Assets Planning and Delivery Group
Engineering

DESIGN STANDARD DS 21

Major Pump Station – Electrical

VERSION 2
REVISION 0

November 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

DISCLAIMER

Water Corporation accepts no liability for any loss or damage that arises from anything in the Standards/Specifications including any loss or damage that may arise due to the errors and omissions of any person. Any person or entity which relies upon the Standards/Specifications from the Water Corporation website does so that their own risk and without any right of recourse to the Water Corporation, including, but not limited to, using the Standards/Specification for works other than for or on behalf of the Water Corporation.

The Water Corporation shall not be responsible, nor liable, to any person or entity for any loss or damage suffered as a consequence of the unlawful use of, or reference to, the Standards/Specifications, including but not limited to the use of any part of the Standards/Specification without first obtaining prior express written permission from the CEO of the Water Corporation.

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 (Section, Clause, Sub-Clause)**	**RVWD.**	**APRV.**
0	0/0	01.05.00	All	New Version	NHJ	AAK
0	0/2	01.08.01	All	Updated	NHJ	AAK
0	0/3	18.09.01	3-5	General revision	NHJ	AAK
				Now removed		
0	1/6	31.07.13	16, 17-18	revised	NHJ	MH
1	0/0	01.05.00	All	New Version	NHJ	AAK
1	0/1	25.07.00	2	1.5 4 revised	NHJ	AAK
1	0/2	01.08.01	1, 2, 3	1.1 revised; 1.4 changed; 1.8.1,1.8.2 revised	NHJ	AAK
1	0/3	18.09.01	1, 2	1.1, 1.6 general revision	NHJ	AAK
1	0/4	30.09.02	1, 2, 3	1.3, 1.8.3 revised	NHJ	AAK
1	1/0	30.07.04	16, 18	1.2 new; 1.3 Preferred Equip List inc.; 1.8.3 new	NHJ	AAK
1	1/0	30.07.04	All	Reformatted	CT	NHJ
1	1/1	30.06.06	17, 18	1.1,1.2, 1.4, 1.6, 1.7 revised	NHJ	AAK
1	1/2	30.04.07	19	1.5 (c) added	NHJ	AAK
1	1/3	02.06.09	15, 16	1.3, 1.5 revised	NHJ	AAK
1	1/4	30.08.11	18-20	1.1, 1.2, 1.3, 1.5, 1.7, 1.8 revised	NHJ	AAK
1	1/5	16.01.12	19-20	Reformatted	KAW	NHJ
1	1/6	31.07.13	19	1.3 Revised	NHJ	MH
1	1/7	27.06.17	18-20	1.3, 1.4, 1.7, 1.8 Revised	NHJ	MSP
1	2/0		All	Whole section revised	NJ	EDG
2	0/0	01.05.00	All	New Version	NHJ	AAK
2	1/0	30.07.04	All	Reformatted	CT	NHJ
2	2/0		All	Whole section revised	NJ	EDG
3	0/0	01.05.00	All	New Version	NHJ	AAK
3	0/1	25.07.00	1	3.2 & 3.3 formulas corrected	NHJ	AAK
3	0/2	01.08.01	2, 3	3.6 revised, 3.10 added	NHJ	AAK
3	0/3	18.09.01	1, 2	3.2, 3.3, 3.4, 3.5, 3.8 general revision	NHJ	AAK
3	1/0	30.07.04	All	Revised	NHJ	AAK
3	1/0	30.07.04	All	Reformatted	CT	NHJ
3	1/1	30.06.06	21, 23	3.1, 3.2, 3.6 revised	NHJ	AAK
3	1/2	30.04.07	24	3.8 (a) – (g) included	NHJ	AAK
3	1/3	02.06.09	19-21, 23, 24	3.3, 3.4, 3.4.1, 3.4.2, 3.4.3, 3.4.4, 3.9, 3.13, 3.14 revised	NHJ	AAK
3	1/4	30/08/11	21-28	3.1, 3.2, 3.3, 3.4, 3.4.2, 3.5, 3.6, 3.10, 3.12, 3.14, 3.15 revised	NHJ	AAK
3	1/5	16.01.12	22-27	Reformatted	KAW	NHJ
3	1/7	27.06.17	22-28	3.2(c), 3.9(d), 3.13, 3.15 revised	NHJ	MSP
3	2/0		All	Whole section revised	NJ	EDG

REVISION STATUS

SECT.	**VER./ REV.**	**DATE**	**PAGES REVISED**	**REVISION DESCRIPTION (Section, Clause, Sub-Clause)**	**RVWD.**	**APRV.**
4	0/0	01.05.00	All	New Version	NHJ	AAK
4	0/2	01.08.01	1, 2	4.2, 4.3.1, 4.4.2, 4.4.7 revised; 4.6.3 added	NHJ	AAK
4	0/3	18.09.01	1-8	4.1, 4.3.3, 4.4.1, 4.4.2, 4.4.3, 4.4.4, 4.4.6, 4.4.7, 4.4.8, 4.4.9, 4.4.12, 4.5.2 general revision	NHJ	AAK
4	1/0	30.07.04	25-32	4.1-4.3.1 new; 4.3.4 ‘load’ added to ‘torque speed’; 4.4.2 ‘cage motors’ added; 4.4.2, 4.4.3, 4.4.6.3, Fig 4.1 new; 4.4.8, 4.5.1, 4.5.2, 4.4.10.1, 4.4.10.3 revised; 4.6.3 new	NHJ	AAK
4	1/0	30.07.04	All	Reformatted	CT	NHJ
4	1/1	30.06.06	26-29, 32, 33	4.2, 4.3.1, 4.4.2, 4.4.3, 4.4.10.4, 4.4.11 revised	NHJ	AAK
4	1/2	30.04.07	27-29, 31, 33, 36	4.1 (g) added; 4.3.1, 4.3.4, 4.4.6.1 revised; 4.4.7 new heading & revised; 4.4.8 revised; 4.7 included	NHJ	AAK
4	1/3	02.06.09	25-37	4.2-4.4.14.2, 4.6.2, 4.6.3, 4.7 revised	NHJ	AAK
4	1/4	30/08/11	30-32, 34-35, 939-41, 43	4.2, 4.3.3, 4.3.6, 4.3.7, 4.4.1, 4.4.3, 4.4.9, 4.4.12.3, 4.4.13, 4.6.2,4.6.4 revised	NHJ	AAK
4	1/5	16.01.12	29-30, 31,34-37,42-43	Reformatted	KAW	NHJ
4	1/7	27.06.17	29-43	4.1, 4.2, 4.3.3, 4.4.9, 4.6.2 revised	NHJ	MSP
4	2/0		All	Whole section revised	NJ	EDG
5	0/0	01.05.00	All	New Version	NHJ	AAK
5	0/2	01.08.01	5-8	5.15.1, 5.15.2, 5.15.6, 5.15.7, 5.15.8, 5.15.11, 5.15.12, 5.18.4 revised; 5.18.8 added	NHJ	AAK
5	0/3	18.09.01	1, 2, 5-8	5.3, 5.8, 5.15.5, 5.15.7, 5.15.11, 5.18.2, 5.18.4, 5.18.6 general revision	NHJ	AAK
5	0/4	30.09.02	1, 2, 5	5.3.5, 5.8, 5.15.2 revision	NHJ	AAK
5	1/0	30.07.04	37-40	5.15.5, 5.15.6, 5.16, 5.17, 5.18.3, 5.18.5, 5.18.6, 5.18.7 revised; 5.19 L/max revised	NHJ	AAK
5	1/0	30.07.04	All	Reformatted	CT	NHJ
5	1/1	30.06.06	39	5.15.6,5.15.7 revised	NHJ	AAK
5	1/2	30.04.07	42	5.15.10 revised	NHJ	AAK
5	1/3	02.06.09	39, 41, 45	5.8, 5.12, 5.14.2, 5.18.8 revised	NHJ	AAK
5	1/4	30.08.11	44-45, 47-48, 51-52	5.3, 5.4, 5.5, 5.8, 5.12, 5.15.1,1.15.12, 5.18.2, 5.18.4, 5.18.8 revised	NHJ	AAK
5	1/5	16.01.12	44-46, 48-50,52	Reformatted	KAW	NHJ

REVISION STATUS

SECT.	VER./ REV.	DATE	PAGES REVISED	REVISION DESCRIPTION (Section, Clause, Sub-Clause)	RVWD.	APRV.
5	1/7	27.06.17	44-53	5.14.5 moved, 5.15.1, 5.18.4, 5.19 revised, 5.14.4 new	NHJ	MSP
5	2/0		All	Whole section revised	NJ	EDG

6	0/0	01.05.00	All	New Version	NHJ	AAK
6	0/3	18.09.01	3, 4	6.2.3, 6.3 general revision	NHJ	AAK
6	1/0	30.07.04	43	6.2.3 revised	NHJ	AAK
6	1/0	30.07.04	All	Reformatted	CT	NHJ
6	1/4	30.08.11	56	6.2.3.2 revised	NHJ	AAK
6	2/0		All	Whole section revised	NJ	EDG

7	0/0	01.05.00	All	New Version	NHJ	AAK
7	0/2	01.08.01	2-5	7.8, 7.10.2, 7.12.3 revised; 7.12.6 added; 7.13.2, 7.14 revised	NHJ	AAK
7	0/3	18.09.01	1-3	7.2,7.4, 7.8, 7.9, 7.10 general revision	NHJ	AAK
7	1/0	30.07.04	44, 47	7.2 new; 7.4 revised; 7.12.1, 7.12.3 new; 7.13 revised	NHJ	AAK
7	1/0	30.07.04	All	Reformatted	CT	NHJ
7	1/1	30.06.06	46, 47	7.2,7.4, 7.8 revised	NHJ	AAK
7	1/2	30.04.07	49, 52	7.1, 7.6, 7.12.3 revised	NHJ	AAK
7	1/3	02.06.09	50-54	7.1, 7.6, 7.7, 7.8, 7.10, 7.12, 7.12.1, 7.12.3, 7.13, 7.14 revised	NHJ	AAK
7	1/4	30.08.11	57-62	7.1, 7.4, 7.8, 7.10, 7.12.1, 7.12.3 revised	NHJ	AAK
7	1/5	16.01.12	58-59, 61-63	Reformatted	KAW	NHJ
7	1/6	31.07.13	63	7.13 Revised	NHJ	MH
7	2/0		All	Whole section revised	NJ	EDG

8	0/0	01.05.00	All	New Version	NHJ	AAK
8	0/2	01.08.01	1	9.1.7 revised	NHJ	AAK
8	1/0	30.07.04	All	Reformatted	CT	NHJ
8	2/0		All	Whole section revised	NJ	NHJ

9	0/0	01.05.00	All	New Version	NHJ	AAK
9	0/2	01.08.01	1, 2, 4, 6, 7, 13-16	9.1.7, 9.1.9 revised; 9.1.12 added; 9.2.9, 9.2.10 revised; 9.2.14 added; 9.5, 9.6.4, 9.6.6, 9.7.1, 9.15, 9.16, 9.19, 9.21 revised; 9.24 added	NHJ	AAK
9	0/3	18.09.01	1-3, 5-17	9.1.2, 9.1.11, 9.2.2, 9.2.13, 9.3.1, 9.3.2, 9.5, 9.6.3, 9.6.5, 9.7.1, 9.9.2, 9.9.3, 9.9.4, 9.9.8, 9.10.4, 9.10.5, 9.10.6, 9.15, 9.17, 9.18, 9.19, 9.20, 9.21, 9.23, 9.24 general revision	NHJ	AAK
9	0/4	30.09.02	7-10, 13, 17	9.6.6 title revision; 9.7.1, 9.9.3 revision; 9.15 addition; 9.24 revision	NHJ	AAK

REVISION STATUS

SECT.	VER./ REV.	DATE	PAGES REVISED	REVISION DESCRIPTION (Section, Clause, Sub-Clause)	RVWD.	APRV.
9	1/0	30.07.04	52, 53, 57-61, 63, 65	9.2.1, 9.2.5 revised; 9.2.6 new; 9.2.7, 9.2.9, 9.8 revise; 9.9.2-9.10.8 new; 9.13, 9.15 revised; 9.18, 9.20, 9.25 new	NHJ	AAK
9	1/0	30.07.04	All	Reformatted	CT	NHJ
9	1/1	30.06.06	52, 54-57, 59-63, 66, 67	9.1.4, 9.2.1, 9.2.4, 9.2.9, 9.2.15, 9.3.2, 9.7.1, 9.8, 9.9.1, 9.9.2, 9.9.4, 9.9.8, 9.9.9, 9.9.11, 9.9.12, 9.20 revised	NHJ	AAK
9	1/2	30.04.07	55-57, 62	9.1.1 revised; 9.1.2, 9.1.3 added; 9.1.5, 9.1.6, 9.1.8, 9.1.13, 9.2.2, 9.9.7 revised	NHJ	AAK
9	1/3	02.06.09	56-65, 69, 70, 72-75	9.1.1-9.1.3, 9.1.5, 9.1.8-9.1.12, 9.1.14, 9.2.1-9.2.3, 9.2.5, 9.2.10, 9.2.13, 9.2.14, 9.2.17, 9.2.18, 9.3.1-9.3.4, 9.4, 9.6.1, 9.6.5, 9.7.1, 9.11, 9.12.1, 9.12.2, 9.13, 9.19, 9.20, 9.22, 9.26 revised	NHJ	AAK
9	1/4	30.08.11	66, 68-73, 75-78, 81-84, 86-87	9.1.4, 9.1.6, 9.1.14, 9.2.2, 9.2.3, 9.2.9, 9.2.10, 9.2.17, 9.2.18, 9.3.1, 9.3.3,9.6.6, 9.7.1, 9.8, 9.9.7, 9.12.1, 9.12.2, 9.15, 9.16,9.18, 9.23, 9.26 revised	NHJ	AAK
9	1/5	16.01.12	65-73, 75, 81-87	Reformatted	KAW	NHJ
9	1/6	31.07.13	85,86,89	9.18 ,9.20,9.26 Revised	NHJ	MH
9	1/7	27.06.17	65-87	9.2.19, 9.4, 9.8, 9.17 revised	NHJ	MSP
9	2/0		All	Whole section revised	NJ	EDG
10	0/0	01.05.00	All	New Version	NHJ	AAK
10	0/2	01.08.01	1, 2	10.2.2 revised; 10.5 added	NHJ	AAK
10	0/3	18.09.01	1, 7	10.2.1., 10.6 general revision	NHJ	AAK
10	1/0	30.07.04	66-70	10.1 revised; 10.2, 10.3, Fig 10.1-10.4 new;	NHJ	AAK
10	1/0	30.07.04	All	Reformatted	CT	NHJ
10	1/1	30.06.06	69	10.1 revised	NHJ	AAK
10	1/2	30.04.07	73-76	10.1, Fig 10.1, Fig 10.2, Fig 10.3 revised	NHJ	AAK
10	1/3	02.06.09	76	10.1, 10.2, 10.3 revised	NHJ	AAK
10	1/4	30.08.11	89	10.3 revised	NHJ	AAK
10	1/5	16.01.12	89	Reformatted	KAW	NHJ
10	1/6	31.07.13	90	10.3 Revised	NHJ	MH
10	2/0		All	Whole section revised	NJ	EDG
11	0/0	01.05.00	All	New Version	NHJ	AAK
11	0/2	01.08.01	1, 7, 8	11.1, 11.3, 11.8 revised; 11.11 added	NHJ	AAK
11	0/3	18.09.01	1, 6-9	11.1, 11.6.2, 11.7, 11.10 general revision; blank page removed	NHJ	AAK
11	0/5	20.01.03	1	Fig 11.2 amended	NHJ	AAK

REVISION STATUS

SECT.	VER./ REV.	DATE	PAGES REVISED	REVISION DESCRIPTION (Section, Clause, Sub-Clause)	RVWD.	APRV.
11	1/0	30.07.04	71-74, 76-79, 80, 81	11.1 new; 11.2 revised; 11.3 new; 11.4.1-11.4.3 revised; Fig 11.1, Fig 11.2, Fig 11.4-11.6, 11.6.3, Fig 11.7, 11.10, 11.12 new	NHJ	AAK
11	1/0	30.07.04	All	Reformatted	CT	NHJ
11	1/2	30.04.07	77-86, 95, 96	11.1, 11.4.1 revised; 11.4.3 included; Fig 11.1-11.6, 11.6.1, 11.6.2, 11.8, 11.9, 13.2.1 revised; 13.2.2 13.2.3 included	NHJ	AAK
11	1/3	02.06.09	80, 81, 87	11.1, 11.3, 11.4, 11.4.1, 11.4.2, 11.4.3, 11.6.3.5, 11.6.3.6 revised	NHJ	AAK
11	1/4	30.08.11	93-95, 100-101, 103	11.1, 11.2, 11.3, 11.4, 11.4.2, 11.4.3, 11.6.3,11.6.3.1, 11.6.3.2, 11.6.3.4, 11.6.3.5, 11.9, 11.10, 11.11 revised	NHJ	AAK
11	1/5	16.01.12	93-95	Reformatted	KAW	NHJ
11	1/6	31.07.13	95,96,101-105	11.3, 11.4, 11.6.3,11.6.3.1,11.6.3.5,11.11,11.12	NHJ	MH
11	1/7	27.06.17	92-104	11.1, 11.8, 11.10 revised	NHJ	MSP
11	2/0		All	Whole section revised	NJ	EDG

12	0/0	01.05.00	All	New Version	NHJ	AAK
12	0/3	18.09.01	1-4	12.1.2, 12.2.4, 12.3-12.6, 12.7.3, 12.8.1 general revision	NHJ	AAK
12	1/0	30.07.04	All	Reformatted	CT	NHJ
12	1/3	02.06.09	90, 92	12.1.3, 12.5 revised	NHJ	AAK
12	1/4	30.08.11	104, 106-108	12.1.1, 12.3, 12.5, 12.6, 1.8.2, 12.8.4	NHJ	AAK
12	1/7	27.06.17	105-109	12.1.1, 12.8.2 revised	NHJ	MSP
12	2/0		All	Whole section revised	NJ	EDG

13	0/0	01.05.00	All	New Version	NHJ	AAK
13	0/3	18.09.01	2	13.2 general revision	NHJ	AAK
13	0/4	30.09.02	6,7	13.1.2 revision	NHJ	AAK
13	1/0	30.07.04	88, 89, 91	13.1.2 table revised; 13.1.3 new; 13.6 revised; 13.7 new	NHJ	AAK
13	1/0	30.07.04	All	Reformatted	CT	NHJ
13	1/3	02.06.09	95, 96, 100	13.1.2, 13.1.3, 13.5, 13.5.1, 13.5.2, 13.5.3, 13.5.4 revised	NHJ	AAK
13	1/4	30.08.11	109-111, 115	13.1.2, 13.1.3, 13.8 revised	NHJ	AAK
13	1/5	16.01.12	113	Reformatted	KAW	NHJ
13	1/7	27.06.17	110-116	13.2.2, 13.6, 13.8 revised	NHJ	MSP
13	2/0		All	Whole section revised	NJ	EDG

14	1/2	30.04.07	95-99	New section	NHJ	AAK
14	1/3	02.06.09	101	14.1 revised	NHJ	AAK
14	2/0		All	Whole section revised	NJ	EDG

15	1/6	31.07.13	123-128	All	NHJ	MH

16	**2/0**	**30.10.23**	**All**	**New section**	**NJ**	**EDG**

17	**2/0**	**30.10.23**	**All**	**New section**	**NJ**	**EDG**

App A	1/7	27.06.17	128	New	NHJ	MSP
App B	**2/0**	**30.10.23**		**New**	**NJ**	**EDG**
App C	**2/0**	**30.10.23**		**New**	**NJ**	**EDG**
App D	**2/0**	**30.1023**		**New**	**NJ**	**EDG**

DESIGN STANDARD DS 21

Major Pump Station - Electrical

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1 INTRODUCTION

1.1 Purpose

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

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

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

This design standard is intended for the guidance 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 DS21) covers key aspects of the power electrical design associated with major pump stations including the incoming power supply, the main pump drives, switchboards rated greater than 315 kVA, switchboards controlling drives rated greater than 150 kW, the main power circuits and other main power electrical equipment.

For the purposes of this standard, major pump stations are defined as pump stations (including large bore sites) having individual drives rated in excess of 150 kW, or an incoming supply rated in excess of 315 kVA. Major pump stations are either stand alone or located within treatment plants.

Key aspects of the design of auxiliary drives, small switchboards and auxiliary services are covered in Electrical Design Standard DS22. Any minor electrical design and installation work associated with a major electrical installation shall align with the requirements of DS22.

1.3 Electrical Systems

1.3.1 General

The Corporate structure has placed responsibility for the control of pumping plant onto Operational Technology (Information & Technology Group) with Engineering (Assets Delivery Group) retaining responsibility for the provision and safety of the Electrical Power System, i.e., the drives, power supplies and power distribution.

Hence, it is the responsibility of Operational Technology to prevent the plant being operated in such a manner that the condition and safety of the electrical plant is not put at risk, whereas it is the responsibility of Engineering to put in place systems which safely shut the electrical plant down if the current mode of operation is exceeding safe design limits of the electrical plant. Consequently, the power system protection facilities must shut down the plant if maximum allowable insulation or bearing temperatures are exceeded, or in the case of larger machines, if maximum allowable vibration limits are exceeded.

As a result, electrical equipment and circuits in pump stations shall be deemed to consist of two separate systems, namely, the Electric Drive System (EDS) and the Plant Control System (PCS).

The function of the electric drive system is to provide protection against overheating of electrical insulation due to inappropriate operation of the electric drive system. In addition, the electric drive system shall include protection against overheating of electrical insulation and excess vibration (motor and pump) due to equipment failure within the electric drive system itself. Furthermore, the function of the electric drive system is also to provide protection against over voltages.

The function of the plant control system is to control the electric drive system to satisfy operational requirements of the overall hydraulic system without over stressing the electric drive system.

1.3.2 Electric Drive System

The electric drive system (EDS) shall be deemed to include:

(a) All High Voltage and Low Voltage equipment and circuits, except single phase power supplies which are integral within those items of equipment specified clause 1.3.3 hereunder

(b) All metering and primary protection equipment and circuits associated directly with the above equipment

1.3.3 Plant Control System

Plant control system (PCS) shall be deemed to include:

(a) All instrumentation measuring hydraulic system parameters

(b) All instrumentation measuring water treatment chemical levels

(c) The remote terminal devices (RTUs) connected to a remote central hydraulic system control centre

(d) The programmable controllers (PLCs) and associated programming directing the operation, but not primary protection of the associated electric drive system(s)

(e) Any local man-machine operational interface(s) for the plant control system including display terminal and including the associated programming

(f) The PLC programming monitoring hydraulic system parameters and PLC logic controlling normal mode operation

1.3.4 EDS to PCS Connections

All connections between the electric drive system and the plant control system shall be at Extra Low Voltage.

All connections between the electric drive system and the plant control system shall be at the EDS-PCS systems interface terminal units, one set for of terminals for each drive and one set for each feeder.

1.3.5 Types of Faults

Electric drive system faults shall be classified as either <u>primary faults</u> or <u>secondary faults</u> as further defined hereunder.

By the time that insulation over temperature or excess vibration conditions are detected, the life of the equipment has begun to degrade, albeit very slightly. Every time these conditions are repeated, the life of the equipment will be degraded further. Similarly, over current faults and overload faults result in raised conductor and insulation temperature. All these faults are deemed to be "primary faults".

Earth faults indicate insulation failure and thus are also deemed to be "primary faults". Similarly, arcing faults within enclosures are deemed to be "primary faults".

Drive excess start frequency and electrical supply under voltage are fault conditions which, if allowed to persist, will lead to insulation over temperature. These faults relate to the manner in which the electric drive system is being operated and are deemed to be "secondary faults".

Drive incomplete start and drive under load shall be deemed also to be a secondary fault.

The detection of start completion and electrical supply conditions shall be included as part of the electric drive system and shall be transmitted to the plant control system which shall take the necessary corrective action.

Electric drive system protection is discussed in more detail in clause 9.5 of this design standard.

1.4 References

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

DS20.1	Design Process for Major Power Electrical Works
DS20.3	General Design Process Requirements and Policy
DS22	Ancillary Plant and Small Pump Stations - Electrical
DS23	Pipeline AC Interference and Substation Earthing
DS24	Electrical Drafting
DS25	Solar Energy Systems
DS26	Type Specifications – Electrical
DS27	Lighting and Surge Protection (Future)
DS28	Water and Wastewater Treatment Plants – Electrical
FS00	Electrical Standard Drawing – Major Pump Station (***Current***)
MN00	Electrical Standard Switchboard Designs - Major Pump Station (***Future***)

Note: MN00 drawings are currently under development. Projects shall use FS00 drawings with direction from the Principal Engineer

1.5 Definitions

Asset Manager:	The Water Corporation officer responsible for the operation of the asset being acquired

Corporation: The Water Corporation (of Western Australia)

Designer: The consulting engineer carrying out the electrical design

Principal Engineer: Senior Principal Engineer – Electrical Standards Section, Engineering

Network Operator: As defined in the WASIR

1.6 National and International Standards

(a) Electrical installations shall be designed in accordance with the latest edition of AS 3000 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 (Energy*Safety*) of the Department of Mines, Industry Regulation and Safety.

(c) Except where a concession is obtained from the Network Operator, the electrical design of all installations to be connected to the Network Operator's system shall be designed in accordance with the Western Australian Service and Installation Requirements (WASIR) and the Technical Rules for the South West Interconnected Network published by Western Power/Horizon Power.

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

1.7 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 DS21 and these Type Specifications shall be used for this purpose whenever practical. Where a relevant Type Specification does not exist, the Designer shall prepare an appropriate specification based on this design standard 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.

1.8 Electrical Safety

Electrical installations shall be designed and constructed to facilitate the safe operation and maintenance of the electrical plant, and with careful consideration of the ongoing safety of workers and members of the public.

High Voltage equipment that does not require a tool to gain entry shall be protected by a unique specialised keyed mechanical interlock to prevent inadvertent access to exposed uninsulated conductors.

EL1 padlocks are not considered an alternative to a mechanical interlock. If the installation of a mechanical interlock it is deemed impractical, then dispensation shall be requested to deviate from this requirement from the Senior Principal Engineer, Standards.

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

Systems employing a “Safety PLC” for High Voltage interlocking shall NOT be permitted.

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

1.9 Mandatory Requirements

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

1.10 Approval Process and HV Submission

The designer shall ensure that the standards in clause 1.6 are adhered to with respect to electrical design and submission of designs for High Voltage sites. The Designer shall make such submissions and as further outlined in clause 3.4 of DS20.

Design submissions (consisting of single line diagrams, protection grading diagrams, earthing diagrams, site layout, equipment selections etc.) shall be approved by the Network Operator prior to the start of the detail design.

All correspondence with the Network Operator relating to the approval process, including agreements and arrangements for supply, shall be documented in the Engineering Summary Report and reference (date and file number) of the approval made on the Design Summary Drawings. Should Network Operator related approval and documentation be delayed, the Engineering Summary Report and Design Summary Drawings shall be updated (by the Designer) and issued as an addendum (report) and revision (drawings).

1.11 Quality Assurance

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

1.11.1 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 or an approved equivalent.

1.11.2 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 or an approved equivalent.

1.11.3 Acceptance Tests

All 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

(b) It is clear that works tests and site tests are separate critical deliverables

1.12 Allowance for Future Upgrades

For 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 a long timeframe, is not an effective use of budgets.

Where there is a firm plan, date (usually within ten years) and budget 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, an allowance for space and/or equipment within the switchboard for near future planned addition of solar power systems, an allowance for a planned motor-pump unit rating upgrade (cubicle space, equipment, site footprint, conduits, ducts, etc.).

Where the Project Manager deems it necessary to make allowance for near future expansion/additions, the Designer shall document this on the Design Summary 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 major pump stations, the Designer shall gather the following design information for use during the design process and preparation of Design Summary drawings in accordance with the MN00 drawing set:

(a) Single Unit Pump Duty kW

(b) Single Unit Pump "non overloading" kW

(c) Pump torque-speed curve

(d) Number of motor-pump units (duty and standby) to be installed immediately

(e) Number of motor-pump units (duty and standby) to be installed in next ten years

(f) Station maximum kW demand initially

(g) Station maximum kW demand in next ten years

(h) Speed of motor-pump units

(i) Motor rated voltage

(j) Estimated running hours per year, and distribution of running hours month by month

(k) Estimated number of motor starts per hour or day

(l) Pump type and pump station configuration

(m) Direction of rotation of motor viewed from coupling end

(n) Hydraulic control parameters

(o) Whether variable speed pump units are required to meet hydraulic control conditions

(p) Low sound level plant requirements

(q) Oil or Dry type transformers and associated accommodation

(r) SCADA I/O and alarm facilities requirements

(s) Water treatment facilities requirements

(t) Other ancillary equipment requirements

(u) Emergency electrical supply facilities requirements

(v) Inverter supply requirements (e.g., solar)

(w) Network Service Provider supply fault levels (and/or source impedance), incoming supply voltage kV, transformer impedance and Network Service Provider Power Quality Limits applicable to the site

3 INCOMING SUPPLY AND FEEDERS

3.1 General Arrangement

The incoming supply to Major Pump Stations shall be taken at High Voltage via cable connections with the necessary step-down transformers and associated primary side High Voltage switchgear being Corporation owned. Refer Appendix B regarding WCWA Incoming Power Supply Policy.

The Corporation's main incoming High Voltage switchboard shall be of the indoor type located in a separate dust free switchroom complying with the requirements documented in clause 15.

A Ring Main Unit (RMU) type High Voltage incoming switchboard in a proprietary outdoor weatherproof and dust limited kiosk as outlined in clause 3.4.4 may be utilised for special applications, where it is either space constrained or uneconomical to construct an indoor switchroom for building retrofit/upgrade (brownfield) applications, individual bores or small regional treatment plants. Should an outdoor solution be recommended by the design team, then agreement in writing shall be obtained from the Asset Manager via the Design Manager. A dispensation request (clause 1.9 refers) shall also be referred to the Principal Engineer for approval of the technical aspects in such cases.

Substations and High Voltage installations shall comply with the requirements of AS 2067, W.A. Electrical Requirements Manual (WAER), the Western Australian Service and Installation Requirements Manual (WASIR) and the Technical Rules Manual.

The standard High Voltage (≤ 33 kV) incoming supply configuration for the Water Corporation owned substation shall be as shown on the MN00 Electrical Standard Switchboard Designs - Major Pump Station drawing set.

3.2 Power Supply Quality Monitoring

Power supply quality measuring equipment shall be installed at all major pump station sites.

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

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

3.3 Supply to Station Auxiliaries

If the motor supply is to be at a voltage higher than 415 Volts, the station auxiliary supply shall be taken from a separate transformer (auxiliary transformer) fed directly from the primary supply voltage switchboard.

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

Except as stated above, the station auxiliaries supply shall be taken from the 415 Volt motor control switchboard.

3.4 Arrangement of Primary Supply Voltage Switchboard

3.4.1 Network Operator Metering Transformers

Network Operator High Voltage metering transformer unit, and it's associated incoming and outgoing switches, will be mounted separately from the Water Corporation's incoming High Voltage switchboard and will be connected to the latter by cable whether the Network Operator metering transformer is to be aerial connected or cable connected. The Network Operator may permit direct bus connection for indoor switchgear on the condition that the same type of equipment is used by the customer. This should only be applied in special circumstances where it can be justified, since this is somewhat restrictive in regard to equipment selection (cost and technical compliance) by the Corporation.

3.4.2 General

Supply voltage switchboard requirements:

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

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

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

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

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

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

(g) All circuit breakers shall be vacuum type

(h) The contacts and operating mechanisms of isolating switches and earthing switches shall be enclosed in sealed dry air-filled pressurised compartment(s) fitted with gas pressure indication (manometer)

(i) All High Voltage busbars shall be fully insulated with appropriate solid insulation

(j) The incoming supply High Voltage switchboard circuit breakers shall be provided with a separate tripping supply unit located adjacent to the switchboard

(k) All High Voltage switchboard circuit breakers shall be fitted with over current and earth fault protection relays and shunt trip releases

(l) If the substation is a single transformer rated $\leq$ 1500 kVA and the High Voltage switchboard circuit breakers are fitted with self-powered over current and earth fault protection relays (i.e., powered from the protection current transformers), the tripping supply unit may be a capacitive tripping supply unit. In such cases the transformer over pressure switch shall be connected directly to the capacitive tripping supply output. Otherwise, the High Voltage switchboard shall be a separate 24 V DC battery backed tripping supply unit

(m) Regardless of the type of tripping supply unit, a 24 V DC relay shall be provided in the tripping circuit of each circuit breaker to facilitate tripping initiated from the associated motor control switchboard

(n) IoT, Internet of Things, connected compatibility for health monitoring suitable for condition based and predictive monitoring

(o) Nearby control capability

Note: SF6 gas insulated switchgear shall only be utilised for special cases and as approved by the Principal Engineer as per the process outlined in clause 1.9.

3.4.3 Pump Station Indoor Substations

Pump station incoming High Voltage supply (Network Service Provider switchboard and Corporation switchboard) shall be housed, in a separate switchroom, within the same building housing the motor pump units with:

(a) Dry type transformers located in a separate room within the building or

(b) Oil type transformers located in a separate fire rated building or

(c) Oil type transformers (≤ 1500 kVA) located within kiosk enclosures separate from the building

A separate building housing only the incoming High Voltage supply is permitted, however, due to voltage drop considerations, the transformers shall be located close to the major load (pump station building) and arranged as per a), b) and c) above.

Note: Dry type transformers shall not be located outdoors in kiosk enclosures.

3.4.4 Prefabricated Outdoor Substations

Prefabricated substations are defined in IEC 62271-202 as a prefabricated type tested assembly comprising an enclosure containing, in general, transformers, High Voltage and Low Voltage switchgear and controlgear, High Voltage and Low Voltage interconnections, auxiliary equipment and circuits.

Prefabricated substations may be used in installations where the individual transformer size does not exceed 1500 kVA. In such instances if more than one transformer is involved, separate prefabricated substations shall be provided for each transformer. An oil filled transformer housed within a kiosk enclosure presents an oil leak risk, hence oil bunding with a volume of 120% that of the oil within the transformer shall be provided integral within the kiosk.

Furthermore, High Voltage distribution switchgear together with its kiosk enclosure shall constitute a prefabricated substation in accordance with Clause 1 of AS 62271.202. In such cases the High Voltage Switchgear shall consist of fully enclosed High Voltage Ring Main Unit type of switchgear (RMU), mounted within the kiosk and switching external High Voltage circuit(s).

The High Voltage distribution switchgear shall be of the modular Ring Main unit type with a degree of protection of enclosed equipment of IP67 in accordance with AS/IEC 60529. The enclosure degree of protection shall not be less than IP23DW (transformer compartment) and IP24DW (switchgear compartment).

Kiosk enclosures housing High Voltage switchgear shall be specified such that the enclosure does not compromise the integrity of the switchgear type testing and arc fault containment performance. Prefabricated substations shall be of a Type Tested design in accordance with IEC 62271-202 (AS 62271.202). In particular, internal arc fault tests verifying the effectiveness of the equipment in protecting persons to IAC-AB is required.

If switchgear anti-condensation heaters are fitted to equipment housed within a kiosk enclosure, such heaters shall operate under temperature control.

If the risk of damage due to vandalism is considered to be low, as determined by the Asset Manager, further protection by fencing can be omitted in such cases.

3.5 Transformer and Motor Control Switchboard Configuration

The main configurations available for major pump stations are:

(a) Single transformer to motor control switchboard. In this case there is no standby transformer

(b) Dual transformer (duty/standby) feed to the motor control switchboard with the transformers connected in parallel

(c) Dual transformer, each rated for the total pump station load demand, feed to the motor control switchboard with the motor control switchboard sectionalised (i.e., a split bus system). Each transformer feeds half of the switchboard under normal conditions but is available to feed the whole switchboard should one transformer circuit be out of commission. Interlocks prevent paralleling of transformers

(d) Unit transformer arrangement whereby each transformer feeds a motor control switchboard and its associated motor-pump unit

Each configuration has its advantages and disadvantages however the most reliable and secure arrangement is the dual transformer with sectionalised motor control switchboard, i.e., item c) above.

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

(a) In the event of a switchboard busbar failure, repair work can be carried out on the faulted section while the remainder of the switchboard remains operable

(b) Maintenance may be carried out on busbar connected equipment without the need to shut down the whole switchboard. In respect to High Voltage switchboards, such maintenance can generally be expected to be less frequent

(c) In the event of a transformer or feeder fault event, one transformer can supply the whole switchboard and its associated load

(d) The fault level presented at the switchboard is lower under a sectionalised arrangement

(e) Being sectionalised, the source impedance is increased so that Network Operator mains voltage disturbances, caused by starting currents or non-linear loads, are reduced

(f) A sectionalised configuration allows for a simpler feeder protection system

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

(a) The amount of switchgear is marginally increased and interlocks slightly more complex

(b) Dual sources of auxiliary supply may be required (e.g., 415 V motor control switchboard)

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

By virtue of their nature, major pump stations are considered to be critical infrastructure assets and as such availability, reliability and functional safety are paramount. Hence the dual transformer with sectionalised motor control switchboard, i.e., item c) above, shall be adopted as the standard transformer and motor control switchboard configuration for major pump stations.

However, a unit transformer arrangement for a large High Voltage/Low Voltage VSC application whereby a dedicated transformer is essential for voltage conversion and phase shifting (multi-pulse) requirements is permitted. (Clause 3.8 d) refers).

If the Designer has convincing reasons to adopt another configuration for a particular project, then approval shall be sought from the Principal Engineer for dispensation (Clause 1.9 refers).

3.6 Motor Control Switchboard Feeder Circuit Breakers

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

Incoming feeder circuit breakers in main motor control switchboards shall be fitted with over current and earth fault protection relays which shall be powered either from a DC tripping supply or shall be self-powered (i.e., powered from the protection current transformers).

Each main motor control switchboard feeder circuit breaker shall be arranged to trip if the High Voltage circuit breaker controlling its associated transformer trips.

3.7 Isolation, Earthing and Interlocking

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

(a) All High Voltage circuit breakers and switch fuses shall be fitted with integral isolators and earth switches

(b) Interlocking shall be provided:

  (i) To prevent any High Voltage earth switch being closed onto live conductors

  (ii) To prevent opening or closing a High Voltage isolator unless the associated circuit breaker or switch fuse is open

  (iii) To prevent access to live transformer High Voltage terminals

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

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

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

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

(e) All High Voltage switchboard equipment other than isolating switches and busbars shall be able to be isolated safely for maintenance while the remainder of the switchboard remains alive

3.8 Transformer Ratings

Transformer rating requirements:

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

(b) Pump stations having motor-pump units supplied from a common drive voltage shall be provided with 100% standby transformer capacity

(c) If a unit transformer configuration (other than a VSC arrangement) is approved for use on a project (Clause 3.5), unit transformers supplying individual fixed speed motors shall have an on-site kVA rating not less than the full load kVA rating of the associated motor

(d) Where large (usually High Voltage but may be Low Voltage for multi-pulse) variable speed controllers without AFE rectifiers are used, it will be necessary to feed such controllers from unit converter transformers in order to limit harmonic distortion to the voltage waveform both to other loads and at the point of common coupling. In such cases, the unit transformer on site kVA rating shall be not less than the rated input demand of the variable speed controller or the motor, whichever is the greater

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

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

(g) Transformers connecting Low Voltage active filters to the site High Voltage network shall be derated as detailed above for additional losses due harmonic currents. It should be noted that in such instances the derating will be particularly severe and that in such cases minimising the eddy current losses and the stray losses may be more important than minimising the 50 Hz copper losses. (Cause 7.9 refers)

3.9 Feeders

Feeder requirements:

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

(b) Low Voltage busbar trunking systems shall be in accordance with IEC 61439-6 Low Voltage switchgear and controlgear assemblies - Busbar trunking systems (busways)

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

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

3.10 Incoming Voltage Surge Protection

Where there is an incoming Network Operator High Voltage aerial line to High Voltage consumers' mains cable transition at the site, suitably rated High Voltage surge diverters will be fitted at the cable termination by the Network Operator. Similarly, the Network operator may install surge diverters at the cable transition point to the Corporation’s substation. Reliance shall not be placed on such surge diverters to provide voltage surge protection for the Corporation’s primary voltage switchboard and transformers. Design, and hence insulation coordination, shall be based on Corporation owned and installed surge diverters.

Suitably rated surge diverters shall be fitted to the primary winding terminals of all incoming supply transformers, with the earth cable connected directly from the surge diverter to the transformer’s metallic tank. Total cable connections lead length (line and earth side) shall be less than 1 metre where practical and in any case less than 1.5 metres.

The Designer shall ensure that the rating of the surge diverter and the length of the associated feeder cable are such that the above surge diverters will provide adequate surge protection for the primary voltage switchboard. If this cannot be achieved, suitably rated surge diverters shall be provided connected directly to the primary voltage switchboard busbars, in addition to the transformer surge diverters. Clause 12 of this standard and clause 8.9 of DS22 refers.

3.11 Connections to Transformers

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

Connections to free standing transformer Low Voltage terminals shall be in fully enclosed cable boxes or within fully enclosed busway terminations as appropriate. Fully enclosed busways (bus duct) shall be considered for transformers rated greater than 1600 kVA at 415 V and 2500 kVA for 690 V.

Connections to Low Voltage terminals on transformers mounted within kiosk enclosures may be of the exposed air insulated type provided adequate safety barriers are provided. The LV connections from transformers within kiosk enclosures to the associated switchboard(s) shall be via underground cable in conduit.

3.12 Protection Against Fire and Explosion

Construction of High Voltage substations shall comply with the requirements of AS 2067 with the aim of minimising the risk of fire and explosion injury to personnel and damage to buildings and other infrastructure, so as to provide continuity of operational services.

A clearance of not less than 1.2 metres shall be provided between all dry type transformer kiosk enclosures and building walls.

3.13 Power Factor Correction

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

Generally, the Network Service provider will require a load power factor close to unity. If the station pump drives are to be variable speed type, the use of active harmonic filters or variable speed controllers with active front ends will allow the pump station to run at close to unity power factor.

Power factor correction equipment may be required for the pump station load. Such power factor compensation shall be of the “Central Compensation” type utilizing Low Voltage capacitor banks via a step-down transformer. Detuning reactors shall be fitted to reduce the risk of harmonic resonance. Appropriate redundant features shall be built into the design so that failure of one bank does not impair the operation of the remaining system. (Type Specification DS26-39 refers).

Alternatively, power factor correction may be electronic utilising the power factor correction control features of active filters (Refer section 14). The Designer may adopt an active filter for a particular project, if suitable for the project.

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

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

Note:

When describing non-linear load, it is important to distinguish between “true” power factor and conventional 50Hz “displacement” power factor (Cos Ø).

The “True” Power Factor = Displacement PF x Distortion Factor

Where: Distortion factor= $1/(\sqrt{(1+THD_i^2)}) = D_F$

Hence: $PF_T = \cos Ø \times D_F$

The distortion factor will decrease as the harmonic content increases; hence the true power factor will be lower.

Therefore, in order to make a valid comparison of power factor between different drive topologies, it is critical that the harmonic distortion factor is considered.

3.14 Overhead Line Design

Corporation owned High Voltage overhead power lines shall be designed and constructed in accordance with the requirements of AS/NZS 7000 Overhead Line Design.

AS/NZS 7000 specifies the general requirements for the design and construction of new overhead lines to ensure that the line is suitable for its intended purpose, provides acceptable levels of safety for construction, maintenance and operation, and meets requirements for environmental considerations.

Where possible, any alterations or upgrade work on existing overhead power lines shall be designed and constructed in accordance with the requirements of AS/NZS 7000.

Where existing overhead lines are proposed to be altered/upgraded such that elements of the overhead line may be overloaded or overstressed to the original design standard, then the overhead line is required to be assessed by a competent person for compliance with the provisions of this AS/NZS 7000.

