DESIGN STANDARD NO. DS 21

Major Pump Station – Electrical
FOREWORD

The intent of Design Standards is to specify requirements that assure effective design and delivery of fit for purpose Water Corporation infrastructure assets for best whole-of-life value with least risk to Corporation service standards and safety. Design standards are also intended to promote uniformity of approach by asset designers, drafters and constructors to the design, construction, commissioning and delivery of water infrastructure and to the compatibility of new infrastructure with existing like infrastructure.

Design Standards draw on the asset design, management and field operational experience gained and documented by the Corporation and by the water industry generally over time. They are intended for application by Corporation staff, designers, constructors and land developers to the planning, design, construction and commissioning of Corporation infrastructure including water services provided by land developers for takeover by the Corporation.

Nothing in this Design Standard diminishes the responsibility of designers and constructors for applying the requirements of WA OSH Regulations 1996 (Division 12, Construction Industry – consultation on hazards and safety management) to the delivery of Corporation assets. Information on these statutory requirements may be viewed at the following web site location:


Enquiries relating to the technical content of a Design Standard should be directed to the Principal Engineer, Electrical Section, Infrastructure Design Branch. Future Design Standard changes, if any, will be issued to registered Design Standard users as and when published.

Manager, Infrastructure Design Branch

This document is prepared without the assumption of a duty of care by the Water Corporation. The document is not intended to be nor should it be relied on as a substitute for professional engineering design expertise or any other professional advice.

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Any interpretation of anything in the Standards/Specifications that deviates from specific Water Corporation Project requirements must be referred to, and resolved by, reference to and for determination by the Water Corporation’s project manager and/or designer for that particular Project.
# REVISION STATUS

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1 INTRODUCTION

1.1 Purpose

The Water Corporation has adopted a policy of outsourcing most of the electrical engineering and electrical detail design associated with the procurement of its assets. The resulting assets need to be in accordance with the Corporation’s operational needs and standard practices.

This design standard (i.e. Electrical Design Standard DS21) sets out design standards and engineering practice which shall be followed in respect to the design and specification of electrical parts of major pump stations being acquired by the Corporation. This design manual does not address all issues that will need to be considered by the Designer in respect to a particular pump station.

It is the Water Corporation’s objective that its assets will be designed so that these have a minimum long term cost and are convenient to operate and maintain. In respect to matters not covered specifically in this manual, the Designer shall aim his designs and specifications at achieving this objective.

This design standard is intended for the guidance of electrical system designers and shall not be quoted in specifications (including drawings) for the purpose of purchasing electrical equipment or electrical installations except as part of the prime specification for a major design and construct (D&C) contract.

1.2 Scope

The scope of this standard (i.e. Electrical Design Standard DS21) covers key aspects of the power electrical design associated with major pump stations including the incoming power supply, the main pump drives, switchboards rated greater than 315 kVA, switchboards controlling drives rated greater than 150 kW, the main power circuits and other main power electrical equipment.

For the purposes of this standard, major pump stations are defined as pump stations (including large boresites) having individual drives rated in excess of 150 kW or an incoming supply rated in excess of 315 kVA. Key aspects of the design or auxiliary drives and auxiliary services are covered in Electrical Design Standard DS22.

1.3 References

Reference should be made also to the following associated design manuals and drawings:

DS 20 Design Process for Major Power Electrical Works
DS 22 Ancillary Plant and Minor Pump Stations
DS 23 Pipeline AC Interference and Substation Earthing
DS 24 Electrical Drafting
DS 25 Electronic Instrumentation
DS 26 Type Specifications
FS00 Drawings: Electrical Standard Drawing, Major Pump Station
Preferred Equipment List

1.4 Definitions

Asset Manager - the Water Corporation officer responsible for the operation of the asset being acquired.

Corporation - the Water Corporation (of Western Australia)

Designer - the consulting engineer carrying out the electrical design

Principal Engineer - Principal Engineer Electrical (Power), Infrastructure Design

1.5 National Standards

a) Electrical installations shall be designed in accordance with the latest edition of AS3000 and except where otherwise specified in this design manual, major pump station electrical design shall be carried out in accordance with the latest edition of all other relevant Australian Standards. In the absence of relevant Australian Standards, relevant international, other national or industry standards shall be followed.

b) Except where a concession is obtained from Energy Safety, electrical design shall be in accordance with the W.A. Electrical Requirements Manual (WAER) produced by the Energy Safety Division (EnergySafety) of the Department of Consumer & Employment Protection.

c) Except where a concession is obtained from the Supply Authority, the electrical design of all installations to be connected to the Supply Authority system shall be designed in accordance with their requirements. Such requirements include the Western Australian Distribution Connection Manual and the Technical Rules for the South West Interconnected Network published by Western Power.

d) All electrical equipment, which incorporates electronic switching or electronic measuring circuits, shall be specified to be in accordance with the European standards IEC 61000-6-4 and IEC 61000-6-2 for Electromagnetic Emissions and Immunity respectively. In addition, all such equipment shall be specified to have been approved by the Australian Communications Authority in respect to Electromagnetic Compatibility.

1.6 Use of Type Specifications

Type Specifications (Design Standard DS26) have been prepared in order to assist the specification of electrical work designed in accordance with this Design Standard (DS21) and these Type Specifications shall be used for this purpose whenever practical. Where a relevant type specification does not exist, the Designer shall prepare an appropriate specification based on this design standard.

1.7 Electrical Safety

Electrical installations shall be designed to facilitate the safe operation and maintenance of the electrical plant.

In respect to High Voltage equipment, mechanically and/or key interlocked isolating switches, earthing switches and access doors shall be employed wherever practical so as to prevent access to live conductors. In instances where interlocking is not practical, High Voltage isolating and earthing
switches and access doors shall be protected with Water Corporation EL1 keyed locking systems. Systems employing a “Safety PLC” for High Voltage interlocking shall not be permitted.

Access doors providing access to exposed live Low Voltage conductors, shall be protected with Water Corporation EL2 equivalent keyed locking systems (Bilock).

Remote closing of High Voltage or Low Voltage circuit breakers via the SCADA system shall NOT be permitted.

1.8 Mandatory Requirements

In general the requirements of this manual are mandatory. If there are special circumstances which would justify deviation from the requirements of this manual, the matter shall be referred to the Principal Engineer for his consideration. No deviation from the requirements of this manual shall be made without the written approval of the Principal Engineer. Such dispensation, if granted, applies only to the case in question based on the merits of the argument and does not set a precedent.

1.9 Quality Assurance

It is a requirement of the Corporation that the following QA systems be applied to electrical equipment manufacturers and electrical installers.

1.9.1 Equipment Suppliers

Suppliers of major electrical equipment (such as transformers, motors, variable speed drives, switchgear, switchboards, instrumentation equipment) shall only supply equipment from a Manufacturer that has in place a Quality Management System certified by an accredited third party to AS/NZS ISO 9001:2000 or an approved equivalent.

1.9.2 Installers

Installers of major electrical equipment (such as transformers, motors, variable speed drives, switchgear, switchboards, instrumentation equipment) shall have in place a Quality Management System certified by an accredited third party to AS/NZS ISO 9001:2000 (excluding Clause 7.3 Design & Development) or an approved equivalent.

1.9.3 Acceptance Tests

In tender documents in which acceptance tests are specified, the cost of providing works tests (including associated test certificates) and site tests (including associated test certificates) shall be shown as separate items in the Bill of Quantities so that:

a) it can be verified that sufficient funds have been allowed to carry out such testing satisfactorily, and

b) it is clear that works tests and site tests are separate critical deliverables.
2  MECHANICAL ENGINEERING INFORMATION

The following mechanical engineering information shall be obtained before electrical design commences:

a) Pump Duty kW
b) Pump "non overloading" kW
c) Pump torque-speed curve
d) Number of motor-pump units to be installed immediately
e) Number of motor-pump units to be installed in next ten years
f) Station maximum kW demand immediately
g) Station maximum kW demand in next ten years
h) Speed of motor-pump units
i) Whether indoor or outdoor motor-pump units
j) Estimated running hours per year, and distribution of running hours month by month approximately
k) Estimated number of motor starts per hour or day
l) Pump type and pump station configuration
3 INCOMING SUPPLY

3.1 General

a) The incoming supply to Major Pump Stations shall be taken at High Voltage via cable connections with the necessary step down transformers and associated primary side High Voltage switchgear being Corporation owned.

b) The Corporation’s main incoming High Voltage switchboard shall of the indoor type located in a separate dust free switchroom or in a proprietary weatherproof and dust free kiosk.

c) Substations and High Voltage installations shall comply with the requirements of AS 2067-2008, W.A. Electrical Requirements Manual (WAER) and the Western Australian Distribution Connection Manual.

3.2 Power Supply Quality Monitoring

a) Power supply quality measuring equipment shall be installed at all major pump station sites having an installed duty transformer capacity in excess of 2 MVA.

b) Such power supply quality measuring equipment shall monitor current, voltage, real power, reactive power, frequency, power factor, voltage harmonic distortion and transient events.

c) As the Supply Authority will not permit customer access to its metering current and voltage transformers for the purpose of power quality monitoring by the customer, a separate High Voltage metering unit shall be installed to provide the primary signals to the power quality monitoring equipment.

3.3 Supply to Station Auxiliaries

a) If the motor supply is to be at a voltage higher than 415 volts the station auxiliary supply shall be taken from a separate transformer fed directly from the primary supply voltage switchboard (i.e. not from the motor control switchboard).

b) Similarly if the motor control switchboard maximum voltage waveform total harmonic distortion is expected to be more than 10%, the station auxiliaries supply shall be taken from a separate transformer fed directly from the primary supply voltage switchboard.

c) Except as above, the station auxiliaries supply shall be taken from the motor control switchboard.

3.4 Arrangement of Primary Supply Voltage Switchboard

3.4.1 Supply Authority Metering Transformers

Supply Authority metering transformer will be mounted separately from the Water Corporation’s incoming High Voltage switchboard and will be connected to the latter by cable whether the Supply Authority metering transformer is to be aerial connected or cable connected. The Supply Authority will permit direct bus connection for indoor switchgear on the condition that the same type of equipment is used by the customer. This should only be applied where it can be justified since this is somewhat restrictive in regard to equipment selection.
3.4.2 General

a) If the Water Corporation’s incoming High Voltage switchboard has no more than three outgoing circuits and the continuous current rating of the Supply Authority’s H.V. metering unit is less than the sum of the long term trip currents of the outgoing circuits, the incoming supply shall be connected to the switchboard via a line side load break switch which shall be considered to be the Main Switch for the installation.

Otherwise the incoming supply shall be connected to the supply via a line side circuit breaker equipped with a disconnector and appropriate overcurrent protection which shall be considered to be the Main Switch for the installation.

b) All incoming line switches and incoming line circuit breakers shall be fitted with earthing switches which can be padlocked in both the open and closed positions. In addition, such earthing switches shall be fitted with key interlocking facilities to allow interlocking with external switches.

c) All incoming supply transformers rated greater than 315 kVA shall be connected to the primary supply voltage busbars via separate SF6 gas or vacuum circuit breakers.

d) All incoming supply transformers rated not greater than 315 kVA shall be connected to the primary voltage busbars via separate switch fuses.

e) If fitted, switchfuses feeding auxiliary transformers shall incorporate three phase tripping and shall be provided with earthing switches on both sides of the fuse connections interlocked with the associated isolator and fuse cartridge access panel to ensure only safe access to fuse cartridges.

f) All circuit breakers and switchfuses supplying transformers shall be fitted with earthing switches mechanically interlocked to prevent earthing switch operation unless the associated circuit is isolated. In addition, such earthing switches shall be fitted with key interlocking facilities to allow interlocking with external switches.

g) All circuit breakers shall be SF6 gas type or shall be vacuum type.

h) The contacts and operating mechanisms of isolating switches and earthing switches shall be enclosed in sealed SF6 filled compartment(s) fitted with gas pressure indicators.

i) All High Voltage busbars shall be SF6 gas insulated or shall be fully insulated with appropriate solid insulation.

j) If the incoming supply High Voltage switchboard is fitted with circuit breakers, a DC battery backed tripping supply shall be provided adjacent to the switchboard.

k) All incoming supply circuit breakers shall be fitted with over current and earth fault protection relays which shall be powered either from a DC tripping supply or shall be self-powered (i.e. powered from the protection current transformers).

l) All incoming supply circuit breakers shall be fitted with a DC shunt trip releases for fault tripping purposes and with a DC undervoltage release to trip in the event of failure of the tripping supply.
3.4.3 Prefabricated Substations

a) Prefabricated substations as specified in clause 7.13 shall be used in installations where the individual transformer size does not exceed 1250 kVA. In such instances if more than one transformer is involved, separate prefabricated substations shall be provided for each transformer.

b) The incoming supply cable shall be connected to an incoming line circuit breaker on the ring main unit of one of the prefabricated substations. This circuit breaker shall be designated as the Main Switch for the installation.

c) The other prefabricated substation(s) shall be cable connected in series with the latter via the ring main unit line switches.

3.4.4 Larger Substations

At installations where an individual transformer size exceeds 1250 kVA, a combined circuit, cable connected switchboard shall be used with a separate circuit breaker feeding each transformer rated greater than 315 kVA and a separate switchfuse feeding any transformers rated not greater than 315 kVA.

3.5 Sectionalising Motor Control Switchboards

a) If dual incoming transformers are provided, sectionalising the motor control switchboard may be warranted. Whether or not the motor control switchboard in a particular pump station should be sectionalised shall be determined on a site by site basis.

b) The advantages of sectionalising the motor control switchboard are as follows:-

i) In the event of a switchboard busbar failure, repair work can be carried out on the faulted section while the remainder of the switchboard remains operable. However in respect to High Voltage switchboards the likelihood of a busbar failure is very small.

ii) Maintenance may be carried out on busbar connected equipment without the need to shut down the whole switchboard. In respect to High Voltage switchboards, such maintenance can be expected to be required only very infrequently.

iii) If the switchboard is operated sectionalized, the source impedance is increased so that Supply Authority mains voltage disturbances, caused by starting currents or non-linear loads, are reduced.

iv) If the switchboard is interlocked so that it can be operated only sectionalized, the feeder protection is simpler.

c) The disadvantages of sectionalising the motor control switchboard are as follows:-

i) Transformer load sharing is compromised, particularly during light load periods.

ii) Interlocking is more complicated and difficult to operate and understand.

iii) The amount of switchgear is increased.

iv) Dual sources of auxiliary supply are required.

v) If the switchboard is operated sectionalised with each switchboard section fed from a separate transformer, the source impedance is increased compared to operating both
transformers in parallel. As a result starting currents or non-linear loads will cause increased motor control centre voltage disturbances

3.6 Motor Control Switchboard Feeder Circuit Breakers

a) All incoming feeders to motor control switchboards shall be connected to the switchboard busbars via switchboard feeder circuit breakers mounted in the motor control switchboard.

b) Switchboard feeder circuit breakers supplied from transformers rated >315 kVA shall be fitted with over current and earth fault protection relays which shall be powered either from a DC tripping supply or shall be self-powered (i.e. powered from the protection current transformers).

c) Switchboard feeder circuit breakers supplied from transformers rated ≤ 315 kVA to motor control switchboards shall be fitted with over current and earth fault protection relays which shall be self powered (i.e. powered from the protection current transformers).

d) Each switchboard feeder circuit breaker which can operate in parallel with another switchboard feeder circuit breaker shall be fitted with a DC shunt trip releases arranged to trip the former in the event that its associated transformer primary voltage circuit breaker is tripped.

3.7 Isolation, Earthing and Interlocking

a) Safe maintenance of the electrical equipment shall be facilitated by means of isolation, earthing, interlocking and warning labels, as detailed hereunder.

b) All High Voltage circuit breakers and switchfuses shall be fitted with integral isolators and earth switches.

c) Interlocking shall be provided:

   i) to prevent any High Voltage earth switch being closed onto live conductors,

   ii) to prevent opening or closing a High Voltage isolator unless the associated circuit breaker or switchfuse is open,

   iii) to prevent access to live transformer High Voltage terminals,

   iv) to prevent access to High Voltage conductors unless these are isolated and earthed, except where access may be gained by the use of tools to remove bolt on switchboard panels, and

   v) to prevent access into transformer kiosks unless the associated primary feeder isolator is open and earthed and the associated secondary circuit breaker is open and, if High Voltage, also earthed.

d) Any bolt on panels which provide access to High Voltage conductors shall be labelled clearly to warn of the potential hazard.

e) Earthing switches shall be provided on all primary voltage switchboard outgoing feeder cables. Similarly earthing switches shall be provided on all High Voltage motor control incoming feeder switches.

f) All High Voltage switchboard equipment other than isolating switches and busbars shall be able to be isolated safely for maintenance while the remainder of the switchboard remains alive.
3.8 Transformer Ratings

a) Transformers feeding common drive voltage busbars shall have an on-site kVA rating not less than the predicted 10 year maximum demand kVA.

b) Pump stations having drives supplied from a common drive voltage and deemed by the Asset Manager to be critical shall be provided with 100% standby transformer capacity.

c) Unit transformers supplying individual fixed speed motors shall have an on-site kVA rating not less than the full load kVA rating of the associated motor.

d) Where large variable speed controllers are used, it will be necessary to feed such controllers from unit transformers in order to limit harmonic distortion to the voltage waveform both to other loads and at the point of common coupling. In such cases, the unit transformer on site kVA rating shall be not less than the rated input demand of the variable speed controller or the motor, whichever is the greater.

e) The on-site kVA rating of a transformer shall include both any derating due to ambient conditions and any derating due to non-linear loads.

f) Transformers supplying non-linear loads shall be derated to allow for additional losses due to harmonic currents in accordance with IEEE Std C57.110 which states that eddy current losses vary as $h^2$ and stray losses vary as $h^{0.8}$ where $h$ is the current harmonic number.

g) Transformers connecting Low Voltage active filters to the site High Voltage network shall be derated as detailed above for additional losses due harmonic currents. It should be noted that in such instances the derating will be particularly severe and that in such cases minimising the eddy current losses and the stray losses may be more important than minimising the 50 Hz copper losses.

3.9 Feeders

a) Low Voltage busbar trunking systems connected to transformers, and both High and Low Voltage main circuit cables connected to transformers, shall have a site current rating of not less than the maximum site current rating of the associated transformer.

b) Low Voltage busbar trunking systems shall be in accordance with:

AS/NZS 3439.2 Low Voltage switch gear and control gear assemblies Part 2: Particular requirements for busbar trunking systems (busways)

c) Feeder circuit breakers shall have a site current setting of not more than the associated feeder cables (or the associated Low Voltage feeder busbar trunking system).

d) Generator output circuit breakers shall be installed directly on the output of the alternator or as close as possible and within 5 metres.

3.10 Incoming Voltage Surge Protection

a) Where there is an incoming Supply Authority High Voltage aerial line to High Voltage consumers' mains cable transition at the site, suitably rated High Voltage surge diverters will be fitted at the cable termination by the Supply Authority. Reliance shall not be placed solely on such surge diverters to provide voltage surge protection for the primary voltage switchboard.
b) Suitably rated surge diverters shall be fitted to the primary winding terminals of all incoming supply transformers.

c) The Designer shall ensure that the rating of the surge diverter and the length of the associated feeder cable are such that the above surge diverters will provide adequate surge protection for the primary voltage switchboard. If this cannot be achieved, suitably rated surge diverters shall be provided connected directly to the primary voltage switchboard busbars.

3.11 Connections to Transformers

a) Connections to transformer High Voltage terminals shall be fully enclosed or shall be fully insulated cable terminations. Similarly all transformer terminal mounted surge diverter connections shall be fully enclosed or fully insulated.

b) Connections to free standing transformer Low Voltage terminals shall be in fully enclosed cable boxes or within fully enclosed busway terminations as appropriate.

c) Connections to Low Voltage terminals on transformers mounted within kiosk enclosures may be of the exposed air insulated type provided adequate safety barriers are provided.

3.12 Clearances for Buildings

a) Clearance of not less than that specified in AS 2067 shall be provided:
   i) between transformers (whether kiosk mounted or free standing), and
   ii) between transformers and buildings or kiosk enclosures

b) A clearance of not less than 1.2 metres shall be provided between oil filled transformer kiosk enclosures and free standing fire walls.

c) A clearance of not less than 1.2 metres shall be provided between dry type transformer kiosk enclosures, switchgear kiosk enclosures and buildings.

3.13 Switchgear Kiosk Enclosures

a) Kiosk enclosures may be used to house the primary supply High Voltage switchboard. If the risk of damage due to vandalism is considered to be low, further protection by fencing can be omitted in such cases.

b) Each kiosk, housing electrical equipment shall be a weatherproof enclosure in accordance with AS60529 providing mechanical, solar and driving rain protection to the equipment. The degree of protection shall not be less than IP26.

c) If oil filled electrical equipment is housed within a kiosk enclosure, oil bunding is required and shall be integral within the kiosk.

d) If switchgear anti condensation heaters are fitted to equipment housed within a kiosk enclosure, such heaters shall operate continuously.

e) Kiosk enclosures housing High Voltage switchgear shall be specified such that the enclosure does not compromise the integrity of the switchgear type testing and arc fault containment performance.
3.14 Power Factor Correction

Western Power's Technical Rules for the South West Interconnected Network specifies power factor requirements for loads. The power factor range specified in the text is subject to change by the Network Operator depending upon network requirements, therefore the Designer shall establish the job specific power factor requirement during the preliminary stage of the project.

As a consequence of the above, power factor correction equipment may be required for the pump station load. Such power factor compensation shall be of the “Central Compensation” type utilizing Low Voltage capacitor banks via a step down transformer. Detuning reactors shall be fitted to reduce the risk of harmonic resonance. Appropriate redundant features shall be built into the design so that failure of one bank does not impair the operation of the remaining system.

The design of the power factor correction assembly shall incorporate features to minimise the risk of an internal arcing fault developing and to minimise the risk to the operator should such a fault develop.

Power factor correction system enclosures shall be fitted with arc light detector protection arranged to trip the High Voltage circuit breaker protection in the event of an arc occurring within the capacitor enclosure.

The following Type Specification refers: DS26.39 Type Specification for Low Voltage Power Factor Controlgear Assembly.

3.15 Overhead Line Design

a) Corporation owned High Voltage overhead power lines shall be designed and constructed in accordance with the requirements of AS/NZS 7000:2010 Overhead Line Design – Detailed Procedures. Existing power lines proposed to be altered or upgraded shall comply with the provisions of AS/NZS 7000:2010.

b) Any alterations or upgrade work on existing overhead power lines shall be designed and constructed in accordance with the requirements of AS/NZS 7000:2010.
4 MOTORS AND CONTROLLERS

4.1 Motor Rating

a) For motors driving pumps, pump duty input power requirements shall be determined as follows:

\[ P_p = \frac{Q \times H \times 9.81}{1000 \times \eta_p} \]

where: \( P_p \) = pump duty power, kW
\( Q \) = pump flow, litres/sec (Note: 1.0 m3/day = 0.01157 litres/sec
\( H \) = pumping pressure (head), metres (1 bar = 100kPa = 10.2 metres of \( H_2O \))
\( \eta_p \) = pump efficiency, per unit

b) Fixed speed motors driving pumps with a "non overloading" power demand characteristic are not required to be fitted with winding over temperature protection provided that the motor on site S1 power rating is not less than 110% of the pump "non overloading" power demand.

c) Except as allowed section 4.1(b) above, all motors shall be fitted with winding over temperature protection and shall have on site S1 power ratings of not less than 110% of the associated maximum load duty power demand.

d) The 10 % margin specified in sections 4.1(b) and 4.1(c) above provides for:

i) a 5 % margin of error in respect to load requirements, and

ii) a 5 % derating if the motor is to be connected directly to the supply mains to allow for voltage unbalance, or

iii) a 5 % derating if the motor is to be connected to a PWM variable speed controller to allow for the harmonic currents generated by the controller.

e) Fixed speed motors shall be specified not to have resonant speeds within + 20 % of the nominal speed. Where a load is driven by a variable speed drive, the Designer shall ensure that neither the motor nor the load has a resonant speed within the proposed drive speed range.

f) All motors to be used with variable speed controllers shall be fitted with winding over temperature protection.

g) For variable speed drive (PWM) applications, the variable speed controller shall not be sized smaller than the motor rating.

4.2 Motor Voltage

Unless special approval to the contrary is obtained from the Principal Engineer, motor rated voltages shall be as detailed in Table 4.1.
### Motor Rated Voltages

<table>
<thead>
<tr>
<th>Motor Rating kW</th>
<th>&gt;150,≤220</th>
<th>&gt;220,≤450</th>
<th>&gt;450,≤800</th>
<th>&gt;800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage kV for Fixed Speed Motors in New Pump Stations</td>
<td>0.415</td>
<td>3.3 or 6.6</td>
<td>3.3 or 6.6</td>
<td>3.3 or 6.6</td>
</tr>
<tr>
<td>Voltage kV for Variable Speed Motors in New Pump Stations</td>
<td>0.415</td>
<td>0.69</td>
<td>0.69</td>
<td>3.3, 4.16, or 6.6</td>
</tr>
<tr>
<td>Voltage kV for Variable Speed submersible motors in deep artesian bores</td>
<td>0.415 or 0.69</td>
<td>0.69 or 3.3 or 4.16</td>
<td>3.3 or 4.16</td>
<td>3.3 or 4.16</td>
</tr>
<tr>
<td>Voltage kV for Fixed Speed Motors in Existing Pump Stations</td>
<td>0.415</td>
<td>0.415</td>
<td>3.3 or 6.6</td>
<td>3.3 or 6.6</td>
</tr>
<tr>
<td>Voltage kV for Variable Speed Motors in Existing Pump Stations</td>
<td>0.415</td>
<td>0.415 or 0.69</td>
<td>0.69</td>
<td>3.3, 4.16 or 6.6</td>
</tr>
</tbody>
</table>

NOTE: Fixed speed submersible motors rated not greater than 250 kW shall be 0.415 kV

#### 4.3 Starting Requirements

##### 4.3.1 General

Depending on the fault level at a particular site, the starting of large motors can cause unacceptable voltage dips and/or unacceptable harmonic distortion of the voltage waveform at the local busbars and at the Supply Authority point of common coupling. This phenomenon is of particular significance in respect to the design of at electrical installations which are required to be suitable for operation from standby generating sets.

