV Authorised Person and permit systems for HV & LV will be different. It is therefore essential that the HV operating area is segregated from that of the LV. Without such segregation the whole of the switch room becomes the province of HV operational safety procedures and under the control of an HV Authorised Person. Sufficient segregation can be achieved by means of a chain link fence (at least 2 metres high) at the boundary of the HV and LV operating areas. Generally as indicated in figure 15 below:

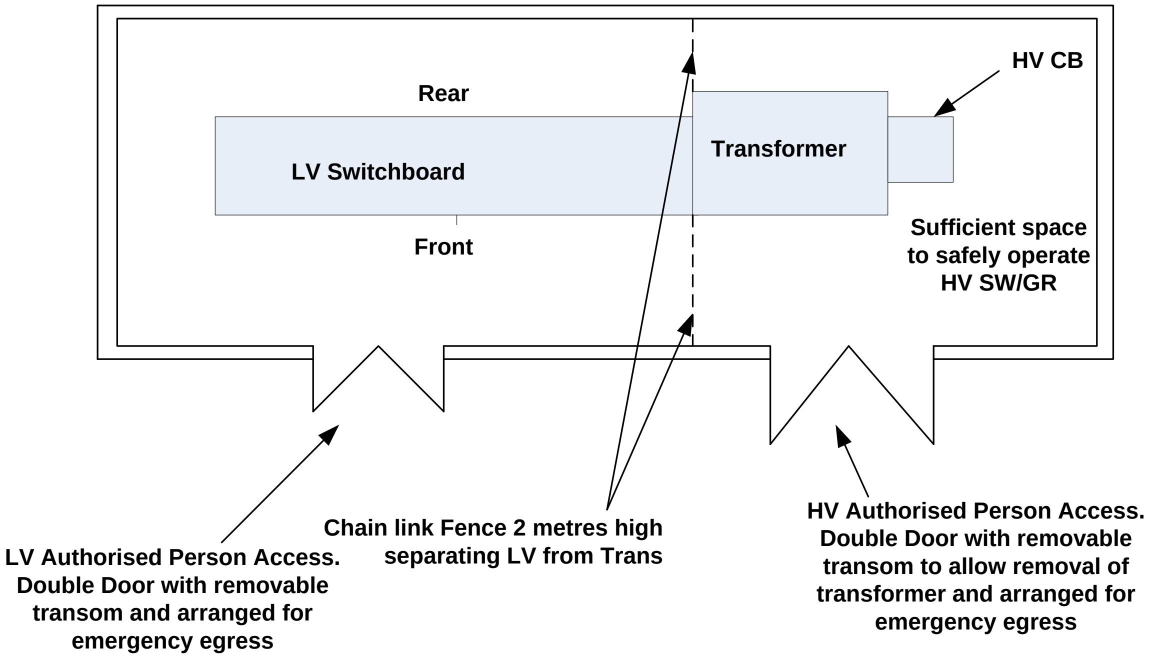


Figure 15 – Typical Layout of Packaged Substation ‘Switch room’

22.2 HV Switchgear and Operating Area

Access to the HV operating area should only be allowed to HV Authorised, or Senior Authorised Persons (APs or SAPs). Preferably this should be by separate means of access and egress from that of the LV, generally as indicated in figure 15. Sufficient space should be allowed to enable those undertaking HV switching activities, to do so safely. Egress doors should be double doors, arranged for emergency egress (break-out) and additionally there should be a removable transom to allow the transformer to be both installed and removed. Non-authorised persons should only be allowed access to the HV operating area under a Permit-to-Work or a Limitation-of-Access Permit, issued by an HV Authorised Person.

22.3 Transformer Type

The transformer will usually be of the Cast Resin dry type as there is less of a fire risk associated with cast resin transformers and they are suitable for indoor use.