3.15 Type Specifications

Type Specifications suitable for specifying prefabricated outdoor substations and the power factor correction assembly are:

DS26-02	Type Specification for 22 kV to 0.433 kV Prefabricated Substation
DS26-37	Type Specification for HV Distribution Switchgear with Kiosk Enclosure
DS26-42	Type Specification for Kiosk Enclosure for HV Switchgear and/or Transformer
DS26-39	Type Specification for Conventional Low Voltage Power Factor Correction Assembly

4 MOTORS AND CONTROLLERS

4.1 Motor Rating

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

$Pp = Q * H * 9.81/ (1000 *\eta_p)$

where: Pp = pump duty power, kW

Q = pump flow, litres/sec (Note: 1.0 m3/day = 0.01157 litres/sec

H = pumping pressure (head), metres *(1 bar = 100 kPa = 10.2 metres of* H_2O*)*

η_p = pump efficiency, per unit

(b) All motors shall be fitted with winding over temperature protection and shall have on-site S1 power ratings of not less than 110% of the associated maximum load duty power demand

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

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

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

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

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

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

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

4.2 Motor Rated Voltage

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

Motor Rated Voltages				
Motor Rating kW	**>150, ≤220**	**>220, ≤450**	**>450, ≤800**	**>800**
Voltage kV for Fixed Speed Motors in New Pump Stations	0.415	3.3 or 6.6	3.3 or 6.6	3.3 or 6.6
Voltage kV for Variable Speed Motors in New Pump Stations	0.415	0.69	0.69	3.3, 4.16, or 6.6
Voltage kV for Variable Speed submersible motors in deep artesian bores	0.415 or 0.69	0.69 or 3.3 or 4.16	3.3 or 4.16	3.3 or 4.16
Voltage kV for Fixed Speed Motors in Existing Pump Stations	0.415	0.415	3.3 or 6.6	3.3 or 6.6
Voltage kV for Variable Speed Motors in Existing Pump Stations	0.415	0.415 or 0.69	0.69	3.3, 4.16 or 6.6.
Fixed Speed submersible bore hole motors rated ≤ 250 kW shall have a rated voltage of 0.415 kV	-	-	-	-

Note: Motors rated greater than 5 MW may have a rated voltage of 11 kV in special applications provided dispensation is granted. For example, high pressure pumps for desalination plant reverse osmosis pumps.

Table 4.1 Motor Rated Voltage versus Motor Output Power

4.3 Motor Starting Requirements

4.3.1 General

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

4.3.2 Voltage Waveform Limits Within the Installation

At the various points of common coupling within the Corporation's installation, motor operation under VSC control or motor starting shall not cause:

(a) The 3-second mean r.m.s. voltage waveform total harmonic distortion to exceed 15% (IEC 61000-2-4 Class 3)

(b) The 10-minute mean r.m.s. voltage waveform total harmonic distortion to exceed 10% (IEC 61000-2-4 Class 3)

(c) The voltage waveform notching level to exceed 20%

(d) The voltage to dip more than 15% (IEC 61000-2-4 Class 3) when supplied from mains power, or

(e) The voltage to dip more than 20% when supplied from an on-site standby generating set

A larger voltage dip (to 25%), when operating from an on-site generating set, is permissible if the steady state voltage control of the generator voltage regulator is set at +5% of the nominal voltage rating. However, this should be considered only in special cases.

Note: The voltage waveform total harmonic distortion limits at a) and b) above shall apply when the installation is being supplied from either the Supply Network or from an on-site generating set.

4.3.3 Voltage Dip Limits at the Network Operator High Voltage PCC

The amount of voltage dip at the Network Operator point of common coupling (PCC) which is permitted to be caused by motor starting will be determined in accordance with AS/NZS 61000.3.7, ultimately by the Network Operator.

However, for most installations covered by this Design Standard, motor starting will be infrequent and the installation will represent a significant proportion of the load on the incoming MV* feeder, so that it is appropriate that determination of permissible voltage dip limit be by the Stage 2 method as described in AS/NZS 61000.3.7. *(Note: Stage 1 limits will not apply to Major pump stations)*

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

$$G_{PstMV} = [L_{PstMV}{}^{3} - (T_{PstHM} * L_{PstHV})^{3}]^{0.333}$$

$$= 0.776$$

Where:

MV* = voltages in the range > 1 kV, ≤ 35 kV

HV = Voltages > 35 kV

G_{PstMV} = global short term flicker emission for all loads supplied directly at MV (per unit)

L_{PstMV} = short term planning level at MV

= 0.9 as per Western Power Technical Rules Table 2.3

L_{PstHV} = short term planning level at HV

= 0.8 as per Western Power Technical Rules Table 2.3

T_{PstHM} = HV/MV flicker transfer coefficient,

= 0.8 being typical value as per AS/NZS 61000.3.7:2012 clause 8.2

Note: *Western Power's Power Quality Group use a default value of 1.0 in their calculations as this aligns with Western Power's Technical Rules manual Table 2.3, note 1*

Then:

$$E_{PstiMV} = G_{PstMV} * (S_i / (S_{MV} * F_{MV}))^{0.333}$$

Where:

E_{PstiMV} = allowed short term flicker emission limit for Corporation installation supplied at MV (per unit)

S_i = Corporation installation maximum load (kVA)

S_{MV} = total kVA of loads supplied directly at MV,

= typically: 0.4* the MV/HV transformer rating per AS/NZS 61000.3.7:2012

F_{MV} = coincidence value for MV loads simultaneously disturbing

= 0.4 mean value as per AS/NZS 61000.3.7:2012

Note 1: For estimating purposes it can be assumed that:

$S_{MV} = 15*10^3 / X_s$

where Xs is the fault reactance at the substation MV busbars, calculated on a 100 MVA base.

Note 2: Should the value of E_{PstiMV} as determined above be less than 0.35, the latter value shall be used as per AS/NZS 61000.3.7:2012 Table 4

Then:

$\Delta U/U = E_{PstiMV} * P_{st1}$

Where:

$\Delta U/U$ = allowable % voltage dip at the point of common coupling

P_{st1} = the value of P_{st} for 230 Volts for the appropriate rectangular voltage changes per minute as per Table A1 and Figure A1 of AS/NZS 61000.3.7:2012

= 7.4 % for a typical water transfer pump station.

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

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

then $\Delta U/U = 0.35*7.4\ \% = 2.6\%$

4.3.4 Harmonic Current Limits

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

The Network Operators seem not to directly address intermittent harmonic interference, such as motor starting via ESSs. In any case, the starting of large motors via ESSs will generate voltage and current harmonics during start and as such his issue shall be raised with the Network Operator, by the Designer, to establish any power quality limit requirements.

4.3.5 Direct-on-Line Starting

Direct-on-Line (DOL) starting is the simplest form of starting and allows the use of squirrel cage induction motors. Direct-on-Line starting shall be used wherever the power supply fault level (including the standby generator if applicable) is high enough to allow such starting without the resulting voltage dips exceeding the allowable limits specified in clauses 4.3.2 and 4.3.3 above.

Direct-on-Line starting of cage induction motors has one significant disadvantage, that being the relatively high starting current (in the order of 6 to 7 times full load current for large motors). This high start current can be reduced by considering the use of deep bar and double cage rotors. There is a small price premium for this type of cage induction motor however this can be balanced against the often-significant cost of reduced voltage starters. Typically, the starting current can be reduced to 4 to 5 times full load current which may suit a particular project voltage dip requirement. The Designer shall consider this type of rotor as appropriate.

4.3.6 Electronic Soft Starting (ESS)

Reference should be made to clause 7.3 of DS22 regarding application, principle of operation and technical information regarding ESSs.

Considerations and requirements for motors covered by this design standard when started by ESSs are:

(a) In instances where the power supply fault level at the site is not high enough to allow the use of Direct-on-Line starting, the Designer shall carry out calculations to ascertain whether the use of Electronic Soft Starting would be appropriate, i.e., would provide the required starting torque without exceeding the voltage dip and harmonic distortion limits specified above. To further assist in meeting stringent voltage dip limits, the Designer shall consider the use of deep bar or double cage rotor motors as discussed in clause 4.3.5. Electronic soft starting of such motors could potentially reduce start currents to 2 to 3 times full load current

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

(c) The torque versus speed and current versus speed characteristics of many commonly available cage motors are such as to make these motors unsuitable for use as centrifugal pump drives if controlled by Electronic Soft Starters

Motors having a speed versus torque characteristic such that the torque increases continually over the speed range 20 % rated speed to break down torque speed are the most suitable type of motor for this application.

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

At sites where the fault level is particularly low and starting currents must be kept below this level (4 times FLC), the Designer shall consider the use of Electronic Soft Starters in conjunction with motors employing double cage or deep bar rotors. A further advantage of motors employing double cage or deep bar rotors is the much higher starting torque which will counteract the torque reduction due to reduced voltage starting.

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

$T_o > 0.2*T_{pump}$

$T_s > 0.1*T_{pump} + (I_{cl}/I_s)^2*T_{pump}$

where: T_{pump} = pump input torque at motor rated speed

I_{cl} = current limit Amps

T_o = motor torque at standstill with current limited to I_{cl}

s = any speed within the range from 20% rated speed to breakdown torque speed

T_s = motor torque at speed **s** with current limited to I_{cl}

I_s = motor DOL current at speed

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

T_{sc} / I_{sc}^2 = critical torque factor

sc = critical speed = 75 % full speed

T_{sc} = DOL motor torque at speed **sc** as % full load torque

I_{sc} = DOL motor current at speed **sc** as per unit motor full load current

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

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

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

(f) Electronic soft starter configurations, requirements and arc fault protection arrangements shall be in accordance with standard drawings MN00. All electronic soft starter switchboards shall be fitted with arc fault detection systems

(g) The use of a soft starter also carries a major negative consequence. The significant decrease in the initial starting torque, due to the reduced voltage applied, during a start sequence, causes an increase in start-up time. In the case of soft starting a pump load torque the cage bar temperature is significantly higher, because much more energy is released in the rotor cage winding compared to a direct-on-line start-up. Therefore, as the soft starter does increase the thermal effects in the motor significantly during start-up, this mode of soft start shall be used only for voltage dip mitigation and not for hydraulic control purposes. Furthermore, soft stopping is not permitted for large motors covered by this design standard unless dispensation is granted by the Principal Engineer

Note: Significant heating, and a resultant temperature rise, within the switchboard can result from extended time soft starting/stopping compromising the switchboard design validation tests.

(h) With reference to item g) above, should soft start and stop be required for hydraulic reasons then a variable speed controller (VSC) shall be used. A VSC substantially reduces the thermal risk to the durability of the rotor cage, as the energy released in the rotor circuit is significantly smaller, and consequently the cage bar temperature is lower than in the case electronic soft starter

4.3.7 Rotor Resistance Starting

In general, the supply network fault level at the Corporation's major sites within Western Australia is comparably lower than in other parts of the country. This is particularly the case in remote country areas of Western Australia where fault levels can be as low as 20 to 50 MVA at 22/33 kV. Hence power quality limits set by the Network Operator can be quite difficult to achieve and requires the implementation of various technologies.

In circumstances where calculations show that neither Direct-on-Line nor Electronic Soft Starting will be acceptable, slip ring (wound rotor) induction motors with rotor resistance starters shall be used. With correct design, the motor start current for pump applications can be limited to 1.25 to 1.5 times FLC.

Rotor resistance starters shall be of the compact 3PA3 self-contained type incorporating cast iron resistance elements which are insulated and cooled by immersion in an oil-filled sheet metal tank fitted with an over pressure valve, oil filler, oil level indicator, lifting lugs, alarm overtemperature detector and shut down overtemperature detector. The designer shall ensure that an oil containment bund is provided for each starter within the pump station and sized to contain 110% of the volume of oil within the starter.

Motors shall be fitted with ring shorting and brush lifting gear (activated after the final run contactor within the resistance starter has closed) to minimize brush wear and the risk of arc flash within the rotor enclosure.

Note: Typical motors without ring shorting and brush lifting gear must have maintenance carried out on the motor (rotor slip ring enclosure) at quarterly intervals to prevent the buildup of carbon dust which can lead to arc flash and subsequent motor damage and outage.

The control circuit for the rotor resistance starter shall be in accordance with standard drawings MN00.

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

The motor per phase to neutral equivalent star equivalent circuit is:

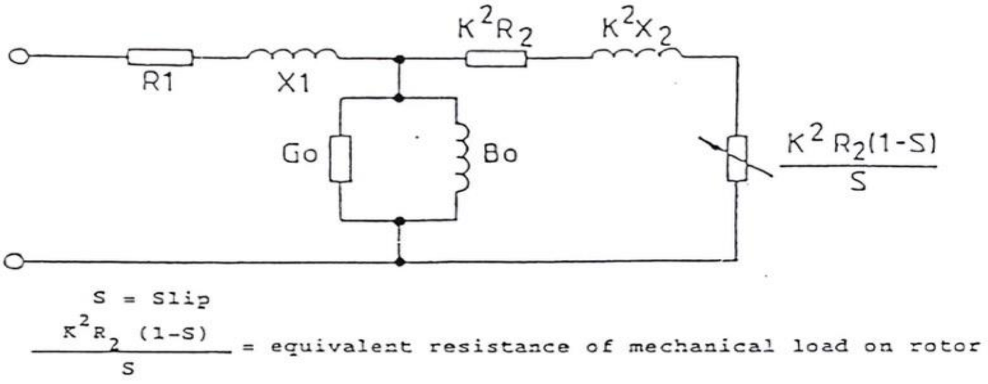


Fig 4.1 Motor Equivalent Circuit

Where:

R1 = Stator resistance	X1 = Stator leakage reactance
G_0 = Core loss conductance	B_0 = Magnetising susceptance
K^2R_2 = Referred rotor resistance	K^2X_2 = Referred rotor reactance
K = Effective turns ratio	S = Slip

The rotor starter resistances are inserted in series with the rotor circuit and the individual step resistances are shorted out during the starting speed ramp.

Note: The number of steps within the resistance starter are determined dependent upon the calculated power quality limits (voltage dip) for each project.

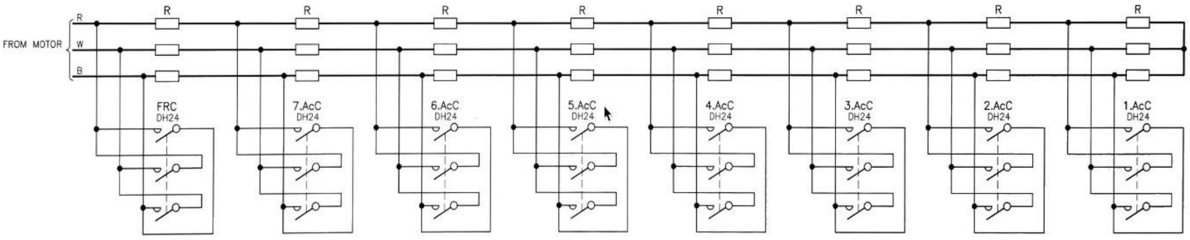


Fig 4.2 Resistance Starter Power Circuit

Where:

AcC = Accelerating Contactor

FRC = Final Run Contactor

The resistors shall be set such that the torque-speed and current-speed curves during start are of the sawtooth shape (even peaks) as shown below. This arrangement will ensure lower torque pulsation and limit current to prescribed values during start sequence.

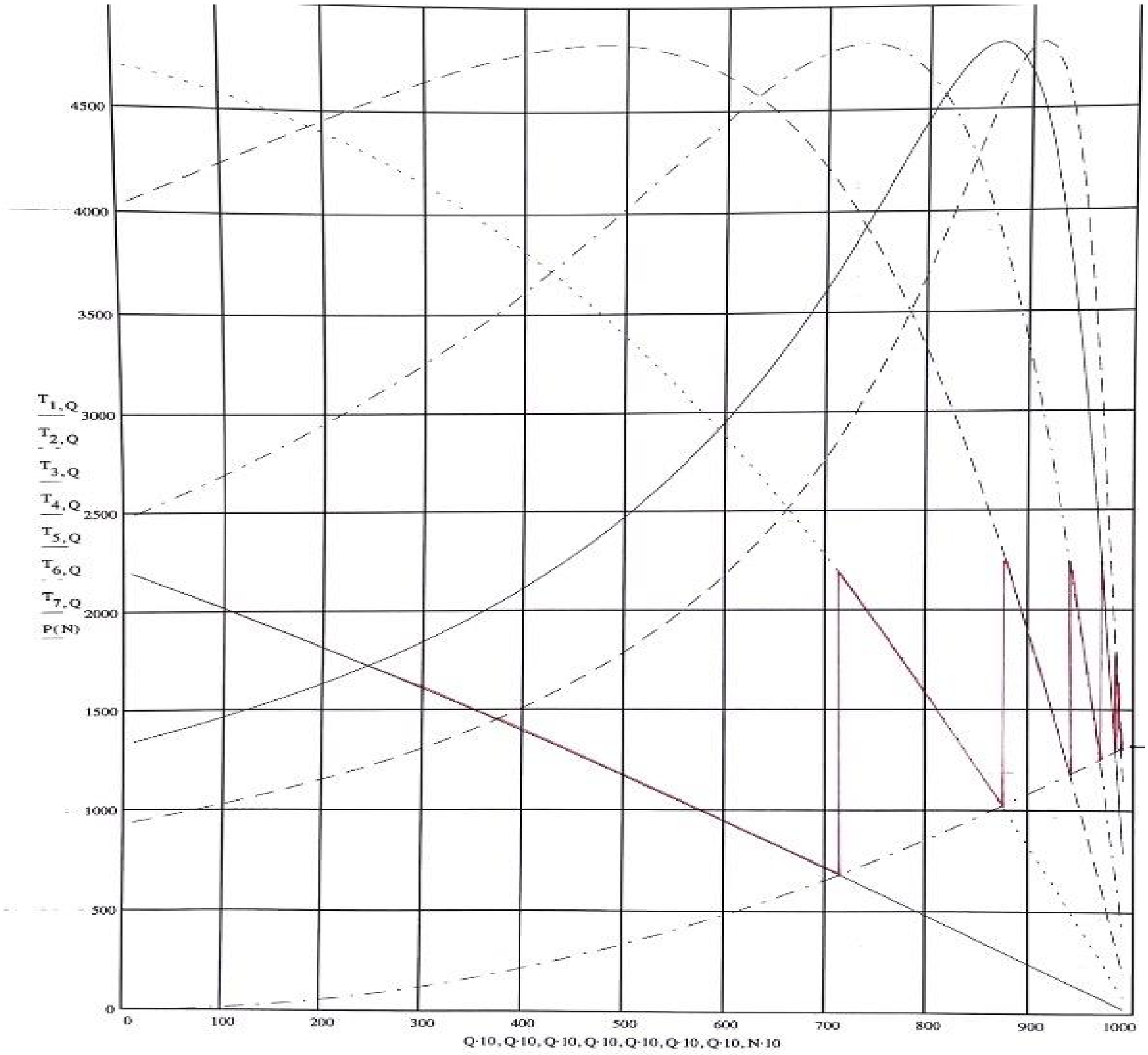


Fig 4.3 Motor Start Torque (NM) vs Motor Speed (rpm)

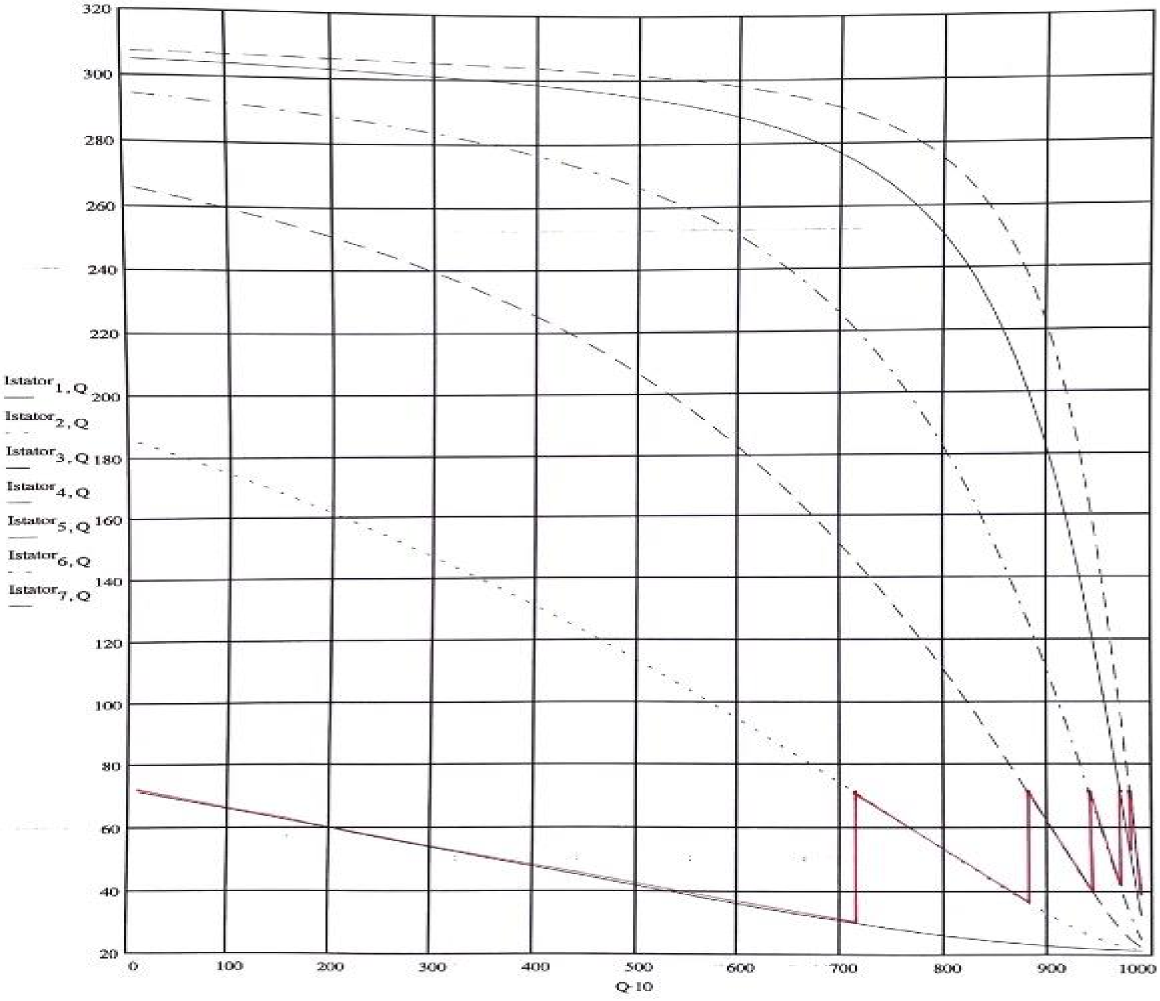


Fig 4.4 Motor Start Current (Amps) vs Motor Speed (rpm)

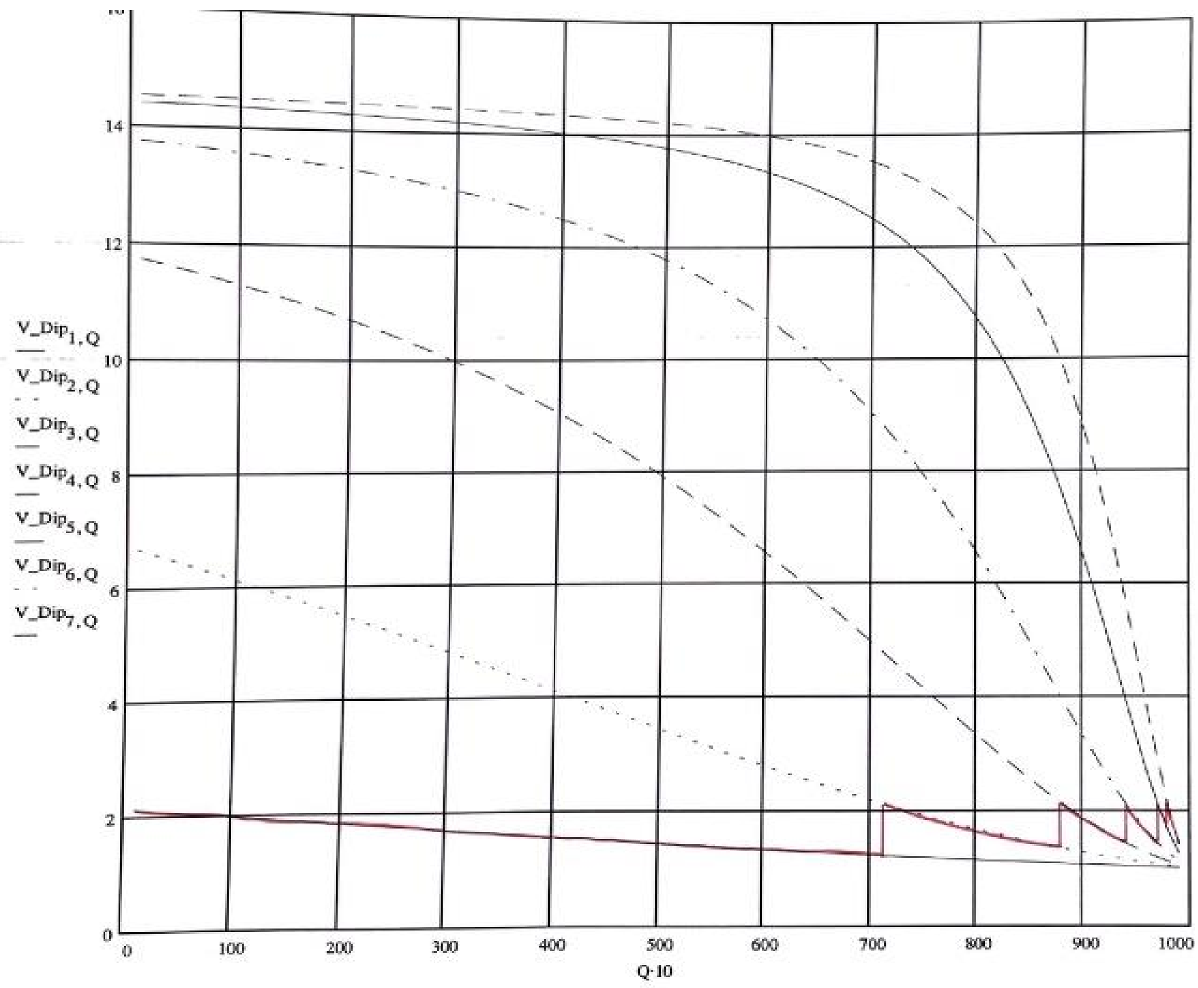


Fig 4.5 Resultant Voltage Dip (%) vs Motor Speed (rpm)

4.3.8 Variable Speed Controllers as Starters

Variable speed controllers can limit the starting current for cage motors to as little as motor full load current. However, their application as starters is limited by the harmonics produced normally and by the consequent additional expense needed to eliminate such harmonics (Refer Section 4.4). Furthermore, the high cost of a VSC does not warrant it's use as a starter.

Variable speed controllers shall not be used as a motor starter unless dispensation is granted by the Principal Engineer following a detailed submission, outlining reasons, by the Designer.

4.4 Variable Speed Controllers for Cage Motors

4.4.1 Types of Controllers

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

Variable speed controller converters (Refer clause 4.4.8 for types) take significant amounts of harmonic current and consequently cause harmonic distortion of the incoming supply voltage and current waveform.

Low Voltage variable speed controllers are available with:

(a) 6 pulse converters without DC bus reactor (choke)

(b) 6 pulse converters with DC bus reactors

(c) 6 pulse converters with AC line reactors*

(d) 6 pulse converters with passive harmonic filters

(e) 18 pulse converters configured with auto transformers

(f) 6 pulse converters with inbuilt active harmonic filters, or

(g) active front end (AFE) converters

*Variable speed controllers fitted with input line reactors shall not be used for control of main pump drive motors due to the inherent voltage drop.

Note: DC reactors located on the DC bus are more effective than AC line reactors in mitigating harmonic currents, especially the 5th and 7th harmonic.

High Voltage variable speed controllers are available with:

(a) 12 pulse converters,

(b) 18 pulse converters,

(c) 24 pulse converters,

(d) 36 pulse converters, or

(e) active front end (AFE) converters

The HV variable speed controller arrangement shall be type **A** or **B**:

A Type **A** variable speed controller arrangement is defined as one where each unit input isolating transformer is mounted integral with the associated variable speed controller enclosure.

Note: An input isolating transformer mounted immediately adjacent to its associated variable speed controller proper shall be considered to be integral.

A Type **B** variable speed controller arrangement is defined as one where each unit input isolating transformer is mounted separately/remote from its associated variable speed controller.

Thyristor or diode converters are available in 6, 12, 18, 24 or 36 pulse type, depending upon the degree of mitigation required, utilising phase shift transformers. The higher the number of pulses the lower the demand for such harmonic currents, but the higher the cost.

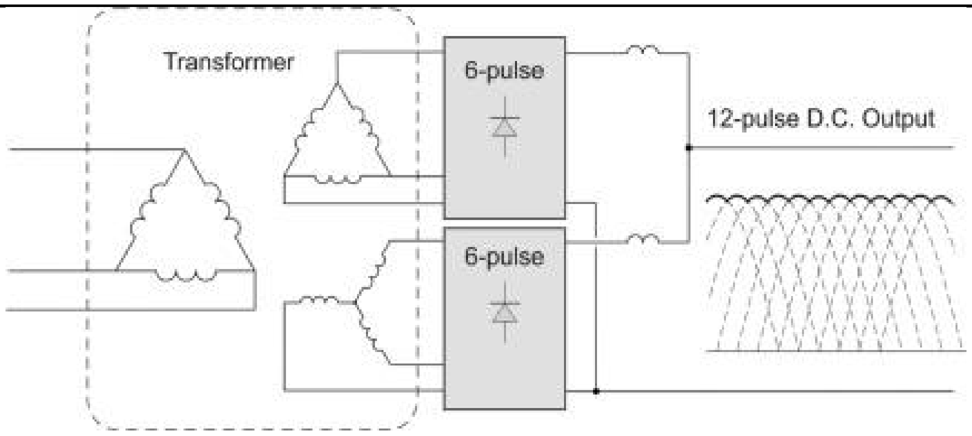


Fig 4.6 Typical 12 Pulse Converter (Rectifier)

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

There are many options to reduce harmonics interference to the Supply Network or within the installation. They all have advantages and disadvantages and all of them have cost implications. The most appropriate solution will depend on meeting the harmonic power quality limits imposed by the Network Operator at the PCC and the harmonic limits imposed within our installation.

The following table provides typical values of harmonic current (% of fundamental current) for each type of VSC converter with a 100% load.

Harmonic Order (h)	**5**	**7**	**11**	**13**	**17**	**19**	**23**	**25**	**THD(i)**
6-pulse w/o reactor	**80%**	**58%**	**18%**	**10%**	**7%**	**6%**	**5%**	**2.5%**	**101.5%**
6-pulse with 3% reactor	**40%**	**15%**	**5%**	**4%**	**4%**	**3%**	**2%**	**2%**	**43.6%**
6-pulse with 5% reactor	**32%**	**9%**	**4%**	**3%**	**3%**	**2%**	**1.5%**	**1%**	**33.9%**
6-pulse with LHF*	**2.5%**	**2.5%**	**2%**	**2%**	**1.5%**	**1%**	**0.5%**	**0.5%**	**4.9%**
6-pulse with AHF	**2.3%**	**2.5%**	**2.6%**	**1.7%**	**0.8%**	**0.7%**	**0.3%**	**0.2%**	**4.5%**
12-pulse	**3.7%**	**1.2%**	**6.9%**	**3.2%**	**0.3%**	**0.2%**	**1.4%**	**1.3%**	**8.8%**
18-pulse	**0.6%**	**0.8%**	**0.5%**	**0.4%**	**3%**	**2.2%**	**0.5%**	**0.3%**	**3.9%**
24-pulse	**2.6%**	**1.6%**	**0.7%**	**0.4%**	**0.2%**	**0.1%**	**1.9%**	**0.8%**	**3.7%**
AFE	**0.7%**	**1.4%**	**1%**	**0.7%**	**1%**	**0.6%**	**0.5%**	**0.4%**	**2.4%**

* LHF: Line Harmonic Filter (passive)

Table 4.2 Typical Harmonic Currents for Various VSC Converters

Note: *For the table above, the short circuit ratio is based on 20 to 50. For higher short circuit ratios, the above values will be higher. A 2% or 3% unbalanced supply voltage to the VSC will also increase the THDi when compared to a balanced supply.*

The most common types of variable speed controller topologies are:

(a) Voltage source controllers, in which the input A.C. voltage is rectified, the energy stored temporarily in a capacitor, then supplied to the associated cage motor as a pulse width modulated voltage waveform

(b) Current source controllers, in which the input A.C. voltage is rectified, the energy stored temporarily in an inductor, then supplied to the associated cage motor as a pulse width modulated voltage waveform or as a six-step voltage waveform

(c) Cycloconverter controllers, in which the input A.C. voltage is converted directly into a six-step output voltage waveform without any D.C. link for energy storage

Cycloconverter controllers variable speed controllers shall not be permitted in electrical installations designed in accordance with this Design Standard, unless otherwise authorised in writing by the Principal Engineer.

Voltage source controllers shall generally be deployed for Corporation projects.

Variable speed controllers are available with various types of incoming converters (i.e., rectifiers), all taking harmonic currents from the incoming electrical supply. The input current total harmonic distortion [THD(i)] varies from greater than 45% to less than 5%, depending on the type of converter (i.e., rectifier) used. Various types of converters are discussed in clause 4.4.8.

Active front end (AFE) variable speed controllers employ sinusoidal rectifier converters which demand low levels of harmonic currents from the supply. The power factor of the currents taken by these variable speed controllers is controlled and can be maintained within 0.95 lagging to 0.95 leading for loads within the range 30% to 100%. Some variable speed controllers are available which will allow the power factor to be set at values between 0.8 lagging and 0.8 leading. However, AFE variable speed controllers are more expensive than units with basic rectifier converters, particularly in smaller sizes.

The harmonic current demand of controllers with basic rectifier converters can be reduced by supplying each controller via a passive harmonic filter. However, the input power factor of such arrangements falls significantly with reducing load. Hence, variable speed controllers fitted with passive harmonic filters shall not be used for control of main pump drive motors. Alternatively, an active harmonic filter at the input to the controller is acceptable.

4.4.2 Continuous Voltage Waveform Distortion Limits

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

Similarly, the continuous operation of non-linear loads within the installation shall not cause distortion of the current waveform at the point of common coupling with the Network Operator's distribution system in excess of the level specified in clause 4.4.15 hereunder.

The amount and type of incoming voltage waveform distortion caused by a variable speed controller depends on the controller's harmonic current demand, the supply impedance and the type of converter (i.e., rectifier) in the variable speed controller.

4.4.3 Harmonic Currents Drawn by the Installation

The electrical design of the installation shall be such that harmonic currents drawn by the installation do not cause harmonic currents to be taken from the incoming electrical supply in excess of limits approved by the Supply Authority.

With a balanced supply voltage, no triplen harmonic currents will be taken from the supply to the variable speed controller. However, a supply voltage imbalance will cause significant triplen harmonic currents to be drawn from the supply to the variable speed controller. However, if the supply to the variable speed controller is via a transformer with a delta winding, no triplen harmonic currents will be drawn from the incoming High Voltage electrical supply.

Supply voltage imbalance will cause an increase in the amount of non-triplen currents drawn from the supply.

AS/NZS 61000.3.6 specifies harmonic current limits assuming a supply voltage imbalance < 2%. However as per the ESAA publication entitled "Customer Guide to Electricity Supply", Australian Supply Authorities "try" to limit HV supply voltage imbalance to 3%.

The design of Low Voltage drive installations rated > 2 MVA and the design of all High Voltage installations shall be such as to limit the harmonic currents drawn for the incoming supply to values determined by the Network Operator in accordance with AS/NZS 61000.3.6. Such determinations may involve considerable time, so that for such installations fairly long delays can be expected in obtaining harmonic current limits.

In Low Voltage installations having a maximum electrical load of < 2 MVA, the design of the installation shall be such as to limit the current total harmonic distortion [THD(i)] in the incoming supply current to 8%, assuming a supply voltage imbalance of 3%, and to 5% assuming a balanced voltage supply.

In such installations the individual non-triplen harmonic currents shall comply with the limits specified in IEEE 519-2014 Table 2.

Installations complying with the above, more than comply with the requirements of AS/NZS 61000.3.6 Stage 1 and accordingly may be approved without the Supply Authority having to carry out extensive investigations to determine project specific harmonic current limits.

Should this not be the case, low harmonic variable speed controllers and active front end variable speed controllers are available commercially which draw somewhat less than harmonic current limits specified in IEEE 519-2014 Table 2.

A THD(i) of 3 % could be considered a practical minimum value. If values of THD(i) lower than this, are required additional filters will need to be installed.

4.4.4 Starting Performance

Starting currents taken by variable speed drives are usually relatively small, i.e., typically less than 150% full load current. Nevertheless, the Designer shall calculate the voltage dip disturbances on starting to confirm that these are in accordance with the requirements specified in clause 4.3.2 and 4.3.3 above.

4.4.5 Rating of Converter Supply Transformers

The current drawn by multi-pulse (6 pulse, 12 pulse, 18 pulse, 24 pulse, etc.) and AFE converters is in the form of alternate positive and negative square wave pulses and this is non sinusoidal. Since transformers are rated for sinusoidal currents, the utilisation factor (k factor) for transformers supplying converter leads will be less than unity depending on the root mean square value of the current waveform. DS22 clause 7.4.7 refers.

The Designer shall determine the appropriate utilisation factor and shall rate the converter supply transformer accordingly.

4.4.6 Screening of Converter Supply Transformers

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

4.4.7 Size of Converter

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

4.4.8 Type of Converter

Converters (rectifiers) can be classified as uncontrolled, controlled or AFE as further defined hereunder.

4.4.8.1 Uncontrolled vs Controlled Converters

Converters in which there is no delay in the instant of conduction are said to be uncontrolled converters or free firing converters (e.g., diode bridge). The power factor of such converters is high.

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

The process of rectification carried out by a controlled converter involves short periods of “commutation” as the source of the rectified current is transferred from one phase to another. This process is known as notching (Clause 4.4.18 refers).

In order to avoid notching in the supply voltage waveform caused by the use of a controlled converter, a passive filter has to be installed. This results in variable speed controller’s power factor declining with declining load (The power factor of controlled converters falls from approximately 0.95 at full load to approximately 0.65 at 30% load) and for this reason use of variable speed controllers with controlled converters shall not be permitted unless dispensation is granted by the Principal Engineer.

An uncontrolled converter consisting of a three-phase set of bridge rectifiers connected to a three-phase supply will produce 6 pulses of D.C. current per cycle. Such a converter is known as a 6-pulse converter. Two 6 pulse converters in parallel and supplied with appropriately phase shifted three phase inputs can be configured to generate a 12-pulse converter. Using a similar technique 18 pulse, 24 pulse and 36 pulse converters can be configured. However, as the pulse number increases so does the susceptibility to increased THD(i) due to supply voltage imbalance. Consequently, in rural areas active front end converters are preferred.

4.4.8.2 Active Front End (AFE) Converters

Active front end converters are also known as sinusoidal rectifiers. Active front end converters are in effect inverters connected backwards and connected to the incoming supply via filters.

The active front end inputs are switched in a pulse width modulated (PWM) mode so as to produce a rectified D.C. output from a substantially sinusoidal input current into the input filter, which in turn prevents significant modulation side band harmonic currents and voltages (switching frequency harmonics) being reflected into the input power supply. Such filters shall be required to include a radio frequency stage.

Input filters are especially essential at low fault level sites (typically below 30 MVA) as the PWM switching frequency harmonic content becomes pronounced resulting in significant voltage increase to the VSC power supply card. This is discussed in some detail in AS/IEC 60034-25.

4.4.9 Harmonic Generation

4.4.9.1 General

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

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

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

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

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

Sinusoidal rectifiers (i.e., active front ends) will draw triplen harmonic currents as well as other harmonic currents albeit all at a relatively low level. However, triplen harmonic currents will be filtered out by transformer delta connections and will not be transferred across isolating transformers.

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

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

$h = k*q \pm 1$

where:

h = harmonic number (integer multiple of the fundamental)

k = any positive integer

q = number of pulses per cycle

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

Theoretically, if the number of pulses per cycle is increased to 12, the 5th and 7th harmonics are eliminated. Theoretically, if the number of pulses per cycle is increased to 24, the 11th, 13th, 17th and 19th harmonic currents will also be eliminated, and so on.

In practice the “eliminated” harmonic currents generated by uncontrolled converters with pulse numbers greater than 6 will be approximately 10 % of the value of these harmonic currents generated by a 6-pulse uncontrolled converter installed in the same situation.

The magnitude of harmonic currents drawn by a converter depends on the source impedance, i.e., an increase in source impedance will result in a fall in the percentage of harmonic current in the total current drawn by the converter. However, a higher source impedance (lower fault level) implies a higher harmonic voltage distortion.

Where uncontrolled converters, incorporating filtering, are to be considered, modelling parameters specific to the make and model of variable speed controller shall be used. As specified clause 4.4.8.1 controlled converters shall be permitted only if fitted with passive front-end filtering.

Note: AC line filters generally have poor power factor at low load and may present problems when connected to the supply, especially a generating set supply.

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

4.4.9.2 Harmonic Performance of Low Voltage Converters

Figure 4.7 shows the total harmonic distortion current [THD(i)] for currents taken by various types of Low Voltage converter against the ratio of the incoming supply fault current level to full load current (I_F/I_L) assuming a balanced voltage incoming supply.

Figure 4.8 shows the total harmonic distortion voltage [THD(v)] for currents taken by various types of Low Voltage converter against the ratio of the incoming supply fault current level to full load current (I_F/I_L) assuming a balanced voltage incoming supply.

It should be noted that the curves for the AFE converter are for a unit using the relatively simple 7 pulse per pole selective harmonic elimination (SHE) switching pattern (which results a 42-pulse overall converter switching pattern). Some Low Voltage AFE converters use a more sophisticated modulation switching pattern which results in more harmonic currents, but at a much lower level, so that the resulting THD(i) is approximately the same.

