Assets Planning and Delivery Group
Engineering

DESIGN STANDARD DS 22

Ancillary Plant and Small Pump Stations - Electrical

VERSION 2
REVISION 2

MAY 2023

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 the Western Australia's Work Health and Safety (General) Regulations 2022 to the delivery of Corporation assets. Information on these statutory requirements may be viewed at the following web site location:

Overview of Western Australia’s Work Health and Safety (General) Regulations 2022 (dmirs.wa.gov.au)

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

Head of Engineering

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.

Users should use and reference the current version of this document.

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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

The revision status of this standard is shown section by section below.

REVISION STATUS						
SECT.	**VER./ REV.**	**DATE**	**PAGES REVISED**	**REVISION DESCRIPTION**	**RVWD.**	**APRV.**
1	0/0	01.08.00	All	New Version	NHJ	AAK
1	0/1	19.11.02	1-3	1.1, 1.3, 1.4, 1.7, 1.8 revision	NHJ	AAK
1	0/2	30.09.04	10, 11	1.2, revised; 1.3 DS28 included; 1.5 IEC61000-6.4 & 6.2 included	NHJ	AAK
1	1/0	30.06.06	12, 13	1.2, 1.3, 1.6, 1.7 revised	NHJ	AAK
1	1/1	30.04.07	13	1.5 (c) included	NHJ	AAK
1	1/3	30.08.11	12-14	1.1, 1.2, 1.3, 1.5, 1.7 revised	NHJ	AAK
1	1/6	12.07.17	14-16	1.3, 1.4, 1.7, 1.8 revised	NHJ	MSP
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3	1/1	30.04.07	16	3.1 (d) included	NHJ	AAK
3	1/2	02.06.09	15	3.1, 3.2 revised	NHJ	AAK
3	1/3	30.08.11	15	3.1 revised	NHJ	AAK
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4	0/0	01.08.00	All	New Version	NHJ	AAK
4	0/1	19.11.02	1, 2	4.2, 4.6, 4.7 revision	NHJ	AAK
4	1/1	30.04.07	18	4.7,4.10 revised	NHJ	AAK
4	1/2	02.06.09	16-18	4.4, 4.6, 4.7, 4.10-4.12 revised	NHJ	AAK
4	1/3	30.08.11	17-20	4.6, 4.11, 4.12	NHJ	AAK
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4	2/2	20.04.23	24-25	Section 4.7 revised	EDG	EDG

5	0/0	01.08.00	All	New Version	NHJ	AAK
5	1/0	30.06.06	19	5.1,5.2 revised	NHJ	AAK
5	1/2	02.06.09	19	5.1 revised	NHJ	AAK
5	1/3	30.08.11	21-22	5.1.1, 5.1.2 revised	NHJ	AAK
5	1/4	31.07.13	24-25	5.1.2 revised	NHJ	MH
5	2/0	22.08.22	All	Whole section revised	NHJ	EDG

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6	0/1	19.11.02	3, 4	6.4.5, 6.8 revision	NHJ	AAK
6	0/2	30.09.04	18, 19	6.1, 6.2, 6.4, 6.5 revised, 6.8 last sentence revised	NHJ	AAK

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6	1/0	30.06.06	20-22	6.1, 6.2, 6.5, 6.6, 6.8.1-6.8.4 revised	NHJ	AAK
6	1/1	30.04.07	20	6.3 (d) included	NHJ	AAK
6	1/2	02.06.09	20, 23	6.1.1, 6.1.2, 6.2, 6.10 revised	NHJ	AAK
6	1/3	30.08.11	23-26	6.1.1, 6.2, 6.3, 6.8.1, 6.8.3, 6.10 revised	NHJ	AAK
6	1/4	31.07.13	28	6.6 revised	NHJ	MH
6	1/6	12.07.17	26	6.1.1 revised	NHJ	MSP
6	2/0	22.09.22	All	Whole section revised	NHJ	EDG

7	0/0	01.08.00	All	New Version	NHJ	AAK
7	0/1	19.11.02	1, 3, 4	7.3.2, 7.7.4 revision	NHJ	AAK
7	0/2	30.09.04	22-26	7.7.1-7.7.4, 7.8.2, 7.8.3 revised, 7.9.2 Fig 7.1 & last sent revised, 7.9.3 Fig 7.2 & last sent revised, 7.9.4 Fig 7.3 revised	NHJ	AAK
7	1/0	30.06.06	24-31, 33	7.1, 7.3.1, 7.6, 7.7.1, 7.7.3, 7.8.1-7.8.7, 7.9.1-7.9.9, 7.10, 7.11 revised	NHJ	AAK
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7	1/3	30.08.11	28-29, 33-35	7.1.4, 7.1.5, 7.1.6, 7.3.5, 7.4.1, 7.4.3	NHJ	AAK
7	1/4	31.07.13	36	7.32 revised	NHJ	MH
7	1/6	12.07.17	30, 40	7.1.3, 7.6.1 revised	NHJ	MSP
7	2/0	22.09.22	All	Whole section revised	NHJ	EDG

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8	0/1	19.11.02	1-4, 9, 12-15	8.1.1, 8.1.6, 8.2.1, 8.2.6, 8.3.3, 8.10.3, 8.13, 8.15, 8.18, 8.19 revision	NHJ	AAK
8	0/2	30.09.04	29-31, 33-37, 39-43	8.1.2 1st sentence revised, 8.1.3 revised, 8.1.7 First para revised, 8.2.3 revised, 8.2.7 1st para revised, 8.7 (a)&(e) CEP-7-C included, 8.9.1, Fig 8.1, 8.9.2, 8.9.3-8.9.12, 8.10, 8.11.3, 8.11.5, Table 8.1, 8.11.6, 8.15, 8.17(a), (f)&(g), 8.18 revised	NHJ	AAK
8	1/0	30.06.06	34, 35, 37, 39, 40, 41-45	8.1-8.2.4, 8.2.6, 8.2.8, 8.2.10, 8.2.11, 8.2.12, 8.5, 8.7, 8.9.2, 8.9.4, 8.9.8, 8.9.9, 8.9.11, 8.9.12, 8.11, 8.11.14, 8.12.1, 8.15 revised	NHJ	AAK

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8	1/1	30.04.07	35, 42-44, 46	8.2.12, 8.11.7, 8.15 revised, 8.19 included	NHJ	AAK
8	1/2	02.06.09	34-39, 41, 45-49	8.1, 8.2.1, 8.2.3, 8.2.4, 8.2.6, 8.2.12, 8.3.3, 8.5-8.9, 8.9.8, 8.11.14, 8.12.5, 8.14, 8.15, 8.19-8.21 revised	NHJ	AAK
8	1/3	30.08.11	40-41, 43-45, 46, 50-52, 54-55, 56	8.2.4, 8.2.6, 8.2.9, 8.2.11, 8.2.12, 8.7, 8.9.8, 8.11.5, 8.11.14, 8.15, 8.19.1, 8.19.2, 8.20, 8.21	NHJ	AAK
8	1/4	31.07.13	49-50,63	8.7 ,8.21 Revised	NHJ	MH
8	1/6	12.07.17	54-59	8.11.7, 8.11.14, 8.15, 8.19.1, 8.19.2 revised	NHJ	MSP
8	2/0	22.09.22	All	Whole section revised	NHJ	EDG
9	0/0	01.08.00	All	New Version	NHJ	AAK
9	0/1	19.11.02	1	9.1,9.2 revision	NHJ	AAK
9	0/2	30.09.04	44, 45, 47-50	9.1, 9.2, Fig 9.1, 9.3, Fig 9.2, 9.4, Fig 9.3, 9.5, 9.7, 9.12.1 Fig 9.4, 9.12.2 Fig 9.5, 9.13 revised	NHJ	AAK
9	1/0	30.06.06	48-51, 55-57	9.2, 9.3, 9.5, 9.12.1, 9.12.2 revised	NHJ	AAK
9	1/1	30.04.07	47	9.3 revised	NHJ	AAK
9	1/2	02.06.09	50, 51, 54, 55, 57-59	9.3, 9.4, 9.7, 9.8, 9.12.1, 9.12.2 revised	NHJ	AAK
9	1/3	30.08.11	57-58, 61, 63-64	9, 9.2,9.3, 9.4, 9.5, 9.8, 9.9	NHJ	AAK
9	1/6	12.07.17	60-71	9, 9.2, 9.3, 9.4, 9.11, 9.12, 9.14 revised	NHJ	MSP
9	2/0	22.09.22	All	Whole section revised	NHJ	EDG
9	**2/1**	**09/01/23**	**9.3**	**Section 9.3 modified, p. 77-78**	**EDG**	**EDG**
10	0/0	01.08.00	All	New Version	NHJ	AAK
10	0/2	30.09.04	51-53	10.1.2, 10.2, 10.6 revised; 10.5 new title	NHJ	AAK
10	1/0	30.06.06	59	10.1.2 revised	NHJ	AAK
10	1/1	30.04.07	47	10.1.2 – table revised	NHJ	AAK
10	1/2	02.06.09	61-63	10.1.2, 10.2, 10.5.1-10.5.4 revised	NHJ	AAK
10	1/3	30.08.11	67-68	10.1.2, 10.2	NHJ	AAK
10	1/4	31.07.13	74	10.1.2 revised	NHJ	MH
10	1/6	12.07.17	75	10.7 revised	NHJ	MSP
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11	1/0	30.06.06	63	11.1,11.2 revised	NHJ	AAK
11	1/6	12.07.17	77	11.1, 11.3 revised	NHJ	MSP
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12	0/0	01.08.00	All	New Version	NHJ	AAK
12	0/2	30.09.04	55	12.3 and 12.6 revised	NHJ	AAK
12	1/0	30.06.06	64	12.1,12.3,12.4,12.6 revised	NHJ	AAK
12	1/3	30.08.11	72	12.1 revised	NHJ	AAK
12	1/4	31.07.13	74	12.9 revised	NHJ	MH
12	2/0	22.09.22	All	Whole section revised	NHJ	EDG
13	0/0	01.08.00	All	New Version	NHJ	AAK
13	0/2	30.09.04	57	13.1 Fig 13.1 revised	NHJ	AAK
13	1/3	30.08.11	75	13.2 revised	NHJ	AAK
13	1/6	12.07.17	80	13 revised	NHJ	MSP
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14	0/0	01.08.00	All	New Version	NHJ	AAK
14	0/1	19.11.02	All	Revision	NHJ	AAK
14	0/2	30.09.04	59-61	14.1.1-14.1.3, 14.2-14.2.1, 14.3.1, 14.4.1 revised	NHJ	AAK
14	1/0	30.06.06	71-73	14.2.6, 14.3.1, 14.3.3, 14.4.2 revised	NHJ	AAK
14	1/1	30.04.07	66	14.1.2, 14.2, 14.2.5 revised	NHJ	AAK
14	1/2	02.06.09	69-71	14.1.1-14.1.3, 14.2.1, 14.2.2, 14.2.6 revised	NHJ	AAK
14	1/3	30.08.11	76-77, 79	14.2.1, 14.2.5, 14.3.1 revised	NHJ	AAK
14	1/6	12.07.17	80	14 revised	NHJ	MSP
14	2/0	22.09.22	All	Minor review	NHJ	EDG
15	1/1	30.04.07	70-72	15 new section	NHJ	AAK
15	1/2	02.06.09	74-76	15.1, 15.3, 15.5-15.7 revised	NHJ	AAK
15	1/3	30.08.11	81-85	15.5, 15.6, 15.7, 15.8, 15.9, 15.10, 15.11	NHJ	AAK
15	1/6	12.07.17	80	15 revised	NHJ	MSP
15	2/0	22.09.22	All	Minor review	NHJ	EDG
16	1/4	31.07.13	93-104	All	NHJ	MH
16	1/6	12.07.17	81	6.1.2 revised	NHJ	MSP
16	2/0	22.09.22	All	Whole section revised	NHJ	EDG
17	1/5	30.04.16	100-106	New section	NHJ	MH
17	2/0	22.09.22	All	Whole section revised	NHJ	EDG

App A	1/6	12.07.17	100-116	New appendix	NHJ	MSP
App B		22.09.22	All	New appendix	NHJ	EDG
App C		22.09.22	All	New appendix	NHJ	EDG
App D		22.09.22	All	New appendix	NHJ	EDG

DESIGN STANDARD DS 22

Ancillary Plant and Small Pump Stations - Electrical

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Section *Page*

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.

The design standard (i.e. Electrical Design Standard DS22) sets out design standards and engineering practice which shall be followed in respect to the design and specification of electrical works being acquired by the Corporation.

This design standard does not address all issues that will need to be considered by the Designer in respect to a particular installation.

It is the 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 standard, the Designer shall aim his designs and specifications at achieving this objective.

This design standard is intended for the guidance and direction 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 DS22) covers the design of electrical equipment in locations where the short circuit fault level is not more than 10 kA or where the Service Protective Device is a current limiting circuit breaker or fuse having a peak cut off current of not more than 17 kA at the site prospective fault level.

The scope of this standard covers individual drives rated not greater than 150 kW and transformers rated not greater than 315 kVA, located within small pump stations and treatment plants.

The scope of this standard covers ancillary plant in major pump stations and in both major and minor treatment works, as well as in small pump stations including small bore sites.

1.3 References

Reference shall be made to the following associated design standards and drawings:

DS 20.2	Design Process for Minor Power Electrical Works
DS 20.3	General Design Process Requirements and Policy
DS 21	Major Pump Station – Electrical
DS 23	Pipeline AC Interference and Substation Earthing
DS 24	Electrical Drafting
DS 25	Solar Energy Systems
DS 26	Type Specifications – Electrical
DS 28	Water and Wastewater Treatment Plants - Electrical
DS 29	Arc Flash hazard Assessment of Switchgear Assemblies
MN 01	Electrical Standard Switchboard Designs-Small Pump Stations

1.4 Definitions

Asset Manager	The 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	Senior Principal Engineer – Electrical Standards Section, Engineering.

1.5 National and International Standards

(a) Electrical installations shall be designed in accordance with the latest edition of AS3000 and except where otherwise specified in this design manual, 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 Mines, Industry Regulation and Safety.

(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 the Western Australian Service and Installation Requirements (WASIR).

(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.

(e) Electrical equipment devices used alone or as part of a system must bear the CE mark. The CE mark (Communauté Européenne) indicates that the product manufacturer conforms to all applicable EU directives. The C-tick label indicates compliance with the applicable technical standards for Electromagnetic Compatibility (EMC), conducted and radiated emission, and is required for placing electrical and electronic devices on the market in Australia and New Zealand.

1.6 Use of Type Specifications

Type Specifications (Design Standard DS26) have been prepared in order to assist the Designer to prepare specifications for electrical work designed in accordance with this Design Standard DS22 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 and in alignment with the intent and specification structure of Design Standard DS26. The Designer shall refer to DS26-01, Directions for Use, when preparing Type Specifications.

1.7 Electrical Safety

Electrical installations shall be designed to facilitate safe operation and maintenance of the electrical plant. In respect to High Voltage equipment, mechanically or key interlocked isolating switches, earthing switches and access covers 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's 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's 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 standard are mandatory. If there are special circumstances which would justify deviation from the requirements of this standard, the matter shall be referred to the Principal Engineer for his consideration. No deviation from the requirements of this standard 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 presented 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 9001:2016 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 9001:2016 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.

1.10 Allowance for Future Upgrades

In some projects it may be appropriate to allow for near future expansion/additions. Making provision where there is a definite plan and timetable has some merit. However, making provision for the future, where there is uncertainty or long timeframe, is not effective use of budgets.

Where there is a firm plan, date and budget (usually within 3years at the most) for expansion/additions to the electrical power system then allowance for equipment, space and conduit runs is permitted if agreed by the Project Manager. For example, allowance for space and/or equipment within the switchboard for near future planned addition of solar power systems, allowance for a planned motor-pump unit rating upgrade (cubicle space, equipment, site footprint, conduits etc.).

Where the Project Manager deems it necessary to make allowance for near future expansion/additions, the Designer shall document this on the Primary Design drawings at Engineering Design stage, so it is clear as to the timeframe and allowances being made.

2 BASIC DESIGN INFORMATION

Prior to the preparation of electrical designs for small pump stations, the Designer shall gather the following design information for use during the design process and preparation of Primary Design drawings in accordance with the MN01 drawing templates.

(a) Single Unit Pumping Duty kW

(b) Pump Duty Flow Rate litres/second

(c) Pump Duty Head metres of water

(d) Pump non overloading kW Upper Limit (not applicable to sewage pumps)

(e) Number of Duty Units and Standby Units initially

(f) Number of Duty Units and Standby Units in 5 years

(g) Nominal Speed of Pump Sets

(h) Station Maximum Pump kW Demand initially and in 5 years

(i) Pump Type (Centrifugal, Turbine, Helical Rotor, etc)

(j) Estimated Pump Set running hours/year

(k) Whether 1 or 2 Duty Levels are required

(l) Estimated 1st Duty Starts/hour and 2nd Duty starts/hour

(m) Maximum Allowable Station Shut-Down Period hours

(n) Direction of Rotation of Motor viewed from Coupling End

(o) Hydraulic Control Parameters

(p) Whether Low Sound Level Plant is required

(q) What SCADA I/O and alarm facilities are required

(r) What Water Treatment Facilities are required

(s) What Other Ancillary Equipment is required

(t) Whether Emergency Electrical Supply Facilities are Required

(u) Whether Inverter Supply is required (e.g., Solar)

(v) Supply Authority fault levels (and/or source impedance), transformer impedance and Power Quality Limits applicable to the site

3 MOTORS RATING

3.1 General Criteria for Selection of Motor Rating

(a) Motors shall be rated at not less than 110% of the maximum motor operating load kW.

(b) The 10% margin specified above provides for:

  (i) a 5% margin of error in respect to the pump load requirements,

  (ii) a 5% derating to allow for phase voltage unbalance if the motor is to be connected directly to the supply mains to allow for a negative phase sequence voltage of up to 2%,

  (iii) a 5% derating to allow for harmonic current generated by a variable speed controller, if the motor is to be connected to the latter. (If the variable speed controller is fitted with an output Sine filter, so as to prevent the flow of harmonic currents to the motor, this amount of derating can be reduced somewhat depending on the voltage regulation of the filter).

  Note: The PWM voltage waveform can increase motor losses and increase winding temperature by as much as 10 to 12 degrees Celsius. In general, a 10°C increase in temperature rise can result in a 50% reduction of motor insulation life.

(c) Motors mounted outdoors in direct sunlight shall be derated by a further 10% so as to allow for additional heating due to sunlight.

(d) The motor rating selected shall be the smallest rating available which meets the above ratings.

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

3.2 Pump Drives

Pump duty point power (kW) shall be calculated as follows:

$$P_{kW} = 9.81*10^{-3}*F*H * \eta^{-1}$$

where P_{kW} = kW at duty point

F = flow rate in litres/sec. at duty point

H = head in metres at duty point

η = pump efficiency per unit at duty point

Further to subsections 3.1(a) and 3.1(b) above, since pump loads may vary considerably from the nominal duty point due to changes in hydraulic conditions, motors driving pumps shall have an S1 rating of not less than 120% of the pump kW demand at the specified maximum duty point, or 110% of the pump kW demand at the pump non overloading duty point, whichever is the least.

However, if thermistor or RTD motor winding protection is used, the S1 rating of the motor (after derating as per subsections 3.1 if applicable) need exceed only 110% of the pump maximum duty point kW demand.

4 GENERAL MOTOR REQUIREMENTS

4.1 Rating

All motors, conventional and submersible bore hole, shall be rated for continuous duty (S1) at the nominated voltage and frequency. The S1 power (kW) output rating of motors shall be determined as per Section 3.

4.2 Type

In general, the motors shall be cage type induction motors. However, in special cases where the supply system impedance is high relative to the size of the motor, the use of wound rotor (slip ring) induction motors may need to be considered. Such instances shall be referred to the Principal Engineer for his approval.

Synchronous motors, for use in pump applications, is being promoted by industry as improving efficiency. Further information and policy are discussed in clause 4.14.

4.3 Standard Specifications

Motors shall be in accordance with the requirements of AS 60034 series and be of a type tested design. Where an Australian standard does not yet exist then reference shall be made to BS EN IEC 60034 series.

4.4 Enclosures and Type of Cooling

All motors rated up to 150 kW, other than bore hole motors, shall be totally enclosed fan cooled type to minimise maintenance costs.

All motors to be installed out of doors shall have enclosures rated at IP56D in accordance with AS 60529.

4.5 Voltage Rating

All motors shall be rated for operation from a 3 phase 4 wire 415/240 volt +/- 10 % 50 Hz power supply having a solidly grounded neutral and a phase sequence of RWB.

The nominal voltage rating of all motors shall be the same as the nominal voltage rating of the supply to which the motor is to be connected, e.g., motors to be connected to a 440 volt, 3 phase supply shall have a nominal rating of 440 volt, 3 phase, not 415 volt, 3 phase.

4.6 Windings

4.6.1 Conventional Motors

(a) Winding insulation temperature rating shall be not less than Class 155 (F) to IEC 60085.

(b) Motors shall be designed to have a full load temperature rise of not more than 80°C (Class B insulation temperature rise) to allow full load operation of motors in full sun outdoors with shade temperatures up to 55°C.

(c) Stator windings on motors shall be delta connected and of the random wound type. Form wound motors should only be considered for large motors used in conjunction with VSCs.

(d) Winding phase to phase impulse voltage rating shall not be less than the values specified in figure 6 of IEC 60034-17 (Refer Fig 4.1 below).

Standard PWM variable speed converters (VSC) with cable lengths of 20 metres or more can produce peak voltages at the terminals of the motor that are in excess of the IEC 60034-17 profile. Hence existing motors, to be used with PWM converters with cable lengths exceeding 20 metres, complying with this IEC standard, or those with unknown compliance, shall be fitted with dv/dt filters or sine filters as appropriate unless a detailed insulation impulse withstand analysis is performed with those IEC complying motors and a particular PWM converter.

Motors specified to be used with PWM VSCs shall have winding phase to phase impulse voltage ratings shall not be less than the values specified in Figure 14 Curve A of IEC 60034.25 (Refer Fig 4.1 below).

This enhanced insulation performance (Curve A of IEC 60034.25) goes some way to reducing the effects of motor insulation failure. The combination of high voltage peaks, fast rise time, switching frequency (Refer note below) cable length (transmission line theory), cable type and motor stator winding type (random versus form wound – inter-turn voltage stress is higher for random wound motors) can all influence the motor insulation failure rate and thus significant reduction in motor life.

Note: Studies have shown that the higher the switching frequency the faster is the motor insulation degradation. If the switching frequency is <u>less</u> than 5 kHz the probability of insulation failure is directly proportional to the switching frequency. If the switching frequency is <u>greater</u> than 5 kHz the probability of insulation failure is quadratically proportional to the switching frequency. Higher switching frequencies can also accelerate bearing damage.

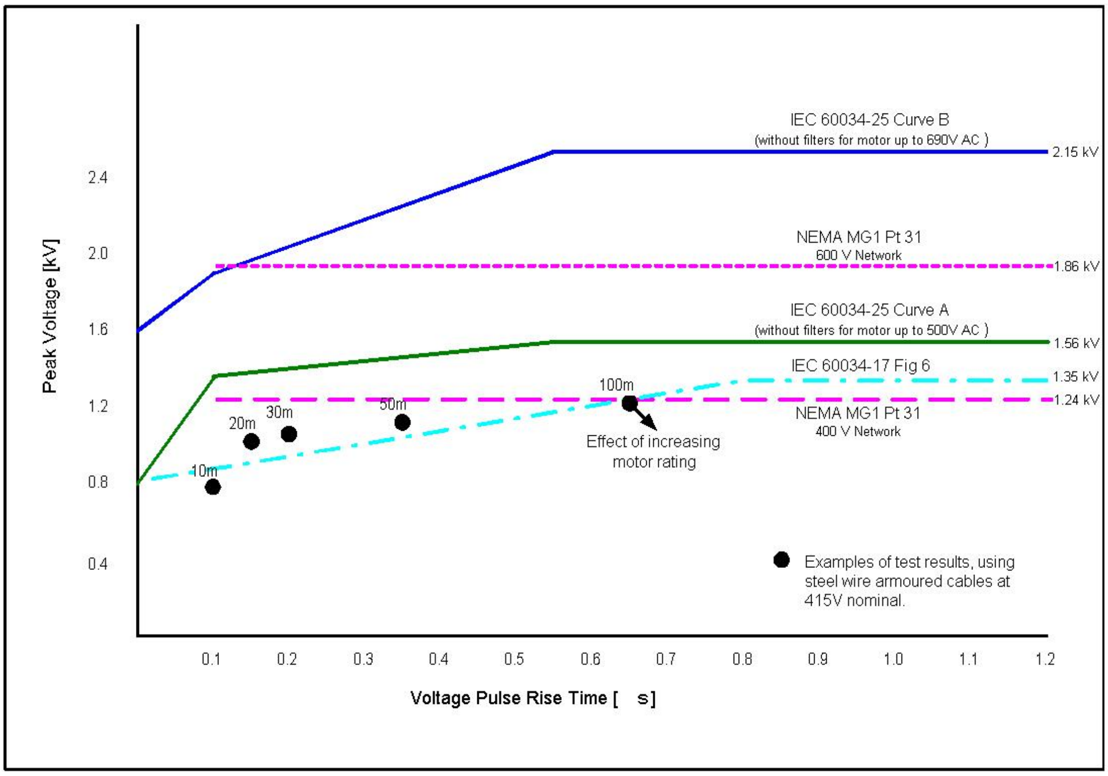


Fig 4.1 Motor Terminal Peak Voltage Limit Curves from IEC60034-17 and 25

Projects requiring the implementation of variable speed converters for new sites shall use new motors compliant with IEC 60034-25. Furthermore, the switching frequency shall be less than 5 kHz and preferably 3 kHz.

The motor manufacturer shall be consulted if the motor is to be used in conjunction with a variable speed converter so that the manufacturer may take account of the increased level of harmonic currents and the increased voltage stress on the insulation.

4.6.2 Submersible Bore Hole Motors

Submersible bore hole motor windings shall be of the wet winding type where water (water/glycol mix) circulates inside the motor distributing the heat more evenly. This reduces the maximum temperatures in the windings by as much as 10 degrees Celsius.

Submersible bore hole motor winding insulation shall have a maximum temperature rating of not less than Class 90 (Y) to IEC 60085. Winding wire shall be copper and double insulated. Stator windings on motors shall be delta connected.

Winding temperature rise, at nameplate full load current, water temperature of 35 degrees Celsius and cooling water flow velocity between 0.15m/sec to 2.5m/sec, shall be such that the final temperature of the upper crown of the winding is 15 Celsius degrees below the maximum allowable winding temperature for the class of insulation installed.

For example, the winding temperature in the upper crown of the winding, with IEC 60085 Class 90 (Y) insulation, shall not exceed 75°C.

4.7 Overtemperature Protection of Windings

Overtemperature protection of motor windings shall be provided as follows:

(a) All conventional standard cage motors rated ≥ 11 kW shall be fitted with thermistor winding protection. It is optional for motors < 11 kW

(b) All submersible sewage pump motors shall be specified to be fitted with thermistor winding protection. Alternative means of winding temperature protection, recommended by the manufacturer such as Flygt Minicas relay, may be utilised for motors not exceeding 100A

(c) All submersible bore hole motors rated ≥ 11kW shall be provided with winding over temperature protection by way of at least one temperature detector installed within the motor. Such temperature detectors shall be resistance temperature detectors (RTDs) or thermistors

If the temperature detectors are in the form of RTDs, they are preferred to be installed in one or more of the following locations, the upper crown of the winding, lower crown of the winding, within the motor frame winding or adjacent to the thrust bearing

In those situations where restricted flow past the submersible bore hole motor is foreseeable/possible (e.g., iron bacteria build-up, use with VSCs or other potential cooling water flow restrictions), the motor shall be fitted with a temperature sensor system (based on 3 wire RTDs) that possess monitoring, alarm and trip functionality

(d) Where over temperature protection of motor windings is to be provided by thermistor protection, the thermistors shall be embedded in the windings during the manufacturing process. Fitting of thermistors to motor windings after motor manufacture is not permitted

(e) Where over temperature protection of motor windings is to be provided by RTDs and the RTDs are to be installed in the motor windings, the RTDs shall be embedded in the motor windings during the manufacturing process. Fitting of RTDs to motor windings after motor manufacture is not permitted

(f) All thermistors shall have a resistance of 1000 Ohms at trip temperature and shall be installed one in each phase winding. All winding RTDs shall be 3 wire industrial platinum resistance sensors in accordance with IEC 60751 class A (PT100)

(g) All motors driven by variable speed converters (PWM) shall be fitted with over temperature protection (thermistors or RTDs) regardless of motor power rating

4.8 Bearings

4.8.1 Conventional

(a) Bearings in motors, other than bore hole motors, shall be ball or roller type and shall be grease lubricated with an extreme pressure grease such as Shell Alvania EPLF2.

(b) Provided that the predicted running hours for the motor over a 10-year period of operation of the plant is less than the rated life of motor bearings, motors other than submersible bore hole motors shall be fitted with sealed for life bearings in those motor ratings for which such bearings are available. Otherwise, all motors other than submersible motors shall be fitted with bearings which have grease nipples and automatic grease pressure venting systems.

4.8.2 Submersible Bore Hole

The motor stainless steel shaft shall run within two hydrodynamic carbon sleeve bearings fitted at both ends of the motor and lubricated by the primary coolant.

Up thrust bearings shall be carbon wear material.

Download thrust bearings shall be Kingsbury type bearings in order to give years of service with negligible wear.

4.9 Motor Resonant Speeds

Where a load is to be driven by a variable speed drive, the Designer shall ensure that neither the motor nor the load has resonant speeds within the proposed drive speed range. Induction motors designed for fixed speed operation shall be specified not to have resonant speeds within +/- 20% of nominal speed.

4.10 Load Protection

(a) Conventional motors driving loads which are prone to jamming shall be fitted with electronic shear pin protection.

(b) Conventional motors rated greater than 22 kW driving sewage pumps which are prone to air locking shall be fitted with underload protection preferably of the underpower rather than under current type.

4.11 Torque Characteristic

4.11.1 General

Reduced voltage motor starting is used to reduce the starting current taken from the electrical supply and limit the voltage disturbance to other customers and equipment.

However, the torque generated by a motor is proportional to the current in the motor windings squared.

Hence if the motor winding current is to be reduced during starting, the torque available to accelerate the motor and its associated load will be reduced by the square of the current reduction. This will extend the start time to full speed and possibly impact successful motor start.

4.11.2 Torque Requirements for Quadratic Loads

The pump torque requirement during starting of a quadratic load such as a centrifugal pump, over the speed range 30% to 100% pump full speed, will be proportional to the square of the speed. At zero speed the pump torque requirement can be expected to be approximately 15% of pump maximum torque falling to approximately 10% of pump full load torque at 30% of pump full speed.

For motor starting to be successful, the motor must generate more torque than the pump requirement over the entire speed range from standstill to pump full speed. For normal cage motor designs, the motor starting torque curve will be closest to the pump starting torque curve at 75% synchronous speed.

On the basis of the pump full load being 90% of the motor rated full load, and after taking into account a small margin of accelerating torque, the motor must generate, at 75% synchronous speed, under reduced voltage starting, a torque of 57% motor full load torque (i.e. 63% pump full load torque).

4.11.3 Torque Requirements for Autotransformer Starting

(a) If an autotransformer is used, the line current will be determined as follows:

$I_{ms} = (I_{lt} - I_{tm}) / N^2$

where I_{ms} = motor starting current

I_{lt} = line current using an autotransformer starter,

N = autotransformer tapping per unit (e.g., = 0.65)

I_{tm} = autotransformer magnetising current,

= say 15% line current (conservative estimate)

Hence using an autotransformer starter on a voltage tapping of less than 80%, the per unit reduction in motor torque is less than the square of the per unit reduction in motor current.

(b) For a typical single cage motor driving a centrifugal pump with a full speed torque requirement of 90% of motor full speed rated torque, the autotransformer tapping to be used shall be determined by the motor infinite bus D.O.L. torque at 75% synchronous speed (0.75 NT) and the pump full load torque (FLT) as follows: -

(i) motor 0.75 NT ≥ 175% pump FLT - 65% tap

(ii) motor 0.75 NT ≥ 150%, <175% pump FLT - 70% tap

(iii) motor 0.75 NT ≥ 130%, <150% pump FLT - 75% tap

(c) For a typical single cage motor driving a centrifugal pump with a full speed torque requirement of 80% of motor full speed rated torque, the autotransformer tapping to be used shall be determined by the motor infinite bus D.O.L. torque at 75% synchronous speed (0.75 NT) and the pump full load torque (FLT) as follows: -

(i) motor 0.75 NT ≥ 155% pump FLT - 65% tap

(ii) motor 0.75 NT ≥ 135%, <155% pump FLT - 70% tap

(iii) motor 0.75 NT ≥ 120%, <135% pump FLT - 75% tap

(d) The values given in sub-paras (b) and (c) above allow for a 10% drop in supply voltage during starting.

(e) If the motor infinite bus D.O.L. torque at 75% synchronous speed is less than 120% of pump full load torque, it may be preferable to use an electronic soft starter.

4.11.4 Use of Electronic Soft Starters

If an electronic soft starter is used, the motor torque will fall as the square of the reduction in motor current. For example, a motor which is suitable for starting with a 65% tap autotransformer starter and which draws 265% motor full load current, would draw 335% motor full load current if used to start the same load with an electronic soft starter.

However, the advantage diminishes for motors requiring autotransformer starters with autotransformer tap settings higher than 75%.

For such motors and electronic soft starters, the starting currents depend on the motor infinite bus D.O.L. torque at 75% speed (0.75 NT) and the pump full load torque (FLT).

For typical motors driving pumps which have a full load torque requirement of 90% of motor full speed rated torque, the maximum currents taken during electronic soft starting will be as follows: -

(i) motor 0.75 NT = 140%, pump FLT - 4 times motor FLC

(ii) motor 0.75 NT = 125%, pump FLT - 4.5 times motor FLC

(iii) motor 0.75 NT = 100%, pump FLT - 4.9 times motor FLC.

4.12 Motor Locked Rotor Current

Generally locked rotor current for conventional motors is limited to 6 to 7 times full load current. In any case the motor locked rotor current shall not exceed 8 times full load current.

4.13 VSC Fed Submersible Borehole Motors

Submersible bore hole motors are more susceptible to harsh voltage conditions such as fast rising pulses (dv/dt) and excessive terminal peak voltage, winding losses and the resulting temperature rise, and common mode current bearing damage when controlled by PWM variable speed controllers. Radio Frequency Interference (RFI) can also be problematic for cables above ground since most bore cables are of the unshielded type.

For example:

a) As the dielectric constant is higher in water (80 times) than air, the cable capacitance is larger which means the characteristic impedance (surge) is lower which ultimately results in higher reflected voltages (and motor terminal peak voltage) at shorter cable lengths. Peak voltages up to twice the DC link voltage (2.7 times the supply voltage) are possible. The combination of high peak voltage and uneven stress distribution in the motor windings can cause low energy partial discharge between turns in the first coil. Such phenomena can cause premature aging of the winding and lead to failure. Submersible bore hole motors, by virtue of their compact design are more susceptible to this phenomenon.

b) Depending upon the frequency range (50Hz and down) temperature rise can be up to 20% higher or more. The thermal inertia of submersible bore motors is significantly lower than for conventional motors.

c) The common mode voltage generated by the PWM variable speed controller causes capacitive discharge current and circulating current within the motor which is more difficult and expensive to address for submersible bore motors.

Traditional dv/dt filters and other mitigation measures commonly employed on conventional motors offer marginal protection and therefore shall not be employed as a mitigation measure.

As the cost of bore motor removal, repair and reinstatement is disproportionately high compared to conventional motors, sound technical mitigation measures must be taken at the design stage to reduce the lifetime operational costs of our bore installations.

Hence, submersible borehole motors driven by PWM variable speed controllers (VSC) shall employ sinusoidal filters (Type 1) on the output of the VSC. Such measures eliminate the need for special screened cable, insulated bearings, enhanced insulation and further derating due to harmonic heating in the motor windings.

Note: 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.

4.14 Motor Efficiency and Synchronous Motor Applications

4.14.1 General

Cage induction motor efficiency has improved remarkedly and, with the use of copper rotor cage bars along with better lamination materials, can achieve international standards (IEC60034-30) IE3 and IE4 efficiency classes with frame sizes complying with the IEC standards up to class IE4 in most ratings. As a copper rotor motor has lower resistance (hence lower losses), the starting current ratio can be higher which must be considered during design *(Note: Inrush current, determined by the effective leakage inductance and resistance, is also significantly increased when moving from class IE1 through to class IE4).* Copper is a superior material however it does come at a premium cost; hence the motor can be more expensive than a standard aluminium rotor motor (up to 30%).

In a general sense, it is important to examine each project situation carefully to see whether the use of higher efficiency motors is the best solution. For example, is selection of an IE4 motor for a small motor application suitable when one considers the higher purchase costs, duty point versus efficiency point (optimal operating range) and the other associated problems as listed below.

The continuous search for efficiency gains in pump applications, and industry applications overall, has led to a determined focus by the general industry for alternative motor technology. Synchronous motors can provide this improvement in efficiency (up to IE5 class), along with higher power factor, however there are significant drawbacks that need to be recognised before attempting to adopt such technology to our pumping systems.

There are basically two motor types being promoted within the pump supply industry, namely Permanent Magnet (PM) and Line Start Permanent Magnet (LSPM) motors. Synchronous Reluctance motors do feature however not as dominant in the water industry as the other two types. The following subsections provide a short overview of these motor technologies.

4.14.2 Permanent Magnet Motors

These motors, unlike cage induction motors, do not have rotor bars but instead have permanent magnets imbedded in the rotor. Consequently, these motors have no slip between the rotating fields of the rotor and stator with the necessary magnetisation provided by the permanent magnets without any associated electrical losses. That is, reduced rotor losses and raised motor efficiency typically between IE3 and IE4. Furthermore, the frame sizes are smaller compared to induction motors with similar efficiency.

However, these motors do have some significant drawbacks, namely:

a) The need for a variable speed controller for operation when it is not required for pump system control purposes. Efficiency gains can be somewhat reduced by the need to use a VSC with the PM motor adding a further 2 to 3 % in losses due to the VSC, not to mention the additional VSC generated harmonic losses within the stator.

b) The risk of permanent demagnetisation due to high current and high temperature. PM motors are more sensitive to elevated thermal conditions.

c) Servicing an d repair. Due to the strong magnets, removing the rotor is difficult and requires special tools and technical expertise not readily available.

d) Higher cost of PM motors along with the additional cost of a VSC and the associated switchboard space for the VSC.

e) Price volatility and availability of rare earth elements, necessary to produce permanent magnets, is of constant concern more so than for materials required for induction motors.

4.14.3 Line Start Permanent Magnet Motors

The line start PM motor is a hybrid combination of a cage induction motor and a PM motor. The rotor has cage bars, but also permanent magnets embedded below the cage.

The significant advantage over normal PM motors is that it can start direct-on-line and run direct from the supply mains without a controller. The cage rotor is active in the start mode and once up to speed the permanent magnets come into play synchronising the rotor with the rotating magnetic field, i.e., synchronous speed. Hence, the LSPM motor will have the same high efficiency, and smaller frame size, as a PM motor. LSPM motors can also operate from a VSC but with a reduction of efficiency due to VSC losses and the damping effect of the cage bars (5 to 10%).

Comparing a LSPM motor with a cage induction motor, the LSPM motor has the following advantages:

a) Higher efficiency when operating direct from the mains supply and thus lower temperature rise.

b) Higher power factor when operating direct from the mains supply.

c) Smaller frame size.

d) Constant speed if necessary for the process.

However, LSPM motors have the following disadvantages:

a) Can only be started direct-on-line or by VSC. Other forms of reduced voltage starting, such as auto transformer, are not possible as such starting will result in severe current and torque oscillations resulting in severe vibration of the motor and load during start. This has been experienced within the Corporation.

b) The starting torque is significantly reduced and oscillates as the permanent magnets develop oscillating torque.

c) The starting current is higher, and the start time is longer. There is a risk of overheating in situations involving a large number of motor starts per hour. Hence the suitability for sewage pump stations must be questioned. Furthermore, the high starting current characteristics can impose restraints on adequate protection grading and may compromise compliance with power quality limits imposed by the Supply Authority.

d) The motor current waveform is distorted with higher order harmonics leading to an increase in motor stray load loss.

e) Not suit able for heavy load (high torque applications) which is generally not a problem for pump type loads.

f) May lose synchronism during voltage sags and surges.

g) Considerations relating to rare earth elements also equally apply to LSPM motors as they do for PM motors, discussed above.

4.14.4 Policy

Based on the information above, clauses 4.15.1 to 4.15.3 inclusive, motors selected for pump applications shall align with the following:

a) Standard cage induction high efficiency (IE2 as a minimum) motors shall be selected for our pump applications.

b) Where premium or higher efficiency (IE3/4) motors are required by the project then copper rotor induction motors shall be considered in line with electrical design advice relating to protection discrimination suitability and power quality compliance limits.

c) LSPM motors shall not be used for pump applications unless specific dispensation is granted, after consideration of all technical compliance issues, for that application by the Principal Engineer.

d) PM motors shall not be employed for pump applications. However small PM motors may be approved for other applications within treatment plants if dispensation is granted by the Principal Engineer.

4.15 Type Specifications and Strategic Product Specification

The following Type Specifications shall be used for specifying the various types of cage induction motors under this standard:

DS26-06	Type Specification for Standard Cage Induction Motors
DS26-20	Type Specification for L.V. Submersible Bore Hole Cage Induction Motor
SPS505	Submersible Sewage Pumps

5 SWITCHBOARD LOCATION

5.1 Switchboards for Pump Stations

5.1.1 General

The Corporation's current outdoor aluminium switchboard design (MN01 and LX drawing series), and its predecessor versions, are designed and design verified (type tested) for outdoor use throughout the state of Western Australia. In order to reduce civil costs (e.g., buildings), all switchboards (main switchboard and pump station switchboard) shall be located outdoors, wherever possible, servicing small pump stations.

However, for installations where the pumping plant is located indoors, the pump station switchboard shall be located in the same building, wherever this is practical. Where this is not practical, all switchboards shall be located outdoors.

5.1.2 Outdoor Switchboards

Switchboards shall not be housed outdoors in metal kiosks as this will compromise the switchboard safety design verification tests, particularly the arc fault and heat rise performance.

Switchboards shall be permitted to be located outdoors provided:

(i) the maximum allowable shut down time is greater than 100 hours,

(ii) the number of switchboard cubicles is not greater than ten and,

(iii) variable speed controllers and associated sine and dv/dt filters provided within the pump station switchboard are rated less than 75 kW.

Note: Sine filters and dv/dt filters installed in outdoor switchboards are derated for operation in a cubicle internal ambient temperature of 60^0C. Sine or dv/dt filters rated greater than 75 kW shall be installed within a building or a transportable enclosure (refer clause 5.4).

5.1.3 Indoor Switchboards

DS20 clause 3.10 provides direction regarding the indoor switchboard configurations that are acceptable.

5.2 Switchboards for Treatment Plants

Outdoor switchboards for small pumping plant and power distribution shall comply with the requirements of clause 5.1.1 and 5.1.2 above.

Indoor switchboards for treatment plants are generally of the MCC (Motor Control Centre in accordance with DS26-17) type, however, the Corporation's standard outdoor switchboard design may be used as an alternative if suitable for the project conditions. In this case compliance with clause 5.1.3 is required.

Switchboards for modular packaged plants have special requirements as detailed in clause 3.11 of DS20 for indoor and outdoor arrangements.

5.3 Incoming Main Switchboards for Sole Use Substations

If the supply to the site is via a Supply Authority owned sole use substation (transformer), the incoming main switchboard shall be an outdoor switchboard located contiguous with (i.e., immediately adjacent to) the transformer compound.

The pump station switchboard may be either integral with or separate from the main switchboard depending upon the site arrangement. Generally, if the pumping plant is greater than 20 metres from the main switchboard then the pump station switchboard shall be located adjacent to the pumping plant.

5.4 Transportable Enclosures

Transportable enclosures housing switchboards and associated equipment are only to be considered where there is a special operational or technical requirement. Transportable enclosures can be used if dispensation is granted, after consideration of all technical compliance and operational issues, for that application by the Principal Engineer.