22.4 Transformer Enclosure

The Transformer should be fully enclosed in a sheet steel enclosure, with lockable doors or bolted panels. If lockable doors are employed it is preferable that they incorporate electrical interlock switches designed to trip the HV circuit breaker if the door is opened. An alternative (and arguably safer) method is to incorporate ‘Castell’ switches such that the HV circuit breaker must be closed in the circuit earth position to allow withdrawal of the ‘Castell’ key for use on the enclosure doors.

22.5 HV Cables and Terminations

Careful consideration should be given to the HV cables where they terminate onto the transformer. The terminations on a cast resin transformer are usually across the body of the transformer, which can be some distance from the gland plate, as illustrated in figure 16, below. If employing 3 core HV cables from the HV Switchgear to the transformer, the cable break-out from the ‘crutch’ at the transformer end can be quite long. A characteristic of power transformers is in-rush current at energisation and this in-rush current can approach the 3 phase short circuit value for a brief period. During this in-rush transient the HV cable ‘tails’ from the ‘crutch’ are forced violently apart by the electro-magnetic forces generated. It is therefore essential that the cable ‘tails’ are adequately braced after the cable gland plate.

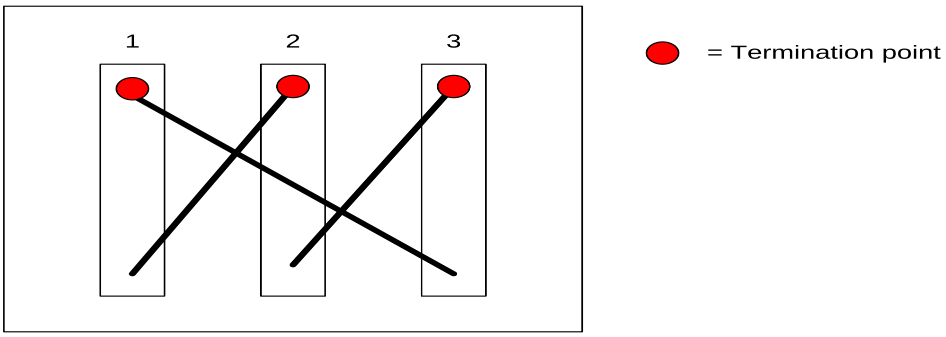


Figure 4 - Typical HV / LV terminations on a cast resin transformer

22.6 Ventilation

A transformer (whether dry type or liquid type) has a significant heat loss when operating. As an example, a 1000 kVA transformer at full load will generate around 14.5 kW of heat (this includes both Iron and Copper losses). Adequate filtered fresh air ventilation must therefore be provided to the switch room to prevent too much heat build up.

22.7 Noise & Vibration

Cast resin transformers can create more noise that a fluid (oil) filled transformer. The reason for this is the fluid acts as a damper to reduce the noise emanating from the laminations of the transformer, whereas a cast resin transformer is solid in construction.

Noise output must be considered when deciding where to place the transformer but certainly it should not be placed adjacent to rooms with sleeping accommodation, offices, classrooms, laboratories or any room containing a low ambient level of noise.

The transformer should be placed on a solid concrete foundation, or the manufacturer's instructions should specify the mounting requirements. Mounting on the roof of a building should be avoided unless adequate anti-vibration mounting measures are incorporated..

22.8 Outdoor Packaged Substation Housings

Where a packaged substation is to be installed in an external environment, it should be housed in a suitable glass reinforced plastic (GRP) building / enclosure. This building is subject to the usual requirements for spacing around the transformer, as well as ventilation, etc.

The GRP building / enclosure should be suitable for housing a transformer and should have adequate fault blast release vents installed that, in the event of a fault, act as weak points allowing the energy to dissipate through them, rather than damaging the building / enclosure

23 Conclusions

As can be ascertained from a reading of this guidance document, the selection of low voltage switchgear and associated protective devices, is a process that requires a great deal of thought and consideration, with regard to:

- The intended use of the assembly
- The criticality of the installation
- Future maintainability requirements
- The environment in which the Assembly will be located
- The required fault rating of the switchgear and components
- The level of discrimination required throughout the installation
- The sizes and types of cables that are to be terminated.

