1. Introduction

Depending on the size of the building or factory site and whether the supply is high voltage or low voltage, there may be requirements for both a main high voltage switchboard (SWB) and one or more low voltage SWBs or just a single low voltage SWB. The preferred name for the switchboard unit is a “Switchgear and Controlgear Assembly” (SCA).

The basic aim of the SWB or SCA is to take the electrical power from the main supply source and then to feed or distribute power to the appropriate circuits within the building. The SWB has to perform this function in such a way that there is proper control of power flow and proper electrical protection against the damaging effects of faults. This protection is necessary to prevent personnel hazards and also equipment hazards and possible fires. It should be able to operate to isolate a faulty section in the minimum possible time consistent with the fault severity. The SWB should also be designed to present no danger of electric shock or injury to the operating personnel in the vicinity during normal or abnormal operation. Explosions in switchboards are a not infrequent occurrence which can cause significant injury to personnel. In many cases, work
is performed on the switchboard components while they are still live.

2. **Component Parts of a Switchboard**

The major components of a switchboard are:

1. **The Incoming Cables**

   These may be either high voltage (HV) or medium or low voltage (MV or LV). For high voltage, they will normally be either impregnated paper insulation (unlikely these days), cross linked polyethylene (XLPE) or ethylene propylene rubber (EPR) insulated cable. The last two types are the preferred types for new installations, with XLPE being the most common. EPR cables are more flexible and are preferred for specialized applications such as trailing leads in mines. For low voltages the cables may be XLPE or elastomer (EPR) type cable

2. **Outgoing circuit conductors**

   These may be any of the following types:
   - Insulated cables,
   - Insulated busbars,
   - Busbar trunking systems
   - Mineral insulated metal-sheathed (MIMS) cables
   - Fire-resistant cables
Figure 1

Typical arrangement of switchgear in a switchboard
Figure 2a: Switchgear enclosures and housings
Figure 2b: Switchgear enclosures and housings
3 Internal busbars

These may be rigid copper (or aluminium) bars (insulated or uninsulated) in large SWBs or simply insulated single phase cables in small SWBs. In large capacity SWBs each phase may have a number of conductor sections.

Bare LV busbars are very close together and are thus subject to high electrodynamic forces on short circuit and resonant force effects must be considered in determining supports. The resonant frequency must be calculated to ensure it is not close to 100 Hz.

Figure 3 shows a general busbar layout in a low voltage (415 V) switchboard.

![SWB layout and internal busbars](image-url)
4 Main isolating switch or section switches

These allow segregation of the switchboard or its component parts to allow maintenance work.

5 Circuit breakers

These are HV or LV depending on the switchboard voltage level.

For HV units the circuit breaker types used are oil, SF6 and vacuum units, contained in withdrawable rack-mounted carriers. Oil CBs are no longer used in new installations but are still very prominent. (In older switchboards there may also still be some high voltage air-break units with insulating splitter plates, but these are very rarely used now). Fig 4 shows a modern vacuum CB in a swb rackmounting unit.

For LV and MV (less than 1000 V) units, the circuit breakers are invariably of the air-break type using the “de-ion” principle, with isolated metal splitter grids. Large MV CB units may be also rack-mounted but the modern SWB will have moulded-case circuit breakers (MCCBs) for the higher current ratings (more than about 100 Amps) and miniature circuit breakers (MCBs) for the lower rating levels (less than 100 Amps). MCBs would normally be used in the smaller sub-main and local SWBs in a building.
6 HRC fuses and CFS units

These are also used in MV and LV switchboards for high level fault protection and, in many cases, there are combinations of HRC (high rupturing capacity) fuses and overload switches with limited interrupting capacity used (combined fuse-switch or CFS units) because of their economy.
See Fig 1 for more detail of typical usage of switchgear and Fig 2 for some examples of rackmounted switchgear. Fig 5 shows examples of MCCBs.

Figure 5
Moulded case LV circuit breakers of varying ratings
Figure 6 shows the operating mechanisms and principles of the de-ion breaker that is the basic feature of MCBs and MCCBs in LV switchboards.
7 Protection relays

These are used for the higher voltages, together with their associated instrument transformers (current transformers (CTs) and voltage transformers (VTs)). Overcurrent protection units are used to activate timing relays so as to provide proper fault protection operation. At lower voltages, the circuit breakers will normally have in-built fault detection sensing and thus no separate relaying is required. Older HV swbs will have induction disc relays while modern SWBs will have microprocessor based digital electronic relays that are much more versatile.