Switchboards may be permitted to be housed in transportable enclosures provided the latter:

(a) are of robust weatherproof construction,

(b) are adequately thermally insulated,

(c) are sized to provide adequate space for operators and service personnel,

(d) are fitted with automatic changeover duty and standby air conditioners sized to take account of the heat losses from the switchboard,

(e) are compliant with the accessibility and emergency exit facility requirements of AS/NZS 3000 and,

(f) are fitted with ambient temperature monitoring with remote alarm facilities.

6 INCOMING SUPPLY

6.1 Supply Authority Arrangements

6.1.1 General

In respect to supply and metering arrangement requirements, reference shall be made to W.A. Electrical Requirements (WAER), the Western Power/Horizon Power publication entitled "Western Australian Service and Installation Requirements (WASIR)." and the Corporation's design standard drawings MN01 inclusive.

Electrical supply shall be taken at Low Voltage, either from the Supply Authority Low Voltage distribution network or from a Supply Authority owned 'sole use' substation (transformer), with the Supply Authority metering being at Low Voltage. Supply arrangements and various connection configurations are detailed on drawing MN01-11-1.

Supply from a Supply Authority owned 'sole use' substation (transformer) has the advantage that while the metering is done at Low Voltage, the point of common coupling in respect to disturbances to the supply voltage waveform (Power Quality) is at the High Voltage terminals of the transformer. Consequently, the starting current and harmonic interference limits for installations connected to a 'sole use' substation (transformer) are less stringent than those applicable to installations connected directly to the Supply Authority's Low Voltage distribution. Clause 14.2.2 of WASIR defines a 'sole use' substation (as does clause 1.2 of WASIR) and outlines the eligibility criteria for connection.

Note: A Supply Authority owned 'sole use' substation (mostly in a padmount kiosk configuration but may be pole mount in rare cases) is a substation located on a Corporation site, and provided on a "sole use" basis, where the supply Point of Attachment (PoA) is at Low Voltage and the Point of Common Coupling (PCC) is at High Voltage. The supply authority substation is owned by the Supply Authority and paid for, either in full or in part, by the Corporation. Refer to clause 9 for the earthing arrangement.

6.1.2 Supplies to Submersible Bore Hole Pump Stations

If the supply to a bore hole pump station is via a Supply Authority owned 'sole use' substation (transformer), special precautions must be taken to prevent surge currents from High Voltage surge diverters flowing to earth via the bore hole motor and pump casings (thus over stressing the motor winding insulation).

Consequently, if the supply to a bore hole pump station is via an overhead High Voltage line and the "sole use" substation (transformer) is to be pole mounted, the transformer protection surge diverters should be located one line bay back from the transformer pole and should be connected to a separate earthing electrode so as to minimize High Voltage surge.

Similarly, if the supply to a bore hole pump station is via an overhead High Voltage line and the 'sole use' substation (transformer) is to be ground mounted, the High Voltage cable protection surge diverters should be located one line bay back from the cable termination pole and should be connected to a separate earthing electrode.

Alternatively (Water Corporation preference), for both pole mount and ground mount transformer arrangements, the High Voltage and Low Voltage earthing shall employ a separate earthing system to AS 2067 at the Supply Authority's substation.

The above arrangements will not normally be in accordance with the Supply Authority's standard practice and the implementation of these arrangements will have to be negotiated with the Supply Authority. All costs associated with agreed changes to the Supply Authority's standard practice shall be to the Corporation's account.

6.1.3 Single Wire Earth Return (SWER) Supply

It is quite common, in remote country areas, to be supplied from a single-phase High Voltage power line consisting of one aerial line with earth return path. The supply is normally 12.7 kV to earth and terminates at a small Supply Authority owned pole mounted transformer protected by a single drop-out fuse.

The secondary of the transformer is typically 480V with output taps to allow for two separate 240V supplies or a 480V two-phase supply (centre point earthed).

Due to the long runs of aerial HV supply the fault levels at the termination points are generally quite low, hence voltage regulation can be problematic. This restricts line capacity and motor starting limits to levels much lower than would be expected from a normal three-phase supply system. Typical supply transformers are limited to 15 or 25 kVA. Furthermore, motors connected to these supplies are limited to a maximum of 7.5 kW.

For pump stations connected to a SWER system, special consideration needs to be given to the earthing, connection and switchboard power circuit arrangements. MN01 set of drawings do not cover this as standard (small number of applications) so the designer must seek advice from the Principal Engineer for such projects.

6.1.4 Maximum Demand

Section 10 of the WASIR manual discusses the issues, and provides guidance, associated with the determination of maximum demand for a consumer's site. Maximum demand is a critical information element for the Supply Authority (Network Operator) and it is important that the information the Designer provides is as accurate as possible. If the Supply Authority doubts the information, then they may challenge this information leading to possible supply time delays and cost increase for the project.

The designer shall calculate (based on AS3000) and document (via a detailed table) the maximum demand for the site on the Primary Design drawings and be prepared to defend the basis of calculation if so challenged by the Supply Authority.

For small pump station sites, the major demand is usually the number of duty pump units designed to run plus small light and power loads. However, some sites may have submains feeds to auxiliary loads such as chemical dosing plants and the like. In these instances, the loads shall be examined in detail, calculated and documented along with the pump station information. Estimating the auxiliary load purely on the basis of the submain's feeder circuit protection device (e.g., circuit breaker or fuse) is not necessarily an accurate reflection of the maximum demand of the submain, and may lead to an exaggerated value. Alternatively, if the submain circuit is an existing installation, maximum demand can be determined via measurement.

6.2 Main Switches and SPD

The function of the Service Protective Device (SPD) is to protect the incoming consumer's mains and the metering equipment. In situations where the site main switchboard is integral with the pump station switchboard the installation Main Switch does not need to be fitted with protective releases to carry out the same function as the SPD and consequently the Main Switch can be a non-auto circuit breaker provided that the length of conductor between SPD and the line side terminals of the next line of protection does not exceed 3 metres and the cables are suitably protected.

Each motor circuit breaker release and associated motor overload protection must grade with the SPD.

SPD, main switch and transfer switch configurations for the Corporation's normal switchboard arrangements are shown on drawings MN01-1-1 to 5 inclusive.

6.3 LV Feeders

Incoming supply LV mains cables shall be double insulated unarmoured cable protected above ground by medium duty steel conduit to AS 1074 and below ground by Heavy Duty PVC underground conduit to AS 2053.

In the instances where the pump station is more than 30m (cable route length) from the point of supply (Pillar) a separate LV pump station switchboard shall be installed and the LV incoming main switchboard located as close as is convenient to the point of supply, so that the length of incoming LV mains cable is minimised.

Incoming supply mains cables for 80 amp supplies shall be single core 25 mm^2 copper conductor XLPE cables and for100 amp supplies shall be single core 25 mm^2 copper conductor XLPE cables as a minimum.

Incoming supply mains cable from the transformer shall be rated for the full load current output of the transformer considering the site installation and temperature derating factors in accordance with AS/NZS 3008.

6.4 Transformer Overcurrent Protection Settings

Where a Supply Authority owned ‘sole use’ substation (transformer) is provided, the SPD shall be a withdrawable circuit breaker with thermomagnetic releases and this device will provide the transformer overload protection. The Supply Authority must approve the protection settings for SPD’s.

The High Voltage fuses supplying Corporation owned transformers provide only short circuit protection. Overload protection must be provided by Low Voltage circuit breaker protection. For Corporation owned transformers the Main Switch shall be withdrawable circuit breaker with thermomagnetic releases.

For a Supply Authority owned sole use substation (transformer) with a rated temperature rise of 60/65ºC, the current protection minimum pick-up current setting should be set at not more than 105% of transformer nominal rated current.

For a Corporation owned transformer with a rated temperature rise of 50/55ºC, the over current protection minimum pick-up current setting should be set at not more than 115% of transformer nominal rated current.

Protection equipment specifications and arrangements are detailed on drawing MN01-11-1/2.

6.5 Supply Authority Metering

All pump station perimeter fence personnel access gates should be locked with the relevant Regional Operations standard series padlock (Bi-Lock), and the electrical standard EM1 keyed locking system padlock in series. Where supply authority metering equipment is located within the pump station building, the building access door should be fitted with a dual barrel lock with night latch, having both the relevant Regional Operations standard series lock barrel and the electrical standard EM1 keyed locking system barrel. As the supply authority meter readers master key is compatible with the electrical standard EM1 keyed locking system, this will allow the meter readers to obtain access to their equipment as required by the Electricity Act Regulations.

As specified in WA Electrical Requirements, supplies with a maximum demand of not more than 100 amp will be direct current metered. Supplies above this size will be current transformer metered with the current transformers located within the main switchboard.

Whether located outdoors or indoors, the main switchboard metering equipment shall be located within the switchboard behind doors fitted with EM1 keyed locking system locks in order to provide supply authority meter reader access. Viewing windows shall not be provided in such doors because of their susceptibility to vandal damage.

Supply Authority metering arrangements are detailed on drawing MN01-11-1.

6.6 Corporation Substations

Corporation substations, consisting of High Voltage switchgear and a two-winding transformer with associated Low Voltage section, shall be of the prefabricated substation kiosk enclosure type in accordance with the requirements of DS26-02. Padmount is the preferred substation arrangement due to reduced maintenance and safer personnel operability and access. However, there may be situations where pole mounted transformers up to 200 kVA (DS26-29), and associated pole mounted aerial HV switchgear, may be necessary due to technical, environmental or pre-existing conditions such as in borefields. Pole mounted substation applications will require the approval of the Principal Engineer.

A clearance of 6 metres shall be provided between pad mounted substations and any adjacent buildings. Substations will not require substation enclosures.

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.

Transformers shall be sized to be the next standard size above the maximum kVA demand of the site and selected to consider the voltage disturbance/voltage distortion limits, taking into account the typical transformer impedances (clause 7.8), discussed in Section 7.

Substation earthing shall be carried out strictly in accordance with the process and technical requirements of DS23 Pipeline AC Interference and Substation Earthing.

6.7 Generator Set Incoming Supply

6.7.1 General

In most Corporation applications the demand for on-site generator sets (engine and alternator), whether permanent or temporary, is due to demand for a back-up power system to ensure the availability of pumping systems for critical sites. There will also be applications where a generator set is required as the sole supply or when used as part of a solar-diesel hybrid power supply system, but these are not so common.

The designer shall refer to the MN01 standard drawing set for single line power, earthing and connection arrangements.

DS26-05 Type Specification for Stand Alone Transportable Generating Set within an enclosure shall be used for specifying the generating set under this standard.

The following clauses 6.7.2 to 6.7.5 outline some basic considerations for diesel generator sets.

6.7.2 Earthing of Alternator Windings Neutral Point

Both portable and permanent generator set neutral/earth connection arrangements shall comply with MN01-2-1 to MN01-2-4 and the associated design notes.

6.7.3 AVR Characteristics for Alternators

The alternator shall be of the salient pole rotor, including laminated laminations, damper windings design to minimise temperature rise by reducing eddy currents in the rotor pole faces.

The alternator automatic voltage regulator (AVR) shall be three phase sensing and shall respond to the RMS value of the alternator output voltage to maintain stability under non-linear and large motor starting loads.

The AVR shall maintain the alternator terminal voltage to within +/- 1.0% of its set point value when at full load. Furthermore, the generator maximum allowable voltage drop is 20% and, the voltage recovery time is 1.5 seconds to +/-5%.

Alternators with 2/3rd pitch is advantageous as they will generate no 3rd order harmonics, and the bulk of the naturally present waveform distortion in the alternator, supplying 3-phase loads, will be in the 5th and 7th orders. This is an advantage to distribution circuits because 3rd order harmonics add directly in the neutral of the system and can potentially cause heating effects that are additive to the heating caused by non-linear loads. Hence, only 2/3 pitch alternators shall be used.

6.7.4 Alternator AVR Power Supply

A separate permanent magnet generator power supply for the AVR shall be specified for alternators supplying non-linear loads and relatively large motor loads in order to minimize the effects of harmonic voltage distortion and motor starting current voltage dip respectively.

A self-excited excitation system, where an auxiliary winding is set into the main stator slots but displaced from the main winding, may be considered as an alternative to a PMG system. Such a system offers a smaller and lighter alternator design without compromising performance requirements as stated for the PMG system. Approval shall be sought from the Principal Engineer.

6.7.5 Sizing of Engines and Associated Alternators

Since the capacity of the generator set is usually small compared with that of a power supply network, generator sets are frequently characterised by having relatively high source impedance. Therefore, besides sizing for static loads, consideration must be given to the effects of starting a motor on the generator set and on other types of equipment that is also connected to the generator output terminals during the motor starting process.

The essential elements that the Designer shall consider in deciding the size of a generator set are:

a) The characteristics of the largest motor to be started (Speed/Torque/Locked Rotor Current relationships).

b) The characteristics of the load of the largest motor to be started (Speed/Torque relationship – most Corporation applications will be centrifugal pumps).

c) The type of starter deployed (Refer clause 7.2.2) and/or if variable speed controllers are used.

d) The size and type of other loads (static).

e) The sub transient reactance of the alternator (X_d”). This (source impedance X_d”) shall be as low as possible since voltage and harmonic distortion values are directly proportional to its magnitude. Typically, this shall be in the range 0.11 to 0.14 PU.

f) The nature of the alternator automatic voltage regulator (AVR) (Refer clauses 6.7.3 and 6.7.4)

g) The voltage deviation (dip) and harmonic voltage distortion tolerance of loads connected to the generator output bus. (Refe r clauses 7.1.1 and 7.1.2)

The engine shall be sized for either Continuous/Prime Power/Emergency Standby Power, as demanded by project requirements, in accordance with ISO8528.1. Oversizing diesel engines results in performance and maintenance problems and should be avoided.

The alternator shall be sized to be able to supply the maximum continuous kVA demand with a minimum power factor of 0.8. In the ‘normal’ generating set, the alternator rated kVA will be 125% of the engine kW prime power rating.

The generator set shall be capable of supplying motor loads and shall be sized such that voltage dips due to motor starting and total harmonic voltage distortion comply with the requirements of clause 7.1.1and 7.1.2 of this Design Standard.

Variable speed controllers demand non-linear currents from the electrical supply and these currents cause distortion of the input voltage waveform, the amount of distortion being dependent on the supply sub-transient reactance (resistance, being small, is ignored). The sub transient reactance of an alternator is approximately 3 times the impedance of a similar sized transformer, so that generally the harmonic distortion problem is much worse if the installation is being supplied from a generator than if it is being supplied by a transformer. This problem could be overcome by oversizing the alternator by a factor of 3. However, this would require a non-standard generating set arrangement. Oversizing the alternator is not considered a practical solution in the commercial sense for portable generating sets but is an option in special cases.

If a pump station is to include variable speed controllers and the installation is to be made suitable for supply from a generating get, the variable speed controllers may need to be fitted with A.C. line reactors or filters (active or passive) depending on the ratio of non-linear load to total load and whether or not the variable speed controllers are fitted with D.C. bus reactors. The Designer shall carry out calculations to determine whether A.C. line reactors or filters are required, and if so, to determine the size of such reactors.

If the generating set is ‘normal’ in respect to engine and alternator ratings and the non-linear load consists of 6 pulse uncontrolled converters, A.C. line reactors or filters will not be required provided that the ratio of non-linear load kW is less than 40% of the generating set engine prime power kW.

Generator sets and UPS equipment are not by nature incompatible but careful consideration must be applied when connecting to generator sets. Generator sets should be sized based on total load applied by the UPS and the Designer should consider the following points:

a) UPS operating at full rated load, even if total load on the UPS is planned to be significantly less than 100% of the UPS rating. This is necessary because after a power failure, the system will current limit to 100- 125% of the steady state rating of the UPS, in order to recharge the system batteries.

b) Battery recharge rate after power restoration to the UPS.

c) UPS operating power factor and efficiency at full load.

d) Voltage waveform distortion limits. As discussed in clause 7.1.2, a THVD of not more than 10% is required when operating on generator set. Note, improved performance can be achieved by careful consideration of alternator size and sub transient reactance value.

6.8 Solar Inverter Supply

Solar energy systems deployed at Corporation pump station sites, to augment conventional energy supply systems, are generally “behind the meter” systems and connection arrangements are detailed on MN01-1-1 to MN01-11-1.

Isolated solar pump drive systems with battery support, hybrid diesel/solar systems and grid connected solar energy systems are not covered by this Design Standard (DS22) nor DS25. The Principal Engineer shall be consulted for guidance on this matter.

Design Standard DS25 deals with isolated borehole pump solar drive systems without battery support and reference shall be made to this document for such projects.

7 MOTOR STARTING AND SPEED CONTROL

7.1 Voltage Disturbances

Motor starting such as DOL starters, autotransformer starters and electronic soft starters (ESSs), and operation of non-linear loads such as variable speed controllers (VSCs) and uninterruptible power supplies (UPSs) cause disturbances in the voltage waveforms at the point of common coupling with the Supply Authority network and within the Corporation's electrical installation. Voltage dips during starting and harmonic distortion of the voltage waveform due to the operation of electronic equipment are the principal types of voltage disturbance and these are discussed hereunder.

7.1.1 Voltage Level Disturbance Limits within the Installation

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

(a) the voltage to dip more than 15% (IEC 61000-2-4 Class 3) when the installation is being supplied from the Supply Authority network,

(b) the voltage to dip more than 20% when the installation is being supplied from an on-site Corporation generating set.

7.1.2 Voltage Harmonic Distortion Limits within the Installation

At points of common coupling within the Corporation's installation, operation of electronic equipment including electronic soft starters and variable speed controllers shall not cause:

(a) the 3 second mean r.m.s. voltage waveform distortion to exceed 15% (IEC 61000-2-4),

(b) the 10 minute mean r.m.s. voltage waveform distortion level to exceed 10% (IEC 61000-2-4 and BSEN 50160), or

(c) the voltage waveform notching level to exceed 20%.

The above limits shall apply when the installation is being supplied from either the Supply Authority Network or from an on-site generating set.

Within the Corporation's installation, any electronic equipment which uses the 50 Hz signal (e.g., for timing or phase reference) shall either, incorporate 50 Hz band pass filtering, or shall be supplied via a 50 Hz band pass filter.

7.1.3 Voltage Level Disturbance Limits at the Supply Authority High Voltage PCC

The Corporation arrangement whereby the site is supplied via a sole use substation or a Corporation owned substation, where the PCC is at HV terminals, applies.

The permissible level of voltage dip at the point of common coupling with the Supply Authority network caused by motor starting will be determined ultimately by the Supply Authority.

Western Power's Technical Rules specify that the limits on voltage dips caused by individual consumers on Western Power 22 kV and 33 kV networks shall be determined in accordance with AS/NZS 61000.3.7 and it can be assumed that other Supply Authorities will apply similar limits.

If at a particular proposed installation, the minimum period between motor starts will be greater than 10 minutes and the motor start kVA will be less than 0.4% of the short circuit kVA, AS/NZS 61000-3-7 recommends that the Supply Authority permit the installation to be connected without further examination. Generally, this will be the case for small pump stations connected with the electrical configurations shown on Standard Drawings MN01. Otherwise, reference should be made to Design Standard DS21 Clause 4.3.3.

7.1.4 Continuous Voltage Harmonic Distortion Limits at the Supply Authority High Voltage PCC

The Corporation arrangement whereby the site is supplied via a sole use substation or a Corporation owned substation, where the PCC is at HV terminals, applies.

The permissible level of harmonic voltage at the point of common coupling with the Supply Authority network caused by an individual consumer will be determined ultimately by the Supply Authority.

Calculation of applicable limits for continuous harmonic distortion to the voltage waveform at the point of common coupling with the Supply Authority are discussed in detail in Section 4 of Water Corporation Design Standard DS21. Calculation of the harmonic limits by this method is relatively complicated and it is probable that the Supply Authority will not be prepared to undertake this design work for the relatively small installations covered by the scope of the Design Standard.

Western Power’s Technical Rules specify that the limits on harmonic voltage distortion caused by individual consumers on Western Power 22 kV and 33 kV networks shall be determined in accordance with AS/NZS 61000-3-6 and it can be assumed that other Supply Authorities will apply similar limits.

In relation to installations having agreed low power demand (i.e., within the scope of this Design Standard) and where the point of common coupling is at High Voltage, AS/NZS 61000-3-6 clause D2.2 Note 4 recommended that the Supply Authority should not set the limit on individual harmonic levels at below 0.1%. Provided that this limit will not be exceeded in respect to such an installation, it can be assumed that the installation will be acceptable to the Supply Authority.

The short circuit ratio R_{sc} for a particular installation is defined as the ratio of short circuit fault kVA to load kVA at the point of common coupling with the Supply Authority network. If at a particular proposed installation, R_{sc} is more than 1000, AS/NZS 61000-3-6 recommends that the Supply Authority permit the installation to be connected without further examination.

7.1.5 Starting Harmonic Distortion Limits at Supply Authority High Voltage PCC

The permissible level of voltage harmonic distortion at the point of common coupling with the Supply Authority network caused by motor starting (short duration bursts) will be determined ultimately by the Supply Authority.

Electronic soft starters, used for reduced voltage motor starting, generate considerable harmonic current during the start mode.

AS/ NZS 61000-3-6 does not address voltage distortion compliance limits due to short duration bursts of harmonic currents. The supply authorities within Western Australia do not address such limits either.

The designer shall discuss this issue with the supply authority where the starting time, using ESS, exceeds 30 seconds.

Note: AS/ NZS 61000-2-12 specifies that for High Voltage public networks, the ratio between the total harmonic distortion (THD) compatibility limit due to short duration (<3 sec.) bursts of harmonic currents which are not less than 10 minutes apart and the continuous THD compatibility limit shall be 1.38 (11÷8).

7.1.6 Power Quality Limits for Stations Supplied from the Supply Authority Low Voltage Distribution

The permissible power quality limits (voltage level disturbance and continuous voltage harmonic distortion) at the L.V. distribution point of common coupling with the Supply Authority network caused by motor starting, or VSD operation, will be determined ultimately by the Supply Authority.

If the supply authority provides a transformer to power a particular site at their own cost (a distribution substation as opposed to a sole use substation), they retain the right to supply other consumers from the L.V. terminals of that transformer (either immediately or in the future). In such cases, the pump station supply shall be considered to be supplied from the L.V. distribution system.

Normally the supply authority will agree without detailed investigation to motors rated up to and including 22 kW being supplied direct from the supply authority L.V. distribution system provided that L.V. distribution is readily available and the motors are started via reduced voltage starters. Beyond this, a sole use substation may be required to comply with supply authority power quality limits (voltage dip and/or harmonics).

For pump stations supplied from the supply authority L.V. distribution, fixed speed motors rated greater than 4 kW shall be started with either closed transition auto transformer starters or electronic soft starters. Should it be determined that, even with reduced voltage starting, the low voltage disturbance limits cannot be met then a sole use transformer shall be requested. The PCC now being at the High Voltage side of the sole use transformer will ensure compliance.

AS/NZS 61000-2-12 does not cover installations which have a Low Voltage point of common coupling with the Supply Authority network. Western Power have previously specified a voltage waveform total harmonic distortion limit of 1.5% for such installations and, in the absence of any instructions to the contrary, this value must be assumed to be the current requirement. (In most cases, where the installation has a Low Voltage point of common coupling, an unfiltered 6 pulse variable speed drive will not cause total harmonic distortion of the Low Voltage waveform of greater than 1.5% provided that the value of R_{sc} is greater than 200).

7.2 Motor Starting General

7.2.1 Maximum Starting Frequency

The type of motor starting to be used will depend on the size of motor, the capacity of the supply authority supply to the pump station, the location of the pump station and the type of pump to be started.

The maximum starting frequency for a motor-pump unit, emptying or filling a tank, is determined by the pump flow rate and the control volume of the control tank.

If:

Q_p = pump flow rate m^3/hr

V_c = control volume m^3 (i.e. volume between start level and stop level)

N = maximum number of starts per hour

Then N = $Q_p * (4V_c)^{-1}$ starts per hour

7.2.2 Approved Types of Starter

The type of starter to be used in any application shall be selected from the following list of approved types, depending on the starting requirements of the application:

(a) direct online starters (6.5 to 7 x FLC)

(b) closed transition (Korndorfer) autotransformer starters (3.5 x FLC)

(c) electronic soft starters (3.5 to 4 x FLC)

(d) variable speed controllers (1 to 1.1 x FLC)

(e) secondary resistance starters (Note: rare for small pump stations) (1.25 to 1.5 x FLC)

Note: Start current shown in brackets above are typical, based on a motor with 6.5 x FLC locked rotor characteristic, dependent upon the motor torque speed profile, motor efficiency class and the driven load characteristic (in majority of our cases, a centrifugal pump).

7.2.3 Non-Approved Types of Starter

The following types of starters are not approved for general use and shall not be selected without special approval from the Principal Engineer:

(a) star delta starters

(b) open transition autotransformer starters

(c) primary reactance starters

(d) primary resistance starters

(e) liquid resistance starters

The key reasons for rejection of these types of starters is either severe current/voltage/torque transients during transition, considerable heat generated during start, higher maintenance (especially liquid type) and space considerations.

7.2.4 Variable Speed Controllers as Starters

Motors controlled by variable speed controllers can deliver full load torque over the whole speed range from standstill to full speed, in some cases without exceeding the motor rated full load current. However, such controllers incorporate converters which introduce harmonics into the mains supply network and do so for the whole operating time, not just during the starting time.

If the fault level at the site is low it will be necessary to incur further significant expense to reduce the harmonic distortion of the supply waveform to acceptable limits as determined by the Supply Authority.

The use of variable speed controllers merely to limit voltage disturbances to the mains supply network, during motor start, is an expensive option and shall be employed only as a last resort. The designer shall seek dispensation from the Principal Engineer should this be the case.

7.2.5 Starting Small Motors

Normally motors rated up to, and including, 4 kW should be started DOL (direct-on-line) unless some special mechanical characteristic of the load requires slow acceleration during the start sequence. However, in locations having very limited electrical supply capacity, assisted starting may be required for such motors.

7.2.6 Starting High Torque Loads

All helical rotor pump motors shall be started DOL, (or with secondary resistance starters or VSCs as a last resort). Other forms of starters, being reduced voltage starters, means the motor cannot develop sufficient starting torque during start and hence are likely to stall.

7.2.7 Starting Quadratic Torque Loads

Quadratic torque loads, such as centrifugal pumps and fans, have the advantage of low starting torque demand for much of the speed range, so reduced voltage starters (auto transformer and electronic) can provide the motor with sufficient accelerating torque while satisfying the voltage disturbance limit requirements of the power system. That is, a motor during start is required to accelerate the pump to more than 93% full speed without exceeding the starting current limit for the application.

7.2.8 Motor Start Torque

The starting torque has two components, namely, the load torque (work) and the accelerating torque. The load torque is the torque required to overcome the mechanical work being done by the pump and includes frictional and windage losses. The load torque is speed dependant with a speed squared relationship for pumps.

The accelerating torque is the torque developed by the motor minus the ‘workload’ requirement of the load (pump). Increased accelerating torque reduces the starting time and vice versa. Hence reduced voltage starters will extend the start time (as will higher inertia loads) and increase motor winding temperatures.

The interdependency of torque and current during motor start of a load is described as follows.

The ratio of Locked Rotor Torque to the required starting torque is equal to the square of the ratio of Locked Rotor Current to the required starting current. Thus:

$$T_{lrt}/T_{st} = (I_{lrc}/T_{st})^2$$

Where:

T_{lrt} = Locked rotor torque of the motor

T_{st} = Required starting torque

I_{lrc} = Locked rotor current of the motor

T_{st} = Required starting current

Hence a good understanding of the motor torque characteristics will ensure starting meets the site voltage disturbance criteria within a reasonable acceleration time to limit temperature rise in the motor to within design criteria. The Designer shall ensure calculations are implemented during the design phase to ensure compliance with these criteria.

7.2.9 Starting Submersible Borehole Motors

Some submersible borehole motors have water lubricated thrust bearings which require the motor to be operating at close to full speed to provide adequate lubrication. Operation of such motors at less than rated speed may cause unacceptable levels of heating and wear on the thrust bearings. The starting run up time of such motors shall be limited to less than 4 seconds.

Many submersible borehole motors have characteristically low starting torque, and in such cases normal reduced voltage starters will not necessarily accelerate the motor to full speed. Consequently, submersible borehole motors shall be started DOL or with ESSs set so the run-up time to full voltage does not exceed 4 seconds. A warning label shall be installed specifying the above maximum run up time.

If a VSC is used for starting and speed control, then the Designer shall discuss the limitations of such technology with the motor manufacturer

7.3 Electronic Soft Starters

7.3.1 Application

Electronic soft starters (ESS) are suitable to limit motor starting current on motors driving centrifugal pumps and to reduce the mechanical stress where this is a requirement. However, these starters do have some significant disadvantages under some situations, as discussed below, and these must be considered for the application at the design stage.

During starting and stopping, electronic soft starters on pump drives will draw up to 4 times full load current at about 75% nominal speed. If an electronic soft starter is used to ramp pump flow up and down, the motor will be required to operate at this speed for much of the ramping time and significant heating of the motor windings will result.

The ramping up times and ramping down times on electronic soft starters fitted to conventional motors having insulation temperature ratings matching to their rated temperature rises shall not exceed 8 seconds for each ramp.

The ramping up times and ramping down times on electronic soft starters fitted to conventional motors having a Class B temperature rise and class F insulation shall not exceed 15 seconds for each ramp.

The ramping up times and ramping down times on electronic soft starters fitted to submersible bore hole motors shall not exceed 4 seconds. Longer ramping times will result in rapid thrust bearing failure as the wedge of water between the surface of the carbon and the stainless-steel pivot shoes will not have been formed.

Electronic soft starters shall not be used to control motors driving high inertia loads such as shaft driven bore hole pumps or pumps fitted with fly wheels. To do so will extend motor acceleration time and increase the temperature rise of the motor beyond its design rating as discussed above.

Electronic soft starters shall not be used for flow control (e.g., for control of water hammer) as required flow control times are well beyond the thermal protection times outlined above (e.g., 30 seconds, 60 seconds, 5 minutes etc.). Variable speed controllers shall be deployed in such applications (flow control).

7.3.2 Principle of Operation

Each phase of the ESS consists of two thyristors connected in inverse parallel to the motor. Dependent upon the firing angle (α) and time of the thyristors, the voltage gradually increases the supply voltage to the motor at a fixed frequency. This gradual voltage increase can either be controlled by an acceleration ramp or by a value of the current limit.

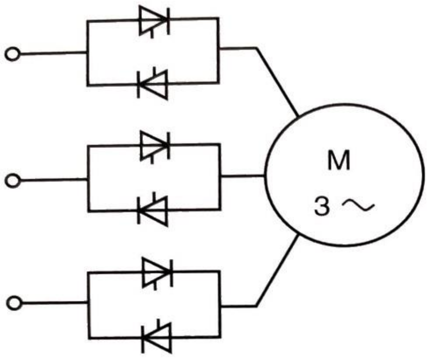


Fig 7. 1 Basic Configuration of ESS

Electronic soft starters limit the RMS starting current by delaying the current flow after each current zero as shown diagrammatically for a resistive load in Fig. 7.2 hereunder. For an inductive load, the current waveform will be rounded off and delayed.

Nevertheless, this starting method introduces a significant amount of harmonic current in the mains supply network during the start or stop sequence. Only odd harmonic currents will be produced, the order of magnitude of which compared to the fundamental will vary depending upon the various start current limit settings and the impedance of the supply system. Table 7.1 below provides an indication of the harmonic current magnitudes.

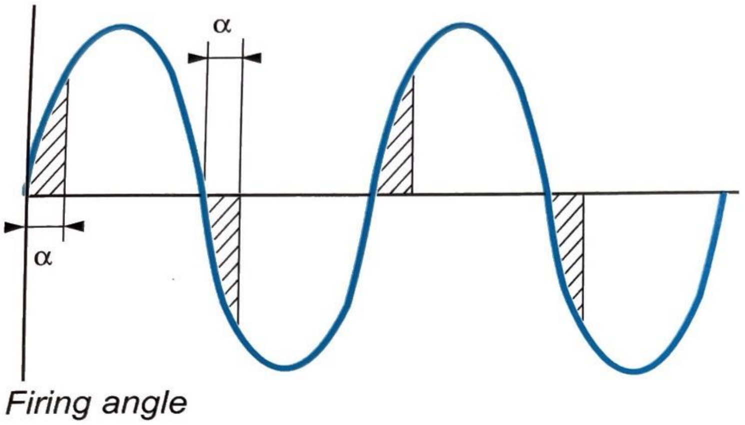
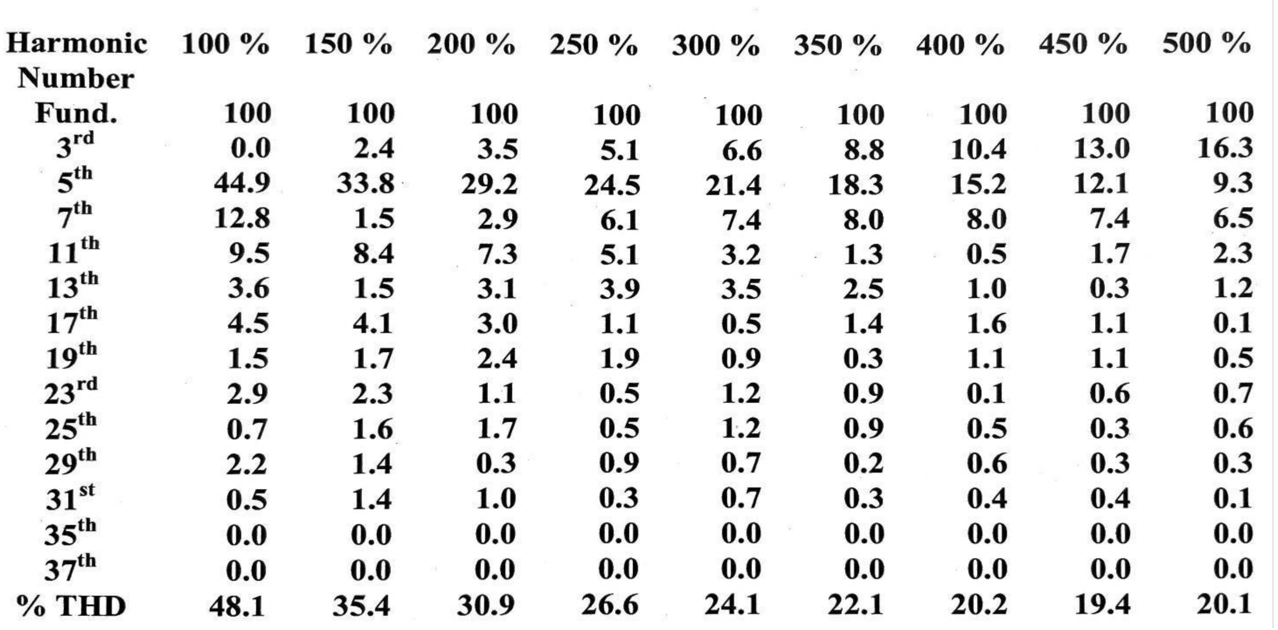


Fig 7.2 Thyristor Limited Current Waveform



Harmonic Number	100 %	150 %	200 %	250 %	300 %	350 %	400 %	450 %	500 %
Fund.	100	100	100	100	100	100	100	100	100
3rd	0.0	2.4	3.5	5.1	6.6	8.8	10.4	13.0	16.3
5th	44.9	33.8	29.2	24.5	21.4	18.3	15.2	12.1	9.3
7th	12.8	1.5	2.9	6.1	7.4	8.0	8.0	7.4	6.5
11th	9.5	8.4	7.3	5.1	3.2	1.3	0.5	1.7	2.3
13th	3.6	1.5	3.1	3.9	3.5	2.5	1.0	0.3	1.2
17th	4.5	4.1	3.0	1.1	0.5	1.4	1.6	1.1	0.1
19th	1.5	1.7	2.4	1.9	0.9	0.3	1.1	1.1	0.5
23rd	2.9	2.3	1.1	0.5	1.2	0.9	0.1	0.6	0.7
25th	0.7	1.6	1.7	0.5	1.2	0.9	0.5	0.3	0.6
29th	2.2	1.4	0.3	0.9	0.7	0.2	0.6	0.3	0.3
31st	0.5	1.4	1.0	0.3	0.7	0.3	0.4	0.4	0.1
35th	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37th	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
% THD	48.1	35.4	30.9	26.6	24.1	22.1	20.2	19.4	20.1

Table 7.1 Typical Current Harmonics for Various Start Current Limit Settings (%) as a Percentage of the Fundamental

Note: As referred to in clause 7.1.5, the Supply Authorities have not applied limits with regards to short duration harmonics. However, this is a consideration within our installation due to possible interference with electronic equipment.

7.3.3 Six Wire Connection

The six-wire connection (Inside Delta) for electronic soft motor starters is as shown at Fig. 7.3 hereunder.

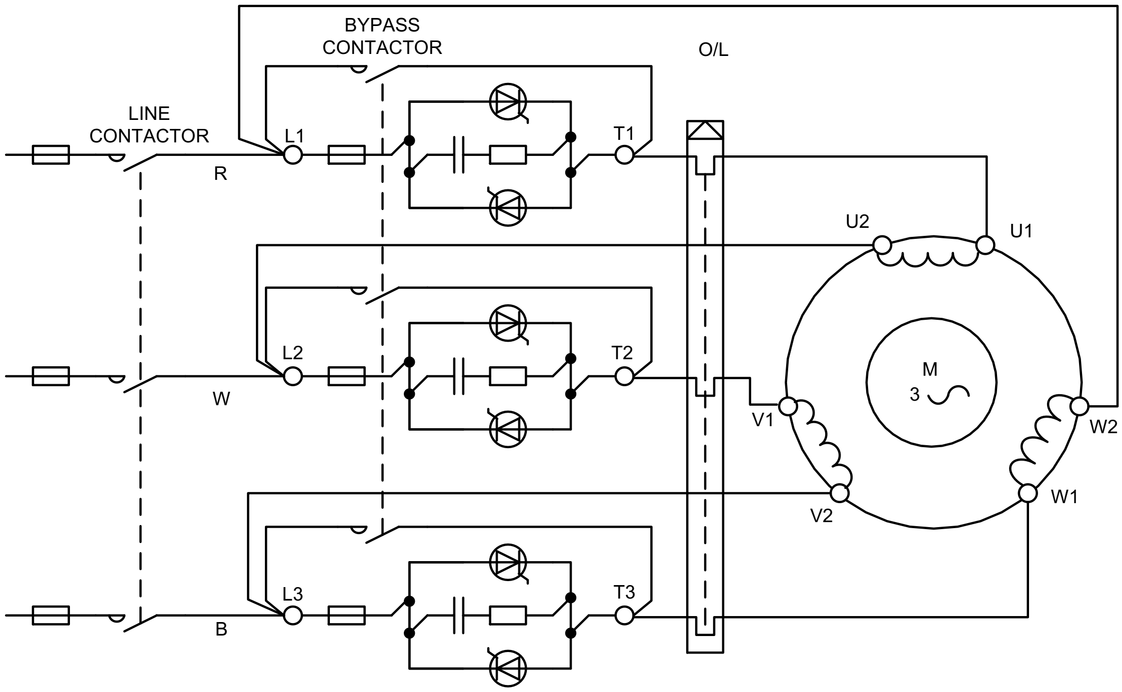


Fig 7.3 Connections for Six Wire Electronic Soft Starter

Connections shown are for clockwise rotation when facing the motor drive end. For anti-clockwise rotation connect the incoming line white phase to starter terminal L3 and the incoming line blue phase to starter terminal L2

This connection provides direct monitoring of the actual currents flowing in the motor windings. The advantage of this connection is that the electronic soft starter can be reduced in rating, and physical size, as the currents are 0.58 lower ($I_{Phase} = I_{Line} /\sqrt{3}$). Consequently, this connection shall generally be applied to the larger motors (>150 kW) covered in DS21.

Note: It would appear that the ESS can be reduced in size to 58% of what is required for outside delta however this is not the case due to the increased SCR heating (I^2t) when connected inside delta. In order to maintain a given average current, the firing angle must be shorter and pass a larger current than would be required for outside delta during starting. Taking this extra SCR heating into account, the ESS must be de-rated a little with the result that the ESS rating can be reduced to 67%, as opposed to 58%, of its outside delta rating.

7.3.4 Three Wire Connection

The simplest form of connection for solid state soft starters is the three-wire connection show at Fig. 7.4 hereunder.

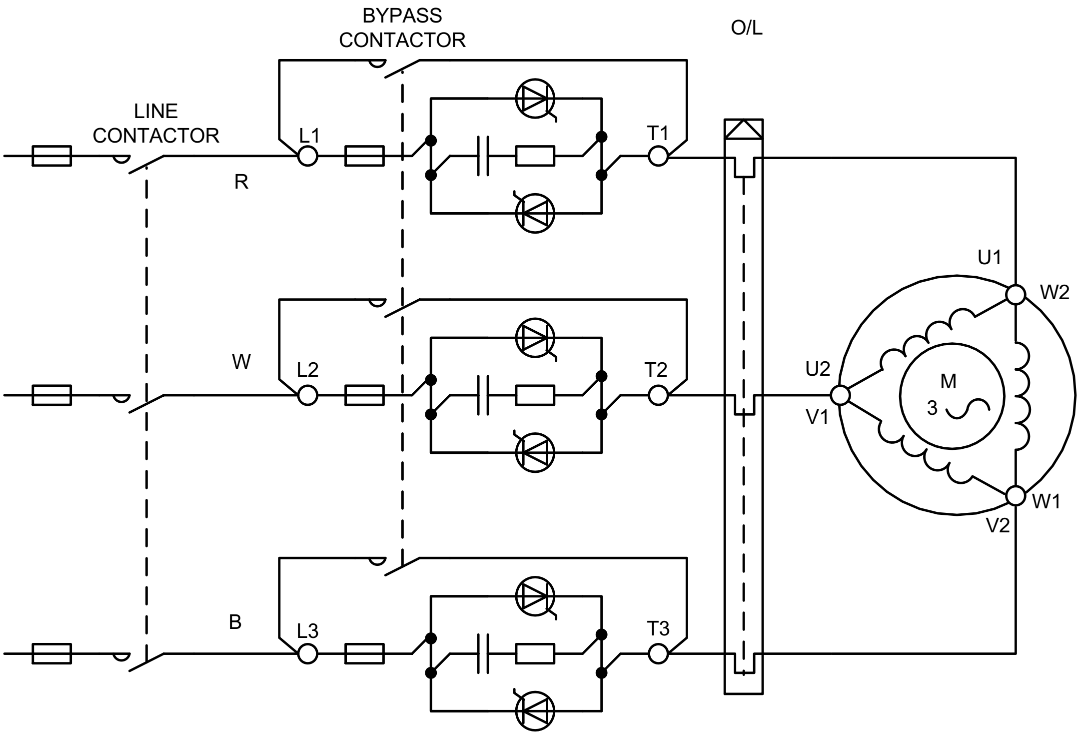


Fig. 7.4 Connections for Three Wire Electronic Soft Starter

This form of connection has the advantage that the starter is in line and the motor cable need be only three-core. Three-wire connection allows for controlled stopping whereas the six-wire is not suitable for controlled stopping. This will be a particular advantage if the associated motor is a bore hole submersible motor. Furthermore, six-wire motor terminal box connection is not generally standard in industry especially for submersible sewage pump motors. Hence, for small pump stations covered by this design standard, the three-wire configuration shall be used.

The MN01 drawing set is based on the three-wire connection arrangement and reference shall be made to these drawings for control and power diagram arrangements.

Semiconductor protection fuses provide protection for the SCRs for electrical faults downstream of the SCRs (high currents flow through the SCRs). The semiconductor protection fuses are expensive, sometimes approaching the cost of an SCR, and generate considerable heat losses adding to the temperature rise within the switchboards. The Corporation’s experience has shown that the risk of such faults is very low and as such the deployment of semiconductor protection fuses for small applications covered by this design standard is considered unnecessary. It must be noted that the circuit is still provided with short circuit protection by upstream motor protection devices.

Hence, for small pump stations covered by this design standard, semiconductor protection fuses shall not be employed. The MN01 drawing set aligns with this determination.

Note: Semiconductor protection fuses shall be used for sizes greater than 150kW as covered by Design Standard DS21.