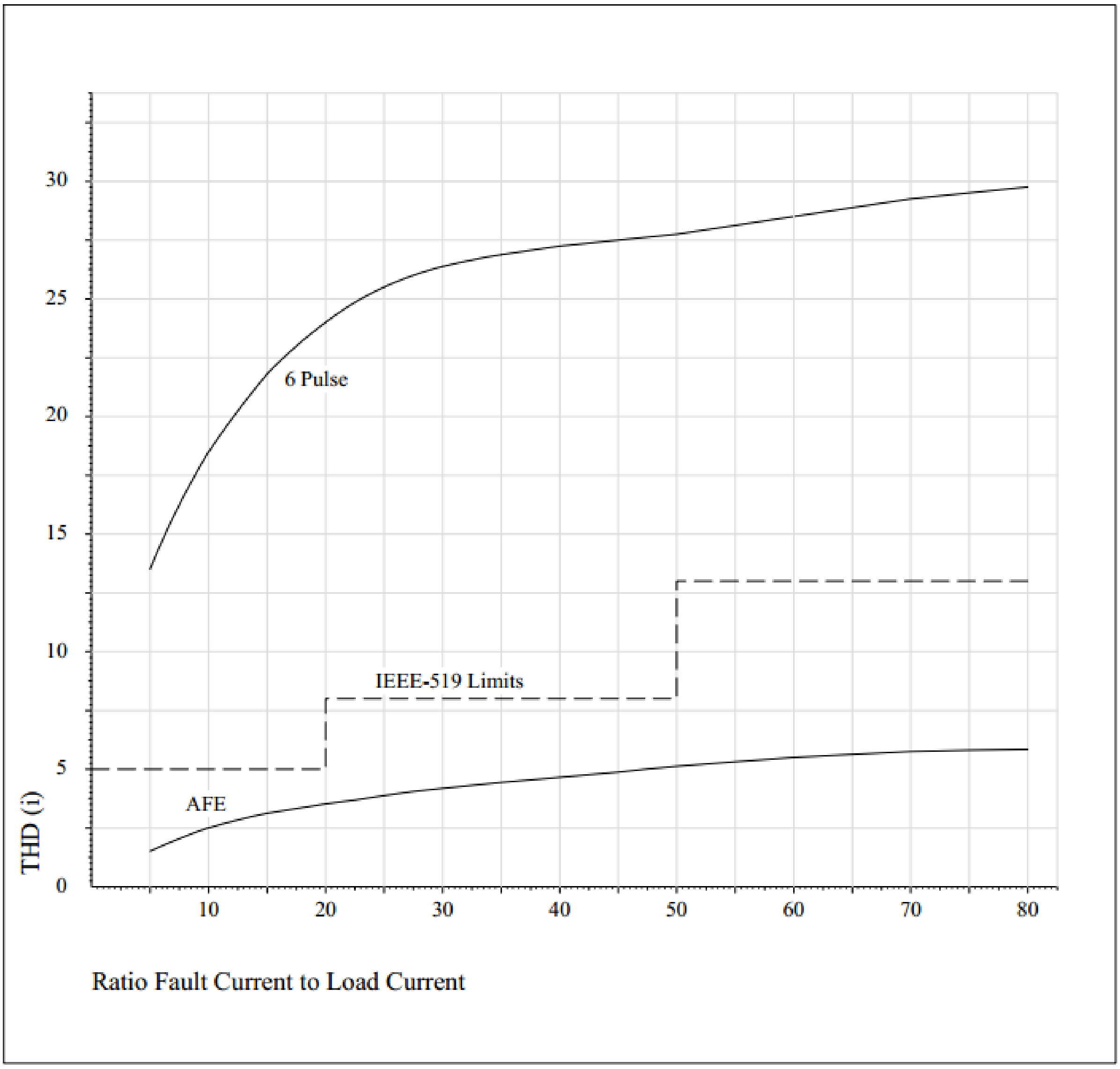


Figure 4.7 Total harmonic current distortion to (I_F/I_L) relationships

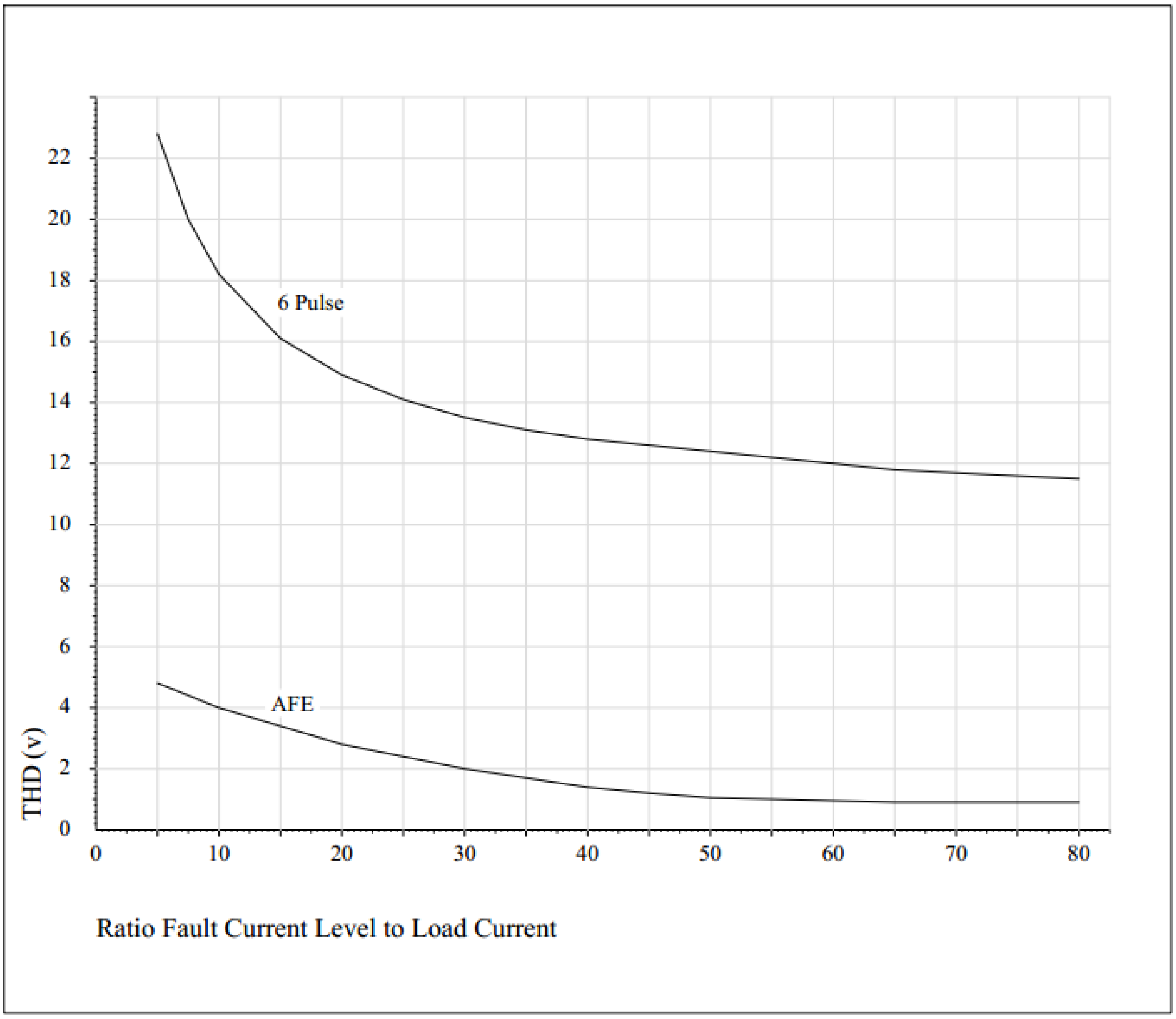


Figure 4.8 Total harmonic voltage distortion to (I_F/I_L) relationships

4.4.9.3 Harmonic Performance of High Voltage Converters

Figure 4.9 shows the total harmonic distortion current [THD(i)] for currents taken by the various types of High Voltage converters against the ratio of the incoming supply fault current level to full load current (I_F/I_L) assuming a balanced voltage incoming supply.

Figure 4.10 shows the total harmonic distortion voltage [THD(v)] for currents taken by various types of High Voltage converter against the ratio of the incoming supply fault current level to full load current (I_F/I_L) assuming a balanced voltage incoming supply. Because of their different harmonic current spectra, THD(v) values for 24 pulse converters and AFE converters are approximately the same.

It should be noted that the curves for the AFE converter are for a unit using the relatively simple 7 pulse per pole selective harmonic elimination (SHE) switching pattern (which results a 42-pulse overall converter switching pattern).

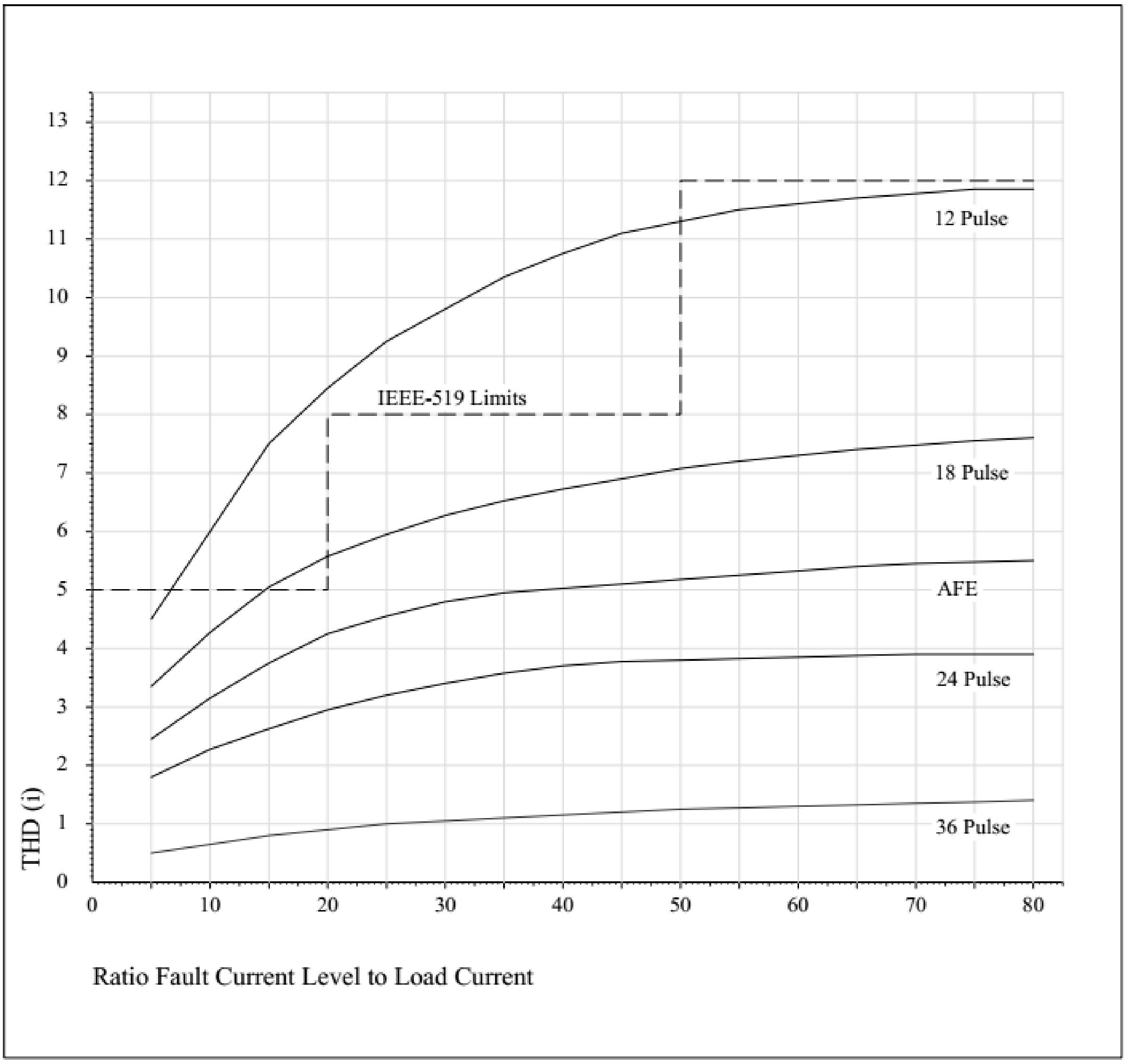


Figure 4.9 Total harmonic current distortion to (I_F/I_L) relationships

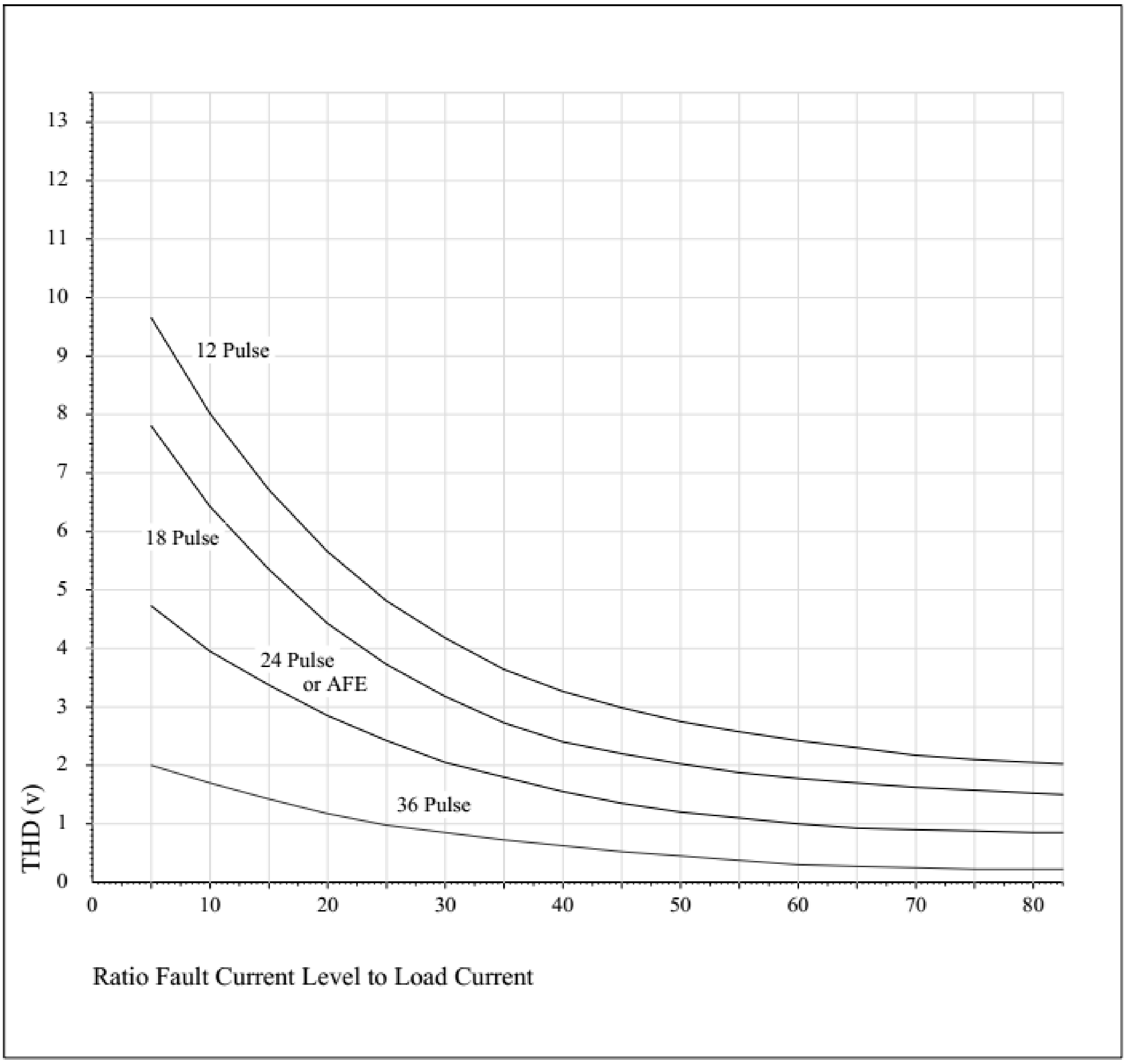


Figure 4.10 Total harmonic voltage distortion to (I_F/I_L) relationships

4.4.9.4 Use of THD(i) and THD(v) Graphs

The THD(i) graphs shown at Figures 4.7 and 4.9 and THD(v) graphs shown at Figures 4.8 and 4.10 are indicative and sufficient to enable the type of controller to be determined for Concept Design purposes only.

However, at the Engineering Design stage, the Designer shall perform harmonic modelling based on the confirmed technical parameters (e.g., source impedance, harmonic currents drawn for the type of converter at the I_F/I_L ratio, etc.) received to confirm that the individual harmonic currents generated at the specified source impedance by the variable speed controller type, and the THD(v) at the PCC, complies with the Network Operator’s power quality limit requirements. Similarly, the Designer shall confirm performance requirements based on the harmonic spectrum of the potential successful tenderer at the tender analysis stage and update the Design Summary drawing accordingly.

In deciding what type of converter to specify, the Designer shall consider the likely levels of voltage imbalance at the site bearing in mind that supply voltage imbalance increases the THD(i) demand of AFE converters less than it does for multi- pulse converters (clause 4.4.3 refers).

4.4.10 Use of Active Harmonic Filters

In situations where the fault level is very low, even relatively low levels of harmonic currents can cause voltage waveform distortion in excess of the allowable limits. In these circumstances the Designer shall investigate the use of active harmonic filters as an alternative to increasing the complexity of the converter system. Section 14 refers.

The active filter operates by injecting a current made up of harmonic currents of the same magnitude as the harmonic currents in the load current, but 180 degrees out of phase with such currents. The theoretical effect is that only the fundamental current is drawn from the supply. Practically there is no complete cancellation (e.g., due to imbalance supply voltages) but resultant currents are very small.

Active filters are available as separate entities as well as being built into Low Voltage low harmonic variable speed controllers.

In instances where multiple Low Voltage variable speed controllers are required, it may be economical to use controllers with basic 6-pulse converters and to provide duplicate (duty/standby) active filters at the associated Low Voltage switchboard so as to ensure that the level of supply incoming current THD(i) is kept within the acceptable limits. For projects requiring multiple Low Voltage variable speed controllers, the Designer shall investigate whether the use of active filters will provide the most economical solution.

For the purposes of the Engineering Design, the required size of active filters shall be determined by the THD(i) expected in the current demand of generic variable speed controllers of the specified type and rating, after allowing a 20% margin.

The Designer shall confirm that the specified ratings for the active filters are adequate once tenders for the variable speed controllers and active filters have been received.

4.4.11 Types of Inverters

Inverters can be classified and described as follows:

4.4.11.1 Voltage Source Inverters

The most common form of variable speed controller inverter is the voltage source pulse width modulated (PWM) type.

In these controllers, energy is temporarily stored in a parallel capacitor at the associated converter output. The constant D.C. voltage supply from the capacitor is switched by the inverter at a carrier frequency and pulse width modulated to produce a chopped D.C. output having fundamental voltage of the required frequency and voltage. The pseudo sine wave motor current is produced at a voltage and motor frequency somewhere between 0 Hz and 100 Hz, depending on the required motor speed.

Depending on the size and particular design, carrier frequencies, within industry, range from 1 kHz to 16 kHz.

When this voltage waveform is applied to the associated motor, the impedance of the motor will present a high impedance to the higher frequencies filtering the harmonic currents to low values, resulting in a smoother current waveform close to the fundamental current.

However high frequency components of the switched voltage waveform (dv/dt) cause can cause adverse effects as discussed in clause 4.4.12 hereunder.

4.4.11.2 Current Source Inverters

In a current source DC link inverter, the output voltage waveform consists of a stepped waveform at the required motor frequency, the voltage level of which is controlled by the associated controlled converter. Power from the converter is stored temporarily in series inductors rather than in parallel capacitors as is the case for voltage source inverters. Current source inverters include capacitors on their outputs which together with the above series inductors provide a filter for high frequency current and voltages.

In a current source variable speed controller, the DC current supply from the converter via the inductor is switched by the inverter at a carrier frequency to produce the required fundamental output currents, frequencies and voltages. The carrier frequencies for typical variable speed controller current source inverters are lower than used those used normally for voltage source inverters and are typically in the range of 400 Hz to 600 Hz.

Additional output sinusoidal filters are not required for variable speed controllers with current source inverters.

4.4.11.3 Multilevel Inverters

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

A multilevel inverter is a Voltage Source Inverter (VSI) applicable to High Voltage VSCs and based on the principle of the Neutral-Point Clamped (NPC) Inverter. Multilevel converters utilising High Voltage IGBT (Insulated Gate Bipolar Transistor) power semiconductors is available to 7 level (line to neutral) or higher. Converter input rectifiers can be passive (6, 12, 18 pulse etc.) or active (AFE).

This type of converter uses diodes to connect the midpoint of the upper and lower legs with the DC bus midpoint (NP). In its simplest configuration it provides three voltage levels at the output of each phase. Likewise, in order to increase the number of output voltage levels, the number of diodes and switches can be increased. The possibility of multiple output voltage levels makes this topology appropriate for medium to high power and high voltage applications. Figures 4.11, 4.12, 4.13 and 4.16 refer.

There are several multilevel converter types, all being a variation in the NPC type shown below. These include:

(a) Neutral-point-clamped (NPC) converter

(b) Active NPC (ANPC) converter

(c) T-type NPC converter

(d) Flying capacitor (FC) converter

(e) Cascaded H-bridge (CHB) converter

(f) Modular multilevel (MM) converter

A typical NPC inverter configuration is shown at Figure 4.11 below.

By way of comparison, Figure 4.12 shows the Active NPC (ANPC) multilevel converter inverter highlighting the replacement of diodes by switches.

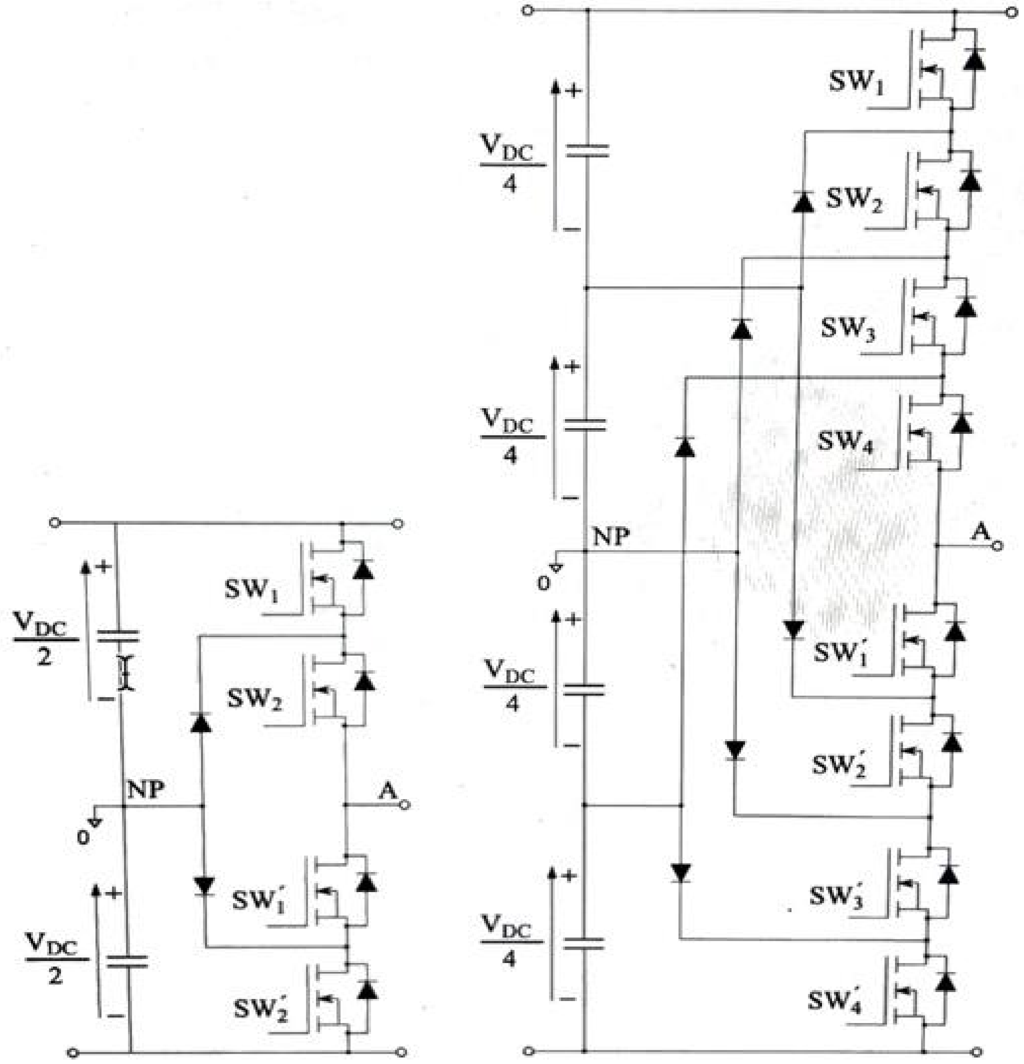


Figure 4.11 Conventional NPC multilevel inverter topologies for three and five levels (only one leg is shown)

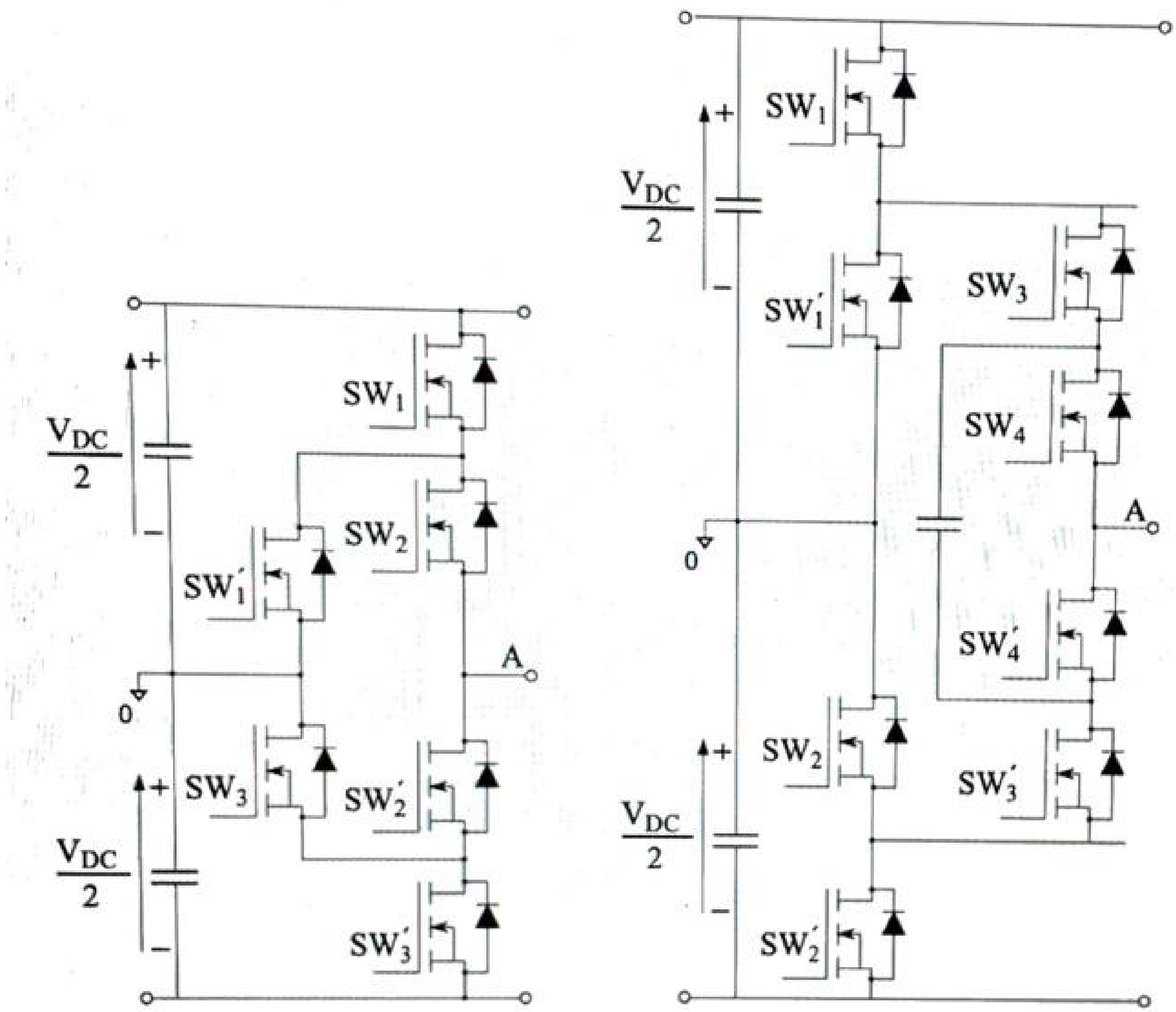


Figure 4.12 Conventional ANPC multilevel inverter topologies for three and five levels (only one leg is shown)

Despite each multilevel topology having its pros and cons, they all synthesize waveforms with higher quality (CMV, etc.) than two-level converters, as well as increase their voltage values and consequently their power ranges.

Motors driven by pulse-width modulated converters face the recurring problem of common-mode voltage (CMV). In fact, this voltage leads to problems such as bearing breakdown, deterioration of the stator winding insulation and electromagnetic interferences (EMI) that can affect the lifespan and correct operation of motors. In this sense, multilevel converters have proven to be a useful tool for solving these problems and mitigating CMV.

Typically, ABB, WEG, Siemens and others now employ this technology.

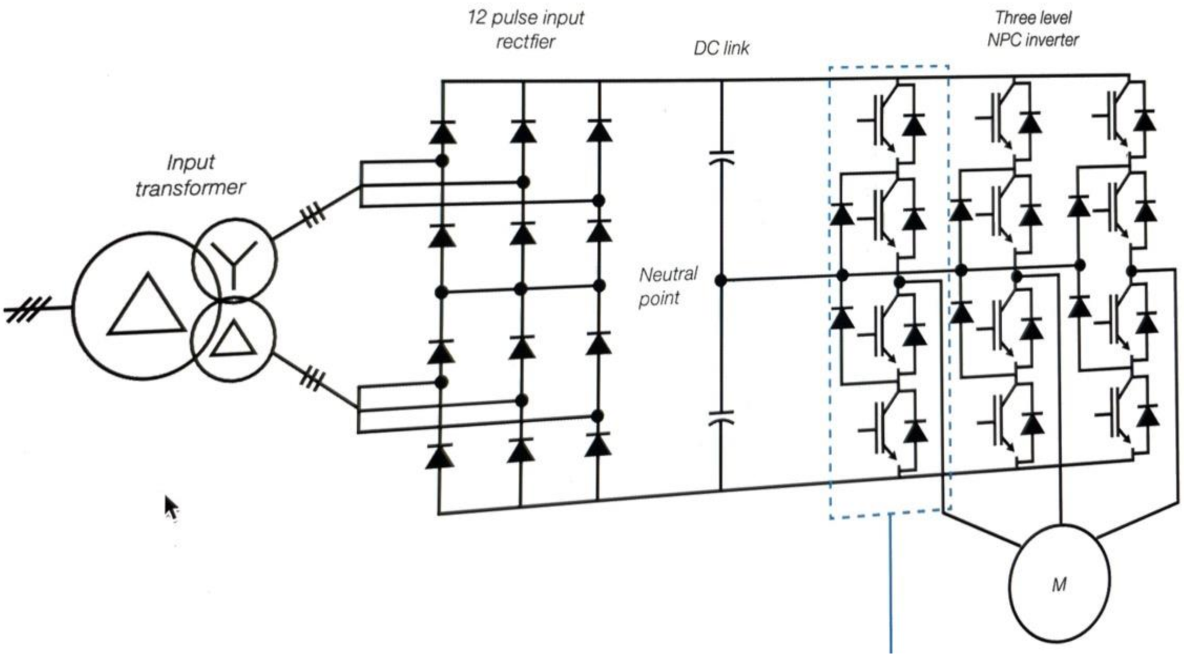


Figure 4.13 Typical 3 level NPC Inverter with 12-pulse Input Rectifier

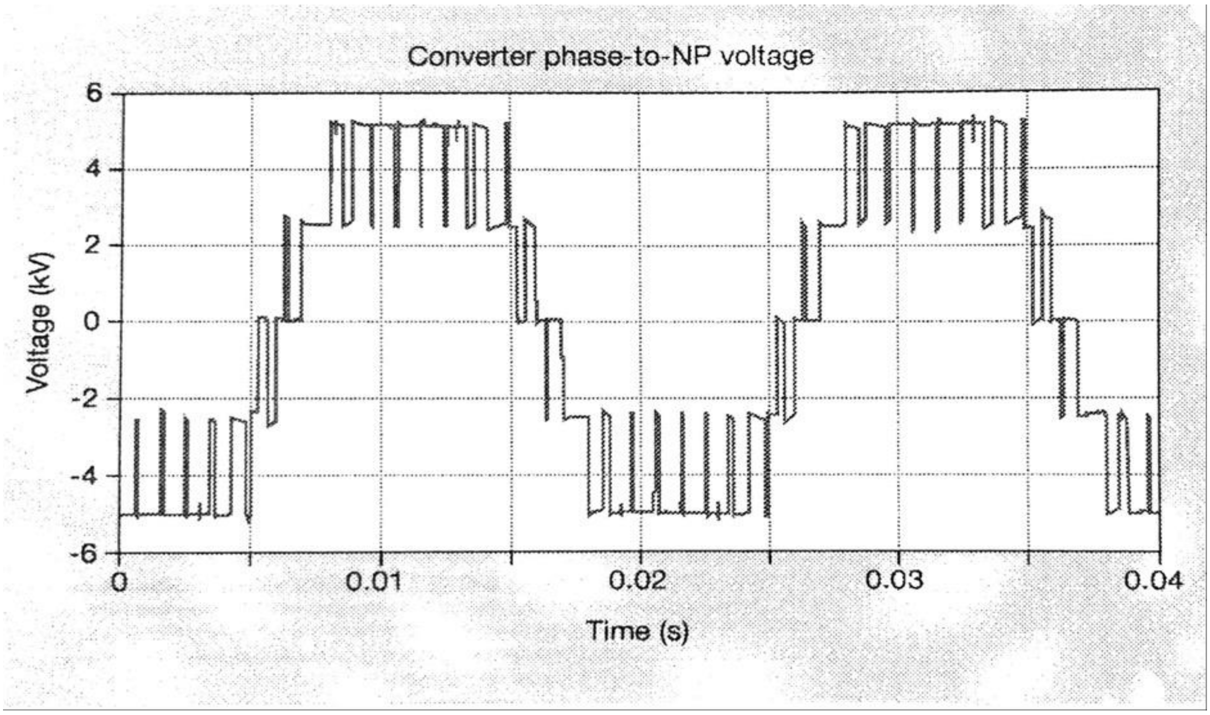


Figure 4.14 Typical 5 level Inverter Output Voltage (Phase to Neutral point)

The five-level inverter delivers a nine-level phase-to-phase voltage to the motor (Ref Fig 4.15)

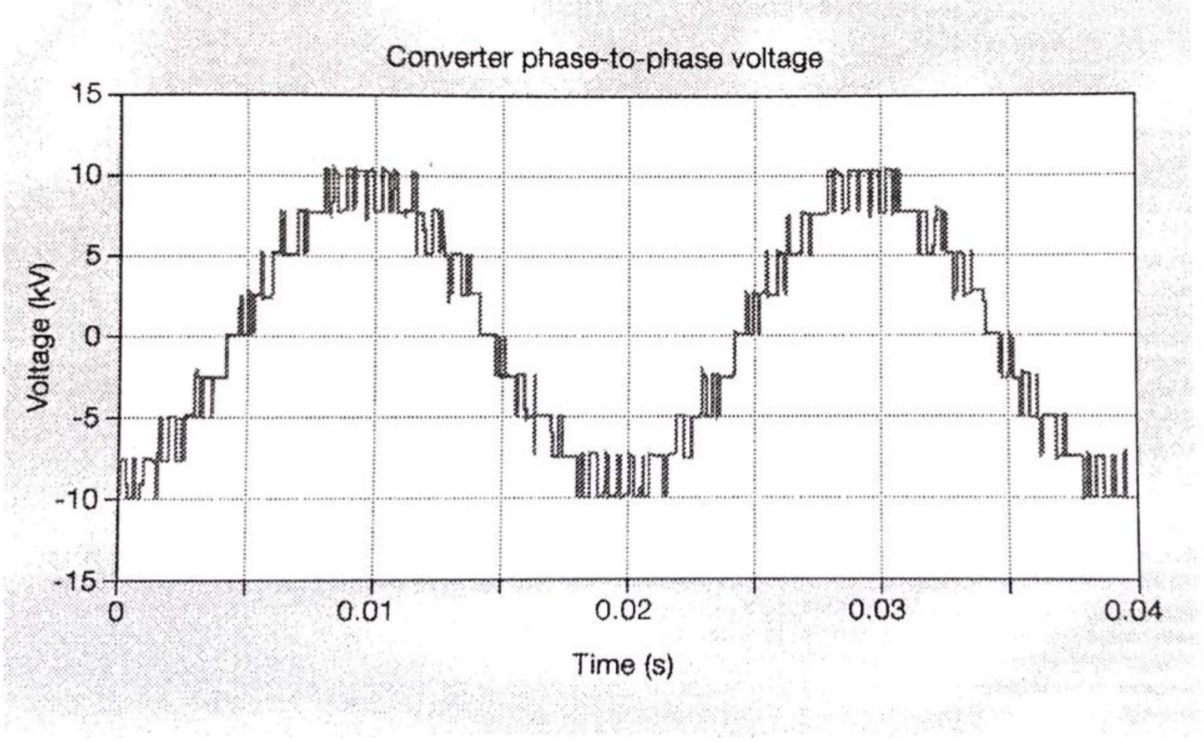


Figure 4.15 Typical 9 level Inverter Output Voltage (Phase to Phase)

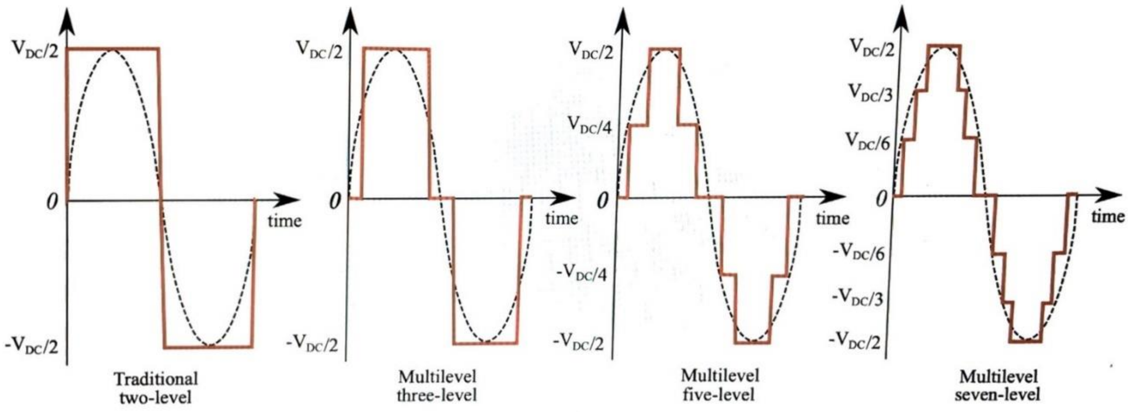


Figure 4.16 Output phase-neutral voltage waveforms as a function of the number of levels

Advantage of multi-level inverters compared to two-level inverters:

(a) Lower output harmonics content

(b) Lower impulse voltages applied to the motor

(c) Significant reduction in common mode voltage (CMV)

4.4.12 Adverse Effects of Modulation (switching) Frequency Voltages

Reference shall also be made to DS22 clauses 7.4.2, 7.4.3 and 7.4.4.

4.4.12.1 Common Mode Voltage

As well as producing high frequency positive sequence voltages at the motor terminals as described in this Design Standard at clause 4.4.11.1, pulse width modulation (PWM) of the motor supply voltages also produces zero sequence phase to earth voltages, known as common mode voltages. Because the PWM waveform has a high dV/dt ratio, the frequency spectrum of these common mode voltages extends upwards beyond 1 MHz.

Unless countermeasures are taken, either within the variable speed controller, or within the design of the motor itself, the above common mode voltages will cause motor bearing currents, resulting in bearing failures as described clause 5.15.4 of this Design Standard. Figure at Appendix D refers.

Adding circuitry in (or at) the variable speed controller to filter out common mode voltages, or to significantly increase the impedance to common mode currents, are common ways of preventing significant bearing currents.

The following forms of bearing current attenuation in (or at) the variable speed controller is permitted:

(a) Common mode filters

(b) Common mode inductors wound on ferrite cores

(c) Feed through common mode ferrite cores in conjunction with dv/dt filters – for Low Voltage variable speed controllers only

4.4.12.2 Ringing

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

4.4.12.3 Electromagnetic Interference

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

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

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

4.4.12.4 Increases Insulation Stress

The voltage stress on the insulation between the motor winding and frame is primarily determined by the magnitude of the surge voltage to earth, whereas the stress on the turn-to-turn insulation is more a function of the rate of rise of surge voltage as the surge penetrates the winding.

Because the voltage waveform generated by variable speed controllers contains fast transients, the turn-to-turn insulation in motors connected to such controllers will be stressed considerably more than that in motors connected to sinusoidal voltage supplies. Consequently, unless output filtering is used, Low

Voltage (415 V, 690 V) motors to be connected to variable speed controllers shall be specified for such duty and shall be specified to have insulation systems in accordance with IEC TS 60034-25: 2022 clause 7.4.1.

For High Voltage motors supplied from a variable speed controller, the motor windings shall be designed for supply from the particular converter type in accordance with the requirements of IEC 60034-25: 2022 clause 7.4.2. The type of multilevel converter or conventional two-level converter will impact the dv/dt rating of the motor, taking into account the reflection coefficient of the PDS (Power Drive System).

4.4.12.5 Comment on Input and Output Screening

Input and output cable screening has to do with the control of common mode currents (zero sequence, $I_{cm} = C*dV/dt$) generated by the IGBT inverter's high dv/dt. These common mode (CM) currents represent interference to sensitive equipment in the form of common mode voltages and radio frequency interference (RFI). Namely EMI in the frequency range of 0.15 MHz to 30 MHz and can typically be in the order of 20 Amps. Size of the VSC has little impact on the magnitude.

The mode of operation is that these IGBT (dv/dt transitions, both rise & fall) generated CM currents travel from motor winding to frame (via stray capacitance), back to the VSC PE then back to the transformer star point, capacitively coupled with the unscreened input cable, and into the LV phase windings through to the input of the VSC. Even if the output motor cables are screened, this does not prevent the flow of CM currents. The screened motor cable provides radiated screening in this case. If the VSC input cables are not screened, then the flow of CM currents back into the VSC will create a source of RFI interference along the input cable. The method of total cable screening back to the transformer is employed to create a Faraday cage effect where the CM currents are controlled within the VSC environment and not transmitted to other parts of the plant.

There are basically three methods of noise mitigation, namely, good earthing, attenuation and shielding. Typically, the Corporation has strong standards and methods for good grounding practice within Corporation sites, so low impedance grounding and bonding to all electrical equipment and structures and the earth system are essential. With respect to noise attenuation there are a few techniques to be aware of. For example, sine filters, dv/dt filters and CM Chokes (inductor with output phases R, W, B conductors all wound in the same direction through a common magnetic core). The last method is shielding where CM currents are controlled in the paths that they take. These shielded cables on both the input and output of the VSC have been shown to confine most of the CM current and keep it out of the earth grid where CM voltages may be developed.

Generally, the use of VSC input shielded power cables back to the main supply is recommended by most major manufacturers. Hence radiated emissions in this cable are minimised.

The appropriate application of good earthing/bonding, cabinet layout, control cable shielding/termination, shielded power cable (input & output), and CM chokes will generally solve most EMI noise problems that may arise. However, there may be situations that require the application of an EMI/RFI filter connected to the VSC input. The EMI filter contains high frequency CM line-to-earth bypass capacitors that short circuit any high frequency noise current returning on the output shielded cable back to the VSC's three phase input terminals. Furthermore, the EMI filter contains phase inductors that present a high impedance block to ensure that minimal high frequency noise current flows into the rest of the power distribution system or earth grid ahead of the EMI filter. Tests using a combination of EMI filter and shielded cables (input & output) have shown full compliance with stringent European limits for both first and second environments.

The standards take a broad view with respect to recommendations for mitigation/control of CM currents, dv/dt impulses on the motor winding, bearing currents and harmonic currents within the motor. Hence, screened cable for the VSC output and input cables are specified for CM control. There is some discussion that if EMI/RFI filters are fitted then screened input cable will not be required. However, this is not always the case in some more sensitive areas. Obviously, if sine filters are applied to the VSC output then screened cable as recommended in clause 11.4.2 will not be required.

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

4.4.13 Output Sine Filters

There are two types of sine filters available commercially:

- Type 1 - those which provide both phase to phase and phase to ground (i.e., common mode) 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 sufficiently. The use of Type 1 sine filters (symmetric plus asymmetric) will eliminate bearing damage, eliminate the need for shielded motor cables, almost eliminate parasitic earth currents and obviate the need to limit cable length.

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

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

4.4.14 Types of Control Strategy

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

4.4.14.1 Flux Vector Control

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

There are two methods of flux vector control, namely, Open Loop (sensor-less vector) and Closed loop (with encoder feedback).

Vector control in comparison with Scaler control (V/f) provides improved speed control, dynamic torque response (response to rapid changes of input) higher starting torque accurate speed control.

Closed loop control can provide full torque at zero speed with encoder feedback. Sensor-less vector control can provide accurate torque control down to 3 Hz - 4 Hz.

4.4.14.2 Scaler Control

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

4.4.15 Network Operator Harmonic Current Limits

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

Western Power's calculation of permissible harmonic current levels is based on the methods described in AS/NZS 61000.3.6:2001. Western Power may determine harmonic current limits on the basis of a computer model of the whole system under worse case conditions, i.e., in accordance with AS/NZS 61000.3.6 Appendix I4 (Third Approximation). Such investigations may involve considerable time, so that the fairly long delays can be expected in obtaining such advice from Western Power.

The Designer can determine current limits in accordance with AS/NZS 61000.3.6 Appendix I3 (Second Approximation) which in general will yield more conservative results (i.e., the amount of filtering required will be greater). Unless harmonic current limits are readily available from the Network Operator, the Designer shall base the Engineering Design on harmonic current limits calculated in accordance with AS/NZS 61000.3.6 Appendix I3 (Second Approximation)

Details of the MV source impedance at the Network Operator's relevant HV/MV substation and at the proposed Water Corporation installation are usually available relatively quickly from Network Operator. Knowledge of the minimum available transformer capacity at the Network Operator's substation is required in order to carry out calculations in accordance with AS/NZS 61000.3.6 Appendix I3. If this is not readily available, a reasonable estimate can be calculated from the MV fault level at the substation by assuming that the transformer will have an impedance of 15%.

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

(a) FML = coincidence factor MV to LV loads = 0.5

(b) FMV = coincidence factor between MV loads = 0.7

(c) ThHM = transfer coefficient HV to MV = 1.0

(d) Minimum harmonic voltage limit of 0.1 % for any harmonic voltage

Note: THD versus TDD

The amount of distortion in the voltage or current waveform is quantified by means of an index called the total harmonic distortion (THD). It is defined as a ratio of the root-mean-square of the harmonic content to the root-mean-square value of the fundamental quantity and expressed as a percent of the fundamental.