8 Metering equipment

The metering of a SWB will include: line and phase voltage, line current in each phase, total power, power factor metering. The current is monitored by a current transformer (CT): in SWBs there may be two CTs, one for protection and one for metering.

9 Over-voltage surge protection

Modern switchboards will also have some over-voltage surge protection designed into both the HV and LV sides to protect equipment against the effects of any over-voltage transients that may be generated within the system or conducted in from external sources.
3. Requirements

Switchboards are usually quite specific to their particular requirements in a building and thus they tend to have a one-off or unique design, with little scope for standard design of large switchboards such as will be found in large buildings. However, in large building systems, the smaller sub-circuit distribution boards, located on each floor level for example, may be of a standard design. Similarly, domestic switchboards are standard designs and are uniform across Australia.

It is fair to say that SWBs (particularly the smaller low voltage type) are not often designed by technically expert persons and, together with their unique one-off design, there is thus a need to perform detailed testing to prove a particular design. Even expert designers may have problems with some operational features (particularly thermal dissipation and temperature rise) where the overall operation may not be what would be expected from the characteristics of the individual components which make up the switchboard.

For example, the thermal interactions of the component parts may limit the thermal ratings of components within the SWB to levels below their normal (isolated) ratings. De-rating factors may be required to be applied. This is particularly a problem for cable bundles entering a SWB. Similarly, the complex magnetic fields in a SWB may cause some variation in the calculated forces on busbars in
the SWB or may cause some unexpected eddy current heating of any metal (particularly steel plate) that may be in the vicinity.

The requirement for such extensive testing of switchboards means that the customer must be very specific in his required specifications when giving these to the SWB designer and constructor. The customer should also specify clearly what tests should be performed to prove the SWB operation and this should be agreed with the builder. In many cases these may be destructive tests and thus it will be necessary to count on multiple numbers for construction.

**Switchgear and busbar requirements**

In general, the requirements for switchgear in new switchboard installations in buildings are:

- A life of about 25-30 years at least
- A substantial (20-40%) spare capacity on new installation to allow for expansion.
- Good quality and reliable switchgear in the various outgoing functional units.
- Proper protection design, particularly in the area of time discrimination with flexible variation of I-t characteristics possible..
- Adequate interrupting capacity for future expansion
- Residual current (earth leakage) protection
- Adequate current carrying capacity
- Protection against ingress of contamination (dust, moisture etc)
- Adequate compartmentalization to limit arc faults
The purchaser should specify, at the least, the following requirements for switchboards and switchgear:

- Voltage, power, current ratings.
- Specific rating for each circuit breaker and busbar system.
- The required fault level and the corresponding protection operating time.
- Internal structure and segregation of compartments (if required).
- Ingress Protection (IP) numbers for protection against dust and moisture.
- Arc containment requirements.
- Earthing requirements.
- Electrodynamical forces and insulator mechanical strength requirements.
- Thermal features - maximum temperature rises etc.
- Testing requirements (Type tests and Routine tests).

### Australian Standards for design of SWBs

The Australian Standard **AS3439.1-2002** (Low Voltage Switchgear and Controlgear Assemblies – Part 1: Type-tested and partially type-tested assemblies) is the document which gives specific requirements for LV SWBs.

There is a similar, though more diverse document, **AS2067-1984** (Switchgear Assemblies and Ancillary Equipment for Alternating Voltages above 1kV). AS2067 also covers
outdoor substations and specifies required clearances for bare HV conductors.

Both documents also provide detailed guidelines for access prevention by un-authorised persons.

**Internal Segregation of circuits in the SWB**

With a number of separate circuits within the switchboard and with the knowledge that SWBs, with a multiplicity of internal components, are more susceptible than most items to faults, the question of whether to segregate chambers or parts within the whole structure is an important feature of design. Segregation of chambers by metal walls will assist in containing faults and prevent them from spreading to involve other sections of the board.