7.3.5 Surge Protection

Because of the solid-state components in electronic soft starters, these units are more susceptible to failure resulting from voltage surges than are electromechanical items of switchgear. Such voltage surges may be caused by lightning or by High Voltage switching. Generally, the lightning impulse withstand voltage (LIWV) of ESSs are rated no higher than 2 kV.

Consequently, Low Voltage surge diverters shall be provided on the incoming terminals switchboards housing electronic soft starters. Reference shall also be made to clause 8.9.5.

7.3.6 Line Contactors

Line contactors provide isolation of the starters when the motors are not running and consequently further reduce the probability of damage to electronic soft starters due to voltage surges. Line contactors shall be provided on all electronic soft starters.

7.3.7 Bypass Contactors

The voltage drop across conducting thyristors is approximately 0.5 volt. The use of bypass contactors eliminates the associated losses and the resulting increase in enclosure temperature. Bypass contactors shall be installed on all electronic soft starters.

7.3.8 Line Chokes

Generally, line chokes (reactors) will not be required at our small pump stations for harmonic suppression during start.

7.3.9 Type 2 Coordination

As previously discussed, clause 7.3.4, semiconductor protection fuses are not required for small applications covered by this design standard. Hence Type 2 co-ordination is not assured.

However, for large applications (>150 kW) covered by Design Standard DS21 Major Pump Stations, electronic soft starters shall be fitted with semiconductor protection fuses in accordance with AS 60269.4.0 so as to provide Type 2 co-ordination in accordance with AS 60947.4.2.

7.4 Variable Speed Controllers

The basic 6 pulse PWM variable speed controller (VSC) configuration is outlined below (Fig 7.5) along with explanatory notes:

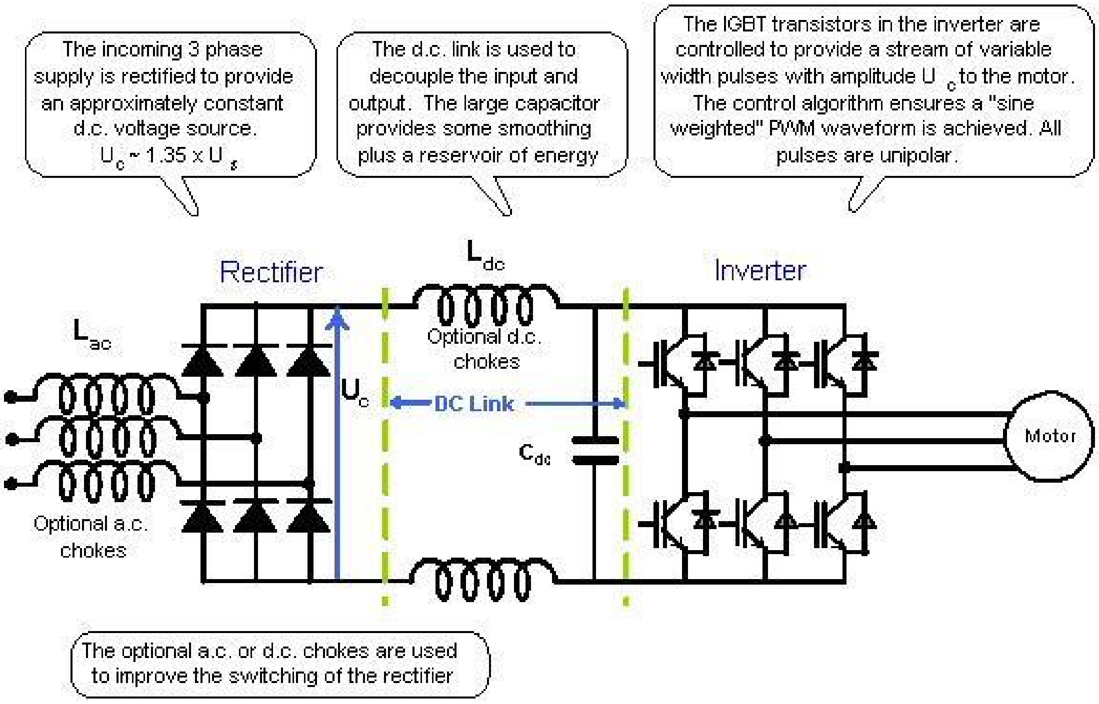


Fig 7.5 Basic Configuration of VSC

7.4.1 Variable Speed Controller Type and Performance

Variable speed controllers (VSC) in the output power range covered by this Design Standard shall be of the type having an uncontrolled 6 pulse converter input (rectifier) and a pulse width modulated (PWM) output.

Variable speed controllers in this range are available with controlled converter inputs such as the active front end type (IGBT rectifier) however these should only be used in special circumstances as approved by the Principal Engineer.

Note: For VSCs with PWM active front ends, the DC link voltage operates approximately 15% higher than for standard 6 pulse VSCs. The effect is similar to increasing the supply voltage by up to 15% (treat a 415 V application as if it was supplied with 480 V), therefore enhanced insulation or other preventative measures will be required.

Variable speed controllers (VSC) in the output power range covered by this Design Standard shall be rated for operation from a 415V 3 phase, 50 Hz (+1.5%) power supply, having a solidly grounded neutral. Low Voltage 690V VSCs shall not be used for applications covered by this Design Standard unless there are special circumstances approved by the Principal Engineer.

The input current of an uncontrolled 6 pulse converter contains a significant number of harmonics (5th, 7th, 11th, 13th, 17th etc.) and in practice the magnitude of these harmonic currents will be dependent upon the source impedance to the site. Hence it is important, when performing harmonic calculations, that the input harmonic spectrum is obtained, from the manufacturer, for the site-specific short circuit ratio.

Note: The short- circuit ratio, R_{sc}, is defined as the ratio between the short circuit apparent power of the supply at the PCC (S_{sc}) and the rated apparent power of the load (S_L).

$$R_{sc} = S_{sc} / S_L$$

Harmonic order (h)	5	7	11	13	17	19	23	25	THDI
6-Pulse (Theoretical)	20%	14.3%	9%	7.7%	5.9%	5.3%	4.3%	4%	29%
6-pulse without line reactor	80.0%	58.0%	18.0%	10.0%	7.0%	6.0%	5.0%	2.5%	101.5%
6-pulse with 2-3% line reactor	40.0%	15.0%	5.0%	4.0%	4.0%	3.0%	2.0%	2.0%	43.6%
6-pulse with 5%-line reactor	32.0%	9.0%	4.0%	3.0%	3.0%	2.0%	1.5%	1.0%	33.9%
6-pulse with line harmonic filter (LHF)	2.5%	2.5%	2.0%	2.0%	1.5%	1.0%	0.5%	0.5%	4.9%
12-pulse (comparison only)	3.7%	1.2%	6.9%	3.2%	0.3%	0.2%	1.4%	1.3%	8.8%

Table 7.2 Typical values of harmonic currents

VSCs shall use Category C3 (industrial environment) RFI filters specified to AS/IEC/EN 61800-3. Equivalent emission class in EN 55011: Class A Group 2, Frequency converters installed in the second environment (industrial) with a supply voltage lower than 1000 V. Built-in RFI filters shall be provided as part of the VSC where EMC conformance can be tested as an integrated unit. Variable speed converters shall comply with the EU directives (CE Mark) applicable to the design and manufacture.

VSCs are available in many different degree of protection ratings (IP) such as IP00, IP20, IP54 IP55 or IP66 (for high humidity, high concentrations of dust or aggressive gases) depending upon application. The Corporation's standard outdoor switchboard design incorporates IP66 VSCs up to 75 kW within a ventilated cubicle (IP20) as described further in standard drawings MN01 and LX**.

Conformal-coating Class Ratings of VSC circuit boards shall be 3C3 as a minimum.

In order to reduce the harmonic demand, variable speed controllers may be fitted with such devices as DC bus reactors, AC line reactors, AC line filters (passive or active), or a combination of such devices, either as standard or as add on modules. Such devices shall be purchased from the vendor as part of each variable speed controller.

Note: Passive AC line filters connected to VSCs generally have leading power factor at low load and may present problems when connected to a generating set supply. Such circumstance can drive the alternator into over voltage conditions potentially causing incorrect operation or damage to the load or the alternator. The ability of an alternator to absorb reactive power is defined by a reverse kVAR limit therefore alternator capability curves must be consulted during design.

7.4.2 Motor Insulation Under Voltage Stress

The dv/dt ratio of the raw output voltage waveforms from PWM variable speed controllers is high and application of this voltage waveform (high rate of rise and magnitude) to the motor terminals may over stress the motor insulation depending on the length of motor cable and the type of motor insulation. Clauses 4.6, 4.13 and Appendix C (VSC PWM Voltage Stress on Motor Winding) refers.

The mitigation measures to be considered for conventional motors include:

a) Enhanced motor winding insulation to IEC 60034-25 (Refer clause 4.6.1)

b) Use of form wound rather than random wound windings

c) Keep motor cable lengths short

d) Output reactors (common mode chokes)

e) Output dv/dt filters

f) Output sine filters

g) Motor termination units

A formal insulation study for the VSC – Motor combination will determine the most appropriate mitigation measure. The Designer shall carry out, or arrange for, such a study relevant to the application. Note that in some cases the selection of mitigation may also assist in the mitigation of bearing currents. Furthermore, for mitigation measures d, e, f and g above, volt drop effects within the VSC-motor circuit must be considered.

By far the best technical solution, for mitigating the majority of damaging effects, is an output sine filter, however it is the most expensive at approximately 50% the cost of the motor. The benefit is removal of harmonic motor losses, reduced motor noise, screened cable is not required, allows standard motors and long motor cables, removes bearing currents (CMC) and reduces RFI.

As discussed in clause 4.6.1, variable speed controllers shall have a switching frequency of less than 5 kHz and preferably set at 3 kHz, except when used in conjunction with sine filters, in which case the switching frequency shall match the requirements of the sine filter.

7.4.3 Motor Bearing Currents and Shaft Voltages

Within asinusoidal supply network, the voltages are balanced and symmetrical under normal conditions meaning that the vector sum of the three phases is always equal to or very close to zero. This is not the case for synthesised voltages by a PWM inverter. This leads to a non-zero neutral at the inverter output which is effectively a common mode voltage source. Bearing damage in power drive systems (PDS) is caused by a high dv/dt 'voltage to earth', or common mode voltage (CMV). Fig 7.7 refers.

This change in voltage relative to earth causes transient current (Common Mode Current - CMC) to flow from motor windings to earth through stray capacitances. CMC is zero sequence current.

CMC: $I_{cm} = C \times dv/dt$ where C is capacitance.

The CMV/CMC may cause bearing damage is three ways:

(a) High frequency circulating currents,

(b) Capacitive discharge currents and,

(c) High frequency shaft grounding currents

The two of major concern for our motors supplied by VSCs is (a) and (b) above. These are shown in Fig 7.6 for clarity.

Note: Capacitive discharge currents phenomena is referred to as EDM or electric discharge machining.

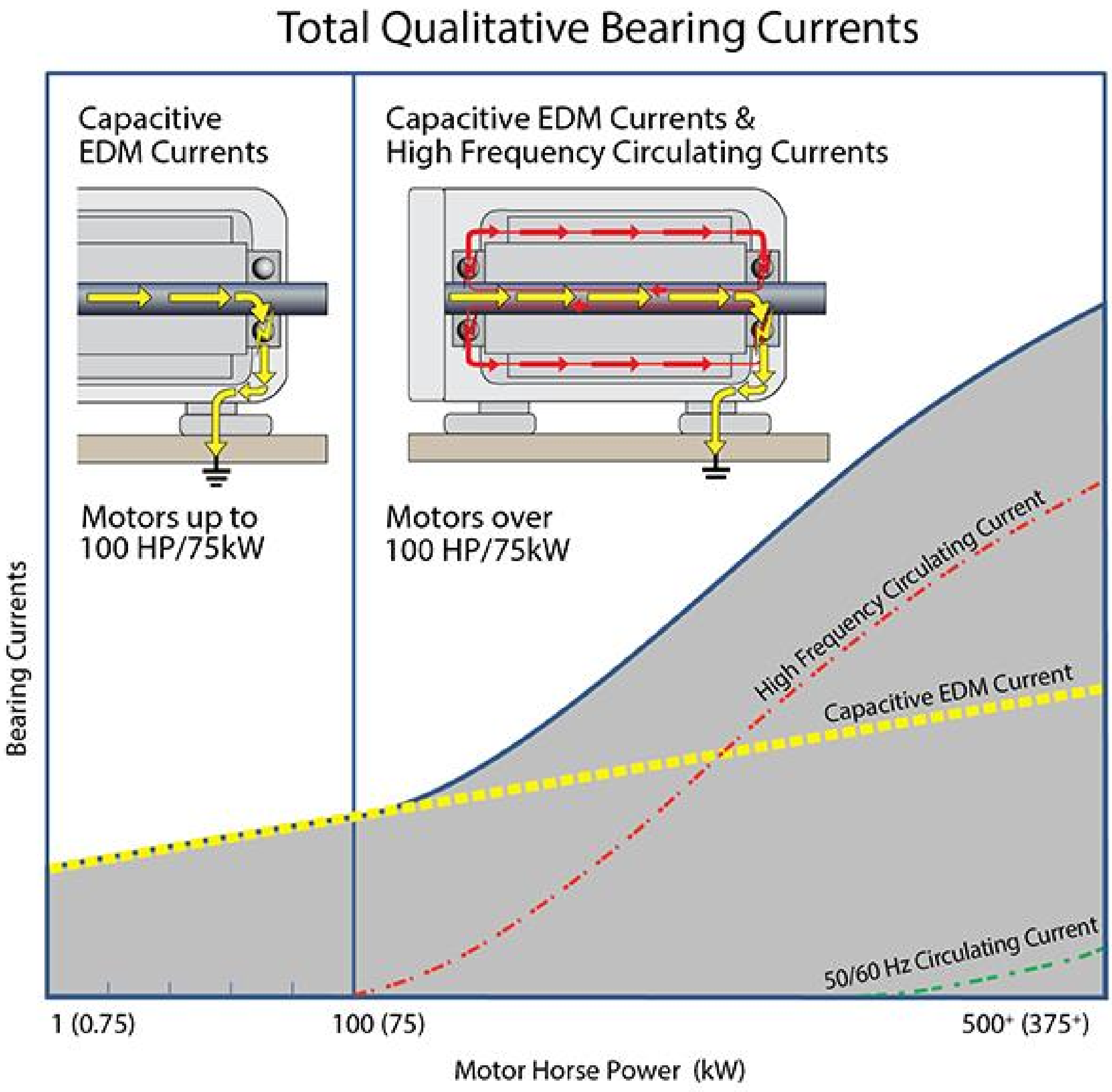


Fig: 7.6 Bearing Current vs Motor Rating

The third CMC mechanism, HF shaft grounding currents, flow through the winding, the motor shaft, coupling, driven shaft, bearings (motor and pump), machinery and on to the Protective Earth. With a current following this path, there is not only a risk of damage to the motor bearings, but also to the bearings of the driven machine. This problem is caused by high dv/dt CMV and by high HF return impedance from the motor frame to the VSC protective earth bus, relative to other earth paths. Hence, EMC-compliant installation standards applicable to grounding and high-frequency equipotential bonding measures are essential to mitigate.

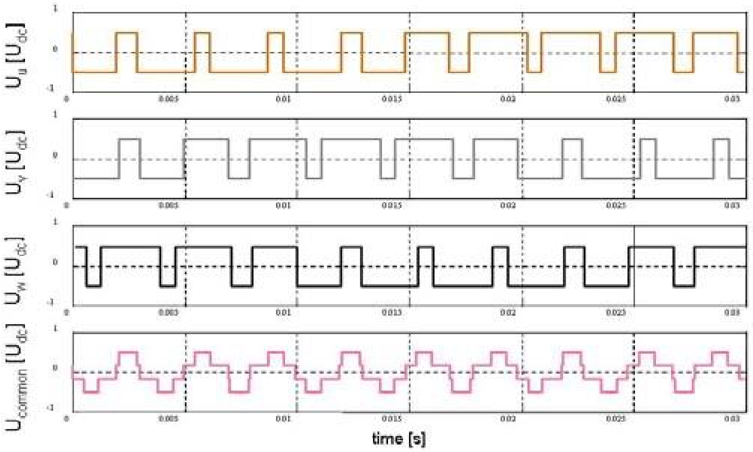


Fig: 7.7 Typical Line voltages for 3 phases and CMV

7.4.4 Bearing Current Mitigation Measures

The following table is a summary of potential mitigation measures for bearing currents.

Item	Mitigation Measure	HF Circulating Currents	Capacitive discharge currents (EDM)	HF shaft grounding currents	Comments
1	Good earthing/bonding installation practice. HF bonding applied between VSC, motor and load.	Not Effective	Not Effective	Effective	Prevents possible damage to driven load. Must ensure lowest possible impedance path on the shield connection.
2	NDE insulated or ceramic bearing	Effective	Not Effective (Only protects one bearing)	Not Effective (Only protects one bearing)	
3	Output dv/dt filter	Limits dv/dt effects	Limits dv/dt effects	Limits dv/dt effects	Still requires other measures
4	Output Sine filter (common mode type 1)	Effective	Effective	Effective	Most effective measure. Eliminates the need for special screened cable, insulated bearings, enhanced insulation and further derating due to harmonic heating in the motor windings.
5	NDE and DE insulated or ceramic bearing	Effective	Effective	Effective	Most effective for small frame sizes. Less practical for large frame sizes (>250) Does not protect bearings in driven load. May require additional countermeasures
6	NDE and DE insulated, or ceramic rolling elements and Insulated coupling	Effective	Effective	Effective	Most effective for Low Voltage motors up to 500 kW. Less practical for large frame sizes. May require additional shaft grounding ring/brush (e.g., AEGIS)

7	Insulated coupling	Not Effective	Not Effective	Effective	Prevents possible damage to driven load.
8	NDE Insulated bearing and one DE shaft grounding ring/brush	Effective	Effective	Effective	Possible higher maintenance
9	One DE shaft grounding ring/brush	Not Effective	Effective	Effective	Possible higher maintenance. Generally fitted to frame sizes 250 and above.
10	Two shaft grounding rings/brushes. DE and NDE.	Effective	Effective	Effective	Possible higher maintenance
11	Modify switching frequency	Only limited effect	Only limited effect	Only limited effect	Still requires other measures
12	High frequency common mode magnetic core inductors around the motor cables.	Not effective	Effective	Effective	Generally fitted to frame sizes 250 and above.

Table 7.3 Potential Mitigation Measures for Bearing Currents

The Corporation’s policy to cover the prevention of bearing damage for small motors (covered by DS22), as a minimum, driven by VSCs is summarised below:

a) HF circulating currents primarily become an issue with frame sizes above 250 (55kW 2P, 55 kW 4P, 45 kW 6P or 37 kW 8P), hence insulated NDE bearings shall be fitted to all motors with a frame size of 250 or greater.

b) EMC- compliant installation standards applicable to grounding and high-frequency equipotential bonding measures shall be applied to all VSC driven motors and consist of:

- Shielded, symmetrical motor cable. Shielded cables with symmetrically arranged three-phase conductors L1, L2 and L3 and an integrated, 3-wire, symmetrically arranged PE conductor. (Clauses 10.1 and 10.2 refer.)
- Shield connected at both ends via 360-degree EMC compliant glands.
- HF potential bonding between motor terminal box and motor frame for frame sizes 250 and above.
- HF potential bonding between motor frame and pump if motor and pump are not on the same metallic baseplate.

The application of dv/dt filters, and especially CM sine filters, are effective measures to mitigate bearing damage and can be used if they are required to mitigate other phenomena (e.g., motor insulation damage, additional heating, RFI, etc.). However, such filters are expensive and need to be carefully considered.

The table of mitigation measures (Table 7.3) may be considered where appropriate and in consultation with the Principal Engineer.

7.4.5 Surge Protection

VSCs are more susceptible to failure resulting from voltage surges (caused by lightning or by High Voltage switching) than are electromechanical items of switchgear. Generally, the lightning impulse withstand voltage (LIWV) of VSCs are rated no higher than 4 kV.

Consequently, Low Voltage surge diverters shall be provided on the incoming terminals of motor control centres or switchboards housing or feeding VSCs. VSCs located greater than 10 metres from the surge diverter shall be fitted with surge diverters at the VSC input terminals. Reference shall also be made to clause 8.9.5.

7.4.6 Motor Harmonic Current Losses

Harmonics distortion raises the losses in AC induction motors and cause increased heating, due to additional copper losses and iron losses (eddy current and hysteresis losses) in the stator winding, rotor circuit and rotor laminations. These losses are further compounded by skin effect, especially at frequencies above 300 Hz.

The efficiency of fixed speed motors supplied with a voltage having a harmonic distortion level at the maximum value allowable as defined in clause 7.1.2 can be expected to suffer approximately a 3% reduction in efficiency and the Designer shall allow for this reduction in available output from fixed speed drive.

Depending on the modulation algorithm used in the particular variable speed controller, motors connected to PWM variable speed controllers may suffer a reduction in efficiency of up to 5% (IEC 60034-17 refers).

Motors shall be derated for such harmonic losses as per clause 3.1 (b) (iii).

7.4.7 Transformer Eddy Current Losses

Harmonic current leads to additional load on transformers and associated additional losses.

Due to harmonic currents, winding eddy current losses are proportional to the square of the load current and approximately proportional to the square of the frequency. The proportionality to the square means that a major part of the winding losses and temperature increase is caused by eddy current losses.

$$P_{EC} = P_{ECR} . \sum_{h=1}^{h=50} \left(\frac{I_h}{I_{rms}}\right) . h^2$$

Where:
P_{EC} = the winding eddy-current losses (watts)
P_{ECR} = the winding eddy-current losses under rated conditions (watts)

h = the harmonic order

h = 50 = the highest significant harmonic number
I_h = the rms current at harmonic “h” (amperes)
I_{rms} = the rms current under rated frequency and rated load conditions (amperes)

Stray load losses in the core, clamps and structural parts will also increase. However, these losses will not increase at a rate proportional to the square of the frequency, as in the winding eddy losses. The effects of these losses will also vary depending on the type of transformer (oil or dry). The temperature rise in these non-winding parts of dry-type transformers is minimal however, these losses are more prominent in oil-filled transformers.

To prevent overload conditions due to harmonic current loads, transformers need to be derated. The derating is generally based on the harmonic load factor or the k-factor. For transformers of ratings within the scope of this design standard, the k-factor is:

$$k = \frac{1}{\sqrt{1+0.1(\sum_{h=2}^{h=50} h^{1.6}}.\ (\frac{I_h}{I_1})^{2})}$$

7.4.8 Electromagnetic Interference from Variable Speed Controllers

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.

If an isolating transformer is being provided, the interference problems shall be avoided by providing an earthed screen between the primary and secondary windings and by installing screened cable between the transformer and the variable speed controller. Otherwise input common mode RFI filtering shall be provided (most likely situation for DS22 type installations).

The output voltage waveform generated by the PWM type of variable speed controller is at a high frequency ($f_v = 1/ (\pi \text{ x } t_{rise}$) and contains multiple recurring fast transients. Consequently, unless an output sine filter is provided, the cable connecting the variable speed controller to the motor shall be screened, with the screen earthed at both ends.

The types of screened cable to be used with variable speed controllers are discussed in Section 10.

7.4.9 Integrated VSC/Motor Package Unit

The combined motor VSC topologies in which the VSC is integrally mounted within the motor enclosure, typically as an extension to the motor casing, is sometimes offered as an economical solution for very small pumping projects.

The very short cable length between the VSC output connections and the motor windings limits the reflections and therefore the peak voltage problems do not exist. Taken in the context of the additional benefits of simplified installation, reduced EMC problems and lower overall costs, this solution is well suited to lower power pumping applications.

Depending upon the application suitability, such VSC/motor topologies are acceptable up to 15 kW motor rating.

7.4.10 Isolation

The standard arrangement for supply to the VSC will not include a line contactor. However, as an option, line contactors may be added to the supply side of VSCs shown on MN01 and LX drawings and as outlined below.

If the variable speed drive is required to be fitted with an emergency stop function in accordance with AS/ NZS 3000, or where motor de-contactors are fitted, the variable speed controller shall be supplied via a line side contactor to provide complete drive isolation under emergency stop or motor isolation (via de-contactor) conditions.

If the controller is to be de-energised as part of normal operations, isolation shall be achieved by use of a line side contactor rather than a circuit breaker.

If the controller is to be left energized, except under conditions outlined above, the controller's cooling fans shall be thermostatically controlled as part of the manufacturer's standard design.

7.4.11 Resonance

Resonance is possible in transformer fed installations which include both power factor capacitors and variable speed controllers. As a rule of thumb such resonances will be avoided provided that the capacitor kVAr is not more than 20% of the supply transformer rating. Since variable speed controllers operate at a relatively high power factor, resonance is not likely to be a problem as far as installations covered by the scope of this Design Standard are concerned.

7.5 Calculation of Voltage Fluctuation

The Designer shall calculate the motor starting kVA (or starting current) and shall obtain the source short circuit fault level kVA (or supply source impedance) from the Supply Authority.

In accordance with Table 4 of AS/NZS 61000.3.7 if the motor starting kVA is less than 0.4% of the short circuit fault level kVA at the point of common coupling with the Supply Authority High Voltage network, the Designer may assume that the voltage dip at the point of common coupling with the Supply Authority High Voltage network caused by motor starting is acceptable without further examination.

If the motor starting kVA is more than 0.4% of the short circuit fault level kVA at the point of common coupling with the Supply Authority network, the Designer shall obtain the site supply source impedance value from the Supply Authority and shall carry out formal and recorded calculations to determine the voltage dip at the point of common coupling with the Supply Authority network caused by motor starting currents, so as to confirm that the allowable voltage dip limits will not be exceeded.

Similarly, the Designer shall carry out formal and recorded calculations to verify conformance with voltage dip limits at the points of common coupling within the Corporation’s installation, both with the supply from the Supply Authority’s network and from the standby generator, if the latter is ever to be provided on either a permanent or temporary basis.

All the above calculations shall be made taking into account the “real” and “imaginary” parts of all the parameters involved.

Unless the actual values of the relevant parameters are known, including the torque speed curve(s) of the particular motor(s) and particular pump(s) to be used in the installation, the following values of starting current may be used in the above calculations.

(i) for DOL starting. 7 times the motor rated full load current at a power factor of 0.30,

(ii) for electronic soft starting 4.0 times the motor rated full load current at a power factor of 0.40 (refer clause 4.11)

(iii) for autotransformer starting, 3.5 times the motor rated full load current at a power factor of 0.30,

7.6 Calculation of Harmonic Distortion

7.6.1 Calculation of Harmonic Distortion for Electronic Soft Starters

The principle of operation of electronic soft starters is discussed in clause 7.3.

The Designer shall obtain the site supply source impedance value from the Supply Authority and shall carry out formal and recorded calculations to verify conformance with voltage waveform harmonic distortion limits at the points of common coupling within the Corporation’s installation, both with the supply from the Supply Authority’s network and from the standby generator, if the latter is ever to be provided on either a permanent or temporary basis.

Similarly, the Designer shall carry out formal and recorded calculations to determine the harmonic distortion to the voltage waveform at the point of common coupling with the Supply Authority H.V.

network caused by motor starting currents, to confirm that the allowable harmonic distortion limits will not be exceeded.

For the purposes of these calculations, the harmonic current content of an electronic soft starter at a particular current limit (e.g., 400% full load current) may be taken from Table 7.1 (Clause 7.3.2).

7.6.2 Calculation of Harmonic Distortion for Variable Speed Controllers

The amount of harmonic current taken by a particular variable speed controller depends on the source impedance of the supply to the variable speed controller, the load, the harmonic filtering built into the controller as standard, and any external filtering provided in the line to the controller.

The Designer shall carry out formal and recorded calculations to determine the harmonic currents taken and the harmonic distortion to the voltage waveform caused at the point of common coupling with the Supply Authority network due to operation of the variable speed controller(s) to confirm that the allowable harmonic distortion limits will not be exceeded.

Similarly, the Designer shall carry out formal and recorded calculations as to verify conformance with voltage waveform harmonic distortion limits at the points of common coupling within the Corporation’s installation, both with the Supply Authority’s network and from the standby generator, if the latter is to be provided on either a permanent or temporary basis.

If the variable speed controller selected ultimately for installation is of a different make or model to the unit on which the engineering design was based, the Designer shall repeat the above calculations with appropriate parameters.

7.6.3 Use of Sole Use Substations for Harmonic Limit Compliance

Compliance with harmonic current and voltage limits applied by the Supply Authority is very difficult at Low Voltage, such as from a distribution transformer (LV reticulation), without very expensive mitigation measures (e.g., active or passive filters).

For very small drives (e.g., 3 kW) the limits may be achievable at the LV PCC however not for the larger drives.

When presented with the problem of non-compliance at the LV bus, the Designer’s first approach shall be to request a sole use substation (transformer) so that the harmonic compliance limits apply to the PCC at the High Voltage terminals of the sole use transformer. Clause 6.1.1 note refers. A simple 6 pulse drive with a sole use substation (limits applied to HV PCC) will almost certainly meet the imposed limits.

Clause 14.2.2 of WASIR, discussing ‘sole use’ substations, outlines the eligibility criteria for connection which includes a disturbing load.

If this approach is rejected, then an active filter shall be pursued with the agreement of the Principal Engineer. A passive filter is not accepted for small drives under this Design Standard DS22.

7.7 Typical Impedances for Overhead Lines

The following values may be used in association with calculations described at Section 7.5 and 7.6.

Overhead line reactance is approximately 0.38 ohms per kilometre for normal rural 3 phase construction using copper or aluminium conductors. Where high tensile steel conductors are used, this figure is increased to approximately 0.7 ohms per kilometre.

Overhead line resistance varies of course with the type and size of the conductor used. Resistance values for the various conductors in common use in normal rural HV construction are:

6/1/3.0	(6/1/.118in) ACSR (common for rural lines)	0.68 ohms/kilometre
6/1/2.4	(6/1/.093in) ACSR	1.09 ohms/kilometre
3/2.75	High tensile galvanised steel	10.3 ohms/kilometre
7/2.03(7/.080 in)	copper	0.79 ohms/kilometre
7/1.63(7/.064 in)	copper	1.23 ohms/kilometre

7.8 Typical Impedances for Transformers

The following values may be used in association with calculations described at Section 7.5 and 7.6.

HV Rating (kV)	**6.6**	**11**	**22**	**33**
KVA Rating	**Impedance %**			
25	3.7	3.7	3.6	4.4
63	3.9	3.9	4.7	5.9
100	3.7	3.7	3.8	4.4
200	3.7	3.7	3.8	4.2
315	4.4	4.4	5.0	4.8

Table 7.4 Typical Transformer Impedances

Note: Western Power standard impedances can be as low as 3.3% for ≤ 100 kVA and 4% for ≤ 315 kVA.

8 SWITCHBOARDS

8.1 Minor Low Voltage Switchboards

8.1.1 Definition

For the purposes of this standard, a Low Voltage switchboard shall be classified as a minor Low Voltage switchboard if the switchboard:

(a) has a full load current rating not greater than 440 amps, and

(b) is rated for installation only in the low fault current level situations described in AS/NZS 61439.1 and as specified Clause 8.1.11.

8.1.2 Corporation's Minor Switchboard Development

In line with the core requirements stated in clause 8.1.3 to 8.1.12 below, national/international standards and general industry practice, the Corporation has successfully completed Design Verification and Arc Fault testing for its suite of Mark 8 and 9 outdoor weatherproof switchboards. The suite consists of three ranges, namely:

a) Less than or equal to 100 Amps (Mark 8)

b) Greater than 100 to less than or equal to 220 Amps (Mark 8)

c) Greater than 220 to less than or equal to 440 Amps (Mark 9)

A summary of the switchboard system, including project engineering design templates, is covered in design standard drawings MN01 - Electrical Standard Switchboard Designs-Small Pump Stations, which shall be read in conjunction with this clause 8. Detailed switchboard construction, circuit and equipment specifications, necessary for the workshop delivery of a project switchboard is detailed on design standard drawings LX** - Electrical Standard Switchboard Designs.

Project switchboards shall strictly adhere to the MN01 and LX** design standard drawings, as any variations may compromise the integrity of the switchboard and pose a safety risk to personnel. Any proposed variations shall be referred to the Principal Engineer for consideration and formal direction.

440A Outdoor Switchboard Testing

A summary of design tests successfully performed are highlighted in (i) and (ii) below:

(i) Design Verification to AS/NZS 61439.1 (Annex D refers)

a) Item 1: Strength of material and parts (clause 10.2.5, Lifting and clause 10.2.4, Resistance to UV radiation)

b) Item 2: Degree of protection of enclosures

c) Item 3: Clearances

d) Item 4: Creepage distances

e) Item 5: Protection against electric shock (clause 10.5.2)

f) Item 6/7/8: By assessment (*no test required*)

g) Item 9: Dielectric properties

h) Item 10: Temperature-rise limits (Special service conditions – based on mean/maximum ambient temperature of 50/55° C)

i) Item 11: Short-circuit withstand (*not required under the standard as fault current ≤ 10* kA_{RMS})

j) Item 12: EMC (not required refer J9.4.2)

k) Item 13: M echanical operation

Test Report PLUS ES Lane Cove 104013 refers (Items 1, 3, 4, 5, 9, 10 &13).

Refer Appendix B for a summary of the Testing Station's Design Verification test results.

(ii) Arc Fault Testing to IEC TS 61641

The Power Switchgear and Controlgear Assembly (PSC) enclosure withstood the internal arc fault tests for Criteria 1 to 6, Arcing Class B (Personal protection and Assembly protection), unrestricted access (Ordinary persons).

Testsconducted on the line and load side of incomer and outgoing unit terminals and busbars (vertical and horizontal). Tests were performed successfully with the front doors open and front doors closed scenarios.

Test Report PLUS ES Lane Cove 104013 refers.

Refer Appendix B for a summary of the Testing Station's Internal Arcing Fault test results.

Standards	AS/NZS 61439-1/2:2016 IEC/TR 61641:2014
Rated Operational Voltage	415 VAC
Rated Insulation Voltage	440 VAC
Rated Impulse Withstand Voltage	8kVpk
Rated Current of Assembly	430A at ambient air temperature (special service conditions)
Rated Short-Time Withstand Current	10 kArms for 1 second
Arc Fault Current	7 kArms Arcing Class B, Unrestricted Access (Ordinary Persons)
Ambient Air Temperature	Mean/average ambient temperature of 50/55 0C (Special service conditions)
Pollution Degree	Pollution degree 3 material group IIIa & IIIb at Ui = 440V
Design Verification	Resistance to corrosion Resistance to UV radiation
Degree of Protection	IP56
Earthing System	TN-C-S (MEN)

VSC Temperature Rise Testing:

The Corporation has successfully completed temperature rise testing of its outdoor VSC (and filter) cubicles. Outdoor VSC assembly based on the Mark 8 cubicle design (1.835m H, 0.65m D, 0.7m W) ventilated (IP21) fitted with a 75 kW, IP66, Danfoss VSC. Ambient air temperature of 50° C.

Top Out (°C)	VSC Out (°C)	VSC Inlet (°C)	Bot Inlet (°C)	Mid VSC L (°C)	Mid VSC R (°C)	Front Door (°C)	Back Door (°C)	Control Card (°C)	Heat sink (°C)
50.9	56.5	53.4	51	51.6	51.2	48.1	47.4	65	69

Result: VSC within manufacturer’s performance limits. Passed.

Refer Western Controls’ Test Report “Outdoor VSD Enclosure Heat Rise Testing - Job No: 8294”

Rules for Project VSC and VSC Filter Outdoor Cubicles:

VSCs for incorporation in outdoor VSC cubicles shown in MN01 shall not be substituted for any other make or model of VSC. *(Only IP66 rated VSC’s can be used, Danfoss have IP66 rated VSC’s)*

VSCs shall not be re-housed in IP56 rated cubicles to suit a project’s requirement to reduce the number of cubicles. All VSC’s and VSC filters are designed to be housed in separate ventilated (IP20) cubicles.
(Heat produced by the VSC and filters cannot escape in an IP56 cubicle.)

VSC and VSC filter model selections shown in MN01 shall not be substituted for larger or smaller Danfoss models without full engineering assessment and re-design by the switchboard manufacturer.
(VSCs and filters are matched.)

Outdoor VSC and VSC filter ventilated cubicles shall not be connected to other IP56 rated cubicles via interconnecting ducts. *(Interconnecting ducts will compromise the IP56 rating of the cubicles*)

Outdoor VSC and VSC filter ventilated cubicle front and rear doors shall have ‘electrical access’ keyed padlocks only. *(Electrical and temperature hazards on both sides. No operator controls to access)*

Outdoor VSC ventilated cubicles and VSC filter cubicles shall not be fitted with internal lighting.
(Risk of exposure to dust, moisture, high temperature)

8.1.3 Standards

Minor Low Voltage switchboards shall be designed, constructed and Design Verified in accordance with:

AS/NZS 61439.0 Low voltage switchgear and control assemblies – Guide to Specifying Assemblies

AS/NZS 61439.1 Low voltage switchgear and control gear assemblies – General Rules

IEC TR 61641 Enclosed low-voltage switchgear and control gear assemblies – Guide for testing under conditions of arcing due to internal fault

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

8.1.4 Special Service Conditions

The maximum ambient air temperature outside switchboards to be installed:

a) in the South-West Region of Western Australia shall be taken to be 45°C whether the switchboard is to be installed indoors or outdoors.

b) in regions of Western Australia other than the South-West Region shall be taken to be 50°C whether the switchboard is to be installed indoors or outdoors.

For outdoor switchboards not provided with full shade, an additional internal temperature rise of 5°C shall be allowed for solar heating.

Note: The Corporation's standard Minor Low Voltage switchboard design has been fully Design Verified for operation throughout Western Australia (i.e., ambient air temperature of 50°C), allowing switchboard relocation as required.

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

8.1.5 Construction

Minor Low Voltage switchboards shall be sheet metal enclosed switchboards of the Form 1 type of enclosure in accordance with AS/NZS 61439.0 Annex B Fig. B2.

Minor Low Voltage switchboard enclosures shall be of robust construction and shall be protected against corrosion by painting or powder coating to not less than ISO service category 4.

Minor Low Voltage Switchboards with a full load rated current greater than 100 amps shall be of the multiple cubicle type assembly (AS/NZS 61439.1 clause 3.3.5 refers) and shall be arranged so that the outgoing terminations are separated from incoming terminations.

All conductors on the line side of the incoming service protection device in minor Low Voltage switchboards shall be insulated fully.

Outdoor Minor Low Voltage switchboard cubicles shall be constructed of 3mm marine grade aluminium and painted gloss white. The rear door of the switchboard shall be fitted externally with a label stating, "Danger 415 Volts behind".

Indoor switchboards of the standard Corporation design shall be constructed of 3 mm marine grade aluminium and be painted gloss white.

8.1.6 Rated Diversity Factor

Minor Low Voltage switchboards shall have a rated diversity factor, in accordance with AS/NZS 61439.1 clause 3.8.11 and Annex E, of 1.0.

8.1.7 Degree of Protection

Outdoor switchboard cubicles shall be such that electrical equipment is provided with a degree of protection of either IP56 or IP55W. A fabricated plinth, with appropriate ventilation/barrier to prevent entrapment of sewage gasses and water, shall be provided for all outdoor switchboards.

Indoor switchboard cubicles shall be such that electrical equipment is provided with a degree of protection of not less than IP53. The installation of switchboards shall 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. Any enclosure of such plinths shall be arranged as to prevent the entrapment of water or of sewerage gases.

8.1.8 Rated Insulation and Operating Voltages

Minor Low Voltage switchboards shall have a rated insulation voltage in accordance with AS/NZS 61439.1, clause 5.2 of 440 volts (106% nominal voltage tolerance of supply authority).

Low Voltage (415V) switchboards shall have a rated operating voltage in accordance with AS/NZS 61439.1, clause 5.2 of not less than 415 volts.

8.1.9 Creepage Distances

Creepage distances across insulating surfaces within minor Low Voltage switchboards shall not be less than the values shown in Table 2 of AS/NZS 61439.1 for atmospheric pollution degree 3.

8.1.10 Rated Impulse Withstand Voltage

Minor Low Voltage switchboards shall have a rated impulse withstand voltage rating of 6 kV (Table G.1 of AS /NZS 61439.1 refers).

8.1.11 Rated Short-Time Current

Minor Low Voltage switchboards shall be rated for connection to an electrical supply having a prospective fault level of not more than 10 kA_{RMS} or a fault current cut off limit of not more than 17 kA_{Pk}.

Unless the main circuit is protected by meter fuses rated not greater than 100 Amp, the main circuit in minor Low Voltage switchboards shall have a short time current rating of not less than 10 kA_{RMS} for 1 second.

8.1.12 Internal Arcing Fault Protection

Minor Low Voltage switchboards shall incorporate measures to provide increased security against the occurrence or effects of internal arcing faults. Such measures shall be based on the guidelines given in AS/NZS 61439.1 Appendix ZC.

The line side of the switchboard short circuit protective device (SCPD) shall be fully insulated. The fault current flowing into the switchboard shall be limited by the SCPD and shall limit the I^2t let through energy to $\leq 1.8*10^6$ amp^2*secs at a prospective fault current level of 10 kA_{RMS}. Hence, arc fault verification tests are not required.

If not of an Arc Fault tested design, compartments shall have no accessible bare conductors (i.e., all conductors are insulated when all insulating covers and sleeves are in place).

8.1.13 Type Specifications

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

DS26-10	Type Specification for Minor L.V. Switchboards for >100 Amps, ≤ 220 Amps. (Applicable for outdoor and indoor)
DS26-11	Type Specification for Extended Range Minor Outdoor L.V. Switchboards for >220 Amps, ≤ 440 Amps. (Applicable for outdoor and indoor)

DS26-36	Type Specification for Minor L.V. Switchboards for ≤ 100 Amps. (Applicable for outdoor and indoor)
DS 26-09	Type Specification for Low Voltage Switchboards – General Requirements

8.2 Switchboard General Requirements

The Corporation's Type Specification DS26-09 covers the general requirements for the design and construction of Low Voltage electrical switchboards. This specification covers the detail design (e.g., access for maintenance, location of controls, keys, thermal derating of equipment), general construction, metalwork construction, protective coatings, cables (e.g., type and colour coding), cable installation (e.g., screening, segregation), busbars (e.g., arrangement of busbars & access to busbar joints, continuous current rating of busbars, busbar verification by testing & calculation) and earthing.

The designer shall reference this standard Type Specification and ensure compliance with respect to the design, construction and performance requirements. Depending upon the stage of the project, the designer shall also comply with the requirements of standard drawings MN01 and LX**.

8.3 Switchboard Equipment and Conductor Access

Good engineering practice requires that access to all electrical equipment and conductors be provided for in switchboard designs to allow for replacement of faulted components. AS/NZS 3000 specifies that electrical equipment which requires attention shall be installed to provide an adequate and safe means of access and working space for such attention.

The degree of accessibility necessary to any component depends on the risk of failure and the consequence of a prolonged outage due to such a failure. It is accepted that switchboards which require dismantling of other equipment to provide access to busbar chambers comply with the minimum requirements of AS/NZS 3000 and therefore may be installed legally without rear access. However, in general the Corporation cannot afford to risk prolonged plant outages and consequently the practice of installing switchboards in such a manner to necessitate substantial dismantling of the switchboard to obtain access to equipment, shall be avoided wherever practical.

Where a switchboard is to be retrofitted into an existing building, and space limitations dictate that it be installed without rear access, as for those arrangements discussed in clause 3.10 of DS20, then approval shall be sought from the Principal Engineer.

8.4 Protection

8.4.1 General

For the purposes of this standard, protection equipment is defined as those electrical devices which are arranged to monitor the operation of associated plant and to shut down that plant automatically if conditions occur which jeopardise the safety of personnel or which will lead to damage to the plant.

Protection equipment shall be set to trip marginally above the full load rating of the associated plant rather than marginally above the normal operating load because the latter settings may lead to nuisance tripping due to minor variations in the associated process. (Refer to Clause 8.6 in respect to the setting of thermal overload relays).

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 protection equipment unless sufficient telemetry (SCADA) is also provided to enable the remote operator to assess the cause of the trip and to ascertain that the fault conditions no longer exist.

Protection equipment shall not be arranged to be reset automatically unless the associated control circuit is arranged to confirm that the prime cause of the fault has been corrected previously.