The total effect of distortion in the current waveform at the PCC is measured by the index called the total demand distortion (TDD), as a percentage of the maximum demand current at the PCC. In other words, it is defined as a ratio of the root mean square of the harmonic content, (considering harmonic components typically up to the 50th order) to the root-mean-square of the maximum demand load current at the PCC and expressed as a percentage of maximum demand load current.

4.4.16 Voltage Notching

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

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

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

As explained in AS 60146.1.2

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

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

The system shall be designed so that voltage notches do not exceed Network Operator requirements.

If controlled converters are to be used, the Designer shall carry out calculations as to verify that the levels of notching at the various points of common coupling are within acceptable limits. Network Operator limitations apply to the level of notching at the point of attachment, i.e., at the point of common coupling with the network operator's system. At any point of common coupling within the Corporation's electrical installation, the level of voltage wave form notching shall not exceed 0.20 per unit.

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

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

However, as per clause 4.4.8.1, the use of variable speed controllers with controlled converters shall not be permitted unless authorised in writing by the Principal Engineer.

4.5 Variable Speed Controllers for Wound Rotor Motors

4.5.1 Rotor Resistance Control

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

4.5.2 Slip Power Recovery Control

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

The advantages of slip power recovery variable speed controllers are:

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

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

The disadvantages of slip power recovery variable speed controllers are:

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

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

4.6 Variable Speed Controller Assemblies

4.6.1 Rated Short-time Current

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

4.6.2 Arcing Fault Protection

The design of the variable speed controller assembly shall incorporate features to minimise the risk of an internal arcing fault developing and to minimise the risk to the operator should such a fault develop.

The available fault energy within a variable speed controller assembly shall be limited by suitably rated semi-conductor protection fuses in accordance with AS 60269.4.0. Such fuses shall be located in a separate arcing fault tested enclosure.

Both High Voltage and Large Low Voltage (Output rating > 150 kW, < 450 kW at 0.415 kV; Output rating > 220 kW, < 800 kW at 0.69 kV) variable speed controller enclosures shall be fitted with arc light detector protection arranged to trip the motor main circuit protection in the event of an arc occurring within the variable speed controller enclosure.

There are very few arc-fault tested VSC enclosures, in accordance with IEC 61641, on the market due to the technical complexities involved. However, a fully Arc Fault tested VSC enclosure may be accepted in lieu of arc fault detection system provided comprehensive verification reports are provided to the Principal Engineer for evaluation. A dispensation request shall be submitted to the Principal Engineer for consideration under such circumstances.

4.6.3 Isolation

The supply to the variable speed controller shall be via circuit breaker fitted with earth fault protection.

If the variable speed controller's cooling fans are thermostatically controlled as part of the manufacturer's standard design and the manufacturer so recommends, the controller may be permitted to remain energised except under emergency stop conditions.

If electrical supply to the variable speed controller is to be interrupted as part of normal operations, the supply to the variable speed controller from the above circuit breaker shall be via a line contactor.

If the supply to the variable speed controller is to be interrupted as part of normal operations, a separate control voltage supply shall be provided to the variable speed controller so that all indications are maintained during off periods.

4.7 Motor Emergency Isolation

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

5 MOTOR PERFORMANCE REQUIREMENTS

5.1 Rating

The S1 kW output rating for site conditions shall be determined as per clause 4.1.

5.2 Type

Motors shall be conventional induction motors.

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

5.3 Electricity Supply

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

(a) Number of phases

(b) Voltage

(c) Whether neutral solidly grounded and earthing requirements

(d) Frequency

(e) Utilisation Voltage Range. The Utilisation Voltage Range shall be specified as plus 10% to minus 11% of the motor rated voltage

(f) Frequency tolerance. The Network Operator is legally obliged to limit frequency excursions to ±2.5%. This figure would have to be specified where the source of supply is a diesel-powered station or similar small supply. However, the main grid frequency is held to ±0.25% and for motors to be powered from the main grid, a frequency tolerance of ±0.5% shall be specified

(g) Supply impedance. The supply per phase resistance and reactance referred to the motor voltage shall be specified

(h) Supply arrangements for the control equipment

If the motor is required to operate from a converter supply (VSC), the following supply information shall be provided in the Specification:

(a) Number of phases

(b) Frequency range of operation

(c) Voltage over the required frequency range

(d) Type of VSC and whether output filtering is provided

(e) Supply impedance. The supply per phase resistance and reactance referred to the motor voltage shall be specified

(f) Details of the converter PWM output voltage type (e.g., 2 level or multilevel etc.)

(g) Neutral and earthing arrangements

(h) Supply arrangements for the control equipment

5.4 Standard and Type Specifications

Motors shall be in accordance with AS 60034. All information required to be submitted by AS 60034 shall be provided. (Only some such items are dealt with specifically in this Manual).

Motors shall comply with the requirements of the following Type Specifications:

DS26-03 Type Specification for High Voltage Slip Ring Induction Motor

DS26-04 Type Specification for Large Cage Induction Motor

DS26-23 Type Specification for Low Voltage Slip Ring Induction Motor

5.5 Enclosures

For major indoor pump stations, drip proof and protected (to AS 60034.5 classification IP22) self-ventilating enclosures shall be used. (In the larger frame sizes, the additional cost for totally enclosed fan cooled enclosures is substantial). Reference should also be made to clause 5.15.10.

Outdoor pumping plant is very difficult to maintain, raises security concerns and more likely to give rise to noise problems. Hence in view of the above, outdoor major pumping plant shall not be permitted.

5.6 Equivalent Circuit

Tenderers shall be instructed in the Tender Document to provide values for the per phase equivalent star, equivalent circuit for the motor offered. These values shall be used by the Designer in the analysis of motor Tenders (see clause 6.1 for cost analysis and clause 6.2 for performance analysis). For cage motors with single cage rotors, equivalent circuit values shall be required at both locked rotor and full speed.

5.7 Full Speed Performance Figures

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

5.8 Other Motor Performance Figures

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

(a) Full load speed in rpm

(b) S1 (continuous running power) rating in kW at site maximum temperature

(c) Rated stator current

(d) Locked rotor torque at rated Volts as a percent of full load torque

(e) Pull up torque (as defined in AS60034) at rated Volts as a percent of full load torque

(f) Pull up torque speed in rpm

(g) Breakdown torque (as defined in AS60034) at rated Volts as a percent of full load torque

(h) Breakdown torque speed in rpm

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

(i) Torque at rated Volts at 75% full speed

(j) Current at rated Volts at 75% speed

(k) Input kVAr at locked rotor when rated Volts from an infinite bus is applied to the motor terminals

Note: Similarly, as per requirement clause 5.8(h), for slip ring motors, Tenderers are usually permitted to submit this figure at 50% rated Volts should they so prefer.

(l) No load current at full speed with rated voltage applied to the motor terminals

(m) Full speed friction and windage loss in kW

(n) Maximum no load sound pressure level in dBA at a distance of 1m from the motor casing, or the maximum no load sound power level

(o) Maximum vibration amplitude at each bearing in μm

(p) Motor winding temperature rise class

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

5.9 Other Required Motor Data

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

(a) Manufacturer's name and place of manufacture

(b) Motor frame size

(c) Type of enclosure (IP rating)

(d) Class of insulation

(e) Rated stator Voltage

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

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

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

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

(j) Whether stator is star or delta connected

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

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

(m) Bearing details

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

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

(p) Type and grade of bearing lubricant

(q) Recommended frequency of lubrication

(r) Direction of rotation when viewed from coupling end

(s) Mass of motor complete

(t) Mass of rotor

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

(v) Ring gear motor type (if slip ring motor)

(w) Ring gear motor Volts and Watts (if slip ring motor)

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

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

(z) Details of paint coatings

(aa) Type Test Certificate (if available)

5.10 Ambient Temperature of Cooling Air

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

5.11 Sound Pressure Levels

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

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

5.12 Vibration Levels

AS 60034 has laid down limits for motor vibration. However, on the basis of AS 2625, the allowable vibration velocities specified in AS 60034 for motors having a shaft height of more than 225mm, are too high for long life machines. Motors shall be specified to have a vibration severity, at works testing, of not more than 1.8mm/s rms over the frequency range 10 Hz to 1 kHz as specified in AS 2625. Because of the characteristics of driven machines and associated foundations, a higher vibration severity of 2.8mm/s can be permitted on load at site. This latter figure assumes that the natural frequency of the foundation including bedplate is greater than 140% of the service speed, and consequently, foundations shall be so specified.

In order to reduce resonance, the void under the bedplate shall be filled with concrete.

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

5.13 Type of Contactor

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

5.14 Terminal Boxes

5.14.1 Location of Cable Terminations

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

5.14.2 High Voltage Terminations

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

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

CAUTION

DEAD-BREAK ELBOWS

DO NOT CONNECT OR DISCONNECT LIVE

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

5.14.3 Low Voltage Terminations

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

5.14.4 Fault Ratings

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

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

5.14.5 Earthing Terminal

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

5.15 Miscellaneous Requirements

5.15.1 Windings

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

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

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

5.15.2 Stator Lightning Impulse Withstand Voltage

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

The stator lightning impulse withstand voltage for 11 kV machines shall be greater than 39 kV (Typical industry standard, e.g., TECO).

5.15.3 Bearings

Bearing requirements:

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

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

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

(d) Motors shall be fitted with bearings rated to have a nominal life (in accordance with AS 2729) of 100,000 hours

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

5.15.4 Protection Against Bearing Currents

5.15.4.1 Bearing Failure Mode

If the voltage across ball or roller bearings is increased so that the insulation provided by the normal lubricant film breaks down, micro-arcing will occur within the bearing, with the resulting bearing current leading to premature bearing failure.
The breakdown voltage depends to some extent on the shape of the voltage waveform. For low frequency sinusoidal voltages, the normal breakdown voltage of the lubricant film varies between 200 mV and 1000 mV depending on lubricant thickness.
For the high frequency common mode voltages as produced by pulse width modulation switching, the minimum breakdown voltage varies between 8 and 15 Volts.

5.15.4.2 Types of Bearing Currents

IEC 60034-25 describes four types of bearing current as follows:

(a) Low frequency circulating currents

(b) High frequency circulating currents

(c) High frequency capacitive discharge currents

(d) High frequency shaft earthing currents

5.15.4.3 Low Frequency Circulating Currents

Under normal sinusoidal voltage excitation, asymmetry in the magnetic circuit of a motor results in a circumferential AC flux (ring flux) in the yoke. This induces an AC voltage in the conductive loop consisting of the motor shaft, the motor bearings, the end brackets and the outer frame of the motor. If the induced voltage is high enough to break down the insulation provided by the bearing lubricant, low frequency currents will flow through the bearings, resulting in premature bearing failure.

Consequently, all motors rated > 400 kW shall be provided with insulated non-drive end bearings whether or not the motors are intended for operation from other than a sinusoidal voltage supply.

Low frequency circulating currents are not considered to be a problem for motors rated < 400 kW.

5.15.4.4 High Frequency Circulating Currents

Under high frequency PWM voltage excitation, a high frequency voltage is induced in the closed loop described above by the high frequency flux circulating around the stator yoke. This flux is caused by capacitive currents leaking from the motor winding into the stator laminations. These high frequency currents will be superimposed on the low frequency circulating currents described above.

5.15.4.5 Capacitive Discharge Currents

The leakage capacitances with motors are relatively small so that the power frequency capacitive leakage currents are negligible. However, leakage capacitances allow high frequency common mode currents to flow which can generate unacceptable voltages across the uninsulated bearings with resulting breakdown on the insulation provided by the lubricating film, thus leading to premature bearing failure.

5.15.4.6 Shaft Earthing Currents

Shaft earthing currents are high frequency currents which may flow from the stator winding to the motor frame by capacitive coupling, through the motor bearings, through the motor/pump shaft and then through the pump bearings, as indicated in Figure 19 of IEC 60034-25.
The problem of shaft earthing currents is of particular concern for variable speed drives coupled to large water pumps.

5.15.4.7 Countermeasures

All motors rated > 150 kW which are to be used in conjunction with variable speed controllers without common mode voltage attenuation as described Clause 4.4.12.1 of this Design Standard shall be fitted with all the following countermeasures against bearing currents:

(a) Insulated drive end and non-drive end bearings

(b) Motor shaft earthing rings

(c) Insulated motor/pump shaft couplings

On motors rated > 150 kW, < 450 kW, motor stator to pump casing bonding in accordance with clause 11.14.1 of this Design Standard may be used instead of insulated motor/pump shaft couplings, though the latter shall be preferred. If insulated motor/shaft couplings are required, the Designer shall ensure that the project mechanical engineering designer is advised in writing of the requirement.

Motor shaft earthing rings shall:

(a) Provide complete circumferential shaft grounding via not less than two complete rings of conductive micro fibre

(b) Limit the high frequency voltage across the associated bearing to less than 4 Volts and

(c) Have a rated life of not less than 100,000 hours

5.15.5 Holding-Down Bolts

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

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

5.15.6 Bearing Thermometer Elements

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

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

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

5.15.7 Winding Overtemperature Protection

All motors rated greater than 150 kW shall be specified to be fitted with winding over temperature protection. Such protection shall be in the form of either Resistance Temperature Detectors (RTD's) embedded in the windings or thermistors (Low Voltage motors only) embedded in the windings. RTD protection is preferred.

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

Thermistor protection shall be of a single P.T.C. thermistor (AS/NZS IEC 60947-8 Mark A), and a warning PTC thermistor, installed within the end turns of each phase winding. The thermistor trip temperature shall be specified to be in accordance with the manufacturer's recommended practice and the temperature-resistance characteristic shall be such that the resistance of each thermistor at trip temperature is 1000 Ohms. The three thermistors shall be specified to be brought out separately, via suitably protected leads, to a special conveniently located terminal box. (Thermistors shall be connected in series in the terminal box and hence connected to the standard detection relay which has a trip resistance of 3000 Ohms.)

As mentioned above, thermistor over temperature protection systems for Low Voltage motors shall consist of two independent sets of thermistors, one set to provide a warning level signal, the other to provide a fault trip level signal. The over temperature fault warning thermistors shall have a switch temperature set midway between the winding rated operating temperature and the over temperature fault trip level. Clause 9.5.3(c) refers.

Winding overtemperature protection (RTDs and thermistors) shall be embedded in the windings during the coil winding process at the factory and shall not be fitted after the motor has been completed in other respects.

5.15.8 Anti-Condensation Heaters

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

5.15.9 Vibration Protection

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

5.15.10 General Construction

Motors shall be self-ventilating by means of a shaft mounted fan. Guards shall be provided on all moving parts. Motors driving pumps shall have no ventilation openings in the drive end face of the enclosure, (so that spray from a leaking pump seal cannot enter the motor directly).

Some motor manufacturers supply motors with ventilation openings in the drive end face of the enclosure that are fitted with baffles such that water cannot enter and cause damage. Such arrangements are considered acceptable provided supporting documentation is provided at the time of tender.

5.15.11 Wound Rotor Motor Brush Gear

All wound rotor motors shall be fitted with brush lifting and ring shorting gear.

Should there be a situation whereby dispensation is granted not to fit brush lifting and ring shorting gear, then wound rotor motors which are not provided with brush lifting gear shall be specified to have the brush gear located in a separate enclosure from the main stator winding, so that carbon dust from brush wear is not carried onto the surface of the stator windings by the circulation of cooling air.

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

5.15.12 Painting

Motors shall be specified to be painted in accordance with the manufacturer's standard practice and which is rated in accordance with AS2312 (and ISO 9223) to provide ‘long term protection’ to steel in industrial environments.

5.16 Coupling

Usually, the coupling is supplied by the manufacturer of the driven machine.

The Water Corporation should arrange to have the motor end half-coupling bored to suit shaft dimensions certified as correct by the motor manufacturer.

The Water Corporation should have the machined motor end half coupling dynamically balanced with a half key fitted. The motor half-coupling should then be supplied to the motor manufacturer for fitting to the motor.

5.17 Motor Installation

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

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

5.18 Motor Testing

5.18.1 Tests During Manufacture

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

5.18.2 Works Efficiency Tests

All motors rated more than 500 kW shall be efficiency tested individually. In the case of motors rated not more than 500 kW (of the same design and rating), one motor in each batch shall be efficiency tested.

Efficiency tests shall be specified to be done by the summation of losses method in accordance with AS60034. Manufacturers of various nationalities tend to submit efficiency figures in accordance with their own national standards. However, since testing methods vary from standard to standard, different efficiency figures are possible for the same motor tested to different standards. Since the efficiency figure is critical in comparing tenders, it is necessary to insist that such values be based on the Australian Standard.

5.18.3 Other Works Performance Tests

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

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

5.18.4 Works Routine Tests

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

(a) Winding resistance measurement

(b) Winding insulation resistance measurement at not less than 500 Volts for Low Voltage machines and not less than 1000 Volts for High Voltage machines

(c) Air gaps measurement

(d) Voltage withstand test in accordance with AS 60034.1

(e) An additional voltage withstand test at 120% of the test voltage specified in AS 60034.1 for 10 seconds (only for motors to be controlled by vacuum contactors)

(f) Confirmation of terminal marking and direction of rotation

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

(h) No load test at rated voltage recordings Volts, Amps, and kilowatts, and

(i) No load vibration test

5.18.5 Works Testing of Driven Machine

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

5.18.6 Site Motor Tests

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

5.18.7 Witnessing Tests

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

5.18.8 Motor and Variable Speed Drive Packages

Further to clause 5.18.2 and 5.18.6 efficiency testing shall be carried out on the motor/VSC combination. The overall efficiency and motor efficiency shall be measured with the VSC in operation.

High Voltage AC power drive systems shall comply with one of the efficiency determination methods specified in IEC 61800-4 deemed most appropriate for the project.

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

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

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

One complete variable speed drive system (transformer (if applicable), VSC, motor) of a batch of the same design and rating, shall be tested under load at the factory prior to despatch, to ensure correct operation and performance requirements are met. This will ensure any issues are resolved within the manufacturing premises rather than at the pump station site.

5.19 Liquidated Damages for Excess Losses

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

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

Where:

La = Actual motor losses at full load as determined during acceptance testing by the summation of losses method in kW

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

W = motor full load rating in kW

η = contract efficiency at full load in %

N = estimated annual operating period in hours

T = energy cost in $/kWh

F_c = interest & sinking fund factor (in accordance with Table 6.1)

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

Note: The value of 1.1 for L_{max} *above represents a 10% allowance for permitted tolerances in the Australian and IEC standards. Similarly for transformers and VSCs.*

6 MOTOR TENDER ANALYSIS

6.1 Cost Analysis

6.1.1 General

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

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

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

6.1.2 Interest and Sinking Fund Charges

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

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

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

Plant Life Years	**INTEREST & SINKING FUND FACTOR**				
	DISCOUNTED INTEREST RATE				
	4%	**6%**	**7%**	**8%**	**10%**
5	**0.2246**	**0.2374**	**0.2439**	**0.2505**	**0.2638**
10	**0.1233**	**0.1359**	**0.1424**	**0.1490**	**0.1627**
15	**0.0899**	**0.1030**	**0.1098**	**0.1168**	**0.1315**
20	**0.0736**	**0.0872**	**0.0944**	**0.1019**	**0.1175**
25	**0.0640**	**0.0782**	**0.0858**	**0.0937**	**0.1102**

Table 6.1

6.1.3 Losses Based AAC Formula

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

$AAC = F_c\, C + N_1\, L_1\, T_1 + N_2\, L_2\, T_2$

Where:

C = Capital value including National Preference Agreement escalations; $

F_c = Interest and sinking fund factor as determined from Table 6.1

N_1 = Annual operating period at duty point 1, hr

L_1 = Losses at duty point 1, kW

T_1 = Energy cost at duty point 1, $/kWh

N_2 = Annual operating period at duty point 2, hr

L_2 = Losses at duty point 2, kW

T_2 = Energy cost at duty point 2, $/kWh

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

6.1.4 Efficiency Based AAC Formula

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

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

Where:

L = losses; kW

W = motor output; kW

η = motor efficiency; %

The AAC formula thus becomes: -

$AAC = F_cC + N_1T_1W_1\eta_1^{-1}(100 - \eta_1) + N_2T_2W_2\eta_2^{-1}(100 - \eta_2)$

Where:

C = Capital value including National Preference Agreement escalations: $

F_c = Interest and sinking fund factor as determined from Table 6.1

N_1 = Annual operating period at duty point 1, hrs

T_1 = Energy cost at duty point 1, $kWh

W_1 = Motor output at duty point 1, kW

η_1 = Motor efficiency at duty point 1, in %

N_2 = Annual operating period at duty point 2, hr

T_2 = Energy cost at duty point 2, \$/kWh

W_2 = Motor output at duty point 2, kW

η_2 = Motor efficiency at duty point 2, in %

If the above form of the AAC formula is used, the Tenderer is required to provide values of C, η_1 and η_2. Other parameters should be determined on a case-by-case basis and the calculated factors shown in the AAC formula.

6.2 Performance Analysis

6.2.1 General

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

6.2.2 Full Speed Performance

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

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

6.2.3 Starting Performance

6.2.3.1 Cage Motors

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

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

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

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

6.2.3.2 Slip Ring Motors

In the case of slip ring motors, the motor accelerating torque characteristics are determined by the starter resistor values as well as motor equivalent circuit values and site supply impedances. By using an appropriate software model, the values of the required starting resistances shall be calculated. Starting characteristics for the on-site starting of the motor offered shall be produced to check that the Network

Operator on-site kVAr limit can be met and that the drive can be accelerated to full speed with the number of starting steps specified.

6.3 Clause By Clause Compliance

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

7 TRANSFORMER SPECIFICATIONS

7.1 General

Transformers shall be specified using either the Water Corporation's Type Specification for ONAN Transformers or the Water Corporation's Type Specification for Dry Type Transformers. The technical data required to be provided in the Schedule of Technical data, to be attached to the Type Specification, shall be determined as detailed hereunder. Transformers shall be in accordance with the following Australian Standards:

AS 2374.1.2	Power transformers - Minimum energy performance standard requirements for distribution transformers
AS/NZS 60076.1	Power transformers - General
AS/NZS 60076.2	Power transformers - Temperature rise for liquid-immersed transformers.
AS/NZS 60076.3	Power transformers - Insulation levels, dielectric tests and external clearances in air.
AS 60076.4	Power transformers - Guide to the lightning impulse and switching impulse testing.
AS/NZS 60076.5	Power transformers - Ability to withstand short circuit.
AS/NZS 60076.7	Power transformers - Loading guide for oil-immersed power transformers.
AS/NZS 60076.10	Power transformers - Determination of sound levels.
AS 60076.11	Power transformers - Dry type transformers.
AS 62271.202	High-voltage switchgear and controlgear - Part 202: AC prefabricated substations for rated voltages above 1 kV and up to and including 52 kV.

7.2 Rating

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

7.3 Vector Group and Connection

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

7.4 Cooling

Oil filled transformers shall be natural oil natural air cooled (ONAN). The use of synthetic cooling liquids, such as less combustible types (e.g., FR3, silicone, Midel where the fire point is > 300°C) may be permitted under special project circumstances in accordance with the dispensation requirements outlined in clause 1.9.

Dry type transformers shall be air natural (AN) cooled or shall be air natural/air forced (ANAF) cooled.

Transformers located in water catchment areas, or in confined areas (e.g., within pump station buildings) where there is as fire risk, shall be dry type transformers. Otherwise, oil filled transformers may be used.

Dry type transformers shall be climatic class C1 with required environmental and fire behaviour classes being determined on the basis of each particular application. All materials used in dry type transformers shall be self-extinguishing and shall produce no toxic gases in the event of a secondary fire or arcing.

The insulation class of windings used in dry type transformers shall be not less than class 180 (H) in accordance with IEC 60085. The associated encapsulation class shall be not less than class 155 (F).

7.5 Temperature Rise of Oil Filled Transformers

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

7.6 Type of Transformer

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

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

7.7 Linear Load Efficiency

Transformers rated < 10 MVA with primary voltages of either 11 kV or 22 kV shall have a high-power efficiency classification in accordance with section 3 of AS 2374.1.2, i.e., such oil filled transformers shall have efficiencies at 50 % full load in accordance with Table 3 of AS 2374.1.2-2003, and such dry type transformers shall have efficiencies in accordance with Table 4 of AS 2374.1.2-2003.

Power transformers other than the above shall have efficiencies at 50% full load not less than the values shown Table 2 of AS 2374.1.2-2003.

7.8 Losses

7.8.1 General

Transformers shall be of a low flux density ($\leq 1.5T$), low iron loss design so as to minimise inrush current, vibration levels, mechanical stress levels, sound levels, and if the transformer is required to supply non-linear loads so as to minimise harmonic current loss levels.

Transformer efficiency shall be determined by the summation of losses method.

7.8.2 Linear Load Losses

Transformer rated linear total load losses are divided into two broad categories as follows:

(a) No load losses (P_{nl})

(b) Load losses (P_{ll-r})

Load losses are divided into two further categories:

(a) Rated winding I^2R losses (P_{w-r})

(b) Total stray losses (P_{tsl-r})

No load losses (P_{nl}) shall be verified by no load test in accordance with AS 60076.1 clause 10.5.

Full load losses (P_{ll-r}) shall be verified in accordance with AS 60076.1 clause 10.4.

Total stray loss can be defined as the loss due to electromagnetic flux in the windings, core, core clamps, magnetic shields, enclosure, or tank walls, etc.

Rated load total stray losses (P_{tsl-r}) are determined as follows:

$$P_{tsl-r} = P_{ll-r} - P_{w-r}$$

7.8.3 Non-Linear Load Losses

Reference should be made to IEEE Std. C57.110 in respect to transformer non-linear load losses.

For the purposes of determining nonlinear load losses total stray losses are divided into two categories as follows:

(a) Rated winding eddy current losses (P_{ec-r})

Winding strand losses include winding conductor strand eddy current losses and losses due to circulating currents between strands or parallel circuits and are considered to be winding eddy current losses.

(b) Rated other rated stray losses (P_{osl-r})

Other stray losses are due mainly to electromagnetic flux in the core, core clamps, and structural parts.

Hence $P_{tsl-r} = P_{ec-r} + P_{osl-r}$

Under non-linear loading, winding I^2R losses will increase in proportion to the square of the load RMS current.

Under non-linear loading, winding eddy current losses will increase at a rate proportional to the square of the load RMS current and the square of the frequency. The design of transformers supplying non-linear loads shall be such as to minimise eddy current losses.

Other stray losses will increase at a rate proportional to the square of the load RMS current and the frequency raised to the power 0.8.

Other stray losses in dry type transformers are relatively low, and in respect to this type of transformer, all total stray losses are considered to increase at a rate proportional to the square of the load RMS current and the square of the frequency. Thus, for dry type transformers all stray losses are treated as winding eddy current losses. This will produce a conservative result.

Other stray losses in oil filled transformers are relatively high, nominally 67% of the total stray losses and consequently these must be treated separately when calculating temperature rises due to non-linear load currents.

IEEE Std. C57-110 provides an outline of the method for determining a transformer’s rating when supplying non-linear loads, as described at clause 7.9 hereunder.

However, particularly in respect to oil filled transformers, some critical factors are a function of the particular proprietary design and require input from the relevant manufacturer.

7.9 Load Harmonic Profile Factors

7.9.1 General

In both dry type and oil filled transformers, harmonic currents caused by non-linear loads cause the RMS value of the current to increase above the value of the fundamental current, thus increasing the transformer I^2R losses above those resulting solely from the fundamental current.

In both dry type and oil filled transformers, harmonic currents caused by non-linear loads cause increased total stray current losses.

In addition, in oil filled transformers, harmonic currents caused by non-linear loads cause increased other stray losses.

In order to take account of the additional losses caused by harmonic currents in non-linear load currents, specifications for all transformers required to supply non-linear loads shall include harmonic loss factors as detailed hereunder, all of which will be determined by the harmonic profile of the intended maximum non-linear load current.

7.9.2 RMS Current Loss Factor

Specifications for both dry type and oil filled transformers shall specify the RMS current loss factor (F_{rms}) determined as follows:

$F_{rms} = \Sigma (I_{hr} / I_f)^2$

for all values of I_{hr} and h_n from $h_n = 1$ up to $h_n = 31$

where h_n = the harmonic number

$I_{hr} = I_h / I_f$

= ratio harmonic current to fundamental current

I_f = fundamental current

I_h = harmonic current at harmonic number h_n

7.9.3 Eddy Current Loss Factor

Specifications for both dry type and oil filled transformers shall specify the eddy current loss factor (F_{ec}) determined as follows:

$F_{ec} = \Sigma (I_{hr}^2 * h_{n2})$

for all values of I_{hr} and h_n from $h_n = 1$ up to $h_n = 31$

where h_n = the harmonic number

$I_{hr} = I_h / I_f$

= ratio harmonic current to fundamental current

I_f = fundamental current

I_h = harmonic current at harmonic number h_n

7.9.4 Other Stray Losses Factor

Specifications for oil filled transformers shall specify the other stray loss factor (F_{osl}) determined as follows:

$F_{osl} = \Sigma\ (I_{hr}^2 * h_n^{0.8})$

for all values of I_{hr} and h_n from $h_n = 1$ up to $h_n = 31$

where h_n = the harmonic number

$I_{hr} = I_h / I_f$

= ratio harmonic current to fundamental current

I_f = fundamental current

I_h = harmonic current at harmonic number h_n

Other stray losses for dry type transformers are considered to be small, so that for dry type transformers the total stray losses are all considered to be eddy current losses. Consequently, specifications for dry type transformers shall not include another stray loss factor (F_{osl}).

7.9.5 Typical Harmonic Profile Loss Factors

For a typical six pulse converter load, the harmonic profile loss factors will be:

$F_{rms} = 1.11$

$F_{ec} = 4.37$

$F_{osl} = 1.29$

For a typical twelve pulse converter load, the harmonic profile loss factor will be:

$F_{rms} = 1.01$

$F_{ec} = 2.05$

$F_{osl} = 1.04$

7.9.6 Calculation of Load Losses

Winding I^2R losses for a particular duty non-linear current (P_{w-d}) will be determined as follows:

$P_{w-d} = P_{w-r} * F_{rms} * (I_{rms-d})^2$

where I_{rms-d} = RMS value of duty load current

Winding eddy current losses for a particular duty non-linear current (P_{ec}-d) will be determined as follows:

$$P_{ec\text{-}d} = P_{ec\text{-}r} * F_{ec} * (I_{rms\text{-}d})^2$$

where $I_{rms\text{-}d}$ = RMS value of duty load current

Other stray losses for a particular duty non-linear current ($P_{osl\text{-}d}$) will be determined as follows:

$$P_{osl\text{-}d} = P_{osl\text{-}r} * F_{rms} * (I_{rms\text{-}d})^2$$

where $I_{rms\text{-}d}$ = RMS value of duty load current

7.10 Impedance

The transformer impedance must be proportioned to limit the fault level on the secondary side to an acceptable level and to provide maximum starting kVAR with secondary voltage drop within acceptable limits. The following impedance values (Table 7.1) have been calculated to meet the above requirements.

TRANSFORMER KVA		***IMPEDANCE %***
315 to ≤ 500		4.7 ± 0.5
> 500 to ≤ 800		5.5 ± 0.5
> 800 to ≤ 1,250		6.0 ± 0.6
> 1,250 to ≤ 3,150		6.3 ± 0.6
> 3,150 to ≤ 6,300		7.2 ± 0.7
> 6,300 to ≤ 12,500		8.4 ± 0.8
> 12,500 to ≤ 25,000		10.0 ± 1.0

Table 7.1 Transformer Impedances

7.11 Inrush Current

Inrush current on delta-star step down transformers with cold rolled steel cores can be as high as nine (9) times full load current and for the sizes of transformer being considered here, could be expected to decay exponentially with a time constant of 0.3 seconds. Use of low flux density transformers can be expected to reduce the magnitude of inrush current to approximately seven (7) times full load current.

Transformers shall be specified to be designed to minimise inrush currents, but inrush current performance should not be quantified.

Note: Transformer primary fuses are usually sized to be able to withstand twelve (12) times full load current for 0.1 seconds and this would be conservative for the transformers being considered here.

7.12 High/Low Voltage Connections

7.12.1 High Voltage

Except for aerial mounted transformers rated ≤ 200 kVA, High Voltage connections to transformers shall be cable connections, using single core XLPE cable, unless otherwise approved in writing from the Principal Engineer.

All single core XLPE cable connections to transformers shall be via suitably rated dead-break elbow connectors having lightning impulse withstand voltage (LIWV) ratings not less than the values detailed in Table 7.2 hereunder.

TRANSFORMER WINDING NOMINAL VOLTAGE KV_{RMS}		***CONNECTOR LIWV (MIN)*** KV_{PK}
6.6		75
11		95
22		150
33		200

Table 7.2 LIWV for HV Connectors

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

Access to transformers in kiosk enclosures shall be protected with EL1 padlocks or shall be interlocked with the High Voltage switchgear to prevent access to the transformer unless the transformer is isolated from all possible sources of electrical supply.

Appropriate bolt on shields shall be provided on transformers to prevent operation of the dead break elbow connectors unless the shields are removed first.

On transformers other than those in kiosk enclosures, such shields shall be fitted with EL1 padlocks or shall be interlocked with the High Voltage switchgear to prevent removal of the shields unless the transformer is isolated from all possible sources of electrical supply.

On outdoor transformers (other than those installed in kiosks), the above shields shall be such as to minimise exposure of the associated dead break elbows to the weather.

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

"Caution

Dead-Break Connectors

Do not connect or disconnect live".

In those instances where High Voltage aerial connections are necessary, normal High Voltage bushing arrangements should be used (i.e., not cable box with aerial connection adaptor).

Arcing horns shall not be fitted to High Voltage bushings.

7.12.2 Low Voltage

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

7.13 Lightning Impulse Withstand Voltage

The lightning impulse withstand voltage (LIWV) rating for transformer High Voltage windings shall be in accordance with Table 7.3 below:

TRANSFORMER WINDING NOMINAL VOLTAGE KV$_{RMS}$	***RATED LIGHTNING IMPULSE WITHSTAND VOLTAGE KV$_{PK}$***	
	Oil Filled	**Dry Type**
3.3	**40**	**40**
6.6	**60**	**60**
11	**95**	**95**
22	**150**	**150**
33	**200**	**200**

Table 7.3 Transformer LIWV

7.14 Protection

7.14.1 General

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

7.14.2 Overcurrent Protection

Minimum protection requirements:

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

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

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

(d) The current carrying capacity of the neutral conductor from the star point of the Low Voltage terminals of the transformer shall not be less than that of the associated active phase conductors. Hence a dedicated neutral protective device for the neutral cable will not be required, simplifying the protective system

7.14.3 Over Pressure Protection

All oil filled transformers rated not greater than 5000 kVA shall be fitted with pressure relief values. If the transformer is to be provided with High Voltage circuit breaker protection, operation of the pressure relief value shall be arranged to trip the circuit breaker.

All oil filled transformers rated greater than 5000 kVA shall be fitted with conservator tanks, explosion vents and Buchholz relays. The Buchholz relay shall be arranged to trip the associated High Voltage circuit breaker.

7.14.4 Earth Fault Protection

Minimum protection requirements:

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

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

(c) Transformers rated greater than 315 kVA with Low Voltage star connected secondary windings shall be provided with "Star Point" earth fault protection (unrestricted earth fault) arranged to trip the High Voltage circuit breaker. To facilitate the earth fault detection, a current transformer measuring the current flowing into the secondary winding star point shall be mounted on or close to the associated transformer LV star point and shall be a class 5P protection current transformer with a 1 Amp rated secondary winding

7.14.5 Differential Protection

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

7.14.6 Over Temperature Protection

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

7.14.7 Voltage Surge Protection

A surge diverter protective device shall be placed as close as possible to the transformer it is to protect. Due to the large change in characteristic impedance from aerial/cable to transformer (e.g., 50/500 Ohms of aerial/cable to 5000 Ohms of transformer) the incident voltage surge will reflect to almost double at the transformer terminals. Placing the surge diverter upstream from the terminals of the transformer can cause the incident voltage at these terminals to reach up to twice the residual voltage (including surge diverter lead voltage L*di/dt) of the upstream surge diverter, resulting in possible transformer insulation damage/failure (Note: an insulation coordination study, as discussed in clause 12, would confirm this).

Hence, and as discussed in clause 3.10, all transformers shall be protected with suitably rated surge diverters installed directly at the primary voltage winding terminals.

7.15 Transformer Audible Sound Pressure Levels

In general, the maximum corrected mean audible sound pressure level generated by each transformer shall not be greater than the standard limit as specified AS/NZS 60076.10 Figure ZA1.

However, if circumstances at the site so require, transformers shall be of a special reduced sound pressure level design, such that the maximum corrected mean audible sound pressure levels shall not exceed the reduced limits specified AS/NZS 600076.10 Figure ZA1.

The maximum corrected mean audible sound pressure level shall be determined in accordance with AS/NZS 60076.10 with microphones located at a distance of 0.3 metres from the principal radiating surface and at a height equivalent to half the height of the transformer.

7.16 Prefabricated Enclosure Housing

Transformers rated not greater than 1500 kVA may be housed in prefabricated enclosures which have been designed and constructed in accordance with IEC 62271-202.

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

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

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

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

7.17 Testing

7.17.1 Type Tests

If the transformer being offered is not of an identical design that has been type tested in accordance with AS 60076, then the transformer shall undergo type tests in accordance with AS 60076.

Transformers shall be type tested in respect to temperature rise and dielectric strength in accordance with AS 60076.2 and AS 60076.3 respectively. In addition, transformers shall be type tested in respect to maximum corrected mean audible sound pressure level in accordance with AS/NZS 60076.11.

All tests and verifications stated in AS 62271.202 shall be performed on kiosk transformer enclosed arrangements.

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

7.17.2 Routine Tests

Transformers shall undergo routine tests in accordance with AS 60076-1 in respect to:

(a) Measurement of winding resistance

(b) Measurement of voltage ratio and phase displacement

(c) Measurement of short circuit impedance and load loss, and

(d) Measurement of no-load loss and current

In addition, transformers shall undergo routine dielectric tests in accordance with AS 60076.3.

8 TRANSFORMER TENDER ANALYSIS

The procedures regarding cost analysis and clause by clause compliance as given in Sections 6.1 and 6.3 for motors shall be applied to the analysis of transformer Tenders.

The losses based AAC formula described in Section 6.1.3 shall be used for comparison of transformer Tenders. Wherever practical the appropriate AAC formula should be included in the Tender Documentation.

9 SWITCHBOARDS

9.1 High Voltage Switchboards

9.1.1 Standards

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

IEC 62271-1	High Voltage switchgear and controlgear - Common specifications (previously IEC 60694)
IEC 62271-100	High Voltage switchgear and controlgear - High Voltage alternating current circuit breakers (AS 62271.100 is equivalent)
IEC 62271-102	High Voltage switchgear and controlgear - Alternating current disconnectors and earthing switches (AS 62271.102 is equivalent)
IEC 62271-103	High Voltage switchgear and controlgear - Switches for rated voltages above 1 kV and less than 52 kV
IEC 62271-105	High Voltage switchgear and controlgear - Alternating current switchfuse combinations.
IEC 62271-106	High Voltage switchgear and controlgear - Alternating current contactors and contactor based motor starters
IEC 62271-200	High Voltage switchgear and controlgear - A.C. metal enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52kV (AS 62271.200 is equivalent)

9.1.2 Service Conditions

Basic service condition requirements:

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

(b) High Voltage switchboards shall have an Internal Arc Classification rating (IAC) of AFL, where A = Accessibility type A, restricted to authorised personnel only. However, if the switchboard is accessible from the rear, the switchboard shall have an IAC of AFLR

(c) High Voltage switchboards installed in prefabricated substations shall be of the Ring Main Unit type such that all busbars and switchgear are enclosed in sealed tank(s) (Refer clause 3.4.2) and all other High Voltage conductors including cable terminations and surge diverters are fully insulated with appropriate solid insulation

(d) Unless authorised otherwise in writing by the Principal Engineer, High Voltage switchboards, other than the type described clause 9.1.2 (c) shall be located indoors in a clean relatively dust free environment (Clause 3.1 refers)

9.1.3 Loss of Service Continuity Category

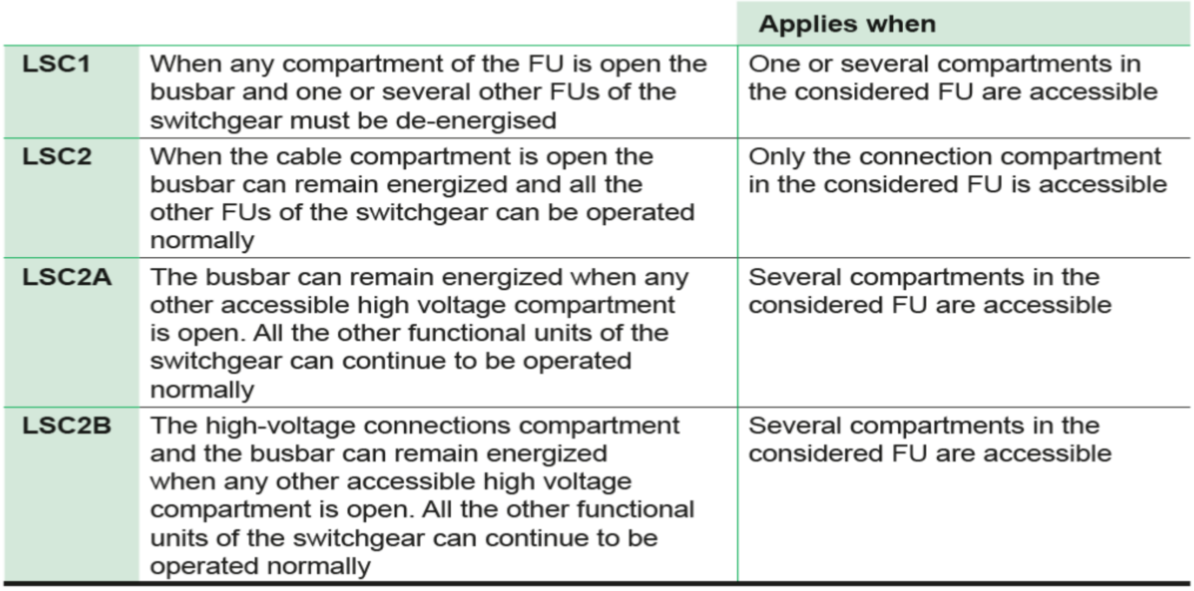
IEC 62271-200 defines four categories of Loss of Service Continuity: LSC1, LSC2, LSC2A, LSC2B. Corporation requirements in this regard are:

(a) The Designer shall ensure that each High Voltage switchboard has a Loss of Service Continuity category (LSC) rating appropriate to its function

(b) High Voltage switchboards of the type described in clause 9.1.2 (c) shall have a LSC category rating of LSC1

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

Definitions:



		Applies when
LSC1	When any compartment of the FU is open the busbar and one or several other FUs of the switchgear must be de-energised	One or several compartments in the considered FU are accessible
LSC2	When the cable compartment is open the busbar can remain energized and all the other FUs of the switchgear can be operated normally	Only the connection compartment in the considered FU is accessible
LSC2A	The busbar can remain energized when any other accessible high voltage compartment is open. All the other functional units of the switchgear can continue to be operated normally	Several compartments in the considered FU are accessible
LSC2B	The high-voltage connections compartment and the busbar can remain energized when any other accessible high voltage compartment is open. All the other functional units of the switchgear can continue to be operated normally	Several compartments in the considered FU are accessible

9.1.4 Low Voltage Compartments

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

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

9.1.5 Degree of Protection

Protection requirements:

(a) High Voltage switchboards of the type described clause 9.1.2(c) shall be provided with a degree of protection of IP67 in respect to High Voltage switches, circuit breakers and busbars. The remainder of such switchboards shall incorporate a degree of protection not less than IP3X

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

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

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

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

9.1.6 Rated Insulation Level

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

9.1.7 Rated Short-Time Withstand Current

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

9.1.8 Internal Arcing Fault Protection

Arc fault protection requirements:

(a) Cable connection compartments of High Voltage switchboards of the type described in clause 9.1.2 (c) shall be type tested for arcing faults in accordance with IEC 62271-200 clause 6.106 and Annex AA at currents not less than the values specified at clause 9.1.8(c) hereunder

(b) All compartments in High Voltage switchboards other than the type described in clause 9.1.2(c) shall be type tested for arcing faults in accordance with IEC 62271-200 clause 6.106 and Annex AA at currents not less than the values specified at clause 9.1.8(c) hereunder

(c) Arcing fault type test currents shall be not less than the following:

  (i) Switchboards rated > 1 kV, < 12 kV - 20 kA for 1 second

  (ii) Switchboards rated > 12 kV, < 36 kV - 12.5 kA for 1 second

9.1.9 Creepage Distances in Air

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

RATED VOLTAGE kV	**MINIMUM CREEPAGE DISTANCE IN AIR**	
	PHASE TO PHASE (mm)	**PHASE TO EARTH (mm)**
3.3	**75**	**50**
6.6	**135**	**90**

11	**195**	**130**
22	**308**	**205**
33	**458**	**305**

These values are appropriate to relatively clean and dry environments and will need to be increased substantially in dusty and/or damp/corrosive conditions.

