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1. Introduction

This document provides a guideline for the application design of Alternating Current (AC) reticulation networks in Transmission and Distribution substations.

2. Supporting clauses

2.1 Scope

2.1.1 Purpose

This document is a guideline for the application design of Alternating Current (AC) reticulation networks in Transmission and Distribution substations.

2.1.2 Applicability

This guide shall apply throughout Eskom Holding Limited, its divisions, subsidiaries and entities wherein Eskom has a controlling interest.

2.2 Normative/informative references

Parties using this document shall apply the most recent edition of the documents listed in the following paragraphs.

2.2.1 Normative

[1] IEC 60898-1 Electrical accessories – Circuit-breakers for overcurrent protection for household and similar Installations – Part 1: Circuit-breakers for AC operation

[2] IEC 60934 Circuit-breakers for equipment

[3] IEC 60947-2 Low voltage switchgear and control gear – Part 2: Circuit-breakers

[4] SANS 156 Moulded case circuit-breakers

[5] SANS 1507-3 Electric cables with extruded solid dielectric insulation for fixed installations (300/500 V to 1 900/3 300 V) – Part 3: PVC distribution cables

[6] SANS 10142-1 The wiring of premises Part 1: Low voltage installations

[7] 240-xxx AC reticulation philosophy for substations

2.2.2 Informative

[8] 32-9, Definition of Eskom documents

[9] 32-644, Eskom documentation management standard

[10] 474-65, Operating manual of the Steering Committee of Technologies (SCOT)

2.3 Definitions

2.3.1 General

Definition	Description
Appliance	A machine, tool, device or instrument that is operated by electricity for the purpose of doing work, or for providing heat, light or motion, or in which electrical energy is modified into another form of energy.

Definition	Description
Circuit-breaker	A mechanical switching device that is capable of making, carrying and breaking currents under normal circuit conditions and of making, carrying for a specified time, and automatically breaking currents under specified abnormal circuit conditions such as those of overcurrent.
Class I Appliance	An appliance that has at least basic insulation throughout, and that is provided with an earthing terminal of earthing contact and is designed (in the case of single phase) for connection by means of a three-phase flexible cord.
Class II Appliance:	An appliance that has double insulation or reinforced insulation (or both) throughout, and that is without provision for earthing.
Distribution Board	An enclosure that contains electrical equipment for the distribution or control of electrical power, from one or more incoming circuits, to one or more outgoing circuits.
Earth Leakage Protection	A form of protection in which an earth leakage unit is used.
Earth Leakage Unit	A device that is capable of detecting the flow of a specified or predetermined current from a circuit to earth, and of disconnecting, automatically and reliably, the affected circuit within a specified time when such current exceeds the specified or predetermined value.
Electrical Installation	Machinery, in or on any premises, that is used for the transmission of electrical energy from a point of control to a point of consumption anywhere on the premises, including any article that forms part of such an installation, irrespective of whether or not it is part of the electrical circuit, but excluding any machinery that transmits electrical energy in telecommunication, television or radio circuits. In Eskom substations, machinery used for supplying electricity and DC systems which are derived from the main AC supply will be part of the electrical installation.
Fixed Appliance	An appliance that is fastened or otherwise secured at a specific location, and that would require the use of tools to be moved to another location.
Protective Conductor (PE)	A conductor provided for purposes of safety (protection against electrical shock), and which also connects the supply earth to the consumer's earth terminal. In Eskom substations, Eskom is both the supplier and consumer of electricity.
Wireway	A wireway is an open or closed route or support such as a rack, tray or ladder, ducting, trunking, sleeving or conduit that is intended to contain conductors or cables.

2.3.2 Disclosure classification

Controlled disclosure: controlled disclosure to external parties (either enforced by law, or discretionary).

2.4 Abbreviations

Abbreviation	Description
AC	Alternating Current
CAP	Committee for Accepted Products
DB	Distribution Board

Abbreviation	Description
DC	Direct Current
DMK	Diameter Marshalling Kiosk
E/L	Earth Leakage
IDMT	Inverse Definite Minimum Time
JB	Junction Box
LAP	List of Accepted Products
LV	Low Voltage
MCB	Miniature Circuit-breaker
MCCB	Moulded Case Circuit-breaker
n/a	not applicable
NECRT	Neutral Earthing Coupling Resistor with Auxiliary Transformer
OLTC	On-load Tap Changer
PB	Plug Box
PRCD	Portable Residual Current Device
PTM&C	Protection, Telecoms, Metering and Control
pu	per unit
PVC	Polyvinyl Chloride
RCBO	Residual Current Circuit-breaker with Overcurrent Protection
RCCB	Residual Current Circuit-breaker
RCD	Residual Current Device
SDB	Service Distribution Box
SRCD	Socket outlet Residual Current Device
SWA	Single Wire Armour
TDB	Transformer Distribution Board
TRFR	Transformer
Z	Impedance

2.5 Roles and responsibilities

Stakeholders involved with the design and application of AC Reticulation at substations shall ensure that the fundamental principles of this document are adhered to.