The major problem with SWBs particularly at low voltage is the arcing fault. The fault current in such SWBs can be very high and the arc that results will be a very high energy entity that can cause very significant damage by virtue of its high temperature, thermal radiation field and convective heat transfer. It can cause very significant damage to the board and to personnel.

The problem is exacerbated by the fact that the arc impedance is significant and can reduce the current level in the fault and this can affect (slow) the response time of the overcurrent protection. High impedance arc faults are a major problem to the protection design engineer.
Arc faults can be detected by various means such as optical sensors, pressure sensors, sensitive earth leakage protection etc. However in many cases there will be some requirement by purchasers to limit the effects of arc faults by detailed design of the SWB, involving segregating the various internal sections in some way to limit the spread of any fault arc within the board structure.

The standard AS3439.1 defines four different forms of switchboard compartment segregation. These are designated as: Forms 1, 2a & 2b, 3a & 3b, 4a & 4b. Note that Form 1 has no internal segregation of compartments within the SWB. The exact details of the design differences are shown in Figure 7.

**Arc Containment**

Internal arcing in switchboards is usually caused by some dielectric insulation failure within the SWB structure, caused for example by insulation ageing, by moisture, by solid particle contamination or even dropped tools while personnel are working live on the switchboard. Segregation of the internal parts can provide some limitation of the spread of the damage caused by arcing. Such damage can be very destructive.

Figure 8 is an extract from AS3439.1 giving some details of how arc faults may be generated and how they can be prevented and contained. Residual current or earth leakage protection may be necessary to detect high impedance arcing faults.
Ingress Protection (IP numbers)

In common with many forms of electrical equipment, switchboards have to be protected against ingress of various contaminants (such as particles, dust and moisture) and there must also be some means of preventing access of personnel to live internal parts. The specific options and requirements are given by the use of IP numbers, such as IP23, where the two numerals represent specific design requirements to prevent ingress.

The first numeral relates to dust and particulate matter (and also to prevention of direct contact by personnel), while the second numeral relates to ingress of moisture. Thus IP00 would provide no protection whatsoever (completely open), while IP68 would be, effectively, a hermetically sealed enclosure.

Because switchboards are normally located indoors and in locked and ventilated rooms with restricted access, the IP numbers are not particularly stringent in commercial building systems. IP21 may be a typical level of protection in a building SWB. However, in industrial manufacturing building SWBs, or for outdoor SWBs, the ingress protection level may need to be something like IP65.

Figure 9 gives the specific design requirements for compliance with each IP numeral. More details are given in AS60529-2004 (Degrees of protection provided by enclosures)
Form 1: no internal separation

Form 2a
terminals not separated from busbars

Form 2b
terminals separated from busbars

Form 2: separation of busbars from functional units

Figure 7
Switchboard compartment forms of segregation
Figure 8
Requirements for arcing fault containment in SWB enclosures
APPENDIX DD

GUIDELINES FOR ASSEMBLIES INTENDED TO PROVIDE INCREASED SECURITY AGAINST THE OCCURRENCE OR THE EFFECTS OF INTERNAL ARCING FAULTS

(Informative)

DD1 INTRODUCTION Many factors may influence the ability of an assembly to satisfactorily limit the effects of an internal arc.

This Appendix, the application of which is subject to agreement between the purchaser and the manufacturer, describes the problem of internal arcing which may occur in an assembly during service, and covers the design principles that should be considered to reduce the risk of its occurrence or to limit its effects. The tests set out in Appendix EE are intended to verify the degree of security provided by the design.

DD2 OBJECT The object of this Appendix is to give guidance to manufacturers with regard to design objectives and to give guidance to purchasers for the selection of an assembly which will provide increased security by the prevention or control of arcing faults within assemblies under normal operating conditions, with all doors closed and all covers and internal barriers in place.

Specific objectives cover one or more of the following:

(a) To provide means to reduce the probability of the initiation of an internal arcing fault.

(b) To protect personnel from injury in the event of a fault under the normal operating conditions of the assembly.

(c) To limit as far as possible the extent of damage to equipment in the event of a fault.

It should be appreciated that while some design features may give increased protection during maintenance, the tests set out in Appendix EE are not intended to apply to a maintenance situation where work is being carried out within the assembly.