9.1.10 Cable Entry

Cable entry into High Voltage switchboards shall be from below. Other than in prefabricated substations cable to High Voltage switchboards shall be run in cable trenches in the floor rather than in conduits.

Under special circumstances, and with the written approval (dispensation) of the Principal Engineer, cable entry may be from the top where cable ladder or cable tray shall be used.

9.1.11 Routine Tests and Protection Relay Tests

Critical test requirements:

(a) All High Voltage switchboards shall be subjected to routine tests at the manufacturer's works in accordance with IEC 62271-200

(b) All protection relays shall be set to the settings as shown on the drawings and secondary injected tested at the manufacturer's works so as to verify both function and accuracy. Such tests shall be made at a minimum of six (6) evenly spaced points along the set protection relay tripping current versus time curve

(c) In addition, one (1) primary injection test shall be made so as to verify correct C.T. arrangement and complete system functionality

9.1.12 On-site Tests

High Voltage switchboards shall be subjected to on-site testing of the resistance of the main circuit in accordance with clause 7.3 of IEC 62271-200.

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

9.1.13 Short Circuit Protection Coordination

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

9.1.14 Type Specifications

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

DS26-02 - Type Specification for 22 kV to 0.433 kV Prefabricated Substation

DS26-08 - Type Specification for High Voltage Switchboards

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

9.2 Large Low Voltage Switchboards

Large low voltage switchboards shall be Design Verified and Arc Fault tested and limited to a transformer supply capacity rated at not more than 2000 kVA at 415V or 3150 kVA at 690V.

The switchboard nominal operating voltage is 415 Volts, 440 Volts or 690 Volts, controlling large low voltage motors rated as per Table 4.1 of clause 4.2 or for site power distribution.

9.2.1 Verification of Design

Design verification requirements:

(a) Low Voltage switchboards shall be of a design which has been verified in respect to both general requirements and arcing fault protection in accordance with the following standards:

  (i) IEC 61439-0 Low Voltage switchgear and controlgear assemblies - Guidelines to specifying assemblies to IEC 61439-2

  (ii) IEC 61439-1 Low Voltage switchgear and controlgear assemblies - General rules

  (iii) IEC 61439-2 Low Voltage switchgear and controlgear assemblies - Power switchgear and controlgear assemblies

  (iv) IEC/TR 61641 Enclosed Low Voltage switchgear and controlgear assemblies - Guide for testing under conditions of arcing due to internal fault.

  (v) IEC 62208 Empty enclosures for Low Voltage switchgear and controlgear assemblies

(b) IEC 61439-1 specifies the following methods of switchboard design verification:

  (i) Verification testing (previously termed type testing)

  (ii) Verification comparison with tested worst case reference design

  (iii) Verification assessment, i.e., confirmation of the correct application of calculations and safety rules, including appropriate safety margins

(c) The following switchboard characteristics shall be verified by verification testing carried out by the Contractor:

  (i) Lifting (IEC 61439-1 clause 10.2.5)

  (ii) Marking (IEC 61439-1 clause 10.2.7)

  (iii) Effective continuity between exposed conductive parts and the protective circuit (IEC 61439-1 para. 10.5.2)

  (iv) Power frequency withstand voltage (IEC 61439-1 clause 10.9.2)

  (v) Impulse withstand voltage (IEC 61349-1 clause 10.9.3)

  (vi) Mechanical operation (IEC 61439-1 clause 10.13)

(d) The following switchboard characteristics shall be verified by the verification comparison method with the reference design having been verification tested by an independent testing authority:

  (i) Resistance to corrosion (IEC 61439-1 clause 10.2.2)

  (ii) Degree of protection of enclosures (IEC 61439-1 clause 10.3)

  (iii) Short circuit strength of protective circuit (IEC 61439-1 clause 10.5.3)

  (iv) Temperature rise limits (IEC 61439-1 clause 10.10)

  (v) Short circuit withstand strength (IEC 61439-1 clause 10.11)

(e) The following switchboard characteristics shall be verified by the verification assessment method with the verification being carried out by the Contractor:

  (i) Insulation resistance to abnormal heat (IEC 61439-1 clause 10.2.3.2)

  (ii) Incorporation of switching devices and components (IEC 61439-1 clause 10.6)

  (iii) Internal electrical circuits and connections (IEC 61439-1 clause 10.7)

  (iv) Terminals for external conductors (IEC 61439-1 clause 10.8)

(f) IEC/TR 61641-1 specifies two levels of arcing fault protection to be provided by the design of the switchboard, as follows:

  (i) Personal protection, i.e., protection against injury provided in spaces more than 300 mm. away from the switchboard

  (ii) Assembly protection, i.e., damage limited to equipment with the switchboard compartment in which the arc occurred

(g) The mechanical design of all switchboards shall provide personal protection against arcing faults

(h) All switchboards shall be provided with assembly protection against arcing faults by one of the following methods:

  (i) By the mechanical design of the switchboard

  (ii) By the provision of arc detection sensors and relays

  (iii) By the provision of fault current limiting devices which limit the fault current a particular switchboard compartment to less than 17 kA_{pk}

(i) IEC/TR 61641-1 design verification shall be by verification comparison with tested worst case reference design of the same degree of protection (IP) rating

9.2.2 Special Service Conditions

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

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

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

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

9.2.3 Construction

Construction requirements:

(a) Low Voltage switchboards shall be A.C. metal enclosed switchboards of the multiple cubicle type.

(b) The form of separation for the incoming circuit breaker functional unit(s) shall be Form 4b in accordance with IEC 61439-2 Table 104. The form of separation for all other functional units shall be either Form 4a or Form 4b in accordance with IEC 61439-2

(c) "Back-to-back" switchboard designs shall not be permitted due to the inherent difficulty in accessing busbars in such switchboards

(d) Rear access cable zones shall not be permitted due to the difficulty of access and problems associated with maintenance logistics

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

9.2.4 Rated Diversity Factor

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

9.2.5 Degree of Protection

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

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

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

9.2.6 Rated Insulation and Operating Voltages

Low Voltage switchboards shall have a rated operating voltage of not less than 120% of the switchboard rated voltage as defined in IEC 61439-1.

Low Voltage switchboards shall have a rated insulation voltage of not less than 150% of the switchboard rated voltage as defined in IEC 61439-1.

9.2.7 Creepage Distances

(a) Low Voltage switchboards shall be rated for operation with an internal micro-environment having an atmospheric pollution level not less than degree 3 in accordance with IEC 61439-1

(b) Creepage distances across insulator surfaces between bare air insulated conductors in Low Voltage switchboards shall be not less than the values shown in IEC 61439-1 Table 2. In addition, bare busbars running vertically through horizontal insulating panels shall be shrouded for not less than 20mm above the horizontal insulating panel

9.2.8 Rated Impulse Withstand Voltage

Each Low Voltage switchboard shall have an impulse voltage rating as shown IEC 61439-1 Table G1 for over voltage category IV (e.g., 6 kV for 415 Volt rated switchboards, 8 kV for 690 Volt switchboards).

9.2.9 Rated Short-Time Current

Low Voltage switchboards shall be suitable for connection to a supply having the calculated prospective short circuit current (I_{cp}) at the input terminals of the switchboard. Unless impedances of the associated transformers are known, such calculations shall be made using the lower values of the transformer impedances specified in Section 7 of this Design Standard.

Low Voltage switchboards shall be specified to have a rated short time withstand current (I_{cw}) of I_{cp} for 300 milliseconds. This rating applies up to the input terminals of the incoming supply circuit breaker(s).

The Designer shall ensure that associated transformer protection equipment will clear a short circuit at the Low Voltage switchboard input terminals in less than 300 milliseconds.

In accordance with IEC 61439-1, Low Voltage switchboards shall be specified to have a rated conditional short time withstand current (I_{cc}) of I_{cp} for the clearance time of the relevant upstream short circuit protective device at its maximum trip time setting.

Note: The required prospective short circuit fault current level of the switchboard shall be the sum of the switchboard incoming supply fault current level and the installation maximum driven motor prospective fault current contribution.

9.2.10 Internal Arcing Fault Protection

Low Voltage switchboards shall incorporate arcing fault protection as follows:

(a) In all main circuit compartments measures shall be taken to provide increased security against the occurrence of, and effects of, internal arcing faults

(b) Except as specified hereunder, the design of all main circuit compartments shall be verified in respect to containment of arcing faults in accordance with subclause 9.2.1(i) above

(c) For switchboards rated $\leq$ 1600 Amps, the prospective fault current level (I_{cp}) used in tests on the associated worse case reference design shall be $\geq$ 30 kA

(d) For switchboards rated > 1600 Amps, the prospective fault current level (I_{cp}) used in tests on the associated worse case reference design shall be $\geq$ 50 kA

(e) Switchboard compartments which are protected by HRC fuses, shall not be required to be type tested for arcing fault containment, provided that the HRC fuses are located outside the particular compartment and limit the peak cut off current to less than 17 kA_{pk}

(f) Switchboard compartments protected by semiconductor protection fuses, shall not be required to undergo arcing fault type test, provided that the semiconductor protection fuses are located outside the particular compartment, are in accordance with AS 60269.4.0, and have a total energy let through I^2t of not more than $0.8*10^6$ Amp^2 sec

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

(h) In accordance with IEC 61641, switchboard compartments having no accessible bare conductors (i.e., when all conductors are insulated and when all insulating covers and sleeves are in place) shall not require arcing fault containment tests

9.2.11 Cable Entry

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

9.2.12 Access to Busbars

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

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

9.2.13 Switchboard Routine Tests

Routine verification testing of Low Voltage switchboards shall include the following:

(a) Routine verification tests as described in IEC 61439-1 clause 11 including impulse voltage withstand test

(b) Tests to verify the accuracy of all instrumentation

(c) Tests of the resistance of the main circuit in order to verify the absence of any poor joints in main circuit conductors

(d) Tests to verify earth continuity between exposed conductive parts of the switchboard in accordance with clause 10.5.2 of IEC 61439-1

(e) Operational tests on the arc detection system using flashlights

(f) Protection relay tests as detailed hereunder

9.2.14 Protection Relay Routine Tests

Low Voltage switchboard protection relays shall be routine verification tested to verify correct operation of current transformer operated protection devices at the proposed operational protection settings specified on the Principal's drawings.

Such tests shall be carried out by secondary injection and shall test each protective device at not less than six (6) points spread evenly over the complete operating range of the device at the specified device settings.

In addition, one (1) primary injection test shall be made so as to verify correct C.T. arrangement and complete system functionality.

9.2.15 On-site Tests

Low Voltage switchboards shall be subjected to on-site testing of insulation resistance measurement using a measuring device at a voltage of at least 500 VDC.

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

9.2.16 Short Circuit Protection Coordination

Short circuit protection coordination shall be provided between contactors and overload relays and their associated short circuit protection devices in accordance with the requirements of AS 60947.1 for type 2 coordination.

9.2.17 Circuit Breaker I_{cs} Ratings

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

It is reasonable to assume that the life of a circuit breaker is approximately proportional to the sum of the I^2t interrupted and that the life of a circuit breaker will be extended by specifying I_{cs} current ratings well above the absolute minimum.

Consequently, switchboard incoming circuit breakers shall be specified to have an I_{cs} current rating in accordance with AS 60947.2 of not less than 200% of the switchboard design fault current rating.

Outgoing circuit breakers shall be specified to have an I_{cs} current rating in accordance with AS 60947.2 of not less than 110% of the switchboard design fault current rating and not less than 200% of the fault current available at the associated circuit load, e.g., at the motor terminals.

9.2.18 Intelligent Switchboards

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

9.2.19 Type Specifications

The following Type Specification is suitable for specifying the various types of large Low Voltage switchboards:

DS26-17 - Type Specification for Large Low Voltage Switchboards

9.3 Main Busbars.

9.3.1 Cubicle Arrangement of Pumping Unit Switchboards

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

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

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

9.3.2 Capacity

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

9.3.3 Arrangement for Low Voltage Busbars

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

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

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

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

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

9.3.4 Extensions

The Designer shall consider the likelihood that the switchboard may need to be extended in the future and shall specify that the switchboard shall be capable of such extension if such a need is considered to be likely within 10 years.

9.4 Location of Controls

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

9.5 Protection – General

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

9.5.1 Definitions

For the purposes of this design standard:

(a) The electrical protection function shall be deemed to mean those devices and functions which monitor the operation of individual items of electrical plant and which initiate the shutdown of such plant if continuing operation in the current operational state would jeopardise the safety of personnel or cause damage individual items of plant

(b) The term interlock function shall be deemed to mean those devices and functions which prevent inadvertent control selections or commands jeopardising the safety of personnel or the safety of plant at the site

(c) The primary protection, as defined clause 1.3.5 shall be deemed to require onsite technical investigation before resetting the associated protection device or variation of the associated protection device set point

(d) Secondary protection, as defined clause 1.3.5 shall be deemed to relate to be those non-critical electrical system faults for which remote resetting of the associated protection device will be safe, as far as the electrical system is concerned, provided that the remote operator takes due care

Note: Provisions made for remote resetting of secondary protection faults must ensure sufficient SCADA information is available to enable the remote operator to assess the cause of the trip and to ascertain that the fault conditions no longer exist.

9.5.2 Specific Fault Types

For the purposes of this design standard, the following electrical faults shall be considered to be primary faults:

(a) Incoming Feeder

  (i) Incoming feeder overcurrent

  (ii) Incoming feeder earth fault

  (iii) Transformer winding over temperature

  (iv) Transformer oil over temperature

(b) Power Factor Correction

  (i) Power factor correction unit over current

  (ii) Power factor correction unit earth fault

(c) Drive System

  (i) Motor winding over temperature

  (ii) Motor bearing over temperature

  (iii) Motor over current and earth fault

  (iv) Motor unbalanced current

   - (v) Motor excess vibration
   - (vi) Starter over temperature
   - (vii) Variable speed controller over temperature and VSC fault
   - (viii) Active filter fault

(d) Pump (Driven Load)

   - (i) Pump bearing overtemperature
   - (ii) Pump excess vibration
   - (iii) Low suction pressure (optional, refer clause 9.8.2)
   - (iv) No flow (optional, refer clause 9.8.1)

(e) Clause 1.3.5 defines the types of faults to be considered as secondary faults

(f) The classification of electrical faults other than those listed above shall be determined by reference to the Principal Engineer

9.5.3 Basic Protection Requirements

Basic protection requirements are:

(a) Protection equipment which detects equipment fault conditions and trips the faulted equipment shall be provided to provide adequate protection, against primary faults, under both normal and emergency situations

(b) Primary protection fault protection devices shall act as directly as possible on the associated circuit and the trip function shall not be implemented via the plant control system (PCS) equipment or via EDS-PCS systems interface terminal unit. Primary protection shall be arranged so that the probable mode of protection circuit failure will result in safe (usually shut down) conditions

(c) All over temperature protection devices shall provide an additional warning signal (i.e., contact closure) set midway between the rated operating temperature and the over temperature trip level

(d) All excess vibration protection devices shall provide an additional warning signal (i.e., contact closure) set midway between the rated operating vibration level and the excess vibration trip level

9.5.4 Drive Protection Self Sufficiency

The term electric drive shall be deemed to include the drive motor and the associated starter or variable speed controller.

Each electric drive and associated incoming feeder shall be self-sufficient in respect to primary protection functions so that the drive may be operated safely under emergency manual control in the event of plant control system failure.

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

9.5.5 Setting and Resetting Primary Protection

Setting and Resetting requirements:

(a) Setting of electric drive primary protection device trip levels shall be possible only locally at the associated protection device and such changes shall not be made without reference to, and agreement from, the relevant design engineer or the Principal Engineer (for operational sites). The associated switchboards shall be labelled accordingly

(b) Primary protection equipment shall not be arranged to reset automatically

(c) Resetting facilities for primary protection shall be available only at site and resetting facilities shall be restricted to qualified electrical personnel. Provision shall not be made for remote resetting of Primary Protection faults. This is to ensure thorough 'on site' diagnosis of the fault is made prior to reset

Note: A repeated cycle of protection tripping and resetting can lead to equipment failure and in some circumstances may be dangerous.

(d) Modifications to interlock functions shall be possible only at the plant site and such changes shall not be made without reference to, and agreement from, the relevant design engineer or the Principal Engineer (for operational sites)

9.5.6 Plant Control System Protection Functions

The plant control system PLC logic, when controlling operation of the system in normal mode, shall be arranged to:

(a) Shut down the associated electric drive in the event of a detected fault condition within the hydraulic system or within the driven plant

(b) Shut down the associated drive if the drive running signal is not received within a specified period after the drive has been called

(c) Stop all drives if the incoming supply voltage healthy signal is absent for a specified period and inhibit starting of any drives until the signal is received continuously for a specified period

(d) Prevent start frequency of each drive exceeding a specified limit

(e) Interrupt the run signal to the associated drive in the event of an EDS primary fault or secondary fault (as defined clause 1.3.5) being notified

(f) Prevent operation of the hydraulic system in such a way as would be likely to result in damage to electric drive system equipment

If, for overall system operational or maintenance purposes, a local display panel showing all current electric drive system primary and secondary faults is required, it shall be implemented within the plant control system.

9.5.7 EDS to PCS Interface

The types of inputs and outputs at the Electric Drive System (EDS) / Plant Control System (PCS) interface terminals:

(a) Analogue inputs and outputs shall be isolated 4/ 20 mA signals

(b) The energy consumption output shall be Extra Low Voltage DC pulses

(c) The digital input and output connections shall be clean contacts

Signals from the PCS to the EDS shall be a minimum of:

(a) Run command for each drive

(b) Drive speed setting for each variable speed drive

(c) Open feeder circuit breaker commands

Signals from the EDS to the PCS shall be a minimum of:

(a) Isolated, stopped, running, warning and fault indications for all drives

(b) Isolated, off, on, warning and fault indications for all feeders

(c) Drive power demand for each drive (kW)

(d) kWh pulses for each incoming supply feeder

(e) Drive speed, if variable speed drive (rpm)

(f) Incoming supply feeder voltage healthy indication

(g) Incoming supply feeder fault indication

9.6 Electrical Protection Grading

9.6.1 General

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

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

Wherever practical, protection should be arranged so that adequate grading is provided between all devices.

The possible use of protection equipment which has zone selectivity functionality shall be investigated in this regard if time-based grading is found to be difficult in an application.

9.6.2 Grading Between Fuses

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

9.6.3 Protection Grading Across Transformers

The self-impedance of a step-down transformer limits the fault current which may be seen by the Secondary Voltage side protective device. Consequently, grading between the Primary Voltage side protective device and the Secondary Voltage side protective device need only be provided over the current range up to the Secondary Voltage maximum fault current.

Note: Consideration shall be given to the difference in the per unit current seen by the Primary Voltage protection device and that seen by the Secondary Voltage protection device for a Secondary Voltage phase to phase fault and for a Secondary Voltage phase to earth fault.

9.6.4 Switchboard Protection

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

9.6.5 Low Fault Level Sites

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

As absolute minimum requirement

(a) Proper time-current protection grading shall be provided between the Network Operator feeder protection and the pump station main circuit breaker, and

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

9.6.6 Motor Line Contactors

Line contactors controlling High Voltage motors shall be vacuum contactors (or SF6 contactors if approved by the Principal Engineer). Such contactors shall be specified to have a rated chopping current of not more than 0.5 Amps.

Circuit breakers shall not be used for this duty.

9.6.7 Contactor Fault Capacity

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

9.7 Motor Protection

9.7.1 Motor Overcurrent Protection

Overcurrent protection requirements:

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

(b) Motor over current protection relays shall comply with the requirements of IEC 60947 and IEC 60255-149 and shall provide both over current and phase current unbalance protection

(c) Reference shall be made to the overcurrent relay manufacturer's handbook in respect to appropriate relay settings. However, such settings shall be such that a long-term continuous current of more than 105% of motor rated full load current causes an "Overcurrent" trip

(d) The earth fault trip setting shall be adjustable over the range 10% to 40% of motor rated full load current

(e) The instantaneous high set over current trip setting shall be adjustable over the range 3 times to 9 times motor rated full load current

9.7.2 Motor Thermistor / RTD Protection

Where the motor overcurrent protection relay includes a facility for connecting motor winding thermistors or RTD's, this facility may be used.

9.7.3 Differential Protection

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

9.8 Pump Protection

9.8.1 No Flow

The method of no flow condition detection shall be by measurement of the motor load kW provided the difference between pump no flow power demand and pump minimum operating power demand is more than 20% of motor continuous running duty rating. Measurement of motor current is not a satisfactory method of detecting flow or no-flow and shall not be used.

Low flow can potentially cause considerable heating and damage to pump seals. If the mechanical plant designer so requests, protection against this fault shall be included in the electric drive system in the same manner as for electric drive primary faults. Otherwise, it will be considered as secondary protection and shall be provided by the plant control system.

9.8.2 Low Pressure

Major clear water pumps shall be fitted with pressure switches to provide protection against low suction pressure and low delivery pressure. Power transducers shall not be used for detection of low or high pressures.

Low suction pressure can cause cavitation, possibly leading to severe mechanical damage to the pump and associated pipework. If the mechanical plant designer so requests, protection against this fault shall be included in the electric drive system in the same manner as for electric drive primary faults. Otherwise, it will be considered as secondary protection and shall be provided by the plant control system.

9.8.3 Bearing Overtemperature and Excess Vibration

As with motors, pump bearing overtemperature and pump excess vibration can potentially result in catastrophic equipment damage. Hence, pump bearing overtemperature and pump excess vibration shall be considered primary protection.

9.9 Protection Current Transformers

9.9.1 General

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

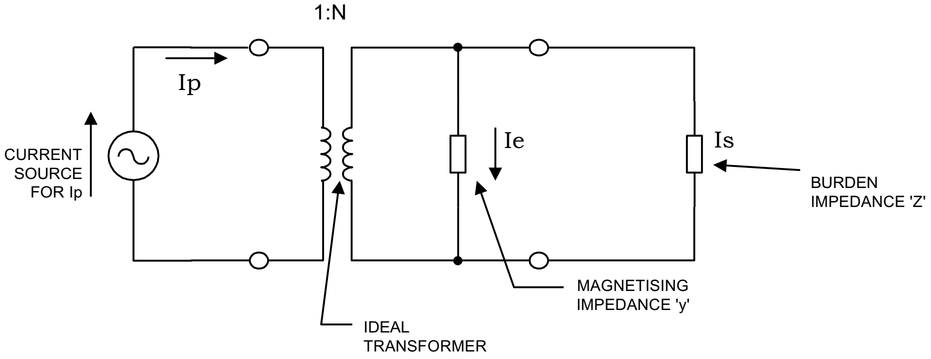


Fig. 9.1 Equivalent Circuit of a Current Transformer

For a protection current transformer, the magnitude of the rated burden admittance $(Z)^{-1}$ will be between one and two orders larger than the magnetising admittance (y). "Knee point voltage" is defined as the point at which a 10% increase in secondary emf produces a 50% increase in exciting current I_e. It is therefore the point at which y starts to increase substantially with increased secondary emf, i.e., the point at which the CT starts to saturate.

The "Rated Secondary Reference Voltage" of a protection CT is the rms value of secondary voltage upon which the performance of the CT is based. For a protection CT the Rated Secondary Reference Voltage will be less than, but of the same order as, the knee point voltage.

9.9.2 Standards

Current transformers shall be in accordance with AS 60044.1 or with IEC 60044-1 and shall be designated in full in accordance with one or other of these standards.

9.9.3 Primary Current Rating

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

9.9.4 Short Time Thermal Current Rating

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

9.9.5 Rated Operating Voltage

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

9.9.6 Rated Insulation Level

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

9.9.7 Rated Secondary Current

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

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

Where the C.T. wiring is contained within the associated switchboard 5 Amp rated secondary current C.T.s shall be selected. Where C.T. secondary wiring is run external to the switchboard 1 Amp rated secondary current C.T.'s shall be considered (e.g., C.T.'s located in the star point of a transformer).

9.9.8 Accuracy Class

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

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

Protection current transformers to be used in balanced protection applications (systems where sensitivity and stability levels required are high) may require the use of a higher accuracy class (i.e., Class PX.).

Note: Class PX is special class protection CT which has defined saturation characteristic and Knee point. Recommended for High Impedance differential protection. Note: One centiradian + 0.57 degrees.

9.9.9 Accuracy Limit Factor

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

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

9.9.10 Burden

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

Qr = (Qd+Qw+Qt)

where :

Qr = CT rated burden VA at rated secondary current

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

Qw = burden VA of the CT secondary circuit switchboard wiring at the CT rated secondary current

Qt = burden VA of external test instruments

= 2.0 VA for 5 A secondaries

= 1.0 VA for 1 A secondaries

9.9.11 Rated Secondary Limiting e.m.f.

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

$V_{sl} = Q_r * F / I_s$

where:

Q_r = CT rated burden VA at rated secondary current, Amps

F = CT rated accuracy limit factor

I_s = CT rated secondary current, Amps

9.9.12 Example Rating Calculation for Protection Current Transformer

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

I_f = fault current available in the motor circuit

= 1800 Amp

1_d = motor full load current = 59 Amps

1_h = motor high set trip current = 480 Amps

I_r = CT rated primary current = 100 Amps

S_f = scale factor

= $I_r/I_d = 100/59 = 1.695$ (which is less than 2, so is OK)

I_s = CT rated secondary current = 5 Amp

Q_d = relay rated burden at rated current = 0.1 VA

Q_w = burden VA of the CT secondary circuit at rated current

= 2.5 VA (by separate calculation)

Q_t = burden VA of external test instruments at rated current

= 2.0 VA

Q_r = CT rated burden VA at rated secondary current

= $(Q_d+Q_w+Q_t)$

= (0.1+2.5+2) = 4.6VA, say 5VA

F = CT rated accuracy limit factor

= $I_h/(I_d*S_f)$

= 480 / (59*1.695) = 4.8

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

V_{sl} = $Q_r*F/I_s = 5*10/5 = 10$ Volt

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

9.10 Rogowski Coil Current Sensors

9.10.1 General

A Rogowski coil is a toroid of wire used to measure an alternating current I(t) through a cable encircled by the toroid. The output of the coil, v(t), is connected to a lossy integrator circuit to obtain a voltage $V_{out}(t)$ that is proportional to cable current I(t).

The coil contains no saturable components, the output increases linearly in proportion to current, has a very wide dynamic range, high accuracy (0.5%) and an excellent transient response.

9.10.2 Primary Current Rating

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

9.10.3 Short Time Current Rating

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

9.10.4 Rated Operational Voltage

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

9.10.5 Rated Insulation Level

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

9.10.6 Rated Secondary Current

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

9.10.7 Accuracy Class

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

9.10.8 Accuracy Limit Factor

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

9.10.9 Burden

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

$$Q_r = (Q_d + Q_w + Q_t)$$

where:

Q_r = sensor rated burden VA at the sensor rated secondary current

Q_d = rated burden VA at the sensor rated secondary current of the switchboard mounted relays, trip coils and other devices to be operated by the sensor.

Q_w = burden VA of the sensor secondary circuit switchboard wiring at the sensor rated secondary current

Q_t = burden VA of external test instruments

= 1.0 VA for 1 A secondaries

9.11 Potential Transformers

Potential transformer requirements:

(a) All metering potential transformers provided and installed by the Corporation shall be of the star/star connection type

(b) Potential transformers installed in Water Corporation High Voltage switchboards shall be fitted with Low Voltage fuses

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

Note: It was previous Western Power standard practice to use two element metering and open delta potential transformers. In such instances it was Western Power standard practice to earth the white phase connection. Western Power have changed to three element metering and star/star potential transformers with the Low Voltage star point earthed. However, two element metering and open delta potential transformers may be provided in some instances.

9.12 Switchgear

9.12.1 High Voltage Switchgear

High Voltage switchgear requirements:

(a) High Voltage circuit breakers shall be vacuum type (Clause 3.4.2 refers)

(b) Switchgear in High Voltage ring main units is normally rated for infrequent use only with circuit breakers in such units typically having an endurance rating of class M1/E2 in accordance with AS 62771-100, i.e., 2,000 mechanical opening operations and 3 electrical interruptions at rated short circuit current

(c) High Voltage circuit breakers other than those described in sub-clause (b) above shall have an endurance rating of not less than class M2/E2 in accordance with AS 62771-100, i.e., 10,000 mechanical opening operations, 40 electrical operations at rated short circuit current and 10,000 electrical operations at rated continuous current

(d) All High Voltage circuit breakers shall be fitted with spring charged tripping mechanisms fitted with D.C. shunt trip releases. (Clause 3.4.2 refers)

(e) High Voltage circuit breakers other than those described in sub-clause (b) above shall be fitted with motorised closing mechanisms to allow closing of these circuit breakers from a control room within the pump station

(f) Routine operational on-off control of High Voltage fixed speed motors shall be via High Voltage contactors (low chopping current type vacuum), having a rated mechanical endurance of not less than 100,000 operations. High Voltage circuit breakers shall not be used for this purpose

(g) Routine operational on-off control of High Voltage variable speed controllers (including transformer if applicable) shall be via High Voltage contactors (low chopping current type vacuum), having a rated mechanical endurance of not less than 100,000 operations. High Voltage circuit breakers shall not be used for this purpose

9.12.2 Low Voltage Switchgear

Low Voltage switchgear requirements:

(a) Low Voltage circuit breakers shall be air-break type

(b) Switchboard main incoming feeder circuit breakers on switchboards rated at more than 315 kVA shall be of the electrically operated type equipped with spring charged closing and tripping mechanisms to allow remote opening and closing of these circuit breakers from a control room within the pump station

Note: Such a facility shall provide open/close control and closed/open indication functionality within a suitable wall mounted enclosure in the control room.

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

9.13 Anti-Condensation Heaters

Anti-condensation heaters in switchboards shall be arranged for continuous operation and the switchboard as a whole shall be rated accordingly.

9.14 Equipment Voltage Ratings

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

9.15 Surge Protection

Surge protection requirements:

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

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

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

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

(e) Surge diverters need not be installed in a particular High Voltage switchboard provided that the switchboard is within the protective range of suitably rated surge diverters. If surge diverters are installed in a High Voltage switchboard, these shall be located to minimise any damage that would be caused by a surge diverter failure

(f) Where practical, Low Voltage incoming surge diverters shall be installed within the switchboard close to the Main Switch. For LV surge diverter selection reference should be made to Design Standard DS22

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

(h) Surge protection, and associated insulation coordination, shall be provided in accordance with the requirements of Section 12

9.16 Main Switchboard Circuits

9.16.1 General

General requirements:

(a) PCS equipment shall not be located in the same enclosure as EDS equipment

(b) Main switchboard power and hard-wired control circuits shall be in accordance with the relevant Water Corporation standard circuits (MN00 refers)

(c) Generally, switchboard internal control circuits shall be hardwired

(d) Generally, the contact status for control should be normally open and close on command instruction

(e) Over current and earth fault protection relays shall be connected to provide protection directly in the associated main control circuit, as well as being connected to provide protection as described clause 9.16.5(b) hereunder

(f) Switchboard internal control circuits shall be independent of the plant control system except for the input and output functions

9.16.2 Subsidiary Protection Cubicle(s)

Subsidiary Protection Cubicle (SPC) requirements:

(a) Over current, earth fault and under/unbalance voltage detection devices shall be located in the main switchboard

(b) Other than the above, feeder and drive fault detection devices shall be located in a subsidiary protection cubicle (or cubicles) separate from the main feeder and drive switchboard

(c) One output contact of the over current and earth fault protection devices shall be connected into the relevant drive hard wired control circuits

(d) Each protective device including the above shall be connected to a DIN rail mounted auxiliary relay which shall be located in the subsidiary protection cubicle. Each auxiliary relay shall have four output contacts for the following functions:

  (i) Signal the fault type to the plant control system

  (ii) Interrupt the associated drive run signal or trip the associated feeder

(iii) Energise primary fault light

(iv) Latch the auxiliary relay closed

(e) A reset push button shall be provided for each of the above auxiliary relays which are associated with primary faults

(f) No equipment shall be mounted on the outside door(s) of the subsidiary protection cubicles

(g) All direct connections between the main switchboard and the subsidiary protection cubicle(s) shall be at Extra Low Voltage, preferably 24 V DC

(h) The protection circuits wiring and connections within the subsidiary protection cubicle(s) shall be in accordance with the Corporation's standard drawings (MN00 refers)

(i) The door(s) to the subsidiary protection cubicle(s) shall be provided with EL2 locks

(j) A separate cubicle (or cubicles) shall be provided to house the EDS-PCS interface terminal units for all feeders and all drives. Space shall be provided in such cubicles for plant control system field terminal units, if these are required

(k) The Extra Low Voltage supply necessary to fault relays in subsidiary protection cubicles shall be derived from the pump station essential services Low Voltage switchboard. Separate ELV output power supply units shall be provided for each drive and feeder

9.16.3 Main Switchboard Drive Cubicles

Main Switchboard Drive Cubicles requirements:

(a) A three-position selector switch shall be provided on each drive switchboard cubicle front panel to allow one of the following modes of switchboard control to be selected:

(i) "Normal Control"

(ii) "Off"

(iii) "Emergency Control"

(b) Normal run-stop operational control of the electric drives shall be via the plant control system. *(The pump sets will have both primary and secondary protection)*

(c) In the emergency control, a local operator shall be able to control each drive manually without the PCS system being operable and with plant control system inoperable. (*Allows control of pump sets directly from each motor cubicle on the main switchboard. The pump sets have primary protection only and the intention is that a local operator is present during this mode. A key shall be provided to switch to this position.)*

(d) Each main switchboard drive cubicle front panel shall be equipped with the following instruments:

(i) An ammeter and phase selector switch (Amps)

(ii) A power meter complete with an indicator showing used energy (kWh) and power transducer output (kW)

(iii) A set of voltage and current test links

  - (iv) A speed (rpm)/frequency (Hz) meter if the drive is variable speed

(e) Normal hardware stop and start pushbuttons shall be provided on each drive cubicle front panel and the control circuit wiring shall be arranged so that these operate only when emergency control is selected

(f) A latched emergency stop button shall be provided on the drive cubicle front panel and shall be connected to shut the drive down in either normal control mode or in emergency control mode

(g) Indicator lights shall be provided on each drive switchboard cubicle front panel to indicate "isolated", "drive running', "drive stopped" and "primary fault"

9.16.4 Main Switchboard Incoming Supply Feeder Panels

Main Switchboard Incoming Supply Feeder Panel requirements:

(a) Each incoming supply feeder switchboard front panel shall be equipped with the following instruments

  - (i) A voltmeter and phase selector switch (Volts)
  - (ii) An ammeter and phase selector switch (Amps)
  - (iii) A power meter complete with an indicator showing used energy (kWh), a power transducer output (kW) and a used energy pulsed output
  - (iv) An analogue kVAr meter with a transducer output

(b) Normal hardware open and close pushbuttons shall be provided on each incoming supply feeder cubicle front panel

(c) Indicator lights shall be provided on each drive switchboard cubicle front panel to indicate "feeder isolated", "feeder off', "feeder on", "feeder fault" and supply Volts healthy

9.16.5 Main Switchboard Drive Internal Control

Main Switchboard Drive Internal Control requirements:

(a) The following protection equipment shall be mounted on the auxiliaries compartment of each main switchboard drive cubicle:

  - (i) Motor over current relay
  - (ii) Earth fault relay

(b) One output contact on the motor overcurrent and earth fault relay(s) shall be connected directly into the motor contactor control circuit while another shall be connected into its associated subsidiary protection panel circuit

(c) The main switchboard internal drive control wiring and circuits shall be in accordance with the Corporation's standard drawings (MN00 refers)

9.16.6 Main Switchboard Feeder Internal Control

Main Switchboard Feeder Internal Control requirements:

(a) The following protection equipment shall be mounted in the auxiliaries compartment of each main switchboard feeder cubicle:

   (i) Feeder over current and earth fault relay(s)

   (ii) Feeder self-resetting under voltage and phase unbalance relay

(b) One output contact on the overcurrent and earth fault relay(s) shall be connected directly into the feeder short circuit protection device control circuit while another shall be connected into its associated subsidiary protection panel circuit

(c) One contact on the under voltage and phase unbalance relay(s) shall be connected to EDS-PCS interface terminals and the other to energise the supply Volts healthy indicator light

(d) The main switchboard internal feeder control wiring and circuits shall be in accordance with the Corporation's standard drawings (MN00 refers)

9.17 PCS Control

9.17.1 General

Normal operation pump control is now a plant control system function and its design is now beyond the scope of this design standard.

The plant control system shall include functions which preclude the electrical system being operated in such a way as to increase the risk of electrical system primary faults as detailed further hereunder.

9.17.2 Supply Under Voltage

In normal operation, the plant control system shall prevent drives being operated if the incoming supply voltage is outside acceptable limits. Consequently:

(a) The plant control system shall stop all drives if the incoming supply healthy signal is absent for a specified period,

(b) The plant control system shall prevent any "drive run" signals being reissued to any drives connected to a particular feeder, unless the feeder "Volts healthy" signal has been present without interruption for a specified period,

(c) The undervoltage delay trip period shall be long enough to ride through short term voltage dips such as those caused by motor starting periods,

(d) In addition, the under-voltage delay trip period shall be short enough to guarantee that in the event of an under-voltage condition, the under-voltage trip occurs well before any drive over current protection trips due to the related drive overcurrent conditions.

9.17.3 Excess Start Frequency

In normal operation, the PCS system shall prevent drives from being started too frequently, i.e., excess start frequency. Consequently:

(a) The plant control system shall monitor the number of normal operation starts of each drive in a specified time period and prevent the hydraulic system being operated so that the drive start frequency does not exceed the safe limit nor compromise agreed voltage disturbance limits with the Network Operator,

(b) The electrical designer shall advise the PCS designer of the number of starts to be permitted in a specified time period (Refer clause 9.19),

(c) An engraved label shall be attached on the front of each drive switchboard cubicle front panel specifying the allowable start frequency.

9.17.4 Incomplete Start

In normal operation, the PCS system shall prevent drives from continuing to run if the drive's starting sequence is not completed in a specified period. Consequently:

(a) The pump control system shall monitor the time between a run command being issued and the associated drive running signal being received, so that if this period exceeds a specified period, the drive shall be stopped as an incomplete start fault and the fault signalled accordingly

(b) The Electrical Designer shall advise the PCS designer of the maximum allowable start period (Refer clause 9.19)

(c) An engraved label shall be attached on the front of each drive switchboard cubicle front panel specifying the allowable start period

9.18 Switchboard Safety Clearances

Clearances around switchboards shall comply with AS3000.

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

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

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

9.19 Drive System Related Settings in the PCS

The Electrical Designer shall submit a formal signed document to the PCS system designer specifying:

(a) The incoming supply undervoltage trip time delay

(b) The incoming supply healthy period to be allowed before restarting drives

(c) The maximum permissible starts per hour for each drive

(d) Maximum allowed start period for each drive

(e) The metering scaling factors for power transducer signals together with the scaling factors for energy pulsed output signals

(f) The drive operating history which is required to be recorded in the plant control system so as to facilitate fault analysis

The above operating history records specified shall include:

(a) Analogue record of each drive input power demand for the 5-minute period before any drive primary or secondary fault

(b) A time and date recording for each time a “drive run” command is issued

(c) A time and date recording of each fault event

9.20 Location of Pump Station Motor Control Switchboards

Switchboard location requirements:

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

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

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

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

(e) Switchboards shall be located only in areas appropriate to the switchboard degree of protection provided (clauses 9.1.5 and 9.2.5 refer)

(f) Variable speed controllers shall be located in separate rooms, i.e., separate from motor or generator control switchboards

(g) Switchboards shall not be located adjacent to ventilation louvres of the building. This avoids/reduces the risk of switchboard damage due to water, dust and vandalism

9.21 Lamp and Actuator Colours

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

(a) Fault tripped condition - Yellow/Amber (flashing if unacknowledged)

(b) Off condition - Green

(c) Run condition - White

(d) Interlock operating - White

(e) Alarm (abnormal) - Yellow/Amber (flashing if unacknowledged)

(f) Valve open - White

(g) Valve closed - Green

(h) Switch or breaker closed - Red

(i) Switch or breaker open - Green

Actuators on switchboards 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

9.22 Fault Current Limiters

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

All main Low Voltage switchboard Low Voltage control circuits, instrumentation circuits and auxiliary circuits shall be protected by HRC fuses.

Further requirements for fault current limiting short circuit protection are provided in DS26-09 “Type Specification for Low Voltage Switchboards – General Requirements”.

9.23 Under Voltage and Phase Unbalance Protection

The motor protective devices will provide protection against motor overheating due to incoming supply undervoltage or phase imbalance. However, such devices are manually reset and will require a visit to site by a suitably qualified person to assess the cause of the tripping and to determine whether or not the device can be reset.

To minimise the operation of motor protective devices due to supply under voltage or phase failure, a ‘phase failure and undervoltage relay’ shall be installed to monitor the incoming supply voltages into each installation.

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

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

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

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

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

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

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

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

9.24 Metering of Variable Speed Drive Loads

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

9.25 Separate Drive Circuits

Each drive circuit shall be complete and independent of other drive circuits. Refer clause 9.5.4.

9.26 Distribution Boards

Distribution board requirements:

(a) In accordance with AS/NZS 3000 a distribution board is defined as being “a switchboard other than the main switchboard”. In this Design Standard the term distribution board shall be deemed to mean any Low Voltage switchboard rated ≤ 250 Amps installed in a major pump station or major treatment plant.

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

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

(d) The circuit breaker at the origin of the circuit supplying the distribution board shall be fitted with delayed short time over current tripping with short time over current and delay time settings which provide the cable feeding the distribution board with short circuit protection, while providing adequate grading with the distribution board main circuit breaker. Instantaneous tripping shall not be provided on this circuit breaker.

(e) Distribution feeder cable overload protection shall be provided by the distribution board main circuit breaker. In addition, the distribution board main circuit breaker shall provide both short circuit and overload protection for the distribution board equipment.

(f) Distribution boards shall have all conductors and terminals on the line side of the distribution board main circuit breaker insulated.

(g) Distribution switchboards shall be Design Verified in accordance with IEC 61439-1 and Arc Fault tested in accordance with IEC/TR 61641.

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

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

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

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

(i) Lighting and general purpose final sub-circuits shall not be supplied directly from the main Low voltage switchboard or from sub-boards rated >250 Amps.

9.27 Switchboard Logic Functions and Pump Control Cubicles

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

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

10 PUMP STATION ELECTRICAL CONFIGURATION

10.1 Standard Supply Configuration

Reference shall be made to clause 3, and in particular clauses 3.1, 3.4 and 3.5, outlining the supply configuration requirements.

10.1.1 Low Voltage Supply to the Pump Station Main Switchboard

Supply configurations shall ensure that the Low Voltage prospective fault current level does not exceed 50 kA_{rms} at the pump station main switchboard. Hence the following standard configurations for the Low Voltage supply to the pump station LV main switchboard, from a Corporation owned substation, shall be:

(a) A 415 V supply to pump station switchboard from substation having dual transformers each rated ≤ 2000 kVA

(b) A 690 V supply to pump station switchboard from substation having dual transformers each rated ≤ 3150 kVA. An auxiliary transformer shall be provided to facilitate 415V supply for small power, lighting and control purposes as discussed in clause 3.3

As discussed in clause 3.5, the Low Voltage pump station main switchboard standard configuration is a sectionalised arrangement so that the dual LV feeders cannot be paralleled.

The single line diagram for the electrical configurations is shown at Fig 10.1(a) and (b).

10.1.2 High Voltage Supply to the Pump Station Main (HV) Switchboard

The HV supply to the pump station main (HV) switchboard, from the Corporation owned HV substation, shall be as discussed in clause 3 and configured as detailed in MN00 drawing set.