2.6 Process for monitoring

This document will be reviewed on a 5 year period. Should there be a need to relook at the content of this document before the 5 year review cycle; this will be addressed by the relevant roleplayers in PTM&C.

2.7 Related/supporting documents

Not applicable

3. Hazards

3.1 General design considerations

In the design of electrical installations and electrical equipment, live parts should not be accessible without the use of a tool or a key. Furthermore, conductive parts that may become live during earth faults shall not be hazardous. The Low Voltage (LV) electrical installation at substations shall have protection against the following hazards:

- Electric shock
- Thermal effects
- Overload
- Short circuits
- Under voltage

3.2 Direct and indirect contact

3.2.1 Description of direct and indirect contact

Electric shock is divided into two parts:

- Direct contact, which refers to a person coming into contact with a conductor that is live during normal conditions.
- Indirect contact, which refers to a person coming into contact with an exposed conductive part that is not normally live, but has become alive accidently (due to insulation failure or some other cause.) Exposed conductive parts are the metal enclosures, din rails, gland plates or any metal part used in the construction of the electrical boards, excluding the busbars and wiring terminals.

3.2.2 Measures to protect against direct contact

In order to protect persons from direct contact, the following basic measures shall be incorporated in the design of LV boards:

- Live parts shall be insulated.
- Live uninsulated parts shall be enclosed or a barrier shall be used.

It must not be possible to touch any live part within arm's reach with the standard test finger (IP2X). For distribution boards where IP2X degree of protection cannot be achieved, then its construction shall consist of an inner door and an outer door. This applies to all Transformer Distribution Boards (TDBs) used in Transmission substations. The toggles of the Moulded Case Circuit-breakers (MCCBs) shall protrude through the inner door. The back of this board shall be covered with a Polyvinyl Chloride (PVC) board. All outgoing MCCBs used in distribution boards shall have a padlocking feature. Locking brackets shall be provided for Miniature Circuit-breakers (MCBs). This will ensure safety during maintenance.

3.2.3 Measures to protect against indirect contact

In order to protect persons from indirect contact, the following basic measures shall be incorporated in the design of the LV installation:

- All metal enclosures of the LV boards shall be bonded to the earth mat, which must cause automatic tripping of the supply MCB in the case of an earth fault.
- The use of class II equipment or equivalent insulation.

In order for the MCB protecting a circuit to operate swiftly during an earth fault, the earth fault loop impedance must have a value low enough to allow sufficient current to flow. The tripping time of the MCB must be fast enough so that voltages appearing on the bonded metalwork would not persist long enough to cause danger. According to 6.11.3 in [6] SANS 10142-1, the touch voltage must not exceed 25 V for periods > 5 s. However, due to varying cable lengths resulting from different substation sizes and layouts, it is advisable to design LV networks where the MCB trips instantaneously for an earth fault. In order for MCBs (with a Type C tripping curve) to trip instantaneously, the fault current must be at least $5 \times I_n$. I_n is the nominal current rating of the MCB. MCCBs > 160 A incorporated in distribution boards shall be fitted with electronic trip units. Magnetic tripping units can be used for a 160 A MCCB, provided it can trip instantaneously at $5 \times I_n$. Most electronic trip units can operate from at least $2 \times I_n$. Therefore in order to provide protection against indirect contacts, the fault level at the end of all circuits protected by an MCCB/MCB must be at least five times the rating of the device protecting it.

3.3 Overload protection

International Standard [1] IEC 60898-1 defines the rated current I_n of a circuit-breaker for LV distribution applications as the current the breaker is designed to carry continuously (at an ambient temperature of 300 °C). The commonly available values for the rated current are 1 A, 2 A, 6 A, 10 A, 16 A, 20 A, 25 A, 32 A, 40 A, 50 A, 63 A, 80 A, 100 A and 125 A. MCBs also have short-circuit ratings, which are the maximum short circuit current the MCB can interrupt safely. Typical kiloamp ratings for MCBs are 4,5 kA, 6 kA, 10 kA and 15 kA at 400 V.