##### 4.3.2 Voltage Waveform Limits Within the Installation

At the various points of common coupling within the Corporation’s installation, motor starting shall not cause:

a) the 3 second mean r.m.s. voltage waveform total harmonic distortion to exceed 15% (IEC 61000.2.4 Class 3),

b) the 10 minute mean r.m.s. voltage waveform total harmonic distortion to exceed 10% (IEC 61000.2.4 Class 3),

c) the voltage to dip more than 15% (IEC 61000.2.4 Class 3) when supplied from mains power, or
d) the voltage to dip more than 25% when supplied from an on-site standby generating set.

The larger voltage dip when operating from an on-site generating set is allowable because of the precise steady state voltage control available on modern alternators. In order to minimise the adverse effects of voltage dip, standby generator voltage regulators shall be set at +5% of the nominal voltage rating.

##### 4.3.3 Voltage Dip Limits at the Supply Authority P.C.C.

The amount of voltage dip at the Supply Authority point of common coupling which is permitted to be caused by motor starting will be determined in accordance with AS/NZS 61000.3.7, ultimately by the Supply Authority.
However, for most installations covered by this Design Standard, motor starting will be infrequent and the installation will represent a significant proportion of the load on the incoming Medium Voltage feeder, so that it is appropriate that determination of permissible voltage dip limit be by the Stage 2 method as described in AS/NZS 61000.3.7. (NB: Stage 1 limits will not apply to Major pump stations)

Hence in most cases the permissible voltage dip limit will be determined as hereunder:

\[ G_{PstMV} = \left[ L_{PstMV}^3 - (T_{PstHM} \times L_{PstHV})^3 \right]^{0.333} = 0.776 \]

Where:

- MV = voltages in the range > 1 kV, ≤ 35 kV
- HV = voltages > 35 kV
- \( G_{PstMV} \) = global short term flicker emission for all loads supplied directly at MV (per unit)
- \( L_{PstMV} \) = short term planning level at MV
  = 0.9 as per Western Power Technical Rules Table 2.3
- \( L_{PstHV} \) = short term planning level at HV
  = 0.8 as per Western Power Technical Rules Table 2.3
- \( T_{PstHM} \) = HV/MV flicker transfer coefficient,
  = 0.8 being typical value as per AS/NZS 61000.3.7:2001 Appendix F (Note: Western Power’s Power Quality Group use a default value of 1.0 in their calculations as this aligns with Western Power’s Technical Rules manual Table 2.3, note 1.)

Then:

\[ E_{PstiMV} = G_{PstMV} \times \left( \frac{S_i}{(S_{MV} \times F_{MV})} \right)^{0.333} \]

Where:

- \( E_{PstiMV} \) = allowed short term flicker emission limit for Corporation installation supplied at MV (per unit)
- \( S_i \) = Corporation installation maximum load (kVA)
- \( S_{MV} \) = total kVA of loads supplied directly at MV,
  = typically 0.4* the MV/HV transformer rating as per AS/NZS 61000.3.7:2001 Appendix F
- \( F_{MV} \) = coincidence value for MV loads simultaneously disturbing
  = 0.4 mean value as per AS/NZS 61000.3.7:2001 Appendix F

Note 1: For estimating purposes it can be assumed that
\[ S_{MV} = 15 \times 10^3 / X_s \]

where \( X_s \) is the fault reactance at the substation MV busbars, calculated on a 100 MVA base.

**Note 2:** Should the value of EPstIMV as determined above be less than 0.35, the latter value shall be used as per AS/NZS 61000.3.7:2001 Table 5

Then:

\[ \Delta U/U = E_{PstIMV} \times P_{st1} \]

Where

\[ \Delta U/U = \text{allowable } \% \text{ voltage dip at the point of common coupling} \]

\[ P_{st1} = \text{the value of } P_{st} \text{ for 230 volts for the appropriate rectangular voltage changes per minute as per Table 3 and Figure 4 of AS/NZS 61000.3.7:2001} \]

\[ = 7.4 \% \text{ for a typical water transfer pump station.} \]

**Note 3:** Consider the worst case situation as per note 2 above

0.1 changes /min. = 6 changes/hr. = 3 starts/hr.

then \( \Delta U/U = 0.35 \times 7.4 \% = 2.6\% \)

### 4.3.4 Harmonic Current Limits

In the case of motors being started infrequently with electronic soft starters, the short term (3 second) total harmonic voltage distortion at the point of common coupling with the Supply Authority network shall not exceed 11\% in accordance with AS/NZS 61000-2-12.

### 4.3.5 Direct on Line Starting

Direct on Line starting is the simplest form of starting and allows the use of cage induction motors. Direct on Line starting shall be used wherever the power supply fault level (including the standby generator if applicable) is high enough to allow such starting without the resulting voltage dips exceeding the allowable limits specified above.

### 4.3.6 Electronic Soft Starting

a) In instances where the power supply fault level at the site is not high enough to allow the use of Direct on Line starting, the Designer shall carry out calculations to ascertain whether the use of Electronic Soft Starting would be appropriate, i.e. would provide the required starting torque without exceeding the voltage dip and harmonic distortion limits specified above.

b) An active harmonic filter may be used in conjunction with an Electronic Soft Starter so as to reduce the harmonic distortion to the system voltage waveform which would be caused otherwise. This has the advantage that the active filter can be programmed to correct power factor once motor starting has been completed.

c) The torque versus speed and current versus speed characteristics of many commonly available cage motors are such as to make these motors unsuitable for use as centrifugal pump drives if controlled by Electronic Soft Starters.
Motors having a speed versus torque characteristic such that the torque increases continually over the speed range 20% rated speed to break down torque speed are the most suitable type of motor for this application.

The DOL current versus speed and DOL torque versus speed characteristics of many standard motor designs make these unsuitable for use with electronic soft starters. However, some standard designs will be such that a current limit of 4 times motor full load current will be practical.

At sites where the fault level is particularly low and starting currents must be kept below this level, the Designer shall give consideration to the use of Electronic Soft Starters in conjunction with motors having double cage or deep bar rotors.

If Electronic Soft Starting is to be applied to a motor driving a centrifugal pump, the motor output torque during starting under the specified current limit shall satisfy both of the following conditions:

\[
T_o > 0.2 \times T_{pump}
\]

\[
T_s > 0.1 \times T_{pump} + (I_{cl}/I_s)^2 \times T_{pump}
\]

where:

- \(T_{pump}\) = pump input torque at motor rated speed
- \(I_{cl}\) = current limit amps
- \(T_o\) = motor torque at standstill with current limited to \(I_{cl}\)
- \(s\) = any speed within the range from 20% rated speed to breakdown torque speed
- \(T_s\) = motor torque at speed \(s\) with current limited to \(I_{cl}\)
- \(I_s\) = motor DOL current at speed

As a general rule, the most critical speed is usually 75% full speed and motors driving centrifugal pumps and having characteristics such that the critical torque factor as defined hereunder is less than 4 will be unsuitable for use with electronic soft starters.

\[
\frac{T_{sc}}{I_{sc}^2} = \text{critical torque factor}
\]

\(sc\) = critical speed = 75% full speed

\(T_{sc}\) = DOL motor torque at speed \(sc\) as % full load torque

\(I_{sc}\) = DOL motor current at speed \(sc\) as per unit motor full load current

The Designer shall calculate the drive torque versus speed curve for various levels of current limit so as to determine the minimum starting current required to accelerate the pump over the full speed range up to normal operating speed.

d) Electronic soft starters shall be specified to be of the voltage ramp type since these ramp the starting current up relatively gradually, and take only the amount of starting current needed to bring the motor up to full speed regardless of circumstances.

e) Using this starting current value, the Designer shall calculate the resulting voltage dip disturbance at the point of common coupling of the motor circuit to the remainder of the installation and at the point of common coupling of the installation to the mains supply, in order to verify that the required voltage dip limits will not be exceeded.
f) In addition, the Designer shall calculate the harmonic voltage distortion to the voltage waveform at the point of common coupling of the motor circuit to the remainder of the installation and at the point of common coupling of the installation to the mains supply, in order to verify that the required harmonic distortion limits will not be exceeded.

g) Electronic soft starter configurations, requirements and arc fault protection arrangements shall be in accordance with standard drawings FS00-6-1.1, FS00-6-1.2 and FS00-6-2.

4.3.7 Rotor Resistance Starting

a) In circumstances where calculations show that neither Direct on Line nor Electronic Soft Starting will be acceptable, slip ring induction motors with rotor resistance starters shall be used. Rotor resistance starters shall incorporate cast iron resistance elements which are insulated and cooled by immersion in an oil-filled sheet metal tank fitted with over pressure valve, oil filler, oil level indicator, lifting lugs, alarm overtemperature detector and shut down overtemperature detector.

The designer shall ensure than an oil containment bund is provided for each starter within the pump station and sized to contain in excess of the volume of oil within the starter

b) The Designer shall calculate the torque versus speed and current versus speed curves for various values of rotor resistance and by using these curves in conjunction with the load torque speed curve shall determine the number and size of the rotor resistance stages necessary to limit the starting current so that the voltage dip does not exceed the required limits. The Designer shall carry out calculations to determine the heat rise in the starter due to motor starting and shall calculate the maximum allowable frequency of starting for the starter specified

4.3.8 Variable Speed Controllers as Starters

Variable speed controllers can limit the starting current for cage motors to as little as motor full load current. However, their application as starters is limited by the harmonics produced normally and by the consequent additional expense needed to eliminate such harmonics. (Refer Section 4.4)

4.4 Variable Speed Controllers for Cage Motors

4.4.1 Types of Controller

The design of the types of variable speed drive controllers which are suitable for the control of cage motors is such that the incoming A.C. voltage is converted to D.C. and then inverted to produce a variable voltage variable frequency A.C. supply.

Variable speed controller converters take significant amounts of harmonic current and consequently cause harmonic distortion of the incoming supply voltage waveform.

Thyristor or diode converters are usually 6 or 12 pulse type, but 24 pulse units are available from some manufacturers in the larger sizes. Such converters take current from the supply in the form of alternating positive and negative D.C. pulses, i.e. the current demand includes significant levels of odd order harmonic currents. The higher the number of pulses the lower the demand for such harmonic currents, but the higher the cost.

Active Front End speed controllers employ IGBT sinusoidal rectifier converters which demand relatively low levels of harmonic currents from the supply, but are more expensive than controllers with thyristor or diode converters, particularly in the smaller sizes.

VSC configurations and requirements shall be in accordance with standard drawings FS00-6-3 and FS00-6-4.
4.4.2 Voltage Waveform Limits within the Installation

The starting and continuous operation of non-linear loads within the installation, such as motor variable speed controllers, shall not cause harmonic distortion to the voltage waveform at the various points of common coupling within the installation in excess of the levels specified paras. 4.3.2 (a) and 4.3.2(b) above.

4.4.3 Supply Authority Harmonic Current Limits

a) The Supply Authority has the authority to determine the level of harmonic currents which any particular installation may be permitted to draw from the supply. Such limits will include limits on individual harmonic currents as well as a limit on the total harmonic distortion of the current drawn by the installation. The Supply Authority reserves the right to revise these limits down at any time.

b) Western Power do not accept HB264 as valid method of calculating permissible harmonic current levels, instead preferring the methods described in AS/NZS 61000.3.6:2001.

c) Western Power may determine harmonic current limits on the basis of a computer model of the whole system under worse case conditions, i.e. in accordance with AS/NZS 61000.3.6 Appendix I4 (Third Approximation).

Such investigations may involve considerable time, so that the fairly long delays can be expected in obtaining such advice from Western Power.

d) The Designer can determine current limits in accordance with AS/NZS 61000.3.6 Appendix I3 (Second Approximation) which in general will yield more conservative results (i.e. the amount of filtering required will be greater).

Unless harmonic current limits are readily available from the Supply Authority, the Designer shall base the Engineering Design on harmonic current limits calculated in accordance with AS/NZS 61000.3.6 Appendix I3 (Second Approximation).

e) Details of the MV source impedance at the Supply Authority’s relevant HV/MV substation and at the proposed Water Corporation installation are usually available relatively quickly from Supply Authority.

f) Knowledge of the minimum available transformer capacity at the Supply Authority’s substation is required in order to carry out calculations in accordance with AS/NZS 61000.3.6 Appendix I3.

If this is not readily available, a reasonable estimate can be calculated from the MV fault level at the substation by assuming that the transformer will have an impedance of 15%.

g) Current limit calculations in accordance with AS/NZS 61000.3.6 Appendix I3 (Second Approximation) shall be carried out on the basis of the following assumptions:

   i) FML = coincidence factor MV to LV loads = 0.5
   ii) FMV = coincidence factor between MV loads = 0.7
   iii) ThHM = transfer coefficient HV to MV = 1.0
   iv) Minimum harmonic voltage limit of 0.1 % for any harmonic voltage.
4.4.4 Notching

a) The process of rectification carried out by a controlled converter involves short periods of “commutation” as the source of rectified current is transferred from one phase to another. During these periods, a short circuit is in effect applied between the two supply phases involved, so causing a short time voltage dip in the supply system voltage waveform.

In the case of a controlled converter, the voltage dips abruptly at the instant of commutation (i.e. at the delay angle), then follows a sinusoidal curve at a lower level during commutation, rising abruptly once commutation is complete. This phenomenon is known as notching. The depth of the notch is defined as the deviation of the leading edge of the wave form expressed per unit of the input A.C. peak voltage.

The notch depth is independent of converter load and varies as the sine of the delay angle. The notch depth is at its maximum at the terminals of the converter and is reduced to zero at the level of an infinite source.

As explained in AS 60146.1.2

i) if the delay angle is 90 degrees the notch depth at the converter terminals will be at its maximum of 1.0 per unit, and

ii) at the point of common coupling, the per unit notch depth will be the ratio of the fault level at the converter terminals to the fault level at the point of common coupling

b) The system shall be designed so that voltage notches do not exceed Western Power requirements as published in the document entitled Western Power, Quality of Electricity Supply, Technical Requirements, Part 2.

c) If controlled converters are to be used, the Designer shall carry out calculations as to verify that the levels of notching at the various points of common coupling are within acceptable limits. Supply Authority limitations apply to the level of notching at the point of attachment, i.e. at the point of common coupling with the network operator’s system.

At any point of common coupling within the Corporation’s electrical installation, the level of voltage wave form notching shall not exceed 0.20 per unit.

Notch filtering may be required for sensitive equipment circuits such as instrumentation circuits.

d) In the case of an uncontrolled converter, where the delay angle is zero, the depth of notch is also zero. For an uncontrolled converter the input voltage dips relatively gradually from the instant of commutation and rises suddenly once commutation is complete. Nevertheless, such a voltage wave form is considered to be free of notching

Generally uncontrolled converters shall be preferred so that the problems associated with notching are avoided.

4.4.5 Rating of Converter Supply Transformers

The current drawn by 6 pulse, 12 pulse or 24 pulse converters is in the form of alternate positive and negative square wave pulses and this is non sinusoidal. Since transformers are rated for sinusoidal currents, the utilisation factor for transformers supplying converter leads will be less than unity depending on the root mean square value of the current waveform.
The Designer shall determine the appropriate utilisation factor and shall rate the converter supply transformer accordingly.

### 4.4.6 Screening of Converter Supply Transformers

Converter supply transformers shall be specified with an earthed screen between the primary and secondary windings to prevent switching pulses being coupled capacitively back into the electrical supply system.

### 4.4.7 Size of Converter

The on-site rated output current of the converter shall not be less than rated full load current of the associated motor.

### 4.4.8 Type of Converter

Converters can be classified as hereunder.

#### 4.4.8.1 Controlled Converters

Thyristor converters, in which the instant of conduction is delayed to vary the power supplied to the connected load, are said to be controlled converters.

The power factor of controlled converters falls from approximately 0.95 at full load to approximately 0.65 at 30% load. Without passive front end filtering, controlled converters cause notching (which cannot be eliminated by the use of active filters (refer para. 4.4.4).

Consequently controlled converters shall be permitted only if fitted with passive front end filtering which:

a) ensures that the input power factor to the filter converter combination is maintained within the range 0.9 to unity for loads between full load and 20% load, and

b) ensures that the level of notching is maintained within acceptable limits (para. 4.4.4 refers).

#### 4.4.8.2 Uncontrolled Converters

Converters in which there is no delay in the instant of conduction are said to be uncontrolled converters or free firing converters. The diode bridge is the most common form of uncontrolled converter. Uncontrolled converters generate a substantially constant output DC voltage and are known as voltage source converters. The power factor of such converters is high.

#### 4.4.8.3 Sinusoidal Rectifiers

Sinusoidal rectifiers are in effect inverters connected backwards and connected to the supply via filters. The sinusoidal rectifier inputs are switched in a pulse width modulated mode so as to produce a rectified D.C. output from a sinusoidal input current into the input filter which in turn prevents significant modulation side band harmonic currents and voltages from being reflected into the input power supply. Such filters are required to include a radio frequency filter stage.

Sinusoidal rectifiers generate a substantially constant output D.C. voltage and are considered to be voltage source converters.

### 4.4.9 Harmonic Generation and Starting Performance

For converters of the same size, controlled converters generate marginally greater harmonic currents than uncontrolled converters and within these categories the greater the number of pulses in the
rectification process the less the harmonic currents generated. However, for any given converter size, active front end converters generate by far the least harmonic currents.

Generally a 12 pulse converter will be more complex and more expensive than a 6 pulse converter of a similar rating, while an active front end converter will be considerably more complex and expensive than both of the other types.

The supply impedance at the point of attachment limits the size of converter which may be connected at any particular site.

The lower the fault level at the point of attachment, the less the level of harmonic currents which may be taken from the electricity supply system. Consequently, the converter size limit for a 12 pulse converter is higher than the limit for a 6 pulse converter and the limit for an Active Front End converter is considerably higher again.

For a particular application the Designer shall determine the type of converter to be used so as to limit the harmonic currents drawn from the supply in accordance with the requirements of AS/NZS 61000.3.6 as determined ultimately by the Supply Authority. (Refer Clause 4.4.3).

Harmonics currents are caused when a non-linear load is connected to a sinusoidal voltage source. A converter (e.g. a rectifier) is such a non-linear load.

In commercial situations where large numbers of single phase uncontrolled converters are connected, triplen harmonic currents will be drawn for the supply and may need to be filtered out.

Sinusoidal rectifiers (i.e. active front ends) will draw triplen harmonic currents as well as other harmonic currents albeit all at a relatively low level.

However, triplen harmonic currents will be filtered out by transformer delta connections and will not be transferred across isolating transformers.

Depending on the delay angle, controlled converters will draw both odd and even harmonic currents.

Theoretically which particular harmonic currents are generated by a particular uncontrolled converter depends on the number of rectification pulses per cycle as follows:

\[ h = k*q \pm 1 \]

where:

- \( h \) = harmonic number (integer multiple of the fundamental)
- \( k \) = any positive integer
- \( q \) = number of pulses per cycle

Hence for a 6 pulse uncontrolled converter, harmonic currents will occur in the input currents to the converter supply transformer at all harmonic frequencies which are odd multiples of the fundamental frequency which are \( > 5 \) other than triplen harmonics.

Theoretically, if the number of pulses per cycle is increased to 12, the 5th and 7th harmonics are eliminated. Theoretically, if the number of pulses per cycle is increased to 24, the 11th, 13th, 17th and 19th harmonic currents will also be eliminated, and so on.
In practice the “eliminated” harmonic currents generated by uncontrolled converters with pulse numbers greater than 6 will be approximately 10% of the value of these harmonic currents generated by a 6 pulse uncontrolled converter installed in the same situation.

The magnitude of harmonic currents drawn by a converter depends on the source impedance, i.e. an increase in source impedance will result in a fall in the percentage of harmonic current in the total current drawn by the converter.

Various computer programmes are available for 6 pulse uncontrolled converters without internal filtering which will enable the amount of harmonic current to be taken in a particular situation to be calculated, and the effect of increasing the number of pulses per cycle may be determined as above.

If the uncontrolled converters being considered incorporate AC line reactors, the value of these impedances can be added to the transformer impedance for the purposes of calculation.

If the uncontrolled converters being considered incorporate filtering other than line A.C. reactors, computer programmes specific to the particular make and model of variable speed controller shall be used. **Note:** AC line filters generally have poor power factor at low load and may present problems when connected to the supply, especially a generating set supply.

As specified clause 4.4.8.1 controlled converters shall be permitted only if fitted with passive front end filtering and the magnitude of harmonic currents drawn by such converters shall be determined by reference to the supplier.

While it can be assumed that harmonic currents taken by sinusoidal rectifiers will be less than those taken by other types of converter, the magnitude of such harmonic currents will vary between designs and should be determined by reference to the supplier.

Starting currents for variable speed drives are usually relatively small, i.e. less than 150% of full load current. Nevertheless, the Designer shall calculate the voltage dip disturbances on starting to confirm that these are in accordance with the requirements specified in clause 4.3 above.

### 4.4.10 Use of Active Harmonic Filters

In situations where the fault level is very low, even relatively low levels of harmonic currents can cause voltage waveform distortion in excess of the allowable limits. In these circumstances the Designer shall investigate the use of active harmonic filters as an alternative to increasing the complexity of the converter system (Section 14 refers). The Designer shall calculate the total harmonic current rating of the required active harmonic filter using harmonic current demand values provided by the supplier of the particular variable speed drive controller being considered. Harmonic filter sizing shall not be based on generic harmonic current levels.

Active harmonic filters are generally available in IP20 enclosures with an operating temperature range of 0°C to 40°C so that an air conditioned environment may need to be provided for such equipment.

The active filter operates by injecting a current made up of harmonic currents of the same magnitude as the harmonic currents in the load current, but 180 degrees out of phase with such currents. The effect is that only the fundamental current is drawn from the supply.

### 4.4.11 Types of Inverter

Inverters can be classified as described hereunder.
4.4.11.1 Pulse Width Modulated Inverters

The most common form of variable speed drive inverter is the voltage source pulse width modulated (PWM) type in which the D.C. supply is chopped at a carrier frequency and modulated to produce a pseudo sine wave motor current at a required voltage and at a required motor frequency somewhere between 0 Hz and 100 Hz, depending on the required motor speed. Depending on size and the particular design, carrier frequencies range from 2 kHz to 16 kHz.

PWM inverters operate from a voltage source DC link.

4.4.11.2 Current Source DC Link Inverter

In a current source DC link inverter, the output voltage waveform consists of a stepped waveform at the required motor frequency, the voltage level of which is controlled by the associated controlled converter.

4.4.11.3 Multilevel Inverters

A more sophisticated development of the PWM inverter is the multilevel inverter in which the pulse width modulation is applied to a stepped waveform consisting of alternate positive and negative pulses and having a cycle time equivalent to the period of the drive required output frequency. The modulation is used to vary the voltage and to change the stepped waveform into a pseudo sine wave.

In the most sophisticated drives of this type there may be a number of DC levels both positive and negative so that the amount of high frequency modulation is reduced.

4.4.12 Adverse Effects of Modulation Frequency Voltages

4.4.12.1 Ringing

If the cable connecting the motor to a PWM variable speed controller is long, the fast modulation switching transients can cause overvoltages at the motor terminals due to the “ringing” and surge impedance mismatch voltage doubling effects. This presents a problem as far as the use of a PWM drive with a deep bore hole motor.

4.4.12.2 Motor Shaft Currents

If a motor is connected to a PWM variable speed controller without output filtering, longitudinal voltages may be generated within the motor shaft, which in turn will cause bearing failure. This problem becomes more apparent in the larger motor sizes. In a particular installation, if the shaft longitudinal voltage is in excess of 300 mV, the motor bearings and coupling shall be isolated, or alternatively, output filters shall be installed on the PWM variable speed controller to reduce the motor shaft longitudinal voltage to an acceptable level.

4.4.12.3 Electromagnetic Interference

Because the voltage waveform generated by PWM variable speed controllers is at a high frequency and contains fast transients, unless output filtering is provided, the cable connecting the variable speed controller to the motor shall be screened, with the screen earthed at both ends.

Unless input filtering is provided, PWM switching will cause common mode interference voltages to appear on the incoming supply cables to the variable speed controller.

Consequently, except in those instances where variable speed controllers are supplied via individual unit screened transformers and where the connection between the unit transformer and its associated variable speed controller is via screened cable, all variable speed controllers shall be fitted with radio
frequency interference filters in order to prevent radio frequency interference signals being conducted back into the supply mains.

The type of screened cables to be used with variable speed controllers are discussed in Section 13.