As discussed in clause 3.5, the High Voltage pump station main switchboard standard configuration is a sectionalised arrangement.

The single line diagram for the electrical configurations is shown at Fig 10.2.

10.2 Standard Drawings

The standard electrical configuration, including variations, for the pump station shall be as shown on the MN00 Electrical Standard Switchboard Designs - Major Pump Station drawing set.

10.3 Variation to Standard Configuration

It is acknowledged that some projects may require a significant variation from the standard configuration or a new configuration due to technical or economic reasons.

If the Designer has convincing reasons to adopt another configuration, or a significant variation to the standard configuration, for a particular project, then approval shall be sought from the Principal Engineer for dispensation (Clause 1.9 refers).

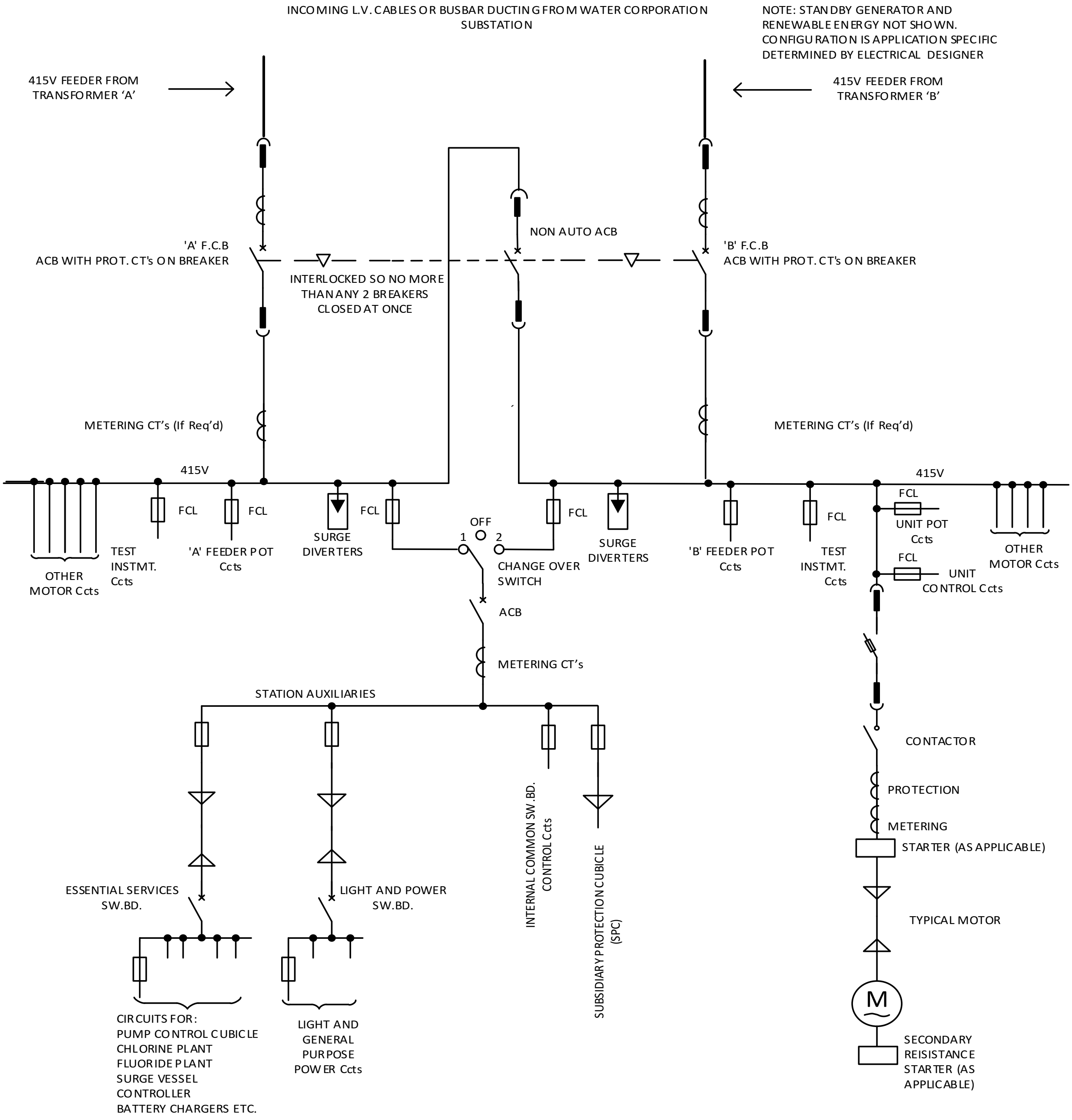


Fig 10.1 (a) LV (415V) Supply from Corporation Substation - Dual Transformers Each Rated ≤ 2000 kVA

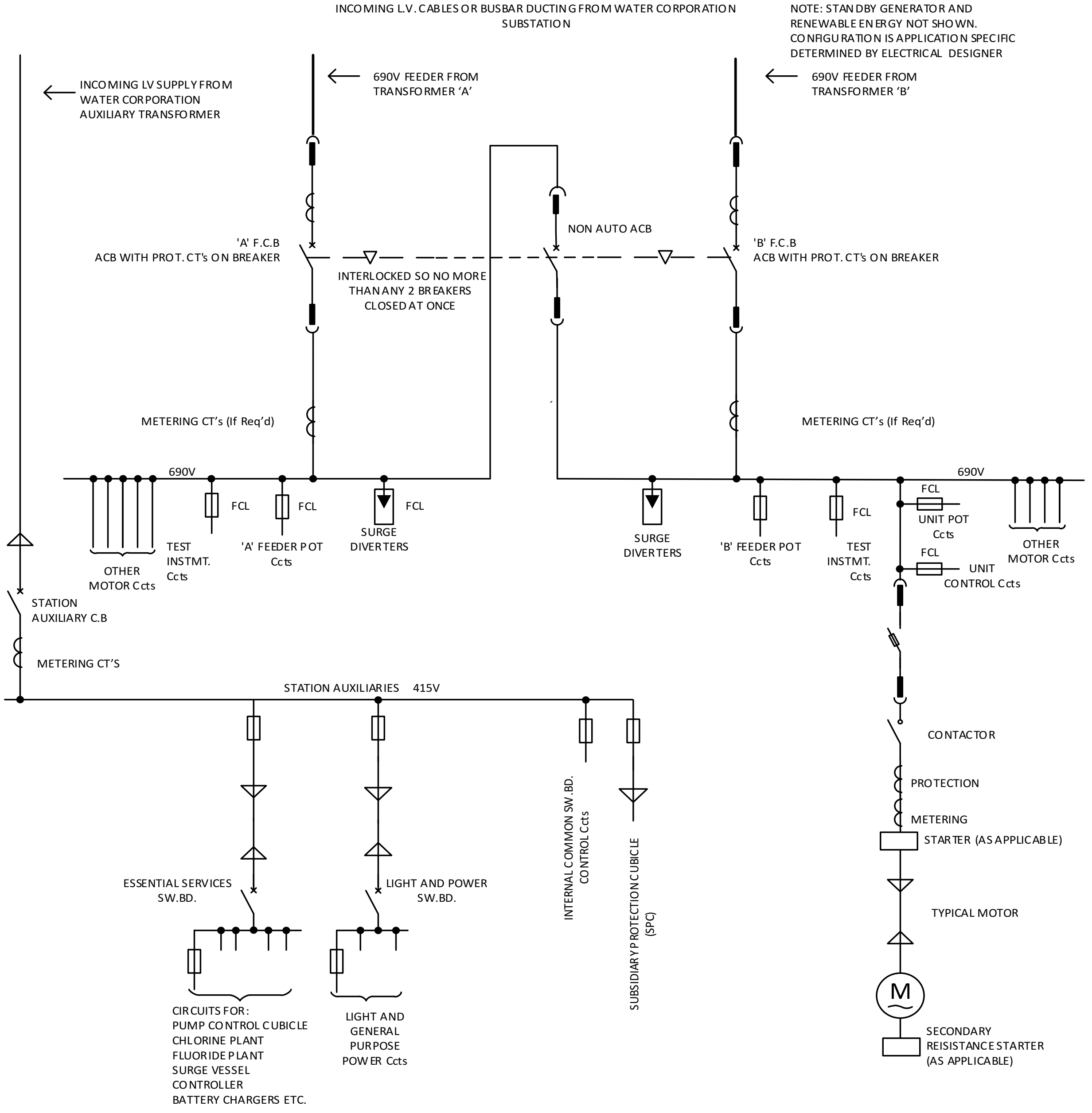
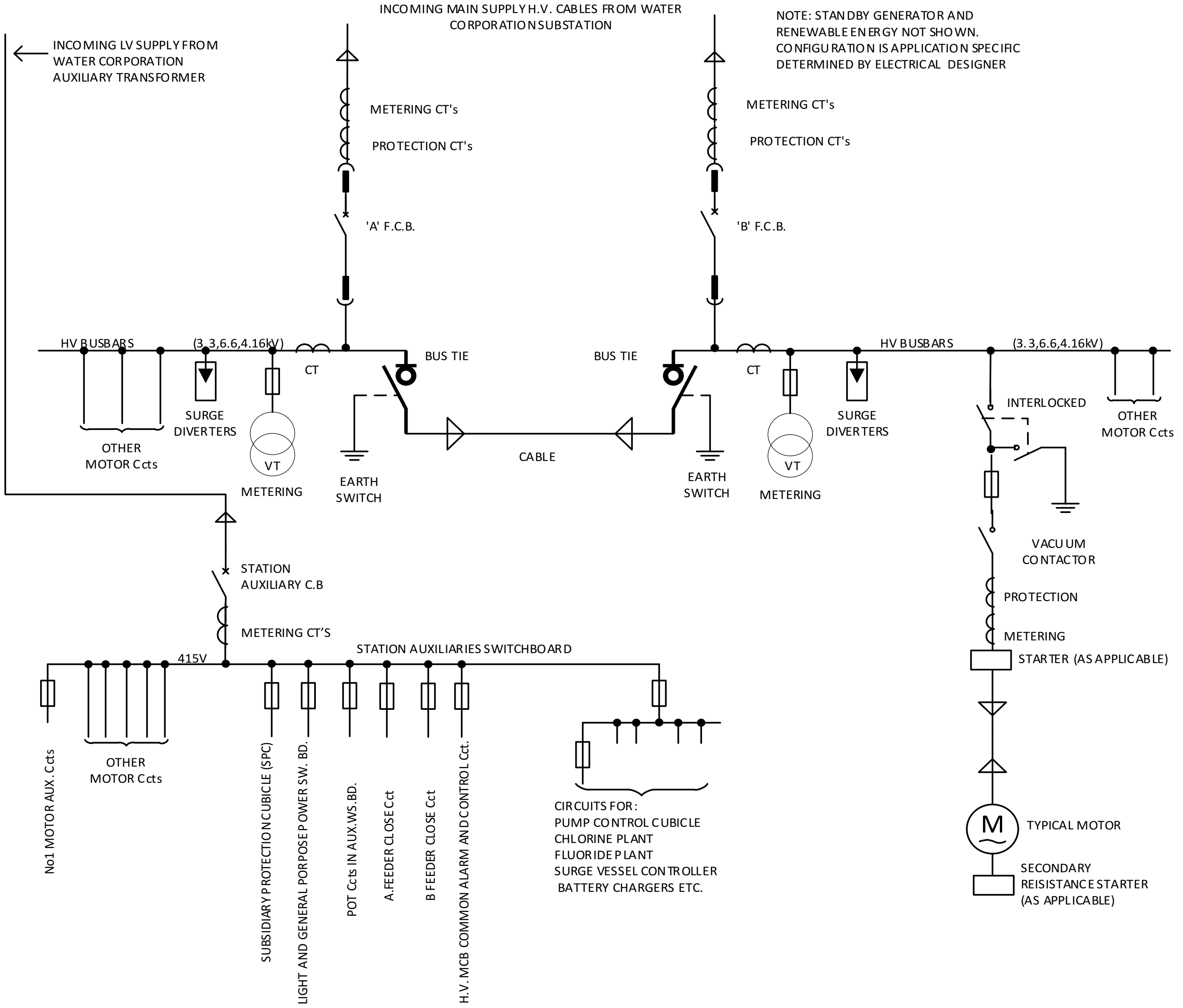


Fig 10.1 (b) LV (690V) Supply from Corporation Substation - Dual Transformers Each Rated ≤ 3150 kVA



NOTE: STANDBY GENERATOR AND RENEWABLE ENERGY NOT SHOWN. CONFIGURATION IS APPLICATION SPECIFIC DETERMINED BY ELECTRICAL DESIGNER

Fig 10.2 HV (3.3, 4.16, 6.6 kV) Supply from Corporation Substation

11 EARTHING

11.1 Principal Earthing System Requirements

The principal earthing system requirements are:

(a) A combined (common) earthing system as described in Figure B2 of AS 2067 shall be designed and implemented for major pump stations. This will permit a “Star Point” earth fault protection (unrestricted earth fault) system to be deployed as per clause 7.14.4 (c)

(b) The earthing system design shall include at least two vertical earth electrodes connected to the substation earth bar (Main). The electrodes shall be located at the opposite ends of the substation earth bar

(c) Individual earth electrodes shall be designed to have a resistance to earth no greater than 10 Ohms under the worst-case climatic/soil conditions

(d) 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 clause 11.3 of DS21 to ensure safe touch and step voltage

(e) Connections from the Main substation earth bar to other main earth bars (e.g., pump station earth bar) shall be via two parallel earth bonding cables each fully rated for the application. Each bonding cable shall be spatially separated for security

(f) It is critical that equipotential bonding is deployed for all Corporation sites to ensure protection of personnel/equipment during earth faults and lightning events. The design shall ensure all metallic structural material, metallic pipework (including valves, etc.), grid mesh, stairs, ladders and all concrete reinforcement steel in the pump station main building, and in any other associated buildings, shall be electrically bonded together and shall be connected to the earth system. Such bonding shall include metallic roof and side cladding, metallic roof structures and reinforcement steel in precast tilt up wall panels

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

(h) Grading rings, grading mats, switchboard enclosures, switchboard support frames, kiosk enclosures, metallic cable trays, metallic (aluminium) cable trench covers, motors, starters, transformers and all other electrical equipment shall be designed to be connected to the relevant earth bar

Note: Removable cable trench/duct covers shall be bonded to each adjacent cover to ensure equipotential bonding and continuity connection to the earth bar.

(i) Surge diverters protecting transformers shall have their earth leads connected directly, and short as possible, to the transformer tank

(j) All major earthing cable connections shall be made with a separate bolt for each cable so that one cable can be disconnected for testing without interfering with other earthing circuits. The Designer shall specify such on the Design Summary Earthing Connections drawing

(k) All permanent earth connections (joints) for earth grading rings or earth mats shall be IEEE Std 837 compliant (e.g., ‘Cadweld’, ‘DMC GroundLok’, ‘Burndy’). The Designer shall specify such on the Design Summary Earthing Connections drawing

(l) Grading rings shall be installed around HV switchrooms, kiosk substations housing HV equipment and aerial switch poles as required by the below ground earthing design and DS23

(m) High Voltage cable screens shall be connected as per clause 11.4.1 below

(n) The principal earthing connections and arrangements appropriate to pump stations with the standard electrical configurations, including variations, for the pump station shall be as shown on the MN00 Electrical Standard Switchboard Designs - Major Pump Station drawing set. Figures 11.1 to 11.3 below provide the basic principles to be followed

(o) The earthing arrangements at pump stations having non-standard configurations shall be in accordance with the requirements and intent of this standard (DS21) and in accordance with the principles illustrated in MN00 drawings and shall be subject to the approval of the Principal Engineer

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

(q) All connections to earth electrodes shall be made within suitable below ground earth cable pits with trafficable lids (suitably accessible for inspection) and marked as “earth”

(r) Surge diverter earth cables installed at the entry to switchboards shall be connected to the associated switchboard earth bar

(s) Transformer neutral Star Point shall be shown connected directly to the Main earth bar, not via the local earth bar associated with the transformer

11.2 Prevention of Corrosion in Earthing Systems

Earth mats and grading rings shall be bare hard drawn copper conductor (35 mm^2 minimum).

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.

Earthing electrodes shall be bare copper conductor (70 mm^2 minimum if soft drawn) or copper clad steel. All major earthing cables shall be copper and shall be terminated with suitable crimp connectors.

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

All saddles, clamps and miscellaneous fastenings shall be non-ferrous metal, stainless steel, zinc plated steel, nylon or P.V.C.

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.

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.

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

11.3 Earth Connections to General Mass of Earth and Safety

Principal requirements:

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

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

(c) The earthing connections to the general mass of earth shall be carried out, prior to the completion of Engineering Design, by a specialist earthing engineering design consultant approved by the Principal Engineer. The former shall be responsible for the design, supervision of installation and verification of performance of the earthing connections to the general mass of earth. Refer DS20 clause 3.18 for the approved panel of specialist earthing design consultants.

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

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

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

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

- Methodology for the determination of body impedance, touch & step voltage allowable safety thresholds, power system fault levels and clearance times.
- Results of site soil resistivity tests along with GPS coordinates or location plans of the measurement routes and results of soil profile modelling.
- Design methodology and input parameters.
- Assumptions and qualifications.
- Earth system design details including simulation results for earth system impedance, EPR and touch/step voltages at critical points both within and outside the site perimeter (GPS coordinates or location plans).
- Design drawings.

Note: Safe touch and step voltage shall not be reliant upon any connection to the Network Operator’s earthing system. That is, it shall be “stand alone”.

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

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

11.4 Major Cable Earthing Screens

11.4.1 High Voltage Supply Cable Screens

The screens on High Voltage supply cables (i.e., High Voltage cables other than those associated directly with variable speed controllers) shall be connected to earth at one end only, namely the source end.

For very long High Voltage cable runs (not common for pump stations), the Designer shall consider having earth screens connected directly to earth potential at both ends. This will reduce potentially hazardous earth screen rise at one end (load end) but will reduce the cable rating due to earth screen circulating currents.

The High Voltage cable connection between HV switchboard bus ties shall have their earth cable screens connected to earth at both ends.

Note: The Network Operator may require their High Voltage supply cable earth screens to be connected to the Corporations Main earth bar (Refer clause 11.4.3 below). The Designer shall confirm this with the Network Operator at the Engineering Design stage and state such on the Design Summary drawings.

11.4.2 VSC Cable Screens

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

The above requirement applies to the following types of cable:

(a) Cable between a screened unit transformer and an associated variable speed controller

(b) Cable between a variable speed controller and its associated motor except where the variable speed controller is equipped with a 50 Hz band pass output filter (Sine filter) and a common mode filter

11.4.3 Earthing of the Incoming Network Operator HV Cable

In the case of the electrical supply to the pump station site being by a HV aerial line, the Network Operator will earth the pump station incoming HV cable screen, the associated surge diverters and overhead earth wire (if available) at the Network Operator's transition pole (aerial to cable) to a suitable earth electrode at the base of the pole. The screen of the incoming cable is usually insulated from the earth at the pump station end.

If the screen of the incoming cable is insulated from earth at the incoming HV switchgear, there will be no direct connection between the Network Operator's earthing system and the Corporation's earthing system at the pump station.

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

If the Network Operator's HV metering unit is installed in the pump station HV switchroom it shall be earthed to the Corporation's earthing system.

11.4.4 Earthing Requirement Arrangement Principles

The following figures (11.1(a/b) to 11.3) outline the major earth connection requirement principles and are aligned with the standard electrical configuration figures in clause 10:

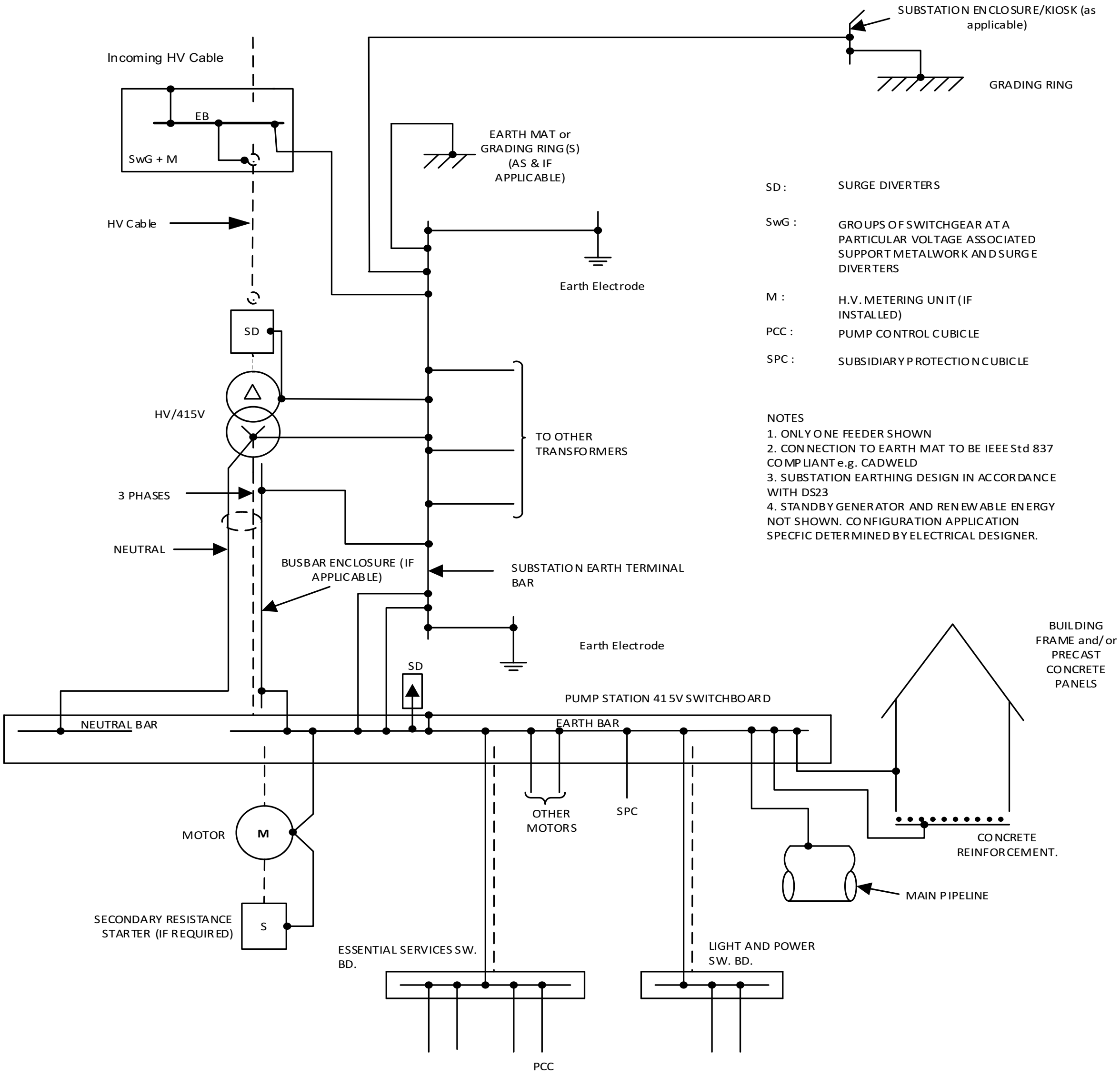
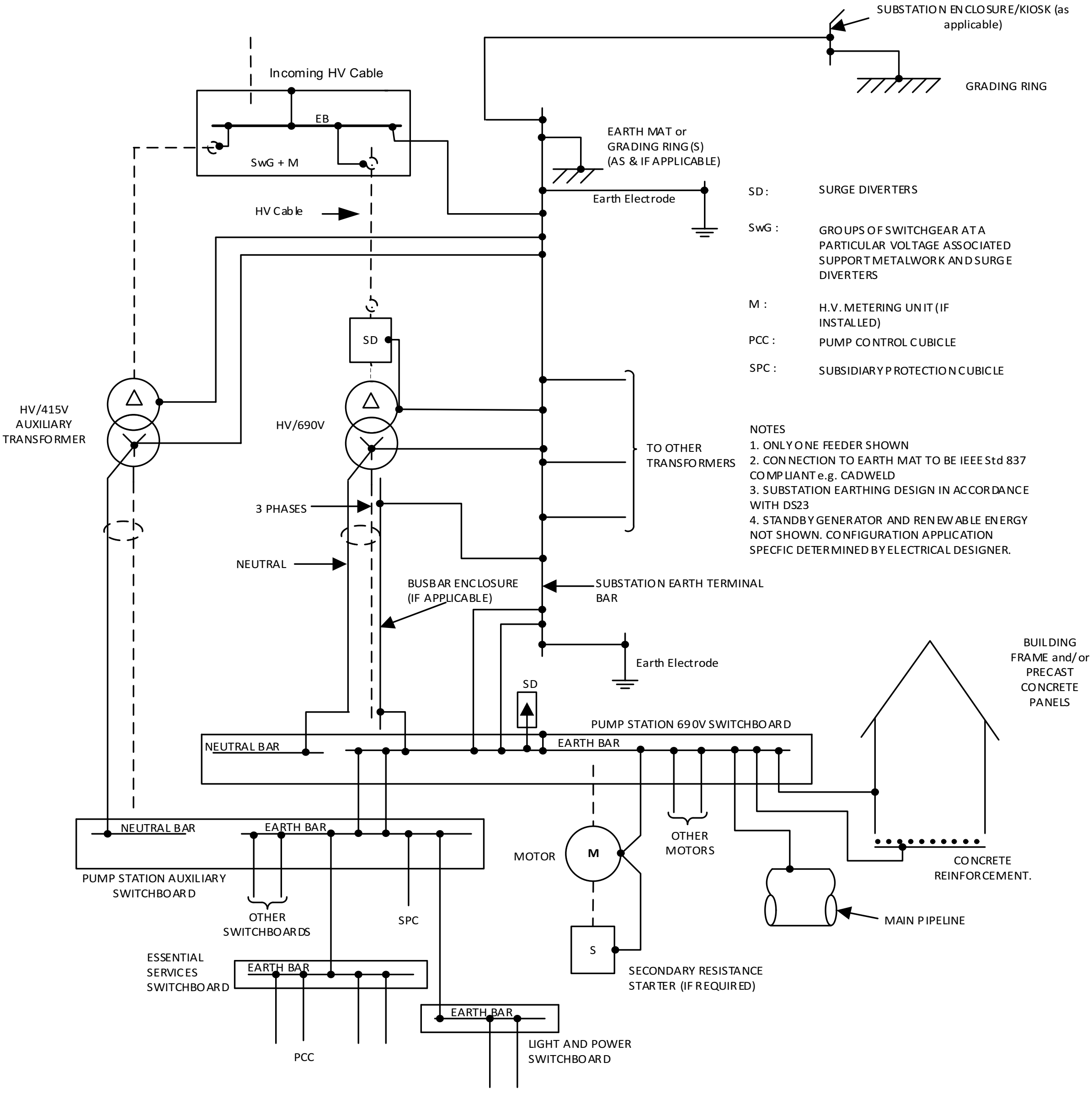


Fig. 11.1 (a) Major Earthing Connections for LV (415V) Supply from a Corporation Substation



SD : SURGE DIVERTERS

SwG : GROUPS OF SWITCHGEAR AT A PARTICULAR VOLTAGE ASSOCIATED SUPPORT METALWORK AND SURGE DIVERTERS

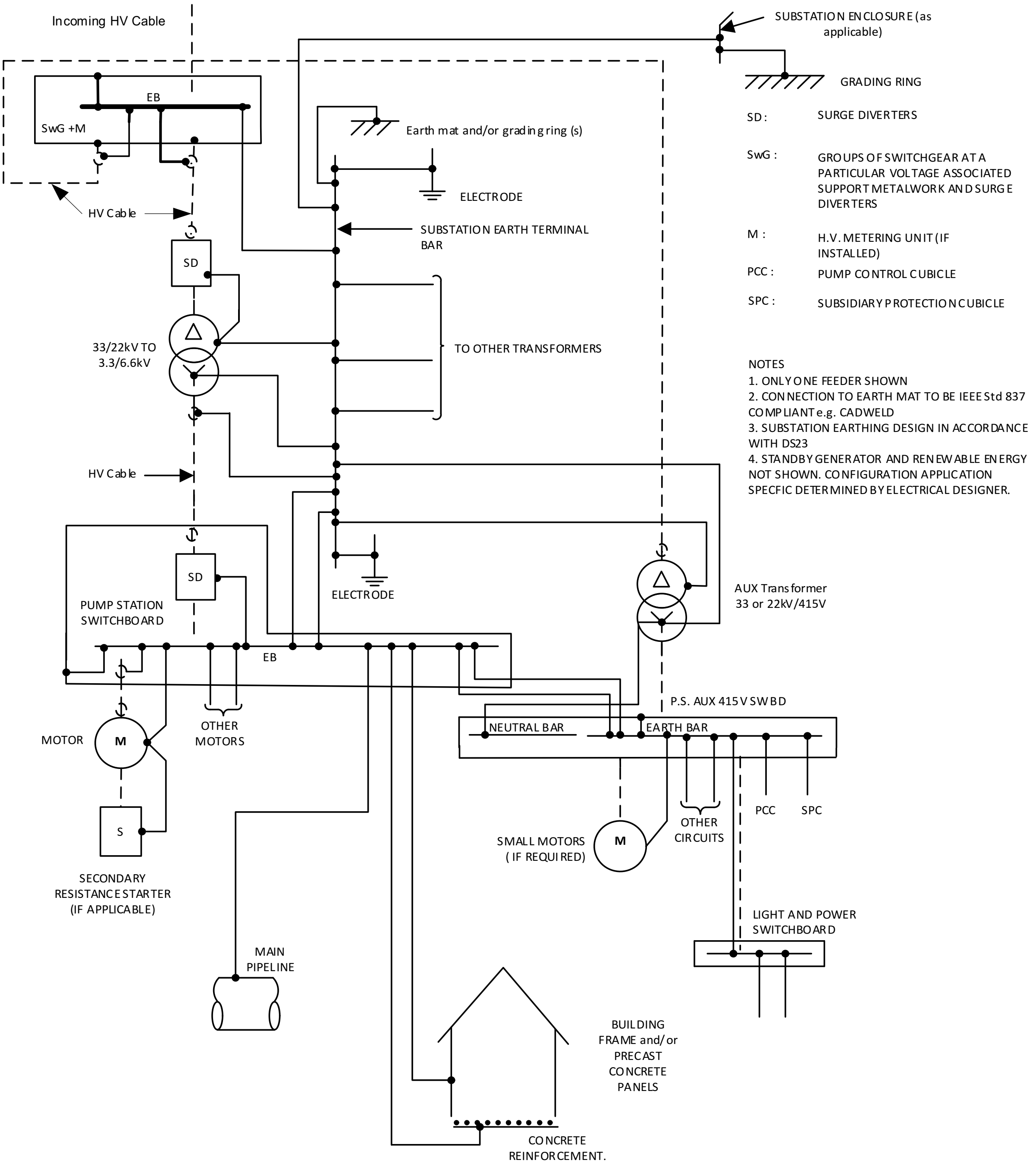
M : H.V. METERING UNIT (IF INSTALLED)

PCC : PUMP CONTROL CUBICLE

SPC : SUBSIDIARY PROTECTION CUBICLE

NOTES
1. ONLY ONE FEEDER SHOWN
2. CONNECTION TO EARTH MAT TO BE IEEE Std 837 COMPLIANT e.g. CADWELD
3. SUBSTATION EARTHING DESIGN IN ACCORDANCE WITH DS23
4. STANDBY GENERATOR AND RENEWABLE ENERGY NOT SHOWN. CONFIGURATION APPLICATION SPECFIC DETERMINED BY ELECTRICAL DESIGNER.

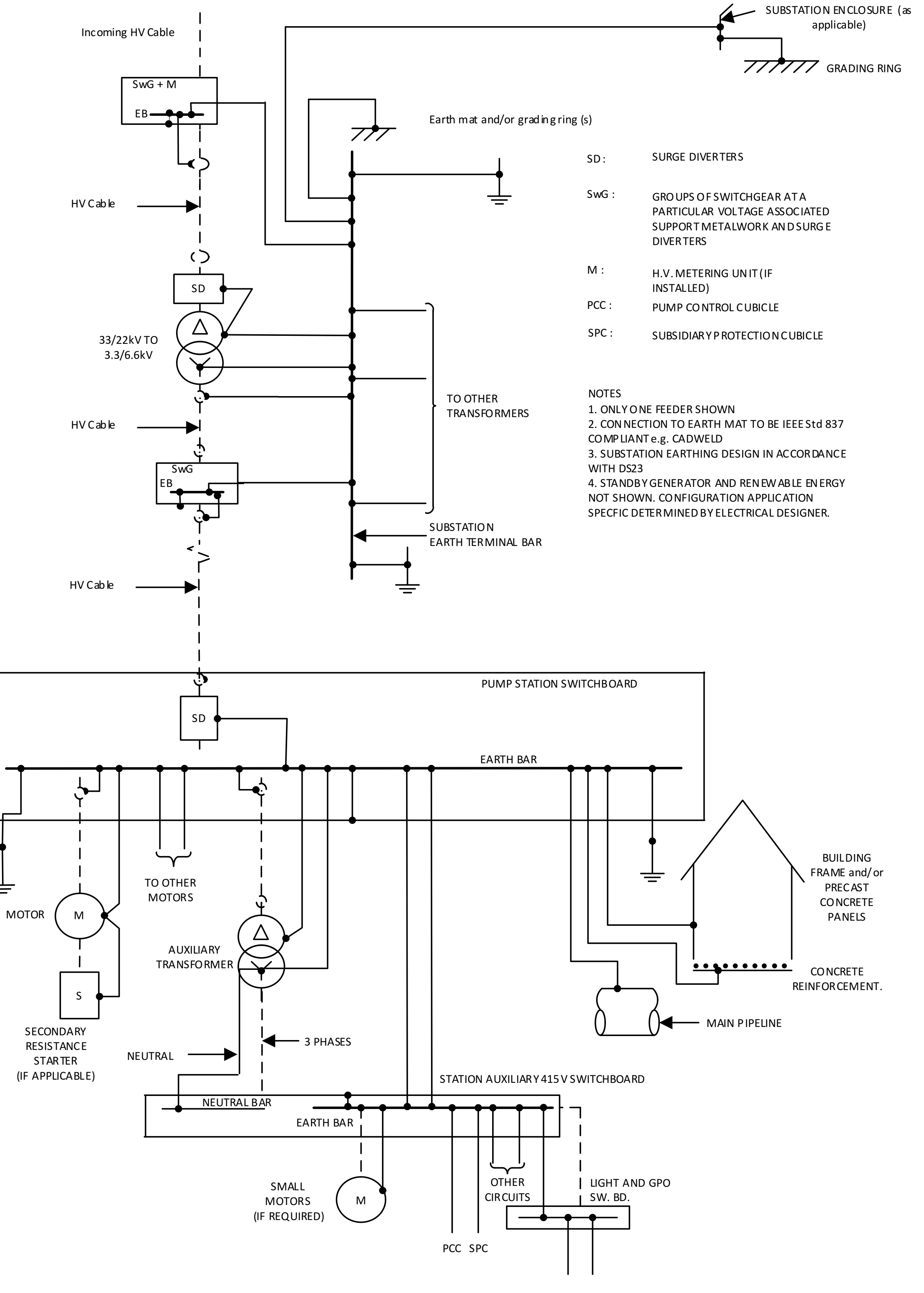
Fig. 11.1 (b) Major Earthing Connections for LV (690V) Supply from a Corporation Substation



SD :	SURGE DIVERTERS
SwG :	GROUPS OF SWITCHGEAR AT A PARTICULAR VOLTAGE ASSOCIATED SUPPORT METALWORK AND SURGE DIVERTERS
M :	H.V. METERING UNIT (IF INSTALLED)
PCC :	PUMP CONTROL CUBICLE
SPC :	SUBSIDIARY PROTECTION CUBICLE

NOTES
1. ONLY ONE FEEDER SHOWN
2. CONNECTION TO EARTH MAT TO BE IEEE Std 837 COMPLIANT e.g. CADWELD
3. SUBSTATION EARTHING DESIGN IN ACCORDANCE WITH DS23
4. STANDBY GENERATOR AND RENEWABLE ENERGY NOT SHOWN. CONFIGURATION APPLICATION SPECFIC DETERMINED BY ELECTRICAL DESIGNER.

Fig. 11.2 Major Earthing Connections for HV Supply from a Corporation Substation



SD :	SURGE DIVERTERS
SwG :	GROUPS OF SWITCHGEAR AT A PARTICULAR VOLTAGE ASSOCIATED SUPPORT METALWORK AND SURGE DIVERTERS
M :	H.V. METERING UNIT (IF INSTALLED)
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NOTES
1. ONLY ONE FEEDER SHOWN
2. CONNECTION TO EARTH MAT TO BE IEEE Std 837 COMPLIANT e.g. CADWELD
3. SUBSTATION EARTHING DESIGN IN ACCORDANCE WITH DS23
4. STANDBY GENERATOR AND RENEWABLE ENERGY NOT SHOWN. CONFIGURATION APPLICATION SPECFIC DETERMINED BY ELECTRICAL DESIGNER.

Fig. 11.3 Major Earthing Connections for HV Supply from a Remote Corporation Substation

Note: This arrangement shall only to be used if an EPR study confirms that safety voltage limits, touch and step voltages limits determined by the application of Design Standard DS23 by the specialist earthing design consultant, are met.

Note: “Remote” shall generally be greater than 50 metres.

11.5 Labelling on Earthing Cables

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

11.6 Earthing of Pipelines

11.6.1 Above Ground Steel Pipelines

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

If insulated flanges are fitted as shown in Fig 11.4, 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.

<u>Note</u>: The appropriate application of an ISP or GI, such as those from Dairyland Electrical Industries (D.E.I.), will provide DC isolation and AC 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.

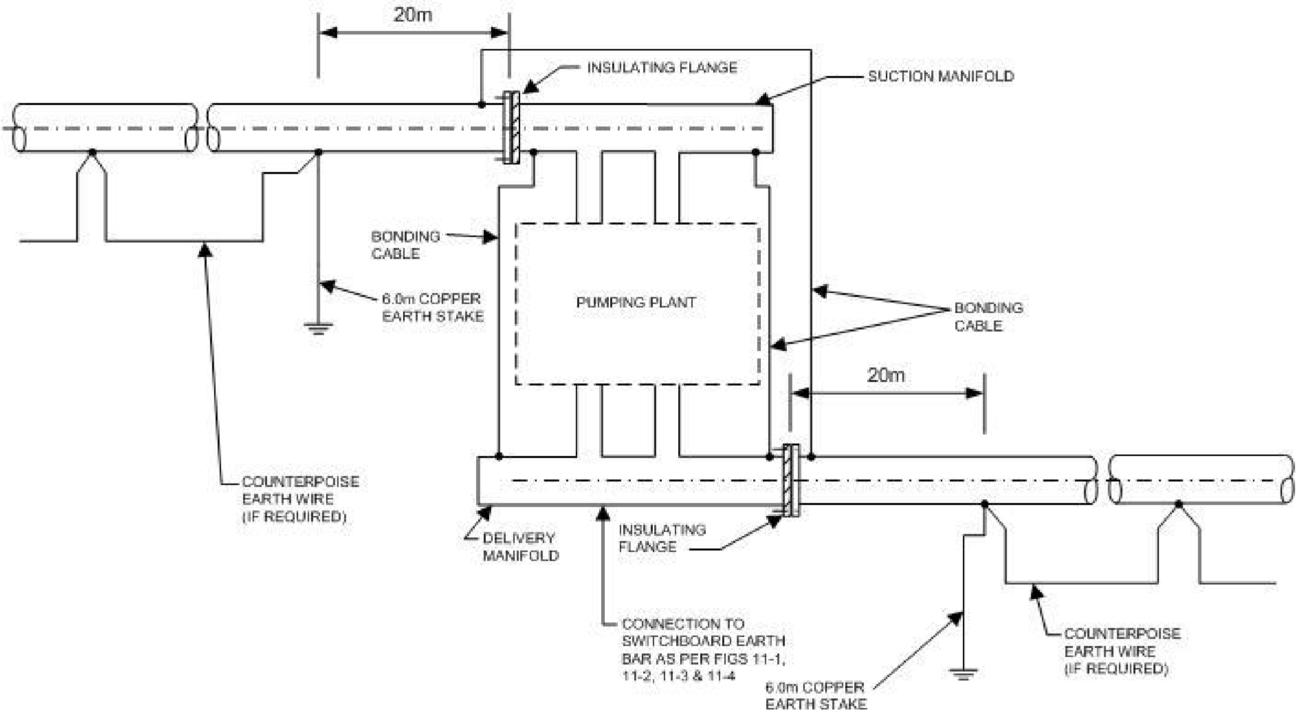


Fig 11.4 Earth and Bonding Requirements for Above Ground Pipeline Connection

11.6.2 Below Ground Steel Pipelines

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

Insulated joint protectors (IJP) with a rated DC breakdown voltage of 500 V shall be fitted across the insulating joints in below ground pipelines to limit the surge voltage that can appear across the pipeline joint to less than 1000V.

Note: IJPs are provided for buried insulating joints rather than ISPs or GIs as the insulating joints are not readily accessible.

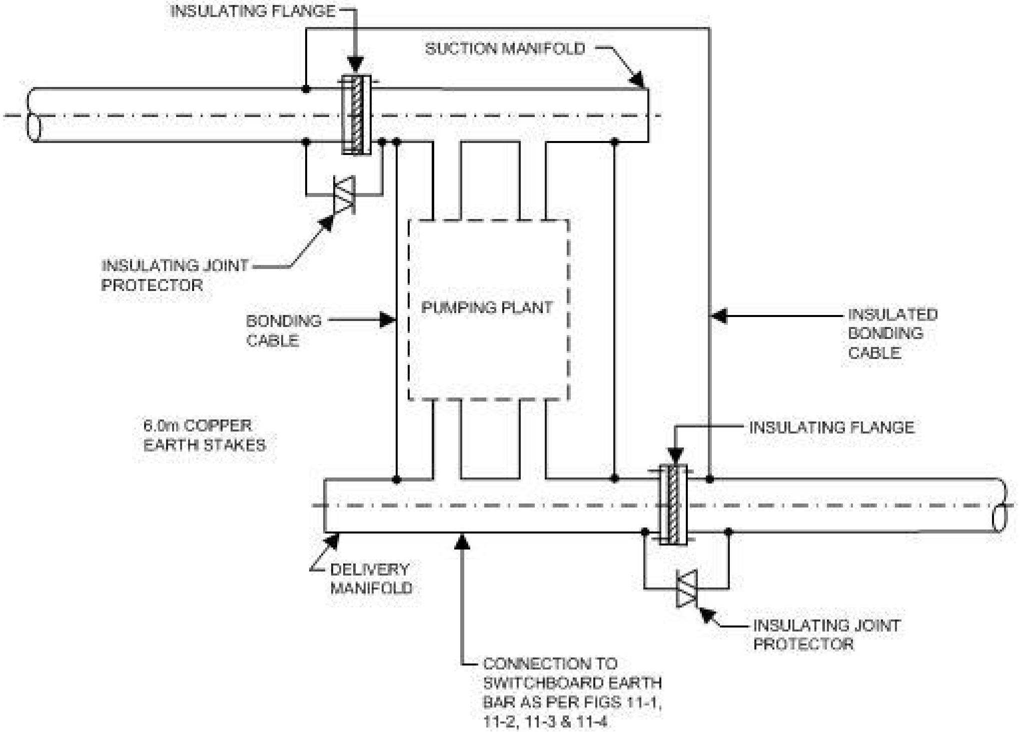


Fig 11.5 Earth and Bonding Requirements for Below Ground Pipeline Connection

11.6.3 AC Voltage Mitigation on Steel Pipelines

Water Corporation metallic pipelines located in the vicinity of and/or within the same easement as High Voltage transmission and High Voltage distribution power line(s) may be subject to unacceptable touch voltages.

The Designer shall ensure that studies are carried out to investigate, analyse, mitigate by design and verify by testing as required, any exposure to touch voltage hazards by the public and Corporation personnel through the application of the Corporation's Design Standard DS23 'Pipeline AC Interference and Substation Earthing' or as directed by the Principal Engineer.

The AC interference analysis and mitigation design shall be carried out by a specialist AC interference/earthing design consultant from the approved panel of specialist earthing design consultants.

11.6.3.1 Introduction

Inductive, conductive (ground current coupling) and capacitive coupling between the above ground power lines and metallic pipelines can result in operational personnel or the public being exposed to hazardous touch voltages.