MCBs are available with different tripping curves, namely curves B, C and D, which indicate the instantaneous tripping current. This is the minimum value of current that causes the circuit-breaker to trip instantaneously (< 100 ms) and is expressed in multiples of I_n. MCBs have thermal-magnetic operation. Therefore the circuit-breaker has a bimetallic strip and an electromagnet. The bimetallic strip caters for overload conditions and the electromagnet responds during short-circuit conditions, giving the instantaneous tripping show in 1. The thermal portion of the circuit-breaker is similar to an Inverse Definite Minimum Time (IDMT) curve with a pick-up value of approximately 1,45 I_n. Therefore the current rating of the cable must be at least 1,45 times I_n when protected by MCBs with Type C tripping curves, which are usually specified for distribution boards employed in Eskom substations.

Table 1: Types of miniature circuit-breaker tripping curves

Type	Instantaneous tripping current
B	3 I_n to 5 I_n
C	5 I_n to 10 I_n
D	10 I_n to 20 I_n
K	8 I_n to 12 I_n
Z	2 I_n to 3 I_n

Type B MCBs are used for the protection of generators, persons and very long cables. Type C MCBs are for the general protection of electric circuits. Type D MCBs are used for the protection of high surge circuits, welders, transformers and motors. Type K MCBs are used for the protection of loads that frequent short duration current peaks (approximately 400 ms to 2 s) in normal operation. Some manufacturers produce a Type MA MCB which has only a magnetic trip at $12 \times I_n$. These MCBs are employed for the protection of motor starters when combined with contactors. Type Z MCBs are used for the protection of loads such as semiconductor devices or measuring circuits using current transformers. B.1 in Annex B shows the curve C of a Moeller MCB. Note from B.1that 1,5 I_n can take up to an hour to trip. 2 shows the tripping currents and times according to the various standards for MCBs. The values in 2 are for overload protection.

When selecting an MCB, care must be taken that MCBs from different manufacturers can be unequal with regard to the overload and short-circuit times. However, in order to achieve discrimination in AC networks, MCBs with similar tripping characteristics have to be employed.

Table 2: Overload protection

Reference	Hold current	Trip current	Trip time (min)
[2] IEC 60934	1,0 I_n	any	60
[1] IEC 60898-1	1,13 I_n	1,45 I_n	60 to 120
[3] IEC 60947-2	1,05 I_n	1,3 I_n	60 to 120
[4] SANS 156	1,0 I_n	1,35 I_n	50 to 100

3.4 Short-circuit protection

In order for an MCB to trip rapidly during a fault, the fault current must operate the magnetic trip unit of the MCB. The magnetic trip unit of a curve C MCB operates from $5 \times I_n$. The resistance of the protective earth conductor in substations is low for the following reasons:

- All distributions boards are bonded to the earth mat.
- The earth mat consists of a network of solid copper rods bonded to the star point of the auxiliary transformer.
- All armouring of cables is connected to earth via the gland and gland plates.

Therefore the minimum LV fault in a substation is a phase-to-phase fault. If the phase-to-phase fault is $> 5 \times I_n$, then the MCB protecting this circuit will trip instantaneously for all types of faults, provided that the distribution boards are solidly earthed.

3.5 Earth leakage protection

Every electrical installation must only be connected to a supply that includes a protective conductor.

In 1, the protective conductor (PE), which is connected to the source earth, is either a separate conductor or the armour of the cable.