DD3 POSSIBLE CAUSES OF FAILURE Examples of possible causes of failure of the assembly due to the initiation of internal arcing are as follows:

(a) Failure of a component, the connections to it, or the busbar system during commissioning, or due to incorrect selection or application of components or faulty maintenance, such as—

(i) the omission of barriers or shrouds;

(ii) damaged insulation;

(iii) incorrect installation of a protective device;

(iv) replacement of a protective device by an inappropriate one;

(v) the presence of a foreign object;

(vi) the substitution of a component by an inappropriate one;

(vii) loose connections;

(viii) the incorrect adjustment of a component; and

(ix) plug-in contacts.

Figure 8 (cont.)
(b) Failure in service due to one or more of the following:
   (i) Ingress of pollution.
   (ii) Ageing of insulation.
   (iii) Damage caused by rodents and vermin.
   (iv) Corrosion.
   (v) Component fatigue or breakage.
   (vi) Overheating due to, for example —
      (A) loose connections;
      (B) contact wear;
      (C) pollution;
      (D) overloading; or
      (E) lack of ventilation.

**DD4 ARCING FAULT CONDITIONS** When an arcing fault occurs between phases or to earth, the current flowing at any given instant is determined by the applied voltage, the source impedance and the arc voltage. The effect of the arc voltage is to reduce the current to a value below that which would flow under bolted fault conditions.

Because of the dynamic nature of the arc it is difficult to predict the value of arc voltage which varies as the arc moves under the effect of the thermal and magnetic forces acting on it. Depending upon the electrode configuration, at any time the instantaneous value of arc current may assume a relatively high value approaching the bolted fault current or a much lower value possibly approximating load current.

Generally, an arc will continue until it becomes unstable and self-extinguishes or until it is extinguished as a result of the operation of a circuit-breaker or fuse interrupting the current or by other means designed into the assembly.

Some such methods are described in Paragraph DD5.

It is not possible to rely on the arc becoming unstable and self-extinguishing.

**DD5 MINIMIZATION OF ARcing** It is recognized that the increased security against personal injury and damage to equipment may be obtained by a number of means, such as the following:

(a) Taking precautions in the design, construction, insulation or arrangement of the assembly which would make the occurrence of an arcing fault extremely unlikely (see Paragraph DD6(a)).

(b) Containment of the arcing fault (see Paragraph DD6(b)).

(c) Provision of adequate means for detection or limitation, or both, of a fault (see Items (c), (d) and (e) of Paragraph DD6).

**DD6 MEANS OF ACHIEVEMENT** Typical means of reducing the probability of initiation of internal arcing or minimizing its magnitude or duration, or both, and limiting its effects, as outlined in Paragraph DD5, are as follows:

(a) By the provision of one or more insulation systems completely surrounding live conductors to include substantial insulation which alone is capable of withstanding the dielectric test voltage of the assembly. Such provision is able to resist without damage all likely mechanical forces and temperatures that may occur in service and during maintenance, e.g., resin encapsulation or other insulation in addition to clearance in air or other insulating media.

(b) By the arrangement of the busbars and functional units of the assembly in vented compartments designed to promote rapid extinction of the arc and to prevent the arc or arc products affecting other parts of the assembly.

(c) By the use of devices (e.g., fuses or circuit-breakers), designed to limit the magnitude and duration of the arcing current by interruption thereof, so as to limit the risk of injury to personnel or damage to the assembly.

(d) By the use of devices sensitive to the energy radiated from an arc which are designed to reliably initiate the interruption of the arcing current, e.g., by means of a circuit-breaker.

(e) By the use of earth current detection devices, e.g., earth-current relays, designed to initiate the interruption of the arcing current, e.g., by means of a circuit-breaker.