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

(i) Primary protection is defined as that essential protection equipment without which the plant shall not be operated even under close and continuous operator supervision. Instantaneous, earth fault and thermal overcurrent relays, overtemperature relays, pump monitoring relays, fuses and circuit breakers shall be considered primary protection.

(ii) Secondary protection is defined as that protection equipment without which the plant can be permitted to operate under close and continuous operator supervision. Hydraulic (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 PLC's or similar equipment. Switchboards shall be designed so that plant can operate in the "emergency" mode with only primary protection connected.

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

Pump condition monitoring and protection shall also comply with the requirements of DS32 Pump Stations – Mechanical, clause 3.13.

8.4.2 Solar Power System Central Protection Relay

The Corporation policy is to install solar power systems (embedded generation) on suitable sites in a behind the meter (BTM) arrangement.

The onus is on the Corporation to provide a protection system for its embedded generator in accordance with good electrical industry practice and Australian Standards (AS/NZS4777.1).

The technical rules requirements for both Western Power Corporation (WPC) and Horizon Power (HP) in conjunction with the requirements in AS/NZS4777.1:2016 – *Grid Connection of Energy Systems via Inverters,* establish specific requirements for protection of the solar power inverter energy system (IES) from disturbances by the connected grid, protection to the connected grid, other customers connected to the same, and potential islanding due to network disconnection of the supply. Such protection shall be provided by a Central Protection Relay.

The Central Protection Relay is considered as performing primary protection (as defined above) and provides additional protection to the inverter. The methodology of tripping shall be direct and not using any interposing logic, logic controllers (such as PLCs or small programmable logic controllers) or non-self-monitoring circuitry. The use of communication networks such as an existing control/alarm network or SCADA system shall not be used.

Engineering Advisory shall be consulted at strategic points throughout the asset acquisition process for all new embedded generation system designs and variations of previously implemented/proven designs.

8.5 Protection Grading

Protection equipment shall be arranged so that adequate grading is provided between all such devices over the range of fault currents available at a particular site.

Adequate grading shall be provided between the Corporation's protection equipment and the supply authority's protection equipment. 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.

The Designer shall carry out a protection grading study for 3-phase overcurrent (overload, short time and instantaneous) and ensure that the results are fully documented on the protection grading drawings as shown on the MN01 design standard drawings template. Earth fault is generally not employed in designs covered by this design standard DS22, due to cost structure and the lower risk to electrical equipment and safety. If the Designer sees a need for earth fault protection, approval for such shall be obtained from the Principal Engineer as this requirement will result in changes to equipment selection within the standard switchboard drawings.

Coordination shall be provided between starters and their associated short circuit protection devices in accordance with AS 60947.4.1 - Type 2.

This requirement shall be deemed to be satisfied for a particular contactor and overload relay if:

(i) the contactor and overload relay are used in conjunction with a specified short circuit protection device which has been tested and certified to provide the combination with type 2 coordination, or

(ii) the contactor and overload relay are used in conjunction with a short circuit protection device which limits the I^2t at 10 kA to less than the I^2t at 10 kA let through of the above specified short circuit protection device.

8.6 Thermal Overcurrent Protection

For submersible bore hole motors, the overload protection relay tripping current/time setting shall be 6FLC/4 or 5 seconds.

For conventional motors and submersible sewage pump motors, the overload protection relay tripping current/time setting shall be 6FLC/10 seconds.

The motor thermal over current relay shall be set at 100% motor full load current.

NOTE: *Western Power's technical rules allow for up to 2% negative sequence voltages in Low Voltage supplies.*

A cage induction motor must be derated 5% in order to account for the additional heating which would be caused by negative sequence voltages of this magnitude (refer clause 3.1). However, 2% negative sequence voltages in the incoming supply to the motor will cause unbalanced phase currents with the highest phase current being typically 13% above the average phase current. Hence, at 90% load the current in one motor phase could be 3% or 4% above motor rated full load current without the motor being overheated. Therefore, if regular nuisance tripping is experienced, motors fitted with thermistors may have the thermal over current relay set to not greater than 105% motor full load current.

8.7 Auto-transformer Starter Thermistor Protection

Auto- transformer starters shall be protected by thermistor protection and be specified to have three thermistors connected in series, each having a temperature-resistance characteristic such that the resistance of each thermistor at trip temperature is 1000 ohms. The thermistor protection relay shall be set to trip if the thermistor loop resistance rises above 3000 ohms.

8.8 Current Transducers

Reference shall be made to DS21 clause 9.9 regarding current transformer and Rogowski Coil current sensor performance criteria and accuracy requirements. In particular, reference shall be made to clause 9.9.8 of DS21 for the accuracy class of metering and protection current transformers.

8.9 Electrical Surge Protection

8.9.1 Service Entry Surge Protection

Appropriate surge diverters shall be installed so as to provide service entry incoming voltage surge protection on all electrical installations within the scope of this design standard. Such surge diverters shall be connected and protected as detailed hereunder.

8.9.2 Factors Affecting Surge Levels

A lightning surge into an electrical installation may cause a destructive over voltage at a particular location within the installation depending on:

(i) the residual voltage and protective range of any surge diverters installed within the installation

(ii) the surge voltage attenuation caused by line side inductances,

(iii) the surge voltage amplification caused by voltage wave reflections at sudden changes of circuit impedance.

8.9.3 Surge Diverter Residual Voltage

The phase to earth protective voltage level provided by a Low Voltage surge diverter connected to a main circuit depends on the residual voltage across the surge diverter and the voltage drops across the connecting leads (line and load side leads) to the surge diverter.

Because of the fast time of the surge current when the surge diverter conducts, the voltage drop across the surge diverter connecting leads is considerable.

$V_c = L*D*di/dt$

where V_c = voltage drop across connecting leads, volts

L = per unit inductance of connecting leads

= 1.2 micro-Henries per metre

D = total length of connecting leads i.e., from phase to fault current limiting fuse, from fault current limiting fuse to surge diverter, and from surge diverter to main earth bar.

di = surge current peak, amps

dt = front time of surge current (8 microseconds for an 8/20 µs wave shape)

For example, if the peak surge current is 5 kA and the length of connecting leads is 1 metre, the voltage drop across the connecting leads will be 750 volts.

8.9.4 Effect of Main Circuit Inductances

For 240/415-Volt three phase circuits AS/NZS 61439.1 recommends that equipment located near the service entry have a rated impulse level of 6 kV, reducing to 4 kV at distribution circuit level and to 2.5

kV at load level. These recommendations suggest that the inductances of circuit wiring cause significant attenuation of a surge current peak voltage.

8.9.5 Effect of Voltage Wave Reflections

IEC 61643-12 suggests that in general surge voltage increases due to reflections of the surge voltage waveform may be disregarded at locations within 10 metres of Low Voltage surge diverters. However, such surge voltage increases may occur if the load presents a high impedance i.e. surge voltage reflections may occur at open contacts or more importantly at converter inputs.

Provided that the surge diverters are in accordance with clause 8.9.12 and are installed in accordance with clause 8.9.7, the residual voltage at the surge diverters will be a little less than the 2 kV and will be higher as the conductor length between the surge diverters and the VSC's (or electronic soft starters) increases.

Surge diverters shall not be required on separately mounted VSC's, provided that the VSC's have a common mode impulse voltage rating of ≥ 4 kV and the cable length between the surge diverters and the VSC's is < 10 metres. Similarly, surge diverters shall not be required on separately mounted electronic soft starters, provided that the electronic soft starters have a common mode impulse voltage rating of ≥ 4 kV (unlikely) and the cable length between the surge diverters and the electronic soft starters is < 10 metres. Refer clauses 7.3.5 and 7.4.5 for ESS and VSC respectively.

8.9.6 Impulse Voltage Rating of Power Electronic Equipment

Despite the preferred impulse withstand voltage values quoted in AS/NZS 61439.1, the standards covering variable speed converters and electronic soft starters only require an impulse withstand voltage rating of 2 kV.

8.9.7 Location and Connection of Surge Diverters

Low Voltage surge diverters shall be fitted on the load side of the installation Main Low Voltage Circuit Breaker as close as practical to the latter consistent with minimizing the length of surge diverter connecting leads (para. 8.9.3 refers). It should be noted that the associated protective zone extends on both the line and load sides of the surge diverters' point of connection.

On Main switchboards, and on switchboards other than Main switchboards, which incorporate a MEN link, Low Voltage surge diverters shall be connected phase to neutral only. The switchboard equipment shall be arranged in such a way that the complete length of connecting leads shall not exceed 1 metre.

On switchboards not incorporating a MEN link, Low Voltage surge diverters shall be connected to neutral and neutral to earth. The switchboard equipment shall be arranged so that the complete length of connecting leads shall not exceed 1 metre. Similarly, the arrangement shall be such that the length of the connection lead neutral to earth bar shall be not more than 1 metre.

MN01-2-1 to 4.2 detail the surge diverter connection arrangements discussed above.

Cables connecting to earth electrodes shall be terminated onto the earth bar as close as practical to the Low Voltage surge diverter connecting lead terminations. Surge diverters shall not be mounted hard up against one another or hard up against other equipment.

8.9.8 Rating of Surge Diverter Fault Current Limiting Fuses

Phase connections to Low Voltage surge diverters shall be via HRC fuses as shown, and as rated, in accordance with the surge diverter's recommendation (based on test results) or MN00 and LX** drawings. The Designer shall ensure adequate protection coordination exists with upstream protection devices.

8.9.9 Surge Protection of Separately Mounted Equipment

Further to clause 8.9.5 above, distribution switchboards located greater than 10 metres from the main surge diverters shall be fitted with additional surge diverters connected as appropriate (whether MEN or no MEN at the distribution board).

8.9.10 Surge Diverter Discharge Current Rating

Low Voltage surge diverters shall have a nominal discharge current rating of not less than 20 kA 8/20 µs in accordance with IEC 61643.1 (which is approximately equivalent to 4kA 10/350 µs and approximately 2 coulombs). Low Voltage surge diverters shall have a three-shot maximum discharge current rating of not less than 40 kA 8/20 µs in accordance with IEC 61643.1.

8.9.11 Surge Diverter Protection Level

Low Voltage surge diverters shall have a voltage protection level of not more than 850 volts at 3 kA discharge current.

8.9.12 Surge Diverter Maximum Continuous Operating Voltage

Low Voltage surge diverters shall have a rated continuous operating voltage not less than 275 volts.

8.9.13 Surge Diverter Type Specification

Low Voltage surge diverters shall be in accordance with Corporation Type Specification DS26-32.

8.9.14 Surge Protection of Extra Low Voltage Equipment

IEC 61326.1 defines Extra Low Voltage control and signal cables as being "long lines" if such cables run outside buildings or run entirely within buildings and are more than 30 metres long.

For the purpose of this Design Standard, the term "buildings" shall mean:

a) metal framed and/or reinforced concrete buildings in which the metal framing and concrete reinforcement are bonded and earthed, and

b) metal outdoor switchboard enclosures.

Extra Low Voltage control and signal cables, which are "long lines" as defined above, shall be connected into electronic control equipment, such as PLC's, only via suitable surge protectors, Critec Type LSP or approved equivalent.

8.10 Switchgear

8.10.1 Thermal Derating

Switch gear designed in accordance with AS/NZS 61439.1 is rated at 35ºC and needs to be derated when used in higher temperature ambient conditions.

Except where special site conditions require switchboards to be designed for higher operating temperatures, switchboards shall be designed on the basis that the maximum ambient temperature within the switchboard will be 50ºC for indoor switchboards and 60ºC for outdoor switchboards. *Note: For outdoor switchboards, 60ºC allows for 50ºC outside ambient air temperature plus 5ºC for solar heating and 5ºC for internal equipment heat losses. For indoor switchboards, 50ºC allows for 45ºC ambient air temperature and 5ºC for internal equipment heat losses.*

Normally, switchgear to be installed in indoor switchboards shall be derated to 88% of its nominal rating.

Similarly, switchgear to be installed in outdoor switchboards shall be derated to 79% of its nominal rating. Similar deratings shall be applied to starter autotransformers. However, electronic soft starters rated for operation in ambient conditions of 35°C shall be derated to 77% of their nominal rating for installation in indoor switchboards and to 63% of their nominal rating for installation in outdoor switchboards.

8.10.2 Connecting Cables

Switch gear designed in accordance with AS/NZS 61439.1 depends to some extent on the connecting cables to act as a heat sink.

Table 11 of AS/NZS 61439.1 specifies the required size of copper conductor in interconnecting cables for various nominal ratings of switchgear under rating tests.

Cables used to interconnect various items of switchboard equipment shall be PVC insulated and sized in accordance with Table 11 of AS/NZS 61439.1 for the nominal rating of the switchgear (i.e., not for the derated value).

8.10.3 Circuit Breaker Type

Circuit breakers shall be air break type.

8.10.4 Motor Control

Operational control of motors shall be by air break contactors. Circuit breakers or manually operated switches shall not be used for this purpose.

8.10.5 Fast Transient Burst Suppression

All contactor coils and similar solenoids shall be fitted with RC fast transient burst suppressors.

All DC relay coils shall be fitted with reverse diode or varistor overvoltage suppressors.

8.11 Power and Control Circuits

Switchboard power and Low Voltage control circuits shall be in accordance with the Corporation's standard power and control circuits (Refer MN01 drawing set) and shall allow the operation of individual drives under emergency manual control with primary protection only (clause 8.4 refers).

Automatic and normal manual control with both primary and secondary protection shall be implemented via switchboard controlling systems.

Control interconnections between various drive control circuits and their associated switchboard controlling system shall be at Extra Low Voltage.

In general, control interconnections between various drive control circuits shall be via the switchboard controlling system. However Extra Low Voltage control interconnections shall be permitted between variable speed controllers operating in master/slave mode. Direct connections between Low Voltage drive control circuits shall not be permitted.

Control switches and push buttons (e.g., Control Selector Switch, Emergency Stop Push Button, etc.) which directly control the operation of motors shall be hardware devices mounted on the switchboard Low Voltage control panel for the associated drive rather than being software functions within the switchboard controlling system.

8.12 Switchboard Control Functions

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 DS22 has been retained as Appendix A0 for information purposes only.

8.13 Supply Voltage Quality Monitoring

The motor protective devices will provide protection against motor over heating due to incoming supply under voltage or phase imbalance. However, such devices are manually reset, or limited cycle remote reset, and may require a visit to site by a suitably qualified person to assess the cause of the tripping and to determine whether the device can be reset. In order to minimise the operation of motor protective devices due to supply under voltage, phase imbalance or phase failure, a phase failure 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 under voltage relay shall be self-resetting and shall be arranged to trip if:

(a) the supply negative sequence voltage is more than 10%

(e.g ., 5% setting on rms type 2P740 phase failure relay),

(b) the supply voltage falls below 80% of nominal voltage.

Since the starting of 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 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.

8.14 Lamp and Actuator Colours

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

(a)	Fault tripped condition	- 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) Switch or Circuit Breaker closed - Red

(g) Switch or Circuit Breaker open - Green

(h) Valve closed - Green

(i) Valve open - White

Actuators on switchboards shall 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

8.15 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. Variable speed controllers and reduced voltage starters shall not be shared between various drives.

8.16 Monitoring Requirements for Small Pump Stations

For the business to operate effectively and efficiently, relevant information relating to the functional and energy status of plant within the pump station site is critical.

Some of the key metrics required are power (active, reactive, apparent), energy (delivered and absorbed), phase current, phase to phase voltage, total harmonic voltage distortion and total harmonic current demand distortion. This functionality shall be provided by the Power Supply Monitor built into the standard outdoor switchboard design. Hence, use of energy pulses from the Supply Authority Meter is not required, making the procurement and installation of Supply Authority meters simpler.

The MN01 standard switchboard drawing set covers the switchboard design requirements and drawing MN01-25-1 provides the detailed requirements for monitoring and communication register allocations.

8.17 Orientation of Outdoor Switchboards

The switchboard orientation shall be such that the front doors of the switchboard face the pumping units. Adequate hard standing area shall be provided around the switchboard to facilitate inspection and maintenance activities. As a minimum the hard standing area shall extend 1300mm from the front edge of the switchboard and 1500mm from the rear edge of the switchboard.

8.18 Motor Cable Disconnection Cubicles

To assist with removal of pumping units from wet well sewage pump stations, submersible bores and the like, motor cable disconnection cubicles may need to be provided depending upon the requirements of the project.

Such motor cable disconnection cubicles shall be:

a) constructed from marine grade aluminium, painted white, minimum IP56 and one access door,

b) no more than 1.2 metres in height,

c) fitted with polycarbonate shrouds over all terminals within the cubicle,

d) fitted with "vandal resistant" bolts to the door and pad-lockable door handles (*Note: Bolts not required if motor disconnect cubicles are located within a secure building.)*,

e) two-point door locking system,

f) fitted with a label on the door stating, "Danger 415 Volts behind" and,

g) fitted with a trip limit switch on the door and wired as an alarm point to SCADA. (*Note: Not required if motor disconnect cubicles are located within a secure building.)*

Refer MN01-21-4 for cubicle dimensions and LX** for details.

8.19 Generator Cable Connection Cubicles

To provide a safe and efficient connection of a temporary or permanent generator set to pump stations or other small installations cable connection cubicles may be provided depending upon the requirements of the project.

Such generator connection cubicles shall be:

a) constructed from marine grade aluminium, painted white, minimum IP56 and one access door,

b) no more than 1.2 metres in height,

c) fitted with polycarbonate shrouds over all terminals within the cubicle,

d) fitted with "vandal resistant" bolts to the door along with pad-lockable door handles if for use with a permanent generator,

e) fitted with pad-lockable door handles if for use with a temporary generator,

f) two-point door locking system,

g) fitted with a label on the door stating, "Danger 415 Volts behind",

h) fitted with a trip limit switch on the door and wired as an alarm point to SCADA if for use with a permanent generator.

Refer MN01-21-4 for cubicle dimensions and LX** for details.

8.20 Mini Cubicles

Mini cubicles have been developed to cover those small Main Switchboard applications necessary for control of relatively small distribution loads less than 100 amps. The Mini cubicle (pole mounted) houses the service protection device, Supply Authority metering, main switch, surge diverters and in some cases up to two distribution circuit breakers. No motor starter equipment can be provided within the cubicle.

They are best suited for water tank installations or difficult to access sites where the point of attachment is at the road curb and the pump station is a considerable distance from the entrance to the site, e.g., L-shaped block of land.

Refer MN01-1-4 power circuits, MN01-21-3 for cubicle dimensions and LX** for details.

9 EARTHING

All earthing system designs shall be based on soil resistivity tests conducted at the site under dry soil conditions. The designer is responsible for arranging soil resistivity tests during the Engineering Design stage and documenting all soil resistivity test results on the Primary Design drawings as shown on template drawings MN01-2.

Soil resistivity tests shall be carried out via the Wenner four-pin method and the measurement methodology outlined in DS23 clause 2.2.4.2 shall be used.

For sites with existing electrode systems installed, the Fall-of-Potential method shall be used to measure the resistance to earth of these small earthing systems.

9.1 Type of Earthing Systems

The type of earthing system to be employed will depend upon the type of electrical supply to the site. The required earthing arrangements applicable to the various types of electrical supply arrangements to the site are defined in clauses 9.2 to 9.4 below.

9.2 Earthing System–Low Voltage Supply Authority District Substation

If the electrical supply to the site is provided at Low Voltage from a Supply Authority Substation (transformer) located off the site, commonly referred to as a district substation (transformer), the Corporation’s earthing system shall comply with the requirements of AS/NZS 3000 for a MEN installation with the added requirement that the overall resistance to earth of the Corporation’s installation electrical earthing system shall be not more than 15 Ohms. Individual earth electrodes resistance to earth shall be less than 30 Ohms. The various earthing connections for such a system are shown at Fig. 9.1.

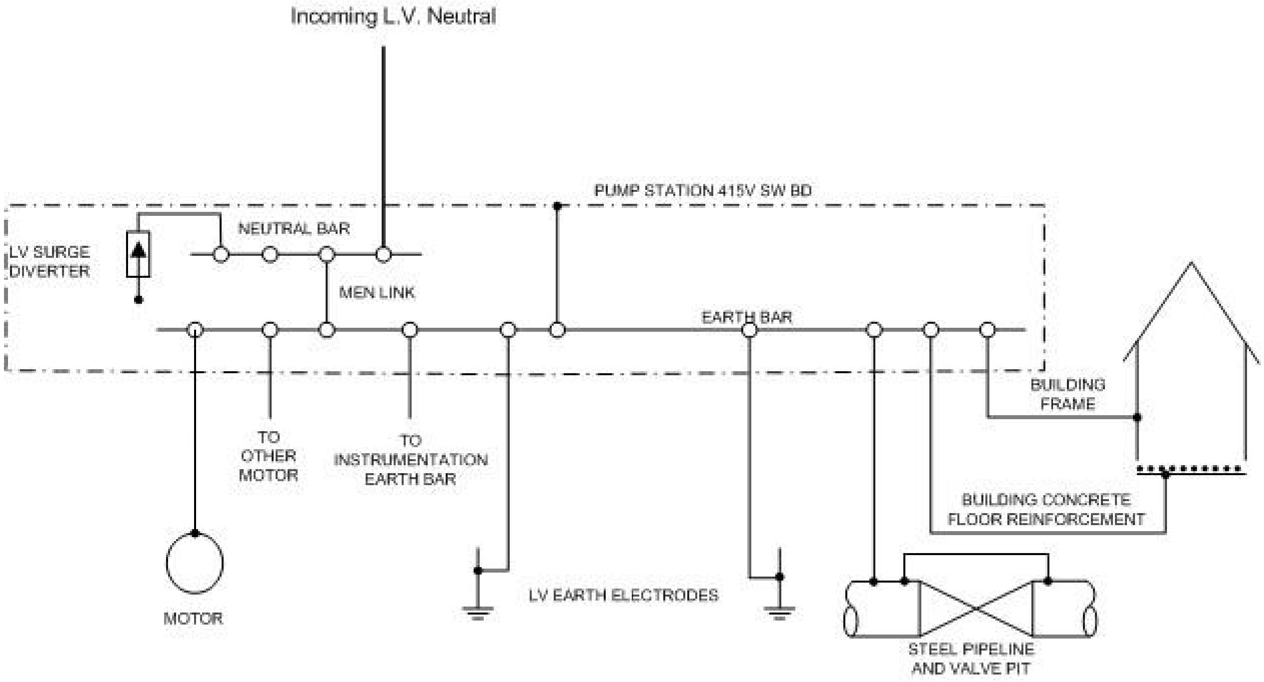


Fig. 9.1 Major Earthing Connections for a Small Pump Station Supplied by L.V. Street Distribution via District Substation

9.3 Earthing System–Supply Authority Sole Use Substation (Transformer)

If the supply to the site is at Low Voltage from a Supply Authority owned Sole Use substation (transformer) located on the Corporation’s site, the Corporation’s Low Voltage earthing system shall comply with the requirements of AS/NZS 3000 for a Low Voltage MEN installation with the added requirement that the overall resistance to earth of the Corporation’s Low Voltage installation electrical system shall be not more than 15 Ohms. Individual earth electrodes resistance to earth shall be less than 30 Ohms.

The Supply Authority will supply, install and test the High Voltage earthing system for their substation to ensure safe touch voltage compliance under EPR conditions.

The supply authority’s requirement is for the customer’s switchboard to be contiguous (as defined in WASIR) with their substation. This raises an issue related to transfer voltage from the substation to the Corporation’s switchboard under earth fault conditions (EPR). This voltage transfer may be direct (due to the practice of connecting the substation’s transformer star point to one earth bar for both H.V. and L.V. which then connects to the Corporation’s switchboard neutral to earth bar link via the consumer mains neutral cable) or via the general mass of earth (dependent upon soil structure).

In relation to the potential for transfer voltage, it is important that the Designer take all reasonable steps to obtain a copy of the verification test or the compliance statement from the Supply Authority to ensure safe touch voltage compliance for Corporation assets adjacent to and within the vicinity of the Sole Use substation. This verification shall be documented on the Primary Design drawings by the Designer as part of the “as constructed” drawings process.

Depending upon the site installation switchboard arrangement, the following earthing connection configurations are:

(a) If the incoming Main Switchboard, housing the installation Main Switch, is integral with the Pump Station Switchboard, the various major earthing connections shall be as shown on MN01-2-1.

(b) If the incoming Main Switchboard, housing the installation Main Switch, is separated from the Pump Station Switchboard by less than or equal to 50 metres, the various major earthing connections shall be as shown in MN01-2-2.1 or MN01-2-3.1 or MN01-2-4.1 depending upon generator set location and multiple master metering requirement.

(c) If the incoming Main Switchboard, housing the installation Main Switch, is separated from the Pump Station Switchboard by more than 50 metres, the various major earthing connections shall be as shown in MN01-2-2.2 or MN01-2-3.2 or MN01-2-4.2 depending upon generator set location and multiple master metering requirement.

Note: Reference shall be made to clause 6.1.2 in respect to the special arrangements to be made for supply to bore hole pump stations.

9.4 Earthing System-Corporation Owned Substation (Transformer)

If, in the rare situation, the L.V. supply to the site is via a Corporation owned substation (HV switchgear & transformer), a combined (common) earthing system as described in Figure B1 of AS 2067 shall be implemented.

Design of the HV earth electrode system shall comply with the requirements of DS23, AS 2067 (in particular clauses B1.1, B1.3, B1.4 & B1.5 relating to the substation earthing requirements) and section 11.3 of DS21 to ensure safe touch and step voltage.

The design, documentation and verification of the H.V. earthing system shall be carried out by one of the Specialist Earthing Design Consultants from the Panel for Specialist Earthing Design Services (Preferred supplier agreement). Clause 3.18 of DS20 refers.

A segregated (separated) earthing system shall not be implemented.

9.5 Connections to Metalwork

It is essential that equipotential bonding is deployed for all Corporation sites to ensure protection of personnel and equipment. Such bonding, and connections to metalwork, shall follow the following requirements:

(a) 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.

(b) The concrete reinforcing steel in floor slabs and precast concrete panels shall be brought out for earthing in accordance with AS 1768 and AS 2067 shall be connected to earth as shown in Figures 9.1 and MN01-2 standard drawings.

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.

Note: 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 g round resistance and can be of a significant benefit in this regard.

(c) Bonding shall be installed across all pump station pipework equipment such as flexible joints, meters, valves and pumps. *Note: Where metallic isolation is required, isolator/surge protectors*

(ISP) or galvanic isolators (GI) shall be fitted across insulating joints to limit the surge voltage that can appear across each insulating joint and provide personnel protection.

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

(e) Switchboards shall be bonded to the pump station main earth bar.

(f) Any sections of metallic fencing located under aerial High Voltage lines shall be earthed as discussed in DS21 clause 11.10 or as specified by the specialist earthing design consultant.

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

(h) A detailed description of the required earthing at valve/meter pits is at section 11 of DS21, as is a more detailed description of bonding requirements for concrete reinforcing steel and structural steel.

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

9.6 Prevention of Corrosion in Earthing Systems

The following measures shall be taken to reduce corrosion within earthing system:

(a) Earth grading rings shall be of copper cable, and earthing electrodes shall be copper clad. All major earthing cables shall be copper and shall be terminated with suitable crimp connectors. *Note: Bare steel or aluminium shall not be used for earthing systems, e.g., bare steel electrodes, galvanised or bare steel or aluminium grading wires, etc.*

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

(c) All saddles, clamps and miscellaneous fastenings shall be non-ferrous metal, stainless steel, zinc plated steel, nylon or PVC.

(d) All bolted connections in earthing systems shall be above ground and accessible for inspection.

(e) All steel work below ground within 10m of copper earthing electrodes or earth mats, should be bitumen coated or encased in concrete in order to minimise galvanic corrosion of the steel or its zinc coating.

(f) Where dissimilar metals are installed adjacent to one another, bimetallic corrosion shall be inhibited by the use of metallic plating or by other methods (e.g., galvanic isolator) approved by the Principal Engineer.

9.7 Calculation of Electrode Earth System Resistance

The formula for calculating the D.C. earthing resistance of a single vertical electrode is:

$R_{vdc} = 0.368*\rho* \log (4*L/d) /L$

where: R_{vdc} = vertical electrode D.C. earthing resistance, ohm
ρ = soil resistivity, ohm-metres
L = electrode length, metres
d = electrode diameter, metres

Alternatively:

$R_{vdc} = \rho/(2* \pi L)* (\ln (8*L/d) – 1)$

Our earthing requirements demand a minimum of two vertically driven electrodes to be connected to the main earth bar. Due to the “proximity effect, the separation between the two electrodes shall be twice the electrode length (S=2*L) as a minimum in order to achieve a system earth resistance approximately half that of a single electrode.

Where two or more electrodes are connected in parallel, the combined earth electrode system resistance to earth is:

$R_n = R* ((1+ \beta a) /n)$

Which:

$a = \rho/(2* \pi *R*S)$

Where:
R = single electrode resistance in isolation, m
S = electrode spacing, m
ρ = soil resistivity, ohm-metres
β = multiplying factor, refer below
n = number of electrodes

Number of Electrodes (n)	Factor (β)
2	1.00
3	1.66
4	2.15
5	2.54
6	2.87

9.8 Earthing of Above Ground Structures for Lightning Protection

Above ground structures such as high-level water towers, communication towers/poles 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.

9.9 Earthing and Bonding at Water Tanks

Earthing, bonding and the provision of lightning air terminals at water tanks shall be designed in accordance with the requirements of AS/NZS 1768.

Lightning protection design of power and instrumentation equipment shall be in accordance with the requirements of the DS20 and DS40 series of design standards.

With respect to the tank, the philosophy is not to protect the tank from a direct strike but rather guide the lightning surge safely to ground. In this regard, it is important to establish a connection from the air termination to a lightning earthing system with a combined resistance to earth of less than 10 ohms. Depending upon the type of tank construction this will involve either two down conductors from the air termination or simply a connection from the metallic tank base to the earthing system. Furthermore, the connection to the earthing system shall be via suitably rated DC De-couplers (e.g., DEI SSD Solid State De-coupler) to provide corrosion/cathodic protection isolation.

For the purpose of this section, the air termination is defined as the metallic roof of the tank and the lightning earthing system is defined as a bare copper conductor buried encircling the tank (grading ring), spaced one metre from the tank wall and connected to three equally spaced earth electrodes along the circumference of the grading ring. The down conductor is defined as an insulated copper conductor from the air termination to the earthing system.

Guidance relating to the basic earthing requirements outlined above for various types of tank construction is given below:

i. Steel roof of ground level concrete tank: Two down conductors terminated into the earthing system.

ii. Steel roof of ground level steel tank: Two connection points from the base of the tank to the earthing system.

iii. Concrete roof of ground level concrete tank: No earthing requirements for the tank. However, any metallic structure, such as ladders or stairs, shall be connected to the earthing system via two separate earth cables.

iv. Concrete roof of elevated concrete tank supported on concrete columns or shaft: Earthing and bonding of any internal metallic structure.

v. Steel roof of elevated concrete tank supported on concrete columns or shaft: Two down conductors terminated into the earthing system. Earthing and bonding of any internal metallic structure.

vi. Steel roof of elevated steel tank supported on concrete columns: Two down conductors terminated into the earthing system.

vii. Steel roof of elevated steel tank supported on steel frame: Two connection points from the base of the tank to the earthing system. *Note: If the steel tank is placed on an insulated base (e.g., wood, etc.), all supported on a steel frame, then a minimum of 3 bonding straps shall be placed from the tank to the steel frame (bond across the insulated base).*

9.10 Earthing and Bonding for Communication Systems

To facilitate the integration of communication system earthing and bonding with the power system earthing and bonding system, standard drawings JT17-1-1, 1-2 and 1-3, detailing the mandatory minimum requirements, shall be referenced during project design.

9.11 Earthing and Surge Protection of Submersible Bore Hole Motors

Since submersible bore hole motors are installed under water, the metallic case of the motor acts as an earth electrode. The current trend is to install non-metallic bore hole casings and non-metallic bore hole pipes, so that in some installations the case of the submersible bore hole motor may have the least earth resistance of all the metalwork connected to the earthing system. In such cases, the submersible bore hole motor earthing conductor shall be rated as for the installation main earthing conductor in accordance with AS3000.

Reference shall be made to clause 6.1.2regarding HV lightning impulse protection for submersible motor installations.

9.12 Earthing of Pipeline Mounted Instrumentation

Electronic instrumentation transducers which are mounted on the main pipeline, or in pipe work within the pump station, shall be electrically isolated from the associated pipework and shall be earthed separately to the instrumentation earth bar.

9.13 Earthing of Steel Pipelines

9.13.1 Above Ground Steel Pipelines

Above ground steel pipelines shall be earthed and bonded at the pump station as shown in Fig 9.2 in order to protect electrical plant against lightning damage, and for personnel safety.

Wherever above ground pipelines terminate electrically, i.e., at an isolating flange, the above ground pipeline shall be connected to a local earthing electrode having an earthing resistance not more than 5 ohms in accordance with AS/NZS 4853.

If insulated flanges are fitted as shown in Fig 9.2, isolator/surge protectors (ISP) or galvanic isolators (GI) shall be fitted across insulating joints in above ground pipelines to limit the surge voltage that can appear across each insulating joint.

Note: 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 low standard peak voltage blocking levels (typically 20V) and are intended for safe electrical isolation of cathodic protected systems subject to 50Hz power faults, systems which are coupled to an AC source and systems subject to lightning transients.

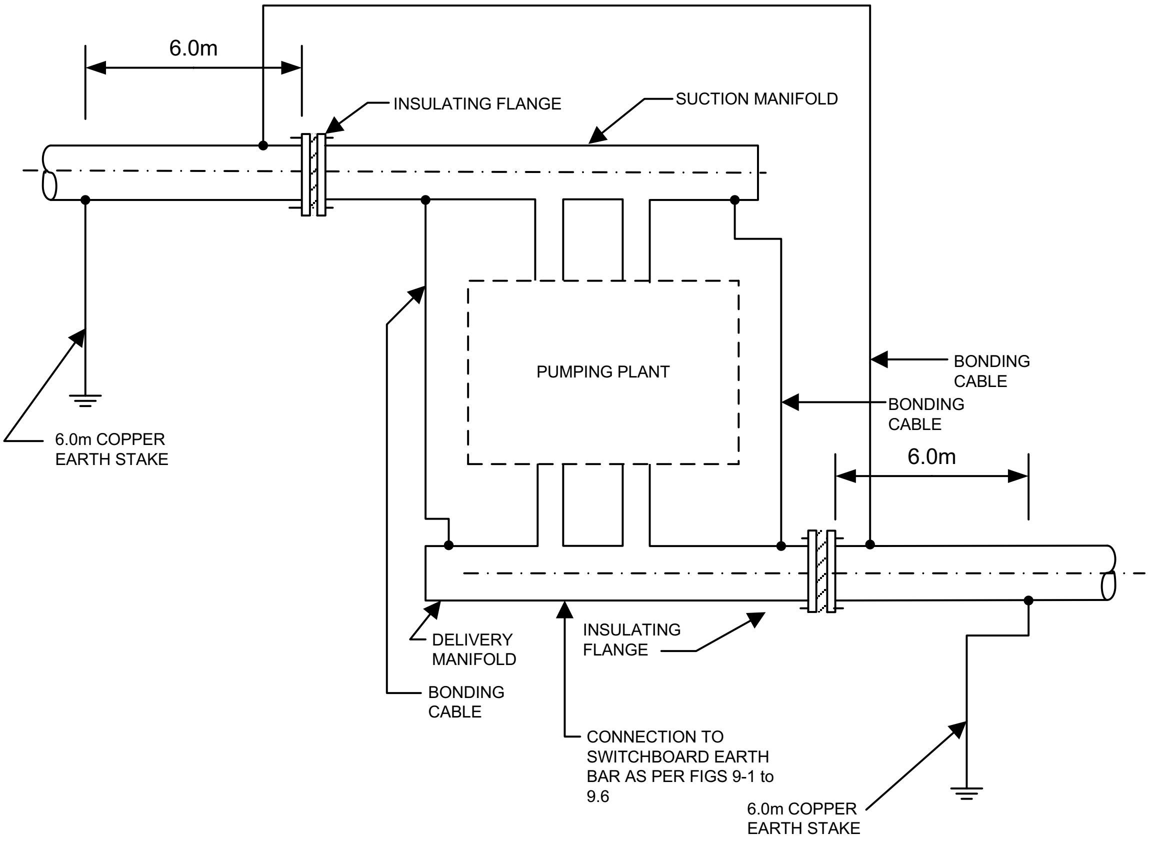


Fig. 9.2 Earth Bonding for Above Ground Pipelines

9.13.2 Below Ground Steel Pipelines

If below ground steel pipelines connecting to pump stations are cathodic protected, these may need to be electrically isolated from the pump station pipework. In such cases the earth bonding shall be as shown in Fig. 9.3.

Insulated joint protectors (IJP) with a rated DC breakdown voltage of 500 V shall be fitted across insulating joints in below ground pipelines to limit the surge voltage that can appear across each insulating joint to 1000 V. *Note: IJPs are provided rather than ISPs or GIs as they are, being buried, not readily accessible.*

Earthing at transitions between below ground and above ground steel pipelines shall be arranged in a similar manner to that shown in Fig. 9.3. In such cases the above ground steel pipeline shall be connected to local earthing electrodes having an earthing resistance not more than 5 Ohms in accordance with AS/NZS 4853.

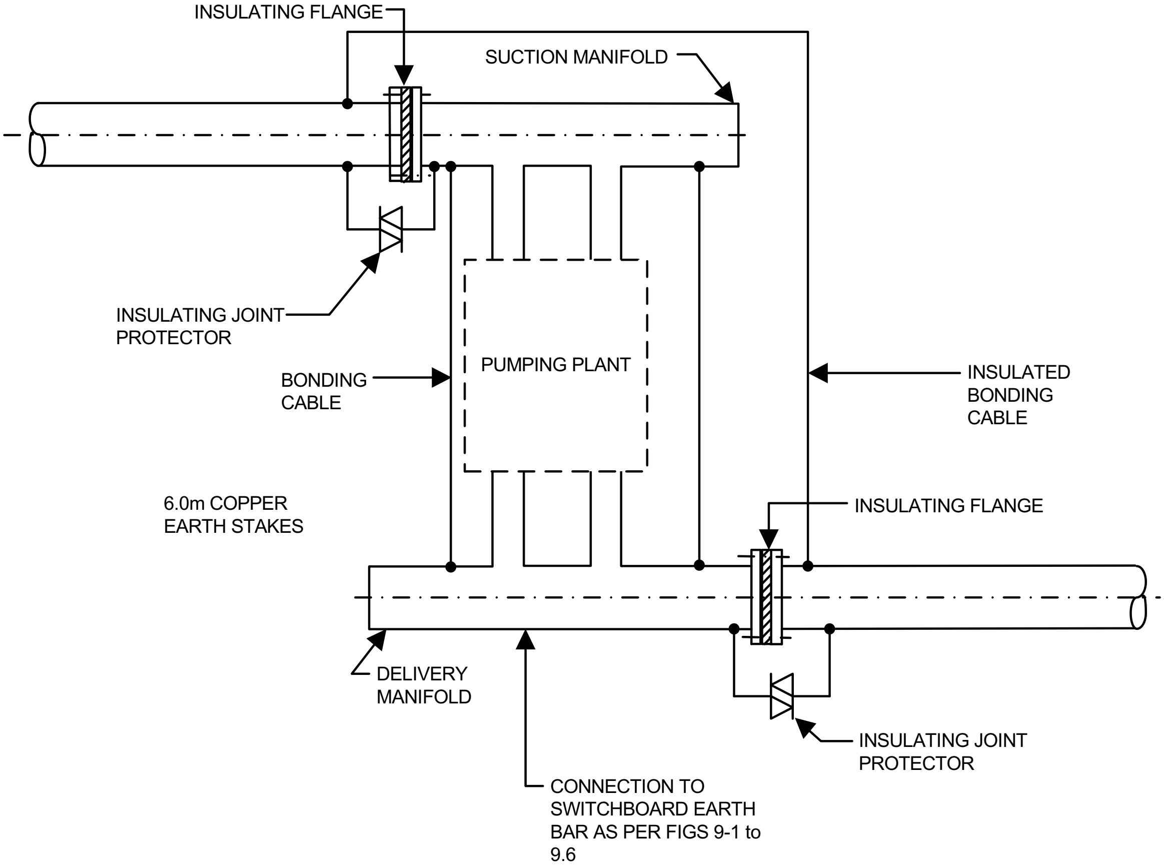


Fig. 9.3 Earth Bonding for Below Ground Pipelines

9.14 Earthing Cable Screens

Screens or screened cables associated with variable speed controllers shall be grounded at both ends (VSC and motor) e.g., the screen or a cable connecting the output of a variable speed controller to a motor shall be connected to the variable speed controller chassis at the variable speed controller end and to the motor frame at the motor end.

Screened cables associated with variable speed controllers shall be terminated at both ends with cable glands which provide a 360º connection of the screen to the associated earthed gland plate.

9.15 VSD Applications – Earthing & Bonding

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.

Proper earthing and bonding can reduce the effect of interference coupling, due to the PWM voltage waveform and very fast rise times associated with VSCs, into other equipment either by conducted or radiated emissions.

Some basic rules for good earthing and bonding practice to ensure electromagnetic compatibility compliance for the Designer to consider are:

a) Dedicated earth cable from the VSC to the motor.

b) Ensure the shielded 3 phase cable screen is connected at both ends to the VSC gland plate and motor terminal box.

c) Ensure 360º HF earthing connection of the screen via metallic glands.

d) Earth the common of the control circuit at the VSC or PLC.

e) Connect shields to the common reference bar.

f) Use cable type specified in clause 10 of this standard.

g) Maintain good separation of cabling as specified in clause 10.7 of this standard.

h) VSC conductive sealing at the door.

i) Ensure clean metal to metal earth/bonding cable connections (unpainted).

j) VSC housing limited hole size (must be less than 80mm diameter).

k) VSC to contain integral RFI filter.

Basically, the above goes towards ensuring an effective Faraday cage is established for the VSC/ cable/mot or drive system.

10 CABLES

10.1 Cable Types

10.1.1 Conductor Type

All cables shall have copper conductors.

10.1.2 Cables for Specific Purposes

The types of cables to be used for various applications shall be as listed hereunder.

APPLICATION	CABLE TYPE
Light current switchboard cables	Refer DS26.09
PLC/RTU input/output cables (external to switchboards)	Twisted pair(s) cable, 7 strand conductor ≥ 0.5mm^2 PVC insulated, overall screened, PVC sheathed cables, SWA if liable to mechanical damage, use of common return conductor not permitted.
240-volt control cables (external to switchboards)	Multi-core cable ≥ 7 strand conductor ≥ 1.5mm^2 PVC insulated, PVC sheathed cables, SWA if liable to mechanical damage.
Incoming cables to transformer HV terminals and/or incoming cables to 33/22/11kV HV switchboards (See notes 1,2)	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.
Cables between transformer LV terminals and the associated LV switchboard	Single core XLPE insulated PVC sheathed cable
Station lighting and general-purpose power	Single core PVC in PVC conduit
Submersible bore motor cables (See note 3)	3 core and insulated earth, R-EP-90 insulated, R-CSP-90 sheathed cable to AS 3116, or Siemens Hydrofirm or equivalent (approved for drinking water applications)
Submersible sewage motor cable (See note 3)	3 core & earth flexible, tinned copper conductors, integral pilot thermistor cores, EPR/CSP
Conventional motors ≤ 15kW (See note 3)	3 core and earth PVC insulated PVC sheathed cables either SWA or in conduit

Conventional motors > 15kW ≤ 30kW (See note 3)	Single core PVC insulated PVC sheathed cables in conduit or in ducts suitably protected
Conventional motors > 30kW ≤ 150kW (See note 3)	Single core XLPE insulated PVC sheathed cables in conduits or in ducts, and suitably mechanically protected. Cables above 50mm^2 in ducts to be in trefoil groups
Protective earth cables	1 core PVC (green with yellow stripe)
Low Voltage variable speed variable speed controller PWM output cables:	Symmetrically shielded 3 phase cable(s) rated 0.6/1 kV and as described further in paragraph 10.2 hereunder.
Pipeline and structural steel bonding and earthing cables	1 core PVC (green with yellow stripe), sized 70mm^2 or size of station main earth conductor, whichever is the greater
Pipeline counterpoise earthwire	35mm^2 stranded bare hard drawn copper conductor

Note 1: Applies to cable buried direct or cables in buried PVC conduit. 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 diameter.