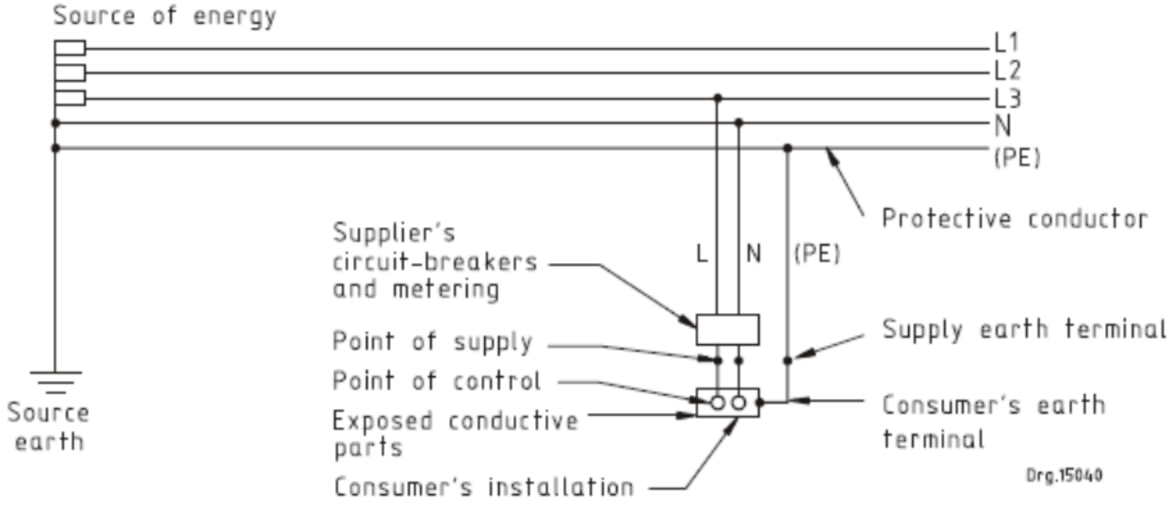


Figure 1: TN-S earthing system

In Eskom substations, the earth mat is the protective conductor. All circuits that supply socket outlets shall be provided with an earth leakage unit. Three-phase welding socket outlets shall have earth leakage units. The earth leakage tripping current shall not exceed 30 mA, when protecting socket outlets. An earth continuity conductor shall not be used to carry any current other than fault currents, and shall have a minimum cross-sectional area of 16 mm^2.

The following conductive parts shall be earthed:

- All Yard Junction Boxes (JBs).
- All panels located in the control room.
- All distribution boards (AC and DC) within the control room.
- All AC distribution boards located in the yard.
- All cable armouring and wireways.
- The earthing terminals of sockets outlets.
- The star point of the secondary winding of the auxiliary supply transformer.
- Earthing terminals of all permanently connected electrical equipment and appliances.
- Conductive parts of discharge luminaires and equipment that need special earthing arrangements.
- All class I equipment.

If any earth leakage unit protecting a cable has a tripping current higher than 30 mA, then a warning label should be attached next to the earth leakage unit, indicating the tripping current.

4. Current ratings of cables

3 shows the current ratings for three- and four-core PVC-insulated PVC-bedded Single Wire Armour (SWA) PVC sheathed 600 V/1000 V cables, manufactured to [5] SANS 1507-3, that are laid in ducts.

Table 3: Current ratings of cables

Cable size (mm^2)	Current rating (ducts) (A)	Impedance (Ω/km)	Three-phase volt drop (mV/A/m)	One-phase volt drop (mV/A/m)	Eskom code (four core)	$R+jX_L$ (Ω/km)
1,5	20	14,48	25,08	28,956	BVX4CCV	14,48
2,5	26	8,87	15,363	17,734	BVX4DCV	8,87
4	34	5,52	9,651	11,034	BVX4ECV	5,52
6	43	3,69	6,391	7,374	BVX4FCV	3,69
10	58	2,19	3,793	4,384	BVX4GCV	2,19
16	75	1,38	2,39	2,759	BVX4HCV	1,374+j0,133
25	96	0,8747	1,515	1,749	BVX4KCV	0,8706+j0,0842
35	116	0,6335	1,097	1,267	BVX4LCV	0,6288+j0,0772
50	138	0,4718	0,817	0,944	BVX4MCV	0,4654+j0,0772
70	171	0,3325	0,576	0,665	BVX4NCV	0,3245+j0,0726
95	205	0,2460	0,427	0,492	BVX4PCV	0,235+j0,072
120	234	0,2012	0,348	0,402	BVX4QCV	0,1885+j0,0703
150	263	0,1698	0,294	0,339	BVX4RCV	0,1541+j0,0714
185	298	0,1445	0,25	0,289	BVX4SCV	0,1255+j0,0716

5. Residual current devices

A Residual Current Device (RCD) is a device designed to cause the opening of one or more contacts when the residual current flowing in the circuit protected by the RCD reaches the rated residual operating current of the device. During earth fault conditions, an unbalance is created when the current returns to the source via the earthing conductor. RCDs are available for single-phase and three-phase loads.

The term RCD is a generic term applied to the following products:

- Residual Current Circuit-breaker (RCCB);
- Residual Current Breaker with Overload protection (RCBO);
- Socket outlet Residual Current Device (SRCD); and
- Portable Residual Current Device (PRCD).