(f) Combinations of Items (a) to (e) above, or other methods designed to either prevent the initiation of an arc, or to reduce the damage or risk of injury resulting from an arc, by sensing of the fault followed by interruption.
### Figure 9
IP number classification system
AS 60529-2004

<table>
<thead>
<tr>
<th>Element</th>
<th>Numerals or letters</th>
<th>Meaning for the protection of equipment</th>
<th>Meaning for the protection of persons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code letters</td>
<td>IP</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>First characteristic numeral</td>
<td>0</td>
<td>Against ingress of solid foreign objects (non-protected)</td>
<td>Against access to hazardous parts with: back of hand finger tool wire</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>≥ 50 mm diameter</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>≥ 12.5 mm diameter</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>≥ 2.5 mm diameter</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>≥ 1.0 mm diameter</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>dust-protected</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>dust-tight</td>
<td></td>
</tr>
<tr>
<td>Second characteristic numeral</td>
<td>0</td>
<td>Against ingress of water with harmful effects (non-protected)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>vertically dripping</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>dripping (15° tilted)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>spraying</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>splashing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>jetting</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>powerful jetting</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>temporary immersion</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>continuous immersion</td>
<td></td>
</tr>
<tr>
<td>Additional letter (optional)</td>
<td>A</td>
<td>-</td>
<td>Against access to hazardous parts with: back of hand finger tool wire</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supplementary letter (optional)</td>
<td>H</td>
<td>Supplementary information specific to: High voltage apparatus</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>Motion during water test</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>Stationary during water test</td>
<td></td>
</tr>
<tr>
<td></td>
<td>W</td>
<td>Weather conditions</td>
<td></td>
</tr>
</tbody>
</table>
4. Design features

In the design of switchboards, there are three major areas which must be addressed;

4.1 The insulation design

This includes the 50Hz power frequency and BIL (Basic Insulation Level or lightning impulse voltage withstand level) insulation levels and also the appropriate creepage and clearance path design requirements.

Because of the potential for accumulation of contaminants such as dust and moisture, the creepage distances over insulation surfaces are very important factors. Surface tracking (creepage) is a major hazard in SWBs where dust and contaminants may accumulate on surfaces. It is also a major problem on outdoor insulators.

Note the distinction between the creepage design distance and the clearance design distance. Clearance distance design is determined by the breakdown characteristics of the air and does not involve any surface effects, whereas creepage is a surface breakdown phenomenon and the creepage distances are determined by the tracking properties of the solid insulation material.

Figure 10 gives details of the power frequency insulation requirements of low voltage SWBs, as specified in AS3439.1.
Figure 11 gives details of the impulse voltage design and testing requirements for switchboards and Figure 12 gives details of the creepage distances required.

### Dielectric Test Voltages (AC)

<table>
<thead>
<tr>
<th>Rated insulation voltage $U_i$ (line to line)</th>
<th>Dielectric test voltage a.c. r.m.s. $V$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U_i \leq 60$</td>
<td>1 000</td>
</tr>
<tr>
<td>$60 &lt; U_i \leq 300$</td>
<td>2 000</td>
</tr>
<tr>
<td>$300 &lt; U_i \leq 690$</td>
<td>2 500</td>
</tr>
<tr>
<td>$690 &lt; U_i \leq 800$</td>
<td>3 000</td>
</tr>
<tr>
<td>$800 &lt; U_i \leq 1 000$</td>
<td>3 500</td>
</tr>
<tr>
<td>$1 000 &lt; U_i \leq 1 500^*$</td>
<td>3 500</td>
</tr>
</tbody>
</table>

* For d.c. only.

(a) for the main circuit

<table>
<thead>
<tr>
<th>Rated insulation voltage $U_i$ (line to line)</th>
<th>Dielectric test voltage a.c. r.m.s. $V$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U_i \leq 12$</td>
<td>250</td>
</tr>
<tr>
<td>$12 &lt; U_i \leq 60$</td>
<td>500</td>
</tr>
<tr>
<td>$60 &lt; U_i$</td>
<td>$2 U_i + 1 000$ with a minimum of 1 500</td>
</tr>
</tbody>
</table>