Note 3: Cables shall be rated for the full load current of the motor.

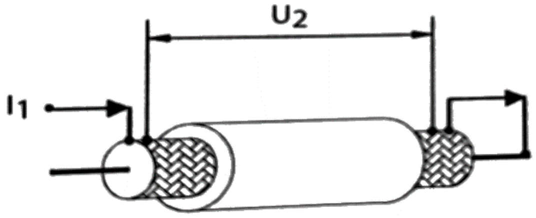
10.2 Cables for Variable Speed Controllers (VVVF)

The high switching speeds of the VSC IGBTs creates Common Mode (CM) currents (zero sequence) that “pollutes” the earthing system and Electromagnetic Interference (EMI) emitted from the power cable that interferes with sensitive equipment. Hence the correct selection of VSC cable and its screen performance is critical.

10.2.1 Shielding Effectiveness

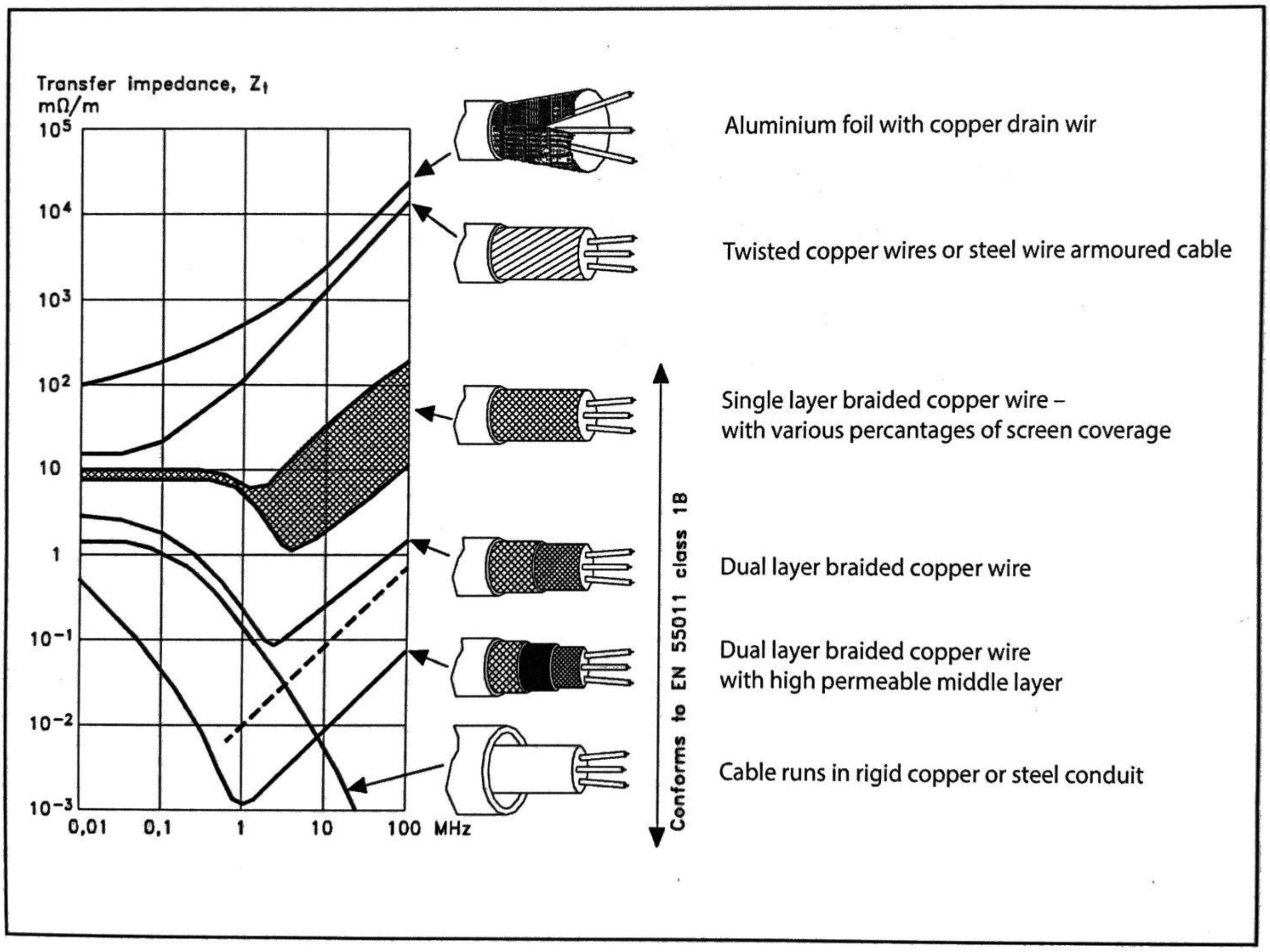
Shielding is used both for immunity (protecting against external interference) and emission (preventing interference to be radiated). In VSC applications, shielded cables are used for power and for control.

The shielding performance of a cable is indicated by its transfer impedance Z_T. The transfer impedance relates a current on the surface of the shield to the voltage drop generated by this current on the opposite end of the shield:



$Z_T = U_2 / (I_1 \times L)$, where L is the cable length

The lower the transfer impedance value the better the shielding performance. The table below shows typical values of transfer impedance for different kinds of motor cable. Even though a single layer braided copper screen has reasonably low transfer impedance (at a reasonable cost) the dual layer braided copper screen shall be used as a minimum, should the recommended cable in clause 10.2.2 not be available.



Transfer impedance can be drastically increased by incorrect shield termination. Critically, the shield of a cable must be connected to the chassis of the equipment (VSC gland plate and motor terminal box) through a 360-degree connection. Using “pigtails” to connect the shield increases transfer impedance severely compromising the shielding effect of the cable. Hence “pigtails” shall not be used.

10.2.2 Cable Type

Variable speed controller cable requirements are as follows.

(a) Variable speed controller cables referred to in paragraph. 10.1.2 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 mm^2, and not less than 50 % of the conductivity of each phase conductor for cables >16 mm^2.

(d) The cable screen shall consist of either

   (i) double copper tape screen or,

   (ii) a single copper tape screen overlaid with a copper wire screen or,

   (iii) a single copper tape screen (e.g., Varolex).

   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 75^0C and shall be site derated accordingly.

(f) If motor cables carrying PWM currents are to be installed in conduits, such cables shall be run in separate conduits.

(g) Motor cables carrying PWM currents may he 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.

(h) Single core cables shall not be used. This is to prevent circulating currents in the screens of single core cables, as the screen must be terminated at both ends.

10.3 Fault Rating

10.3.1 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 DS26-09.

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 DS26-09 are satisfied.

10.3.2 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.

10.4 Continuous Rating of Cables

10.4.1 Power Cables for non-distorting Loads

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, Part I and III, for the applicable derating factors.

10.4.2 Power Cables for Distorting Load

Cables shall be derated to compensate for additional heat caused by the harmonic currents and the associated skin effect. Skin effect depends on the conductor size and, hence, large cable sizes will require greater derating. Power cables commonly lie very close to one another, and therefore the high-frequency currents in the outer skin of one conductor influence the spread and behaviour of high-frequency currents in the skin of the adjoining conductors, giving rise to a “proximity effect.

The skin effect and proximity effect are proportional to the square of a frequency. Cables therefore shall be derated if there is significant harmonic distortion, particularly if the current THD is greater than 10%.

Unless information is provided by the cable manufacturer, power cables used in VSC applications shall be derated by 4% up to 120mm^2 and 6% for cables greater than 120 mm^2.

10.5 High Voltage Cable Terminations

10.5.1 Manufacturer’s Recommendations

All 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.

10.5.2 Dead-break Elbow Connectors

Dead-break elbow cable terminations on 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).

10.5.3 Indoor Air Insulated Terminations

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.

10.5.4 Pole Top Terminations

Pole top terminations on single core XLPE cables shall be made with approved outdoor heat shrink terminations, such as Raychem Type OXSU-F heat shrink terminations.

10.6 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. Low voltage cables installed in underground conduit is preferred to direct buried and shall be applied wherever practical.

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.

10.7 Minimum Separation for Power and Control Cables

As far as is practical, the minimum separation between power cables and signal cables shall be as stated below:

	Example		**Separation (mm)**			
Class of Signal	Cable 1 Cable 2		**1 Sensitive**	**2 Slightly sensitive**	**3 Slightly interfering**	**4 Interfering**
1 Sensitive	*Low level, analogue, sensors/probes, measuring, Profibus, Ethernet*		-	100	500	1000
2 Slightly sensitive	*Low level digital, low level DC power supplies, control circuits to resistive loads*		100	-	200	500
3 Slightly interfering	*Control circuits with inductive loads, clean AC power supplies, main power supplies 0.6/1kV, ≤400A*		500	200	-	200
4 Interfering	*Switching power supplies, VSD circuits, major LV power circuits,>400A*		1000	500	200	-
5 HV Cable	*HV cable, (≤33kV),*		1000	1000	1000	1000

The table above shows 5 types of signal cable categories and the spacing required between them.

“Sensitive” means the signal on the cable is sensitive to interference. “Interfering” means the signal on the cable causes interference.

For example, if the signal on cable 1 is “slightly interfering’ and the signal on cable 2 is ‘sensitive’, the distance between the cables should be 500mm.

These separation distances may be reduced if separate metallic conduits or metallic (magnetic material) cable trays/ducts are provided for power and/or signal cables. Such separation distances shall be in accordance with the recommendations of IEC 61000-5-2, BS 6739, HB29-2007, AS3080 and reputable company product installation guides.

A minimum separation of 1 m shall be maintained between HV cables and any power or signal cable, no matter what barrier is provided.

11 PUMP STATION AND SUBSTATION LIGHTING

Indoor and outdoor lighting have vastly different requirements based on the location and activity performed.

11.1 Internal Lighting

11.1.1 General

Interior lighting within pump stations and indoor substations shall be designed in accordance with the AS/NZS1680 series of standards.

AS/NZS1680.2.4: Industrial Tasks and Processes provides recommendations for lighting to assist with industrial tasks and processes within buildings. The lighting levels and other characteristics shall be designed to conform with the recommendations given in AS/NZS 1680.2.4 for Petroleum, Chemical and Petrochemical Works.

High bay light fittings may be used if the design of the building allows, and adequate provision is made to enable servicing of these fittings. The high bay lighting system shall be arranged so the light fitting assembly can be lowered to the floor level for maintenance.

Where necessary, additional lighting fittings shall be located so that the inside of switchboard cubicles can be reasonably illuminated if open for maintenance.

The main lighting in the pump station shall be evenly distributed over a 3-phase circuit switched by a contactor so that possible stroboscopic effects with rotating plant are avoided.

11.1.2 Emergency Lighting

Emergency lighting within pump stations and indoor substations shall be designed in accordance with the AS/NZS2293 series of standards.

Emergency lighting shall be installed in pump station and substation buildings to guide people towards the safest exit route. The AS/NZS 2293 series of standards sets requirements for lighting and exit signs for buildings. Part 1 specifies the system design, installation and operation of such lighting, Part 2 relates to routine service and maintenance requirements that the designer must consider, and Part 3 covers emergency luminaires and exit signs.

Emergency lighting shall be designed and installed to allow access lighting for periods of up to 15 minutes after mains failure.

11.2 External Lighting

All doorways, valve and flowmeter pits within the pump station environs, and all pipework trenches adjacent to the pump station walls should be illuminated to a minimum average value of 20 lux.

All substations shall be provided with sufficient lighting for safety of access and equipment operation.

All lighting fittings used externally should be fitted with guards to minimise possible damage by acts of vandalism.

All external doorway lighting should be controlled by a single 'on-off' switch located on the pump station or substation building wall. Where the building is located inside a perimeter security fence, the switch should be located on the external face of the wall adjacent to the main personnel access door. Where the building is not provided with a perimeter security fence, this switch should be located on the internal face of the wall adjacent to the main personnel access door.

Lighting on pipework trenches adjacent to the pump station building should be controlled similarly.

Wherever practical, external light fittings should be mounted on the walls of the pump station or substation. The number of lighting poles within the pump station enclosure should be minimised, so that as few as possible obstructions are presented to trucks manoeuvring in the pump station yard. All lighting poles shall incorporate a means to raise and lower the column for luminaire maintenance without the need for specialised access equipment, e.g. “See-Saw” poles.

External lighting shall be designed in accordance with AS/NZS 1158 series of standards. Furthermore, as external lighting relates to general security of the site, reference shall also be made to the Corporation’s security team for advice and requirements.

11.3 Prevention of Falls

Reference shall be made to the Corporation’s standard S151- Prevention of Falls regarding lighting fixtures in pump stations and other buildings.

12 VALVE ACTUATORS

12.1 General

Electrically powered actuators for valves used in water supply systems and treatment plants are usually of the 'part-turn' or 'multi-turn' type.

The part-turn actuator is the simpler and cheaper of these two types and its use is usually restricted to relatively small valves requiring to be simply opened or shut, without any requirement for positioning to any intermediate position, and without any restrictions on the speed of operation.

Electric actuators are to be equipped with an electric motor/gearbox combination, particularly developed for valve automation, providing the torque required for operating the moving elements of gate or butterfly valves as well as ball and globe valves. Manual valve operation via a handwheel shall be provided as standard. The actuator shall record travel and torque data from the valve, control process data and switch the actuator motor on and off. Controls shall be integrated within the actuator and equipped with a local control unit and electrical interface for external communications.

The electricity supply to the valve actuator shall be via a padlocked isolator.

12.2 Standards and Type Specification

The actuator shall comply with the requirements of EN 15714-2 Industrial valves —Actuators Part 2: Electric actuators for industrial valves — Basic requirements and the further requirements of Type Specification ‘DS26-41 Type Specification for an Electric Actuator for a Waterworks Valve’.

The Specification covers the design, manufacture, supply, delivery, testing and documentation of an electric actuator.

12.3 Electricity Supply

Electrically powered valve actuators shall be specified to operate from one of the following power sources as appropriate: -

(i) 3 phase 4 wire grounded neutral, 415V +6% -11% line to line, 50Hz +2.5%, AC.

(ii) 1 phase grounded neutral, 240V +6% -11%, 50Hz +2.5% AC.

(iii) 24V +25% -15%, unsmoothed, unfiltered DC.

12.4 Environmental and Performance Criteria

Refer Type Specification DS26-41 for all performance and environmental criteria.

12.5 Duty Classification

The duties for multi-turn actuators shall be:

(a) ON/OFF Control

S2 (Short time duty),15 minutes

(b) Inching

S4 (Intermittent periodic duty with starting), 25% (Cyclic duration factor), 60 starts per hour.

(c) Modulating

S4 (Intermittent periodic duty with starting), 25% (Cyclic duration factor), 600 starts per hour

The specified maximum number of starts per hour shall be not less than 20 for part turn actuators.

12.6 Safety Isolation Requirements

The designer shall design valve actuator systems such that these are capable of being safely isolated by an authorised person who is not a Licensed Electrical Worker. All electrically actuated valve installations shall incorporate electrical isolating devices for the power supply to actuators. Such devices shall be either:

(a) Decontactor or,

(b) Switch socket with interlock and padlock facility

The design of isolating facilities shall satisfy the following requirements/features:

(i) Located adjacent or close (within visual range) to the actuator

(ii) Location is not subject to flooding and suitably IP rated.

(iii) Mounted on a suitable stand.

(iv) Suitably labelled to identify the isolation device with the associated valve.

(v) Where not secured from vandalism, the device shall be installed in a suitable IP56 aluminium enclosure.

13 HYDRAULIC SURGE VESSELS

The control of hydraulic surge vessels 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 DS22 has been retained as Appendix A1 for information purposes only.

14 SWITCHBOARD CONTROLLING SYSTEMS

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 DS22 has been retained as Appendix A2 for information purposes only.

15 LOCAL AREA PRESSURE BOOSTER PUMP STATIONS

The control of high-level booster pump stations 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 DS22 has been retained as Appendix A3 for information purposes only.

16 UNINTERRUPTIBLE POWER SUPPLIES

16.1 Definition

An uninterruptible power supply (UPS) is defined in AS 62040.1.1 as a combination of converters, switches and energy storage devices (e.g., batteries) constituting a power system for maintaining continuity of load power in case of input power failure.

16.2 Standards

UPSs are covered by the following Australian Standards:

AS 62040.1	Uninterruptible power systems (UPS) - Safety Requirements
AS IEC 62040.2	Uninterruptible power systems (UPS) - Electromagnetic compatibility (EMC) requirements
AS IEC 62040.3	Uninterruptible power systems (UPS) - Method of specifying the performance and test requirements

16.3 Application

(a) UPSs are most commonly used to maintain continuity of power supply to electronic equipment which incorporates an internal switch mode power supply (SMPS).

(b) Switch mode power supplies can maintain the associated internal supplies for a least 10 milliseconds at full load and somewhat longer at lighter loads. Consequently, if the application is such that the load on the UPS consists solely of electronic equipment with internal switch mode power supplies, interruptions in the UPS output voltage will be acceptable provided these are not longer than 10 milliseconds

(c) Switch mode power supplies provide galvanic isolation between the incoming power supply and the associated electronic circuits. Consequently, if the UPS load equipment consists solely of electronic equipment with switch mode power supplies, there is no need for the UPS to provide galvanic isolation.

16.4 Types of UPS Topology

16.4.1 UPS Topologies in Current Use

The following general types of UPS topologies are in current use.

(a) line interactive,
(b) double conversion
(c) standby,
(d) standby- ferro,
(e) delta conversion online

16.4.2 UPS Topologies Covered by AS 62040

The following UPS topologies are described in Annex B of AS IEC 62040.3:

(a) line interactive,
(b) line interactive with bypass
(c) double conversion,
(d) double conversion with bypass,
(e) passive standby

UPSs provided in accordance with this Design Standard shall be either “line interactive with bypass” type or “double conversion with bypass” type, unless approved otherwise in writing by the Principal Engineer.

16.4.3 Rating Limits

For the reasons detailed hereunder UPSs rated greater than 5 kVA are usually of the double conversion with bypass type while UPSs rated less than 750 watts are usually of the line interactive with bypass type.

Which type of UPS topology is used for applications in the output range 750 watt to 5,000 watt will depend on the application and shall be determined by the Designer after consideration of the “pros and cons” of the two topologies as described hereunder.

16.5 Line Interactive with bypass UPS

16.5.1 Output Dynamic Performance

The line interactive with bypass type of UPS can provide an output dynamic performance as shown in Figure 16.1 and defined in AS IEC 62040.3 as classification 1

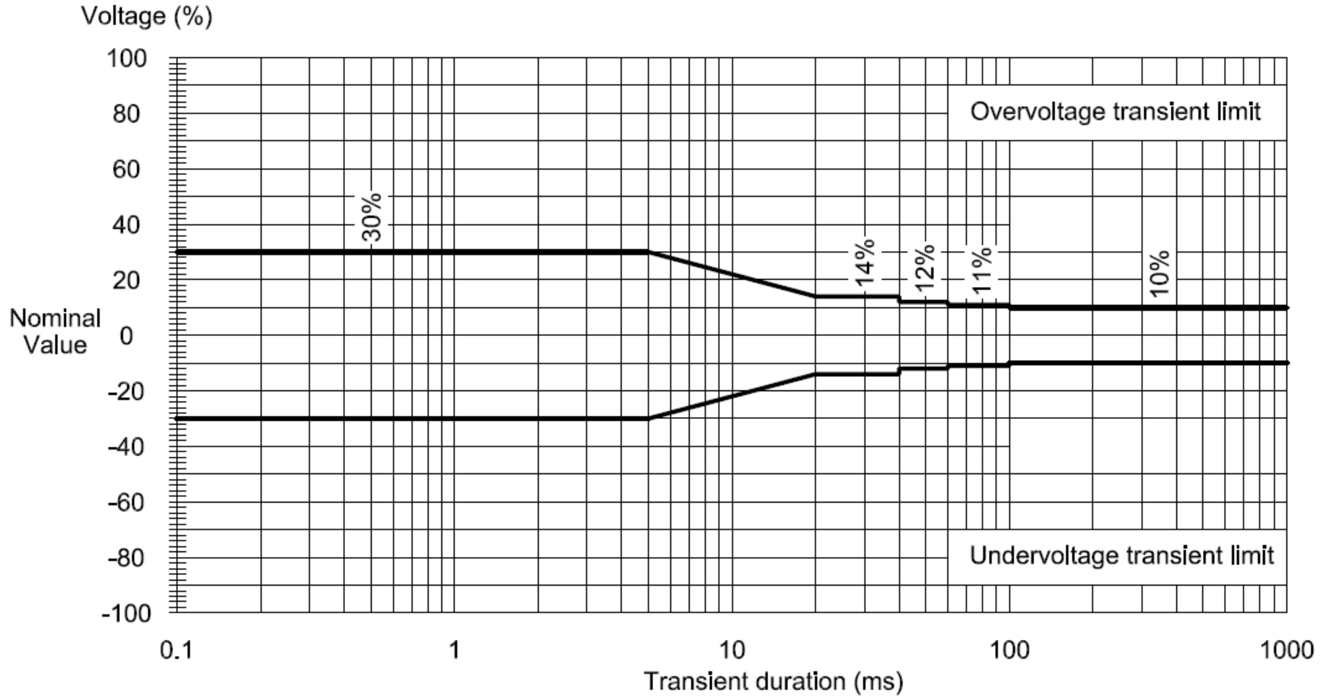


Figure 16.1

16.5.2 Topology

The topology of the line interactive with bypass UPS is shown at Figure 16.2.

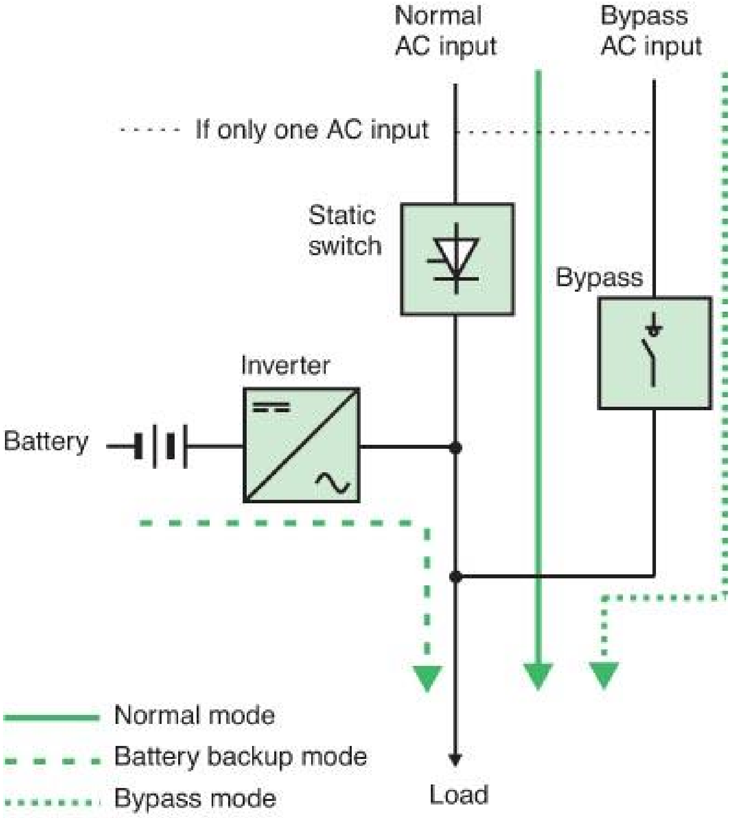


Figure 16.2

16.5.3 Operation

Operational sequence is:

(a) When AC input voltage is present the power interface equipment shown in Figure 16.1 filters the A.C input supply, suppresses voltage spikes and provides sufficient voltage regulation to operate within classification 1 output dynamic performance requirements.

(b) In the normal mode of operation, the load is supplied with conditioned power via a parallel connection from the A.C. input and the UPS inverter, with the input power coming from the A.C. input supply and approximately 10 % of the rated current of the UPS being supplied to maintain battery charge.

(c) When the A.C. input supply voltage is out of UPS pre-set tolerances, the inverter and the battery maintain continuity of output voltage and the UPS switch disconnects the A.C. input supply to prevent back feed from the inverter. Such transitions may cause the UPS output voltage to fall to zero for up to 1 millisecond.

The UPS continues to supply the load for the duration of the stored energy time or until the A.C. input voltage returns to normal.

(d) The bypass switch can be used to connect the load directly to the incoming supply in the event of:
    (i) UPS failure,
    (ii) load current transients (i.e., inrush currents or fault currents),
    (iii) Peak loads

(e) While the line interactive will filter the voltage being supplied to the load, it will not alter the wave shape of the current being drawn by the load. Consequently, if the load consists of electronic equipment with switch mode power supplies without power factor correction, the load current will be drawn in short duration peaks.

16.6 Double Conversion with bypass UPS

16.6.1 Output Dynamic Performance

The double conversion with bypass type of UPS can provide an output dynamic performance as shown in Figure 16.3 and defined in AS IEC 62040.3 as classification 3

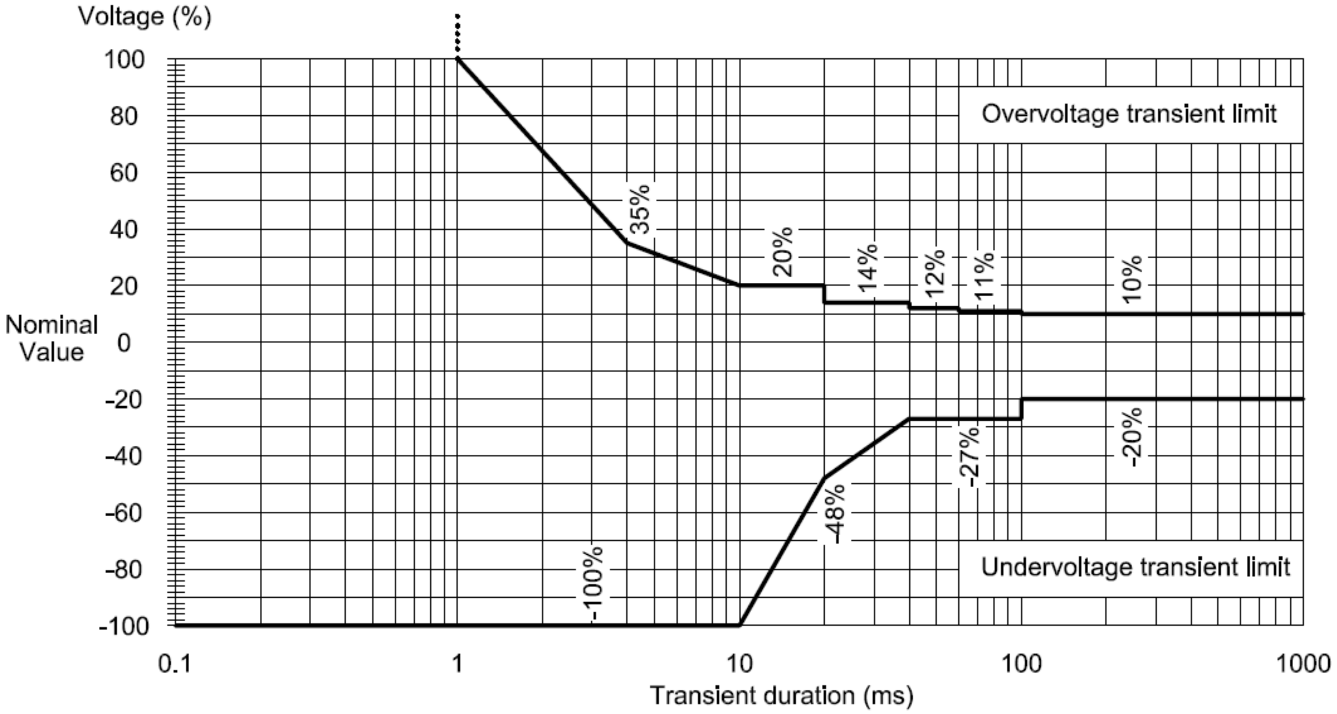


Figure 16.3

16.6.2 Topology

The topology of the double conversion with bypass UPS is shown at Figure 16.4.

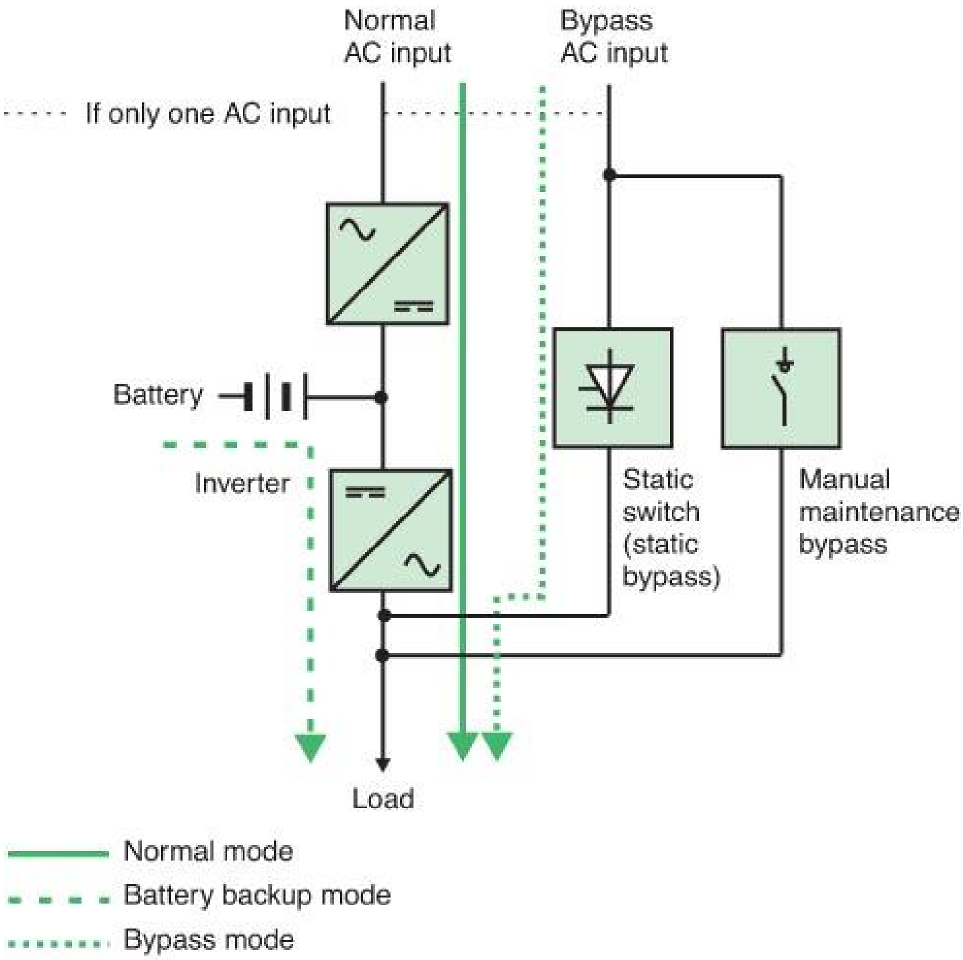


Figure 16.4

16.6.3 Operation

Operational sequence is:

(a) In the normal mode of operation, the load is supplied primarily by the rectifier inverter combination, i.e., all the load current flows through the rectifier/inverter combination.

(b) When the A.C. input supply voltage is out of UPS pre-set tolerances, the UPS enters the stored energy mode of operation, where the battery/inverter combination continues to support the load for the duration of the stored energy time, or until the A.C. supply returns to within UPS design tolerances, whichever is the sooner.

(c) In the event of a rectifier/inverter failure, or the load current becoming excessive, either transiently or continuously, the UPS enters the bypass mode in which the load is supplied temporarily via the bypass line. However, in some makes of double conversion UPS, such transitions may cause the output voltage to drop to zero for up to 10 milliseconds.

(d) Most modern UPS designs incorporate a separate battery charger module (not shown in Figure 16.4).

(e) As well as performing the A.C. to D.C. conversion, the rectifier section provides power factor correction, so that it draws current from the A.C. line as a smooth sine wave rather than in pulses even though currents drawn by the load may be drawn in pulses.

(f) Double conversion without bypass can be used to convert from 50 Hz to 60 Hz, and vice versa, if required.

16.7 Comparison between Types of UPS

16.7.1 Losses

In normal operation only approximately 10 % of the load current flows through the rectifier/inverter combination in a line interactive UPS, whereas in a double conversion UPS all the load current flows through the rectifier/inverter combination. Consequently, the heat losses from a double conversion UPS are much higher than those from a line interactive UPS.

16.7.2 Reliability

A line interactive UPS has a smaller component count than a double conversion UPS and so theoretically the line interactive UPS should be the more reliable. However, the quality of design and manufacture may have a greater impact on reliability.

16.7.3 Physical Size

Even though double conversion UPS's have a greater component count than line interactive UPS's, the components in the former are smaller, so that the physical dimensions and weight of a typical double conversion UPS will be smaller than those of a line interactive UPS of the same power rating.

16.7.4 Power Factor Correction

Unlike the double conversion UPS, the line interactive UPS does not incorporate power factor correction, so that load currents drawn, from line interactive UPS's, by switch mode power supplies, will be drawn in pulses from the A.C. incoming supply.

16.7.5 Operation from a Generating Set

(a) AS IEC 62040.3 requires the specification to include source impedance and generator characteristics.

(b) Normally double conversion UPSs are equipped with power factor correction which means that a double conversion UPS will present a largely capacitive impedance to the incoming supply system. However, generating sets can supply only approximately 10 % of alternator rated current at 0.1 power factor. On the other hand, line interactive UPS's do not present this problem.

16.7.6 Tolerance to A.C. Input Voltage Disturbances

Double conversion UPSs can tolerate greater A.C. input voltage disturbances without reverting to stored energy mode than can line interactive UPSs.

16.7.7 Battery Voltage

Since line interactive UPSs are relatively small, these can be equipped with Extra Low Voltage batteries, whereas double conversion UPSs usually are designed with higher battery voltages.

16.7.8 Local Availability

(a) Line interactive industrial UPSs are readily available as single-phase units with ratings up to 3 kVA and suitable for indoor or outdoor installation.

(b) Double conversion general purpose UPSs suitable for use in air-conditioned environments are readily available as follows:

(i) single phase/single phase - > 1 kVA ≤ 4 kVA
(ii) single phase/three phase - ≥ 6 kVA, ≤ 8 kVA,
(iii) three phase/single phase - ≥ 10 kVA, ≤ 60 kVA
(iv) three phase/three phase - ≥ 10 kVA, ≤ 900 kVA

(c) Double conversion industrial UPSs suitable for use in indoor environments without air-conditioning are available as follows;

(i) single phase to single phase- ≥ 5 kVA, ≤ 200 kVA
(ii) three phase to three phase - ≥ 10 kVA, ≤ 200 kVA

16.7.9 Type Specifications

DS26.30 - Type Specification for Double Conversion L.V. Uninterruptible Power Supply covers double conversion general purpose and double conversion industrial UPSs.

DS26.31 - Type Specification for Line Interactive L.V. Uninterruptible Power Supply covers line interactive industrial UPSs.

16.7.10 Cost

Both the capital cost and the running costs of double conversion UPSs are higher than those of line interactive UPSs.

16.8 Manual Isolation and Bypass Switches

The UPS shall be provided with the following facilities:

(a) Double conversion UPSs with static bypass facilities shall also be fitted with internal manual bypass switches to facilitate the checking of the UPS while maintaining the supply to the load from the bypass electrical supply.

(b) All UPSs shall be provided with external bypass and isolation switches which isolate the UPS from the incoming supply and the load.

(c) If the battery voltage exceeds 48 V DC, such switches shall also isolate the UPS proper from the battery supply.

(d) Suitable warning notices shall be provided to warn against the hazards due to multiple sources of electrical supply.

16.9 Operator Interface Panel

All UPSs shall be provided with operator interface panels which shall display UPS operating mode, alarms, etc.

16.10 Communications

All UPSs shall be provided with communications links which shall allow remote monitoring of the operating status of the associated UPS.

16.11 Batteries

16.11.1 Types of Battery

Nickel cadmium batteries could be used in UPS installation, however there are inherent environmental problems associated with the disposal of this type of battery and consequently the use of such batteries should be avoided if this is practical.

In lead acid batteries, the electrodes are made of various alloys and compounds of lead and these electrodes are generally referred to as plates. A sulphuric acid electrolyte is used to provide an electrical connection between positive and negative plates and the electrical energy is stored by reversible chemical conversions at the plates and within the electrolyte.

Lead acid batteries which provide direct access to the acid electrolyte are termed “flooded batteries” or “vented batteries” Such batteries could be used in some UPS installations but would present considerable operation and maintenance problems.

Most UPS installations employ valve regulated lead acid (VRLA) batteries in which the electrolyte is restrained. Clause 17 refers. This Standard is based on the use of such batteries.

16.11.2 VRLA Batteries - General

VRLA batteries are often described as “sealed lead acid batteries”.
These batteries are sealed under normal operating conditions but include pressure relief valves to vent gases in the event of overcharging.

The acid electrolyte in VRLA batteries is trapped within each battery cell so that the possibility of spillage of the acid electrolyte is avoided, i.e., VRLA batteries are leak proof.

VRLA batteries would be better described as “recombinant batteries” because in these batteries the oxygen evolved at the positive plates combines with the hydrogen ready to evolve at the negative plate, so recreating water. (In the vented battery these gases escape, thus requiring the periodic addition of distilled water.)

There are two types of VRLA batteries, i.e., the absorbed glass mat (AGM) battery and the Gel battery as described further hereunder and in clause 17.

16.11.3 AGM Batteries

In the AGM type of VRLA battery, the acid electrolyte is held within glass mats between the plates (as opposed to freely flooding the plates)

The glass mats are made of fine glass fibres woven into mats so to provide the surface areas needed to hold sufficient acid electrolyte on the cells over their design life.

In the AGM battery the pores in the glass mat provide a densely porous medium to the oxygen to facilitate its movement from the positive electrode to the negative electrode.

16.11.4 Gel Batteries

In the Gel type of VRLA battery, the acid electrolyte is combined with fumed silica making the resultant mass gel-like and immobile.

In the Gel battery, the cracks in the gel provide a densely porous medium to the oxygen to facilitate its movement from the positive plate to the negative plate.

16.11.5 AGM versus Gel Battery Comparison

(a) Gel batteries are superior to AGM batteries in the following respects:

(i) Service life,
(ii) Capacity stability over life,
(iii) Thermal runaway,

(iv) Endurance of cycles,
(v) Battery design constraints,
(vi) Deep discharge tolerance.

(b) AGM batteries are superior to Gel batteries in the following respects:

(i) Internal resistance,
(ii) Power density,
(iii) Cost

16.11.6 Battery Service Life

Generally, the service life of a VRLA battery is defined as the time taken for the battery amp*hour capacity to fall to 80% of the battery design amp*hour capacity. However, some manufacturers quote service life as being the time taken to fall to 60% of the battery design life.)

The design life of a VRLA battery depends on the type and make of battery and is generally 5 or 6 years. However, Gel batteries with a design life of up to 18 years are available.

For normal VRLA batteries the expected battery service life values are given for batteries operated at 20ºC.and the expected service life is halved for every 8ºC to 10ºC temperature rise above 20ºC. (The reduction in service life with ambient temperature for Gel type batteries with tubular positive electrodes is less, i.e., the battery capacity is reduced by 30% for every 8ºC to 10ºC temperature rise above 20ºC.)

However, Gel batteries with small amounts of silver alloyed into the lead electrodes are available for high ambient temperature applications such that these batteries have a service life of 4 years at operating temperatures up to 70ºC.

16.11.7 Battery Capacity Stability

AGM batteries are prone to the electrolyte in the glass mat separators drying out during service life which increases the internal resistance, and which causes the glass mat separators to contract, thus reducing contact with the plates.

On the other hand, in the Gel battery, the gel creeps with time thus maintaining good contact with the plates.

16.11.8 Battery Internal Resistance

The lower internal resistance of AGM batteries means that these batteries are ideal for UPS applications in air-conditioned environments because under float charging the lower internal resistance means that charging times are reduced.

16.11.9 Battery Thermal Runaway

The internal resistance of a VRLA batteries falls as the battery temperature increases.
With float voltage charging, the drop in internal resistance results in an increase in charging current and hence a cycle of increased heating and increased current until the battery is overheated and destroyed.

In addition, AGM batteries have a lower diffusion resistance thus a higher internal recombination rate than Gel batteries because in the latter diffusion is hindered by the gel and the micro porous separator.

Further, the heat conduction from the battery electrodes and to the environment via the battery case is approximately 15% better in the Gel battery than in the AGM battery.

Thus, AGM batteries are more prone to thermal runaway than Gel batteries, so that Gel batteries are more suitable for use in higher temperature environments.

16.11.10 Battery Cycle Endurance

Both AGM and normal Gel batteries provide good cycle life with the latter being better in this respect.

Excessive cycling can cause acid stratification in AGM batteries as well as the formation of dendrite structures on the plates, which in turn leads to reduced service life.

Gel batteries are available which are specially designed for multiple cycle duty. These batteries are not as good in other respects and should not be specified for applications not involving very high cyclic duty.

16.11.11 Battery Design Constraints

Tubular plate design is possible in Gel batteries which has the benefit described clause 16.11.6 above.

The cell height in AGM batteries is limited to approximately 350 mm whereas no such restrictions apply to Gel batteries

16.12 UPS Application to Environmental Conditions

(a) Line interactive uninterruptible power supplies may be installed in the following locations provided they are specified accordingly:

  (i) indoors in a control room environment,
  (ii) indoors in a weather protected environment (other than a control room environment), or
  (iii) outdoors

(b) Double conversion uninterruptible power supplies may be installed in the following locations provided they are specified accordingly:

  (i) indoors in a control room environment, or
  (ii) indoors in a weather protected environment (other than a control room environment).
  (iii) shall not be installed in an outdoor environment.

(c) Type specifications D S26.30 and DS26.31 shall be used for double conversion uninterruptible power supplies and line interactive uninterruptible power supplies respectively.

16.13 UPS MEN and Neutral Continuity

When designing a UPS system, back-feed protection as required by AS62040-1 and requirements of AS3000 with regards to the continuity of the neutral conductor and connection to the MEN must be considered. Refer “UPS Investigation” report at Appendix D for further information and connection diagrams.

There are differences in the requirements of back-feed protection for plug-in and hardwired UPSs and, as a general rule, the following points are recommended:

16.13.1 Permanently connected UPS

(a) Permanently connected UPSs should be supplied from circuit breakers that do not switch the neutral input to the UPS as the output neutral is reliant on the input neutral

(b) There is no general requirement to add a connection between the UPS output neutral to earth as the output neutral is always connected to the input neutral and installation MEN.

(c) Depending on the specific details of the installation, input or output isolation transformers may be necessary and the UPS manufacturer should provide guidance on these requirements.

16.13.2 Plug-in UPS

(a) UPS should be connected as detailed in the manufacturer's installation instructions.

(b) There is no general requirement to add a connection between UPS output neutral and earth.

(c) When the UPS is operating in 'battery mode', the UPS output is disconnected from the main installation earthing system. The UPS operates as an IT earthing system which is permitted by AS3000 5.1.4, and protection of personnel and equipment is adequately provided by the UPS.

(d) Where the IT earthing system is considered unacceptable, an output isolation transformer may be used. Alternatively, a permanently connected UPS may be considered. For existing installations, some UPS manufacturers provide conversion kits whereby a plug-in UPS can be converted to a permanently connected UPS.

17 DIESEL ENGINE STARTING BATTERY SYSTEMS

17.1.1 Scope

This section of the standard applies to battery systems for diesel engines which are designed for service in a fixed location, and which are permanently connected to the load.

Batteries operating in such applications are called 'stationary batteries'.

A battery system is defined as the batteries and associated battery chargers and/or battery management systems.

The scope of this section covers the general requirements, characteristics, performance requirements and selection rules of battery systems for diesel engine standby power supplies.