The Corporation's Design Standard DS23 'Pipeline AC Interference and Substation Earthing' outlines the process for determination of permissible touch voltages and the requirements dealing with the mitigation of any dangerous touch voltages. AS/NZS 4853 places the onus on the pipeline owner or operator to ensure the application of the standard.

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

11.6.3.2 Inductive Coupling Hazard.

In joint use corridors, or separate parallel corridors, where both metallic pipelines and power lines are present a portion of the energy contained in the magnetic field surrounding the High Voltage power line is captured by the pipeline resulting in induced AC voltages which vary in magnitude throughout the length of the pipeline.

Voltages will appear on the pipeline both during the steady state and the transient state (fault condition) however the voltage present during the transient state will be considerably more severe. A touch voltage hazard exists between the earth and the pipeline.

11.6.3.3 Conductive Coupling Hazard.

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

11.6.3.4 Capacitive Coupling Hazard.

Pipelines suspended above the ground underneath High Voltage power lines are subject to capacitive coupling.

The voltage (with respect to earth) on the suspended pipe section, due to the strong electric field from the power line, can be quite high and a person touching the pipe provides a much lower resistance path to earth and therefore subject to hazardous voltages and currents.

This hazard is usually only of concern during construction when the pipe sections are lifted into position. The capacitive effect of installed pipes is normally negligible compared to the inductive and conductive effects.

11.6.3.5 Mitigation.

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

11.6.3.6 Interaction with Cathodic Protection Design.

There is a direct dependency between the voltage mitigation system analysis/design and the cathodic protection system design.

Critical cathodic protection design information must be conveyed to the specialist earthing design consultant in order for the specialist earthing designer to complete an accurate model (and accurate design) of the system. Such information relates to whether bonds will be applied across rubber ring joints, whether cathodic protection is sacrificial or current impressed, whether pipe sections must be isolated, etc.

The specialist earthing design consultant shall take such information into consideration during the analysis and design of the voltage mitigation system and ensure that compatibility is maintained with the cathodic protection design.

11.7 Earthing of 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.

The earthing and bonding at water tanks shall comply with the requirements documented in DS22 clause 9.9 “Earthing and Bonding at Water Tanks”.

11.8 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.

11.9 Earthing of Pipeline Mounted Instrumentation

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

Reference shall be made to SCADA Design Standards series DS 40 in regard to the requirements for earthing electronic instrumentation transducers.

11.10 Earth Bonding of Pump Station Internal Pipework

Electrical cable bonds shall be provided across all pump station pipework equipment including pumps, valves, flexible joints and pipeline mounted instrumentation except for items of equipment that are connected by insulated pipeline joints.

Insulated joint protectors (e.g., Dairyland Electrical Industries type) shall be provided across insulated pipeline joints to provide AC continuity. (Typically, insulated joints are installed in pipelines to provide DC isolation for cathodic protection purposes.)

11.11 Earth Bonding at External Valve and Meter Pits

All metalwork at valve and/or meter pits shall be bonded together as shown in Fig. 11.6, to protect electrical plant against damage and for personnel safety.

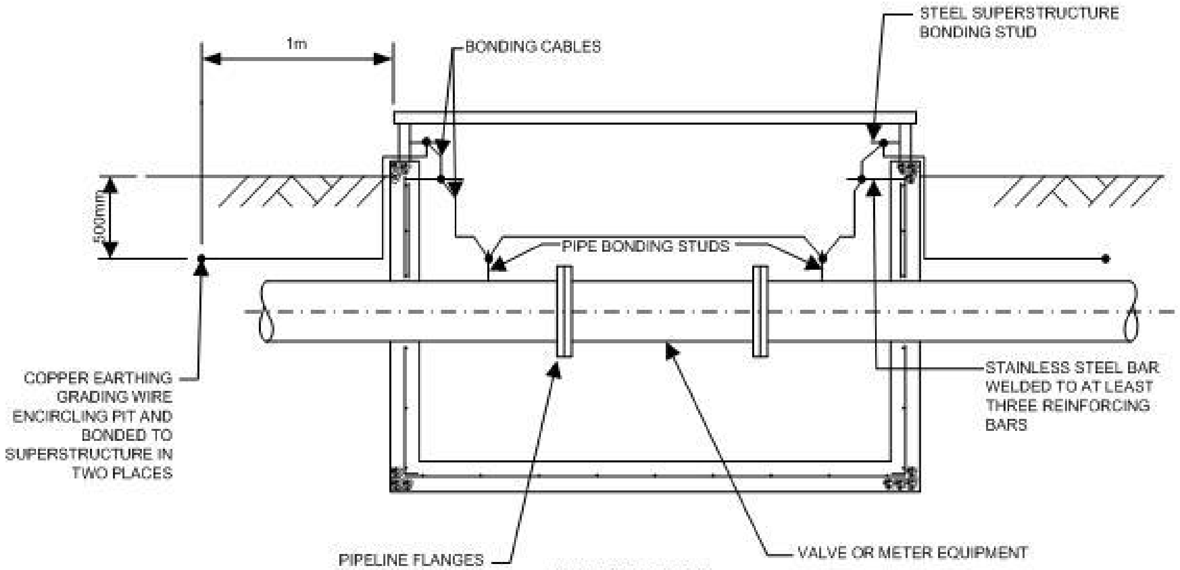
For buried valves (refer Fig. 11.6) the valve body shall be connected to a grading ring encircling (1m radius) the spindle and buried 500mm deep. For buried valves or flowmeter, a bonding cable shall be installed across each device.

Sacrificial anode cathodic protection may be required in some instances in order to inhibit increased galvanic corrosion of steelwork due to the copper/iron couple. This shall be investigated on a site-by-site basis and may require special measures including selective application of insulated joint protectors or isolator/surge protectors (ISP) or galvanic isolators (GI).

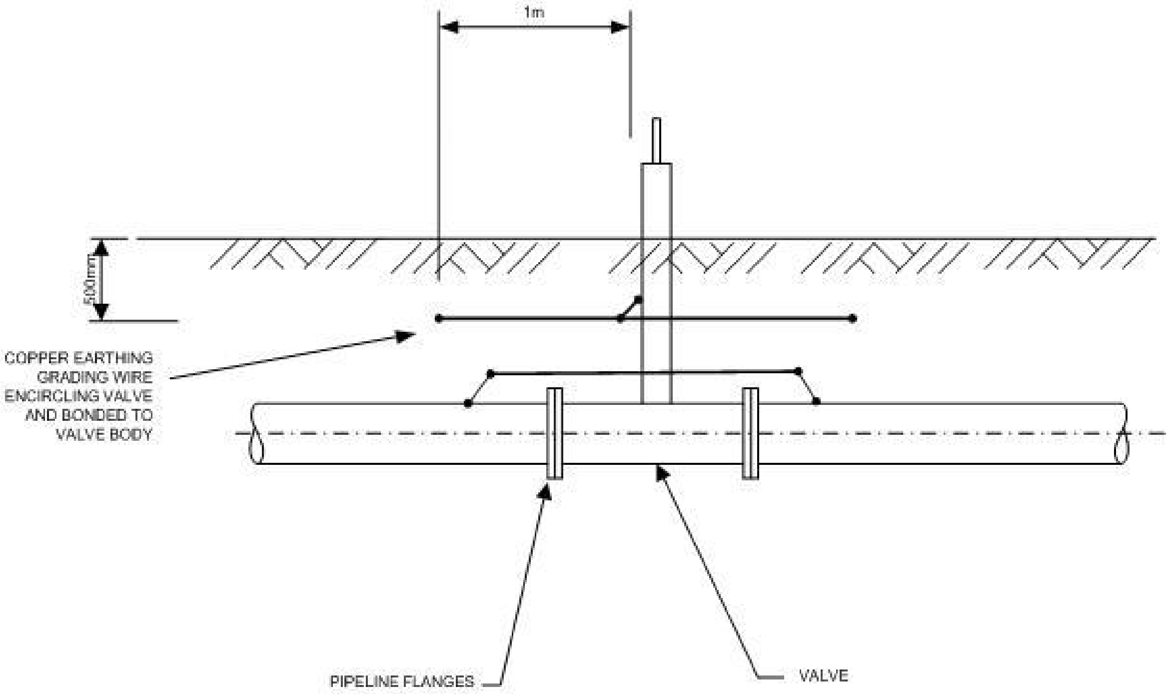
The appropriate application of an ISP or GI, such as those from Dairyland Electrical Industries (D.E.I.), will provide DC isolation and AC continuity. These ISP/GI’s have standard peak blocking levels between 10 Volts and 20 Volts and are intended for safe electrical isolation of cathodically protected systems subject to 50Hz power faults, systems which are coupled to an AC source and systems subject to lightning transients.

Note: For general applications the grading ring shall be deployed as indicated below. For applications subject to an AC Interference study, the design of the ring/mat shall be in accordance with the pipeline Voltage Mitigation design by the specialist earthing design consultant.

For specific details refer to standard drawings EG20-5-4 and EG20-6-7.



VALVE OR METER IN PIT



VALVE DIRECT BURIED

Fig. 11.6 Valve and Meter Bonding/Earthing Arrangements

11.12 Earthing and Bonding of Concrete Reinforcing Steel

Earthing and Bonding of Concrete Reinforcing Steel requirements:

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

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

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

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

(e) Since concrete has a relatively low resistivity, electrically bonded reinforcing steel in concrete members which are in direct contact with the ground will reduce the overall electrical earth ground resistance and can be of a significant benefit in this regard

However, 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 situations the concrete reinforcing steel must be isolated from the power system electrical earth, hence a galvanic isolator (e.g., Dairyland Electrical Industries type) shall be connected between the reinforcing steel and the power system electrical earth.

11.13 Earthing and Bonding of Fences

Any sections of metallic fencing located under aerial High Voltage lines shall be earthed to the pump station High Voltage earthing system or to separate earthing points as determined by the specialist earthing design consultant by two earthing connections, one either side of the point where the High Voltage aerial line crosses the fence line.

Metallic fencing earthing/bonded to the pump station earth system shall be as directed by an EPR study in accordance with DS23, carried out by the specialist earthing design consultant, confirming that touch voltages and transferred voltages are within safe limits.

11.14 VSC System Applications - Earthing and 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 VSC installations. The Designer shall consult these standards and apply such EMC techniques as demanded by the installation configuration.

11.14.1 Variable Speed Drive Motor to Pump Bonding

As described in clause 4.4.12.1 of this Design Standard, unless common mode voltage filtering is provided, a pulse width modulated voltage supply to a motor will cause circulating currents of the following types:

(a) Circulating currents

(b) Capacitive discharge currents

(c) Shaft earthing currents

Countermeasures against circulating currents and capacitive discharge currents are addressed in clause 5.15.4.7 and clause 7.4.3/4 of DS22.

To minimise the risk of pump bearing failure, the best countermeasure against shaft earthing currents is the use of an insulated motor to pump shaft coupling. However, if this is not practical or is not desirable a solution is to install a high frequency bond between the motor stator and the pump casing.

Such high frequency bonds shall:

(a) Be of flat braided copper strap

(b) A cross sectional area not less than 70 mm^2

(c) Be a short as is practical and

(d) Have a length to width ratio of not more than five

11.14.2 VSC Earthing and Bonding Practice

Sound earthing and bonding design and practice 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.

Mitigation measures, to ensure electromagnetic compatibility compliance, shall be considered by the Designer during the design stage.

Such earthing and bonding measures shall include:

(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 360° 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 13 of this standard and clause 10 of DS22

(g) Maintain good separation of cabling as specified in clause 10.7 of DS22

(h) VSC conductive sealing at the enclosure door

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

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

12 INSULATION CO-ORDINATION

12.1 General

12.1.1 Background

Insulation coordination is the correlation of the insulation of electrical equipment with the characteristics of protective surge diverters such that the insulation is protected from excessive voltages. Thus, in a substation, the insulation of transformers, circuit breakers, busbar supports, etc. shall have insulation strength in excess of the voltage levels that can be provided by protective equipment such as surge diverters.

The level of excessive impulse/surge voltages is unknown for all sites, so in order to protect substation equipment, surge diverters shall be installed at all substations (aerial, indoor, padmount etc.). The insulation coordination study determines the most suitable rating and location to ensure the insulation of substation equipment is protected during severe impulses/surges. It is a reasonably complex area of electrical engineering where surge diverter residual voltage characteristics, connection arrangement, location, cable length, characteristic impedance changes (especially at the worst case of transformer terminals) and earth fault factor play a critical role in the appropriate selection of surge diverters.

Suitably selected surge diverters shall be located at the transformer primary HV terminals with the total cabling less than 1 metre in length and the earth side connected to the transformer tank (Clause 7.14.7 refers).

A detailed insulation co-ordination investigation and design shall be carried out to ensure that the risks of insulation failure due to lightning and switching surges is minimised. Such design shall match surge protection levels and insulation impulse withstand levels including adequate safety margins and shall take into account the connection and positioning of earthing conductors. Reference shall be made to IEC 60071-1 Insulation Co-ordination - Part 1: Definitions, Principles and Rules and IEC 60071-2 Insulation Co-ordination - Part 2: Application Guidelines.

12.1.2 Self-Restoring and Non-Self-Restoring Insulation

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

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

Non-self-restoring insulation, on the other hand, is permanently damaged and degraded by overvoltage failure. Motor and transformer winding insulations are examples of non-self-restoring insulation.

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

12.1.3 Types of Overvoltage

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

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

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

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

As illustrated in the figure below, surge diverters play a critical role by keeping the voltage (lightning and switching overvoltage) at a level that is below the withstand voltage of the equipment, by an adequate safety (protective) margin. However, surge diverters are ineffective to limit oscillatory power frequency temporary overvoltage (TOV) and must be designed/selected to withstand such temporary overvoltage, together with the maximum operating voltage of the system, without sustaining damage.

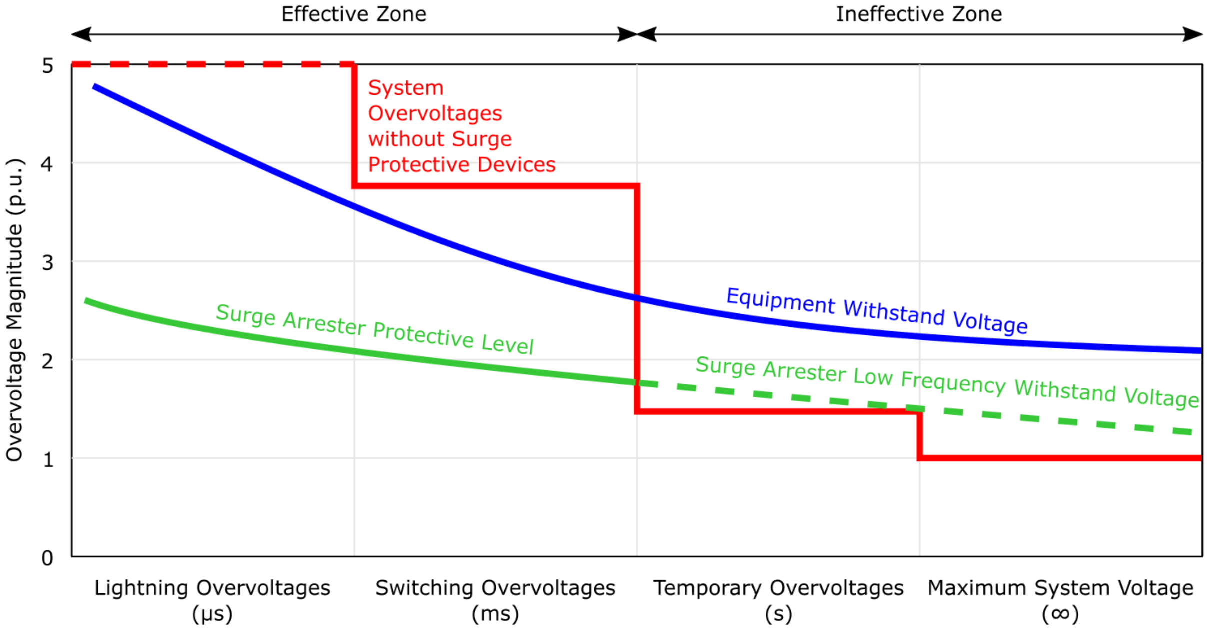


Figure 12.1. Types of Overvoltage vs Diverter Effectiveness

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

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

12.2 Types of Overvoltage Protective Devices

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

12.2.1 Rod Gaps

Rod gaps are the simplest and cheapest form of surge diverter. However, such devices have several shortcomings, as discussed hereunder.

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

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

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

Rod gaps shall not be deployed on Corporation assets.

12.2.2 Gap Type Surge Diverters

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

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

12.2.3 Gapless Surge Diverters

A surge diverter having several non-linear metal-oxide (ZnO) varistors with highly non-linear voltage-current characteristics, connected in series, but having no integrated series or parallel spark gaps.

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

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

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

12.2.4 Hybrid Surge Diverters

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

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

12.3 Performance Characteristics of Gap Type Surge Diverters

The protective level of gap type surge diverters shall be determined in accordance with the voltage ratings specified in IEC 60099 for 2.5 kA, 5 kA and 10 kA light duty diverters and shall be defined as which is the greater of the following:

(a) The highest front of wave spark over voltage divided by 1.15

(b) The highest standard lightning impulse spark over voltage or

(c) The highest residual voltage at nominal discharge current

12.4 Performance Characteristics of Gapless Surge Diverters

The relevant characteristics of gapless surge diverters shall be in accordance with IEC 60071-4 Surge arresters - Part 4: Metal-oxide surge arresters without gaps for a.c. systems.

The voltage-current (V-I) characteristic illustrates how a surge diverter's resistance varies with voltage, whilst also providing insights into its operation. The highly non-linear V-I characteristics of the metal oxide varistor makes it suitable for surge protection application. The varistor's resistance depends inversely on the applied voltage i.e., the greater the voltage, the lower the resistance.

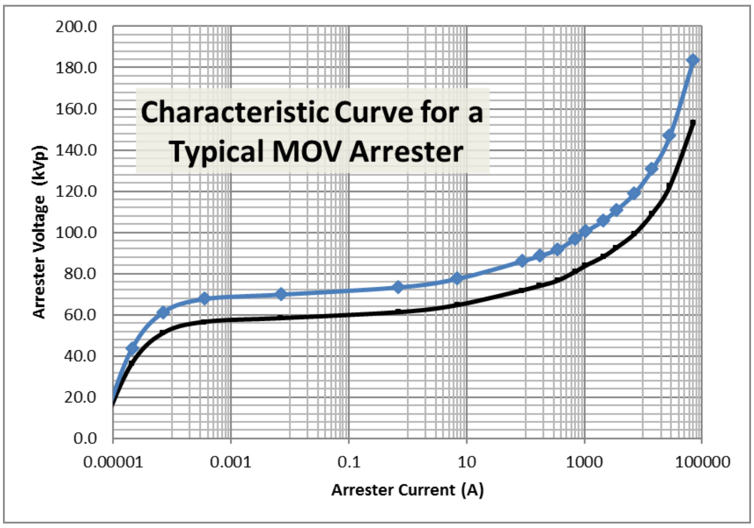


Figure 12.2. V-I Characteristic Curve

Note: Blue & black curves represents different MCOV rating.

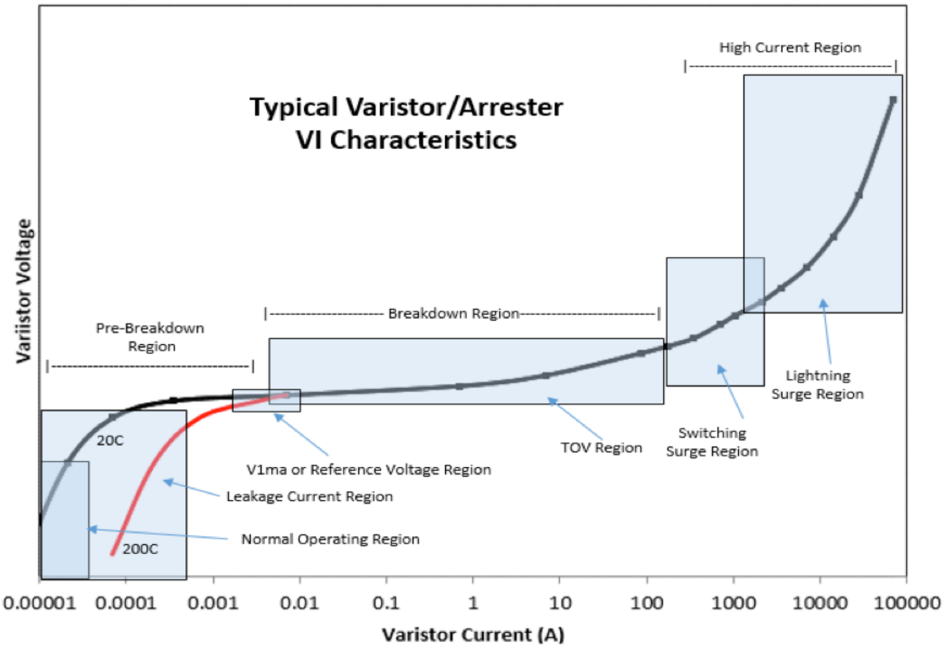


Figure 12.3. V-I Curve Showing Voltage Regions

12.5 Performance Characteristics of Hybrid Surge Diverters

The performance characteristics of the Siemens 3EF hybrid surge diverters, for example, are:

(a) Power frequency rated voltage

(b) Continuous operating voltage

(c) Maximum 5/200 µs impulse sparkover voltage

(d) Maximum discharge residual voltage with 0.5 kA 30/60 µs impulse current

(e) Energy absorption capacity kJ/kV of rated voltage

The power frequency rated voltage is defined as the maximum permissible power frequency voltage which may occur in case of an earth fault.

The continuous operating voltage is defined as the maximum permissible continuous power frequency voltage to earth during normal operation.

The protective level of the Siemens 3EF hybrid surge diverter can be defined as the greater of the following:

(a) Maximum 5/200 µs impulse sparkover voltage

(b) Maximum discharge residual voltage with 0.5 kA 30/60 µs impulse current

12.6 Pressure Relief and Explosion Resistance

Power frequency over voltages in excess of the minimum power frequency residual voltage, long time surge current impulses and direct lightning strokes can all cause a surge diverter short circuit.

IEC 60099-4 defines Design A gapless surge diverters as those units having an enclosed volume of gas in excess of 50% of the volume of the enclosed volume of the diverter housing. These surge diverters typically have enclosures made of porcelain or similarly brittle polymer material.

Gap type inverters also have a significant volume of enclosed gas.

If a short circuit occurs in a gap type surge diverter or in a Design A gapless surge diverter the resulting internal arc and associated increased internal gas pressure will result in violent shattering of the diverter housing unless the design of the enclosure includes some means of pressure relief. The risk being surge diverter housing explosions can cause extensive secondary damage as they are usually located near other electrical equipment.

Some such surge diverters are provided with specific pressure relief devices while others have enclosures with prefabricated weak spots to limit the extent of shattering of the enclosure.

Gap type surge diverters and Design A surge diverters shall be permitted only if fitted with specific pressure relief devices.

IEC 60099-4 defines Design B gapless surge diverters as those units having an enclosed volume of gas less than 50% of the volume of the enclosed volume of the diverter housing. Typically Design B gapless surge diverters have no enclosed volume of gas and have enclosures made of shatter resistant material, thus avoiding the possibility of violent shattering.

Generally, Design B gapless surge diverters are preferred.

12.7 Surge Impedance

12.7.1 Definition

Surge impedance is defined as the square root of the conductor per unit series inductance divided by the conductor per unit shunt capacitance,

i.e. $\mathbf{Z_0 = (L_C/C_C)^{0.5}}$ **Ohms**

12.7.2 Cable Surge Impedance

The surge impedance of a cable is typically 50 Ohms.

12.7.3 Line Surge Impedance

An overhead line has characteristic surge impedance, depending on its inherent series inductance, and shunt capacitance.

The surge impedance $\mathbf{Z_O = 138 \ Log \ [2h \ (ar)^{-\frac{1}{2}}]}$ **Ohms**

Where: h = height of conductor above ground, m

r = radius of each phase conductor, m

a = intra-phase conductor separation, m

(= r, if single conductor per phase)

The above expression assumes a long line and consequently can only be applied where end effects will be negligible, i.e., line lengths of greater than 100h, say 1 km.

The surge impedance of an overhead line is typical 500 Ohms.

12.7.4 Transformer Surge Impedance

The surge impedance of a transformer winding is typically 5000 Ohms.

12.8 Application of Surge Diverters

12.8.1 Effect of Cable Length

When a lightning surge propagated along an overhead line impinges on a cable, the latter acts substantially as a capacitor and the steepness of the original surge is reduced as the surge enters the cable (because of the cable's lower surge impedance). Nevertheless, because of the transformer's large surge impedance, the surge will be reflected at the transformer terminals, thus building on the incoming surge and increasing the voltage to earth. This process will be repeated when the return surge reaches the overhead line, and so on.

The Designer shall carry out design calculations to determine if the surge diverters will limit the surge voltage at the end of a cable to no more than 80% of the rated lightning impulse withstand voltage (LIWV) of the connected equipment including the cable terminations (i.e., a 25% safety margin – refer clause 12.8.3 below). If the cable length is too long to make these practical, additional surge diverters shall be installed at the equipment end of the cable. *Note: In any case, all transformers shall be fitted with surge diverters as discussed in clause 7.14.7 and 3.10.*

12.8.2 Selection of Surge Diverter Power Frequency Voltage Rating

The maximum power frequency voltage that can be developed at a surge diverter during an earth fault depends on the ratio of system positive and zero sequence impedances, assuming an earth fault at the surge diverter location on another phase.

IEC 60099-5 Annex A details the method for determining power frequency over voltages due to earth faults. It should be noted that the system neutral earthing resistance has a major effect, and care should be taken that realistic values of same are used in such calculations. Care must also be taken to ensure that the scale factors derived from IEC 60099-5 Annex A are applied to the maximum system voltage, not the nominal system voltage.

Power frequency over voltages can be caused by sudden load shedding as described IEC 60099-5 clause 2.2.1. On extended systems the system phase to earth over voltage may be as high as 1.5 per unit.

For a rural 33 kV effectively earthed system, surge diverters installed at pump stations shall be specified to have a maximum continuous operating voltage rating of 30 kV, unless detailed calculations have been made to indicate that a lower figure would be adequate.

For a similar 22kV system, a diverter maximum continuous operating voltage rating of 20 kV would be appropriate, unless detailed calculations have been made to indicate that a lower figure would be adequate.

For pump station 6.6kV systems, surge diverters shall be specified to have a maximum continuous operating voltage rating of 7.2kV.

12.8.3 Selection of Equipment LIWV Rating

The lightning impulse withstand voltage (LIWV) rating of protected equipment shall be not less than 1.25 ET kV, where ET is the equipment terminal maximum surge voltage, kV.

12.8.4 Protective Range

Where the incoming Network Operator overhead line is on wooden or unearthed cross arms, surge diverters connected directly to the line shall be located within 1 metre of the equipment to be protected by the surge diverters. In such circumstances the earth connection from the surge diverters shall be made directly to the frame of the equipment to be protected and hence to earth.

Where the incoming Network Operator overhead line is on earthed steel cross arms, surge diverters connected directly to the line may be located not more than 15 metres away from the equipment to be protected by the surge diverters. If the equipment to be protected is on the same pole as the surge diverters, the earth connection from the surge diverters shall be made directly to the frame of the equipment to be protected and hence to earth.

If the equipment to be protected and the surge diverters are on different poles, the earth connection from the surge diverters and the earth connection from the frame of the equipment to be protected shall be run separately and directly to the substation earth mat.

Surge diverters shall be installed at all HV cable to overhead line cable terminations.

12.8.5 Discharge Current Rating

Surge diverters fitted to 33 kV or 22 kV systems shall be rated for a discharge current of 10 kA.

12.9 Selection and Configuration of Surge Diverters

The general philosophy when selecting surge diverters for any system, entails matching the electrical and mechanical characteristics of the diverter with the system's electrical demands and mechanical requirements. The following simplified flow chart, figure 12.4, demonstrates the general method and procedure for configuring a metal oxide diverter. More detail is shown in IEC 60071.1.

The requirements for optimal and satisfactory selection of surge diverters dictate that surge diverters should provide an adequate protection margin and that they should also be suitable for stable continuous operation. An 'adequate protection margin' means that the device overvoltages are always below its withstand voltage, with a sufficient safety factor (safety margin). Whereas 'stable continuous operation' refers to the surge diverter's ability to handle all long-term, temporary, or transient stresses (which can be caused by system operation), whilst remaining electrically and thermally stable throughout its useful working life.

Unfortunately, both the adequate protection margin and stable continuous operation cannot be satisfied independently. A reduction in the diverter's protective level (to provide a greater protective margin) inevitably results in higher electrical stresses during continuous operation. Also, the rated voltage of the diverter cannot be increased arbitrarily without raising its protective level (which results in a corresponding decrease in the protective margin). Thus, a compromise is necessary, where both requirements are balanced to arrive at an optimal solution.

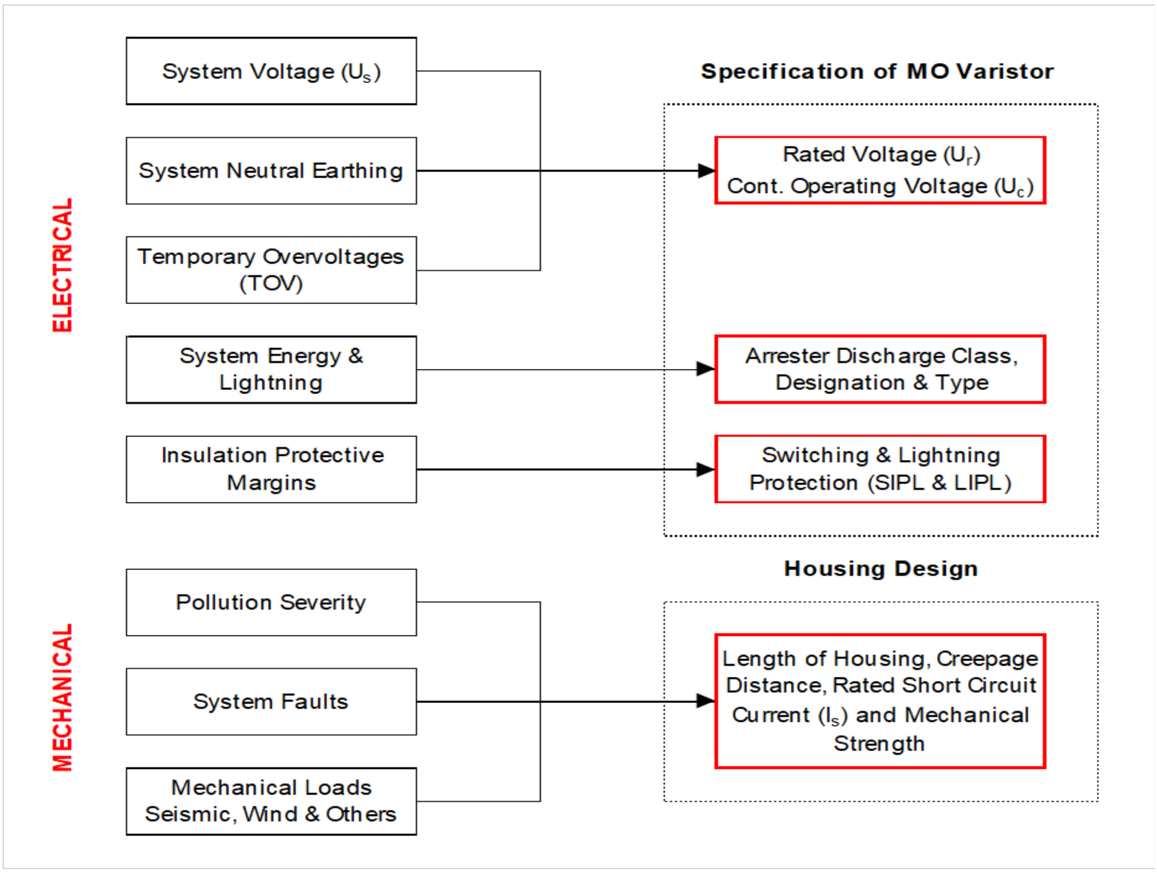


Figure 12.4. Flow Chart – Diverter Selection

12.10 Insulation Coordination Report

The Designer shall prepare a comprehensive Insulation Coordination report addressing the essential criteria of protection, surge diverter selection and surge diverter location.

The report shall address, as a minimum, the following items:

(a) The calculated lightning impulse level at the transformer terminals and how this compares to the LIWV of the transformer

(b) The calculated lightning impulse level at the other HV equipment terminals and how this compares to the LIWV of the equipment

(c) A statement regarding the safety margin achieved (Corporation requires 25% where possible)

(d) The calculated earth fault factor at the installation

(e) The calculated AC voltage rating of the surge diverters. (Based on the earth fault factor, EFF)

(f) Drawing showing location of surge diverters

(g) Surge diverter type/model selected and its associated performance parameters such as:

  (i) Maximum system voltage U_S

  (ii) Maximum continuous operating voltage, MCOV, U_C

  (iii) Rated voltage (temporary over voltage) U_R for 10 seconds

  (iv) Peak residual voltage at a discharge current peak of 10 kA 8/20 µs wave

  (v) Creepage distances

  (vi) Mechanical details

  (vii) Other relevant electrical characteristics

(h) All assumptions

(i) Detailed discussion regarding the simulation/study outcome, design and any special considerations

(j) Discussion of any non-compliance issues

13 CABLES.

13.1 Cable Types

13.1.1 Conductor Type

All cables shall have copper conductors.

13.1.2 Cables for Specific Purposes

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

APPLICATION	CABLE TYPE
Light current switchboard cables	Refer DS26-09
Conventional LV Motor Stator Cables (Refer note 5)	Single core XLPE insulated PVC sheathed cables installed in ducts in trefoil groups.
Starter Resistor Cables (within cubicle)	R-S-150 insulated, glass fibre braided, single core (size and voltage rating to suit).
HV Motor Stator Cables (6.6kV and 11kV)	Single core XLPE insulated 3.8/6.6 kV or 6.35/11kV cables constructed with copper conductor, semi-conducting screen, XLPE insulation, semi-conducting screen, light duty copper screen, PVC sheath overall. Cables to be run in trefoil groups. The conductor size not to be less than 25mm^2 and screen size not to be less than 16mm^2.
HV Motor Rotor Cables	Single core XLPE insulated cables constructed with copper conductor, semi-conducting screen, XLPE insulation, semi-conducting screen, light duty copper screen PVC sheath overall. Cable voltage rating to be one increment higher than the relevant motor rotor open circuit voltage.
Incoming cables to transformer HV terminals and/or incoming cables to 33/22 kV HV switchboards (Refer notes 1,2, and 3)	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.
Incoming cables to 6.6 kV switchboards (Refer notes 1,2 and 3)	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.
Substation earthing conductor	1 core PVC (green with yellow stripe), sized 70mm^2 minimum.
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 and grading wire (Refer note 6)	35mm^2 stranded bare hard drawn copper conductor.
Cables connecting Low Voltage (≤690V) variable speed controller converters to associated isolating transformers (Refer note 4)	Symmetrically shielded 3 phase cable(s) rated 0.6/1 kV and as described further clause 13.1.3 hereunder.
Low Voltage (≤690V) variable speed controller PWM output cables	Symmetrically shielded 3 phase cable(s) rated 0.6/1 kV as described further clause 13.1.3 hereunder.
Cables connecting High Voltage (≤6600 V) variable speed controller converters to associated isolating transformers (Refer note 4)	Symmetrically shielded 3 phase cable(s) rated 3.8/6.6kV, and as described further clause 13.1.3 hereunder.
High Voltage (≤6600 V) variable speed controller 9 level PWM output cables	Symmetrically shielded 3 phase cable(s) rated not less than 120% of the controller nominal maximum rated output voltage, and as described further clause. 13.1.3 hereunder.

Note 1: Applies to cable buried direct or cables in buried PVC conduit buried. Cables installed in ducts within the confines of the building may be specified without termite protection.

Note 2: When cables are installed in conduits, the conduits shall be 150mm in diameter.

Note 3: Parallel runs of buried HV power cable shall not be placed in the same trench as this reduces security of supply.

Note 4: Not required if RFI suppression scheme is fitted to the variable speed controller.

Note 5: Cables shall be rated for the full load current of the motor.

Note 6: If 35mm2 bare hard drawn copper conductor is not available, 70mm2 soft drawn copper may be used if approval is granted by the Principal Engineer.

13.1.3 Cables for Variable Speed Controller (VVVF)

The correct selection of VSC cable and its screen performance is critical to the operation of the plant and reduction of electrical interference to other electrical equipment. Reference shall also be made to clause 10 of DS22 in this regard.

The basic variable speed controller cable requirements are:

(a) Variable speed controller cables referred to in clause 13.1.2 above 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^{o}C 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) For the minimum separation between power cables and signal cables and positioning refer clause 13.7.

(h) Converter input cables shall be derated to allow for the transformer secondary winding utilisation factor appropriate to the particular type of converter, i.e., for bridge connected converters, the converter input cables should have a site 50 Hz. rating of 125 % of the converter duty current rating of the converter transformer secondary winding.

13.2 Continuous Rating of Cables

13.2.1 General

The continuous current rating of power cables depends to a large extent on the rate that heat generated by cable losses can be dissipated. Various derating factors are applicable to take account of various ambient parameters. Reference shall be made to AS3008 Electrical Installations - Selection of Cables, and to the Electrical Research Association document “Current Rating Standards for Distribution Cables, Parts I and III”, for the applicable derating factors.

13.2.2 Increase in Effective Resistance Due to Harmonic Currents

Cable resistance values published in AS 3008 are for cables carrying only 50 Hz currents. A.C. currents in cables cause an increase in the cable’s effective resistance. The increase in cable effective resistance at 50 Hz above the D.C. resistance is relatively small. However, the increase in cable effective resistances due to harmonic currents is significant particularly for the higher harmonic currents and large cables.

The factors which affect A.C. resistance is skin effect, proximity effect due to other conductors and proximity due to metallic enclosure. If the use of metallic conduit is excluded, the following equation applies:

$$R_{ach} = R_{dc}*(1 + y_{sh} + y_{ph})$$

Where:

R_{ach} = A.C. resistance to harmonic current h

R_{dc} = conductor DC resistance at operating temperature

y_{sh} = skin effect factor at harmonic h

y_{ph} = proximity factor at harmonic h

h = harmonic number

The skin effect depends on the conductor resistance and the harmonic frequency whereas the proximity effect depends on the conductor diameter, the axial spacing of phases and the harmonic frequency.

The matter of increase in effective cable resistance due to harmonic currents is addressed in IEC 60287-1-1 Electrical Cables - Calculation of Current Ratings - Part 1 Current Rating Equations (100 % Load Factor) and Calculation of Losses – General.

IEC 60287-1-1 states that its equations have limited accuracy, i.e., are accurate only to a value of m_r no greater than 2.8 where:

$$m_r = 0.05* (f / R_{dc})\ 0.5$$

f = frequency of harmonic current

R_{dc} = conductor resistance Ohms /km

Accurate calculation of skin effect for values of m_r greater than 2.8 requires the use of Bessel functions and is beyond the scope of this design manual.

Other available literature provides factors for increase in effective cable resistance due to harmonic currents for values of m_r up to 4 and factors for values of m_r up to 6 can be inferred reasonably.

For the purposes of this Design Standard, the inaccuracy in the IEC Std. 60287-1-1 skin effect calculations is not significant for values of m_r up to 4.

Skin effect resistance values given in this Design Standard for values of m_r greater than 4 are based on values provided in the available technical literature.

Proximity effect resistance increases with frequency to a lesser extent than skin effect resistance and in the absence of any other information the proximity effect resistance values given in this Design Standard are based on the IEC 60287-1-1 equations for values of m_r up to 6 increased by the ratio of the values of skin effect resistance calculated by the two above methods.

The amount of derating necessary for cables supplying converters is relatively small because most cable losses are due to the fundamental current, e.g., for single core double insulated 300 mm2 copper cables supplying a typical 6 pulse converter, the necessary derating factor to be applied to the cable 50 Hz rating will be only 0.97.

Per unit resistance values for significant harmonic currents in the range up to the 25th harmonic is given in Table 13.1 for single core copper conductor double insulated cables in non-metallic conduit.

Where:

$\mathbf{F_r}$ = per unit resistance increase at harmonic current **n**

p.u. = per unit

Increase in Effective Resistance of 50 Hz Cables due to Harmonic Current									
Cable Size	**35mm^2**	**50 mm^2**	**70 mm^2**	**95 mm^2**	**120mm^2**	**150mm^2**	**185mm^2**	**240mm^2**	**300mm^2**
Harmonic Number	**Fr**	**Fr**	**Fr**	**Fr**	**Fr**	**Fr**	**Fr**	**Fr**	**Fr**
	p.u.	**p.u**	**p.u**	**p.u**	**p.u**	**p.u**	**p.u**	**p.u**	**p.u**
1	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
5	**1.02**	**1.02**	**1.05**	**1.09**	**1.15**	**1.22**	**1.30**	**1.46**	**1.59**
7	**1.02**	**1.05**	**1.10**	**1.16**	**1.27**	**1.38**	**1.47**	**1.67**	**1.86**
11	**1.05**	**1.10**	**1.19**	**1.32**	**1.51**	**1.65**	**1.66**	**2.05**	**2.27**
13	**1.07**	**1.13**	**1.25**	**1.41**	**1.61**	**1.78**	**2.00**	**2.25**	**2.42**
17	**1.12**	**1.20**	**1.36**	**1.56**	**1.83**	**2.02**	**2.21**	**2.49**	**2.73**
19	**1.15**	**1.25**	**1.43**	**1.66**	**1.91**	**2.11**	**2.35**	**2.61**	**2.92**
23	**1.20**	**1.32**	**1.55**	**1.88**	**2.11**	**2.26**	**2.49**	**2.84**	**3.20**
25	**1.23**	**1.36**	**1.62**	**1.98**	**2.17**	**2.38**	**2.68**	**2.94**	**3.34**

Table 13.1 Increase in Effective Resistance of 50 Hz Cables due to Harmonic Current

13.2.3 Cables to Active Filters

Cable continuous current ratings published in AS 3008 are for cables carrying only 50 Hz currents. Cables connecting active filters carry only harmonic currents and consequently the current rating of cables used for this duty must be derated to allow for an increase in effective cable resistance due to skin and proximity effects. Determining the appropriate cable size is by necessity an iterative process as described hereunder.

(a) Calculate:

The RMS current.

$\mathbf{I_{rms} = (\Sigma\, I_n^2\,)^{0.5}}$ for all values of $\mathbf{I_n}$.

Where $\mathbf{I_n}$ = current in Amps at harmonic **n**
$\mathbf{I_{rms}}$ = rms current in Amps

(b) Calculate:

$\mathbf{max(I_n * n/5)}$ in Amps for all values of **n.**

(c) Select:

A cable with an on-site rating $\mathbf{I_r}$ of approximately 120% of $\mathbf{I_{rms}}$ or 120% of:

$\mathbf{max(I_n * n/5)}$, whichever is the greater.

Where: $\mathbf{I_r}$ = cable on site 50 Hz rated Amps

(d) Determine:

$\mathbf{R_n}$ for each harmonic current to flow in the selected cable as follows:

$$\mathbf{R_n = R_{50} * F_r}$$

Where: $\mathbf{R_n}$ = conductor effective resistance in Ohms/km at harmonic current **n**
$\mathbf{R_{50}}$ = conductor resistance in Ohms/km at 50 Hz
$\mathbf{F_r}$ = per unit resistance increase at harmonic current **n** as shown Table 13.1

(e) Calculate:

The total cable losses per km as follows:

$$\mathbf{P_{tl} = \Sigma\ (I_n{}^2 * R_n)} \text{ for all values of } I_n$$

Where: $\mathbf{P_{tl}}$ = total losses in the cable in Watts/km due to the harmonic currents.

(f) Calculate:

The cable power losses at rated 50 Hz current as follows:

$$\mathbf{P_{50l} = Ir^2 * R_{50}}$$

Where: $\mathbf{P_{50l}}$ **=** losses in the cable at rated 50 Hz current.

(g) Calculate:

$$\mathbf{P_{tl} / P_{50l}}$$

Result: If ratio is above unity the selected cable is too small. The ratio should be as close to unity as practical without exceeding unity.

13.3 Fault Rating

13.3.1 Switchboard Wiring

Where practical, cable tails between major circuit busbars and auxiliary circuit fuses should be protected against short circuit faults by the installation of busbar mounted fault current limiters. The size of the fault current limiters should be as shown in the Type Specification for Switchboard Construction 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.