Used in conjunction with each section of this guidance, Appendix B of this provides a 'Sample Low Voltage Purchase Specification' that will go some way to focussing the thoughts of those responsible for the selection of low voltage switchgear assemblies and protective devices.

24 Appendices

24.1 Appendix A – Standards Referenced In This Document

Reference	Description
PD IEC/TR 61439-0:2013	*Low voltage switchgear and controlgear assemblies. Guidance to specifying assemblies*
BS EN 61439-1: 2011	*Low-voltage switchgear and controlgear assemblies. General rules*
BS EN 61439-2: 2011	*Low-voltage switchgear and controlgear assemblies. Power switchgear and controlgear assemblies*
BS EN 61439-3:2012	*Low-voltage switchgear and controlgear assemblies. Distribution boards intended to be operated by ordinary persons (DBO) (incorporating corrigenda September 2013 and December 2015)*
BS EN 61439-4:2013	*Low-voltage switchgear and controlgear assemblies. Particular requirements for assemblies for construction sites (ACS)*
BS EN 61439-5:2011	*Low-voltage switchgear and controlgear assemblies. Assemblies for power distribution in public networks*
BS EN 61439-6:2012	*Low-voltage switchgear and controlgear assemblies. Busbar trunking systems (busways)*
BS EN 60947-1:2007	*Low-voltage switchgear and controlgear. General rules (+A2:2014) (incorporating corrigendum January 2014)*
BS EN 60947-2:2006	*Low-voltage switchgear and controlgear. Circuit-breakers (+A2:2013) (incorporating corrigendum November 2013)*
BS EN 60947-3:2009	*Low-voltage switchgear and controlgear. Switches, disconnectors, switch-disconnectors and fuse-combination units (+A2:2015) (incorporating corrigenda September 2012 and November 2013)*
BS EN 60947-4-1:2010	*Low-voltage switchgear and controlgear. Contactors and motor-starters - Electromechanical contactors and motor-starters (+A1:2012)*
BS EN 60947-5-1:2004	*Low-voltage switchgear and controlgear. Control circuit devices and switching elements. Electromechanical control circuit devices (+A1:2009) (incorporating corrigendum November 2004)*
BS EN 60947-6-1:2005	*Low-voltage switchgear and controlgear. Multiple function equipment. Transfer switching equipment (+A1:2014)*
BS 7671:2008+A3:2015	*Requirements for Electrical Installations. IET Wiring Regulations*
IEC 60617-7:1996	*Graphical symbols for diagrams. Switchgear, controlgear and protective devices*
SI 1989/635	*Electricity at Work Regulations 1989*
BS EN 60204-1:2006+A1:2009	*Safety of machinery. Electrical equipment of machines. General requirements*
Guidance Note 2	*The IET*
BS EN 60909-0: 2001	*Short-circuit currents in three-phase a.c. systems*

PD CLC/TR 50480:2011	*Determination of cross-sectional area of conductors and selection of protective devices*
BS 88-1:1967	*Specification for cartridge fuses for voltages up to 660 volts. Performance and dimensions of fuse links* ***(now withdrawn)***
BS EN 60269-1:1994, BS 88-1:1988, IEC 60269-1:1986	*Low-voltage fuses. General requirements*
ENATS 41-26	*Distribution Switchgear For Service Up To 36 kV (cable And Overhead Conductor Connected) [As published by the Energy Networks Association]*
BS EN 62305 2011	*Protection against lightning*
BS 9999: 2008	*Code of practice for fire safety in the design, management and use of buildings*
BS 5839-1: 2013	*Fire detection and fire alarm systems for buildings*
BS EN 81346	*Industrial systems, installations and equipment and industrial product. Structuring principles and reference designations*
2004/108	*Electromagnetic Compatibility Regulations 2006*
BS 7430:2011+A1:2015	*Code of practice for protective earthing of electrical installations*
BS EN 61238-1	*Compression and mechanical connectors for power cables for rated voltages up to 36 kV (Um = 42 kV). Test methods and requirements*