4.4.12.4 Increases Insulation Stress

Because the voltage waveform generated by variable speed controllers contains fast transients, the turn to turn insulation in motors connected to such controllers will be stressed considerably more than that in motors connected to sinusoidal voltage supplies. Consequently, unless output filtering is used, motors to be connected to variable speed controllers shall be specified for such duty and shall be specified to have a dV/dt rating of not less than 1.8 kV/µs for 415 V motors or 6 kV/µs for 3.3 kV motors.

4.4.13 Output Sine Filters

There are two types of sine filters:

- Type 1 - those which provide both phase to ground and phase to phase filtering, and
- Type 2 - those which provide only phase to phase filtering.

Type 2 sine filters (symmetric), despite all their advantages, are not able to improve the common mode problems. The use of Type 1 sine filters (symmetric plus asymmetric) will eliminate bearing damage, eliminate the need for shielded motor cables, almost eliminate parasitic earth currents and obviate the need to limit cable length.

The use of Type 1 sine filters on the output of PWM variable speed controllers overcomes all of the problems detailed in para. 4.4.12 above. On the other hand there will be some losses in the filter and the overall capital cost of the variable speed controller will be increased. Nevertheless the use of such filters is often warranted and the Designer shall carry out calculations to determine if the use of such filters is warranted.

Type 1 sine filters shall be used on the output of PWM variable speed controllers when connected to submersible borehole motors and submersible sewage pump motors.

4.4.14 Types of Control Strategy

There are two basic control strategies employed in PWM variable speed controllers, as follows:

4.4.14.1 Flux Vector Control

Under flux vector control the torque producing and magnetising currents within the motor are separately and accurately controlled as vectors under closed loop control. (These two components are almost in quadrature). This sophisticated method of control is appropriate for applications where a fast speed response is required in order to compensate for rapid load changes, or where a large speed control range is required.

4.4.14.2 Scaler Control

Under scaler control the vector sum of the torque producing and magnetising currents within the motor is controlled under open loop control. This method is less precise, but is adequate for most applications involving loads with a quadratic torque/speed characteristic (e.g. centrifugal pumps). Variable speed controllers employing scaler control can be expected to be considerably cheaper than those employing the more sophisticated vector control method.
4.5 Variable Speed Controllers for Wound Rotor Motors

4.5.1 Rotor Resistance Control

The speed of a wound rotor motor can be controlled by varying the effective resistance in the rotor circuit. Physical resistors can be used for this purpose, but such controllers have the disadvantage that the power absorbed in the resistors by the rotor currents is wasted as heat which must be dissipated. Such controllers are only cost effective for drives connected to loads with a quadratic torque/speed characteristic and which require only a small range of speed control.

4.5.2 Slip Power Recovery Control

The slip power recovery drive system is a variation of rotor resistance control in which the rotor currents are rectified and then inverted and fed back into the supply system rather than being wasted in heating physical resistors. Such drives are effective over a speed range of 75% to 100% of motor nominal speed and consequently are suitable for many drives connected to loads with a quadratic torque/speed characteristic.

The advantages of slip power recovery variable speed controllers are:

a) In such drives only a small portion of the motor input power needs to be converted electronically, so that the cost of the controller itself will be considerably less than for a variable speed controller for a similar sized cage motor.

b) For the same reason, the amount of harmonic voltage distortion caused by a slip power recovery drive will be much smaller than that caused by a variable speed controller for a similar sized cage motor.

The disadvantages of slip power recovery variable speed controllers are:

a) A wound rotor must be used which is more costly and requires more maintenance than a cage motor,

b) Many such variable speed drives are susceptible to supply voltage dips causing surges of over current with consequent tripping of the drive and in some cases operation of expensive high speed fuses. Slip power recovery variable speed controllers shall be specified to include circuitry which either allows the controller to ride through supply voltage dips without interruptions to operation, or at least, shuts the controller down without operating protective devices such as fuses. Tenderers for slip power recovery variable speed controllers shall be required to define the level of supply voltage disturbance which the units offered can tolerate without shutting down.

4.6 Variable Speed Controller Assemblies

4.6.1 Rated Short-time Current

The variable speed controller assembly shall have a rated short-time current of 120% of the calculated maximum fault current available at the assembly for 1 second.

4.6.2 Arcing Fault Protection

The design of the variable speed controller assembly shall incorporate features to minimise the risk of an internal arcing fault developing and to minimise the risk to the operator should such a fault develop.
The available fault energy within a variable speed controller assembly shall be limited by suitably rated semi-conductor protection fuses in accordance with AS 60269.4.0. Such fuses shall be located in a separate arcing fault tested enclosure.

Alternatively variable speed controllers shall be fitted with arc light detector protection arranged to trip the motor main circuit protection in the event of an arc occurring within the variable speed controller enclosure. For motors > 150kW an arc fault detection system shall be fitted to the enclosure.

4.6.3 Isolation

a) The variable speed controller shall be supplied via a line side contactor in order to provide complete drive isolation under emergency stop conditions.

b) If it is the manufacturer's preference to leave the controller energised except under emergency stop conditions, the cooling fans shall be thermostatically controlled as part of the manufacturer's standard design.

c) If a line side circuit breaker is to be operated as part of normal operations, the circuit breaker shall be rated for frequent duty.

d) If a line side contactor or circuit breaker is to be operated as part of normal operations, a separate control voltage supply shall be provided to the variable speed controller so that all indications are maintained during off periods.

4.6.4 Circuit Breaker Feeders

The circuit breaker feed to the VSC assembly shall be fitted with earth fault protection.

4.7 Motor Emergency Isolation

A mechanically latched emergency stop push button shall be provided adjacent to each motor which has a power output rating within the scope of this Design Standard. The push button shall be mounted on an upstand as close to the motor drive end as is practical without hindering ready access to the coupling guard, motor hold down bolts and motor terminal boxes.
5 MOTOR SPECIFICATIONS

5.1 Rating

The S1 kW output rating for site conditions shall be determined as per Sub-Section 4.1.

5.2 Type

Motors shall be conventional induction motors.

Whether motors are to be squirrel cage or wound rotor type shall be determined as per Sub-Section 4.3.

5.3 Electricity Supply

In order that the motor manufacturer is fully informed as to the on-site supply conditions the following supply information shall be given in the Specification.

a) Number of Phases.
b) Voltage
c) Whether neutral solidly grounded
d) Frequency
e) Utilisation Voltage Range. The Utilisation Voltage Range shall be specified as plus 10% to minus 11% of the motor rated voltage.
f) Frequency tolerance. The supply authority is legally obliged to limit frequency excursions to ±2.5%. This figure would have to be specified where the source of supply is a diesel powered station or similar small supply. However, Western Power holds the main grid frequency to ±0.25% and for motors to be powered from the main grid, a frequency tolerance of ±0.5% shall be specified.
g) Supply impedance. The supply per phase resistance and reactance referred to the motor voltage shall be specified.
h) Supply arrangements for the control equipment.

5.4 Standard Specifications

a) The motors shall be in accordance with AS60034.
b) All information required to be submitted by AS60034 shall be provided. (Only some such items are dealt with specifically in this Manual).

5.5 Enclosures

For major indoor pump stations, drip proof and protected (to AS60529 classification IP22) self-ventilating enclosures shall be used. (In the larger frame sizes, the additional cost for totally enclosed fan cooled enclosures is substantial ). Reference should also be made to clause 5.15.10.
Outdoor pumping plant is more difficult to maintain, raises security concerns and more likely to give rise to noise problems. Hence in view of the above, outdoor major pumping plant shall be avoided.

5.6 Equivalent Circuit

Tenderers shall be instructed in the Tender Document to provide values for the per phase equivalent star, equivalent circuit for the motor offered. These values shall be used in the analysis of motor Tenders (see Section 6). For cage motors with single cage rotors, equivalent circuit values shall be required at both locked rotor and full speed.

5.7 Full Speed Performance Figures

Tenderers shall be instructed to submit guaranteed figures for full speed power factor and efficiency at 100% rated load, 75% rated load and 50% rated load. These values shall be used in the analysis of motor Tenders (see Section 6).

5.8 Other Motor Performance Figures

Tenderers shall be instructed to submit guaranteed figures for the following:-

- a) Full load speed in rpm.
- b) $S_1$ (continuous running power) rating in kW at site maximum temperature.
- c) Rated stator current.
- d) Locked rotor torque at rated volts as a percent of full load torque.
- e) Pull up torque (as defined in AS60034) at rated volts as a percent of full load torque.
- f) Pull up torque speed in rpm.
- g) Breakdown torque (as defined in AS60034) at rated volts as a percent of full load torque.
- h) Breakdown torque speed in rpm.

(Note: In the case of slip ring motors, many manufacturers will not permit locked rotor torque, pull up torque or breakdown torque to be measured at rated volts. Consequently it is usual to allow Tenderers to quote these torque values at a reduced voltage not less than 50% rated voltage).

- i) Torque at rated volts at 75% full speed,
- j) Current at rated volts at 75% speed,
- k) Input kVAR at locked rotor when rated volts from an infinite bus is applied to the motor terminals. (Similarly to requirement 5.8(h), for slip ring motors, Tenderers are usually permitted to submit this figure at 50% rated volts should they so prefer).
- l) No load current at full speed with rated voltage applied to the motor terminals.
- m) Full speed friction and windage loss in kW.
n) Maximum no load sound pressure level in dBA at a distance of 1m from the motor casing, or the maximum no load sound power level.

o) Maximum vibration amplitude at each bearing in μ m.

p) Motor temperature rise above ambient with only heater on in °C.

q) Brush wear rate at 100% rated load, 75% rated load and 50% rated load (if wound rotor motor).

5.9 Other Motor Data

Tenderers shall be instructed to give the following sundry details in respect to the motors offered.

a) Manufacturer's name and place of manufacture.

b) Motor frame size.

c) Type of enclosure. (IP rating)

d) Class of insulation.

e) Rated stator voltage.

f) Rated stator lightning impulse withstand voltage (if High Voltage motor).

g) Winding PTC thermistor trip temperature, or RTD specification.

h) Rated rotor voltage (if wound rotor motor).

i) Rated rotor current (if wound rotor motor).

j) Whether stator is star or delta connected.

k) Whether rotor is star or delta connected (if wound rotor motor).

l) Rotor cage bar design type (if cage motor).

m) Bearing details.

n) Brush size, type and grade (if wound rotor motor).

o) Location of terminal boxes (refer Sub-Section 5.14).

p) Type and grade of bearing lubricant.

q) Recommended frequency of lubrication.

r) Direction of rotation when viewed from coupling end.

s) Mass of motor complete.

t) Mass of rotor.

u) Voltage and watts of anti-condensation heater (if fitted, see Sub-Section 5.15.8).

v) Ring gear motor type (if slip ring motor).
w) Ring gear motor volts and watts (if slip ring motor).

x) Duration of ring shorting brush lifting sequence in seconds (if slip ring motor).

y) Rating of ring gear limit switches (if slip ring motor).

z) Details of paint coatings.

aa) Type Test Certificate (if available).

5.10 Ambient Temperature of Cooling Air

Because of the heat generated by motor losses, the cooling air maximum temperature for inside the pump station shall be taken to be 5°C above the maximum monthly average daily maximum outside shade temperature for the site.

5.11 Sound Pressure Levels

The sound pressure level to be specified will depend on the particular installation. Though the motor will emit most noise at full load, manufacturers usually only have test facilities and figures for no load testing. The full load sound pressure level is usually 2 to 3 dB(A) above the no load figure.

The no load sound pressure level shall be specified rather than the full load figure, and the no load value specified shall be the required full load figure, less 3 dB(A). For a normal unmanned two or three unit pump station, the mean no load sound pressure level shall be specified not to exceed 83 dB(A) at a distance of 1m from the motor casing.

5.12 Vibration Levels

AS60034 has laid down limits for motor vibration. However, on the basis of AS2625, the allowable vibration velocities specified in AS60034 for motors having a shaft height of more than 225mm, are too high for long life machines. Motors shall be specified to have a vibration severity, at works testing, of not more than 1.8mm/s rms over the frequency range 10 Hz to 1 kHz as specified in AS2625. Because of the characteristics of driven machines and associated foundations, a higher vibration severity of 2.8mm/s can be permitted on load at site. This latter figure assumes that the natural frequency of the foundation including bedplate is greater than 140% of the service speed, and consequently, foundations shall be so specified.

Motors shall be works balanced and vibration tested with a half key fitted to the drive shaft. (See Sub-Section 5.18)

5.13 Type of Contactor

Because some vacuum switches can induce transient voltage spikes in the motor windings, it is necessary to specify the type and make of vacuum contactor if such is to be used. Some manufacturers recommend an increase in winding turn to turn insulation even if the vacuum contactors to be used are of a type suited to the particular duty. (See Sub-Sections 5.15.1, 5.18.4 and 9.15)
5.14 Terminal Boxes

5.14.1 Location of Cable Terminations

Cable terminations shall be positioned at or above shaft horizontal centre line and on the right hand side of the motor when viewed from the drive end, (i.e. in accordance with the standards), unless there is a special reason for locating the termination on the opposite side. In any case, position shall be specified.

5.14.2 High Voltage Terminations

For preference, motors having High Voltage stator windings should be fitted with EN50181 Type A or Type C High Voltage terminal bushings suitable for High Voltage cold fit fully screened dead-break elbow connectors so as to allow the termination of High Voltage single core XLPE insulated cables with light duty screens.

The termination shall be located within a bolted or locked steel enclosure fitted on the front with an aluminium warning label engraved as follows:-

CAUTION

DEAD-BREAK ELBOWS

DO NOT CONNECT OR DISCONNECT LIVE

Otherwise, High Voltage stator windings shall be terminated in fully enclosed steel cable boxes with DIN, CENELEC or ANSI standard bushings which are suitable for use with cold fit insulating boots.

5.14.3 Low Voltage Terminations

Low Voltage terminations shall be specified to be in metal terminal boxes which provide adequate space for termination of the associated cable or cables. Separate terminal boxes shall be provided for main stator cables, main rotor cables (if wound rotor motor), anti-condensation heaters, and winding temperature sensors. Low Voltage terminal boxes shall be fitted with non-ferrous metal gland plates.

5.14.4 Fault Ratings

Motor terminal boxes shall be able to withstand the forces due to the short circuit currents available at the site.

Motor terminal boxes shall be able to withstand an internal arcing fault without danger to nearby personnel or damage to adjacent plant.

5.14.5 Earthing Terminal

An external motor earthing terminal located in an accessible position close to the stator termination shall be provided.
5.15 Miscellaneous Requirements

5.15.1 Windings

a) Winding insulation shall be not less than Class F (155°C) to IEC 60085. The winding temperature rise at maximum power output rating shall not exceed the temperature rise limits specified in AS 60034.1 for class B insulation (i.e. class 130 to IEC 60085). Windings shall be specified to be form wound, to have an even temperature distribution free from hot spots, and to be suitably braced to give adequate rigidity under short circuit and starting conditions. Windings shall be suitably impregnated to render them damp proof and oil resistant. Preference should be given to vacuum impregnated winding systems because these improve both damp proofing and winding rigidity.

b) Windings in High Voltage machines shall be suitable for use in conjunction with vacuum contactors.

c) On slip ring motors, the rotor winding star point shorting ring shall be located at least 10mm clear of the rotor iron laminations.

5.15.2 Stator Lightning Impulse Withstand Voltage

The stator lightning impulse withstand voltage for High Voltage machines shall be greater than 31 kV for 6.6 kV machines and greater than 18 kV for 3.3 kV machines. (Generally, four times the stator rated nominal operating voltage plus 5 kV.)

5.15.3 Bearings

a) Bearings shall be ball or roller type and grease lubricated. The grease used shall be a lithium based mineral oil grease, preferably Shell Alvania EPLF2.

b) The bearing system shall be able to carry enough axial thrust to allow the motor to be run disconnected from the load.

c) The bearing housings shall be fitted with grease nipples and automatic grease pressure relief valves and grease venting system.

d) Motors shall be fitted with bearings rated to have a nominal life (in accordance with AS2729) of 100,000 hours.

e) Tenderers shall be asked to provide details of nominal life rating and design loading ratio factor for the bearings offered.

5.15.4 Protection Against Bearing Currents

To be added in future revision

5.15.5 Holding-Down Bolts

a) The holes for holding-down bolts or set screws and cable terminations shall be drilled to a common template to facilitate interchangeability of motors of the same rating. The drilling templates shall be such that the location of holes relative to the motor’s centre line remains constant from motor to motor.

b) Jacking screws shall be provided at each motor foot in order to facilitate levelling of the machine prior to installation of necessary shims and final bolting down.
5.15.6 Bearing Thermometer Elements

a) Motors shall have thermometer pockets complete with Resistance Temperature Detector (RTD) in each bearing housing. RTD elements shall be three wire platinum element type with 6mm OD stainless steel sheath, shall be grade B accuracy in accordance with BSEN 60751 and shall have a resistance of 100 ohms at 0°C and a fundamental interval of 38.50 ohms.

Bearing temperature RTD’s shall be brought out separately, via suitably protected leads, to a special conveniently located terminal box. Bearing temperature RTD’s may be terminated in the same terminal box as motor winding over temperature RTD’s if these are fitted, but shall be kept separate from any other circuits.

b) Generally, driven machines such as pumps associated with motors fitted with bearing temperature detectors will also be fitted with bearing temperature detectors.

5.15.7 Winding Overtemperature Protection

All motors rated greater than 500 kW shall be specified to be fitted with winding over temperature protection. Such protection shall be in the form of either Resistance Temperature Detectors (RTD’s) embedded in the windings or thermistors embedded in the windings. RTD protection is preferred.

RTD’s shall be three wire platinum element type having grade B accuracy in accordance with BSEN 60751 and shall have a resistance of 100 ohms at 0°C and a fundamental interval of 38.50 ohms. Two RTD’s shall be embedded within the end of each phase wiring and all RTD’s shall be brought out separately, via suitably protected leads, to a special conveniently located terminal box, so that one set of RTD’s can be used for winding temperature indication and protection and the other set retained as a spare. The trip temperature shall be set in accordance with the manufacturer’s recommended practice.

Thermistor protection shall take the form of a single P.T.C. thermistor installed within the end turns of each phase winding. The thermistor trip temperature shall be specified to be in accordance with the manufacturer's recommended practice and the temperature-resistance characteristic shall be such that the resistance of each thermistor at trip temperature is 1000 ohms. The three thermistors shall be specified to be brought out separately, via suitably protected leads, to a special conveniently located terminal box. (Thermistors shall be connected in series in the terminal box and hence connected to the standard detection relay which has a trip resistance of 3000 ohms.)

5.15.8 Anti-Condensation Heaters

All motors shall be specified with inbuilt anti-condensation heaters. Heaters shall be rated to raise the temperature of the motor 4°C above ambient. Heaters should be 240VAC single phase units and used in conjunction with earth leakage circuit breakers with 30mA sensitivity.

5.15.9 Vibration Protection

Vibration indication and protection equipment shall be provided on all motors (and associated pumps) rated over 2000 kW or air blower motors in sewage treatment plants. Application of vibration equipment to smaller motors shall be determined on an individual case basis and the application.

5.15.10 General Construction

Motors shall be self-ventilating by means of a shaft mounted fan. Guards shall be provided on all moving parts. Motors driving pumps shall have no ventilation openings in the drive end face of the enclosure, (so that spray from a leaking pump seal cannot enter the motor directly).
Some motor manufacturers supply motors with ventilation openings in the drive end face of the enclosure that are fitted with baffles such that water cannot enter and cause damage. Such arrangements are considered acceptable provided supporting documentation is provided at the time of tender.

5.15.11 Wound Rotor Motor Brush Gear

a) Wound rotor motors with an estimated number of running hours in excess of 1000 per year shall be fitted with brush lifting and ring shorting gear.

b) Wound rotor motors which are not provided with brush lifting gear shall be specified to have the brush gear located in a separate enclosure from the main stator winding, so that carbon dust from brush wear is not carried onto the surface of the stator windings by the circulation of cooling air.

c) Since the secondary resistance starter selected for the motor will have an upper voltage limit, this limit should be included in the motor specification.

5.15.12 Painting

Motors shall be specified to be painted in accordance with the manufacturer's standard practice and which is rated in accordance with AS2312 (and ISO9223) to provide ‘long term protection’ to steel in industrial environments.

5.16 Coupling

Usually the coupling is supplied by the manufacturer of the driven machine. The Water Corporation should arrange to have the motor end half-coupling bored to suit shaft dimensions certified as correct by the motor manufacturer. The Water Corporation should have the machined motor end half coupling dynamically balanced with a half key fitted. The motor half-coupling should then be supplied to the motor manufacturer for fitting to the motor.

5.17 Motor Installation

Normally delivery to site, unpacking, mechanical installation and alignment of the motor, and supervision of final electrical connection are specified as the motor supplier's responsibility.

If a motor is required for testing of the driven machine, it is normal to make the motor supplier responsible for the supply and delivery of one motor to and from the driven machine test bay and for the supervision of the motor’s operation during such tests.

5.18 Motor Testing

5.18.1 Tests During Manufacture

Provided that the manufacturer has adequate Quality Assurance, the Specification need not require inspection during manufacture or for general materials testing during manufacture.

5.18.2 Works Efficiency Tests

All motors rated more than 500 kW shall be efficiency tested individually. In the case of motors rated not more than 500 kW, one motor in each batch shall be efficiency tested. Efficiency tests shall be specified to be done by the summation of losses method in accordance with AS60034. Manufacturers of various different nationalities tend to submit efficiency figures in accordance with their own national standards. However, since testing methods vary from standard to standard, different
efficiency figures are possible for the same motor tested to different standards. Since the efficiency figure is critical in comparing tenders, it is necessary to insist that such values be based on the Australian Standard.

5.18.3 Other Works Performance Tests

One motor in each batch shall be works performance tested to ensure that the contract performance values are achieved. In particular, motor winding temperature rise tests shall be performed at full load.

As the values are not as critical as efficiency, it is only necessary to specify that these tests be done in accordance with a recognised national standard and to require the Tenderer to specify the standard applicable to the Tenderer’s offer.

5.18.4 Works Routine Tests

Routine Check Tests shall be defined as those tests applied to the machine necessary to show that it is able to withstand the appropriate dielectric tests, and is in correct working order both electrically and mechanically. All motors shall be specified to be subjected to Routine Check Tests at the manufacturer’s works. Routine Check Tests shall be required to include the following:

a) winding resistance measurement,

b) winding insulation resistance measurement at not less than 500 volts for Low Voltage machines and not less than 1000 volts for High Voltage machines,

c) air gaps measurement,

d) voltage withstand test in accordance with AS60034.1,

e) an additional voltage withstand test at 120% of the test voltage specified in AS60034.1 for 10 seconds (only for motors to be controlled by vacuum contactors),

f) confirmation of terminal marking and direction of rotation,

g) open circuit induced secondary voltage (for wound rotor induction motors),

h) no load test at rated voltage recordings volts, amps, and kilowatts, and

i) no load vibration test.

5.18.5 Works Testing of Driven Machine

If driven machine works tests are to be carried out, such tests shall be required to be witnessed by the motor supplier.

5.18.6 Site Motor Tests

Each motor shall be required to run under its normal load for a period of 3 hours after installation. In addition, provision shall be made in the Specification to allow the Contract Superintendent to test the on-site performance of the motor in accordance with the Specification. Such things as on-site, starting current, voltage flick and motor temperature rise may be measured at this time. Motor efficiency tests should be conducted for motors greater than or equal to 500 kW.
5.18.7 Witnessing Tests

All tests shall be specified to be witnessed by a Water Corporation representative. It may be necessary to commission overseas consulting engineering firms to act on the Water Corporation's behalf in this regard.

5.18.8 Motor and Variable Speed Drive Packages

Further to 5.18.2 and 5.18.6 efficiency testing shall be carried out on the motor/VSC combination. The overall efficiency and motor efficiency shall be measured with the VSC in operation. High Voltage AC power drive systems shall comply with one of the efficiency determination methods specified in IEC 61800.4 deemed most appropriate for the project.

Motor winding temperature rise tests shall be performed at full load at the manufacturer’s works and shall be measured with the VSC in operation.

In the case where the motor/VSC combination is required for driven machine works testing (clause 5.18.5), the efficiency of the VSC/Motor/Pump should be measured.

Efficiency measurements shall be carried out using the 3 wattmeter method only. A 2 wattmeter method could lead to a 1% to 1.5% overstated efficiency and therefore shall not be used.

5.19 Liquidated Damages for Excess Losses

The amount of liquidated damages for which the motor supplier shall be liable, should acceptance testing show that the motor full load efficiency to be less than the minimum allowed under the contract, shall be specified. The amount shall be determined as hereunder:

\[
C = (L_a - L_{\text{max}})*N*T/F_c = \text{amount of liquidated damages in $}
\]

Where:

\[
L_a = \text{Actual motor losses at full load as determined during acceptance testing by the summation of losses method in kW}
\]

\[
L_{\text{max}} = 1.1*W*(100-\eta)/\eta = \text{maximum allowable losses in kW}
\]

\[
W = \text{motor full load rating in kW}
\]

\[
\eta = \text{contract efficiency at full load in %}
\]

\[
N = \text{estimated annual operating period in hours}
\]

\[
T = \text{energy cost in $/kWhr}
\]

\[
F_c = \text{interest & sinking fund factor (in accordance with Table 6.1)}
\]

The above formula including values for N and T shall be included in the specification.
6 MOTOR TENDER ANALYSIS

6.1 Cost Analysis

6.1.1 General

Cost analysis shall be done on an Annual Assessed Cost (AAC) basis. Wherever practical, the appropriate AAC formula shall be included in the Tender Document.