(b) for auxiliary circuits

---

Figure 10
Insulation requirements for switchboard components and structures
<table>
<thead>
<tr>
<th>Maximum value of rated operational voltage to earth, a.c. r.m.s. or d.c. V</th>
<th>Preferred values of rated impulse withstand voltage (1,2/50 μs) at 2000 m kV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IV</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>1.5</td>
</tr>
<tr>
<td>100</td>
<td>2.5</td>
</tr>
<tr>
<td>150</td>
<td>4</td>
</tr>
<tr>
<td>300</td>
<td>6</td>
</tr>
<tr>
<td>600</td>
<td>8</td>
</tr>
<tr>
<td>1000</td>
<td>12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rated impulse withstand voltage $U_{imp}$</th>
<th>Test voltages and corresponding altitudes $U_{1,2/50}$, a.c. peak and d.c.</th>
</tr>
</thead>
<tbody>
<tr>
<td>kV</td>
<td>Sea level</td>
</tr>
<tr>
<td>0.33</td>
<td>0.36</td>
</tr>
<tr>
<td>0.5</td>
<td>0.54</td>
</tr>
<tr>
<td>0.8</td>
<td>0.95</td>
</tr>
<tr>
<td>1.5</td>
<td>1.8</td>
</tr>
<tr>
<td>2.5</td>
<td>2.9</td>
</tr>
<tr>
<td>4</td>
<td>4.9</td>
</tr>
<tr>
<td>6</td>
<td>7.4</td>
</tr>
<tr>
<td>8</td>
<td>9.8</td>
</tr>
<tr>
<td>12</td>
<td>14.8</td>
</tr>
</tbody>
</table>

Figure 11
Impulse voltage design and test levels for switchboards
4.2 The thermal design

Thermal design is a very important consideration in the design and is complicated by the difficulties present in the theoretical calculation of temperature rise in such complex structures where the heat loss is primarily by convection, which is notoriously difficult to model analytically. This is further complicated by the enclosed nature of the SWB and the interactive heating effects between the many different and very closely spaced components. Much experience and general “rules of thumb” and empirical modeling procedures apply, but the only sure way of proving a
thermal design is by performing temperature rise tests on prototype SWB designs. Thus almost all large switchboards will normally have a prototype built and tested before the final version is installed.

Figure 13 gives typical temperature rise limits in SWB components.

4.3 The protection against electric shock

This is particularly important in the open-type switchboards and it is necessary to have some means of protection against direct contact (with live parts) or indirect contact (with exposed conductive parts) during maintenance procedures on SWBs.

Figure 14 details the requirements for attaining adequate protection against shock.

An essential feature of most methods of protection against indirect contact is proper earthing of the switchboard. Fig 15 shows the various earthing schemes which have been designated by the International Electrotechnical Commission (IEC). For protection against direct contact, the IP number system outlined above can give adequate design requirements. The IEC earthing methods used are: TT, IT and TN. The most applicable ones to SWBs are the TN group.
<table>
<thead>
<tr>
<th>Parts of ASSEMBLIES</th>
<th>Temperature rise limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Built-in components 1)</td>
<td>In accordance with the relevant requirements for the individual components, if any, or, in accordance with the manufacturer’s instructions, taking into consideration the temperature in the ASSEMBLY.</td>
</tr>
<tr>
<td>Terminals for external insulated conductors</td>
<td>70 2)</td>
</tr>
<tr>
<td>Busbars and conductors, plug-in contacts of removable or withdrawable parts which connect to busbars 6</td>
<td>Limited by:</td>
</tr>
<tr>
<td></td>
<td>• mechanical strength of conducting material;</td>
</tr>
<tr>
<td></td>
<td>• possible effect on adjacent equipment;</td>
</tr>
<tr>
<td></td>
<td>• permissible temperature limit of the insulating materials in contact with the conductor;</td>
</tr>
<tr>
<td></td>
<td>• effect of the temperature of the conductor on the apparatus connected to it;</td>
</tr>
<tr>
<td></td>
<td>• for plug-in contacts, nature and surface treatment of the contact material.</td>
</tr>
<tr>
<td>Manual operating means:</td>
<td>15 2)</td>
</tr>
<tr>
<td>• of metal</td>
<td>25 2)</td>
</tr>
<tr>
<td>Accessible external enclosures and covers:</td>
<td>30 4)</td>
</tr>
<tr>
<td>• metal surfaces</td>
<td>40 4)</td>
</tr>
<tr>
<td>Discrete arrangements of plug and socket-type connections</td>
<td>Determined by the limit for those components of the related equipment of which they form part 5)</td>
</tr>
</tbody>
</table>