24.2 Appendix B – Sample Low-voltage Switchboard Purchase Specification

LV SWITCHBOARD PURCHASE SPECIFICATION		
Schematic Diagram Drawing No:		
1.	Supply Voltage Rating	…………..V
2.	Fault Rating or Supply Transformer Rating	…………..kA (…………………MVA)
3.	I P Rating	IP …………..
4.	Colour	Manufacturers Standard/Other
5.	Access Cable Terminations	Front/Rear/All round
6.	Supply Arrangement	Single Source/Multiple Source (Specify sources and operational arrangement)
7.	Earthing Arrangement	Combined NE Separate NE Include NE Link Yes/No
8.	Main Incoming Cable	Top/Bottom
9.	Main Incoming Cable	Multicore/Singles Copper/Aluminium Conductors Size ……………. Type …………… No ………………
10.	Main Incoming Gland Plate(s)	Steel/Alum/Paxoline Non Ferrous Clamps Fixed/Adjustable
11.	Main Incoming Switch	Isolator/Non Auto MCCB Auto MCCB/ACB/FS/3 Pole 4 Pole Integral Protection Module Fixed/Withdrawable
12.	CT Driven Protection	REF/UREF/O/C and E/F/Other
13.	Relays for TX Protection	WT Alarm/Trip-Bucholz
14.	Inter-trip Facility to HV Switch	Yes/No
15.	Main Incoming Switch	Ammeter/Voltmeter/KWH Meter Phase Selector Switch VM Yes/No AM Yes/No
16.	Interlocking – Mech/Elec/Castell	Yes/No (Please specify on separate sheet)
17.	ASTA Cert Panel ASTA Cert System/Components	Yes/No Yes/No

18.	Metering to outgoing functional units	See mains schematic total quantity

19.	Segregation	Form 1/2/3/4 Type (1 to 7) …………
20.	Relative Position of Main Incomer	……………..
21.	Floor/Wall Mounted	……………..
22.	Busbar Rating	………… Amps
23.	Bus Section Switch	Rating ………. Amps 3 Pole/4 Pole
24.	Outgoing Cables	Top Exit/Bottom Exit/Top and Bottom Exit Gland Plates – Fixed/Removals
25.	Outgoing Circuits	ACB/MCCB/FS Ammeter/Voltmeter/KWH Meter Lockable in ON and/or OFF position.
26.	Integral Dist Boards	Yes/No BS 88 Fuses/MCB's/MCCB's MCB Types B/C/D Mixed
27.	Lockable Hinged Doors	Yes/No Suited Locks/Dedicated Locks
28.	Witnessed Factory Test	Yes/No Please Detail
29.	Witnessed Site Tests	Yes/No Please Detail
30.	Label Schedule Required	Yes/No
31.	Facility to Accommodate Power Factor Correction Equipment	Yes/No
32.	Max Overall Dimensions with regard to Intended Location	
33.	Max Cubicle Dimensions for Shipping and Handling with regard to Access Arrangements to the Switchroom e.g. Corridors, Doorways etc.	
34.	Plinth Required	Yes/No If YES height …………….mm
35.	Other ………………………………………………… ………………………………………………………….. …………………………………………………………..	
NB	Whenever Possible Enclose a Cable Schedule of Incoming and Outgoing Cables Sizes and Types to Allow Adequate Provision for Termination	