Strictly speaking, the annual assessed cost for any particular item of plant should include interest and sinking fund charges, cost of energy losses and cost of maintenance. Motors offered in conformity to particular tender document specification will have similar maintenance requirements and costs. Consequently the maintenance cost component can be omitted from the AAC formula stated in the Tender Document. (However, should a non-conforming tender be considered, any additional maintenance costs likely to be incurred because of the non-conformity shall be included in the AAC calculated as part of the tender analysis).

Current energy costs shall be used in AAC calculations (as shall current maintenance costs if applicable).

6.1.2 Interest and Sinking Fund Charges

The capital value used in AAC calculations for tender analysis purposes should include all charges into store and all National Preference Agreement escalations.

Interest rates used in AAC calculations should be the current borrower's interest rate discounted to allow for inflation.

Interest and sinking fund charges which depend on both plant life and interest rate, shall be obtained by multiplying the capital value by the appropriate factor determined from Table 6.1.

<table>
<thead>
<tr>
<th>Plant Life Years</th>
<th>INTEREST &amp; SINKING FUND FACTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DISCOUNTED INTEREST RATE</td>
</tr>
<tr>
<td></td>
<td>4%</td>
</tr>
<tr>
<td>5</td>
<td>0.2246</td>
</tr>
<tr>
<td>10</td>
<td>0.1233</td>
</tr>
<tr>
<td>15</td>
<td>0.0899</td>
</tr>
<tr>
<td>20</td>
<td>0.0736</td>
</tr>
<tr>
<td>25</td>
<td>0.0640</td>
</tr>
</tbody>
</table>
6.1.3 Losses Based AAC Formula

The losses based form of the AAC formula is as follows:

\[
AAC = F_c C + N_1 L_1 T_1 + N_2 L_2 T_2
\]

Where:

- \( C \) = Capital value including National Preference Agreement escalations; $ 
- \( F_c \) = Interest and sinking fund factor as determined from Table 6.1 
- \( L_1 \) = Losses at duty point 1; kW 
- \( N_1 \) = Annual operating period at duty point 1; hr 
- \( T_1 \) = Energy cost at duty point 1; $/kWhr 
- \( L_2 \) = Losses at duty point 2; kW 
- \( N_2 \) = Annual operating period at duty point 2; hr 
- \( T_2 \) = Energy cost at duty point 2; $/kWhr

If this form of AAC formula is used, values of \( C, L_1 \) and \( L_2 \) must be provided by the Tenderer. Other parameters should be determined on a case by case basis and the calculated factors shown in the AAC formula.

6.1.4 Efficiency Based AAC Formula

Rather than requiring the Tenderer to specify losses, it is usually more convenient for motor contracts, to express the AAC formula in terms of motor efficiency.

Hence, \( L = W(100 - \eta) \eta^{-1} \)

Where:

- \( L \) = losses; kW 
- \( W \) = motor output; kW 
- \( \eta \) = motor efficiency; % 

The AAC formula thus becomes:

\[
AAC = F_c C + N_1 T_1 W_1 \eta_1^{-1}(100 - \eta_1) + N_2 T_2 W_2 \eta_2^{-1}(100 - \eta_2)
\]

Where:

- \( C \) = Capital value including National Preference Agreement escalations; $ 
- \( F_c \) = Interest and sinking fund factor as determined from Table 6.1 
- \( N_1 \) = Annual operating period at duty point 1; hrs 
- \( T_1 \) = Energy cost at duty point 1; $/kWhr
\[ W_1 = \text{Motor output at duty point 1; kW} \]
\[ \eta_1 = \text{Motor efficiency at duty point 1; \%} \]
\[ N_2 = \text{Annual operating period at duty point 2; hrs} \]
\[ T_2 = \text{Energy cost at duty point 2; $/kWhr} \]
\[ W_2 = \text{Motor output at duty point 2; kW} \]
\[ \eta_2 = \text{Motor efficiency at duty point 2; \%} \]

If the above form of the AAC formula is used, the Tenderer is required to provide values of \( C \), \( \eta_1 \) and \( \eta_2 \). Other parameters should be determined on a case by case basis and the calculated factors shown in the AAC formula.

### 6.2 Performance Analysis

#### 6.2.1 General

The performance figures provided by the Tenderer shall be checked by comparison with similar values calculated from the equivalent circuit values provided.

#### 6.2.2 Full Speed Performance

By using an appropriate computer model and the appropriate full speed equivalent circuit values, the full speed performance figures shall be calculated and compared with the full speed performance figures quoted.

The value of efficiency is the most important since this will determine the size of the losses and will be an important factor in the annual cost calculation. In such calculations the efficiency at 3/4 load is generally used. Provided that the power factor is greater than 0.80 between 50\% and 100\% load, power factor need not be considered further in Tender Analysis unless the supply authority provides a financial incentive for power factor correction beyond that figure.

#### 6.2.3 Starting Performance

##### 6.2.3.1 Cage Motors

By using an appropriate computer model and the appropriate equivalent circuit values, values of locked current, locked rotor torque and locked rotor kVAR shall be calculated and checked against the values supplied by the Tenderer.

In the case of double cage machines the torque-speed and current-speed curves shall be calculated and compared with the curves submitted by the Tenderer. (It should be remembered that the tendered curves are 'worst case' curves so that the calculated curves should be somewhat 'better' than the tendered curves.) Values of LRC/FLC, start pf, run pf and motor efficiency shall be calculated assuming supply from an infinite bus.

Once the tendered performance values have been verified, the supply impedance shall be entered into the computer model and the on-site performance values calculated.

The on-site worst case motor torque-speed curve must be above the driven machine torque-speed curve by not less than 10\% of motor full load torque.
6.2.3.2 Slip Ring Motors

In the case of slip ring motors, the motor accelerating torque characteristics are determined by the starter resistor values as well as motor equivalent circuit values and site supply impedances. By using an appropriate computer model, the values of the required starting resistances shall be calculated. Starting characteristics for the on-site starting of the motor offered shall be produced to check that the Supply Authority on-site kVAR limit can be met and that the drive can be accelerated to full speed with the number of starting steps specified.

6.3 Clause By Clause Compliance

The Tenderer's offer shall be compared with the Conditions of Tendering and the Specification on a clause by clause basis and the results shown in a tabulated form. Where the Tenderer does not bind himself clearly to the Specification, he shall be required to clarify the matter in writing. As a general rule tenders not complying with the Specification should not be accepted. However, some minor variations will be present in all offers and inevitably must be accepted. Variations from the Specification in recommended tenders must be minor, relatively few, and must be clearly described in the recommendation.
7 TRANSFORMER SPECIFICATIONS

7.1 General

Transformers shall be specified using either the Water Corporation’s Type Specification for ONAN Transformers or the Water Corporation’s Type Specification for Dry Type Transformers. The technical data required to be provided in the Schedule of Technical data to be attached to the Type Specification shall be determined as detailed hereunder. Transformers shall be in accordance with AS60076 – Power Transformers General and AS60076.11 – Dry Type Power Transformers.

7.2 Rating

The kVA rating of transformers shall be the next standard rating greater than the calculated maximum demand for the particular transformer (para. 3.8 refers).

7.3 Vector Group and Connection

Unless there are special requirements to the contrary, step down transformers shall be specified to be Group 3 (Dyn1) with delta primary and star secondary windings.

7.4 Cooling

a) Transformers shall be the natural oil, natural air cooled (ONAN) type or dry type as appropriate for the project. If the transformer is located within a water catchment area (or similar environmentally sensitive area), dry type transformers shall be used. The use of synthetic cooling oils shall not be permitted.

b) Transformers which must be located in confined spaces or within pump station buildings where there is a fire risk shall be dry type. All materials used in dry type transformers shall be self-extinguishing and shall produce no toxic gases in the event of a secondary fire or arcing. Dry type transformers shall have class 180 winding insulation to AS 2768 and class 155 encapsulation insulation to AS 2768.

7.5 Temperature Rise of Oil Filled Transformers

To enable oil filled transformers to be used in any location within the State, and to reduce maintenance, low temperature rise units, (i.e. 50°C rise for oil, 55°C rise for windings) have been specified in the type specifications. This will enable the transformers to operate at full load in ambient temperature up to 50°C.

7.6 Type of Transformer

a) Core type transformers have been specified in the type specifications because of difficulty in repairing shell type transformers.

b) Transformers connecting Low Voltage active filters to High Voltage systems shall be three phase star/star connected three limb core type transformers.
7.7 Losses

a) Transformers shall be of a low flux density, low iron loss design so as to minimise vibration levels, mechanical stress levels, sound levels and inrush current.

b) Transformers with primary winding nominal voltages of either 11 kV or 22 kV shall have a high power efficiency classification in accordance with Section 3 of AS 2374.1.2-2003, i.e. such oil immersed transformers shall efficiencies at 50 % full load in accordance with Table 3 of AS 2374.1.2-2003 and such dry type transformers shall have efficiencies in accordance with Table 4 of AS 2374.1.2-2003.

c) Transformers with primary winding nominal voltages of 3.3 kV, 6.6 kV or 33 kV shall have efficiencies at 50 % full load not less than the values shown on Table 2 of AS 2374.1.2-2005.

d) The design of transformers supplying non-linear loads shall be such as to minimise eddy current losses since such losses caused by harmonic currents are proportional to the square of the magnitude of the harmonic current and the square of the harmonic number. Transformer capability when supplying non sinusoidal loads shall be determined in accordance with IEEE STD. C57.110.

7.8 Impedance

The transformer impedance has to be proportioned to limit the fault level on the secondary side to an acceptable level and to provide maximum starting kVAR with secondary voltage drop within acceptable limits. The following impedance values have been calculated to meet the above requirements.

<table>
<thead>
<tr>
<th>Transformer KVA</th>
<th>Impedance %</th>
</tr>
</thead>
<tbody>
<tr>
<td>315</td>
<td>4.7 ± 0.5</td>
</tr>
<tr>
<td>500</td>
<td>4.7 ± 0.5</td>
</tr>
<tr>
<td>630</td>
<td>5.5 ± 0.5</td>
</tr>
<tr>
<td>800</td>
<td>5.5 ± 0.5</td>
</tr>
<tr>
<td>1000</td>
<td>6.0 ± 0.6</td>
</tr>
<tr>
<td>1250</td>
<td>6.0 ± 0.6</td>
</tr>
<tr>
<td>1500</td>
<td>6.3 ± 0.6</td>
</tr>
<tr>
<td>2000</td>
<td>6.3 ± 0.6</td>
</tr>
</tbody>
</table>

For transformers greater than 2000kVA, the typical values specified in AS60076 should be used.

7.9 Inrush Current

Inrush current on delta-star step down transformers with cold rolled steel cores can be as high as nine (9) times full load current and for the sizes of transformer being considered here, could be expected to decay exponentially with a time constant of 0.3 seconds. Use of low flux density transformers can be expected to reduce the magnitude of inrush current to approximately seven (7) times full load current. Transformers shall be specified to be designed to minimise inrush currents but inrush current
performance should not be quantified. (Transformer primary fuses are usually sized to be able to withstand twelve (12) times full load current for 0.1 seconds and this would be conservative for the transformers being considered here).

7.10 Connections

a) High Voltage connections to transformers shall be cable connections, preferably using single core XLPE cable.

b) All single core XLPE cable connections to transformers should be via suitably rated dead-break elbow connectors having lightning impulse withstand voltage ratings (LIWV) not less than the values tabulated hereunder.

<table>
<thead>
<tr>
<th>Transformer Winding</th>
<th>Connector Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Voltage</td>
<td>LIWV</td>
</tr>
<tr>
<td>6.6kV</td>
<td>60kV</td>
</tr>
<tr>
<td>11kV</td>
<td>95kV</td>
</tr>
<tr>
<td>22kV</td>
<td>150kV</td>
</tr>
<tr>
<td>33kV</td>
<td>200kV</td>
</tr>
</tbody>
</table>

Cable connections to transformer primary windings shall be via EN50181 Type A High Voltage terminal bushings suitable for High Voltage cold applied fully screened dead-break elbow connectors so as to allow the termination of High Voltage single core XLPE insulated cables with heavy duty screens. Such connectors shall be fitted with suitably rated integral surge diverters (Refer section 12).

Appropriate bolt-on steel shields shall be provided to minimise the exposure of the dead-break elbows to the weather. Such shields shall be arranged to prevent operation of the dead-break elbow connectors, unless the shields are removed first. Such shields shall be padlocked with an EL1 key or with a key interlocked with the H.V. switchgear.

An aluminium label shall be fitted to these shields engraved as follows:-

"Caution

Dead-Break Connectors

Do not connect or disconnect live"

c) Transformer connections rated at Low Voltage should be suitable for the connection of bar feeder duct, if the latter is to be used. Otherwise, Low Voltage cable boxes shall be specified.

d) In those instances where High Voltage aerial connections are necessary, normal High Voltage bushing arrangements should be used (i.e. not cable box with aerial connection adaptor). Arcing horns should not be fitted to High Voltage bushings.
7.11 Lightning Impulse Withstand Voltage

The lightning impulse withstand voltage rating for transformer High Voltage windings shall be in accordance with the following:

<table>
<thead>
<tr>
<th>Winding Nominal Voltage kV</th>
<th>Rated Lightning Impulse Withstand Voltage kV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Oil Filled</td>
</tr>
<tr>
<td>3.3</td>
<td>40</td>
</tr>
<tr>
<td>6.6</td>
<td>60</td>
</tr>
<tr>
<td>11</td>
<td>95</td>
</tr>
<tr>
<td>22</td>
<td>150</td>
</tr>
<tr>
<td>33</td>
<td>200</td>
</tr>
</tbody>
</table>

7.12 Protection

Electrical protection relays shall generally be of the solid state type and shall comply with the relevant provisions of IEC 60255 and suitable for operating in an ambient temperature of 60°C. The relay shall have adjustment of the operating parameters over a wide range. The operation of any particular protection mode or function shall be signalled by LED type indicators or equivalent and auxiliary contacts.

7.12.1 Overcurrent Protection

a) All transformers rated > 315 kVA shall be provided with individual short circuit protection by primary side overcurrent relays and circuit breakers.

b) All transformers rated ≤ 315 kVA shall be provided with individual short circuit protection either by primary side overcurrent relays and circuit breakers or by current limiting H.R.C. fuses.

c) All transformers shall be provided with secondary side time lagged relay and circuit breaker overcurrent protection.

d) Earth fault and neutral conductor over load protection shall be provided for the secondary windings on all transformers rated >315 kVA feeding Low Voltage motor control switchboards. To this end, a current transformer shall be installed at each such transformer between the Low Voltage winding star point and the neutral and earth connection points. The associated protection relay shall provide both short circuit and overload protection and shall be arranged to trip the High Voltage circuit breaker controlling the associated transformer (Clause 3.6 (b) refers).

7.12.2 Over Pressure Protection

a) All oil filled transformers rated not greater than 5000 kVA shall be fitted with pressure relief values. If the transformer is to be provided with High Voltage circuit breaker protection, operation of the pressure relief value shall be arranged to trip the circuit breaker.
b) All oil filled transformers rated greater than 5000 kVA shall be fitted with conservator tanks, explosion vents and Buchholz relays. The Buchholz relay shall be arranged to trip the associated High Voltage circuit breaker.

7.12.3 Earth Fault Protection

a) All transformers rated > 315 kVA shall be provided with primary side earth fault protection set to allow for transformer inrush currents.

b) All transformers with High Voltage secondary windings shall be fitted with restricted earth fault protection on the High Voltage secondary windings and the associated secondary voltage switchboard feeder cables. The restricted earth fault protection relay shall be arranged to trip the High Voltage circuit breaker controlling the associated transformer (Clause 3.6 (b) refers).

c) Earth fault protection shall be provided as described sub-clause 7.12.1 (d), for the secondary windings on all transformers rated >315 kVA feeding Low Voltage motor control switchboards.

7.12.4 Differential Protection

All transformers rated greater than 5000 kVA shall be provided with harmonic restraint type differential protection arranged to trip the particular transformer’s High Voltage circuit breaker.

7.12.5 Over Temperature Protection

All transformers rated greater than 200 kVA shall be fitted with over temperature protection arranged to trip either the High Voltage circuit breaker or the associated feeder Low Voltage circuit breaker.

7.13 Prefabricated Enclosures

a) Transformers rated not greater than 1250 kVA may be housed in prefabricated enclosures which have been designed and constructed in accordance with IEC 62271.202.

b) The prefabricated enclosure may be either a single compartment type housing only the transformer, or may be multiple cubicle type housing High Voltage switchgear and the associated transformer each in a separate compartment.

c) If provided, the High Voltage switchgear compartment of the enclosure shall be weather proof with a degree of protection of not less than IP25 in accordance with AS 60529 providing mechanical, sun and driving rain protection to the switchgear.

d) The transformer compartment of the enclosure shall have a degree of protection of not less than IP23 in accordance with AS 60529 providing mechanical, sun and normal rain protection to the transformer. The transformer compartment shall be provided with adequate drainage for any water entering the compartment during heavy storms.

e) Prefabricated enclosures housing transformers shall be in accordance with the appropriate Water Corporation type specification.
7.14 Testing

a) The transformers shall undergo routine tests in accordance with AS60076. If the transformer being offered is not of a design that has been type tested in accordance with AS60076, then the transformers shall undergo type tests in accordance with AS60076.

b) For 22kV oil filled transformers, where impulse testing is required at 150kV, the bushings are often rated at only 125kV IWV. In this situation the bushings shall be changed to 33kV 170kV IWV to allow the testing of the transformer at 150kV IWV.

c) Noise level tests in accordance with AS60076 shall also be performed. Standard noise level tests should be specified unless the designer determines that a reduced noise level is a project requirement.
8 TRANSFORMER TENDER ANALYSIS

The procedures regarding cost analysis and clause by clause compliance as given in Sections 6.1 and 6.3 for motors shall be applied to the analysis of transformer Tenders. The losses based AAC formula described in Section 6.1.3 shall be used for comparison of transformer Tenders. Wherever practical the appropriate AAC formula should be included in the Tender Document.
9 SWITCHBOARDS

9.1 High Voltage Switchboards

9.1.1 Standards

High Voltage switchboards shall be type tested switchboards, designed, constructed and tested in accordance with the following standards as applicable to the particular type of switchboard:

IEC 62271.1 High Voltage switchgear and controlgear - Common specifications

IEC 62271.100 High Voltage switchgear and controlgear - High Voltage alternating current circuit breakers (AS 62271.100 is equivalent)

IEC 62271.102 High Voltage switchgear and controlgear - Alternating current disconnectors and earthing switches (AS 62271.102 is equivalent)

IEC 62271.103 High Voltage switchgear and controlgear - Switches for rated voltages above 1 kV and less than 52 kV

IEC 62271.105 High Voltage switchgear and controlgear - Alternating current switchfuse combinations

IEC 62271.106 High Voltage switchgear and controlgear - Alternating current contactors and contactor based motor starters

IEC 62271.200 High Voltage switchgear and controlgear - A.C. metal enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52kV (AS 62271.200 is equivalent).

9.1.2 Service Conditions

a) The Designer shall ensure that each High Voltage switchboard is appropriately rated for the service conditions in which the switchboard is to be installed.

b) If the switchboard is accessible from the rear, the switchboard shall have an IAC of AFLR. Otherwise the switchboard shall have an IAC of AFL.

c) High Voltage switchboards installed in prefabricated substations shall be of the Ring Main Unit type such that all busbars and switchgear are enclosed in sealed SF6 tank(s) and all other High Voltage conductors including cable terminations and surge diverters are fully insulated with appropriate solid insulation.

d) Unless authorised otherwise in writing by the Principal Engineer, High Voltage switchboards, other than the type described clause 9.1.2 (c) shall be located indoors in a clean relatively dust free environment.

9.1.3 Loss of Service Continuity Category

a) The Designer shall ensure that each High Voltage switchboard has a Loss of Service Continuity category (LSC) rating appropriate to its function.
b) High Voltage switchboards of the type described in clause 9.1.2 (c) shall have a LSC category rating of LSC1.

c) High Voltage switchboards other than the type described in clause 9.1.2(c) shall have an LSC category rating of LSC2A.

9.1.4 Low Voltage Compartments

a) Fully segregated compartments shall be specified in each switchgear unit for housing low voltage controls, metering and protection equipment and wiring.

b) Indicating instruments and protection relays shall be flush mounted into the doors of such compartments. Each such compartment shall have a front opening access door. Indicating instruments, protection relays and terminals requiring access for testing shall be mounted not more than 1900mm above floor level.

9.1.5 Degree of Protection

a) High Voltage switchboards of the type described clause 9.1.2(c) shall be provided with a degree of protection of IP 67 in respect to High Voltage switches, circuit breakers and busbars. The remainder of such switchboards shall incorporate a degree of protection not less than IP3X.

b) Indoor switchboards of a type other than described in cause 9.1.2(c) shall have a degree of protection rating of not less than IP2X for all compartments except the busbar compartment which shall have a degree of protection rating of not less than IP4X.

It should be noted that these degrees of protection do not provided any specified protection against the ingress of dust or water. Consequently such switchboards shall be located in dry dust free environments located so as to avoid the possibility of water falling or impinging on the switchboard. Floor mounted switchboards shall be mounted on a fabricated plinth so that water splashed onto the floor cannot enter the switchboard proper.

Indoor High Voltage switchboards located in environments which are subject to condensation shall be fitted with dehumidifying equipment

c) Outdoor High Voltage switchboards shall have a degree of protection rating of not less than IP5W for all compartments except switching mechanism compartments which shall have a degree of protection rating of not less than IP4W.

9.1.6 Rated Insulation Level

High Voltage switchboards shall have rated insulation levels in accordance with the values shown at Table 1 IEC 62271 for installations which are not severely exposed to overvoltages unless there is some special circumstance which justifies the need to specify the higher values.

9.1.7 Rated Short-Time Withstand Current

High Voltage switchboards shall have a rated short-time symmetrical withstand current of 16kA for 1 second, or 120% of the calculated fault current available at the site for 1 second, whichever is the larger.
9.1.8 Internal Arcing Fault Protection

a) Cable connection compartments of High Voltage switchboards of the type described in clause 9.1.2 (c) shall be type tested for arcing faults in accordance with IEC 62271-200 Annex A at currents not less than the values specified at clause 9.1.8(c) hereunder.

b) All compartments in High Voltage switchboards other than the type described in clause 9.1.2(c) shall be type tested for arcing faults in accordance with IEC 62271-200 Annex A at currents not less than the values specified at clause 9.1.8(c) hereunder.

c) Arcing fault type test currents shall be not less than the following:
   
i.) switchboards rated $> 1$ kV, $< 12$ kV - 20 kA for 1 second
   
ii.) switchboards rated $> 12$ kV, $< 36$ kV - 12.5 kA for 1 second.

9.1.9 Creepage Distances

Creepage distances across high grade insulator surfaces between bare air insulated conductors in High Voltage switchboards shall be not less than the values listed hereunder, with such creepage distances being no more than 30% in any one plane.

<table>
<thead>
<tr>
<th>RATED VOLTAGE</th>
<th>MINIMUM CREEPAGE DISTANCE IN AIR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PHASE TO PHASE</td>
</tr>
<tr>
<td></td>
<td>mm</td>
</tr>
<tr>
<td>3.3</td>
<td>75</td>
</tr>
<tr>
<td>6.6</td>
<td>135</td>
</tr>
<tr>
<td>11</td>
<td>195</td>
</tr>
<tr>
<td>22</td>
<td>308</td>
</tr>
<tr>
<td>33</td>
<td>458</td>
</tr>
</tbody>
</table>

These values are appropriate to relatively clean and dry environments, and will need to be increased substantially in dusty and/or damp conditions (reference BS159).

9.1.10 Cable Entry

Cable entry into High Voltage switchboards shall be from below. Other than in prefabricated substations cable to High Voltage switchboards shall be run in cable trenches in the floor rather than in conduits. Under special circumstances, and with the written approval of the Principal Engineer, cable entry may be from the top where cable ladder or cable tray shall be used.

9.1.11 Routine Tests and Protection Relay Tests

a) All High Voltage switchboards shall be subjected to routine tests at the manufacturer’s works in accordance with IEC 62271-200.
b) All protection relays shall be set to the settings as shown on the drawings and secondary injected tested at the manufacturer’s works so as to verify both function and accuracy. Such tests shall be made at a minimum of 6 evenly spaced points along the set protection relay tripping current versus time curve.

c) In addition one primary injection test shall be made so as to verify correct C.T. arrangement and complete system functionality.

9.1.12 On-site Tests

a) High Voltage switchboards shall be subjected to on-site testing of the resistance of the main circuit in accordance with clause 7.1 of IEC 62271-200.

b) High Voltage switchboards shall be subjected to on-site power frequency overvoltage tests in accordance with IEC 62271-200 at 80% of the values shown in Table 1(a) of IEC 62271-1.

9.1.13 Short Circuit Protection Coordination

The short circuit protection coordination between a High Voltage contactor and the associated High Voltage fuse shall be determined in accordance with the requirements of IEC 62271-106.