1) The term ‘built-in components’ means:  
- conventional switchgear and controlgear;  
- electronic sub-ASSEMBLIES (e.g. rectifier bridge, printed circuit);  
- parts of the equipment (e.g. regulator, stabilized power supply unit, operational amplifier).  
2) The temperature-rise limit of 70 K is a value based on the conventional test of 6.2.1. An ASSEMBLY used or tested under installation conditions may have connections, the type, nature and disposition of which will not be the same as those adopted for the test, and a different temperature rise of terminals may result and may be required or accepted. Where the terminals of the built-in component are also the terminals for external insulated conductors, the lower of the corresponding temperature-rise limits shall be applied.  
3) Manual operating means within ASSEMBLIES which are only accessible after the ASSEMBLY has been opened, for example emergency handles, draw-out handles which are operated infrequently, are allowed to assume higher temperature rises.  
4) Unless otherwise specified, in the case of covers and enclosures which are accessible but need not be touched during normal operation, an increase in the temperature-rise limits by 10 K is permissible.  
5) This allows a degree of flexibility in respect of equipment (e.g. electronic devices) which is subject to temperature-rise limits different from those normally associated with switchgear and controlgear.  
6) The requirements for built-in components, busbars and conductors, plug-in contacts of removable or withdrawable parts which connect to busbars, limited by:  
- mechanical strength of conducting material;  
- possible effect on adjacent equipment;  
- permissible temperature limit of the insulating materials in contact with the conductors;  
- the effect of the temperature of the conductor on the apparatus connected to it; and  
- for plug-in contacts, the nature and surface treatment of the contact material  
would generally be considered to be complied with if temperature rises do not exceed 70 K for H.C. copper busbars and 55 K for H.C. aluminium busbars. The temperature rise limits of 70 K and 55 K are based on maximum temperatures of 105°C and 90°C, respectively, under the normal service conditions according to Clause 6.1.  

Figure 13  
Temperature rise limits for switchboards  
(AS3439.1-2002)  

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Figure 14
Requirements for protection against electric shock from switchboards

1. Protection against direct contact
   - By insulation of live parts: which can only be removed by destruction or by use of a tool. Insulation not inferior to cable insulation, i.e. 3.5kV withstand, PVC cable hardness, suitable for maximum temperature of 105°C.
   - By barriers or enclosures: protection against direct contact of at least IP2X.

2. Protection against indirect contact
   - By using protective circuits
   - By other measures: such as electrical separation of circuits or total insulation

4.3.1 IEC earthing methods

TN systems: one point directly earthed, exposed conductive parts connected to that point by protective conductor (PE). Three types:
   - TN-S system: separate neutral (N) and PE throughout
   - TN-C system: N and PE combined into a single conductor throughout.
   - TN-C-S system: N and PE combined into a single conductor in a part of the system.

Note that the TN-C-S method corresponds to the MEN system (Multiple Earthed Neutral system used in Australia).
Figure 15: Earthing systems for switchboards

TN-S

TN-C-S

TN-C
**TT system**: one point directly earthed, exposed conductive parts connected to earth via separate earth electrode.

**IT system**: no direct connection between live parts and earth, exposed conductive parts connected to earth.

Note that the IT system covers a relatively wide range of methods that may be in use in restricted locations in industry. It covers:

- **Unearthed systems** used to improve supply reliability
- **High impedance earthing** to reduce fault current level
- **Resonant earthing** (Petersen coil) to limit arcing faults
4.4 Testing of Switchboards

In addition to the above design features, the testing of SWBs is of paramount importance in proving the design. Fig. 16 shows the various tests which need to be performed before a SWB should be accepted. There are both **Type Tests** (done only on one unit representative of the design) and **Routine Tests** (done on every manufactured unit) listed.

The full list of tests can be very expensive to perform as they can be very lengthy in their set up and instrumentation and test performance times (e.g. thermal tests may take many hours to achieve thermal equilibrium) and it may be necessary to sacrifice a SWB when carrying out short circuit and arcing tests.