24.3 Appendix C – Sample Checklist for Switchgear Pre-delivery Inspection and Factory Acceptance Tests

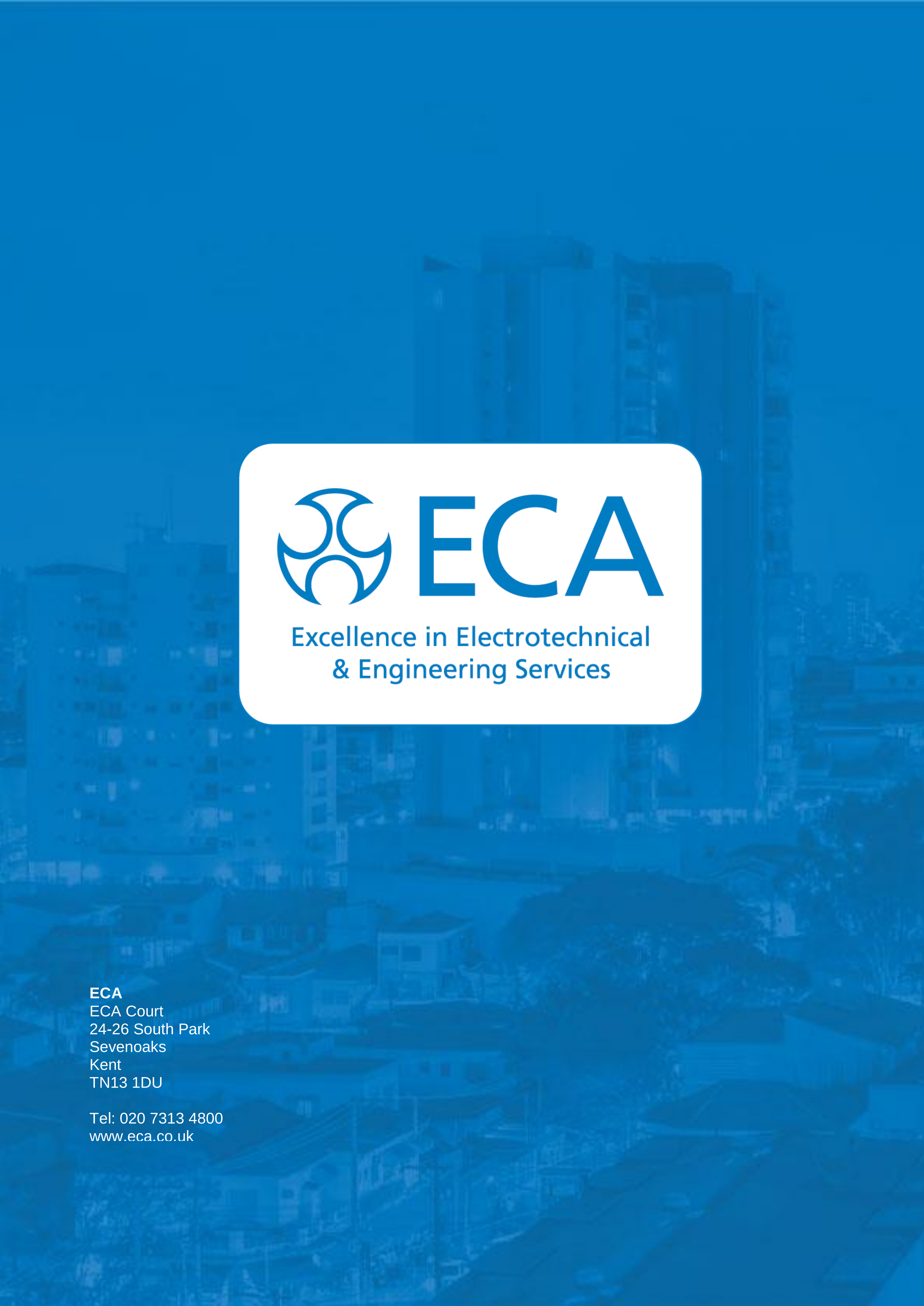
Checklist for Switchboard Pre-Delivery Inspection and Factory Acceptance Tests.		
Contract:	**Contract No:**	**Sheet of**
Equipment Ref:		**Drawing No:**