9.1.14 Type Specifications

The following Type Specifications are relevant to the specification of High Voltage switchboards to be used in Major Pump Station electrical installations:

DS26.02 - Type Specification for 22 / 0.433 kV Prefabricated Substation

DS26.08 - Type Specification for H.V. Switchboards

DS26.37 - Type Specification for HV Distribution Switchgear and Kiosk Enclosure

9.2 Low Voltage Switchboards

9.2.1 Standards

Low Voltage switchboards shall be type tested or partially type tested switchboards, designed, constructed and tested in accordance with either:

AS/NZS3439.1 Low Voltage switchgear and control assemblies

Type-tested and partially type-tested assemblies, and

AS 4388 A method of temperature rise assessment by extrapolation for partially type tested assemblies (PTTA) of low voltage switchgear and controlgear,

AS 60529 Degrees of protection provided by enclosures (IP Code), or

IEC 60439.1 Low voltage switchgear and control assemblies – type tested and partially type tested assemblies,

IEC 60641 Enclosed low-voltage switchgear and control gear assemblies – Guide to testing under conditions of arcing due to internal fault, and
IEC 60529 Degrees of protection provided by enclosures (IP Code).

9.2.2 Special Service Conditions

a) All Low Voltage switchboards within the scope of this Standard (i.e. all Low Voltage switchboards rated greater than 315 kVA) shall be located indoors.

b) The maximum ambient temperature directly outside Low Voltage switchboards installed indoors in the South West Region of Western Australia shall be taken to be 45°C.

c) The maximum ambient temperature directly outside Low Voltage switchboards installed indoors in the regions of Western Australia other than the South West Region shall be taken to be 50°C.

d) Under maximum ambient and operating conditions, the air temperature rise within the switchboard compartments due to equipment losses shall be such that the temperature or air surrounding any items of electrical equipment does not exceed the equipment’s maximum ambient temperature rating.

9.2.3 Construction

a) Low Voltage switchboards shall be AC metal enclosed switchboards of the multiple cubicle type in accordance with AS/NZS 3439.1:2002 clause 2.3.3.2 and shall be of the Form 4a type of enclosure in accordance with AS/NZS 3439.1:2002 Annexure D Fig. D2.

b) “Back to back” switchboard designs shall not be permitted due to the inherent difficulty in accessing busbars in such switchboards. Rear access cable zones shall not be permitted due to the difficulty of access and problems associated with maintenance logistics.

c) In order to reduce risk to operational personnel, fuse and/or circuit breaker distribution panels controlling lighting and general purpose power final circuits shall not be incorporated into main circuit Low Voltage switchboards.

9.2.4 Rated Diversity Factor

Low Voltage switchboards shall have a rated diversity factor of 1.0.

9.2.5 Degree of Protection

a) Switchboards to be installed in environments with a pollution degree rating of not more than 2, shall have a degree of protection rating of not less than IP31 ventilated.

b) Switchboards having a higher degree of protection than IP31 ventilated shall be acceptable for installation in pollution degree 2 environments provided that the design of such switchboards is supported by appropriate type testing.

c) Switchboards specified to be installed in locations with a pollution degree higher than 2 shall have a degree of protection rating of not less than IP53. The installation of such switchboards should be such as to minimize the possibility of water falling or impinging onto the switchboard. Floor mounted switchboards shall be mounted on a fabricated plinth so that water splashed onto the floor cannot enter the switchboard proper.
9.2.6 Rated Insulation and Operating Voltages

a) Low Voltage (415V) switchboards shall have a rated insulation voltage of not less than 630 volts or the highest phase to phase operating voltage of equipment mounted in the switchboard, whichever is the greater.

b) Low Voltage (415V) switchboards shall have a rated operating voltage of not less than 500 volts.

c) For other low voltages, the rated operating voltage shall be 120% of the nominal voltage.

9.2.7 Creepage Distances

a) Low Voltage switchboards shall be rated for operation with an internal micro-environment having an atmospheric pollution level not less than degree 3 in accordance with AS 3439.1.

b) Where practical, switchboard components shall be provided which are rated for operation in an internal micro-environment having an atmospheric pollution level of degree 4 in accordance with AS 3439.1.

c) Creephage distances across insulator surfaces between bare air insulated conductors in Low Voltage switchboards shall be not less than the values shown in Table 16 of AS3439.1. In addition, bare busbars running vertically through horizontal insulating panels shall be shrouded for not less than 20mm above the horizontal insulating panel.

9.2.8 Rated Impulse Withstand Voltage

Low Voltage switchboards main circuit shall have a rated impulse withstand voltage rating of not less than 6kV. Switchboard control and auxiliary circuits shall have a rated impulse withstand voltage of not less than 4kV.

9.2.9 Rated Short-Time Current

Low Voltage switchboards shall have a rated short time current in accordance with AS/NZS 3439.1 not less than the calculated fault current level at the input terminals of the switchboard. Unless impedences of the associated transformers are known, such calculations shall be made using the lower values of transformer impedance quoted in Section 7 of this Design Standard.

9.2.10 Internal Arcing Fault Protection

Low Voltage switchboards shall incorporate arcing fault protection as follows:

a) In all main circuit compartments measures shall be taken to provide increased security against the occurrence of, or effects of, internal arcing faults. Such measures shall be based on the guidelines given in AS/NZS 3439.1 Appendix ZC.

b) Except as specified hereunder, all main circuit compartments shall be arcing fault tested in accordance with AS/NZS 3439.1 Appendix ZD or with IEC 0641.

For switchboards rated ≤ 1600 amps the prospective fault current level used in such tests shall be \( \geq 30 \text{ kA} \).

For switchboards rated > 1600 amps the prospective fault current level used in such tests shall be \( \geq 50 \text{ kA} \).
c) Arc fault tests on the line side of the switchboard incoming circuit breaker shall be unlimited tests.

For switchboards rated ≤ 1600 amps, the test arc let through $I^2t$ shall be ≥ 100*10^6 amp^2*sec.

For switchboards rated > 1600 amps, the test arc let through $I^2t$ shall be ≥ 300*10^6 amp^2*sec.

Arcing fault tests in other main circuit compartments shall be carried out as limited tests in accordance with the standards.

d) Switchboard compartments which are protected by HRC fuses, shall not be required to be type tested for arcing fault containment, provided that the HRC fuses are rated not greater than 400 amp, have a total energy let through $I^2t$ of not more than 1.8*10^6 amp2 sec., and are located outside the particular compartment.

e) Switchboard compartments protected by semiconductor protection fuses, shall not be required to undergo arcing fault type test, provided that the semi-conductor protection fuses are in accordance with AS 60269.4.0, and are located outside the particular compartment.

f) Switchboard compartments fitted with arc detection equipment connected to trip a line side circuit breaker, shall not be required to undergo arcing fault testing provided that the line side circuit breaker is located outside the compartment.

g) In accordance with IEC 60641, switchboard compartments having no accessible bare conductors (i.e. when all conductors are insulated and when all insulating covers and sleeves are in place) shall not require arcing fault containment tests.

9.2.11 Cable Entry

Wherever practical, cable entry into Low Voltage switchboards shall be from below via cable trenches (not conduits) in the floor. Under special circumstances, and with the approval of the Principal Engineer, cable entry may be from the top where cable ladder or tray shall be used.

9.2.12 Access to Busbars

Low Voltage switchboards shall be designed so that the main busbars and busbar joints are accessible for inspection and maintenance without dismounting switchboard equipment and without disconnecting cables.

If the switchboard design is such that access to busbars is provided by the removal of back panels, the switchboard shall be installed so that a clearance of at least 600 mm is provided behind the switchboard.

9.2.13 Routine Tests, Temperature Rise Validation and Protection Relay Tests

The full load temperature rise within all partially type tested assemblies within Low Voltage switchboards compartments shall be verified by either temperature rise tests in accordance with AS/NZS 3439.1 or by calculations in accordance with AS 4388.

9.2.14 Routine and Protection Relay Tests

a) All Low Voltage switchboards shall be subjected to routine tests at the manufacturer’s works in accordance with AS/NZS 3439.1.
b) All protection relays shall be set to the settings as shown on the drawings and secondary injected tested at the manufacturer’s works so as to verify both function and accuracy.

Such tests shall be made at a minimum of 6 evenly spaced points along the set protection relay tripping current versus time curve.

c) In addition one primary injection test shall be made so as to verify correct C.T. arrangement and complete system functionality.

9.2.15 On-site Tests

a) Low Voltage switchboards shall be subjected to on-site testing of insulation resistance in accordance with Clause 8.3.4 of AS3439.1.

b) Low Voltage switchboards shall be subjected to on-site testing of the resistance of the main circuit.

9.2.16 Short Circuit Protection Coordination

Short circuit protection coordination shall be provided between contactors and overload relays and their associated short circuit protection devices in accordance with the requirements of AS3947.4.1 for type 2 coordination.

9.2.17 Circuit Breaker Iₐₛ Ratings

Australian Standard AS 60947.2 requires circuit breakers to be able to interrupt short circuit currents at rated Iₐₛ current for only three times.

9.2.18 Intelligent Switchboards

Where there is a requirement for “intelligent” switchboards the fieldbus system shall be specified to be Profibus. Brand names for the “intelligent” protection relays shall not be specified in design or tender documents as this will compromise Type Testing and Arc Fault Testing of multi-vendor switchboards.

9.2.19 Type Specifications

The following Type Specifications are suitable for specifying the various types of Major Pump Station Low Voltage switchboards:

DS26.17 - Type Specification for Large Low Voltage Switchboards
9.3 Main Busbars

9.3.1 Cubicle Arrangement of Pumping Unit Switchboards

a) For preference, unit cubicles shall be numbered to match the numbers assigned to associated pumping units and unit cubicles shall be arranged in numerical order from left to right facing the front of the switchboard. Similarly, the High Voltage cubicles shall be numbered to match the number assigned to the transformer.

If the pumping units are configured in such a way that this numbering cannot be adopted the Designer shall employ a system of numbering which is logical and will not lead to confusion. The use of alphabetic identification of pumping units should be avoided.

b) Large Low voltage switchboards may be arranged with the incoming feeders central and the unit cubicles on either side.

9.3.2 Capacity

The busbar capacity in the incoming cubicles shall match the capacity of the incoming feeders. The number of bars in parallel per phase may be reduced in the outer unit cubicles to match the smaller current demand in these cubicles.

9.3.3 Arrangement for Low Voltage Busbars

For preference, Low Voltage busbars which are substantially in one plane shall be arranged in order Red - White - Blue as follows:

a) When the run of busbars is horizontal, Red shall be top, or to the left, or farthest away as viewed from the front of the switchboard.

b) When the run of busbars is vertical, the Red shall be left or farthest away as viewed from the front of the switchboard.

c) When the neutral busbar is in the same plane as the phase busbars, the neutral shall occupy an outer position, and shall be readily distinguishable from phase busbars.

d) Busbars not arranged as above, shall be colour coded in each compartment.

9.3.4 Extensions

The Designer shall consider the likelihood that the switchboard may need to be extended in the future and shall specify that the switchboard shall be capable of such extension if such a need is considered to be likely within 15 years.

9.4 Location of Controls

All operator control devices including operating handles, control switches, indicators and meters shall be specified to be located no more than 1.9 metres and not less than 0.3 metres above floor level. However, the location of meters, secondary indicators, fault relays, etc. in a panel separate from the associated main switchboard panel shall be permitted provided that control switches and on-off indicators are mounted on the main switchboard panel with which these are associated.
9.5 Protection - General

Protection equipment which detects equipment fault conditions and trips the faulted equipment shall be provided to provide adequate protection to personnel and plant.

For the purposes of this Manual, protection equipment has been classified as either primary or secondary protection as follows:

a) Primary protection is defined as that essential protection equipment without which the plant shall not be operated even under close and continuous operator supervision. Fuses, circuit breakers, instantaneous earth leakage and thermal overcurrent relays shall be considered primary protection.

b) Secondary protection is defined as that protection equipment without which the plant may be permitted to operate under close and continuous operator supervision. Overtemperature relays, flow and pressure relays, sequence detectors, etc. shall be considered secondary protection.

Primary protection shall act as directly as possible on the associated circuit and shall not be connected via P.L.C.’s or similar equipment. Switchboards shall be designed so that plant operates in the emergency mode with only primary protection connected.

Where motor winding thermistor or RTD protection is required, it shall be used as an input to the motor protection relay or integral VSD / soft starter protection. Where this is not possible, the thermistor or RTD shall be connected as secondary protection via the PLC.

Where the safety of personnel would be endangered by the failure of a protection or alarm circuit, the circuit shall be arranged where practical, so that the probable mode of circuit failure would result in safe (usually shut down) alarm condition. Where only equipment would be endangered by the failure of a protection or alarm circuit, the circuit shall be arranged to maximise overall plant reliability and to minimise false trips and alarms.

A repeated cycle of protection tripping and resetting can lead to equipment failure and in some circumstances may be dangerous. Provision shall not be made for remote resetting of electrical/mechanical plant faults (eg: motor over-temperature, starter over-temperature, bearing over-temperature/vibration, overloads, incomplete start, electrical fault relays etc). Provision shall be made for remote resetting of hydraulic faults provided sufficient telemetry is available to enable the remote operator to assess the cause of the hydraulic trip and to ascertain that the fault conditions no longer exist. This is the basis of the standard control logic shown on the drawings.

9.6 Electrical Protection Grading

9.6.1 General

Protection time current curves shall be plotted for all over-current devices, earth fault devices, and fuses in the system. Electrical protection relays shall generally be of the solid state type and shall comply with the relevant provisions of IEC 60255 and rated for operation in an ambient of 60°C.

The Designer shall carry out a protection grading study for both 3 phase overcurrents and for earth faults. The Designer shall ensure that the results of this study are reported fully on the protection grading drawings.

Wherever practical, protection should be arranged so that adequate grading is provided between all devices.
The possible use of protection equipment which has zone selectivity functionality shall be investigated in this regard if time based grading is found to be difficult in a particular application.

### 9.6.2 Grading Between Fuses

Wherever practical fuse grading should be arranged such that the total $I^2t$ for the minor fuse does not exceed the pre-arcing $I^2t$ for the major fuse. Manufacturer’s tolerance and ambient temperature derating effects shall be taken into account.

### 9.6.3 Protection Grading Across Transformers

The self-impedance of a step down transformer limits the fault current which may be seen by the Low Voltage side protective device. Consequently, grading between the High Voltage side protective device and the Low Voltage side protective device need only be provided over the current range up to the Low Voltage maximum fault current. Consideration shall be given to the difference in the per unit current seen by the HV protection device and that seen by the LV protection device for an LV phase to phase fault.

### 9.6.4 Switchboard Protection

Switchboard incoming main circuit breakers shall be fitted with overcurrent and earth fault protection rated to provide both overload and earth fault protection for the switchboard main circuit as well as to provide overload protection for the incoming feeder (Section 7.12.1 refers).

### 9.6.5 Low Fault Level Sites

In installations where the fault level is low, the Supply Authority feeder protection setting is likely to be low also. In such circumstances complete protection grading between the Supply Authority protection equipment and each item of pump station electrical equipment may not be practical using time-current grading. In such circumstances the Designer shall investigate the possible use of zone selectivity techniques.

As absolute minimum requirement

a) proper time-current protection grading shall be provided between the Supply Authority feeder protection and the pump station main circuit breaker, and

b) either proper time current or zone selectivity grading provided between the pump station main circuit breaker and the motor protection equipment.

### 9.6.6 Motor Line Contactors

Line contactors controlling High Voltage motors shall be either vacuum contactors or SF6 contactors. Such contactors shall be specified to have a rated chopping current of not more than 0.5 amps. Circuit breakers shall not be used for this duty.

### 9.6.7 Contactor Fault Capacity

Because High Voltage vacuum contactors which are intended for motor control duty are designed to have a low chopping current rating, these have a relatively low fault current rating. Typically such a vacuum contactor is rated to be able to interrupt 4kA at 0.3p.f. but only 2kA at 0.2p.f.
9.7 Motor Protection

9.7.1 Motor Overcurrent Protection

Motors shall be protected by electronic thermal model motor overcurrent and earth fault relays. In addition, where grading allows, motors shall be provided with instantaneous high set overcurrent protection.

The GE Multilin 269 plus and the GE Multilin 369 are preferred types of motor over current/earth fault relays.

The CT burden due to the connection of a 1 amp version of the GE Multilin 269 Plus is 0.04VA at 1 amp and 4.5VA at 13 amp.

The CT burden due to the connection of a 5 amp version of the GE Multilin 269 Plus is 0.06 VA at 5 amp and 8.5 VA at 65 amp.

Reference shall be made to the overcurrent relay manufacturer’s handbook in respect to appropriate relay settings. However, such settings shall be such that a long term continuous current of more than 103% of on-site rated current causes an “Overload” trip.

The “Earth Fault” setting shall be in the range of 10% to 40% of motor rated full load current.

9.7.2 Motor Thermistor / RTD Protection

Where the motor overcurrent protection relay includes a facility for connecting motor winding thermistors or RTD’s, this facility shall be used and the associated motor over temperature protection shall be considered to be primary protection. Otherwise over temperature protection shall be considered to be secondary protection and shall be arranged accordingly.

9.7.3 Differential Protection

Slip ring motors rated equal to or greater than 1500 kW shall be fitted with harmonic restraint differential protection. Where such motors are supplied from unit transformers the differential protection shall be applied from the transformer primary terminals to the motor stator winding star point connections.

9.8 Pump Protection

In some instances pump protection can be achieved by detecting the pump no flow condition directly. A paddle operated flow switch mounted in the pump delivery line is the most direct method of detecting no flow. However, such devices require 5 diameters of straight clear pipe upstream and downstream of the mounting point and are thus normally not practical in larger pump stations.

If a tilting disc or a swing check non-return valve is used, the spindle can be extended and a cam driven limit switch used to detect disc position and inferentially flow or no flow.

The preferred method of no flow condition detection is by measurement of the motor load kW provided the difference between pump no flow power demand and pump minimum operating power demand is more than 20% of motor continuous running duty rating. Measurement of motor current is not considered a satisfactory method of detecting flow or no-flow and shall not be used.
Major clear water pumps shall be fitted with pressure switches to provide protection against low suction pressure and low delivery pressure. Power transducers shall not be used for detection of low or high pressures.

## 9.9 Protection Current Transformers

### 9.9.1 General

The equivalent circuit of the current transformer is as shown hereunder (Fig. 9.1).

![Equivalent Circuit of a Current Transformer]

**Fig. 9.1**

For a protection current transformer the magnitude of the rated burden admittance \((Z)^{-1}\) will be between one and two orders larger than the magnetising admittance \((y)\). "Knee point voltage" is defined as the point at which a 10% increase in secondary emf produces a 50% increase in exciting current \(I_e\). It is therefore the point at which \(y\) starts to increase substantially with increased secondary emf, i.e. the point at which the CT starts to saturate. "Rated Secondary Reference Voltage" of a protection CT is the rms value of secondary voltage upon which the performance of the CT is based. For a protection CT the Rated Secondary Reference Voltage will be less than, but of the same order as, the knee point voltage.

### 9.9.2 Standards

Current transformers shall be in accordance with AS 60044.1 or with IEC 60044.1 and shall be designated in full in accordance with one or other of these standards.

### 9.9.3 Primary Current Rating

In any particular circuit, the primary current rating of associated current transformers shall be the next largest available current rating greater than the circuit continuous maximum demand current and shall not be greater than twice the continuous maximum demand current.

### 9.9.4 Short Time Thermal Current Rating

Current transformers shall have a short time thermal current rating not less than the short time current rating specified for the whole of the associated switchboard with the exception that current transformers installed on the load side of current limiting fuses need only have a short time thermal current rating providing an allowable let through \(I_2t\) greater that the total \(I_2t\) of the associated current limiting fuse.
9.9.5 Rated Operating Voltage

Current transformers shall have a rated operating voltage not less than the rated operating voltage specified for the whole of the associated switchboard.

9.9.6 Rated Insulation Level

Current transformers shall have a rated insulation level not less than the rated insulation level specified for the whole of the associated switchboard.

9.9.7 Rated Secondary Current

Metering current transformers shall have a secondary current rating of 5 amp.

Protection current transformers shall have a secondary current rating of either 1 amp or 5 amp.

As a general rule, where the C.T. wiring is contained within the associated switchboard 5 amp rated secondary current C.T.’s should be selected. Where C.T. secondary wiring is run external to the switchboard 1 amp rated secondary current C.T.’s should be considered (e.g. C.T.’s located in the star point of a transformer).

9.9.8 Accuracy Class

Metering current transformers used in association with power or energy transducers shall be accuracy class 0.5 M (i.e. rated current error of 0.5 % and phase error of 0.9 crad at 100% current), otherwise metering current transformers shall be accuracy class 1.0 M (i.e. rated current error of 1.0 % phase error of 1.8 crad at 100% current).

Protection current transformers shall be of accuracy class 5P (i.e. rated composite error of not more than 5%).

Protection current transformers to be used in balanced protection applications may require to be of a higher accuracy class (i.e. Class PX.).

9.9.9 Accuracy Limit Factor

Metering current transformers shall have a rated accuracy limit factor of not less than 1.20.

Protection current transformers shall have a rated accuracy limit factor of not less than 10.

9.9.10 Burden

Current transformers shall have a rated burden VA in accordance with the following:

\[ Q_r = (Q_d + Q_w + Q_t) \]

where:

\[ Q_r \] = CT rated burden VA at rated secondary current

\[ Q_d \] = rated burden VA at the CT rated secondary current of the switchboard mounted instruments, relays, trip coils and other devices to be operated by the CT

\[ Q_w \] = burden VA of the CT secondary circuit switchboard wiring at the CT rated secondary current
Qt = burden VA of external test instruments
  = 2.0 VA for 5 A secondaries
  = 1.0 VA for 1 A secondaries

9.9.11 Rated Secondary Secondary Limiting e.m.f.

The rated secondary secondary limiting e.m.f. (expressed in volts) for a protection current transformer shall be determined as follows:

\[ V_{sl} = Q_r \times F/Is \]

where:

\( Q_r \) = CT rated burden VA at rated secondary current, amps
\( F \) = CT rated accuracy limit factor
\( Is \) = CT rated secondary current, amps

9.9.12 Example Rating Calculation for Protection Current Transformer

As an example the Protection Class CT rating required for a 560 kW 6.6 kV slip ring motor fitted with a GE Multilin 269 plus overcurrent and earth fault relay would be as follows:

\( I_f \) = fault current available in the motor circuit
  = 1800 amp

\( I_d \) = motor full load current = 59 amps

\( I_h \) = motor high set trip current = 480 amps

\( I_r \) = CT rated primary current = 100 amps

\( S_f \) = scale factor
  = \( I_r/I_d = 100/59 = 1.695 \) (which is less than 2, so is OK)

\( I_s \) = CT rated secondary current = 5 amp

\( Q_d \) = relay rated burden at rated current = 0.1 VA

\( Q_w \) = burden VA of the CT secondary circuit at rated current
  = 2.5 VA (by separate calculation)

\( Q_t \) = burden VA of external test instruments at rated current
  = 2.0 VA

\( Q_r \) = CT rated burden VA at rated secondary current
  = \( (Q_d+Q_w+Q_t) \)
\[
\begin{align*}
\text{VA} &= (0.1+2.5+2)=4.6\text{VA, say 5VA} \\
F &= \text{CT rated accuracy limit factor} \\
&= \frac{I_h}{(I_d*S_f)} \\
&= \frac{480}{(59*1.695)} = 4.8 \\
\end{align*}
\]

Hence select \( F = 10 \) which is the next highest standard value and the lowest value allowed in accordance with para. 9.9.8 above.

\[
V_{sl} = Q_r*F/Is = 5*10/5 = 10\text{ volt}
\]

Hence the CT specification to AS/NZS 60044.1 would be: 5VA, Class 5P10, 100/5A.

### 9.10 Rogowski Coil Current Sensors

#### 9.10.1 Primary Current Rating

In a particular circuit, the maximum operating range of associated Rogowski coil current sensors shall not be more than five times the circuit continuous maximum demand current.

#### 9.10.2 Short Time Current Rating

Rogowski coil current sensors shall have a short time current rating not less than the short time current rating specified for the whole of the associated switchboard with the exception that Rogowski coil current sensors installed on the load side of current limiting fuses need only have a short time current rating providing an allowable let through \( I^2t \) greater than the total \( I^2t \) of the associated current limiting fuse.

#### 9.10.3 Rated Operational Voltage

Rogowski coil current sensors shall have a rated operating voltage not less than the rated operating voltage specified for the whole of the associated switchboard.

#### 9.10.4 Rated Insulation Level

Rogowski coil current sensors shall have a rated insulation level not less than the rated insulation level specified for the whole of the associated switchboard.

#### 9.10.5 Rated Secondary Current

Rogowski coil current sensors shall have a secondary current rating of 1 amp at the maximum operating current.

#### 9.10.6 Accuracy Class

Rogowski coil current sensors shall have a rated composite error of not more than 5\% over the complete operating range.

#### 9.10.7 Accuracy Limit Factor

Rogowski coil current sensors shall have a rated accuracy limit of not less than 10 times the maximum operating current.
9.10.8 **Burden**

Rogowski coil current sensors shall have a rated burden VA in accordance with the following:

\[ Q_r = (Q_d + Q_w + Q_t) \]

where:

- \( Q_r \) = sensor rated burden VA at the sensor rated secondary current
- \( Q_d \) = rated burden VA at the sensor rated secondary current of the switchboard mounted relays, trip coils and other devices to be operated by the sensor.
- \( Q_w \) = burden VA of the sensor secondary circuit switchboard wiring at the sensor rated secondary current
- \( Q_t \) = burden VA of external test instruments
  - = 1.0 VA for 1 A secondaries

9.11 **Potential Transformers**

a) It was previous Western Power standard practice to use two element metering and open delta potential transformers. In such instances it was Western Power standard practice to earth the white phase connection.