17.2 Standards

Batteries and battery chargers are covered by the following Australian Standards:

AS 2149	Starter Batteries – Lead-Acid
BS E N 61429	Marking of secondary cells and batteries with the international recycling symbol ISO 7000-1135
AS 4029.1	Stationary Batteries – Lead-Acid. Part 1: Vented type
AS/NZS 4029.2	Stationary Batteries – Lead-Acid. Part 2: Valve Regulated type
AS 4029.3	Stationary Batteries – Lead-Acid. Part 3: Pure lead positive pasted plate type *(Withdrawn)*
AS 2562	Hydrometers – Portable syringe-type for lead-acid batteries *(Withdrawn)*
AS/NZS 2401.2	Battery Chargers for Lead-acid Batteries – Domestic type – Battery Chargers for valve-regulated cells
AS 4044	Battery Chargers for Stationary Batteries

17.3 Acronyms and Definitions

AGM – Absorbed Glass Mat

BMS - Battery Management System

DOD - Depth of Discharge

LiFePO4 – Lithium Iron Phosphate

LTO - Lithium Titanate LTO

NCA - Lithium Nickel Cobalt Aluminium

NMC - Lithium Nickel Manganese Cobalt

SLA – Sealed Lead Acid

UPS - Uninterruptable Power Supply

VRLA - Valve Regulated Lead Acid

17.4 Discussion

The Water Corporation operates diesel engine battery power plants in varied climatic conditions throughout Western Australia. The North West region of the state can reach maximum temperatures of 49°C (Bureau of Meteorology 2015) with high humidity and dust levels.

These power plants are often remote and unmanned leading to a desire for a minimal maintenance regime. It is therefore important to address the service life implications of battery systems used in often harsh and high temperature environments. Battery integrity is critical to the stand-by/ emergency power performance of diesel engine system applications in maintaining service obligations.

A fully sealed VRLA battery does not allow for benign release of gasses generated under continuous charging. In high temperature environments and subject to float charging, the battery cells can suffer water loss to the extent the electrolyte falls below the top edge of the plates. This results in a low resistive bridge forming at the top of the plates and, when current starts to flow, can cause an arc or spark in one of the cells. Subsequently, electrode warping causes a short and an explosion of the hydrogen/oxygen gas mixture and rupture of the battery.

There have been several battery explosions involving VRLA batteries (those without access to the electrolyte), fitted to back-up/emergency diesel engine systems, exposed to high operating temperatures and subject to float charging.

This section of the standard addresses alternative battery types and battery chargers/BMSs for diesel engine starting systems to reduce risk of battery failure described above.

It is important that the battery selection provide for 6 cranking cycles of 5 seconds as minimum.

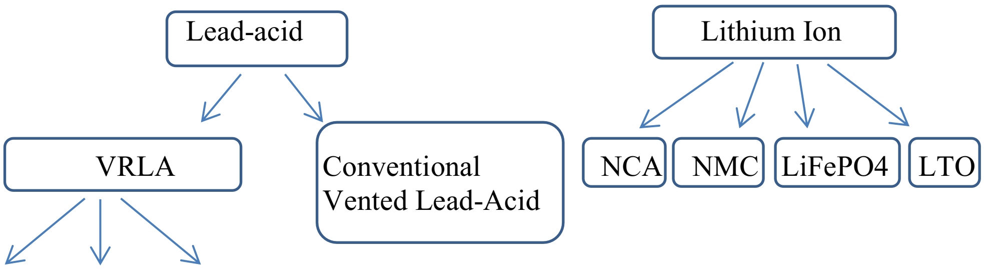
Recommendations on the selection of diesel engine starting battery systems for floating operation are given in clause 17.8, Summary and Recommendations.

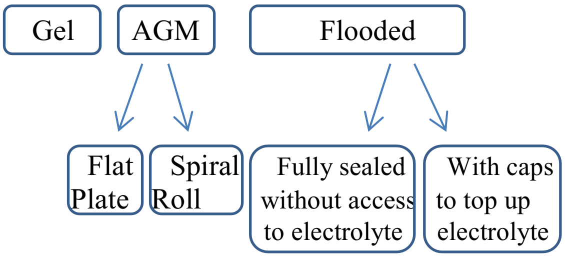
17.5 Investigation of Battery Types

The investigation into existing batteries determined three main battery types that can be used for the diesel engine starting systems, namely:

a) Lithium iron phosphate, LiFePO4.
b) VRLA, AGM Flat Plate or Spiral Roll type.
c) VRLA ‘flooded’ type that can be periodically topped up electrolyte.

The diagram below illustrates the battery types examined for the diesel engine starting application.





17.5.1 Lead Acid Technology

Lead acid batteries are one of the oldest rechargeable battery chemistries and have dominated the market due to their low cost and well researched characteristics (Buchmann 2011). In modern lead acid batteries, the electrodes are manufactured from lead calcium alloys and suspended in a diluted sulphuric acid electrolyte.

A sulphuric acid electrolyte is used to provide an electrical connection between positive and negative plates and the electrical energy is stored by reversible chemical conversions at the plates and within the electrolyte.

Conventional lead acid batteries which provide direct access to the electrolyte are termed ‘flooded batteries’, ‘wet’ cells or ‘vented batteries’. ‘Flooded’ batteries can be used in emergency diesel engine starting system installations but can present some operational and maintenance problems. That is, this type of battery needs to be frequently topped up with water due to electrolysis of water to hydrogen and oxygen.

Known for its simplicity Valve Regulated Lead Acid (VRLA) batteries have a pressure relief valve which will activate when the battery starts building pressure of hydrogen gas, generally a result of being recharged. VRLA batteries are available fully sealed without access to electrolyte or can be provided with caps to top up electrolyte.

The majority of current VRLA batteries have the diluted acid electrolyte solution immobilised, either by soaking a fiberglass mat in it (absorbed glass-mat, AGM), or by turning the liquid into a paste-like gel by the addition of silica and other gelling agents (Gel). In this type of VRLA, recombinant gas batteries, the gases are retained within the battery as long as the pressure remains within safe levels. Under normal operating conditions the gases can recombine within the battery itself, sometimes with the help of a catalyst, and no topping-up with water. However, if the pressure exceeds safety limits, safety valves open to allow the excess gases to escape, and in doing so regulate the pressure back to safe levels.

VRLA AGM cells may be made of flat plates similar to a conventional flooded lead acid battery or may be made in a spiral roll form to make cylindrical cells.

17.5.2 Lithium-Ion Technology

Lithium-ion batteries first appeared in the 1960s with rechargeable Lithium-ion batteries being produced and sold in the mid to late 1990s.

The term lithium-ion refers to a family of batteries in which ions move from the negative electrode (anode) to the positive electrode (cathode) during discharge and back again when being charged. The point to note in this definition is that it refers to a ‘family of batteries’. Just like the VRLA family which contains AGM and Gel types, there are several different ‘lithium-ion’ technologies within the lithium-ion family. They each utilise different materials for their cathode and (to a lesser degree) anode and as a result exhibit different characteristics. They are therefore best suited for different applications.

It is usually the material composition of the cathode which gives its name to the lithium-ion type, with the anode often being graphite. Lithium titanate is one such exception.

The important thing to note is that the best battery technology depends on the application e.g., LiFePO4 batteries are extremely stable and safe to use. This safety, combined with their light weight has seen them picked up widely for use in both military and commercial applications.

17.6 Characteristics and Performance of Preferred Batteries

17.6.1 VRLA AGM Flat Plate and Spiral Roll Batteries

VRLA AGM batteries offer several advantages compared with VRLA ‘flooded’ lead acid and conventional lead acid batteries. The battery can be mounted in any position since the valves only operate on over pressure faults.

The hydrogen suppression efficiency (measure of hydrogen and oxygen gasses recombination within the cell) in valve-regulated AGM cells varies with cell technology, but typically exceeds 90%. Since the battery system is designed to be recombinant and eliminate the emission of gases on overcharge, room ventilation requirements are reduced, and no acid fume is emitted during normal operation.

AGM batteries employ a glass micro fibre mat separator that holds the liquid electrolyte like a sponge. Shrinkage of a separator does not occur as the battery ages and the electrolyte remains in direct contact with the plates. VRLA AGM made in a spiral roll has one excellent advantage over the flat plate type in as much that because the cells are separate; their heat accumulation values are low.

The main downside to the AGM design is that the immobilizing agent also impedes the chemical reactions that generate current. For this reason, the AGM batteries have lower peak power ratings than equivalent conventional battery designs.

VRLA AGM battery characteristics:

a) Suitable for deep discharge current applications e.g., engine starting (internal resistance 1.2 mΩ to 4.5 mΩ). The lower the resistance, the less restriction the battery encounters in delivering the needed power spikes.
b) Have shorter recharge time than flooded lead acid.
c) Typically, 500 discharge/charge cycles at 50% Depth of Discharge.
d) Cannot tolerate overcharging: overcharging leads to premature failure.
e) Have shorter service life, compared to properly maintained wet cell battery.
f) Compared with flooded lead acid battery, discharges significantly less hydrogen gas.
g) AGM batteries are by nature, safer for the environment, and safer to use than flooded lead acid battery.
h) No cell equalising charge is required.
i) Can be used or positioned in any orientation.
j) VRLA AGM flat plate battery is approximately 40% cheaper than equivalent VRLA AGM spiral roll type.
k) VRLA AGM flat plate battery is approximately three to six times cheaper than equivalent lithium iron type of battery.

17.6.2 Lithium- Iron Phosphate Batteries

Lithium iron phosphate (LiFePO4) discovered in 1999 is a well know lithium technology in Australia due to its wide use and suitability for a wide range of applications. Compared to other lithium-ion types, such as lithium cobalt and lithium manganese, it has over twice the cycle life and is much less prone to thermal runaway which can result in the battery catching fire and thus has hindered the uptake in lithium -ion batteries in the past.

The cell voltage of 3.2V/cell also makes it the lithium technology of choice for sealed lead acid replacement in several key applications, including diesel engine starting systems.

LiFePO4 battery capacity fade behaviour, primarily the result of loss of active lithium that is most likely associated with anode degradation, and life modelling for this battery has not been well established.

More importantly, there is little insight regarding the aging mechanisms associated with this type of battery.

The lithium iron phosphate battery characteristics:

a) Internal resistance 2 mΩ to 20 mΩ.
b) Low combustion energy, therefore, excellent safety characteristics.
c) Good use of capacity can accept 80% Depth of Discharge.
d) Typically, 5000 discharge/charge cycles at 70% Depth of Discharge.
e) Moderate specific energy: Whr/kg or Whr/L.
f) Despite dramatic reduction in cost over the past decade, LiFePO4 batteries remain expensive. A LiFePO4 battery cost is three to six times more than equivalent size of VRLA AGM battery.
g) Lithium-ion batteries require a Battery Monitoring System (BMS).

17.7 Battery Management Systems (BMS)/Chargers

17.7.1 VRLA Battery Chargers

Current limited float charging or temperature compensation of the float voltage in accordance with the manufacturer’s recommendation must be specified for alleviating the risk of thermal runaway. Furthermore, the charger shall include a facility to stop charging when the ambient temperature exceeds a specified maximum.

Avoid boost (fast) charging as this only charges the surface of battery plates, can increase the chance of overheating, cause permanent damage and lead to excessive build-up of explosive gasses. A manually selectable boost charge facility is authorised only during engine start and run periods. It is essential to consult the battery manufacturer to ensure that the battery charger and charge rates are properly selected, and maintenance schedules are established.

As recommended by the battery manufacturer, VRLA batteries require a multistage charge sequence for accurate charging.

Current multistage chargers deliver four primary charge stages:

a) Bulk charge: Around 80% of the battery capacity is recovered in this stage.
b) Absorption charge: The remaining 20% capacity is replaced allowing the current to drop as the battery approaches its full charge.
c) Float: The charge voltage is lowered and held at a constant and safe predetermined level. This prevents the battery from being overcharged.
d) Maintenance: This stage is a regular timed ‘return to bulk’ stage.

The VRLA battery chargers must provide the following protection features:

a) Reverse polarity: With user replaceable fuses.
b) Over charge: Initiation of a fault shutdown and raise of a fault alarm.
c) Over temperature: Unit shutdown and raise a fault alarm.
d) Output short circuit: With user replaceable fuses. This will initiate a fault shutdown and raise a fault alarm.
e) Temperature sensing (battery temperature sensor) for temperature compensation.
f) Cooling: Forced air ventilation (if specified by a manufacturer).

17.7.2 Lithium Iron Phosphate Battery Management System

A Li-ion battery (a set of Li-ion cells in series) is charged in three stages:

a) Constant current.

b) Balance.

c) Constant voltage.

During the constant current stage, the charger applies a constant current to the battery at a steadily increasing voltage, until the voltage limit per cell is reached.

During the balance stage, the charger reduces the charging current (or cycles the charging on and off to reduce the average current) while the state of charge of individual cells is brought to the same level by a balancing circuit, until the battery is balanced. Some chargers accomplish the balance by charging each cell independently.

During the constant voltage stage, the charger applies a voltage equal to the maximum cell voltage times the number of cells in series to the battery, as the current gradually declines towards 0, until the current is below a set threshold of about 3% of initial constant charge current.

Failure to follow current and voltage limitations can result in an explosion.

Lithium Iron Phosphate (LiFePO4) batteries require a Battery Monitoring System for equipment safety and to protect the cells from damage.

A BMS protects the batteries from several potentially damaging and unsafe scenarios, such as:

a) Over temperature.
b) Over charge/discharge current and voltage. Over-voltage (during charging) and Under-voltage (during discharging).
c) Cell not balancing themselves through charge/discharge cycles
d) Overcurrent and short circuit.

These will initiate a fault shutdown and raise a fault alarm.

The BMS must monitor the following parameters:

a) Voltage: Total voltage, voltages of individual cells.
b) Temperature: Temperature of individual cells.
c) State of charge.
d) Depth of discharge.
e) Current: Current in or out of the battery.

These will initiate a warning alarm.

External cell level balancing is required to maintain a consistent state of charge in the long term. Lithium Iron Phosphate batteries are not self-balancing meaning the cells do not balance themselves through charge/discharge cycles. Individual cells must be monitored for over/under voltage and temperature conditions. This is essential to ensure equipment safety and increase life span.

Detection devices should incorporate a short delay to avoid spurious operation of alarms by transient voltages.

17.8 Summary and Recommendations

The diesel engine starting systems are required to be designed to provide long service life capability in adverse environmental conditions.

Conventional lead acid non-valve regulated batteries can be used in diesel engine starting system installations but these batteries present high personal and equipment safety risk if not correctly maintained. Furthermore, conventional lead acid non-valve regulated battery systems are characterised by high maintenance cost. The lead acid non-valve regulated batteries are not recommended for use for diesel engine starting systems unless regularly maintained.

Fully sealed VRLA batteries without access to electrolyte, under continuous charging and high temperature can suffer water loss and have been known to explode. This type of battery shall not be used in diesel engine starting systems installations.

Lithium-ion battery technology has potential to provide significant savings in the future. Scaling up the lithium battery technology for diesel engine starting applications is still problematic since issues such as costs, stability of performance, wide operational temperature and materials availability, are still to be resolved. The lithium-ion technology is unproven for this application and environment, therefore at this stage, is not recommended for use in diesel engine starting systems installations. Development of lithium battery technology product standards and field verification may well lead us towards reassessing their use for diesel engine starting systems in the future.

Where a regular (monthly) maintenance regime can be implemented for the site, then conventional VRLA ‘flooded’ type batteries, that can be periodically topped up with electrolyte, are recommended. In these instances, temperature compensated chargers shall also be specified.

Where a reduced maintenance regime is required for the site, then VRLA AGM Flat Plate or VRLA AGM Spiral Roll batteries with temperature compensated chargers are recommended.

18 Electrical Installation

18.1 General

Electrical installation design shall be carried out in accordance with the requirements of the relevant electrical Design Standards and drawings as listed in clause 1.3 of this Design Standard (DS22), the National & International standards and sound engineering installation practice.

18.2 Type Specifications

Type Specifications have been prepared for all electrical installations covered by this Design Standard DS22 to streamline the installation design and tendering process.

In particular, the following Type Specifications are relevant to minor electrical installations:

a) DS26-44 Type Specification for Minor Electrical Installations

b) DS26-46 Design & Construction Specification for Minor LV Switchboard Replacement under ‘Technology Licence Agreement’

c) DS26-47 Design & Construction Specification for Minor Electrical Works

The purpose, extent and contracting strategy for the three Type Specifications are:

a) DS26-44. This covers the basic technical installation requirements for electrical installation.

b) DS26-46. This is for the engineering and switchboard design, switchboard construction and installation of the switchboard for projects involving switchboard replacement only. Connection is made to existing plant within the confines of the existing building/site. Generally, there is no (or minimal) mechanical and civil design or construction/installation involvement. Further explanation and detail can be found in the guidance notes to DS26-46.

c) DS26-47. This document is designed to accommodate the demand for electrical input to the civil engineering Design & Construct process for new projects. Further explanation and detail can be found in the guidance notes to DS26-47 and in clause 3.17 of DS20.

APPENDICES

APPENDIX A

Control System

A SWITCHBOARD CONTROL FUNCTIONS

Control function requirements:

(a) All sites are to be integrated into the Corporation wide supervisory control and data acquisition (SCADA) system or at least be “SCADA ready” for when these are able to be integrated.

(b) Normally the control logic for each small pump station having an electrical rating within the scope of the design standard shall be implemented, via the above standard Low Voltage control circuits, by the use of a single programmable logic controller (PLC) functioning as the “controlling system” as defined at Fig. 1 of AS/NZS 4382 and by use of a SCADA system remote terminal unit (RTU) functioning as the connection to the “superordinated controlling system”, again as defined at Fig. 1 of AS/NZS 4382. All local control and protection functions shall be executed in the PLC.

(c) For small standalone sewerage pump stations only, (i.e. those which are not located within waste water treatment plants), normal operational control and monitoring functions shall be incorporated into the RTU. However, a very small PLC controlled by a single contact on an independent level probe shall be installed to provide basic load control of the pumping plant in the event of an RTU failure. This PLC shall be programmed in accordance with the Corporation’s standard logic diagram for this particular emergency control application.

(d) The RTU’s to be used for the control of small standalone sewerage pump stations shall be of a make and model approved by the Principal Engineer. Such RTU’s shall be provided by the manufacturer already programmed for control and monitoring in accordance with a standard Water Corporation specific programme which has been approved by the Principal Engineer. However, facilities shall be provided for entering project specific parameters into the programme.

(e) The above RTU’s shall be provided with detailed descriptions of the control logic, preferably in the Corporation’s control block logic form, so as to facilitate factory testing of the switchboard controlling system.

(f) Subject to the written approval of the Principal Engineer, minor variations may be made to the standard power voltage control and metering circuits so as to make use of functions which are built into the RTU as standard functions. No such modifications will be approved unless it can be demonstrated that the functions in questions are in fact manufacturer’s standard built in functions, the reliability of which has been approved by extensive field trials and experience.

(g) The switchboard controlling system shall be in accordance with Section 14 of the Design Standard.

(h) An Operator’s Interface Panel may be provided for viewing critical status and alarm points and to provide protected access to trip points. Operator Interface Panels installed in indoor switchboards shall be rated for operation at a maximum temperature of not less than 50ºC whereas Operator Interface Panels installed in outdoor switchboards shall be rated for operation at maximum temperature of not less than 60ºC

A1 HYDRAULIC SURGE VESSELS

A1.1 Principle of Operation

(a) Hydraulic Surge Vessels may be necessary at pump stations to dampen pressure surges in pipelines that can be caused by sudden changes in flow rate. The basic operation of a hydraulic surge vessel electrical installation is shown diagrammatically in Fig. A1.1 and the detailed logic is shown in the Corporation's FS00 series of drawings.

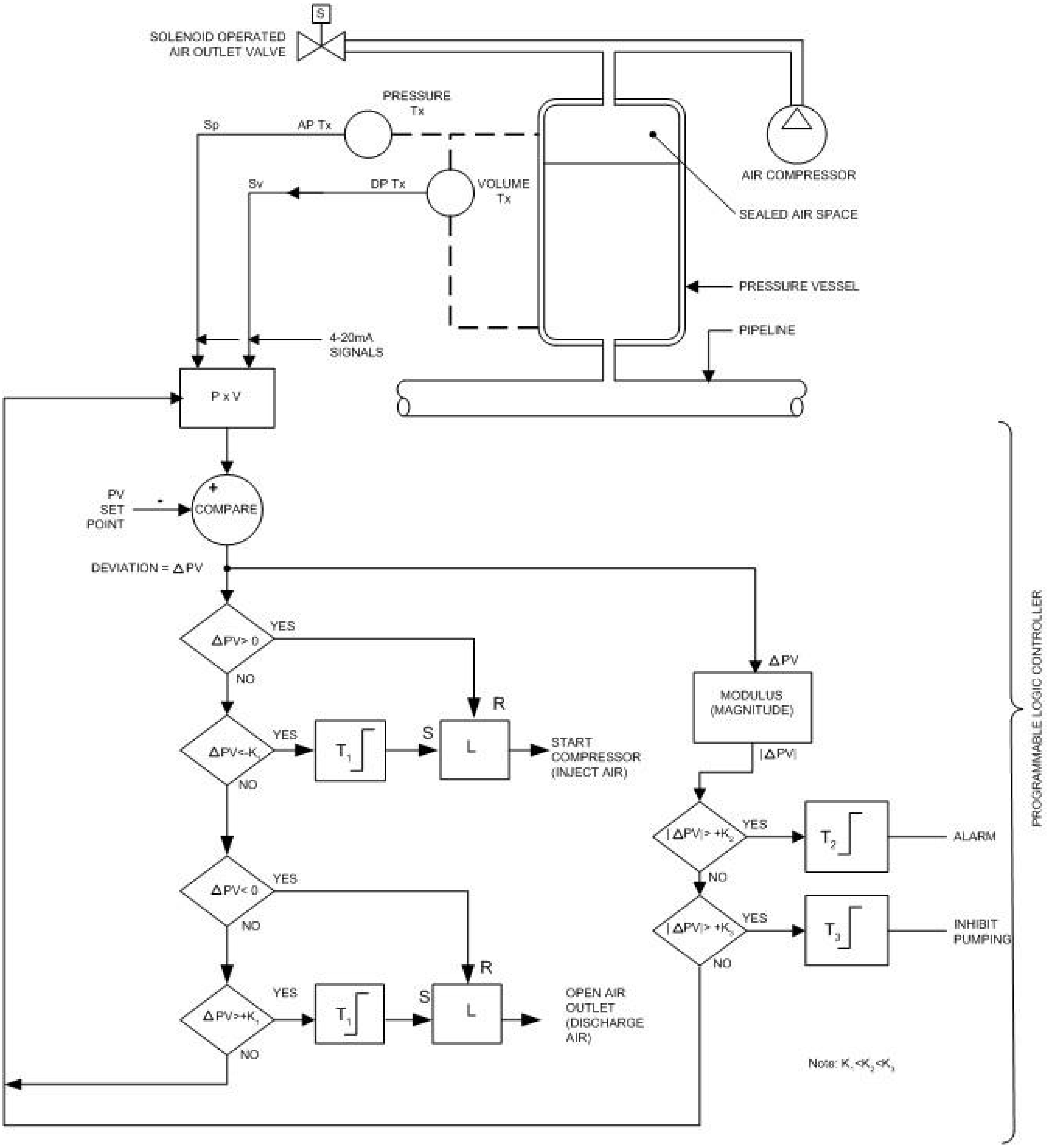


Fig. A1.1 Basic Operation of Surge Vessel

(b) The air in the sealed space above the water acts as a pneumatic spring and hence damps sudden pressure changes in the pipeline.

The purpose of the compressor is simply to make up enclosed air lost by dissolving into the water or by air system leakage.

Since the operation of the vessel is dependent on the volume of air at normal operating pressure, no temperature compensation is provided in the air measurement system. This means that the allowable variation in and the subsequent selection of the K factors must be such that the normal diurnal variation in temperature does not initiate control or alarm functions. Seasonal temperature variations are catered for by the normal air make-up or release operations over time.

(c) The time delay settings for a particular site should be determined by observing the settling time for PV (t_o) after shutting down a pump. Delay times should be set as follows:

$t_1 = 2t_o$

$t_2 = 3t_o$

$t_3 = 4t_o$

(d) PV_{max}(%) should be determined such that, for process conditions L_{nom} and P_{nom} the normalised value of PV will be 50%.

The PV set point should be set initially at 50%.

A1.2 Controller

(a) Standard drawings FS00-2-8.1 and FS00-2-8.2 detail the standard logic necessary to achieve the mode of operation shown diagrammatically in Fig A1.1.

(b) The above standard logic shall be coded into the common control PLC in the pump station associated with the surge vessel

A2 SWITCHBOARD CONTROLLING SYSTEMS

A2.1 General

A2.1.1 Definition

(a) The switchboard controlling system (as defined by IEC 60050-351) shall consist of the programmable logic controller(s) and associated ancillary equipment which control the switchboard main circuit equipment via the switchboard Low Voltage control circuits.

(b) The switchboard controlling system shall interface with the associated supervisory control and data acquisition system (SCADA) or with the associated treatment plant overall control system.

A2.1.2 Separation

(a) Generally, the switchboard controlling system shall be separate from the associated SCADA system and from the treatment plant overall control system.

(b) However, for small sewage pump stations only, the switchboard controlling system logic may be implemented within the associated SCADA system remote terminal unit (RTU). In the case where the RTU is used in this manner the RTU shall comply with the requirements of this section.

(c) However, all of the requirements specified hereunder in respect to software format, logic conventions, controller programming and logic documentation shall apply to all switchboard controlling systems regardless of where the logic is to be executed.

A2.1.3 Housing

(a) SCADA system RTU's and PLC's shall be located so as to minimise fast transient burst interference from the main power circuit equipment.

(b) For High Voltage switchboards and for Low Voltage switchboards rated >100 amps, the switchboard controlling system and associated SCADA system remote terminal unit (RTU) shall be housed in a cubicle or cubicles separate from the associated main switchboard.

(c) For Low Voltage switchboards rated < 100 amps, the switchboard controlling system and associated RTU may be housed within the switchboard.

(d) Within a pump station having a separate cubicle housing the switchboard controlling system, this cubicle shall be designated as the Pump Control Cubicle.

A2.2 Hardware Format

A2.2.1 General

(a) Switchboard controlling systems shall incorporate industrial programmable logic controllers (PLC's) in accordance with AS IEC 61131.

(b) The input power supply to PLC's, RTU's and other electronic equipment in major pump stations shall be at 24 VDC, whereas the input power supply to such equipment in treatment plants shall be at either 240 VAC or 24 VDC in accordance with the requirements of DS28.

(c) 24 VDC input power supplies to the above electronic equipment shall be battery backed and shall have the negative rail earthed.

(d) 240 VAC input power supplies to the above electronic equipment shall be via battery backed uninterruptible power supplies.

(e) Switchboard controlling systems installed in Major Pump Stations shall employ a separate PLC for the control functions associated with each pumping unit, and a separate PLC for the common control function. Such PLC's shall be interconnected via an Ethernet switch in the manner indicated on Corporation drawing FS00-8-2.

(f) Switchboard controlling systems for small pump stations as defined in clause 1.2 of this Design Standard shall be implemented using a single PLC.

(g) Switchboard controlling systems shall include an operator interface providing a visual display of the state of the electrical system being controlled and providing a means of resetting protection equipment.

In its simplest form, such an operator interface would consist of indicating lights and fault reset push buttons.

For Major Pump Stations and for those Minor Pump Stations which utilize analogue control signals, the operator interface would consist of liquid crystal display panels incorporating system state indications (faults, etc), analogue values, control set points, analogue trends, alarm histories, etc. Typical screen displays for operator interfaces in Major Pump Stations are shown on Corporation standard drawings FS00-8-3.1/6.

(h) Switchboard controlling systems shall be implemented in such a manner that failure of the liquid crystal display will not interfere with the operation of the pump station. Touch screen software switches shall not be used as duty select switches or as unit control mode select switches.

(i) However touch screens may be used as a means of adjusting analogue control circuit set points, provided the access to such functions is software limited to authorized personnel.

A2.2.2 Electromagnetic Compatibility

(a) All electronic equipment used in switchboard controlling systems shall be certified to comply with the requirements of AS/NZS 61000.6.1. regarding electromagnetic emissions in respect to residential, commercial and light industrial locations.

(b) PLC's used in a switchboard controlling system shall be certified to comply with the requirements for operation in Zone B environments in accordance with Criterion A as defined in AS IEC 61131-2.

(c) Other electronic equipment used in switchboard controlling systems shall comply with the requirements of AS/NZS 61000-4-4 Level 3 in respect to fast transient burst interference.

(d) Other electronic equipment used in switchboard controlling systems shall comply with the requirements of AS/NZS 61000-4-5 Level 3 in respect to electrical surge protection.

A2.2.3 Programmable Memory

PLC's shall be of a type which employs a solid state non-volatile memory for the working programme memory. PLC employing integrated circuit EEPROM memories for this function are preferable.

A2.2.4 Power Supplies

All PLC power supplies shall be protected against voltage transients and similar forms of electromagnetic interference (EMI).

A2.2.5 Input/Output Voltage

The operating voltage of all PLC input/output circuits should be limited to Extra Low Voltage as defined in AS 3000. PLC's shall have a rated supply voltage tolerance of +10% - 15% of nominal supply voltage.

A2.2.6 Inputs

(a) Cable which run in switchboard cubicles containing main circuit equipment, and which are being connected to PLC's rated at less than Zone C in accordance with AS IEC 61131 Criterion A shall be connected via ferrite chokes.

(b) Cables which run in switchboard cubicles containing main circuit equipment, and which are being connected to RTU's and other electronic equipment rated at less than Level 4 in accordance with AS/NZS 61000-4-4 shall be connected via ferrite chokes.

(c) Where analogue inputs are required these shall have a 4-20mA range.

(d) PLC's, SCADA, RTU's and other electronic equipment used in switchboard controlling systems shall employ optically isolated digital signal inputs which shall have Type 1 characteristics as defined in AS IEC 61131.2.

(e) Digital inputs into PLC's, RTU's and other electronic equipment shall be of the 24 VDC current sinking type. The inherent problem with current sourcing digital inputs is that a short circuit to earth will not appear as a fault. Consequently, the associated fuse will not operate and the input will see the status as a closed input.

(f) Digital inputs into PLC's, RTU's and other electronic equipment shall be light current (15 mA maximum). Any contacts generating such inputs shall be of a type suitable for this application in order to avoid malfunction due to dust or surface corrosion on the contact surfaces. Any contacts which do not have a wiping action shall be of the dust proof type.

Special bifurcated "PLC input" auxiliary contacts should be preferred where practical. In some instances it may be necessary to install special interface relays to provide the correct type of contact input.

(g) Wherever possible a spare input capacity of 20% shall be provided. Digital signal input cards shall not exceed 16 inputs.

A2.2.7 Outputs

(a) Generally, digital outputs should be fully isolated relay contact outputs. All PLC output relay contact loads shall be fitted with switching voltage surge suppression devices to eliminate contact arcing. Care should be taken to ensure that the output contact load connected is consistent with the PLC output contact rating and the equipment life required.

(b) Relay contact outputs shall not be used for outputs which have a long term average switching rate exceeding 5 per hour. PLC's shall use current sourcing output modules.

(c) Wherever possible, the spare output capacity should be 20%.

A2.2.8 Equipment Separation

(a) In order to avoid radiated electromagnetic interference, a separation of not less than 100 mm shall be maintained between the case of any piece of equipment which contains repetitive electronic switching devices and the case of any other piece of electronic equipment, except where both pieces of equipment are of the same manufacture and the manufacturer advises that a lesser clearance will be acceptable.

(b) Similarly, a separation of not less than 100 mm shall be maintained between the power supply cable running to any piece of equipment which contains electronic circuitry and the case of any other piece of equipment which contains electronic repetitive switching devices, except where both pieces of equipment are of the same manufacture and the manufacturer advises that a lesser clearance will be acceptable.

A2.3 Logic Diagrams

A2.3.1 General

(a) Formal logic diagrams for all logic to be executed within the switchboard controlling system shall be designed, drawn and approved prior to the commencement of PLC programme coding.

(b) Logic diagrams shall be arranged for ease of understanding rather than economy of logic elements.

(c) The convention shall be adopted that latch “sets” override “resets”.

(d) Electrically maintained latches shall be used for on/off control functions.

(e) Permanent memory latches shall be used for protection and alarm functions.

A2.3.2 Use of Block Logic Format

(a) 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.

(b) Logic programmes shall be arranged in modules with each module having a total input/output count of not more than 32.

(c) Inputs and outputs to logic modules shall be either PLC external connections or internal linkages designated as “Internal Buses”.

(d) Module boundaries shall be arranged so that Internal Buses only occur at ‘Milestones’ in the logic flow.

(e) All Internal Buses shall be annotated on the logic diagram describing the Milestone represented.

A2.3.3 Use of Standard Logic Modules

Wherever practical switchboard pump control logic functions shall be programmed using the Water Corporation’s standard pump station logic module system.

A2.3.3 Arrangement of Logic Drawings

(a) An exact copy of the current revision of each standard logic module used in the logic design for the particular project shall be given a project specific drawing number and made a drawing in the project drawing set. Such drawings shall include a note confirming that the logic shown is an exact copy of the logic shown on the specified revision of the associated FS00-2 or FS01-2 series standard drawing.

(b) Any special logic modules developed for a particular application shall be documented on separate project specific logic module diagram drawings in the same form as shown on the Water Corporation’s standard pump station logic module diagram drawings.

(c) The interconnection of standard modules and any special modules shall be shown on project specific module connection diagrams in the same form as shown on the Water Corporation’s typical pump station logic module connection diagram drawings. These project specific module connection diagrams shall show the drawing number and revision number for each of the standard logic modules included in the diagram.

(d) Separate project specific logic module connection diagrams shall be prepared for each pump station unit and for the common control function.

A2.4 PLC Programming and Documentation

A2.4.1 General

(a) All PLC programme coding shall be developed on a PC based high level language programmer.

(b) PLC programme read out and documentation shall be in block logic format or in the ladder diagram format. PLC programmes shall be independent of programme scan order. PLC programming shall be in the same logic modules as shown on the relevant logic diagram.

(c) Standard logic modules shall be coded into the PLC programme in accordance with the instructions for use detailed on Corporation drawing FS00-1-2 for major pump stations and Corporation drawing FS01-1-2 for small pump stations.

A2.4.2 Ladder Diagrams

(a) Where the PLC coding documentation is in the ladder diagram format, an introduction shall be included at the beginning of the ladder diagram documentation. The introduction shall include a list of the logic modules and their functions. It also shall include a list of Internal Buses used.

(b) All ladder diagram "Contacts" and "Coils" relating to Internal Buses and external I/O shall be labelled with the same descriptions used in the logic diagram. Annotations shall be included on ladder diagrams to explain the function of each programme module.

(c) Contacts and Coils internal to programme modules shall be labelled descriptively if this will aid understanding of programme function. Internal Buses and external I/O should be labelled in upper case lettering. All other lettering should be lower case.
As far as is practicable within the limits of the particular PLC being used, contacts, coils, and logic rungs should be cross referenced. Similarly, as far as is practicable, coils should be arranged in coil number order within each programme module. Each latch reset function shall be located immediately before the associated latch set function.

(d) Once the programme has been tested successfully, the programmer shall mark up the project drawing set logic diagrams (including the logic diagrams for the standard logic modules used) to show the PLC address of each logic bus and logic function.

A3 HIGH LEVEL AREA BOOSTER PUMP STATIONS

A3.1 General

(a) Ground level tanks are often located on hill tops so as to provide water pressure to consumers located down the hill. In order to provide water pressure to consumers located at higher levels, previous practice has been to provide relatively small tank on a high tank stand next to the ground level tank and to supply such consumers from this tank. In such situations a small pump station is provided and operated under float switch control maintain water in the small tank. However such “water towers” are relatively expensive and unsightly.

(b) The basic purpose of a High Level Area Booster (HLAB) pump station is to provide water pressure to consumers in high level areas using variable speed pumps pumping directly into the local water distribution system.

In these systems the pump station differential pressure shall be controlled to a specified value at any particular flow rate from zero flow rate up to the water distribution system maximum demand flow rate.

(c) HLAB pump stations consist of multiple identical pumps with a cascade control system controlling pump speed and number of operating pumps so as to maintain the required pressure over the flow rate demand range. The number of operating pumps is increased and decreased in proportion to the flow rate demand.

(d) The control system is based on the use of a cascade controller complying with the requirements of Type Specification DS26.33.

(e) The control system is such that, at any one time, all operating pumps run at the same speed.

(f) If the cascade controller were to be arranged to control the pump station delivery gauge pressure, the hydraulic characteristics of centrifugal pumps are such that the control system could provide compensation for only a relatively small variation in suction pressure. Consequently HLAB pump stations designed in accordance with this Design Standard shall be based on controlling the differential pressure between the pump suction and the pump delivery.

(g) In order to compensate for pipework friction head loss, it is desirable to arrange for the pump station differential pressure to increase slightly as the pump station flow rate increases.

In practice it will be found, that at best, the pressure versus flow rate characteristics of available pumps will mean that the set increase in pump station differential pressure from no flow to maximum flow rate will need to be limited to less than 40 %. However, depending on the pump selected, this value may be much lower.

A3.2 Shortcomings of HLAB Pump Stations

While HLAB pump stations have the advantages of lower capital cost and better public acceptance, they have the following disadvantages in respect to the alternative described in para. A3.1(a):

(a) the control equipment is technically more complex which may be a maintenance problem in remote areas,

(b) maintaining the water pressure relies on power being available continuously, whereas the water in an elevated tank will provide water supply pressure for the time that it takes for the elevated tank to empty,

(c) the continuous pump operation and the increased need for standby generating plant increases the average acoustic noise levels emanating from the pump station, and

(d) since these pump stations must be controlled on the basis of pump station differential pressure, variations in pump station suction pressure will be reflected as variations in pump station delivery pressure.

As a consequence HLAB pump stations must pump from a relatively local suction tank.

A3.3 Incoming Power Supply

The incoming electrical supply arrangement shall be in accordance with standard drawings MN01. The Main Switchboard (housing the service protective device and metering) and the Pump Station Switchboard may be separate or combined depending upon project requirements.

A3.4 Standby Power Supply

All HLAB pump stations shall be provided with facilities for the connection of a standby generating set.

Whether a standby generating set is installed permanently will be decided on a project by project basis depending on the criticality of the water supply, the dependability of the power supply and the level of access to a portable generating set.

A3.5 Pump Characteristics

(a) The flow rate versus performance characteristics of centrifugal pumps are often specified graphically with pump output flow rate being assigned the symbol Q defined in m^3/hr or litre/sec. and with pump differential pressure being assigned the symbol H and specified in “metres head of water”

(1 m^3/hr =0.278 litre/sec. 1 metre head of water = 9.8 kPa)

In the following discussions flow rates are specified in m^3/hr and assigned the symbol Q. and pressures are specified in metres (head of water) but given the standard symbol for pressure, i.e. the lower case “p”.

(b) The performance characteristics of centrifugal pumps are substantially non-linear.

(c) Reducing the pump speed reduces both output pressure and flow rate.

Pump output pressure varies as the square of pump speed and pump output flow rate varies directly with the pump speed. These relationships are known as the “affinity laws”

(d) Pump differential pressure versus flow rate characteristics at various speeds for a typical HLAB pump are shown at Figure A3.1 together with pump efficiency versus flow rate characteristics.

(e) If pump cavitation is to be avoided, a pump cannot be operated beyond the “end of curve” point on the pressure/flow rate curve for a particular pump speed, i.e. the pump must not be operated under pressure/flow rate conditions outside the shaded area shown on Figure A3.1

(f) From the typical example shown at Figure A3.1, it can be seen that pump efficiency falls sharply at flow rates less than 30% of pump end of curve flow rate for any particular speed.

(g) Pump suitability for cascade control is discussed at clause A3.9.

A3.6 Maintaining Pressure at Zero flow

(a) Even at minimum speed some outflow from a pump is required to prevent the pump from overheating. Consequently in order to maintain the pressure with no outflow from the pump station either:

(i) a diaphragm tank shall be installed on the delivery main so that the pump drives can be put into sleep mode, or

(ii) a bypass line shall be installed to circulate a small amount of water from the delivery main back to the suction main (preferably into the suction tank).

(b) If a bypass line is installed, the control system shall be arranged so that the bypass line is closed if the demand is such that more than one pump is required to operate.

A3.7 Hydraulic Parameters

(a) Pump hydraulic parameters used in the following discussions are defined hereunder. (Figure A3.3 refers).

(i) N = pump speed as a % of 50 Hz pump speed,

(ii) N_{max} = pump maximum speed setting % of 50 Hz pump speed,

(iii) pressure/flow rate curve = pressure versus flow rate relationship at speed N

(iv) p_{so} = pump shut off pressure at speed N
(i.e. pump pressure at no flow at speed N)

(v) p_{somax} = pump shut off pressure at speed N_{max}

(vi) p_{ec} = pump end of curve differential pressure at speed N

(vii) p_{ecmax} = pump end of curve differential pressure at N_{max}

(viii) Q_{ec} = pump end of curve flow rate at speed N

(ix) Q_{ecmax} = pump end of curve flow rate at speed N_{max}

(x) $\delta Q/\delta N$ = slope of flow rate versus speed curve at particular pressure and at a particular flow rate- refer Fig. A3.4

(xi) n_p = number of pumps

(xii) Q_{umax} = individual unit pump flow rate at pressure p_{ts}
= Q_{ts}/n_p - refer A3.7(b)(iii)

(b) Control system hydraulic parameters used in the following discussions are defined hereunder.

(i) p_{0t} = system zero flow rate theoretical differential pressure

(ii) p_{ts} = differential pressure with all pumps operating, set point ,
(i.e. pressure for total pumping capacity set point)

(iii) Q_{ts} = system maximum flow rate with all pumps operating at p_{ts} , set point (i.e. total pumping capacity flow rate at p_{ts} set point)

(iv) p_{1s} = differential pressure with one pump operating, set point

(v) p_{shs} = pump station maximum allowable suction pressure, set point,

(vi) p_{sls} = pump station minimum allowable suction pressure, set point,

A3.8 Cascade Control Functions

A3.8.1 Differential Pressure Control

For reasons discussed at para. A3.9 pump station pressure control shall be on the basis of pump station differential pressure rather than pump station delivery gauge pressure.

A3.8.2 Suction Pressure

The cascade controller shall shut the pump station down should the suction pressure rise above the allowable maximum pump station suction pressure (p_{shs}), or fall below the allowable minimum pump station suction pressure (p_{sls}), but shall allow the system to restart once the suction pressure is within acceptable limits.

A3.8.3 Control Pressure Curve

(a) Ideally the cascade controller should be able to be set to increase the output pressure from pump station zero flow to pump station maximum flow with pump station output pressure rising approximately in proportion with the square of the flow rate, so as to compensate for friction head loss in the delivery pipe work.

(b) However it is not practical in cascade controllers using pump speed as a measure of flow rate to control the output pressure in accordance with such an ideal control pressure curve.

(c) Consequently these cascade controllers shall increase the pump differential pressure set point in rising steps approximately in proportion to the square of the flow rate, i.e. rather than following a continuously rising control pressure curve.

System pressure step ups shall be set to occur at pump station total flow rate increments of Q_{umax} i.e. at the staging on of each additional pump.

In Figure A3.2 pressure step downs have been set midway between step up flow rates. The example system design detailed in para. A3.11 has assumed these values.

Figure A3.3 indicates the pump pressure/flow rate operating characteristics for each control step.

(d) Pump speeds corresponding to the required step up and step down flow rates shall be calculated as per example calculation at clause A3.11.

These calculated pump step up and step down speeds in terms of Hz shall be entered into the cascade controller

(e) Once pump speed has reached the set step up speed for a particular pressure control step, the cascade controller shall call in an additional pump and reduce the pump speed of the operating pumps accordingly.

(f) Similarly for all control pressure steps other than the initial step, once the pump speed falls to less than the set step down speed for a particular pressure control step, the cascade controller shall drop out one pump and increase the pump speed of the operating pumps accordingly.

(g) At each pressure step, the pump shall operate over the flow rate range defined by the step up and step down speed settings.

(h) System step up and step down flow rates for the typical example at clause A3.11 are shown on Figure A3.2. The related pump step up and step down flow rates are shown on Figure A3.3

A3.9 Pump Suitability for Cascade Control

(a) Within a cascade controlled system the pump step down flow rate can be as low as 25 % of pump controlled full speed flow rate.

(b) As shown in Figure A3.4, the ratio of flow rate change to speed change ($\delta Q/\delta N$) rises sharply at lower flow rates.