13.3.2 Distribution Cables

The fault rating of a cable depends on the allowable temperature rise of the conductor and insulation and on the thermal storage capacity of the cable. Most manufacturers publish data relating allowable fault current and fault duration to cable size for various types of cable.

The fault capacity of all cables selected shall be checked against the protective equipment to be used to ensure the adequacy of the former. Such checks shall include a check of the earth fault capacity of cable screens against the relevant earth fault protection equipment.

13.4 Intermittent Rating

Some cables such as rotor cables connected to motors having automatic ring shorting equipment, are only subject to intermittent or short time loading and shall be rated accordingly.

13.5 High Voltage Cable Terminations

13.5.1 Manufacturer’s Recommendations

All High Voltage cable terminations shall be made in strict accordance with the manufacturer’s recommendations. Clearances in air shall be maintained at the manufacturer’s recommended level or at the value specified in the relevant Australian Standard, whichever is the greater. Attention shall be taken to ensure that recommended phase to phase and phase to earth clearances for unscreened sections of the cable terminations are maintained.

13.5.2 Dead-break Elbow Connectors

Dead-break elbow cable terminations on High Voltage screened single core XLPE insulated cables shall be made with approved fully screened, cold fit, dead-break elbow connectors such as Raychem Types RSTI and RSES dead-break elbow connectors (depending on current rating).

13.5.3 Indoor Air Insulated Terminations

High Voltage screened single core XLPE insulated cables within switchboards and air insulated cable boxes shall be terminated with approved heat shrink cable terminations such as Raychem series IXSU-F heat shrink terminations.

If the spacing between bushings is such that insulating boots are required to be fitted over the bushings, such insulating boots shall be approved cold applied insulating boots of an appropriate voltage rating, e.g., Raychem type RCAB for voltages up to 11 kV.

13.5.4 Pole Top Terminations

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

Incoming supply pole top terminations on “triplex” XLPE cables shall be made with approved outdoor heat shrink terminations and approved mounting brackets, such as Raychem Type OXSU-F heat shrink terminations and Raychem Type EPPA-031 pole top termination brackets.

13.6 Conduits and Cable Trays/Ladders

13.6.1 General

Conduits shall have the colours stipulated in AS 1345.

Conduits shall be orange for power cables and conduits for communication cables shall be white.

Outdoor cable trays and ladders shall be installed with covers. Indoor cable trays and ladders shall be installed with covers if exposed to the risk of mechanical damage. Where possible, multilayered cable tray or cable ladder arrangements should be avoided due to the additional cable de-rating required and accessibility.

Metallic cable trays and ladders shall be earthed at multiple points and have bonding straps across all joints.

13.6.2 Non-metallic cable tray/ladder systems

There is no current restriction in the use of non-metallic (e.g., PVC) based cable tray/ladder systems provided that the non-metallic based system is fit for purpose appropriate to the project and environmental conditions under consideration. Hence, whether non-metallic based cable trays systems are used at a site will be determined by the designer of the project.

Non-metallic cable tray/ladder systems shall be non-flammable, UV stabilised suitable for outdoor use, minimum service temperature performance of -20 to 60 degrees Celsius and verification tested by a third party to IEC (BS EN) 61537.

Benefits to consider are:

(a) Increased electrical safety due to double insulation

(b) No requirement for tray/ladder earthing

(c) Reduced installation costs. (No earthing cables, no bonding across joints, lack of sharp edges, ease of handling, ease of cutting)

(d) Reduced maintenance costs (no corrosion and no earthing system to maintain)

13.7 Cable Positioning

13.7.1 General

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

Motor cables carrying VSC PWM currents may be run on the same cable tray or cable ladder as other power cables. However, control and signal cables shall not be run on the same cable tray or cable ladder as motor cables carrying VSC PWM currents.

The minimum separation between power cables (HV, LV and VSC cables), and between power cables (HV, LV and VSC cables) and signal cables, shall comply with the requirements of clause 10.7 of DS22.

Power cables (HV, LV and VSC cables) shall not be buried in the same trench as water or sewage pipes. If power cables are to be buried in parallel with the water or sewage pipes on Corporation property, then a separate trench shall be provided and spaced 2 metres apart.

13.7.2 Public Road Reserves

Pipelines exiting a Corporation site usually do so via an easement (or road reserve) allowing certain rights of access for operation and maintenance purposes. Corporation owned power supply cables (HV, LV) shall not exit the Corporation's site to be run in this pipeline easement. (For example, a power supply from a pump station feeding a high-level tank on a separate site shall not be permitted. A separate application for a power supply to the tank site shall be made to the relevant Network Service Provider.

Note: The Corporation is not a utility provider for underground electrical power services, under the "Utility Providers Code of Practice for Western Australia" (published by the Utility Providers Services Committee), in public road reserves.

13.8 Cable Route Marking

All underground High Voltage and Low Voltage power cable routes shall be marked at all bends and at 25 metre intervals. Cable route markers shall be either of the concrete block type or the post type depending upon ground surface conditions and vehicle access area requirements.

Post markers shall be supplied and installed in accordance with drawing 54930-15-01 for HV cables and drawing 54930-14-01 for LV cables.

14 ACTIVE FILTERS

14.1 Application

Non-linear loads such as the front-end converters in variable speed controllers take harmonic currents from the electrical supply and in doing so may cause unacceptable harmonic distortion of the incoming supply voltage waveform (clause 4 refers.)

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

14.2 Principle of Operation

Active filters (Power Quality Filters) can perform the triple function of harmonic filtering, reactive power compensation (power factor correction) and load balancing (load current distributed evenly over three phases).

14.2.1 Harmonic Filtering

The prime purpose for active filters within Corporation sites is harmonic filtering.

Active filters operate to neutralise unwanted harmonic currents by causing other harmonic currents to flow which are of the same magnitude as the unwanted harmonic currents and are 180 degrees out of phase with the unwanted harmonic currents. The basic principle of operation is shown diagrammatically at Fig. 14.1, below.

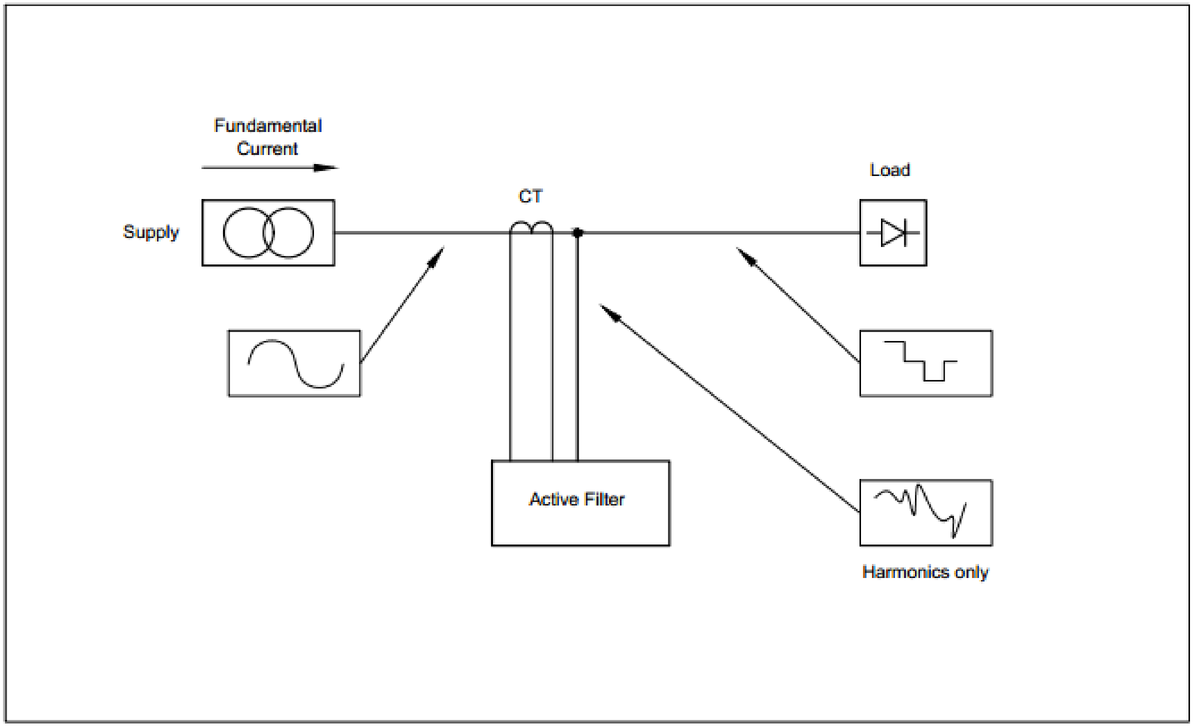


Fig. 14.1 Basic Principle of Operation

There are two types of Active Filters namely “Broadband” (designed to filter all harmonic currents) and “Targeted Individual” (designed to filter out selected harmonic currents). Generally, the total harmonic distortion (voltage & current) for large VSC pump stations can be met by applying the correct technology (e.g., multi-pulse systems, AFE etc.) for the installation. However, it is often the Network Operator’s requirement that individual current harmonics be reduced hence the targeted individual harmonic filter type must be used. The Corporation’s standard requirement is for this targeted harmonic filter type to be used. If a broadband type of filter is to be considered, then Principal Engineer approval will be required.

Normally in pump stations, zero sequence harmonic currents are filtered out by transformer delta connections, so that active filters for pump station duty are normally designed to filter only non-zero sequence harmonic currents.

As discussed in clause 7.8.3 eddy current losses in transformers increase very significantly with harmonic frequency, so that in instances where the active filter must be transformer coupled to the High Voltage system, only active filters of the individual harmonic type shall be used.

14.2.2 Power Factor Correction

The secondary purpose for active filters within Corporation sites is displacement power factor correction.

The reactive power compensation mode allows to compensate precisely up to target power factor values for both inductive as well as for capacitive loads.

The operation of the filter for power factor correction acts in much the same way as it does for harmonic mitigation. That is, the filter generates and injects reactive current of equal amplitude and opposite displacement angle to precisely correct for the poor power factor.

Compared to traditional capacitor banks, the reactive compensation of the active filter is continuous (stepless), fast and smooth (no transients). Furthermore, there are no detuning reactors required to avoid resonance and it can respond to changing power factor due to load changes.

14.2.3 Load Balancing

This mode of operation allows balancing of the load across the phases and phases and neutral. As Corporation sites consist mostly of balanced three phase loads balancing is not seen as a problem and hence is not discussed further within this standard.

14.3 Limiting Network Characteristics

There are practical limits on the ability of an active filter to correct a network distorted voltage waveform and these may vary according to individual filter designs. Typical limiting values are as follows:

(a) Maximum network voltage tolerance: ± 10%

(b) Maximum network frequency tolerance: ± 5%

(c) Maximum rate of network frequency variation: 20 % /sec

(d) Maximum network unfiltered phase to phase voltage distortion: 20 %

(e) Minimum network fault level: 2 MVA

(f) Maximum network voltage notch depth: 50 %

(g) Maximum network voltage notch area: 76 U Volts*ms

where U = phase to phase voltage

14.4 Principal Components

The principal components of an active filter system are as follows:

(a) Short circuit protective device

(b) A filter capacitor pre-charging network

(c) Line reactors

(d) An inverter switching frequency filter

(e) An IGBT inverter

(f) An IGBT inverter controller

(g) A filter system control interface (HMI)

(h) A filter cooling system

(i) An overall enclosure, and

(j) Separately mounted current transformers measuring the non-linear load currents

If the currents to be filtered out are in the High Voltage system, a power coupling transformer will be required in addition.

The above components are connected as shown in Fig 14.2, below.

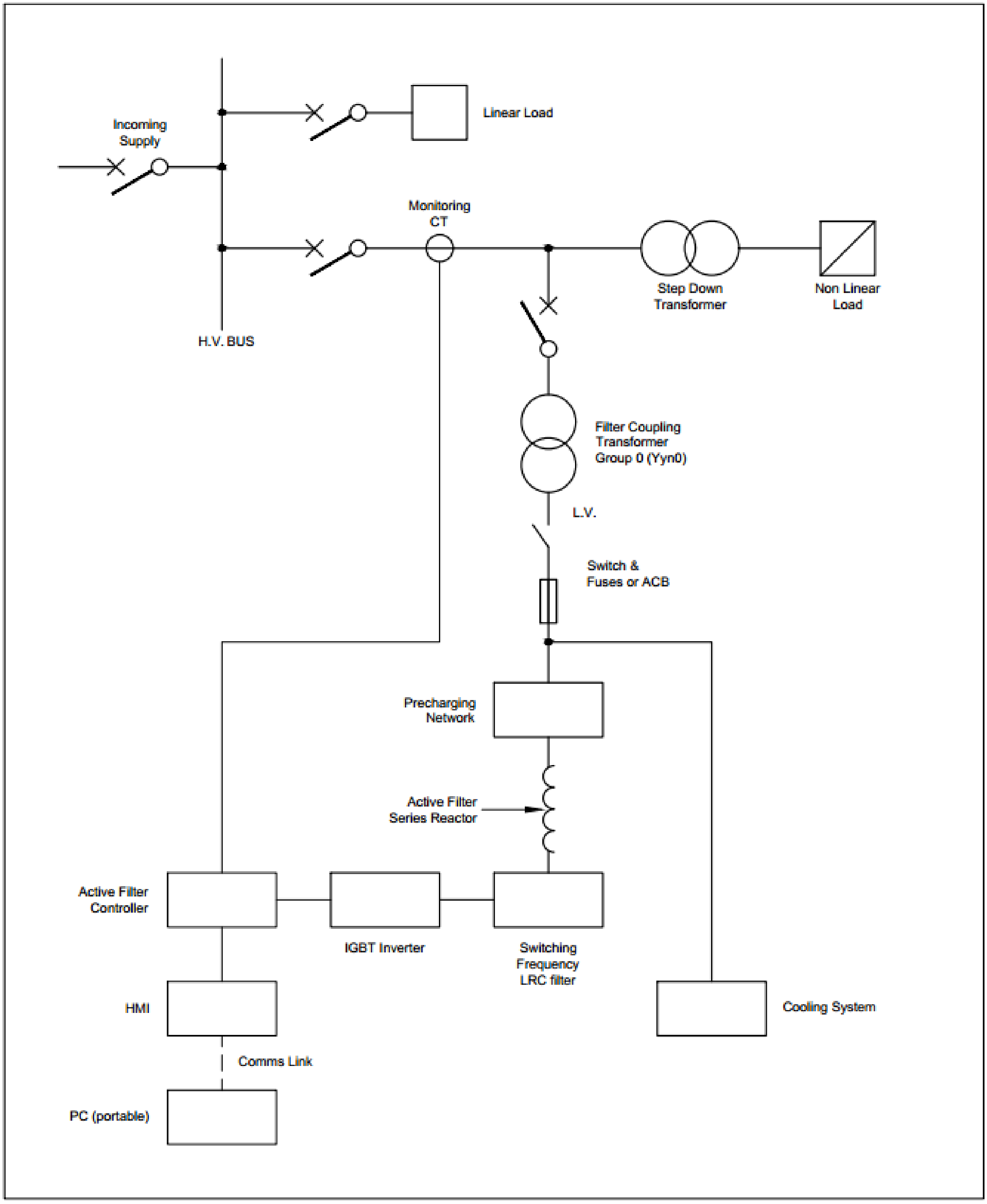


Fig. 14.2 Basic Components for Active Filter System for HV Connection

14.5 Filter Short Circuit Protective Device

If the filter is fitted with a set of fuses as a short circuit protective device, the fuses shall be semiconductor protection fuses in accordance with AS 60269.4.0.

However, if the short circuit protective device is a circuit breaker it shall be a high-speed type suitable for protecting semiconductors.

14.6 Filter Pre-charging Network

The active filter shall include a network which shall limit the inrush current to the inverter switching frequency filter capacitors. This network shall be bypassed during filtering operations.

14.7 Active Filter Reactors

The inverter "D.C. bus voltage" is determined by the fundamental frequency input voltage to the active filter.

For a non-zero sequence harmonic current active filter, the series reactors shall be sized to pass the rated current of the filter all as a 5th harmonic current.

For a zero sequence harmonic current active filter the active filter reactors shall be sized to pass the rated current of the filter all as a 3rd harmonic current.

14.8 Inverter Switching Frequency Filter

A filter is required to prevent significant levels of inverter switching frequency currents being injected into the power network. Such a filter shall be of either the L/C or L/R/C type, preferably the latter and shall limit the power port high frequency emission disturbance voltages to less than the limits specified in AS 61800.3 (IEC 61800-3).

14.9 Power Coupling Transformer

The power coupling transformer is required to have zero phase shift. Consequently, the transformer shall have a Yy0 connection.

In order to avoid excess third harmonic phase to neutral point voltages, the transformer shall be of the three phase three limb core type. The use of a three phase shell type transformer, or of a three phase five limb transformer, or of three single phase transformers shall not be permitted.

The power coupling transformer associated with an active filter will be required to pass only harmonic currents and its 50 Hz kVA rating will need to be derated very substantially in order to pass the harmonic currents to be injected into the High Voltage system (refer clause 3.8).

14.10 Active Filter Rating

The following factors shall be considered when determining the required rating of an active filter.

14.10.1 RMS Current Rating

The rated current of the active filter shall be not less than the root mean square sum of the harmonic currents to be filtered out.

14.10.2 Maximum Equivalent 5th Harmonic Current

As a consequence of the sizing of the series reactor as described clause 14.7 above, the maximum particular harmonic current $\mathbf{I_h}$ available from a non-zero sequence harmonic filter will be as follows:

$I_h = I_r * 5/h$

Where:

I_h = maximum current available at harmonic **h**

I_r = rated current of the active filter,

h = harmonic number

Consequently, the active filter rated current shall not be less than the maximum value of $I_h*h/5$.

14.10.3 Effect of Transformer Impedance

If an active filter is transformer coupled to the supply, the impedance limiting the injected harmonic currents will be the filter reactor impedance plus the transformer impedance. Consequently, in such circumstances, the active filter rated current will have to be increased so that the filter reactor impedance is decreased to compensate for the transformer impedance.

14.11 Derating of Connecting Cable

The Low Voltage power cables connecting the active filter carry harmonic currents and shall be derated substantially in accordance with clause 13.2.3.

14.12 Arc Fault Protection

Active filter enclosures shall be fitted with an arc fault detection system arranged to trip the feeder circuit breaker (protection for the non-linear load circuit) in the event of an arc occurring within the filter enclosure.

14.13 Type Specifications

The following Type Specifications are suitable for specifying active filters:

DS26-34 - Type Specification for High Voltage System Active Filter

DS26-35 - Type Specification for Low Voltage System Active Filter

15 SWITCHROOMS

15.1 General

15.1.1 Location

Switchrooms shall be purpose-built rooms, complying with the requirements of AS 2067 and the further requirements specified hereunder, located within a suitable building for the purpose of housing HV and LV switchboards.

The design associated with the incoming supply within the switchroom shall comply with the Network Operator's requirements and standards and Energy Safety.

15.1.2 Prefabricated Substation

Switchrooms in prefabricated substations shall only be used in special applications and with the written approval of the Principal Engineer as per the process outlined in clause 1.9.

Switchrooms in prefabricated substations are generally unsuitable for the Corporation's long-life assets due to:

(a) The requirement for continuous air conditioning and the associated ongoing energy/maintenance costs

(b) The requirement for a duty/standby air conditioner arrangement to ensure security of supply

(c) The requirement for safe arc product venting system

(d) Accessibility and service requirements

(e) The requirement for a service life greater than 40 years

(f) The requirement to integrate the switchroom within a building constructed for other site assets (e.g., pumping equipment, treatment facilities, etc.)

If approval is granted to use a switchroom located in prefabricated substation, it shall comply with the requirements specified for switchrooms in AS 62271.202

15.1.3 Switchroom General Requirements

General requirements for switchrooms:

(a) Switchrooms housing HV switchgear shall comply with the requirements of AS 2067 and the further requirements specified hereunder

(b) Switchrooms housing high current LV switchboards (i.e., LV switchboards rated > 800 Amps) and/or critical items of electronic equipment shall comply with the requirements of AS 2067 and the further requirements specified hereunder

(c) Switchrooms shall be designed to have a service life of not less than 40 years and shall be designed to facilitate the safe and convenient operation and maintenance of the switchgear housed therein

(d) The switchroom ceiling height shall be not less than 2.8 metres above the floor, or 600 mm above the top of any HV and/or high current LV switchboards in the switchroom, whichever is the greater

(e) Cable duct covers within HV switchrooms shall be solid fire-resistant plywood

(f) HV switchboards and LV switchboards shall be located in separate switch rooms with separate fire isolated cable trenches

(g) Switchrooms shall be identified clearly with signage as to their function and access restrictions

15.2 Arc Fault Discharge

Arc Fault Discharge requirements:

(a) The duct volume beneath HV switchboards with AFLR accessibility and which discharge down into the cable duct shall be arranged to be > 1.0 cubic metres

(b) The covers over the cable duct into which arc fault gases are to be discharged shall be bolted in place and shall be sufficiently strong to contain the arc fault gases

(c) Where HV switchgear with AFLR accessibility is provided with duct(s) to discharge arc fault gases outside the switchroom, fencing shall be provided to prevent access to gaseous discharge outlet(s). Signs warning of arc discharge shall be provided on the fence

(d) HV switchboards with AFL accessibility which discharge arc fault gases to the rear shall be located close enough to the rear wall to prevent personnel access and far enough away from the rear wall to prevent any part of the switchboard coming in contact with the rear wall in the event of an arcing fault gaseous discharge. The discharge of arc fault gases shall be downwards only

(e) Such switchboards (item d) above) shall be spaced from the rear wall in accordance with the manufacturer's recommendations. AS 62271.200 specifies the nominal clearance to be 100 mm.+ 30 mm

15.3 Cable Trenches and Ducts

Cable trench requirements:

(a) Cable trenches shall extend at least 600 mm beyond both ends of all HV switchboards and high current LV switchboards

(b) Cable entry into switchboards shall preferably be from below, but overhead bus duct entry into LV switchboards is permitted if necessary

(c) Cable ducts/trenches shall be designed to facilitate the ease of installation and removal of cabling

(d) The width of switchroom cable trenches shall be not less than 600 mm

(e) The depth of switchroom cable trenches shall be 600 mm deep, or 110% of maximum cable size minimum bending radius, whichever is the greater

Note: Special requirements for cable trenches/ducts *apply to switchboards housing Network Operator High Voltage equipment and the design shall be compliant with such. WASIR refers.*

(f) Cables entering cable ducts under HV switchboards and under high current LV switchboards shall be sealed with a suitably fire-resistant material. Such sealing shall be rodent and vermin resistant and shall be accessible for inspection

(g) Cable ducts shall be sealed outside switchrooms to prevent the ingress of water into these ducts and trenches

(h) Cable trenches covers within HV switchrooms shall be solid fire-resistant plywood

(i) Formed concrete cable trenches within high current LV switchboard switchrooms, shall be fitted with aluminium covers bonded to each other and connected to the switchroom main earth bar

15.4 Structural Flooring

Structural flooring requirements:

(a) Floors in HV switchrooms and LV switchrooms shall be solid concrete.

(b) Removable flooring (i.e., so called “computer room flooring”) shall not be used in HV switchrooms. However removable flooring may be used in high current LV switchrooms provided that the requirements specified clause 15.3 are satisfied and that approval is obtained from the Principal Engineer in accordance with clause 1.9

(c) Any removable flooring used shall be sufficiently strong to carry the full weight of associated switchboards during installation or removal

(d) Removable flooring modules shall be suitable for single person lift (i.e., <15 kg.)

(e) Floor surfaces within 900 mm. of the front of all HV switchboards and high current LV switchboards shall be electrically non-conductive (e.g., rubber floor tiles or fire-resistant plywood)

(f) Steel members supporting switchboards shall be located to suit switchboard mounting feet and to facilitate cabling. Such steel members shall be hot dipped galvanised and shall be stiff enough so that their deflection under load does not cause distortion of the associated switchboard frames

(g) Switchrooms shall be sized and positioned to facilitate the installation and removal of switchboards with shipping section lengths up to 3 metres

(h) Switchrooms shall be designed to facilitate the installation of planned future additional switchboard tiers without compromising clearance requirements

(i) Provision shall be made in all switchrooms for electrical bonding of all structural metal work including concrete reinforcing steel (clause 11 refers)

15.5 Fire Protection

Fire protection requirements:

(a) Compliance with clause 6.7 of AS 2067

(b) Plywood used as duct covers shall have a fire resistance level rating of FRL60/60/60

(c) All surfaces (including ceiling, floors and walls) within 900 mm horizontally and 1500 mm vertically of HV switchboard, or of high current LV switchboards, shall have fire resistance level rating of FRL120/120/120

(d) Fire extinguishers rated for use on electrical fires shall be provided adjacent to each switchroom exit door

(e) Smoke detectors shall be provided in all switchrooms and these shall be connected to local and remote (SCADA) systems

(f) Smoke detectors shall be located above the switchboard

Note: FRL under the NCC (National Construction Code) consists of three elements: structural adequacy, integrity and insulation

(a) *Structural Adequacy: Ability for a load bearing element to continue to hold a specified load when subject to fire*

(b) *Integrity: Ability for the building element to resist passage of flames and hot gases to other areas of the building*

(c) *Insulation: Ability of the non-exposed surfaces to remain below a specific temperature*

15.6 Switchroom Doors

Switchroom door requirements:

(a) Further to AS 2067, inward opening doors shall not be permitted. All doors shall be outward opening

(b) Bollards shall be provided at outdoor opening doors to prevent vehicles being parked that may restrict outward opening doors and egress of personnel in an emergency

(c) Indoor outward opening doors shall be free of any obstacles to allow ready egress of personnel during an emergency

(d) Access doors shall be positioned at either end of the switchroom to provide a dual means of egress. Two doors at opposite ends of the switchroom shall be provided as per AS 2067 clause 5.5 and figure 5.12

(e) Access doors shall not be provided directly between High Voltage and Low Voltage switchrooms

(f) Switchroom doors shall be proportioned to facilitate switchboard installation. Switchrooms shall be provided with one set of double opening doors of minimum dimensions 2400 mm high by 1800 mm wide

(g) All doors shall be fitted with emergency “crash bars” to allow emergency egress.

15.7 Switchroom Security

Switchroom Security requirements:

(a) Doors enabling access to switchrooms containing High Voltage equipment shall be provided with Water Corporation EL2 equivalent keyed locking systems (Bilock) to limit access to suitably qualified electrical staff

(b) Doors enabling access to switchrooms containing high current LV switchboards shall be provided with appropriate locks (equivalent keyed locking systems (Bilock)), the keys to which are issued on a controlled basis to restrict access to authorised personnel

(c) Doors to switchrooms containing HV equipment or high current LV switchboards shall be fitted with locks that can be opened from the inside without a key by using a latch or other simple device, even when the doors are locked from the outside (e.g., “crash bars”)

(d) Intruder sensors shall be provided in all switchrooms and shall be connected to local and remote (SCADA) systems

15.8 Signs

Switchroom sign requirements:

(a) Doors allowing access to switchrooms containing High Voltage electrical equipment shall be provided with information and warning plates in accordance with AS 2067, clause 6.9

(b) Warning signs as detailed hereunder shall be installed on all doors allowing access to switchrooms containing high current LV switchboards. The lettering on such signs shall be not less than 12 mm high.

WARNING
High Fault Level Electrical Equipment
Authorised Persons Only

15.9 Lighting

Reference shall be made to DS22 clause 11 “Pumps Station and Substation Lighting’ for general and emergency lighting requirements.

15.10 Ventilation and Air Conditioning

15.10.1 General

Switchroom ventilation shall be natural ventilation or fan forced ventilation, with the former being preferred where this is practical.

Switchroom ventilation and air conditioning shall comply with the requirements and recommendations of Clause 5.5.7 of AS 2067 so that:

(a) Suitable indoor climate conditions are provided to ensure correct operation of the electrical equipment, e.g., by adequate cooling, heating, dehumidifying, ventilation or by attention to the design of the building, and

(b) Adequate ventilation is provided to dissipate heat generated by electrical equipment

15.10.2 Protection against Solar Heating

The switchroom walls and ceiling shall be insulated and adequate shading provided to reduce solar heating to a practical minimum.

15.10.3 Redundant Equipment

Any ventilation fans and/or air-conditioning units installed shall be provided on a duty/standby basis.

Switchrooms equipped with ventilation fans and/or air conditioning units shall be provided with automatic temperature monitoring and control equipment:

(a) To run the standby unit if the switchroom temperature rises significantly above the set value, or if the duty unit trips out on fault, and

(b) To raise an alarm if either of the above occurs

15.10.4 Location of Power Electronic Equipment

Variable speed controllers and active filters, for ventilation fans and/or air-conditioning units, housed within switchrooms shall be located on outside walls and arranged so that equipment cooling air carrying at least 80% of the associated heat load is discharged directly to outside the building.

15.10.5 Protection Against Corrosive Gases

Switchrooms in locations subject to significant sewer gas pollution shall be provided with forced ventilation with carbon filtered air inlets.

15.10.6 Protection Against Dust

Measures shall be taken to reduce dust intrusion to the switchroom that is compatible with the IP rating of the switchboard. Such measures may include extension of a concrete or bitumen apron around the outside of the switchroom building, appropriate door seals and air intake filters.

15.10.7 Equipment Service Conditions

The switchroom ventilation and/or air conditioning shall ensure that the following minimum service conditions are achieved:

(a) The ambient air temperature does not exceed 40^0C and its average measured over a period of 24 hours does not exceed 35^0C

(b) The average ambient air humidity measured over a period of 24 hours does not exceed 95% and measured over a period of one month does not exceed 90%

(c) The average value of water vapour pressure measured over a period of 24 hours does not exceed 2.2 kPa and measured over a period of one month does not exceed 1.8 kPa

(d) The ambient air is not polluted by dust to a level which would interfere with operation of the electrical equipment or reduce its life significantly

(e) The ambient air is not polluted significantly by smoke, corrosive and/or flammable gases, vapours or salt which would interfere with operation of the electrical equipment or reduce its life significantly

15.11 Workstation Areas and Control Rooms

The prime purpose of switchrooms is to house the HV and high current LV switchboards as discussed above. In order to reduce the risk of personnel exposure to arc flash and other incidents, the switchroom shall not house plant control cubicles and associated equipment or an office environment with a workstation. Any control room or workstation shall be located in a separate room.

The switchroom shall not house furniture or act as a storage area.

15.12 Access to Switchboards

Clearances around switchboards shall provide safe access and egress during normal and emergency conditions and comply with AS 2067 clause 5.5.4.

15.13 Pin Up Boards

Pin up boards shall be provided on the walls in convenient locations within switchrooms to allow circuit diagram drawings to be pinned up for reference purposes.

16 ELECTRICAL INSTALLATION

16.1 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 1.4 of this Design Standard (DS21), the National & International standards and sound engineering installation practice.

The design process associated with the installation, tendering, tender analysis and recommendation work for major pump stations and major electrical installations shall comply with the relevant requirements of sections 1 and 3 of DS20 “Design Process for Electrical Works”.

16.2 Type Specifications

Type Specifications have been prepared for all electrical installations covered by this Design Standard DS21 to streamline the installation design and tendering process.

In particular, the following Type Specification is relevant to major pump stations and major electrical installations:

DS26-07 Type Specification for Major Electrical Installations.

The Specification covers the requirements for the construction and testing of a major electrical installation having a maximum rating of greater than 315kVA or a maximum voltage of greater than 1kV.

Note: Any minor electrical installation work associated with a major electrical installation shall align with the requirements of Type Specifications DS26-44 and DS26-46 as outlined in DS22 clause 18.

17 RENEWABLE ENERGY SYSTEMS

Solar energy systems deployed at Corporation pump station sites, to augment conventional energy supply systems, are generally “behind the meter” systems and general connection arrangements are shown on the MN00 standard drawings.

Isolated solar pump drive systems with battery support, hybrid diesel/solar systems and grid connected solar energy systems are not a feature for large pump stations and therefore not covered by this Design Standard (DS21) nor DS25. The Principal Engineer shall be consulted for guidance should this be considered in the future.

APPENDIX A

A1 Control System - Switchboard Logic Functions and Pump Control Cubicles

(a) Apart from the basic logic functions inherent in the Water Corporation's standard control circuits, all pump station logic functions shall be performed in programmable logic controllers or similar devices mounted in cubicles (called Pump Control Cubicles) external to the main switchboard.

(b) Wherever applicable, switchboard control logic functions shall be programmed in accordance with the Water Corporation's standard logic diagrams.

(c) Switchboard logic functions shall be designed and documented in the block logic format, not in the system functional chart format, nor in ladder logic format.

(d) Pump Control Cubicles shall be designed in accordance with the requirements of design standard DS 22. Pump control shall be carried out by a combination of a 'Common Control PLC' and 'Unit Control PLC's'. To provide the optimum level of security, each pump set shall have a dedicated Unit Control PLC. This PLC will enable the pump set to continue to operate under manual control, with full primary and secondary protection, in the event of a failure in the Common Control PLC. The Unit Control PLCs shall communicate with the Common Control PLC via a serial communications link.

(e) The purpose of the Unit Control PLC is to provide all the logic required for the motor/pump control, protection and indication functions. The purpose of the Common Control PLC is to provide the logic for all the functions common to the pump station including pump selection, building security, surge vessel control, interfacing to other equipment (such as RTU's, main circuit breakers, station flow metering, station pressure metering etc.) under voltage protection, etc.

The Pump Control Cubicle shall have an Operator Interface Panel (OIP) located on the front door with a serial connection to the Common Control PLC. Information from all the Unit Control PLCs shall be routed to the OIP via the Common Control PLC. The OIP shall be a 6-inch (minimum) colour touch screen, programmed for graphical representation of the pump station (including display of process functions, status and alarms) and suitable for 48-hour trending of analogue signals such as flow, pressure and power. Simpler alpha-numeric displays shall also be provided for each Unit Control PLC for viewing critical status and alarm points and access to the setting of trip points (security access required). Control switches and pushbuttons necessary for control of the pumps shall remain as hardware and not incorporated as software switches within the OIP. The philosophy here is that in the event of an OIP failure, pumps can still be selected via the hardware switches.

APPENDIX B

B1 WCWA Incoming Power Supply Policy - Background

This policy relates to the 315 kVA delineation between “Sole Use” supply and High Voltage supply.

For the Corporation to operate its business effectively, efficiently and at a sustainable whole of life cost, a “Sole Use” transformer supply from the Network Operator has been limited to 315 kVA due to the technical complexities associated with:

(a) Outdoor contiguous switchboards of suitable rating.

The Water Corporation’s Design Standards stipulates that external switchboards MUST have a minimum IP rating of IP56. The Corporation’s in-house design capability allows for its outdoor design verified and arc fault tested switchboards rated up to 315 kVA (440 Amps), 10 kA_{rms} fault current, to be located outdoors and contiguous with the Network Operator’s sole use transformers. Hence compliance with the requirements of WASIR.
However, there is no switchboard manufacturer that has a design verified, arc fault tested, IP56 switchboard suitable for outdoor deployment with ratings greater than 315 kVA. The best available is generally IP54. Hence these high-power switchboards must be located indoors and therefore cannot meet the Network Operator’s contiguous requirements. Furthermore, switchboards of high-power rating have much difficulty in maintaining temperature rise within defined limits especially when solar radiation heating is considered.

(b) Motor starting.

Much of the Corporation’s business is associated with pumping systems employing both small and large induction motors. Starting of these motors to meet the Network Operator’s stringent voltage disturbance limits, or harmonic interference limits in the case of VSCs, is often a challenge for the Corporation’s Designers and as such special technology (e.g., secondary resistance, variable speed drives, active filters, large electronic soft starters, etc.), unsuitable for outdoor applications, need to be used. Such technology cannot be deployed outdoors due to the harsher environmental conditions (water, condensation, dust, temperature).

(c) Protection grading.

The selection of motor protection fuses and circuit breakers require current ratings to be higher than for static loads due to the motor starting characteristics. Hence, protection discrimination between the supply authority’s protection device and Corporation’s device is difficult or not possible.
The HV supply fuse to sole use transformers is restricted to defined sizes by the Network Operator. With motor starting, even though the transformer size may be adequate for the running load the fuse can be too small. The Network Operator’s solution is to increase the transformer size in order to provide a larger fuse for discrimination purposes. However, this can lead to unusual situations where, for example, a 1000 kVA transformer is provided for a 250 kW motor load at a pump station. The LV fault level then rises well above what is desirable for the site.

(d) Motor voltage selection.

For various reasons such as cost effectiveness, technical limits, operating requirements & installation effectiveness, the secondary voltage at our sites must often be other than 415V, as provided by sole use transformers. Table 4.1 (Motor Rated Voltage versus Motor Output Power) of this Design Standard provides an insight to the voltage requirements to accommodate high motor power ratings. As can be seen, depending upon the technology or application, 690V, 3.3 kV, 4.16 kV or 6.6 kV motors/drives are required. This specialised voltage cannot be provided by the Network Operator.

(e) Power distribution throughout large sites.

Many Corporation sites, for pump stations or treatment plants, are geographically large. The Corporation requirement is for loads to be distributed sparsely throughout these sites due to civil process requirements and, as such, 415V is impractical even if the electrical load may be relatively small in power demand. It is critical the Corporation has the flexibility to distribute at High Voltage whether the load demand is large or small.

Of concern to the Network Operator is the reduced accuracy of the metering CTs for HV supplies at low loads since the CTs are provided as a standard size. However, agreement has been reached with the Network Operator (specifically Western Power) whereby smaller CTs may be installed at our sites. The Corporation will pay for the resizing of the CTs for its sites to ensure accuracy of metering is not compromised.

A HV supply provides the flexibility to deploy the right technology for a particular application, the opportunity to deploy more practical power distribution schemes, more sophisticated/practical protection schemes to protect equipment and personnel. Importantly, provides improved discrimination with the Network Operator’s protection feeder and able to better meet power quality limits.

Normally the Western Australian Service and Installation Requirements (WASIR) is applied for sole use connection arrangements however WPC has accepted the 315 kVA limit (May 2019 via email) as a non-standard arrangement for Water Corporation.

Hence, incoming supply “Sole Use” transformers greater than 315 kVA shall not be deployed for Corporation projects.

APPENDIX C

C1 High Voltage Motors - Vacuum Contactor Switching

Motors can be subject to winding stress due to high frequency, high amplitude, fast rise time voltage impulses caused by vacuum contactor switching.

Vacuum contactors (and vacuum circuit breakers) give rise to high voltage surges at the motor terminals during switching on and switching off and are particularly severe during ‘abort’ start situations. Submersible motors, having comparably weaker insulation systems than conventional motors, are more susceptible to damage due to vacuum switching.

It is well known that opening of vacuum contactors creates the condition of current chopping (sudden interruption of current before current zero) which leads to high transient voltages (V_{imp}) at the motor terminals. Combined with transmission line theory, at the change of impedance of the motor circuit, the voltage generated from the contactor opening leads to significant over voltage factor (e.g., near 2 times) at the motor. This phenomenon can be addressed by the application of suitable surge diverters located at the HV switchboard.

$$V_{imp} = \sqrt{\frac{L}{C}} * I_{ch}$$

Where: L = Inductance, C = Capacitance, I_{ch} = Chopped Current

However, there is a couple of other mechanisms during switching which cause significant, and sometimes severe, voltage impulses to impinge on the motor windings. These relate to voltage escalation due to multiple re-ignitions and virtual current chopping. This mechanism occurs when the arc reignites after the first current interruption and then is able to interrupt the high frequency transient current which appears after the re-ignition. The voltage increases with each re-ignition (voltage escalation) so that very high voltages at high frequency can result along with very fast rise times. With increasing voltage (escalation) the corresponding high frequency transient current rises with each re-ignition and can be coupled into the other two phases, which are still carrying 50Hz current. The induced high frequency currents of the other two phases also have current zeros which when interrupted causes virtual (induced) current chopping. Hence high voltages are also possible to be generated by this mechanism. These multiple re-ignitions and virtual chopping do not occur at every contactor operation – intermittent. It should be noted that should the vacuum contactor open immediately after it closes (abort) then the situation becomes worse.

One other mechanism to add to the mix is that of pre-strikes during vacuum contactor closing. Oscillations can be set up whereby the over voltage factor can range, depending upon suitable conditions, from 3 to 6 times.

The above high frequency voltages are subject to travelling wave theory whereby the voltage can be close to doubling at the motor windings. Furthermore, windings have characteristic natural resonances due to the inductive & capacitive coupling of the individual winding turns with one another and earth which is determined by the winding geometry. If the high frequency voltage pulse equals the resonance frequency, then very high voltages may result within the winding. Note the external voltage impinging on the motor terminals would be lower than the resonance voltage experienced in the winding.

Laboratory testing in Europe has shown that such high frequency mechanisms discussed above occur approximately 16% of all switching operations. That is, 160 times in 1000 opening operations.

Hence, turn-to-turn voltage stress, and winding to earth voltage stress, are possibly very high due to steep fronted surges during vacuum switching. This is repetitive over a long period of time.

The installation of suitable surge diverters will limit the overvoltage peak value, which is often the solution at the origin (High Voltage switchboard). However, the multiple re-ignition, virtual chopping and resonance effects of high frequency surge voltages can only be effectively handled by an RC circuit at the HV switchboard. RC circuits create a bypass for high frequency currents & voltages to earth instead of reaching the motor. RC circuits also damp travelling waves and prevent reflection at the motor terminals thus reducing repetitive stress of the motor insulation. Additionally, motor winding resonance is minimised or eliminated.

To reduce the risk of motor damage due to vacuum switching, the designer must consider incorporating surge diverters and RC circuits into HV switchboards feeding motors (especially submersible motors) during the Engineering Design stage to address the phenomenon as described above.

APPENDIX D

D1 Motors – CMV Mechanism

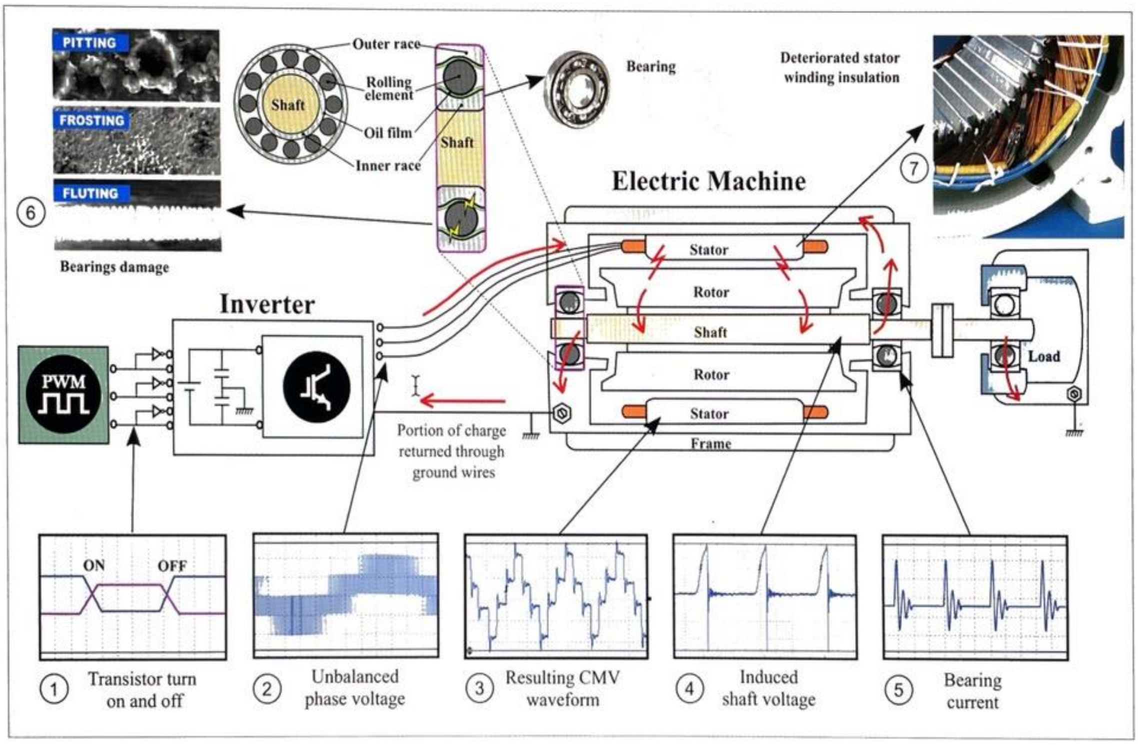


Fig. D1 Common-Mode Voltage (CMV) mechanism in Electric Drive Systems

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