Western Power are now changing to three element metering and star/star potential transformers with the Low Voltage star point earthed. However two element metering and open delta potential transformers may be provided in some instances.

b) The Designer shall ensure that all metering potential transformers provided and installed by the Corporation are of the star/star type.

c) Potential transformers installed in Water Corporation High Voltage switchboards shall be fitted with Low Voltage fuses in accordance with AS 62271-200 Table 2.

d) The accuracy of metering potential transformers shall be not less than class 1M in accordance with AS1243. Potential transformer secondary voltage shall be Category A, 110 volts phase to phase.

9.12 **Switchgear**

9.12.1 **High Voltage Switchgear**

a) For preference High Voltage circuit breakers should be vacuum type because of the lower maintenance requirement of this type of circuit breaker. However, SF6 circuit breakers may be used in instances where it is demonstrated that the whole of life cost of such breakers is less than that of vacuum circuit breakers.

b) Switchboard main incoming feeder circuit breakers on switchboards controlling either, transformers rated at more than 315 kVA, or High Voltage motors of any rating, shall be of the electrically operated type equipped with spring charged closing and tripping mechanisms so as to allow remote opening and closing of these circuit breakers from a control room within the pump.
station. Such a facility shall provide open/close control and closed/open indication functionality within a suitable wall mounted enclosure in the control room.

c) In instances where the motor is supplied directly from a High Voltage bus, the operational control of the motor is preferred to be by the use of a low chopping current type vacuum contactor. In instances where the motor is supplied via a unit transformer, the operational control of the motor shall be by the use of a vacuum circuit breaker switching the primary of the unit transformer. SF6 circuit breakers shall not be used in this application.

9.12.2 Low Voltage Switchgear

a) Low Voltage circuit breakers shall be air break type.

b) Switchboard main incoming feeder circuit breakers on switchboards rated at more than 315 kVA shall be of the electrically operated type equipped with spring charged closing and tripping mechanisms so as to allow remote opening and closing of these circuit breakers from a control room within the pump station. Such a facility shall provide open/close control and closed/open indication functionality within a suitable wall mounted enclosure in the control room.

c) Operational control of Low Voltage motors shall be by the use of air break contactors. Circuit breakers shall not be used for this purpose because of the high maintenance requirements of these devices if used in such an application.

9.13 General Construction of Switchboards

a) Switchboards shall be specified to be in accordance with the relevant Water Corporation Type Specifications.

b) For High Voltage switchboards, switchgear anti-condensation heaters shall be rated and arranged for continuous operation.

9.14 Equipment Voltage Ratings

All switchboard mounted equipment shall have voltage ratings not less than those specified for the switchboard assembly as a whole.

9.15 Surge Protection

a) Switchboards shall be protected against lightning or switching overvoltage surges on incoming feeders by suitably rated surge diverters.

b) Apart from surge diverters installed at the incoming supply point of attachment, all surge diverters shall be installed on the load side of the installation Main Switch.

c) High Voltage surge diverters shall be protected by fact acting earth leakage protection or by current limiting H.R.C. fuses.

d) Low Voltage surge diverters shall be protected by current limiting H.R.C. fuses.

e) Surge diverters need not be installed in a particular High Voltage switchboard provided that the switchboard is within the protective range of suitably rated surge diverters. If surge diverters are installed in a High Voltage switchboard, these shall be located to minimise any damage that would be caused by a surge diverter failure.
f) Where practical, Low Voltage incoming surge diverters shall be installed within the switchboard close to the Main Switch. For L.V. surge diverter selection reference should be made to Design Standard DS22.

g) Vacuum switches can cause overvoltage surges due to current chopping when switching low load currents. The problem is much more severe with vacuum circuit breakers than with vacuum contactors, hence the requirement to use vacuum contactors for direct operational control of motors. Vacuum circuit breakers and vacuum contactors shall be fitted with hybrid surge diverters to limit any overvoltages which may be so caused.

h) Surge protection shall be provided in accordance with the requirements of Section 12.

9.16 Standard Power and Control Circuits

a) Switchboard power and control circuits shall be in accordance with the Water Corporation’s standard power and control circuits.

b) Power transducers, shown on the motor power circuit standard drawings, shall incorporate a 4 - 20mAADC output terminal on the front of the motor cubicle or the pump control cubicle for the connection of a portable “Yatesmeter”. Alternatively a “Yatesmeter” I/O interface enclosure, hard wired to the Pump Control Cubicle, may be installed adjacent to the pump unit. This requirement shall only apply to water pump stations.

c) Generally, the contact status for alarms should be normally open and close on a fault condition. Similarly, the contact status for control is normally open and close on command instruction. Exceptions to this for alarms are normally associated with special situations.

9.17 Switchboard Logic Functions and Pump Control Cubicles

Plant control is now beyond the scope of this design standard and will become a subject addressed in a different design standard.

In the meantime this section of DS21 has been retained as Appendix A for information purposes only.

9.18 Switchboard Safety Clearances

Some switchboards are so designed that during an arcing fault, the arcing products are vented to the rear of the switchboard and as such could present a risk to personnel should the rear of the switchboard be accessible when the equipment is live.

Under normal circumstances such switchboards should be located such that the rear of the switchboard is approximately 100 mm. off the switchroom wall or as recommended by the switchboard manufacturer.

If access to the rear of the switchboard is required for maintenance purposes, the Designer shall ensure that a suitable barrier and appropriate warning sign is specified in the design documentation so that access behind the switchboard is not permitted when the switchboard is live. The Designer shall address this issue for all switchboards having incorporated venting via rear panels.

9.19 Pump Station Control Philosophy

Major pump station operation has three modes of control. The three modes of control are:

a) Remote (or Automatic) (C.S.S. selected to ‘auto/remote’ and LMSS selected to ‘normal’)
b) Manual (C.S.S. selected to ‘local’ and LMSS selected to ‘normal’)

c) Emergency (C.S.S. selected to ‘local’ and LMSS selected to ‘emergency’)

C.S.S. is control selector switch

LMSS is local mode selector switch.

Remote and Manual control modes are via the Pump Control Cubicle PLC’s. Emergency control mode is via the controls on the main switchboard, bypassing the PLC’s. The standard pump control and logic drawings reflect these modes of control.

The Remote (or Automatic) mode is the normal operation and operates through the PLC’s either automatically or from remote control. In this mode, the pump sets have both primary and secondary protection.

The Manual mode will allow operator control of the pumps at the site with all control, protection and alarm circuits operating through the PLC’s. In this mode, the pump sets have both primary and secondary protection.

Emergency control will allow control of pump sets directly from each motor cubicle on the main switchboard. Control is not available from the PLC. In this mode, the pump sets have primary protection only and the intention is that electrical personnel are present during this mode and the pump sets are closely monitored by such personnel.

9.20 Location of Pump Station Motor Control Switchboards

a) Operators have the authority, necessity, training and competence to carry out certain limited switching functions on pump station motor control switchboards. Mechanical fitters and similar personnel are given access only under controlled environments.

b) Pump station motor control switchboards shall not be located within the same enclosure as incoming supply transformers, primary side switchgear or the substation earth bar, access to which should be limited to electrical personnel.

c) Pump station compounds and pump stations shall be accessible only through locked doors having special keys issued on a controlled basis. General public access shall not be available nor permitted.

d) Switchboards which control the operation of motors or generators shall be located so that the latter are clearly visible from the relevant switchboard panel.

e) Switchboards shall be located only in areas appropriate to the switchboard degree of protection provided (clauses 9.1.5 and 9.2.5 refer.). Motor or generator control switchboards, and variable speed controllers, shall be located in separate switchrooms.

f) Switchboards shall not be located adjacent to ventilation louvres of the building. To do so increases the risk of damage due to water, dust and vandalism.

9.21 Lamp and Actuator Colours

Lamps on switchboards associated with motor control should be colour coded as follows:

a) Fault tripped condition - Yellow/Amber (flashing if unacknowledged)
b) Off condition - Green  
c) Run condition - White  
d) Interlock operating - White  
e) Alarm (abnormal) - Yellow/Amber (flashing if unacknowledged)  
f) Valve open - White  
g) Valve closed - Green  
h) Switch or breaker closed - Red  
i) Switch or breaker open - Green

Actuators on switchboards should be colour coded as follows:

a) Start condition - Green  
b) Stop condition - Red  
c) Emergency stop - Red  
d) Reset condition - Blue  
e) Acknowledge - Black  
f) Lamp test - Black

### 9.22 Fault Current Limiters

Fault current limiters, as defined in AS 3000, shall be provided on all switchboard circuits so as to ensure that the instantaneous current ratings of equipment and cabling are not exceeded by the available fault current levels.

All main Low Voltage switchboard Low Voltage control circuits, instrumentation circuits and auxiliary circuits shall be protected by HRC fuses. Miniature circuit breakers shall not be used.

Clause 9.26 of this Design Standard details the requirements for fault current limiting in respect to distribution boards.

### 9.23 Under Voltage and Phase Unbalance Protection

The motor protective devices will provide protection against motor overheating due to incoming supply undervoltage or phase imbalance. However such devices are manually reset and will require a visit to site by a suitably qualified person to assess the cause of the tripping and to determine whether or not the device can be reset. In order to minimise the operation of motor protective devices due to supply under voltage or phase failure, a phase failure and undervoltage relay shall be installed to monitor the incoming supply voltages into each installation.

In the event of the supply voltages moving outside the set limits for more than a prescribed time, the control logic shall be arranged so that the plant is tripped off before the motor overheating protective device can operate. The control logic shall be arranged to prevent restarting until the supply voltages
have returned to a healthy state for a reasonable period of time to allow the complete operation of any relevant Supply Authority High Voltage Reclosers.

The phase failure and undervoltage relay shall be self resetting and shall be arranged to trip if:

a) The supply negative sequence voltage is more than 10% (i.e. 5% setting on rms type 2P740 phase failure relay),

b) The supply voltage falls below 80% of nominal voltage.

Since the starting of the motors within the installation may cause short term under voltage dips greater than the value specified above, the control system shall be arranged so that the phase imbalance and the under voltage trip function is disabled during motor starting periods.

Phase failure and under voltage relays shall be of a type suitable for operation in conjunction with motor loads.

It should be noted that phase failure relays can detect only relatively large phase voltage imbalances such as would be caused by a blown High Voltage incoming line fuse.

Smaller phase imbalances, caused for example by unbalanced incoming High Voltage line construction, may be sufficient to trip motor protective devices but may not be large enough to be detected by phase failure relays.

### 9.24 Metering of Variable Speed Drive Loads

Power and energy meters measuring pulse width modulated voltages and currents shall be three element type because, due to capacitive currents, the vector sum of the input currents may differ from zero. (Refer AS 1359.102.1 clause A2.)

### 9.25 Separate Drive Circuits

Each drive circuit shall be complete and independent of other drive circuits, i.e. each drive circuit shall include a separate isolator, separate short circuit and overload protection devices, a separate starter (or variable speed controller), motor cable and motor.

### 9.26 Distribution Boards

a) In accordance with AS/NZS 3000:2007 a distribution board is defined as being “a switchboard other than the main switchboard”. In this Design Standard the term distribution board shall be deemed to mean any Low Voltage switchboard rated ≤ 200 amps installed in a major pump station.

b) Each distribution board shall have an input fault current rating calculated as being the fault current rating of the main Low Voltage switchboard less the drop in fault current level due to the impedance of the associated submain cable.

c) The feed from the main switchboard to each distribution board shall be via a feeder circuit breaker on the main switchboard or on a sub-board rated >200 amps.

d) The circuit breaker at the origin of the circuit supplying the distribution board shall be fitted with instantaneous over current tripping which provides the cable feeding the distribution board with short circuit protection.
Distribution feeder cable overload protection shall be provided by the distribution board main circuit breaker.

In addition, the distribution board main circuit breaker shall provide both short circuit and overload protection for the distribution board.

In order to provide adequate protection grading the instantaneous tripping current of the circuit breaker at the origin of the circuit supplying the distribution board shall be set at greater than 1.5 times the instantaneous trip current setting of the distribution board main circuit breaker.

e) Distribution boards shall be fitted with main circuit breakers which will limit the I^2t let through energy to ≤ 1.8*10^6 amp^2*sec

f) Distribution boards shall have been type tested in accordance with AS/NZS 3439.1. However arcing fault type testing shall not be required.

g) Distribution boards shall have all conductors on the line side of the distribution board main circuit breaker insulated.

h) The short circuit current rating of all distribution board final sub-circuit circuit breakers shall be not less than the required fault current rating for the complete distribution board.

   Such fault current ratings may be determined by the cascading method providing that:

   i) the distribution board incoming circuit breaker and the final sub-circuit circuit breakers are from the same manufacturer, and

   ii) the manufacturer guarantees that the fault current rating of the particular combination of incoming circuit breaker and final sub-circuit breaker has been verified experimentally in accordance with AS 60947.2 to be in excess of the fault current rating required in the particular application.

   i) Lighting and general purpose final sub-circuits shall not be supplied directly from the main Low voltage switchboard or from sub-boards rated >200 amps

   The following Type Specification refers: DS26.38 Type Specification for Distribution Board ≤ 200 amps.
10 PUMP STATION ELECTRICAL CONFIGURATION

10.1 Standard Supply Configurations

The following are the standard configurations for the supply to the pump station switchboard from a Water Corporation substation:

a) L.V. supply to pump station switchboard from substation having a total rating ≤ 2000 kVA,

b) L.V. supply to pump station switchboard from substation with dual transformers each having a rating >1000 kVA and ≤ 2000 kVA,

c) H.V. supply to pump station switchboard.

Single line diagrams for these electrical configurations are shown at Figs. 10.1 to 10.3 respectively.

Supply configurations shall be such that Low Voltage prospective fault current levels do not exceed 50 kA.

Non-standard configurations including those which include sectionalised High Voltage motor control switchboards may be considered subject to prior written approval of the Principal Engineer. (Section 3.5 refers.)

10.2 Low Voltage Transformer Connections

The L.V. connections from transformers in prefabricated substations to the associated switchboard(s) shall be via underground cable in cable ducts. The main circuit L.V. connections from transformers rated greater 1600 kVA to the associated switchboard shall be via busbar ducting.

10.3 Approval Process

The designer shall ensure that the W.A. Electrical requirements are adhered to with respect to the submission of designs for High Voltage sites. The Designer shall make such submissions. Design submissions (consisting of single line diagrams, protection grading diagrams, earthing diagrams, site layout, equipment selections etc) shall be approved by the Supply Authority prior to the start of the detail design. All correspondence with the Supply Authority relating to the approval process, including agreements and arrangements for supply, shall be documented in the Engineering Summary Report and reference (date and file number) of such approval made on the Design Summary Drawings.
Pump Station Standard Supply Configuration

LV Supply from Water Corporation Substation - One or Two Transformers Total Rating ≤ 2000 kVA

Fig 10.1
Pump Station Standard Supply Configuration

L.V. Supply from Water Corporation Substation - Dual Transformers Each Rated > 1000 kVA ≤ 2000 kVA

Fig 10.2
Pump Station Standard Supply Configuration

H.V. Supply from Water Corporation Substation

Note: For sectionalised bus bar arrangements refer clause 3.6 and standard drawing FS00-4-7.

Fig 10.3
11 EARTHING

11.1 Earthing System Configurations

a) A combined earthing system in accordance with AS 2067 shall be used at each site.

b) The principal earthing connections and arrangements appropriate to pump stations with the standard electrical configurations indicated at Figs. 10.1 to 10.3 inclusive are shown at Figs. 11.1 to 11.3 inclusive.

c) The earthing arrangements at pump stations having non-standard configurations shall be generally in accordance with the principles illustrated in Figs. 11.1 to 11.3 inclusive and shall be subject to the approval of the Principal Engineer.

d) Each earthing system shall include at least two vertical earth electrodes.

e) Individual earth electrodes shall be designed to have a resistance to earth no greater than 10 ohms under the worst case climatic conditions.

f) In accordance with AS1768, all metallic structural material and all concrete reinforcement steel in the pump station main building, and in any other associated buildings, shall be electrically bonded together and shall be connected to earth. Such bonding shall include metallic roof and side cladding, metallic roof structures and reinforcement steel in precast lift up wall panels.

g) Where it is necessary to connect earth cables to pipework or structural steel, a stainless steel set screw shall be welded to the steel to provide a corrosion free earthing stud.

h) All major earthing cable connections shall be made with a separate bolt for each cable so that one cable can be disconnected for testing without interfering with other earthing circuits.

i) All permanent earth connections (joints) for earth grading rings or earth mats shall be IEEE Std 837 compliant (e.g. Cadweld, DMC GroundLok, Burndy).

j) The bond between earth bars shown in figures 11.1 to 11.3 inclusive shall be made using two parallel bonding cables each fully rated for the application.

k) Grading rings shall be installed around H.V. switchrooms, kiosk substations housing H.V. equipment and aerial switch poles.

11.2 Prevention of Corrosion in Earthing Systems

Earth mats and grading rings shall be bare hard drawn copper conductor (35 mm² minimum). Earthing electrodes shall be bare copper conductor (70 mm² minimum if soft drawn) or copper clad steel. All major earthing cables shall be copper and shall be terminated with suitable crimp connectors.

Wherever practical stainless steel bolts, nuts and washers should be used for earth connections in locations exposed to the weather.

All bolted connections in earthing systems shall be above ground and accessible for inspection.
11.3 Earthing Connections to General Mass of Earth

a) Earthing connections to the general mass of earth shall be taken to mean all earth electrodes, earth mats, uninsulated reinforced concrete foundations and earth grading rings.

b) The design of the earthing connections to the general mass of earth shall be such that, under the worst case climatic conditions and without reliance on connection to the Supply Authority earth system, the touch and step voltages do not exceed the limits determined by the application of AS2067 and Design Standard DS23.

c) The earthing connections to the general mass of earth shall be carried out, prior to the completion of Engineering Design, by a specialist earthing engineering consultant approved by the Principal Engineer. The former shall be responsible for the design, supervision of installation and verification of performance of the earthing connections to the general mass of earth.

d) Prior to the design of the connections to the general mass of earth, the specialist earthing engineering consultant shall carry out specialised earth resistivity testing in order to establish detailed earth resistivity profiles at the site and the associated design shall be based on such measurements.

e) Once installation of the earthing connections to the general mass of earth has been completed, the specialist earthing engineering consultant shall carry out low current ‘off frequency’ earth injection tests in accordance with AS2067 so as to verify the effectiveness of the connections to the general mass of earth and to verify that the step and touch voltages will not exceed the limits determined by the design for the installation in accordance with AS 2067 and Design Standard DS23.

f) The Designer shall ensure that the basic earthing design criteria are shown on the earthing Design Summary Drawing(s) in tabular form. Such data shall include results of soil resistivity profiles, fault levels, fault clearing times, calculated earth system impedance, calculated earth potential rise, calculated touch voltages, calculated step voltages and final verification test results (touch & step voltages, EPR and earth system impedance as a minimum). All test results shall reference GPS coordinates or location plans so as to facilitate future maintenance tests.

g) The specialist earthing engineering consultant shall prepare an earthing design report, in accordance with the process and technical requirements of DS23, covering the following critical issues:

- Methodology for the determination of body impedance, touch & step voltage allowable safety thresholds, power system fault levels and clearance times.
- Results of site soil resistivity tests along with GPS coordinates or location plans of the measurement routes and results of soil profile modeling.
- Design methodology and input parameters.
- Assumptions and qualifications.
- Earth system design details including simulation results for earth system impedance, EPR and touch/step voltages at critical points both within and outside the site perimeter (GPS coordinates or location plans).
- Design drawings.
h) The specialist earthing engineering consultant shall prepare an earthing verification report, in accordance with the process and technical requirements of DS23, covering the following critical issues:

- Methodology for determination of earth system impedance, EPR, touch voltages and step voltages at the critical points identified in the design report.
- Test equipment details and qualifications.
- Results with comparison to the simulation results.
- Conclusions and recommendations.

11.4 Major Earthing Screens

11.4.1 VSC Cable Screens

Screens on main circuit cables associated with both High Voltage and Low Voltage variable speed controllers shall be earthed at both ends with cable glands which provide a 360° connection of the screen to the associated earthed gland plate.

This requirement applies to the following type of cable:

a) the cable between a unit transformer and an associated variable speed controller,

b) the cable between a common switchboard and a variable speed controller,

c) the cable between a variable speed controller and its associated motor except where the variable speed controller is equipped with a 50 Hz band pass output filter.

11.4.2 High Voltage Supply Cable Screens

The screens on High Voltage supply cables (i.e. High Voltage cables other than those associated directly with variable speed controllers) shall be connected to earth at one end only, in the manner indicated on Figs. 11.1 to 11.3, as appropriate.

11.4.3 Earthing of Incoming Supply Authority HV Cable

In the case of the electrical supply to the pump station site being by a H.V. aerial line, the Supply Authority will earth the pump station incoming H.V. cable screen, the associated surge diverters and overhead earth wire (if available) at the Supply Authority’s transition pole (aerial to cable) to a suitable earth electrode at the base of the pole. The screen of the incoming cable shall be insulated from the earth at the pump station end.

The screen of the incoming cable shall be insulated from earth at the incoming H.V. switchgear i.e. there shall be no direct connection between the Supply Authority’s earthing system and the Corporation’s earthing system at the pump station.

If the Supply Authority’s H.V. metering unit is installed in the pump station H.V. switchroom it shall be earthed to the Corporation’s earthing system.

However it is acknowledged that there may be instances where earthing of the incoming cable screen to the Corporation’s substation earth system may be warranted or requested by the Supply Authority.
In such cases a detailed study of the interconnected systems (Supply Authority and Water Corporation) shall be undertaken by a specialist earthing engineering consultant, as part of the overall substation earthing design (refer clause 11.3), to ensure safe touch and step voltages are not compromised.

Major Earthing Connections

For L.V. Supply from a Local Water Corporation Substation

Fig. 11.1
Major Earthing Connections

For H.V. Supply from a Local Water Corporation Substation

Fig. 11.2
Major Earthing Connections
For H.V. Supply from a Remote Water Corporation Substation

Fig. 11.3
11.5 Labelling on Earthing Cables

All major earth connection cables shall be clearly labelled at both ends.

11.6 Earthing of Pipelines

11.6.1 Above Ground Steel Pipelines

Above ground steel pipes connected to pump stations shall be earthed and bonded at the pump station as shown in Fig. 11.4 in order to protect electrical plant against lightning damage, and for personnel safety. If the pumping plant includes High Voltage drives, a counterpoise earthwire shall be installed at a depth of 500mm adjacent to the pipeline for 240m either side of the pump station, and shall be bonded to the pipeline every 80m.

11.6.2 Below Ground Steel Pipelines

If below ground steel pipelines connecting to pump stations are cathodically protected, these may need to be electrically isolated from the pump station pipework. In such cases the earth bonding should be as shown in Fig. 11.5. Reference shall be made to Electrical Design Standard DS 23 in regard to earthing required on such pipelines.

Insulated joint protectors with a rated D.C. breakdown voltage of 500 V shall be fitted across the insulating joints in the pipeline to limit the surge voltage that can appear across the pipeline joint to less than 1000V.
11.6.3 AC Voltage Mitigation on Steel Pipelines

Water Corporation metallic pipelines located in the vicinity of and/or within the same easement as High Voltage transmission and High Voltage distribution power line(s) may be subject to unacceptable touch voltages. The Designer shall ensure that studies are carried out to investigate, analyse, mitigate by design and verify by testing as required, any exposure to touch voltage hazards by the public and Corporation personnel through the application of the Corporation’s Design Standard DS23 ‘Pipeline AC Interference and Substation Earthing’, AS/NZS 4853 or as directed by the Principal Engineer. The AC interference analysis and mitigation design shall be carried out by a specialist AC interference/earthing engineering consultant approved by the Principal Engineer.

11.6.3.1 Introduction

Inductive, conductive (ground current coupling) and capacitive coupling between the above ground power lines and metallic pipelines can result in operational personnel or the public being exposed to hazardous touch voltages. The Corporation’s Design Standard DS23 ‘Pipeline AC Interference and Substation Earthing’ outlines the process for determination of permissible touch voltages and the requirements dealing with the mitigation of any dangerous touch voltages. AS/NZS 4853 places the onus on the pipeline owner or operator to ensure the application of the standard.

To determine the extent of the hazard to persons touching an exposed pipeline, an AC Interference Analysis is carried out followed by a design to mitigate the dangerous exposure. In order to mitigate the touch voltage hazard extensive earthing and bonding is applied to the pipeline, at specific locations, where access for operational and maintenance purposes or the public are required.

11.6.3.2 Inductive Coupling Hazard.

In joint use corridors, or separate parallel corridors, where both metallic pipelines and power lines are present a portion of the energy contained in the magnetic field surrounding the High Voltage power line is captured by the pipeline resulting in induced AC voltages which vary in magnitude throughout the length of the pipeline. Voltages will appear on the pipeline both during the steady state and the
transient state (fault condition) however the voltage present during the transient state will be considerably more severe. A touch voltage hazard exists between the earth and the pipeline.

11.6.3.3 **Conductive Coupling Hazard.**

During a fault on a power line, energisation of the earth by the supporting structures near the fault can result in large voltages appearing locally between the earth and the steel pipeline. A touch voltage hazard exists between the soil at high potential and the pipeline at remote earth potential.