(c) The cascade control system uses pump speed as a measure of flow rate, which provides an adequate level of control precision.

(d) Pumps in such systems should be selected such that, in step 1 the pump pressure/flow rate operating conditions will always be above the end of curve pressure limit, i.e. p_{1s} must be above p_{ecmax} .

(e) It can be seen from Figure A3.3 that there is limited scope to move these operating characteristics up and down to account for variations in suction pressure, which accounts for the requirement that the basis of control is required to be the differential pressure across the pump station.

As a general rule p_{ts} should not be greater than 140% of p_{ec} at 100% rated speed and p_{0t} should not be less than 25% of p_{ec} at 100% rated speed

A3.10 Determination of Step-Down Set Points

(a) Step down and step-up frequencies shall be determined graphically on the basis of flow rates as indicated in a typical example in para. A3.11

It should be noted that the controller steps down in stage order with a delay between successive steps. Consequently, it does not matter if the step-down frequencies are close together.

(b) An example of the design process is given hereunder

A3.11 Example Calculation

(a) Figure A3.2 illustrates the determination of set points for a typical HLAB pump station.

(b) In these calculations pressures are expressed in metres H_2O

(c) In this example the following operational requirements were:

(i) $p_{ts} = 22$ metres
= system maximum flow rate differential pressure setting

(ii) $Q_{ts} = 44$ cub.m/hr = system maximum flow rate at pressure p_{ts}

(iii) $p_{0t} = 18$ metres = system zero flow rate theoretical differential pressure

(iv) $n_p = 4$ = number of duty pumps

(v) $Q_{umax} = Q_{ts} / n_p = 44/4 = 11$ cub,m/hr
= individual pump flow rate at pressure p_{ts}

(d) On the basis of values given in para. A3.11(c) the system pressure/flow rate control curve for Figure A3.2 is determined as follows:

N_{max} = pump maximum speed setting
In this example, N_{max} is selected to be 100% of 50 Hz pump speed,

on N_{max} curve in figure A3.3, $p_{st} - p_{0t} = 22-18 = 4$ metres

= pipe friction head at Q_{ts}

$Q_{ts}/2 = 44/2 = 22$ cub. m/hr = 50% system maximum flow rate

Friction head at $Q_{ts}/2 = (p_{ts} - p_{0t}) * 0.5^2 = 1$ metre

Hence control pressure at $Q_{ts}/2 = 18+1 = 19$ metres
Thus the control curve is drawn as a smooth curve through
18 metres at zero flow,
19 metres at 22 cub. m/hr,
22 metres at 44 cub. m/hr

(e) All pumps step up at an individual pump flow rate of 11 cub. m/hr i.e. at Q_{umax} , as shown on Figure A3.3

(f) On the basis of system step down flow rates shown in Figure A3.2 the per pump step down flow rates are as follows:

(i) stage 2 per pump step down flow rate = 0.5*11/2 = 2.75 cub. m/hr
(ii) stage 3 per pump step down flow rate = 1.5*11/3 = 5.5 cub. m/hr
(iii) stage 4 per pump step down flow rate = 2.5*11/4 = 6.88 cub. m/hr

(g) The step pressures derived in Figure A3.2 are as follows;

$p_{step\ 1} = 18.3$ metres $= p_{1s}$
$p_{step\ 2} = 19$ metres
$p_{step\ 3} = 20.2$ metres
$p_{step\ 4} = 22$ metre $= p_{ts}$

(h) In order to generate pump step down speeds it is necessary to generate flow rate versus speed curves at $p_{step\ 1}$, $p_{step\ 2}$, $p_{step\ 3}$ and $p_{step\ 4}$ using the flow rate values at each step pressure on the pressure/flow rate curves provided.

Points on each such curve are determined from Figure A3.3 as hereunder. (Refer para. A3.5(c) in respect to calculation of speeds at zero flow rate.)

(i) If pressure $= p_{step\ 1} = 18.3$ m
at 0 cub.m/hr, speed $= 80*(18.3/19.5)^{0.5} = 77.5$ %
at 5.2 cub.m/hr, speed = 80%
at 9.6 cub.m/hr, speed = 90%
at 12.5 cub.m/hr, speed = 100%

(ii) If pressure $= p_{step\ 2} = 19$ m,
at 0 cub.m/hr, speed $= 80*(19/19.5)^{0.5} = 79.0$%
at 3.6 cub.m/hr, speed = 80%
at 9.2 cub.m/hr, speed = 90%
at 12. 3 cub.m/hr, speed = 100%

(iii) If pressure $= p_{step\ 3} = 20.2$ m,
at 0 cub.m/hr, speed $= 80*(20.2/19.5)0.5 = 81.4$%
at 8.4 cub.m/hr, speed = 90%
at 11.8 cub.m/hr, speed = 100%

(iv) If pressure $= p_{step\ 4} = 22$ m,
at 0 cub.m/hr, speed $= 80*(22/19.5)0.5 = 85.0$%

at 6.9 cub.m/hr, speed = 90%
at 11.0 cub.m/hr, speed = 100%

Each of the required flow rate versus speed curves is generated by drawing a smooth curve through the relevant points determined above, as shown on Figure A3.4

(i) The required speeds at each of the required step down flow rates are determined from Figure A3.4 as indicated.

The required step down frequencies thus determined and corrected to nearest whole number frequency are:

Step 2 79.5 % = 40 Hz
Step 3 84.5% = 42 Hz
Step 4 90.0% = 45 Hz

(j) The required speeds at each of the required step up flow rates can be determined from Figure A3.4 as indicted.

The required step up frequencies thus determined and corrected to nearest whole number frequency are:

Step 1 94.4% = 47 Hz
Step 2 95.5% = 48 Hz
Step 3 97.4% = 49 Hz

(k) From Figure A3.3, p_{ecmax} on the 94.4% speed pressure/flow rate curve is estimated at 16 m which is less than the p_{0t} value of 18 m,

i.e. $p_{ecmax} < p_{0t}$ as required para. A3.9 (d), so O.K.

A3.12 Equipment Redundancy

(a) Water supply HLAB pump stations provide a critical service in that the failure of such a pump station means that the supply of water ceases to consumers served by the pump station.

Consequently such pump stations shall be designed with a sufficient level of redundancy, so that the failure of any one component, other than the cascade controller itself, shall not cause the pump station to cease to perform its primary function. However some interruption to some minor functions shall be permitted.

(b) Control systems are available which incorporate a standby cascade controller as well as the duty cascade controller.
Whether a standby cascade controller is installed shall be decided on a project by project basis depending on the criticality of the water supply and the availability of maintenance staff.

(c) Adequate facilities shall be provided to allow supervisory control and monitoring of the pump station from a local operator interface panel and from a SCADA system central control station.

A3.13 Maximum Starting Frequency

(a) If a diaphragm tank is required, the size of the tank will be determined by the Mechanical Designer.

(b) The size of the diaphragm tank is dependent in part on the permissible frequency of starting of the pump drive, the smaller the allowable starting frequency, the larger must be the diaphragm tank.

Since a variable speed drive will not draw more than full load current when starting, a high frequency of starting can be permitted.

Consequently up to 200 starts per hour shall be permitted.

A3.14 Electrical Control System Specification

The electrical control system shall comply with Type Specification DS26.33 and with the Water Corporation FS01-9-21/35 series of standard drawings.

A3.15 PLC Logic Diagrams

(a) The control system specified in Type Specification DS26.33 is required to operate under the supervisory control of an on-site PLC.

(b) PLC logic shall be implemented in accordance with the standard logic diagrams documented on Water Corporation standard drawings FS01-9- 21/35.

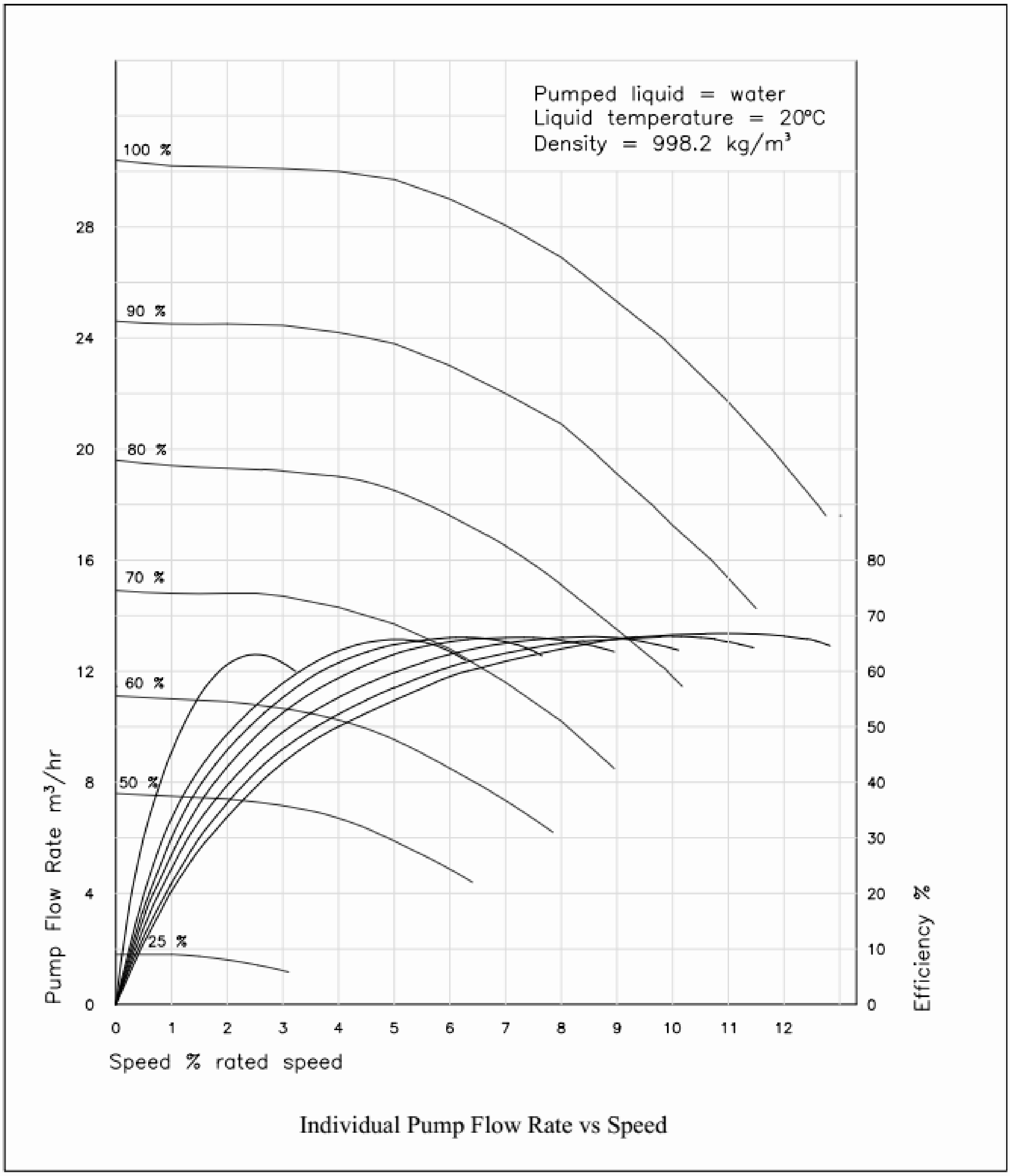
These drawings have been prepared for a PLC supervising two cascade controllers, but also shall be used for applications requiring only one cascade controller.

(c) Such use shall be in accordance with para. 6.2(b) of the Standard Logic Systems Directions for Use as documented on Water Corporation standard drawing FS01-1-2.

(d) The nomenclature specified for applications requiring two cascade controllers shall be retained on logic drawings for applications requiring only one cascade controller.

A3.16 Related Mechanical Standard

The mechanical design requirements for HLAB pump stations are specified in Design Standard DS32-02 High Level Area Booster Pump Stations – Mechanical.



Individual Pump Flow Rate vs Speed

Figure A3.1

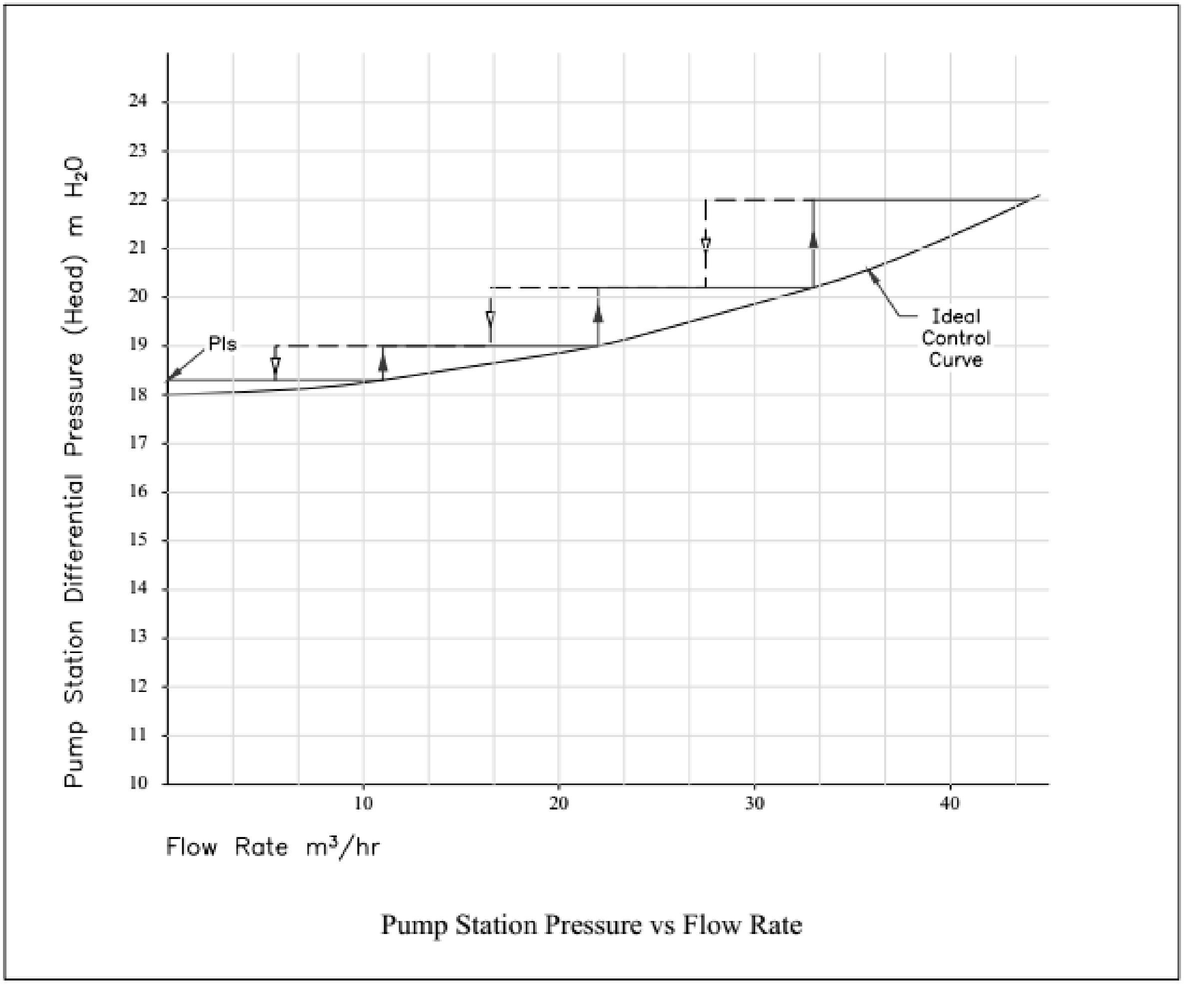

Pump Station Differential Pressure (Head) m H_2O
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
10
20
30
40
Flow Rate m³/hr
Pls
Ideal Control Curve
Pump Station Pressure vs Flow Rate

Figure A3.2

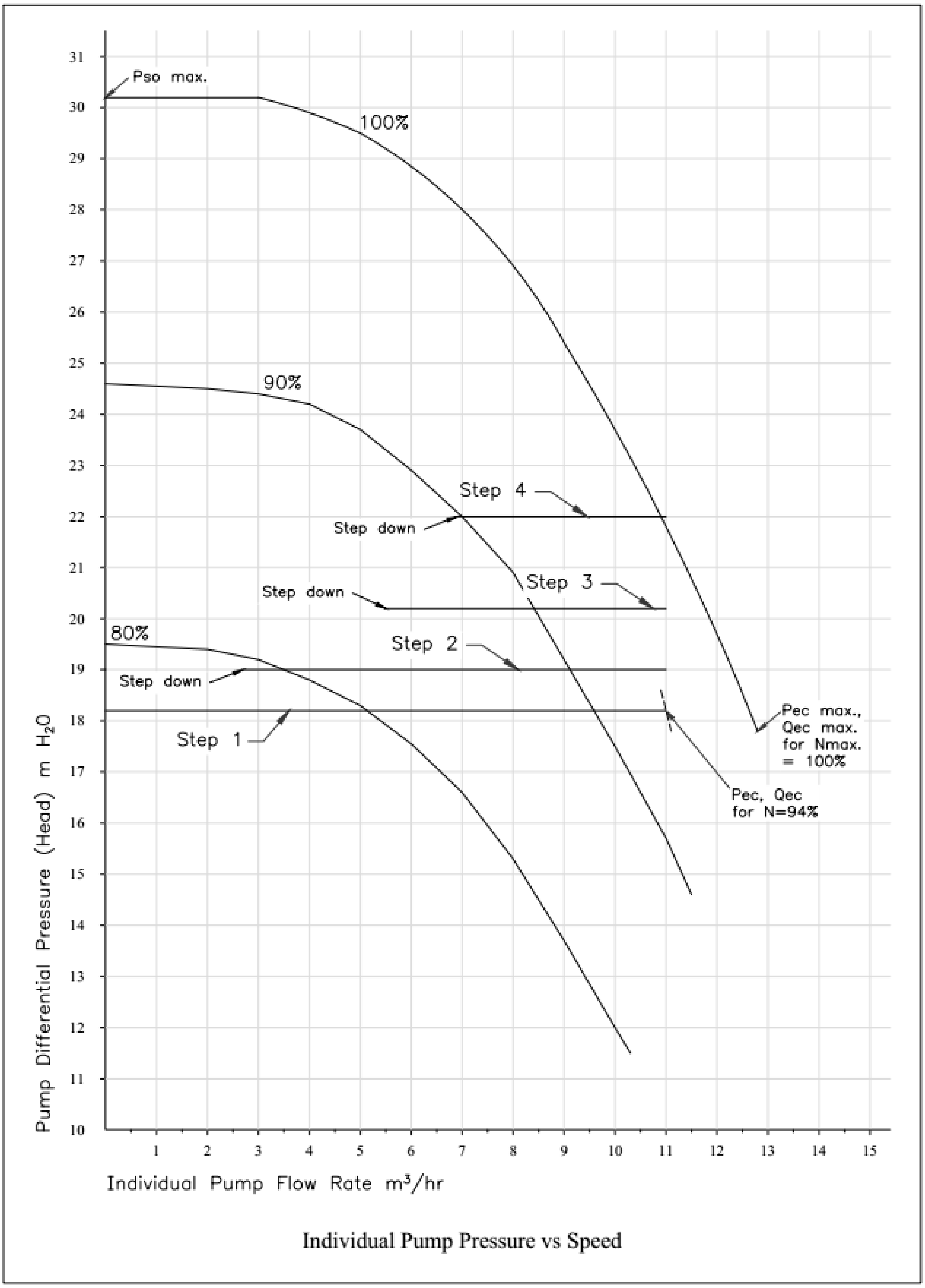

Pso max.
100%
90%
80%
Step 4
Step down
Step 3
Step down
Step 2
Step down
Step 1
Pec max., Qec max. for Nmax. = 100%
Pec, Qec for N=94%
Pump Differential Pressure (Head) m H_2O
Individual Pump Flow Rate m^3/hr
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Individual Pump Pressure vs Speed

Figure A3.3

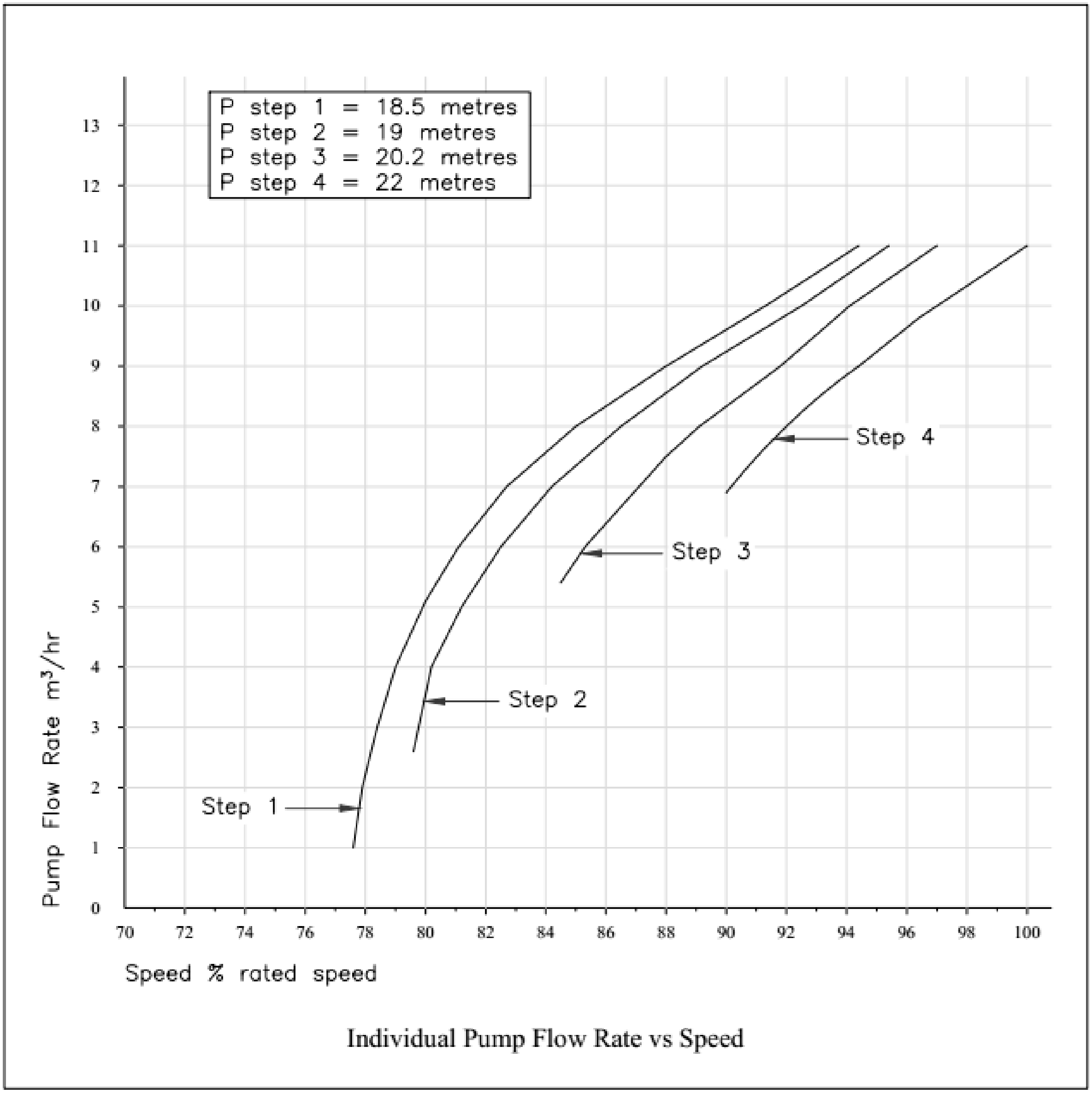

P step 1 = 18.5 metres
P step 2 = 19 metres
P step 3 = 20.2 metres
P step 4 = 22 metres
Step 1
Step 2
Step 3
Step 4
Pump Flow Rate m³/hr
0
1
2
3
4
5
6
7
8
9
10
11
12
13
70
72
74
76
78
80
82
84
86
88
90
92
94
96
98
100
Speed % rated speed
Individual Pump Flow Rate vs Speed

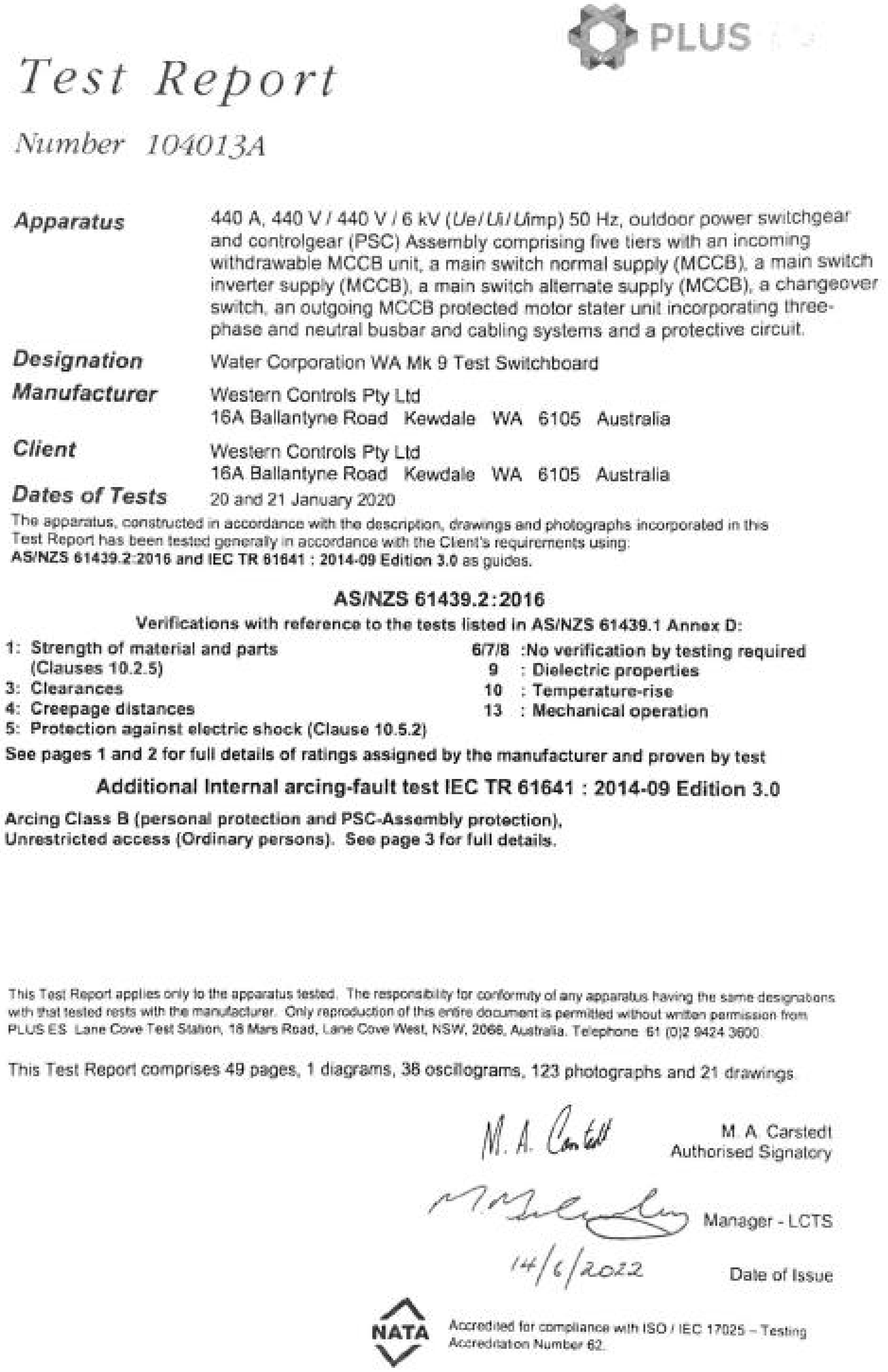
Figure A3.4

APPENDIX B

Design Verification Summary
For
Water Corporation Mk 9 Outdoor Switchboard

Test Report PLUS ES Lane Cove 104013 (Portion only – 4 Pages)

B Test Report PLUS ES Lane Cove 104013 (Portion only)



PLUS

Test Report

Number 104013A

Apparatus	440 A, 440 V / 440 V / 6 kV (*Ue / Ui / Uimp*) 50 Hz, outdoor power switchgear and controlgear (PSC) Assembly comprising five tiers with an incoming withdrawable MCCB unit, a main switch normal supply (MCCB), a main switch inverter supply (MCCB), a main switch alternate supply (MCCB), a changeover switch, an outgoing MCCB protected motor stater unit incorporating three-phase and neutral busbar and cabling systems and a protective circuit.
Designation	Water Corporation WA Mk 9 Test Switchboard
Manufacturer	Western Controls Pty Ltd 16A Ballantyne Road Kewdale WA 6105 Australia
Client	Western Controls Pty Ltd 16A Ballantyne Road Kewdale WA 6105 Australia
Dates of Tests	20 and 21 January 2020

The apparatus, constructed in accordance with the description, drawings and photographs incorporated in this Test Report has been tested generally in accordance with the Client's requirements using:
AS/NZS 61439.2:2016 and IEC TR 61641 : 2014-09 Edition 3.0 as guides.

AS/NZS 61439.2:2016

Verifications with reference to the tests listed in AS/NZS 61439.1 Annex D:

1: Strength of material and parts (Clauses 10.2.5)
3: Clearances
4: Creepage distances
5: Protection against electric shock (Clause 10.5.2)

6/7/8 :No verification by testing required
9 : Dielectric properties
10 : Temperature-rise
13 : Mechanical operation

See pages 1 and 2 for full details of ratings assigned by the manufacturer and proven by test

Additional Internal arcing-fault test IEC TR 61641 : 2014-09 Edition 3.0

Arcing Class B (personal protection and PSC-Assembly protection),
Unrestricted access (Ordinary persons). See page 3 for full details.

This Test Report applies only to the apparatus tested. The responsibility for conformity of any apparatus having the same designations with that tested rests with the manufacturer. Only reproduction of this entire document is permitted without written permission from PLUS ES Lane Cove Test Station, 18 Mars Road, Lane Cove West, NSW, 2066, Australia. Telephone 61 (0)2 9424 3600

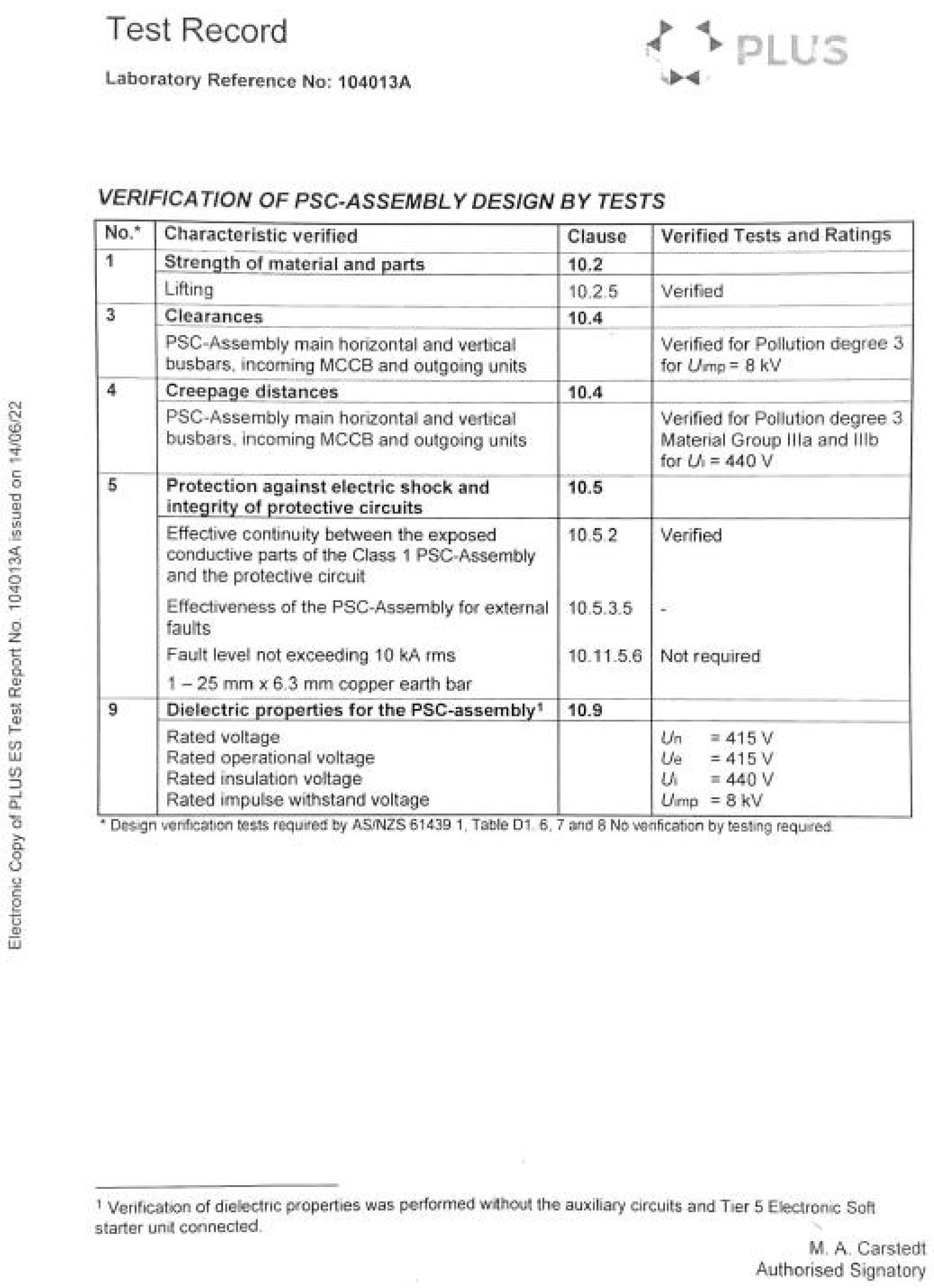
This Test Report comprises 49 pages, 1 diagrams, 38 oscillograms, 123 photographs and 21 drawings.

M. A. Carstedt
Authorised Signatory

Manager - LCTS

14/6/2022
Date of Issue

NATA
Accredited for compliance with ISO / IEC 17025 – Testing
Accreditation Number 62.



Test Record

Laboratory Reference No: **104013A**

PLUS

VERIFICATION OF PSC-ASSEMBLY DESIGN BY TESTS

No.*	Characteristic verified	Clause	Verified Tests and Ratings
1	**Strength of material and parts**	**10.2**	
	Lifting	10.2.5	Verified
3	**Clearances**	**10.4**	
	PSC-Assembly main horizontal and vertical busbars, incoming MCCB and outgoing units		Verified for Pollution degree 3 for U_{imp} = 8 kV
4	**Creepage distances**	**10.4**	
	PSC-Assembly main horizontal and vertical busbars, incoming MCCB and outgoing units		Verified for Pollution degree 3 Material Group IIIa and IIIb for U_i = 440 V
5	**Protection against electric shock and integrity of protective circuits**	**10.5**	
	Effective continuity between the exposed conductive parts of the Class 1 PSC-Assembly and the protective circuit	10.5.2	Verified
	Effectiveness of the PSC-Assembly for external faults	10.5.3.5	-
	Fault level not exceeding 10 kA rms	10.11.5.6	Not required
	1 – 25 mm x 6.3 mm copper earth bar		
9	**Dielectric properties for the PSC-assembly[1]**	**10.9**	
	Rated voltage Rated operational voltage Rated insulation voltage Rated impulse withstand voltage		U_n = 415 V U_e = 415 V U_i = 440 V U_{imp} = 8 kV

* Design verification tests required by AS/NZS 61439 1, Table D1. 6, 7 and 8 No verification by testing required.

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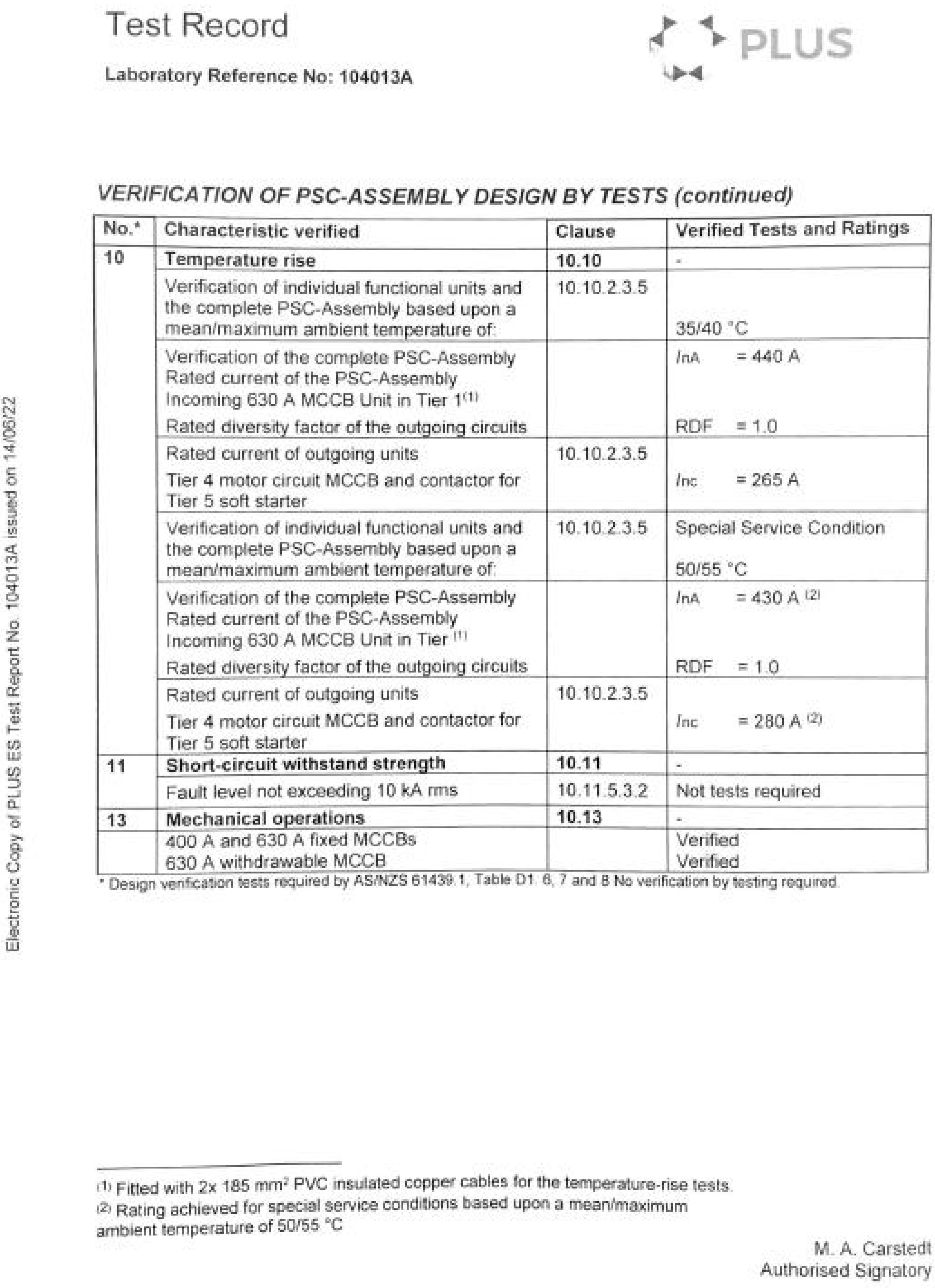
[1] Verification of dielectric properties was performed without the auxiliary circuits and Tier 5 Electronic Soft starter unit connected.

M. A. Carstedt
Authorised Signatory



Test Record

PLUS

Laboratory Reference No: 104013A

VERIFICATION OF PSC-ASSEMBLY DESIGN BY TESTS (continued)

No.*	Characteristic verified	Clause	Verified Tests and Ratings
10	**Temperature rise**	**10.10**	-
	Verification of individual functional units and the complete PSC-Assembly based upon a mean/maximum ambient temperature of:	10.10.2.3.5	35/40 °C
	Verification of the complete PSC-Assembly Rated current of the PSC-Assembly Incoming 630 A MCCB Unit in Tier 1(1) Rated diversity factor of the outgoing circuits		I_{nA} = 440 A RDF = 1.0
	Rated current of outgoing units Tier 4 motor circuit MCCB and contactor for Tier 5 soft starter	10.10.2.3.5	I_{nc} = 265 A
	Verification of individual functional units and the complete PSC-Assembly based upon a mean/maximum ambient temperature of:	10.10.2.3.5	Special Service Condition 50/55 °C
	Verification of the complete PSC-Assembly Rated current of the PSC-Assembly Incoming 630 A MCCB Unit in Tier (1) Rated diversity factor of the outgoing circuits		I_{nA} = 430 A (2) RDF = 1.0
	Rated current of outgoing units Tier 4 motor circuit MCCB and contactor for Tier 5 soft starter	10.10.2.3.5	I_{nc} = 280 A (2)
11	**Short-circuit withstand strength**	**10.11**	-
	Fault level not exceeding 10 kA rms	10.11.5.3.2	Not tests required
13	**Mechanical operations**	**10.13**	-
	400 A and 630 A fixed MCCBs 630 A withdrawable MCCB		Verified Verified

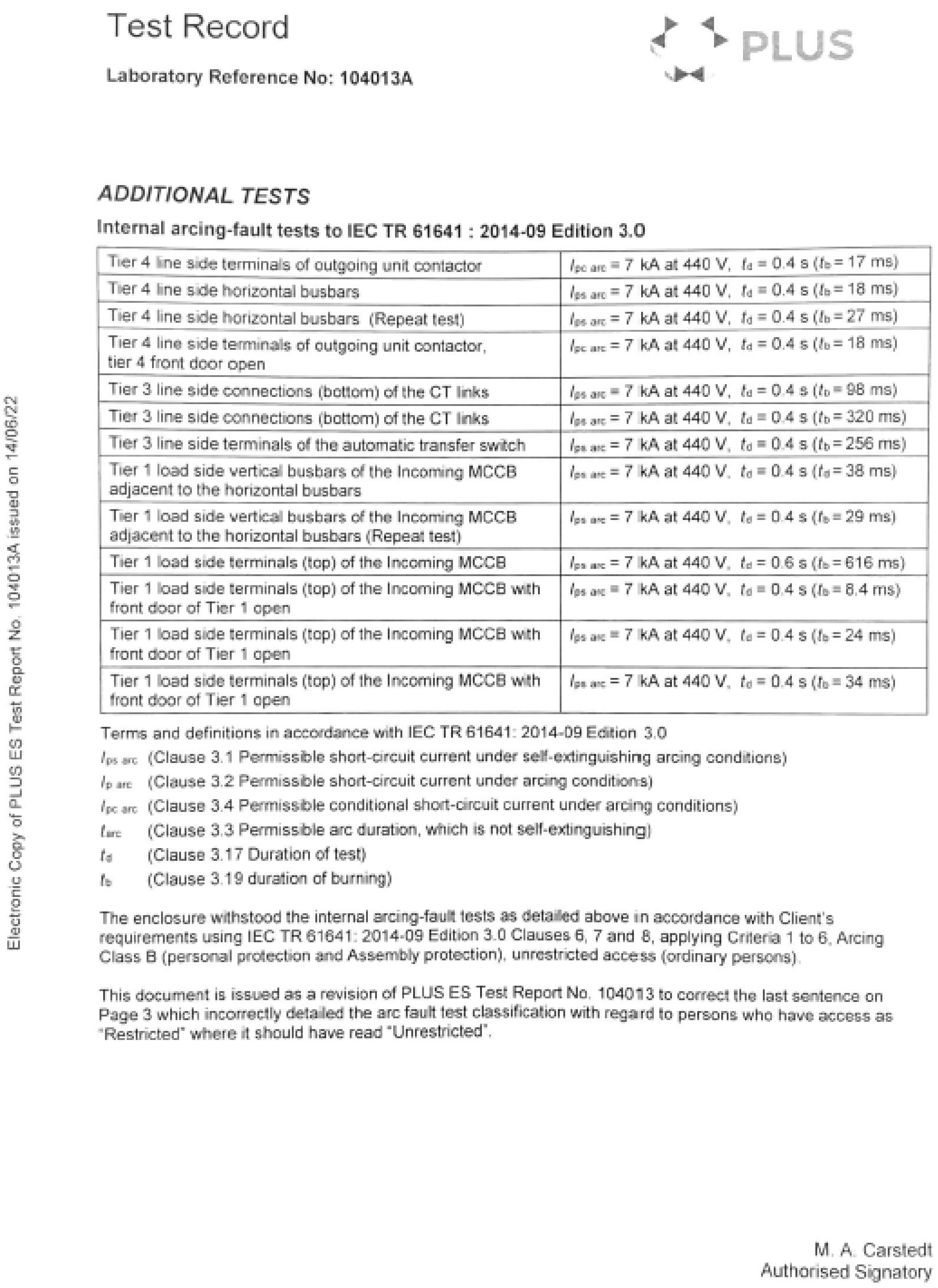
* Design verification tests required by AS/NZS 61439.1, Table D1. 6, 7 and 8 No verification by testing required.