There are few test laboratories available with a full range of adequate facilities in Australia. The primary one is the Testing and Certification Australia (TCA) high current testing station at Lane Cove, Sydney. There is also another smaller and more limited facility at TestSafe Australia (associated with WorkCover NSW) at Londonderry, near Sydney. Figure 17 shows an arc fault test being performed on a switchboard to the arc withstand capability.
## Figure 16
Details of required tests on switchboards

<table>
<thead>
<tr>
<th>No.</th>
<th>Characteristics to be checked</th>
<th>Sub-clauses</th>
<th>TTA</th>
<th>PTTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Temperature-rise limits</td>
<td>8.2.1</td>
<td>Verification of temperature-rise limits by test (type test)</td>
<td>Verification of temperature-rise limits by test or extrapolation</td>
</tr>
<tr>
<td>2</td>
<td>Dielectric properties</td>
<td>8.2.2</td>
<td>Verification of dielectric properties by test (type test)</td>
<td>Verification of dielectric properties by test according to 8.2.2 or 8.3.2, or verification of insulation resistance according to 8.3.4 (see Nos. 9 and 11)</td>
</tr>
<tr>
<td>3</td>
<td>Short-circuit withstand strength</td>
<td>8.2.3</td>
<td>Verification of the short-circuit withstand strength by test (type test)</td>
<td>Verification of the short-circuit withstand strength by test or by extrapolation from similar type-tested arrangements</td>
</tr>
<tr>
<td>4</td>
<td>Effectiveness of the protective circuit</td>
<td>8.2.4</td>
<td>Verification of the effective connection between the exposed conductive parts of the assembly and the protective circuit by inspection or by resistance measurement (type test)</td>
<td>Verification of the effective connection between the exposed conductive parts of the assembly and the protective circuit by inspection or by resistance measurement</td>
</tr>
<tr>
<td></td>
<td>Effective connection between the exposed conductive parts of the assembly and the protective circuit</td>
<td>8.2.4.1</td>
<td>Verification of the short-circuit withstand strength of the protective circuit by test (type test)</td>
<td>Verification of the short-circuit withstand strength of the protective circuit by test or appropriate design and arrangement of the protective conductor (see 7.4.3.1.1, last paragraph)</td>
</tr>
<tr>
<td></td>
<td>Short-circuit withstand strength of the protective circuit</td>
<td>8.2.4.2</td>
<td>Verification of the short-circuit withstand strength of the protective circuit by test (type test)</td>
<td>Verification of the short-circuit withstand strength of the protective circuit by test or appropriate design and arrangement of the protective conductor (see 7.4.3.1.1, last paragraph)</td>
</tr>
<tr>
<td>5</td>
<td>Clearances and creepage distances</td>
<td>8.2.5</td>
<td>Verification of the clearances and creepage distances (type test)</td>
<td>Verification of clearances and creepage distances</td>
</tr>
<tr>
<td>6</td>
<td>Mechanical operation</td>
<td>8.2.6</td>
<td>Verification of mechanical operation (type test)</td>
<td>Verification of mechanical operation</td>
</tr>
<tr>
<td>7</td>
<td>Degree of protection and internal separation</td>
<td>8.2.7</td>
<td>Verification of the degree of protection (type test) and internal separation</td>
<td>Verification of the degree of protection and internal separation</td>
</tr>
<tr>
<td>8</td>
<td>Wiring, electrical operation</td>
<td>8.3.1</td>
<td>Inspection of the assembly including inspection of wiring and, if necessary, electrical operation test (routine test)</td>
<td>Inspection of the assembly including inspection of wiring and, if necessary, electrical operation test</td>
</tr>
<tr>
<td>9</td>
<td>Insulation</td>
<td>8.3.2</td>
<td>Dielectric test (routine test)</td>
<td>Dielectric test or verification of insulation resistance according to 8.3.4 (see Nos. 2 and 11)</td>
</tr>
<tr>
<td>10</td>
<td>Protective measures</td>
<td>8.3.3</td>
<td>Checking of protective measures and of the electrical continuity of the protective circuits (routine test)</td>
<td>Checking of protective measures</td>
</tr>
<tr>
<td>11</td>
<td>Insulation resistance</td>
<td>8.3.4</td>
<td>Verification of insulation resistance unless test according to 8.2.2 or 8.3.2 has been made (see Nos. 2 and 9)</td>
<td>Verification of insulation resistance unless test according to 8.2.2 or 8.3.2 has been made (see Nos. 2 and 9)</td>
</tr>
</tbody>
</table>

TTA = type-tested assemblies  
PTTA = partially type-tested assemblies
Figure 17
Arc fault testing of a low voltage switchboard in a short circuit testing laboratory