11.6.3.4 **Capacitive Coupling Hazard.**

Pipelines suspended above the ground underneath High Voltage power lines are subject to capacitive coupling. The voltage (with respect to earth) on the suspended pipe section, due to the strong electric field from the power line, can be quite high and a person touching the pipe provides a much lower resistance path to earth and therefore subject to hazardous voltages and currents. This hazard is usually only of concern during construction when the pipe sections are lifted into position. The capacitive effect of installed pipes is normally negligible compared to the inductive and conductive effects.

11.6.3.5 **Mitigation.**

In order to reduce the touch voltages to safe levels and to comply with the requirements of DS23 and AS/NZS 4853 in respect to earthing and bonding, strategically placed and specifically designed earth electrodes, equipotential mats, cancellation wires and gradient control wires shall be applied.

11.6.3.6 **Interaction with Cathodic Protection Design.**

There is a direct dependency between the voltage mitigation system analysis/design and the cathodic protection system design. Critical cathodic protection design information must be conveyed to the voltage mitigation designer in order for the voltage mitigation designer to complete an accurate model (and accurate design) of the system. Such information relates to whether bonds will be applied across rubber ring joints, whether cathodic protection is sacrificial or current impressed, whether pipe sections must be isolated etc. The voltage mitigation designer shall take such information into consideration during the analysis and design of the voltage mitigation system and ensure that compatibility is maintained with the cathodic protection design.

11.7 **Earthing of Pipeline Mounted Instrumentation**

Electronic instrumentation transducers which are mounted on the main pipeline, or on pipework within the pump station, shall be electrically isolated from the associated pipework and shall be earthed separately to the instrumentation earth bar. Reference shall be made to Electrical Design Standard DS 25 in regard to the requirements for earthing electronic instrumentation transducers.

11.8 **Earth Bonding at External Valve and/or Meter Pits**

a) All metalwork at valve and/or meter pits shall be bonded together as shown in Fig. 11.6, in order to protect electrical plant against damage and for personnel safety. For buried valves (refer Fig. 11.6) the valve body shall be connected to a grading ring encircling (1m radius) the spindle and buried 500mm deep. For buried valves or flowmeter, a bonding cable shall be installed across each device.

b) Sacrificial anode cathodic protection may be required in some instances in order to inhibit increased galvanic corrosion of steelwork due to the copper/iron couple. This should be investigated on a site by site basis and may require special measures including selective application of insulated joint protectors or isolator/surge protectors (ISP) or galvanic isolators (GI).
The appropriate application of an ISP or GI, such as those from Dairyland Electrical Industries (D.E.I.), will provide D.C. isolation and A.C. continuity. These ISP/GI's have standard peak blocking levels between 10 volts and 20 volts and are intended for safe electrical isolation of cathodically protected systems subject to 50Hz power faults, systems which are coupled to an AC source and systems subject to lightning transients.

**Note:**

a) *For general applications the grading ring shall be deployed as indicated below. For applications subject to an AC Interference study, the design of the ring/mat shall be in accordance with the pipeline Voltage Mitigation design by the specialist Earthing Design Consultant.*

*For specific details refer to standard drawings EG20-5-4 and EG20-6-7.*
11.9 Earthing and Bonding of Concrete Reinforcing Steel

a) The concrete reinforcing steel in buildings housing major electrical plant shall be bonded to earth. (Refer Figs. 11.1, 11.2, 11.3)

b) A multiplicity of steel tie wire connections occur between reinforcing rods in any one structural element, so that it is not necessary to provide individual bonds to each reinforcing rod. It is sufficient to provide a welded bond between three adjacent parallel major reinforcing bars, and to...
provide a welded connection to this internal bonding point using a "Wricon C70 Earthing Connector" or a stainless steel bar of suitable dimensions. (Refer Fig. 11.6)

c) Each electrically separate reinforced concrete element should be provided with a reinforcing bar bonding connection point as described above.

d) The resistivity of concrete in air is typically 80 ohm. Metres. However, because of the inherent alkaline composition and hygroscopic nature of concrete, concrete in contact with soil can be expected to have a resistivity of 40 ohm - metres.

e) Since concrete has a relatively low resistivity, electrically bonded reinforcing steel in concrete members which are in direct contact with the ground will reduce the overall electrical earth ground resistance and can be of a significant benefit in this regard. In locations where the soil resistivity is less than 30 ohm metres (e.g. in damp black soil or swampy situations), there is a small risk of galvanic corrosion of the reinforcing steel due to the galvanic couple between the steel and the electrical system copper electrode. In such locations a galvanic isolator (e.g. DEI) should be installed between the reinforced concrete and the earth electrode system.

11.10 Earthing and Bonding of Structural Steel and Fences

a) Grid flooring, metallic cable trench covers, metallic cable trays and ladders, stairs, ladders and all structural steel work shall be bonded together and connected to the pump station main earth bar.

Bolted connections between items of steelwork shall be considered satisfactory bonding provided that unbolting any single removable element does not disconnect any other part of the steelwork from earth.

b) Bonding shall be installed across all pump station pipework equipment such as flexible joints, meters, valves and pumps.

c) Any sections of metallic fencing located under aerial High Voltage lines shall be earthed to the pump station High Voltage earthing system by two earthing connections, one either side of the point where the High Voltage aerial line crosses the fence line.

d) Metallic fencing may be bonded to the pump station earth system only if an EPR study in accordance with DS23 has been carried out and the study confirms that touch voltages and transferred voltages are within safe limits.

11.11 Earthing and Bonding of Above Ground Structures for Lightning Protection

Above ground structures such as high level water towers, dam intake towers, water tanks and buildings shall be subjected to a lightning risk assessment in accordance with AS1768. Based on this assessment of risk, the appropriate earthing and bonding shall be applied in accordance with AS1768 and this standard, to ensure safety to personnel and equipment.

11.12 Earthing and Bonding for VSD Applications

IEC TS 60034-17 and IEC TS 60034-25 give good guidance for earthing, bonding and cabling of motors and driven loads to enhance EMC performance of VSD installations. The Designer shall consult these standards and apply such EMC techniques as demanded by the installation configuration.
In order to minimise the risk of pump bearing failure, a low inductance bond shall be provided between each motor frame and the frame of the associated pump. The bond shall be as short as practical and the bonding conductor shall be flat copper flexible single braid having a cross sectional area not less than 70 mm$^2$. 
12 INSULATION CO-ORDINATION

12.1 General

12.1.1 General

Detailed insulation co-ordination investigation and design shall be carried out to ensure that the risks of insulation failure due to lightning and switching surges is minimised. Such design shall match surge protection levels and insulation impulse withstand levels including adequate safety margins, and shall take into account the connection and positioning of earthing conductors. Reference shall be made to IEC 60099.1, IEC 60099.4, IEC 60099.5, AS1307.2 and AS1824.2.

12.1.2 Self-Restoring and Non-Self-Restoring Insulation

Electrical insulation used in electrical plant is of two types, i.e. self-restoring and non-self-restoring.

Self-restoring insulation is defined as the type of insulation that reverts to its original insulating characteristics once the arc following electrical breakdown is extinguished. Aerial insulators normally fail in this mode and generally are considered self-restoring.

Non-self-restoring insulation, on the other hand, is permanently damaged and degraded by overvoltage failure.

Motor and transformer winding insulations are examples of non-self-restoring insulation.

Overvoltage protection of electrical plant shall be arranged so that overvoltages applied to non-self-restoring insulation does not exceed the overvoltage rating of the insulation. On the other hand, self-restoring insulation may be permitted to fail in certain circumstances, provided protection equipment is arranged to interrupt the resulting fault current.

12.1.3 Types of Overvoltage

Overvoltages are classified into three types, each characterised by an internationally agreed set of parameters defining the waveform, as follows:-

a) Power frequency overvoltage, which takes the form of a sinusoidal wave at 50 Hz.

b) Switching impulse overvoltage, which takes the form of a double exponential wave shape, having a front time of 250μs and a time to decay to half magnitude on the tail of 2500μs.

c) Lightning impulse overvoltage, which takes the form of a double exponential wave shape having a front time of 1.2μs and a time to decay to half magnitude on the tail of 50μs.

For transformers rated less than 315 kVA, insulation having the appropriate power frequency withstand voltage will also provide adequate protection against any switching impulse which is likely to occur.

The insulation used in motor windings is, however, less able to withstand impulsive overvoltage and the provision of protection against switching surges needs to be considered for motors, particularly where vacuum contactor switching is employed.

It should be recognised that all surge diverters have a voltage-time characteristic in their own right, and to provide complete protection against lightning impulses, the voltage-time characteristic of the surge diverter must lie below the associated insulation withstand voltage-time characteristic.
12.2 Types of Overvoltage Protective Devices

The principal types of impulsive overvoltage shunt connected protective device in common use are discussed hereunder.

12.2.1 Rod Gaps

a) Rod gaps generally do not provide protection against lightning impulses with rise times less than 2μs.

b) Rod gaps are not self-quenching so that if long term outages are to be avoided, rod gaps must be used in conjunction with automatically reclosing circuit breakers.

c) The flashover characteristic for rod gaps is dependent on atmospheric conditions and is different for positive and negative going waves. Rod gap voltage-time characteristics are thus quite broad band.

12.2.2 Gap Type Surge Diverters

Gap type surge diverters are self-quenching and do not require to be used in conjunction with automatically reclosing circuit breakers. Gap type surge diverters respond faster and limit the residual voltage to lower values than do rod gaps.

Some High Voltage gap type surge diverters can be fitted with disconnectors. Care shall be taken with equipment arrangements to ensure that operation of disconnectors is not inhibited and will not give rise to other faults.

12.2.3 Gapless Surge Diverters

Gapless surge diverters are self-quenching and do not require to be used in conjunction with reclosing circuit breakers.

Gapless surge diverters respond faster and limit fast front discharge voltages to lower values, than do either rod gaps or gap type surge diverters. However, gapless surge diverters are more sensitive to ambient temperature than are gap type surge diverters, and this aspect shall be given careful consideration before the former are specified.

Some High Voltage gapless surge diverters can be fitted with disconnectors. Care shall be taken with equipment arrangements to ensure that operation of disconnectors is not inhibited and will not give rise to other faults.

12.2.4 Hybrid Surge Diverters

Some specialised surge diverters are now available, which combine air gaps with metal oxide varistors in lieu of silicon carbide non-linear resistors. The Siemens type 3EF1 series of surge diverters are of this type. Such devices have a relatively low discharge current rating and are intended for suppression of switching surges and not for the suppression of lightning surges.

Hybrid surge diverters limit switching surge residual voltage levels to slightly lower values than other types of surge diverters, and have the added advantage of being less sensitive to ambient temperature effects. However, their relatively low discharge current rating means that hybrid surge diverters must be protected from lightning surges.
12.3 Performance Characteristics of Gap Type Surge Diverters

The protective level of gap type surge diverters shall be determined in accordance with the voltage ratings specified in Table 8 of IEC 60099.1 for 2.5 kA, 5 kA and 10 kA light duty diverters and shall be defined as which is the greater of the following:

a) the highest front of wave spark over voltage divided by 1.15,
b) the highest standard lightning impulse spark over voltage or,
c) the highest residual voltage at nominal discharge current.

12.4 Performance Characteristics of Gapless Surge Diverters

The relevant characteristics of gapless surge diverters shall be in accordance with AS13701.2, Surge Diverter Protection Level.

The protective level of a gapless surge diverter (EP) is as defined in AS1307.2 Clause 2.39.

12.5 Performance Characteristics of Hybrid Surge Diverters

The relevant performance characteristics of hybrid surge diverters are as listed hereunder:

a) Power Frequency Rated Voltage:

The rated voltage of a hybrid surge diverter is the maximum power frequency voltage that can be applied continuously across the surge diverter without ill-effect.

The rated power frequency voltage rating of a hybrid surge diverter must not be less than the maximum line voltage which can be developed under earth fault conditions, because surge diverters are not thermally capable of limiting power frequency overvoltages.

b) Minimum Sparkover Power Frequency Voltage
c) Maximum 1.2/50μs Impulse Sparkover Voltage
d) Maximum Discharge Residual Voltage

The maximum discharge residual voltage of a hybrid surge diverter can be defined in the same terms as a gap type surge diverter. (Refer IEC 60099.1 Clause 2.35).

e) Surge Diverter Protective Level:

The protective level of a hybrid surge diverter can be defined in the same terms as a gap type surge diverter.

12.6 Pressure Relief and Explosion Resistance

The primary reasons for the destruction of surge diverters are power frequency over-voltages in excess of the minimum power frequency sparkover voltage, long-time surge current impulses and direct lightning strokes.

Surge diverters in electrically exposed locations shall be specified to incorporate a pressure relief system, so that in the event of an internal fault, the hot gases are expelled through a pressure relief
membrane, in such a way as to ignite a shunting arc at a predetermined location external to the surge diverter. The aim of such pressure relief systems is to limit pressure increases within surge diverter housings to safe levels. Nevertheless, because surge diverters are usually located near other electrical equipment, a surge diverter housing explosion can cause extensive secondary damage. For this reason, surge diverters shall be specified to have a controlled housing rupture characteristic, in accordance with IEC 60099.1 Clause 8.7.1.

12.7 Surge Impedance

12.7.1 Definition

Surge impedance is defined as the square root of the conductor per unit series inductance divided by the conductor per unit shunt capacitance,

\[ Z_0 = \left( \frac{L}{C} \right)^{0.5} \text{ ohms} \]

12.7.2 Cable Surge Impedance

The surge impedance of a cable is typically 45 ohms.

12.7.3 Line Surge Impedance

An overhead line has characteristic surge impedance, depending on its inherent series inductance, and shunt capacitance.

The surge impedance \[ Z_0 = 138 \log \left[ 2h (ar)^{0.5} \right] \]

Where:
- \( h \) = height of conductor above ground, m
- \( r \) = radius of each phase conductor, m
- \( a \) = intra-phase conductor separation, m

(= \( r \), if single conductor per phase)

The above expression assumes a long line and consequently can only be applied where end effects will be negligible, i.e. line lengths of greater than 100h, say 1 km.

The surge impedance of an overhead line is typical 500 ohms.

12.7.4 Transformer Surge Impedance

The surge impedance of a transformer winding is typically 5000 ohms.

12.8 Application of Surge Diverters

12.8.1 Effect of Cable Length

When a lightning surge propagated along an overhead line impinges on a cable, the latter acts substantially as a capacitor and the steepness of the original surge is reduced as the surge enters the cable (because of the cable’s lower surge impedance). Nevertheless, because of the transformer’s large surge impedance, the surge will be reflected at the transformer terminals, thus building on the incoming surge and increasing the voltage to earth. This process will be repeated when the return surge reaches the overhead line, and so on.
This process is described in more detail in Section 6 of AS 1824.2. Surge diverters shall be installed at all cable to overhead line cable terminations. The Designer shall carry out calculations to determine if these surge diverters will limit the surge voltage at the other end of the cable to no more than 80% of the rated lightning withstand voltage of the connected equipment including the cable terminations. If the cable length is too long to make this practical, additional surge diverters shall be installed at the equipment end of the cable.

12.8.2 Selection of Surge Diverter Power Frequency Voltage Rating

a) The maximum power frequency voltage that can be developed at a surge diverter during an earth fault depends on the ratio of system positive and zero sequence impedances, assuming an earth fault at the surge diverter location on another phase.

b) IEC 60099.5 Annex A details the method of determining the value of such overvoltages. It should be noted that the system neutral earthing resistance has a major effect, and care should be taken that realistic values of same are used in such calculations. Care must also be taken to ensure that the scale factors derived from IEC 60099.5 Annex A are applied to the maximum system voltage, not the nominal system voltage.

c) For a rural 33 kV effectively earthed system, surge diverters installed at pump stations shall be specified to have a maximum continuous operating voltage rating of 30 kV, unless detailed calculations have been made to indicate that a lower figure would be adequate.

d) For a similar 22kV system, a diverter maximum continuous operating voltage rating of 20 kV would be appropriate, unless detailed calculations have been made to indicate that a lower figure would be adequate.

e) For pump station 6.6kV systems, surge diverters shall be specified to have a maximum continuous operating voltage rating of 7.2kV.

12.8.3 Selection of Equipment LIWV Rating

The lightning impulse withstand voltage (LIWV) rating of protected equipment shall be not less than 1.25 ET kV, where ET is the equipment terminal maximum surge voltage, kV.

12.8.4 Protective Range

a) Where the incoming Supply Authority overhead line is on wooden or unearthed cross arms, surge diverters connected directly to the line shall be located within 1 metre of the equipment to be protected by the surge diverters. In such circumstances the earth connection from the surge diverters shall be made directly to the frame of the equipment to be protected and hence to earth.

b) Where the incoming Supply Authority overhead line is on earthed steel cross arms, surge diverters connected directly to the line may be located not more than 15 metres away from the equipment to be protected by the surge diverters. If the equipment to be protected is on the same pole as the surge diverters, the earth connection from the surge diverters shall be made directly to the frame of the equipment to be protected and hence to earth.

c) If the equipment to be protected and the surge diverters are on different poles, the earth connection from the surge diverters and the earth connection from the frame of the equipment to be protected shall be run separately and directly to the substation earth mat.

12.8.5 Discharge Current Rating

Surge diverters fitted to 33 kV or 22 kV systems shall be rated for a discharge current of 10 kA.
13 CABLES

13.1 Cable Types

13.1.1 Conductor Type

All cables shall have copper conductors.

13.1.2 Cables for Specific Purposes

The types of cables to be used for various specific purposes shall be as listed hereunder.

<table>
<thead>
<tr>
<th>APPLICATION</th>
<th>CABLE TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light current switchboard cables</td>
<td>Refer DS26.09</td>
</tr>
<tr>
<td>Conventional LV Motor Stator Cables (see note 5)</td>
<td>Single core XLPE insulated PVC sheathed cables installed in ducts in frefoil groups.</td>
</tr>
<tr>
<td>Starter Resistor Cables (within cubicle)</td>
<td>R-S-150 insulated, glass fibre braided, single core (size and voltage rating to suit)</td>
</tr>
<tr>
<td>HV Motor Stator Cables (6.6kV and 11kV)</td>
<td>Single core XLPE insulated 3.8/6.6 kV or 6.35/11kV cables constructed with copper conductor, semi-conducting screen, XLPE insulation, semi-conducting screen, light duty copper screen, PVC sheath overall. Cables to be run in trefoil groups. The conductor size not to be less than 25mm² and screen size not to be less than 16mm².</td>
</tr>
<tr>
<td>HV Motor Rotor Cables</td>
<td>Single core XLPE insulated cables constructed with copper conductor, semi-conducting screen, XLPE insulation, semi-conducting screen, light duty copper screen PVC sheath overall.</td>
</tr>
<tr>
<td>Cable voltage rating to be one increment higher than the relevant motor rotor open circuit voltage.</td>
<td></td>
</tr>
<tr>
<td>Incoming cables to transformer HV terminals and/or incoming cables to 33/22 kV HV switchboards (see notes 1,2, and 3)</td>
<td>Single core XLPE insulated cables constructed with copper conductor, semi-conducting screen, XLPE insulation, heavy duty copper screen, tape bedding double brass taping PVC sheathed overall, rated and sized to suit both continuous and fault current requirements, and laid in trefoil groups. As an alternative to double brass taping, termite protection may be provided in the form of a PVC sheath with a nylon jacket and an overall sacrificial PVC sheath.</td>
</tr>
<tr>
<td>Incoming cables to 6.6 kV switchboards (see notes 1,2 and 3)</td>
<td>Single core XLPE insulated cables constructed with copper conductor, semi-conducting screen, XLPE insulation, heavy duty copper screen, tape bedding</td>
</tr>
</tbody>
</table>
double brass taping PVC sheathed overall, rated and sized to suit both continuous and fault current requirements, and laid in trefoil groups. As an alternative to double brass taping, termite protection may be provided in the form of a PVC sheath with a nylon jacket and an overall sacrificial PVC sheath.

<table>
<thead>
<tr>
<th>Pipeline and structural steel bonding and earthing cables</th>
<th>1 core PVC (green with yellow stripe), sized 70mm² or size of station main earth conductor, whichever is the greater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipeline counterpoise earthwire and grading wire</td>
<td>35mm² stranded bare hard drawn copper conductor</td>
</tr>
<tr>
<td>Cables connecting Low Voltage (≤690V) variable speed controller converters to associated isolating transformers (see note 4)</td>
<td>Symmetrically shielded 3 phase cable(s) rated 0.6/1 kV and as described further para 13.1.3 hereunder</td>
</tr>
<tr>
<td>Low Voltage (≤690V) variable speed controller PWM output cables</td>
<td>Symmetrically shielded 3 phase cable(s) rated 0.6/1 kV as described further para. 13.1.3 hereunder</td>
</tr>
<tr>
<td>Cables connecting High Voltage (≤6600 V) variable speed controller converters to associated isolating transformers (see note 4)</td>
<td>Symmetrically shielded 3 phase cable(s) rated 3.8/6.6kV, and as described further para. 13.1.3 hereunder</td>
</tr>
<tr>
<td>High Voltage (≤6600 V) variable speed controller 9 level PWM output cables</td>
<td>Symmetrically shielded 3 phase cable(s) rated not less than 120% of the controller nominal maximum rated output voltage, and as described further para. 13.1.3 hereunder</td>
</tr>
</tbody>
</table>

Note 1: Applies to cable buried direct or cables in buried PVC conduit buried. Cables installed in ducts within the confines of the building may be specified without termite protection.

Note 2: When cables are installed in conduits, the conduits shall be 150mm in diameter.

Note 3: Parallel runs of buried HV power cable shall not be placed in the same trench as this reduces security of supply.

Note 4: Not required if RFI suppression scheme is fitted to the variable speed controller.

Note 5: Cables shall be rated for the full load current of the motor.

### 13.1.3 Variable Speed Controller Cables

a) Variable speed controller cables referred to in para. 13.1.2 shall be symmetrically constructed shielded cables either with three symmetrically placed internal protective earth cores or with a shield rated as the protective earth. Phase conductors, internal protective earth cores and the shield shall be copper.

b) If internal protective earth cores are provided, the conductivity of the shield shall be not less than 10% of the conductivity of each phase conductor.
c) The combined conductivity of the shield and the internal protective earths (if fitted) shall be not less than, the conductivity of each phase conductor for cables < 16 mm², and not less than 50% of the conductivity of each phase conductor for cables > 16 mm².

d) The cable screen shall consist of either double copper tape screen or a single copper tape screen overlaid with a copper wire screen. Copper braid screens shall not be used for fixed installations. Cable screens shall be terminated and earthed concentrically. Double copper tape screens shall be terminated in glands employing a lead clamping cone. Combined single copper tape and copper wire screens shall be terminated in armoured cable “cable glands”.

e) Variable speed controller cables shall be rated for a maximum conductor temperature of 75°C and shall be site derated accordingly.

f) Converter input cables shall be derated to allow for the transformer secondary winding utilisation factor appropriate to the particular type of converter, i.e. for bridge connected converters, the converter input cables should have a site 50 Hz. rating of 125% of the converter duty current rating of the converter transformer secondary winding.

13.2 Continuous Rating of Cables

13.2.1 General

The continuous current rating of power cables depends to a large extent on the rate that heat generated by cable losses can be dissipated. Various derating factors are applicable to take account of various ambient parameters. Reference shall be made to AS 3008 Electrical Installations - Selection of Cables, and to the Electrical Research Association publication Current Rating Standards for Distribution Cables, Parts I and III, for the applicable derating factors.

13.2.2 Increase in Effective Resistance Due to Harmonic Currents

Cable resistance values published in AS 3008 are for cables carrying only 50 Hz currents. A.C. currents in cables cause an increase in the cables effective resistance. The increase in cable effective resistance at 50 Hz above the D.C. resistance is relatively small. However the increase in cable effective resistances due to harmonic currents is significant particularly for the higher harmonic currents and large cables.

The factors which affect A.C. resistance are skin effect, proximity effect due to other conductors and proximity due to metallic enclosure. If the use of metallic conduit is excluded, the following equation applies:

\[ R_{ac_h} = R_{dc} \times (1 + y_{sh} + y_{ph}) \]

where \( h \) = harmonic number

\( y_{sh} \) = skin effect factor at harmonic \( h \)

\( y_{ph} \) = proximity factor at harmonic \( h \)

\( R_{dc} \) = conductor DC resistance at operating temperature

\( R_{ac_h} \) = A.C. resistance to harmonic current \( h \)

The skin effect depends on the conductor diameter and the harmonic frequency whereas the proximity effect depends on the conductor diameter, the axial spacing of phases and the harmonic frequency.
The matter of increase in effective cable resistance due to harmonic currents is addressed in IEC 60287-1-1 Electrical Cables - Calculation of Current Ratings - Part 1 Current Rating Equations (100 % Load Factor) and Calculation of Losses - General (BS 7769.1.1)

IEC 60287.1.1 states that its equations have limited accuracy, i.e. are accurate only to a value of \( mr \) not greater than 2.8 where:

\[
\begin{align*}
mr & = 0.05 \times (f / R_{dc})^{0.5} \\
f & = \text{frequency of harmonic current} \\
R_{dc} & = \text{conductor resistance ohms/km}
\end{align*}
\]

Accurate calculation of skin effect for values of \( mr \) greater than 2.8 requires the use of Bessel functions and is beyond the scope of this design manual.