Item	**Inspection Details**	**Y/N/NA**
1	Confirm Correct Dimensions	
2	Free from visible damage	
3	No exposed live parts	
4	Identification marks on bus bars	
5	Compartments identified correctly	
6	Correct breakers, size/type/rating	
7	Fuses/Relays/Terminals etc. labelled/marked correctly	
8	Correct earth bonding of doors, gland plates etc.	
9	Correct location of neutral earth link (should normally be fitted on live side of main ACB)	
10	Continuity and polarity checks to all outgoing feeders	
11	All outgoing feeders shall be checked for correct operation and indication of switches	
12	Gland plates are of correct material (ferrous/nonferrous)	
13	Electrical/mechanical and/or Castell arrangement correct	
14	All CT terminations and ratio to be checked to drawing	
15	All panels to be cleaned out prior to testing	
16	Joint resistance tests on all bus bars earth bars and across all circuit breakers, switches, fuse switches, MCCBs etc	
17	Insulation resistance and pressure tests shall be carried out with all switching devices in the closed position at manufacturers recommended test voltages	
18	Insulation resistance and continuity tests of control wiring to be tested at 500volts	
19	All circuit breaker and relay settings to be applied prior to testing if available	
20	Restricted earth fault tested by primary injection to prove stability and sensitivity any inter-tripping to HV or signals to BMS to be proved	
21	Meters to be checked by primary injection to prove ratio of CT and correct programming of meter, both for reading on meter and output to BMS	
22	Check Synch if fitted, to be proved with 2 supplies to allow closing of breakers, then 2 phases changed to show 'out of synch' breakers should not close	
23	BMS schedule if available should be checked for availability of correct signals.	
24	Winding Temperature relay to be checked for tripping HV/LV and BMS signals	
25	Inter-tripping from HV to LV	
26	Any removable covers with exposed live bars behind should have warning labels fitted	

24.4 Appendix D – Sample Checklist for Substation / Switch Room Layout

Checklist for Substation Layout and Installation		
Contract:	**Contract No:**	**Sheet of**
Equipment Ref:		**Drawing No:**

Item	**Inspection Details**	**Y/N/NA**
1	Sub Station doors must be secure and lockable	
2	Is access required by the Client and the DNO? If so, ensure the locking provision allows access by either party	
3	Lighting and emergency lighting is adequate / correctly located?	
4	Are all cable penetrations fire sealed / watertight?	
5	Are cable trenches covered?	
6	Ensure cable access to cast resin transformer enclosures and any locations which contain 'live conductors' are restricted to prevent persons entering	
7	Operational space around switchgear and transformers to be 1 meter min. If withdrawable switchgear, check space requirements are achieved when switchgear is withdrawn	
8	Ensure clear and unhindered exit routes are provided	
9	Ensure all equipment is removable / accessible for maintenance	
10	Ensure escape travel distance does not exceed 7 meters from any point within a high voltage switch room	
11	If battery trip unit required; is this provided?	
12	Do batteries require to be charged prior to mains being energised?	
13	If transformers are located within substation, is adequate ventilation provided?	
14	Ensure mains schematic is displayed in switchroom / substation	
15	Ensure electrical shock resuscitation notice is displayed in HV / LV switchrooms, substation identification and on HV switchrooms 'Danger High Voltage' notices are displayed	
16	If inter-tripping with the DNO's equipment, are interposing relays required?	
17	If inter-tripping is required, has the cabling been designed / installed?	
18	Are emergency power off buttons required? Who are supplying these (DNO or Contractor)? Has location been agreed?	
19	Has the electricity meters been ordered? Has sufficient space been allocated / agreed for the metering equipment?	
20	Is a substation log book required?	
21	Is a fire extinguisher required?	
22	Is an anti-condensation heater / thermostat required?	
23	Have 13 Amp sockets been installed? (check for mounting height requirement)	
24	Has adequate attention been given to noise / vibration from transformers (particularly roof mounted)?	



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