---

(1) Fitted with 2x 185 mm² PVC insulated copper cables for the temperature-rise tests.

(2) Rating achieved for special service conditions based upon a mean/maximum ambient temperature of 50/55 °C

M. A. Carstedt
Authorised Signatory



Test Record

Laboratory Reference No: 104013A

Electronic Copy of PLUS ES Test Report No. 104013A issued on 14/06/22

ADDITIONAL TESTS

Internal arcing-fault tests to IEC TR 61641 : 2014-09 Edition 3.0

Tier 4 line side terminals of outgoing unit contactor	$I_{pc\ arc}$ = 7 kA at 440 V, t_d = 0.4 s (t_b = 17 ms)
Tier 4 line side horizontal busbars	$I_{ps\ arc}$ = 7 kA at 440 V, t_d = 0.4 s (t_b = 18 ms)
Tier 4 line side horizontal busbars (Repeat test)	$I_{ps\ arc}$ = 7 kA at 440 V, t_d = 0.4 s (t_b = 27 ms)
Tier 4 line side terminals of outgoing unit contactor, tier 4 front door open	$I_{pc\ arc}$ = 7 kA at 440 V, t_d = 0.4 s (t_b = 18 ms)
Tier 3 line side connections (bottom) of the CT links	$I_{ps\ arc}$ = 7 kA at 440 V, t_d = 0.4 s (t_b = 98 ms)
Tier 3 line side connections (bottom) of the CT links	$I_{ps\ arc}$ = 7 kA at 440 V, t_d = 0.4 s (t_b = 320 ms)
Tier 3 line side terminals of the automatic transfer switch	$I_{ps\ arc}$ = 7 kA at 440 V, t_d = 0.4 s (t_b = 256 ms)
Tier 1 load side vertical busbars of the Incoming MCCB adjacent to the horizontal busbars	$I_{ps\ arc}$ = 7 kA at 440 V, t_d = 0.4 s (t_d = 38 ms)
Tier 1 load side vertical busbars of the Incoming MCCB adjacent to the horizontal busbars (Repeat test)	$I_{ps\ arc}$ = 7 kA at 440 V, t_d = 0.4 s (t_b = 29 ms)
Tier 1 load side terminals (top) of the Incoming MCCB	$I_{ps\ arc}$ = 7 kA at 440 V, t_d = 0.6 s (t_b = 616 ms)
Tier 1 load side terminals (top) of the Incoming MCCB with front door of Tier 1 open	$I_{ps\ arc}$ = 7 kA at 440 V, t_d = 0.4 s (t_b = 8.4 ms)
Tier 1 load side terminals (top) of the Incoming MCCB with front door of Tier 1 open	$I_{ps\ arc}$ = 7 kA at 440 V, t_d = 0.4 s (t_b = 24 ms)
Tier 1 load side terminals (top) of the Incoming MCCB with front door of Tier 1 open	$I_{ps\ arc}$ = 7 kA at 440 V, t_d = 0.4 s (t_b = 34 ms)

Terms and definitions in accordance with IEC TR 61641: 2014-09 Edition 3.0

$I_{ps\ arc}$	(Clause 3.1 Permissible short-circuit current under self-extinguishing arcing conditions)
$I_{p\ arc}$	(Clause 3.2 Permissible short-circuit current under arcing conditions)
$I_{pc\ arc}$	(Clause 3.4 Permissible conditional short-circuit current under arcing conditions)
t_{arc}	(Clause 3.3 Permissible arc duration, which is not self-extinguishing)
t_d	(Clause 3.17 Duration of test)
t_b	(Clause 3.19 duration of burning)

The enclosure withstood the internal arcing-fault tests as detailed above in accordance with Client's requirements using IEC TR 61641: 2014-09 Edition 3.0 Clauses 6, 7 and 8, applying Criteria 1 to 6, Arcing Class B (personal protection and Assembly protection), unrestricted access (ordinary persons).

This document is issued as a revision of PLUS ES Test Report No. 104013 to correct the last sentence on Page 3 which incorrectly detailed the arc fault test classification with regard to persons who have access as "Restricted" where it should have read "Unrestricted".

M. A. Carstedt
Authorised Signatory

APPENDIX C

VSC PWM Voltage Stress on Motor Winding

C VSC PWM Voltage Stress on Motor Winding

C1 General

To obtain an understanding of the stresses imposed on a motor (conventional and submersible) by the PWM voltage output of a VSC, the following discussion outlines the critical elements to be considered by the Designer for Corporation projects.

C1.1 Cable Capacitance

Shielded cables and cables submersed in water have significantly higher capacitance than cables in air. Since water has a dielectric constant that is approximately 80 times higher than for air, cables that are submersed in water experience much higher capacitance and thus lower characteristic impedance than for cables in air.

Capacitance is directly proportional to the dielectric constant (k), therefore a higher dielectric constant will result in higher capacitance. Consider the basic equation for capacitance between two parallel plates (conductors):

$$C = \frac{\left(\frac{k}{4\pi}\right)A}{l}$$

Where C = Capacitance in Farads, k = dielectric constant, A = area of one plate (cm^2), and l = the distance between the two plates (cm).

Higher capacitance means lower characteristic (surge) impedance (Z_C) for these cables, which will result in higher reflected voltages and motor terminal peak voltages at shorter cable lengths.

$$Z_c = \sqrt{\left(\frac{L_c}{C_c}\right)}$$

C1.2 PWM Voltage Pulse reflection

VSC applications with long motor cable lengths can create voltage reflections at the motor terminals resulting in high terminal voltages impinging the windings (up to twice the nominal voltage). The primary factors that influence the magnitude of the reflected voltage and dv/dt include:

a) Cable length

b) IGBT rise time

c) PWM pulse velocity on the cable

d) Dielectric medium surrounding the cable

e) Characteristic impedance of motor and cable

Since the characteristic impedance of motors is considerably higher than for cables, the motor terminal peak voltage will be higher than the VSC terminal voltage. When voltage reflection occurs, the peak voltage measured at the motor terminals consists of the peak voltage of the initial PWM pulses, plus the peak voltage of the reflected pulses. The magnitude of voltage reflection can be determined based on the reflection coefficient (ρ) equation:

$$\rho = \frac{Z_m - Z_c}{Z_m + Z_c}$$

Where Z_m *= motor characteristic impedance and* Z_c *= cable characteristic impedance.*

For typical induction motors, the characteristic impedance may range from a few hundred ohms (large power ratings) to several thousand ohms (small power ratings), and for cables it can range from 30 ohms (large power ratings) to 100 ohms (small power ratings). Hence, a mismatch between the motor and cable characteristic impedances can lead to significant reflected voltages. Based on motor cables of sufficient length and conductors in air, some typical reflection coefficients (ρ*)* are as follows:

Motor Size (kW)	Reflection Coefficient (ρ)	Voltage Peak at Motor (V_{pk})
0.75	1	2.00 x V_{DC} = 1120
18.5	0.9	1.90 x V_{DC} = 1064
75	0.75	1.75 x V_{DC} = 980
150	0.65	1.65 x V_{DC} = 924
315	0.5	1.50 x V_{DC} = 840

Based on $415V_{AC}$ *motor, standard 6 pulse VSC DC voltage of approximately 1.35 x* V_{AC} *=* $560V_{DC}$*.*

Note, the reflection coefficient for applications involving submersible electrical cables can be higher, due to the increased capacitance discussed above. Therefore, the effects on submersible motors subjected to PWM impulses becomes more pronounced.

Note: For VSCs with active front end rectifiers, the DC link voltage is approximately 15% higher than for standard rectifiers and this must be taken into consideration as it has a significant impact on the motor terminal voltage.

C1.3 Safe Motor Cable Length

The critical cable length identifies the cable length where over-voltage begins to occur and exceeding this length may be detrimental to the motor. Critical cable length is a function of the pulse rise time and the velocity at which the pulse travels on the cable. The pulse rise time is primarily influenced by the switching technology (IGBT, BJT, GTO), and the pulse velocity (metres/second) is a function of the cable inductance and capacitance as shown in the equation below:

$$\nu = \frac{1}{\sqrt{LC}}$$

Typical values for pulse velocity through air, range from about 100 to 150 meters per second. The higher values of capacitance for submersible cables cause slower pulse velocity and hence reduces the critical cable length. Critical cable length may be calculated using the equation below:

$$L_c = v.\frac{t_r}{2}$$

Where: t_r *= pulse rise time in micro-seconds*

As an example, the critical cable lengths for various pulse rise times using an average pulse velocity rate (125m/sec) is:

Pulse Rise Time (µ seconds)	**Critical Cable Length for cables in air (m)**
0.040	2.50
0.050	3.10
0.100	6.25
0.150	9.37
0.200	12.5
0.250	15.6
0.300	18.75
0.400	25
0.500	31
1	62
2	125
Sine Wave	No limit (Only limited by volt drop considerations)

Induction motors with long cables controlled by PWM VSCs can be subjected to harsh voltage conditions such as fast rising pulses (dv/dt) and excessive peak voltage. Furthermore, PWM voltage comprises significant harmonics resulting in harmonic currents within the motor winding, thus increasing winding temperature and shortened motor life. Submersible motors are a special case where the problems can be more severe and may appear at shorter cable lengths.

C1.4 Comment on Mitigation by either dv/dt or Sine Filter

For most manufacturers of dv/dt filters, voltage clamping is specified to be at 150% of DC bus voltage (at 300 metres). Voltage reflection still occurs with traditional dv/dt filters and motor heating is still prevalent. The dv/dt filter is considered inadequate for protecting submersible motors but can be a suitable mitigation measure for conventional motors.

The Sine Wave filter eliminates reflected voltage and minimises high frequency voltage noise of the motor voltage waveform. The Sine Wave filter will reduce motor losses and temperature rise while increasing motor life.

APPENDIX D

UPS INVESTIGATION REPORT

D UPS INVESTIGATION REPORT

Copy of report below:

UPS INVESTIGATION

D1 BACKGROUND

The Water Corporation has previously issued a recommendation requiring that the output neutral of a UPS is earthed under all circumstances and if not, a link must be installed between output neutral and earth. Refer Appendix A.

This recommendation requires re-examination as it conflicts with the advice of UPS manufacturers and questions regarding UPS installation requirements have been raised in the field. Refer Appendix B and C.

D2 RELEVANT STANDARDS

AS 3000 Electrical installations (known as the Australian/New Zealand Wiring Rules)

AS 62040.1.1-2003 (R2013) : Uninterruptible power systems (UPS) - General and safety requirements for UPS used in operator access areas

D3 FINDINGS

There are a number of factors and requirements of standards that influence UPS earthing design and installation.

D3.1 Neutral continuity

Electricity converters, particularly static converters, such as UPS, shall be arranged to ensure that the continuity of the neutral conductor to the load is not interrupted during bypass or maintenance switching.

D3.2 Backfeed protection

A backfeed situation can occur if there is a static switch thyristor failure. In this situation, UPS input terminals may be energised even when the UPS is disconnected from the mains power supply and this poses a safety hazard.

Backfeed protection prevents power from being fed back to the input terminals of the UPS and is a requirement of AS62040 5.1.4.

For a UPS with a plug-in connection, the male pins of the input plug can become live. Backfeed protection is provided by a contactor which operates on the phase and neutral input conductors isolating the input pins.

For permanently connected UPSs, backfeed protection may be provided internally or externally to the UPS and acts only on the phase conductors.

D3.3 Earthing

AS3000 4.12.6 requires that the output of an electricity converter shall be provided with the same type of earthing system used for the associated electrical installation.

D3.4 Example- Permanently connected UPS (with maintenance bypass switch)

In the example shown in Figures 1 and 2, the installation manual requires that the ‘Bypass Input Supply’ be supplied from a 3 pole circuit breaker that does not switch the neutral input. When the UPS is online, i.e. the load is supplied from the ‘rectifier’, ‘static bypass’ or ‘battery’, the ‘Bypass input supply’ switch located within the ‘Maintenance Bypass Switch’ is always closed. This ensures that the UPS output neutral is always connected to the UPS input neutral, and therefore connected to the main installation earthing system and MEN. Refer Figure 1.

When the load is supplied by the ‘Maintenance Bypass’, the UPS output neutral remains connected to the UPS input neutral as shown in Figure 2.

Therefore, under all operating conditions in which the load is supplied, the UPS load is connected to the main installation earthing system and MEN.

This installation is in compliance with AS3000 4.12.6 Earthing and AS62040.1.1-2003 5.1.4 Backfeed Protection. Note that there is no requirement to install an additional connection between the UPS output neutral and earth and doing so would be in contravention of AS3000 5.5.3.1 (b) (i) which does not allow for more than one MEN in an electrical installation.

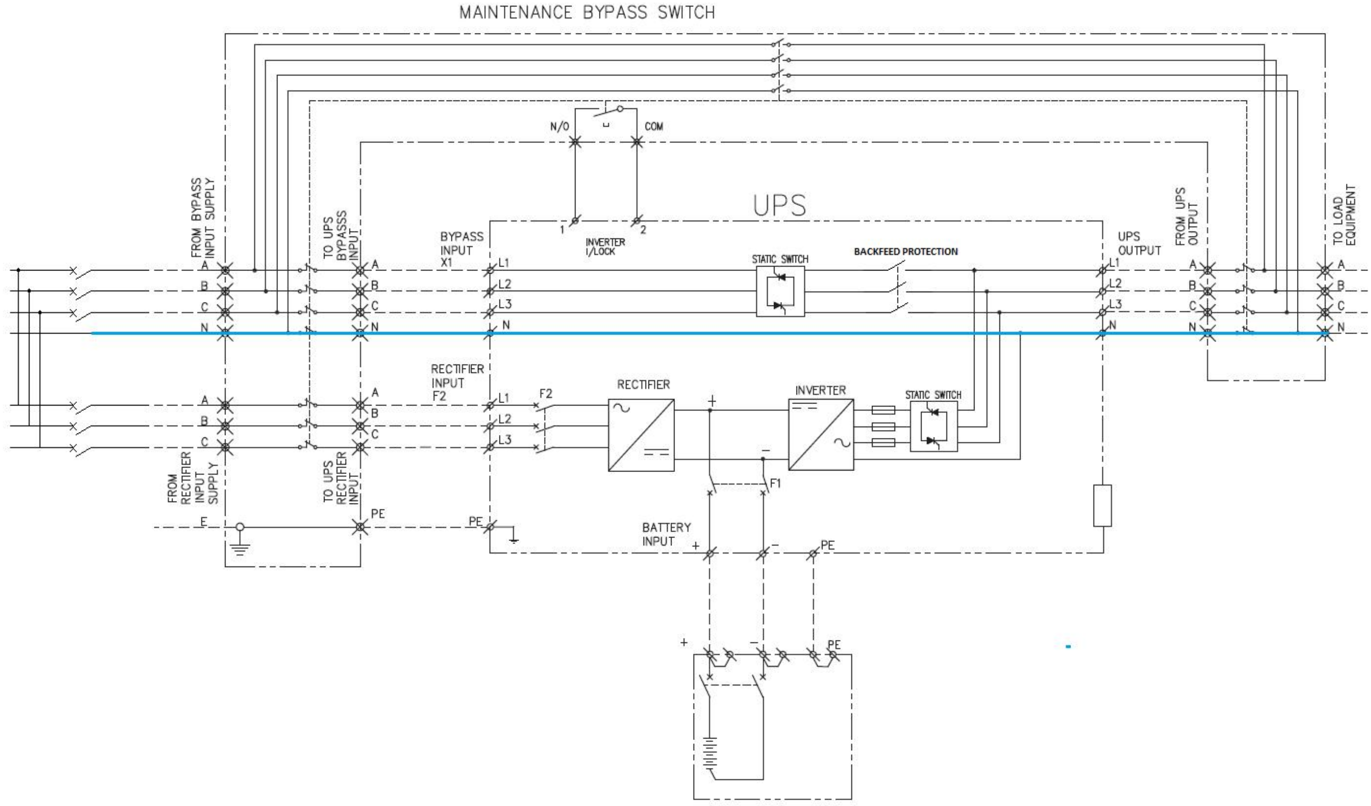


Figure 1- Input and output neutral continuity for permanently connected UPS with load supplied from ‘rectifier’, ‘static bypass’ or ‘battery’.

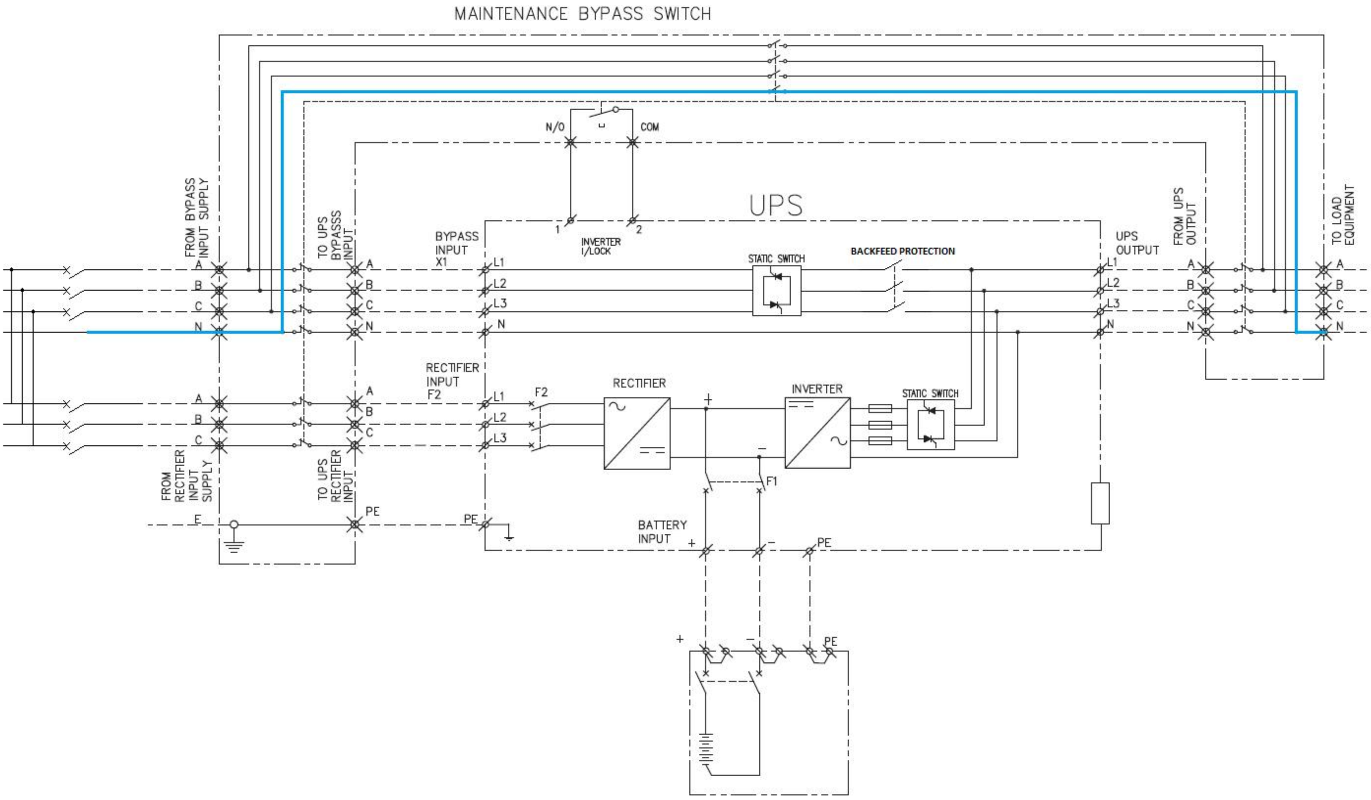


Figure 2- Input and output neutral continuity for permanently connected UPS with load supplied from 'maintenance bypass'.

D3.5 Example- Plug-in UPS

When the UPS is operating in 'rectifier mode' or 'bypass mode', the backfeed contactor is closed and the UPS output neutral is connected to the UPS input neutral and to the main installation MEN. Refer Figure 3.

When the UPS is operating in 'battery mode', backfeed protection is active and the backfeed contactor is open. UPS output active and neutral are disconnected from input active and neutral. The active and neutral pins of the input plug cannot become live and there is no connection to the site installation MEN. The same scenario occurs when the UPS is unplugged. As a result, neutral and earth are not tied to one another and voltage may be measured between neutral and earth at the UPS output, as confirmed by the 93VAC that was measured on site. Refer Appendix B and Figure 4.

The plug-in UPS differs from the permanently connected UPS installation because in 'battery mode' the UPS output neutral is not continuous with the input neutral. The earthing system becomes an IT earthing configuration, which is permitted by AS3000 5.1.4(d) Other Earthing Systems. With regards to AS3000 4.12.6 referenced in Section 3.3 above, the interpretation is that while in 'battery mode' the UPS is disconnected from the upstream MEN TN-C-S system and as a result, there is no requirement for the UPS output earthing system to be TN-C-S.

In some particular installations, and depending on the load, an IT earthing may be considered unacceptable. For instance, an IT system may experience overvoltages and may not be appropriate for equipment that is voltage sensitive. An output isolation transformer may be used in these circumstances to create an MEN earthing system at the UPS output. Refer Figure 5. Alternatively, a permanently connected UPS may be selected instead of a plug-in UPS. For installations where a plug-in UPS is already in use, it may be possible to modify the UPS to a permanently connected UPS and the manufacturer should be consulted. Refer Fig 6.

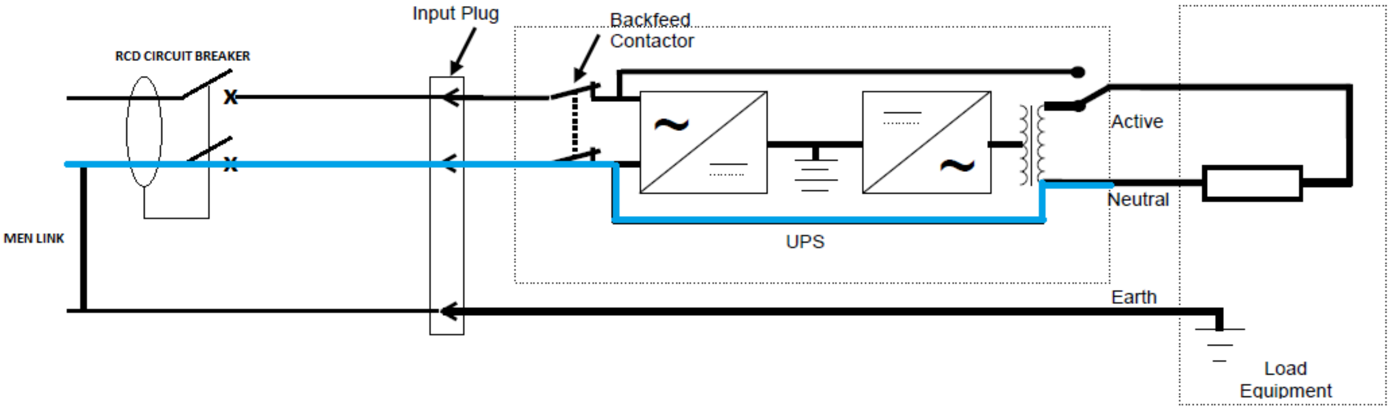


Figure 3. Input and output neutral continuity for plug-in UPS with load supplied in 'rectifier mode' or 'bypass mode'

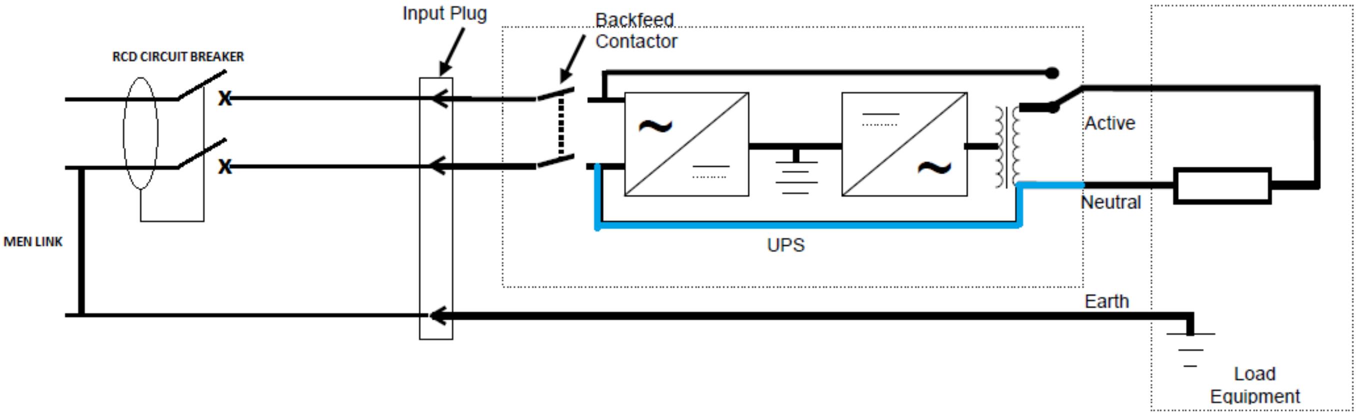


Figure 4. Input and output neutral discontinuous for plug-in UPS with load supplied in 'battery mode'

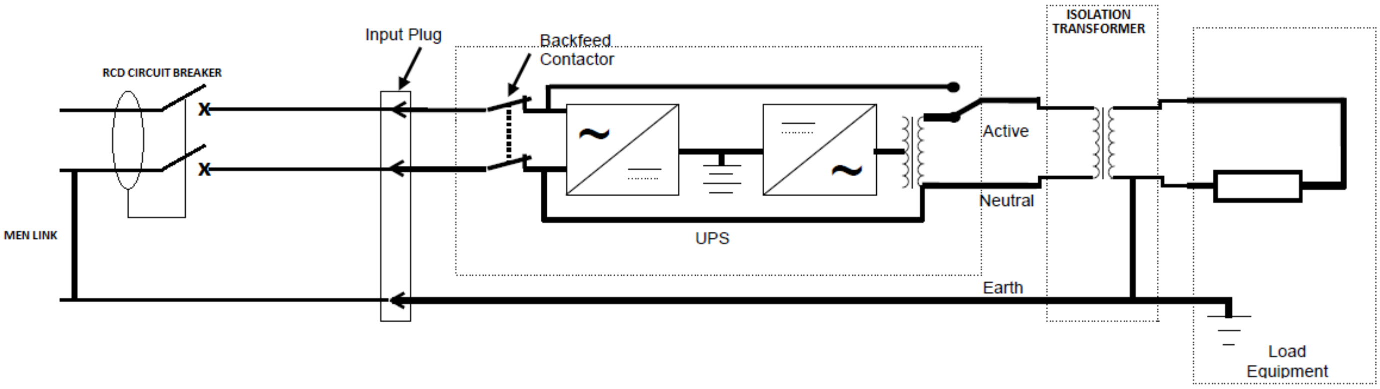


Figure 5. Plug-in UPS with output isolation transformer

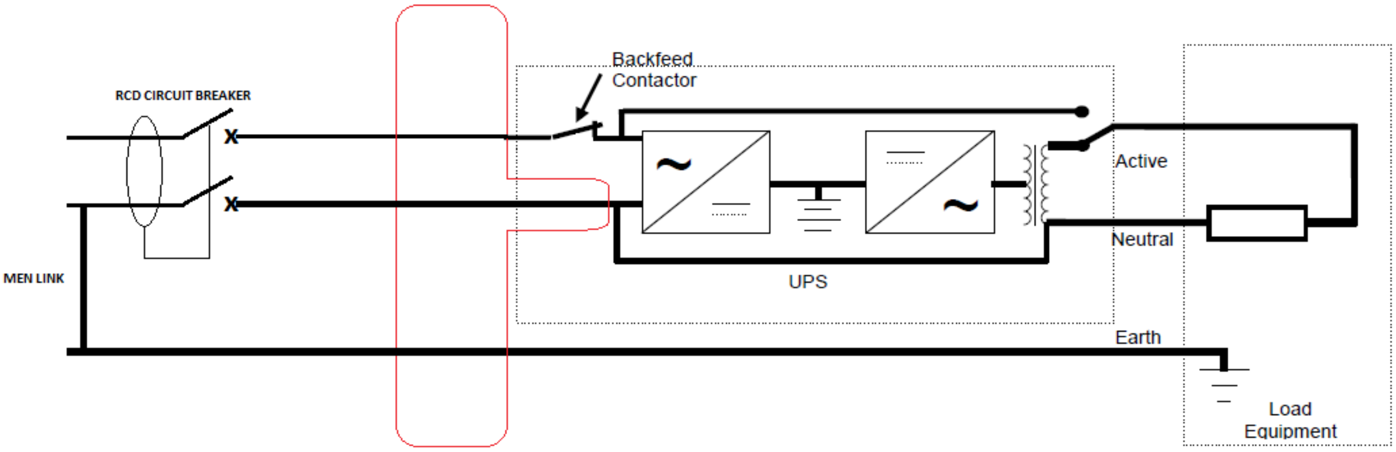


Figure 6. Plug-in UPS converted to permanently connected UPS. Input plug and backfeed protection of the neutral connection have been removed

D4 CONCLUSION

When designing a UPS system, backfeed protection as required by AS62040-1 and requirements of AS3000, in particular with regards to the continuity of the neutral conductor and connection to the MEN, must be considered.

There are differences in the requirements of backfeed protection for plug-in and hardwired UPSs and as a general rule, the following points are recommended.

D4.1 Permanently connected UPS

Permanently connected UPSs should be supplied from circuit breakers that do not switch the neutral input to the UPS as the output neutral is reliant on the input neutral.

There is no general requirement to add a connection between the UPS output neutral to earth as the output neutral is always connected to the input neutral and installation MEN.

Depending on the specific details of the installation, input or output isolation transformers may be necessary and the UPS manufacturer should provide guidance on these requirements

D4.2 Plug-in UPS

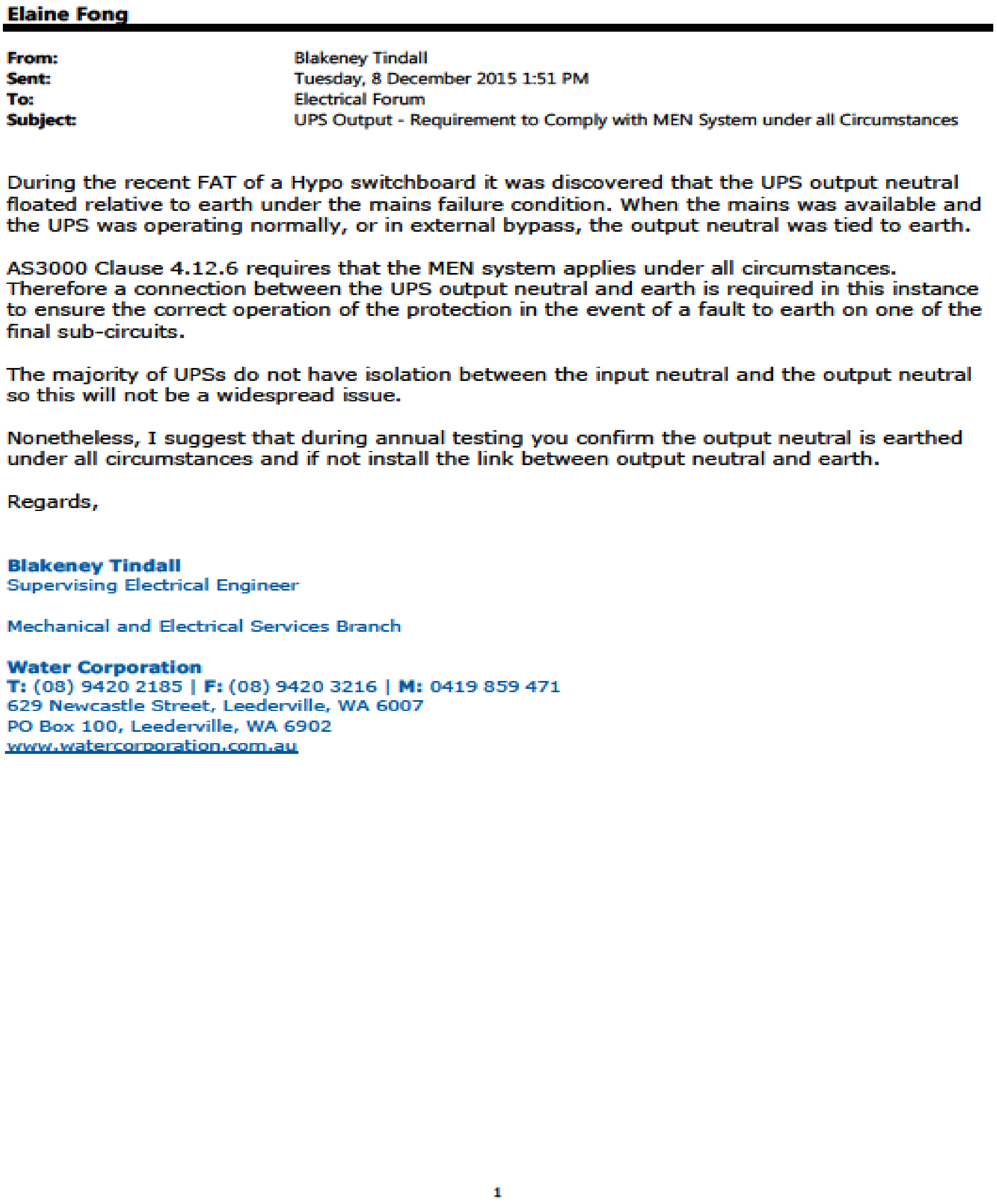
UPS should be connected as detailed in manufacturers installation instructions

There is no general requirement to add a connection between UPS output neutral and earth

When the UPS is operating in ‘battery mode’, the UPS output is disconnected from the main installation earthing system. The UPS operates as an IT earthing system which is permitted by AS3000 5.1.4 and protection of personnel and equipment is adequately provided by the UPS

Where the IT earthing system is considered unacceptable, an output isolation transformer may be used. Alternatively, a permanently connected UPS may be considered. For existing installations, some UPS manufacturers provide conversion kits whereby a plug-in UPS can be converted to a permanently connected UPS.

APPENDIX A



Elaine Fong

From:	Blakeney Tindall
Sent:	Tuesday, 8 December 2015 1:51 PM
To:	Electrical Forum
Subject:	UPS Output - Requirement to Comply with MEN System under all Circumstances

During the recent FAT of a Hypo switchboard it was discovered that the UPS output neutral floated relative to earth under the mains failure condition. When the mains was available and the UPS was operating normally, or in external bypass, the output neutral was tied to earth.

AS3000 Clause 4.12.6 requires that the MEN system applies under all circumstances. Therefore a connection between the UPS output neutral and earth is required in this instance to ensure the correct operation of the protection in the event of a fault to earth on one of the final sub-circuits.

The majority of UPSs do not have isolation between the input neutral and the output neutral so this will not be a widespread issue.

Nonetheless, I suggest that during annual testing you confirm the output neutral is earthed under all circumstances and if not install the link between output neutral and earth.

Regards,

Blakeney Tindall
Supervising Electrical Engineer

Mechanical and Electrical Services Branch

Water Corporation
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629 Newcastle Street, Leederville, WA 6007
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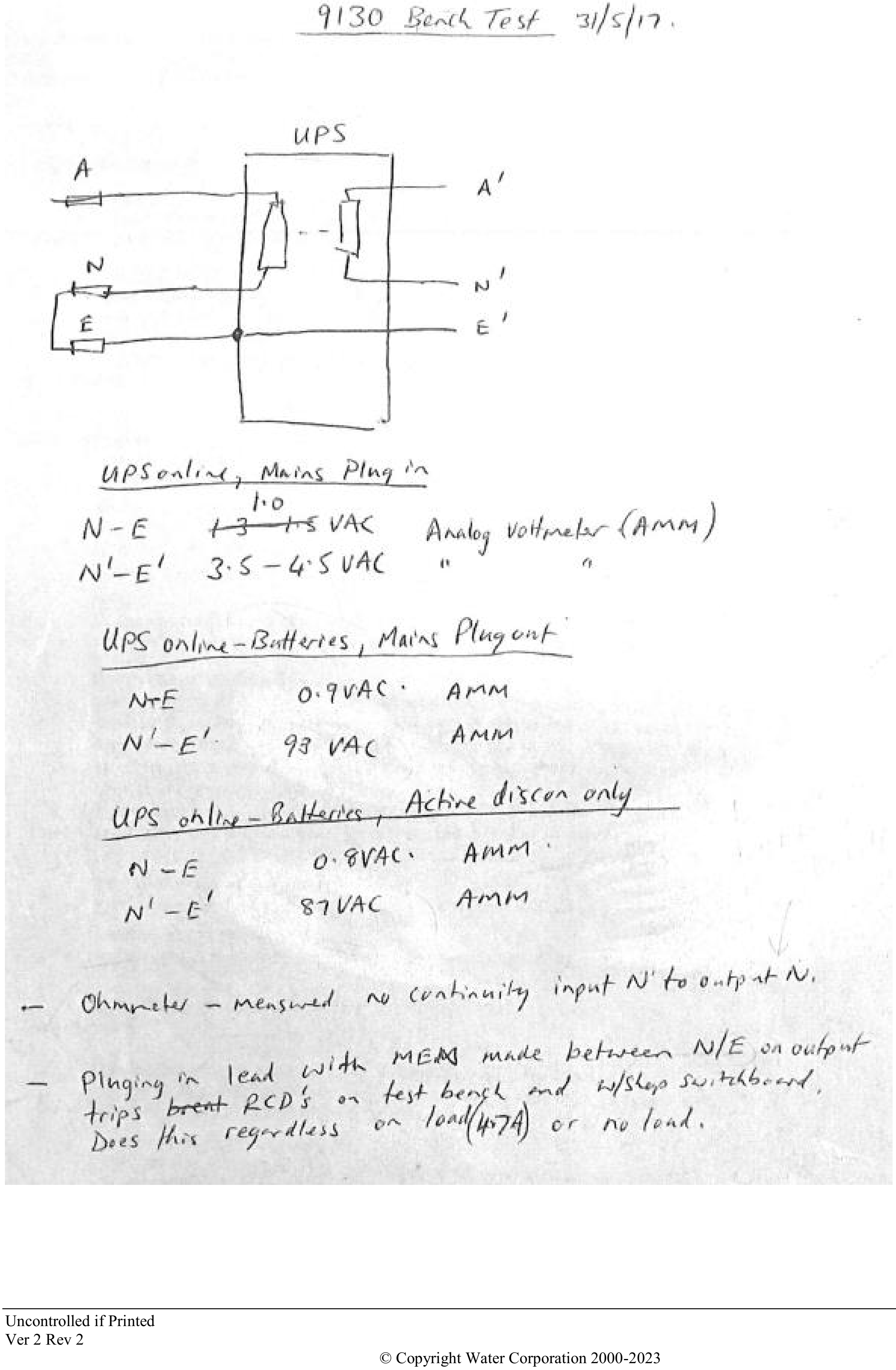
APPENDIX B



9130 Bench Test 31/5/17.

UPS online, Mains Plug in

N - E ~~1·3 – 1·5~~ 1·0 VAC Analog voltmeter (AMM)
N' – E' 3·5 – 4·5 VAC " "

UPS online - Batteries, Mains Plug out

N-E 0·9VAC. AMM
N' – E' 93 VAC AMM

UPS online - Batteries, Active discon only

N - E 0·8VAC. AMM
N' - E' 87VAC AMM

- Ohmmeter - measured no continuity input N' to output N.
- Pluging in lead with MEN made between N/E on output trips ~~brent~~ RCD's on test bench and w/shop switchboard. Does this regardless on load (4.7A) or no load.

APPENDIX C

From: Gene Taylor
Sent: Friday, 23 June 2017 11:14 AM
To: Blakeney Tindall
Cc: Chris Gidley
Subject: UPS MEN Connections

Hi Blakeney,

The Kelmscott electrical team have noticed a number occasions during testing of UPS systems that N to E voltage differences have risen to unacceptable levels. This has been mostly when technicians disconnect the mains input plug to invoke battery mode, where voltages on digital or analogue multimeters have been seen over 100VAC. This level of difference was also observed when I bench tested an Eaton 9130 UPS, isolating only the active conductor. Testing also revealed that significant voltage differences (e.g. 5VAC) can still occur with input mains input connected.

Even if only the active conductor is manually isolated, backfeed protection within the UPS will ensure that the input neutral conductor is automatically disconnected. The system loses connection to the MEN and voltage differences between output neutral and earth may be observed

In an email you sent out to the Electrical Forum 8th December 2015, you also describe this possibility of N – E drift, which is due to lack of input-output N continuity on some UPS models. The Eaton 9130 bench tested above had no continuity measurable between input and output. As you rightly point out, the MEN must always be provided as per AS3000, clause 4.12.6, and this is repeated in the UPS standard AS 62040.1.1-2003, which says:

(AS62040) 4.4 Power interfaces

(cont.)… In the case of the output neutral conductor being isolated from the input neutral conductor, the service person responsible for the installation shall connect this output neutral conductor as required by the local wiring rules and as detailed in the installation instructions.

This clause has the disclaimer ‘as required’ and for the majority of typical Water Corporation installations, connection of output neutral conductor to either the output earth or the input neutral is not recommended by the manufacturer.

For the recent installation of a Riello UPS at North Dandalup Dam, an isolating transformer was installed on the output, at the recommendation of the supplier. Riello advised against connecting input and output neutrals, or installing output MENs, as they said it could damage the UPS. To comply with AS3000, a new MEN was provided at the isolating transformer output, which had already been joined at the coil by Grants Transformers.

Recently, as an experiment, I tried making an MEN connection on the output of the Eaton 9130 unit, but was unable to successfully run it on mains. I found it consistently tripped the test bench RCD and also the workshop power circuit RCD. Even though most of our UPS’s would not be feed by RCD breakers, I felt there may be some issue with directly joining output neutral and earth.

Connection of the UPS output neutral and earth creates an alternative path for the neutral current which bypasses the UPS input RCD. This is imbalance is sensed by the RCD which trips as a response.

When asking EPT (Elec Power Technologies) about what they do, they said it was not a good idea to put a MEN connection on a UPS output, as when the unit is bypassed there will be two MENs. As they suggest, more than one MEN connection in any one outbuilding is not allowed according to AS3000 clause 5.5.3.1 (b)(i). EPT advise that the isolation provided by a UPS when it is in battery mode is sufficient to prevent shock, in a similar fashion to an isolating transformer. This is more or less described in the Powerware technical bulletin MEN 01-2003 attached.

Another point raised by EPT is that the neutral conductor, even when connected from UPS input to output, will be disconnected by the back-feed prevention protection, which must be provided according to the UPS regulation AS 62040 clause 5.4.1. Effectively we can't rely on any of our UPS's passing through the MEN because of this.

I thought we had better check with you to see if we should go to the trouble of installing isolating transformers to all our UPS installations, or to rely on the adequacy of the floating isolation provided by the UPS systems, when they are isolated from the supply neutral. As the floating voltages observed were capable of being sustained on a coil multimeter, I wouldn't be keen on touching a 'floating' UPS output myself ! Also, a UPS active touching an earthed case will not operate input supply protection, even if there is RCD protection. This is also shown in the Powerware bulletin.

With reference to plug-in UPS installations, it is generally not necessary to provide output isolating transformers on all UPSs. The UPS will measure and monitor and provides adequate safety for personnel and equipment in a fault event. The UPS output neutral and earth are not referenced to one another so any measurable voltage difference is not meaningful.

I look forward to your thoughts on this matter.

Regards,

Gene Taylor

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WATER CORPORATION | AROONA ALLIANCE

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