Other available literature provides factors for increase in effective cable resistance due to harmonic currents for values of \( mr \) up to 4 and factors for values of \( mr \) up to 6 can be inferred reasonably.

For the purposes of this Design Standard, the inaccuracy in the IEC Std. 60287-1-1 skin effect calculations are not significant for values of \( mr \) up to 4.

Skin effect resistance values given in this Design Standard for values of \( mr \) greater than 4 are based on values provided in the available technical literature.

Proximity effect resistance increases with frequency to a lesser extent than skin effect resistance and in the absence of any other information the proximity effect resistance values given in this Design Standard are based on the IEC 60287-1-1 equations for values of \( mr \) up to 6 increased by the ratio of the values of skin effect resistance calculated by the two above methods.

The amount of derating necessary for cables supplying converters is relatively small because most cable losses are due to the fundamental current, e.g. for single core double insulated 300 mm2 copper cables supplying a typical 6 pulse converter, the necessary derating factor to be applied to the 50 Hz rating will be only 0.97.

Per unit resistance values for significant harmonic currents in the range up to the 25th harmonic are given in Table 13.1 for single core copper conductor double insulated cables in non-metallic conduit.

<table>
<thead>
<tr>
<th>Harmonic No.</th>
<th>Fr</th>
<th>Fr</th>
<th>Fr</th>
<th>Fr</th>
<th>Fr</th>
<th>Fr</th>
<th>Fr</th>
<th>Fr</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>5</td>
<td>1.02</td>
<td>1.02</td>
<td>1.05</td>
<td>1.09</td>
<td>1.15</td>
<td>1.22</td>
<td>1.30</td>
<td>1.46</td>
</tr>
<tr>
<td>7</td>
<td>1.02</td>
<td>1.05</td>
<td>1.10</td>
<td>1.16</td>
<td>1.27</td>
<td>1.38</td>
<td>1.47</td>
<td>1.67</td>
</tr>
<tr>
<td>11</td>
<td>1.05</td>
<td>1.10</td>
<td>1.19</td>
<td>1.32</td>
<td>1.51</td>
<td>1.65</td>
<td>1.66</td>
<td>2.05</td>
</tr>
<tr>
<td>13</td>
<td>1.07</td>
<td>1.13</td>
<td>1.25</td>
<td>1.41</td>
<td>1.61</td>
<td>1.78</td>
<td>2.00</td>
<td>2.25</td>
</tr>
<tr>
<td>17</td>
<td>1.12</td>
<td>1.20</td>
<td>1.36</td>
<td>1.56</td>
<td>1.83</td>
<td>2.02</td>
<td>2.21</td>
<td>2.49</td>
</tr>
<tr>
<td>19</td>
<td>1.15</td>
<td>1.25</td>
<td>1.43</td>
<td>1.66</td>
<td>1.91</td>
<td>2.11</td>
<td>2.35</td>
<td>2.61</td>
</tr>
</tbody>
</table>
Table 13.1

13.2.3 Cables to Active Filters

Cable continuous current ratings published in AS 3008 are for cables carrying only 50 Hz currents. Cables connecting active filters carry only harmonic currents and consequently the current rating of cables used for this duty must be derated to allow for increase in effective cable resistance due to skin and proximity effects. Determining the appropriate cable size is by necessity an iterative process as described hereunder.

a) calculate the RMS current, i.e.

\[ I_{\text{rms}} = \left( \sum I_n^2 \right)^{0.5} \]

where \( I_n \) = current in amps at harmonic \( n \)

\( I_{\text{rms}} \) = rms current in amps

b) calculate \( \max(I_n^* n/5) \) in amps for all values of \( n \)

c) select a cable with a on-site rating \( I_r \) of approximately 120% of \( I_{\text{rms}} \) or 120% of \( \max(I_n^* n/5) \), whichever is the greater

i.e. \( I_r \) = cable on site 50 Hz rated amps

d) determine \( R_n \) for each harmonic current to flow in the selected cable as follows:

\[ R_n = R_{50} * F_r \]

where \( R_n \) = conductor effective resistance in ohms/km at harmonic current \( n \)

\( R_{50} \) = conductor resistance in ohms/km at 50 Hz

\( F_r \) = per unit resistance increase at harmonic current \( n \) as shown Table 13.1

e) calculate the total cable losses per km as follows:

\[ P_{tl} = \sum(I_n^2 * R_n) \]

where \( P_{tl} \) = total losses in the cable in watts/km due to the harmonic currents

f) calculate the cable power losses at rated 50 Hz current as follows:

\[ P_{50l} = I_r^2 * R_{50} \]

where \( P_{50l} \) = losses in the cable at rated 50 Hz current

g) calculate \( P_{tl} / P_{50l} \)

If ratio is above unity the selected cable is too small. The ratio should be as close to unity as practical without exceeding unity.

13.3 Fault Rating

13.3.1 Switchboard Wiring

Where practical, cable tails between major circuit busbars and auxiliary circuit fuses should be protected against short circuit faults by the installation of busbar mounted fault current limiters. The size of the fault current limiters should be as shown in the Type Specification for Switchboard Construction.
Where the installation of busbar mounted fault current limiters is not practical, short cable tails may be installed between the busbar connection point and the line side of the auxiliary circuit fuse, provided the conditions specified in the Type Specification for Switchboard Construction are satisfied.

13.3.2 Distribution Cables

The fault rating of a cable depends on the allowable temperature rise of the conductor and insulation and on the thermal storage capacity of the cable. Most manufacturers publish data relating allowable fault current and fault duration to cable size for various types of cable.

The fault capacity of all cables selected shall be checked against the protective equipment to be used to ensure the adequacy of the former. Such checks shall include a check of the earth fault capacity of cable screens against the relevant earth fault protection equipment.

13.4 Intermittent Rating

Some cables such as rotor cables connected to motors having automatic ring shorting equipment, are only subject to intermittent or short-time loading and shall be rated accordingly.

13.5 High Voltage Cable Terminations

13.5.1 Manufacturer’s Recommendations

All High Voltage cable terminations shall be made in strict accordance with the manufacturer’s recommendations. Clearances in air shall be maintained at the manufacturer’s recommended level or at the value specified in the relevant Australian Standard, whichever is the greater. Attention shall be taken to ensure that recommended phase to phase and phase to earth clearances for unscreened sections of the cable terminations are maintained.

13.5.2 Dead-break Elbow Connectors

Dead-break elbow cable terminations on High Voltage screened single core XLPE insulated cables shall be made with approved fully screened, cold fit, dead-break elbow connectors such as Raychem Types RSTI and RSES dead-break elbow connectors (depending on current rating).

13.5.3 Indoor Air Insulated Terminations

High Voltage screened single core XLPE insulated cables within switchboards and air insulated cable boxes shall be terminated with approved heat shrink cable terminations such as Raychem series IXSU-F heat shrink terminations.

If the spacing between bushings is such that insulating boots are required to be fitted over the bushings, such insulating boots shall be approved cold applied insulating boots of an appropriate voltage rating, e.g. Raychem type RCAB for voltages up to 11 kV.

13.5.4 Pole Top Terminations

Pole top terminations on High Voltage single core XLPE cables shall be made with approved outdoor heat shrink terminations, such as Raychem Type OXSU-F heat shrink terminations.

Incoming supply pole top terminations on “triplex” XLPE cables shall be made with approved outdoor heat shrink terminations and approved mounting brackets, such as Raychem Type OXSU-F heat shrink terminations and Raychem Type EPPA-031 pole top termination brackets.
13.6 Conduits and Cable Trays/Ladders

Conduits shall have the colours stipulated in AS1345.

Conduits shall be orange for power cables.

Conduits for communication cables shall be white.

Outdoor cable trays and ladders shall be installed with covers. Indoor cable trays and ladders shall be installed with covers if exposed to the risk of mechanical damage. Where possible, multilayered cable tray or cable ladder arrangements should be avoided due to the additional cable de-rating required and accessibility.

13.7 Cable Positioning

If motor cables carrying PWM currents are to be installed in conduits, such cables shall be run in separate conduits.

Motor cables carrying PWM currents may be run on the same cable tray or cable ladder as other power cables. However control and signal cables shall not be run on the same cable tray or cable ladder as motor cables carrying PWM currents.

13.8 Cable Route Marking

All underground High Voltage and Low Voltage power cable routes shall be marked at all bends and at 25 metre intervals. Cable route markers shall be either of the concrete block type or the post type depending upon ground surface conditions.
14 ACTIVE FILTERS

14.1 Application

Non-linear loads such as the front end converters in variable speed controllers take harmonic currents from the electrical supply and in doing so may cause unacceptable harmonic distortion of the incoming supply voltage waveform (para. 4.4.8 refers.)

Active filters are available generally only in IP20 enclosures with an operating temperature range of 0°C to 40°C so that an air conditioned environment may need to be provided for such equipment.

14.2 Principle of Operation

Active filters operate to neutralise unwanted harmonic currents by causing other harmonic currents to flow which are of the same magnitude as the unwanted harmonic currents and are 180 degrees out of phase with the unwanted harmonic currents. The basic principle of operation is shown diagrammatically at Fig. 14.1

![Diagram of Active Filter Principle](image-url)
Active filters may be designed to filter all harmonic currents (i.e. broadband filters) or may be designed to filter out selected harmonic currents (i.e. individual harmonic filter).

Normally in pump stations, zero sequence harmonic currents are filtered out by transformer delta connections, so that active filters for pump station duty are normally designed to filter only non-zero sequence harmonic currents.

As discussed para. 3.8.6 eddy current losses in transformers increase very significantly with harmonic frequency, so that in instances where the active filter must be transformer coupled to the High Voltage system, only active filters of the individual harmonic type shall be used.

14.3 Limiting Network Characteristics

There are practical limits on the ability of an active filter to correct a network distorted voltage waveform and these may vary according to individual filter designs. Typical limiting values are as follows:

a) maximum network voltage tolerance: ±10%,
b) maximum network frequency tolerance: ±5%,
c) maximum rate of network frequency variation: 20 %/sec.,
d) maximum network unfiltered phase to phase voltage distortion: 20 %,
e) minimum network fault level: 2 MVA,
f) maximum network voltage notch depth: 50 %,
g) maximum network voltage notch area: 76 U volts*ms

where U = phase to phase voltage.

14.4 Principal Components

The principal components of an active filter system are as follows:

a) short circuit protective device,
b) a filter capacitor precharging network,
c) line reactors,
d) an inverter switching frequency filter,
e) an IGBT inverter,
f) an IGBT inverter controller,
g) a filter system man-machine interface,
h) a filter cooling system,
14.5 Filter Short Circuit Protective Device

If the filter is fitted with a set of fuses as a short circuit protective device, the fuses shall be semiconductor protection fuses in accordance with AS 60269.4.0.

However if the short circuit protective device is a circuit breaker it shall be a high speed type suitable for protecting semiconductors.
14.6 **Filter Precharging Network**

The active filter shall include a network which shall limit the inrush current to the inverter switching frequency filter capacitors. This network shall be bypassed during filtering operations.

14.7 **Active Filter Reactors**

The inverter “D.C. bus voltage” is determined by the fundamental frequency input voltage to the active filter.

For a non-zero sequence harmonic current active filter, the series reactors shall be sized to pass the rated current of the filter all as a 5th harmonic current.

For a zero sequence harmonic current active filter the active filter reactors shall be sized to pass the rated current of the filter all as a 3rd harmonic current.

14.8 **Inverter Switching Frequency Filter**

A filter is required to prevent significant levels of inverter switching frequency currents being injected into the power network. Such a filter shall be of either the L/C or L/R/C type, preferably the latter and shall limit the power port high frequency emission disturbance voltages to less than the limits specified in AS 61800.3 (IEC 61800.3).

14.9 **Power Coupling Transformer**

The power coupling transformer is required to have zero phase shift. Consequently the transformer shall have a Yy0 connection.

In order to avoid excess third harmonic phase to neutral point voltages, the transformer shall be of the three phase three limb core type. The use of a three phase shell type transformer, or of a three phase five limb transformer, or of three single phase transformers shall not be permitted.

The power coupling transformer associated with an active filter will be required to pass only harmonic currents and its 50 Hz kVA rating will need to be derated very substantially in order to pass the harmonic currents to be injected into the High Voltage system (refer para. 3.8).

14.10 **Active Filter Rating**

The following factors shall be taken into account when determining the required rating of an active filter.

14.10.1 **RMS Current**

The rated current of the active filter shall be not less than the root mean square sum of the harmonic currents to be filtered out.

14.10.2 **Maximum Equivalent 5th Harmonic Current**

As a consequence of the sizing of the series reactor as described para. 14.6 above, the maximum particular harmonic current $I_h$ available from a non-zero sequence harmonic filter will be as follows:

$$I_h = I_r \times 5/h$$
where

\[ I_h = \text{maximum current available at harmonic } h \]

\[ I_r = \text{rated current of the active filter,} \]

\[ h = \text{harmonic number} \]

Consequently, the active filter rated current shall not be less than the maximum value of \( I_h^*h/5 \).

### 14.10.3 Effect of Transformer Impedance

If an active filter is transformer coupled to the supply, the impedance limiting the injected harmonic currents will be the filter reactor impedance plus the transformer impedance. Consequently, in such circumstances, the active filter rated current will have to be increased so that the filter reactor impedance is decreased to compensate for the transformer impedance.

### 14.11 Derating of Connecting Cable

The Low Voltage power cables connecting the active filter carry harmonic currents and shall be derated substantially in accordance with para. 13.2.3.

### 14.12 Type Specifications

The following Type Specifications are suitable for specifying active filters:

DS26.34 - Type Specification for High Voltage System Active Filter

DS26.35 - Type Specification for Low Voltage System Active Filter
15 SWITCHROOMS

15.1 General

a) Switchrooms in prefabricated substations shall comply with the requirements specified for switchrooms in AS 62271.202

b) Except for switchrooms in prefabricated substations, switchrooms housing H.V. switchgear shall comply with the requirements of section 5.5 of AS 2067-2008, the WADCM and the further requirements specified hereunder.

c) Switchrooms housing high current L.V. switchboards (i.e. L.V. switchboards rated > 800 amps) and/or critical items of electronic equipment shall comply with the requirements of section 5.5 of AS 2067-2008, section 2.9.2 of AS/NZS 3000 and the further requirements specified hereunder.

d) Switchrooms shall be designed to have a service life of not less than 40 years and shall be designed to facilitate the operation and maintenance of the switchgear housed therein.

e) Switchrooms shall be clearly identified with signage as to their function and access restrictions.

15.2 Arcing Fault Discharge

a) The duct volume beneath H.V. switchboards with AFLR accessibility and which discharge down into the cable duct shall be arranged to be > 1.0 cubic metres.

b) The covers over the cable duct into which arc fault gases are to be discharged shall be bolted in place and shall be sufficiently strong to contain the arc fault gases.

c) Where H.V. switchgear with AFLR accessibility is provided with duct(s) to discharge arcing fault gases outside the switchroom, fencing shall be provided to prevent access to gaseous discharge outlet(s).

d) The switchroom ceiling height above the type of H.V. switchgear described para. 15.2(a) and 15.2(b) above shall be > 2 metres and not less than 600 mm. greater than the height of the H.V. switchgear.

e) H.V. switchboards with AFL accessibility which discharge arcing fault gases to the rear shall be located close enough to the rear wall to prevent personnel access and far enough away from the rear wall to prevent any part of the switchboard coming in contact with the rear wall in the event of an arcing fault gaseous discharge.

f) Such switchboards shall be spaced from the rear wall in accordance with the manufacturer’s recommendations. AS 62271.200 specifies the nominal clearance to be 100 mm.+ 30 mm.
g) Except for switchboards as described paras. 15.2(a) and 15.2(b) above, the switchroom ceiling height shall be not less than 2.8 metres, or 600 mm. above the top of any H.V. and/or high current L.V. switchboards in the switchroom, whichever is the greater.

h) Cable duct covers within H.V. switchrooms shall be solid fire resistant plywood.

i) Except for prefabricated substations, H.V. switchgear and L.V. switchgear shall be located in separate switch rooms with separate fire isolated cable trenches.

15.3 Cable Ducts

a) Cable ducts shall extend at least 600 mm beyond both ends of all H.V. switchboards and of all high current L.V. switchboards.

b) Cable entry into switchboards shall be from below, but overhead bus duct entry into L.V. switchgear shall be permitted.

c) Cable ducts shall be designed to facilitate the installation and removal of cabling

d) The width of switchroom cable ducts shall be not less than 600 mm.

e) The depth of switchroom cable ducts shall be 600 mm deep, or 110% of maximum cable size minimum bending radius, whichever is the greater. *Note: Special requirements for cable ducts apply to switchboards housing Supply Authority High Voltage equipment. Refer WADCM*

f) Cables entering cable ducts under H.V. switchboards and under high current L.V. switchboards shall be sealed with a suitably fire resistant material. Such sealing shall be rodent and vermin resistant and shall be accessible for inspection.

g) Cable ducts shall be sealed outside switchrooms to prevent the ingress of water into these ducts during flooding.

15.4 Structural

a) Apart from cable ducts, switchroom floors in H.V. switchrooms shall be solid concrete. Removable flooring (i.e. so called “computer room flooring”) shall not be used in H.V. switchrooms. However removable flooring may be used in high current L.V. switchrooms provided that the requirements specified clause 15.3 are satisfied.

b) Any removable flooring used shall be sufficiently strong to carry the full weight of associated switchboards during installation or removal.

c) Removable flooring modules shall be suitable for single person lift (i.e. ≤15 kg.)

d) Floor surfaces within 900 mm. of the front of all H.V. switchboards and high current L.V. switchboards shall be electrically non-conductive (e.g. rubber floor tiles or fire resistant plywood)

e) Steel members supporting switchboards shall be located to suit switchboard mounting feet and to facilitate cabling.
f) Such steel members shall be hot dipped galvanised and shall be stiff enough so that their deflection under load does not cause distortion of the associated switchboard frames.

g) Switchrooms shall be sized and positioned so as to facilitate the installation and removal of switchboards with shipping section lengths up to 3 metres.

h) Switchrooms shall be to facilitate the installation of planned future additional switchboard tiers without compromising clearance requirements.

i) Provision shall be made in all switchrooms for electrical bonding of all structural metal work including concrete reinforcing steel.

15.5 Fire Protection

a) Plywood used as duct covers shall have a fire resistance level rating of FL60/60/60.

b) All surfaces (including ceiling, floors, walls, and doors) within 900 mm horizontally and 1500 mm vertically of H.V. switchgear, or of high current L.V. switchboards, shall have fire resistance level rating of FL120/120/120.

c) Fire extinguishers rated for use on electrical fires shall be provided adjacent to each switchroom exit door.

d) Smoke detectors shall be provided in all switchrooms and these shall be connected to local and remote alarm systems.

15.6 Switchroom Doors

a) Further to AS 2067-2008, inward opening doors shall not be permitted except as authorised in writing by the Principal Engineer.

b) Bollards shall be provided to prevent motor vehicles being parked so as to restrict outward opening doors.

c) Access doors shall be positioned at either end of the switchroom so as to provide a dual means of egress.

d) Access doors shall not be provided directly between High Voltage and Low Voltage switchrooms.

e) Switchroom doors shall be proportioned so as to facilitate switchboard installation. Except for H.V. switchrooms required to house ring main unit switchgear, switchrooms shall be provided with one set of double opening doors of minimum dimensions 2400 mm high by 1800 mm wide.
15.7 Switchroom Security

a) Doors enabling access to switchrooms containing High Voltage equipment shall be provided with Water Corporation EL2 locks so as to limit access to suitably qualified electrical staff.

b) Doors enabling access to switchrooms containing high current L.V. switchboards shall be provided with appropriate locks, the keys to which are issued on a controlled basis so as to restrict access to authorised personnel.

c) Doors to switchrooms containing H.V. equipment or high current L.V. switchboards shall be fitted with locks that can be opened from the inside without a key by using a latch or other simple device, even when the doors are locked from the outside (e.g. “crash bars”).

d) Intruder sensors shall be provided in all switchrooms and shall be connected to local and remote alarm systems.

15.8 Signs

a) Doors allowing access to switchrooms containing High Voltage electrical equipment shall be provided with information and warning plates in accordance with AS 2067-2008 clause 6.9.2.

b) Warning signs as detailed hereunder shall be installed on all doors allowing access to switchrooms containing high current L.V. switchboards. The lettering on such signs shall be not less than 12 mm high.

WARNING
High Fault Level Electrical Equipment
Authorised Persons Only

15.9 Ventilation and Air Conditioning

15.9.1 General

Switchroom ventilation shall be natural ventilation or fan forced ventilation, with the former being preferred where this is practical.

Switchroom ventilation and air conditioning shall comply with the requirements and recommendations of Clause 5.5.7 of AS 2067-2008 so that:

a) suitable indoor climate conditions are provided to ensure correct operation of the electrical equipment, e.g. by adequate cooling, heating, dehumidifying, ventilation or by attention to the design of the building, and

b) adequate ventilation is provided to dissipate heat generated by electrical equipment.

15.9.2 Protection against Solar Heating

The switchroom walls and ceiling shall be insulated and adequate shading provided so as to reduce solar heating to a practical minimum.
15.9.3 **Redundant Equipment**

Any ventilation fans and/or air-conditioning units installed shall be provided on a duty - standby basis.

Switchrooms equipped with ventilation fans and/or air conditioning units shall be provided with automatic temperature monitoring and control equipment:

a) to run the standby unit if the switchroom temperature rises significantly above the set value, or if the duty unit trips out on fault, and

b) to raise an alarm if either of the above occurs

15.9.4 **Location of Power Electronic Equipment**

Variable speed controllers and active filters housed within switchrooms shall be located on outside walls and arranged so that equipment cooling air carrying at least 80% of the associated heat load is discharged directly to outside the building.

15.9.5 **Protection Against Corrosive Gases**

Switchrooms in locations subject to significant sewer gas pollution shall be provided with forced ventilation with carbon filtered air inlets.

15.9.6 **Protection Against Dust**

Measures shall be taken to reduce dust intrusion to the switchroom that is compatible with the IP rating of the switchboard. Such measures may include extension of a concrete or bitumen apron around the outside of the switchroom building and appropriate door seals.

15.9.7 **Equipment Service Conditions**

The switchroom ventilation and/or air conditioning shall ensure that the following minimum service conditions are achieved:

a) the ambient air temperature does not exceed 40°C and its average measured over a period of 24 hours does not exceed 35°C,

b) the average ambient air humidity measured over a period of 24 hours does not exceed 95% and measured over a period of one month does not exceed 90%.

c) the average value of water vapour pressure measured over a period of 24 hours does not exceed 2.2 kPa and measured over a period of one month does not exceed 1.8 kPa.

d) the ambient air is not polluted by dust to a level which would interfere with operation of the electrical equipment or reduce its life significantly,

e) the ambient air is not polluted significantly by smoke, corrosive and/or flammable gases, vapours or salt.
15.9.8 Operations Centres

Switchrooms which are intended to be manned continuously for periods greater than one hour shall be air conditioned in accordance with normal office air conditioning standards.

Similarly, switchroom housing electronic equipment rated for commercial conditions (rather than industrial conditions as specified above) shall be air conditioned in accordance with normal office air conditioning standards.

15.10 Pin Up Boards

Pin up boards shall be provided on the walls in convenient locations within switchrooms so as to allow circuit diagram drawings to be pinned up for reference purposes.
APPENDIX A

Control System

A1 Switchboard Logic Functions and Pump Control Cubicles

a) Apart from the basic logic functions inherent in the Water Corporation’s standard control circuits, all pump station logic functions shall be performed in programmable logic controllers or similar devices mounted in cubicles (called Pump Control Cubicles) external to the main switchboard.

b) Wherever applicable, switchboard control logic functions shall be programmed in accordance with the Water Corporation’s standard logic diagrams.

c) Switchboard logic functions shall be designed and documented in the block logic format, not in the system functional chart format, nor in ladder logic format.

d) Pump Control Cubicles shall be designed in accordance with the requirements of design standard DS 22. Pump control shall be carried out by a combination of a ‘Common Control PLC’ and ‘Unit Control PLC’s’. To provide the optimum level of security, each pump set shall have a dedicated Unit Control PLC. This PLC will enable the pump set to continue to operate under manual control, with full primary and secondary protection, in the event of a failure in the Common Control PLC. The Unit Control PLC’s shall communicate with the Common Control PLC via a serial communications link.

e) The purpose of the Unit Control PLC is to provide all the logic required for the motor/pump control, protection and indication functions. The purpose of the Common Control PLC is to provide the logic for all the functions common to the pump station including pump selection, building security, surge vessel control, interfacing to other equipment (such as RTU’s, main circuit breakers, station flow metering, station pressure metering etc.) under voltage protection, etc.

The Pump Control Cubicle shall have an Operator Interface Panel (OIP) located on the front door with a serial connection to the Common Control PLC. Information from all the Unit Control PLC’s shall be routed to the OIP via the Common Control PLC. The OIP shall be a 6 inch (minimum) colour touch screen, programmed for graphical representation of the pump station (including display of process functions, status and alarms) and suitable for 48 hour trending of analogue signals such as flow, pressure and power. Simpler alpha-numeric displays shall also be provided for each Unit Control PLC for viewing critical status and alarm points and access to the setting of trip points (security access required). Control switches and pushbuttons necessary for control of the pumps shall remain as hardware and not incorporated as software switches within the OIP. The philosophy here is that in the event of an OIP failure, pumps can still be selected via the hardware switches.
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