An RCCB differs from an RCBO in that the RCBO will additionally respond to overcurrent conditions, whereas the RCCB will not respond to such conditions. However, add-on RCCBs are available from all manufacturers of MCBs and MCCBs. RCCBs are available for single-phase (two pole) and for three-phase (four-pole) applications.

Three types of RCDs are available. They are categorized in terms of their response to different current waveforms:

- Type AC RCDs, which can detect full-wave AC residual currents only.
- Type A RCDs, which can detect full-wave AC and pulsating DC residual currents. Pulsating DC currents are produced by power control devices such as rectifiers and thyristors.
- Type B RCDs, which can detect full wave AC, pulsating DC and pure DC residual currents.

The RCCB Type B RCBs are specifically suited for the following applications:

- Three-phase controllers and variable speed drives.
- Three-phase battery chargers and inverters.

Delayed response (S-type) RCDs must be fitted upstream of General-type (Instantaneous) RCDs. RCDs are intended to provide protection against electric shock and fire arising from an electrical fault. RCDs rated above 30 mA are not suited for personal protection. However, RCDs with an upper limit of 300 mA can be used for fire protection. RCDs can be used on installations where the fault level is not high enough to enable instantaneous tripping of the MCBs. Low initial arc currents are difficult for MCBs to detect. Therefore this arc can continue for long periods of time and start a fire, which will jeopardize the entire substation. RCDs ensure control and isolation of electrical circuits.

An earth fault can occur in cables due to insulation failure. Insulation of cables can fail due to:

- Overheating
- Cracks developing due to time decay of dielectric properties
- Mechanical damage
- Overvoltage
- Rodent action

The main effects of earth fault currents are:

- Livening up of exposed conductive parts
- Electric arcs
- Disturbances to telecommunication systems
- Erosion phenomena of earth electrodes

The following RCD characteristics need to be taken into account when selecting RCDs:

- Rated voltage and current
- Rated load current (*I*n)
- Rated residual operating current (*I*Δn)
- Rated making and breaking capacity (*I*m)
- General or S Type
- Residual current protection, Type AC, Type A or Type B
- Number of poles to be broken
- Type of poles: solid neutral, switched neutral or fully rated pole
- Response to loss of supply and restoration of supply

RCDs provide a high degree of protection against the risk of electrocution and fire, even when an installation deteriorates due to poor maintenance or lack of compliance with [6] SANS 10142-1. All MCBs that will supply plug boxes in Transmission substations and form the AC Board Type 1 will in future be fitted with a 300 mA RCD. This is due to the fact that these cable runs are extremely long and distances vary from site to site.

6. Double busbar substations – Transmission

6.1 Voltage drop and cable sizes

According to 6.2.7.1 in [6] SANS 10142-1, the voltage drop between the point of supply and any point of outlet or terminals of fixed appliances shall not exceed 5% of the standard or declared voltage. In the case of a 230 V/400 V system, the voltage drop for single-phase circuits shall not exceed 11,5 V (5% of 230 V) and the voltage drop for three-phase circuits shall not exceed 20 V (5% of 400 V). In Eskom substations, the maximum allowed voltage drop between the auxiliary transformer and any fixed appliance shall not be > 5%. If the voltage drop between the auxiliary transformer and the TDB Type 1 is seen as negligible, then 5% of the nominal voltage is allowed to be shed between the TDB Type 1 and any fixed appliance such as a battery charger. If we allow 3,5% of the voltage to be shed between the TDB Type 1 and the AC board, then the maximum cable lengths connected to a TDB Type 1 are shown in 4. The maximum cable lengths are calculated at 70% of the MCCB/MCB rating. This is because most MCCBs are overrated, in order to cater for temporary abnormal overload conditions. MCCB/MCB ratings are usually one size higher than the full load current of the circuit they are intended to protect. A 3,5% voltage drop is allowed on circuits 3, 4 and 6. A 5% voltage drop is allowed on circuits 7, 8 and 9.

Table 4: Maximum cable lengths – TDB type 1

Circuit	MCCB	Destination	Cable size (min.)	Cable lengths (max.)
1	Supply 1	From Auxiliary Transformer	2 × 120 mm^2	
2	Supply 2	From another TDB Type 1 (Standby supply)	1 × 120 mm^2	230 m
3	250 A	Supply to another TDB Type 1	1 × 120 mm^2	230 m
4	250 A	Supply to AC Board Type 1	1 ×120 mm^2	230 m
5	250 A	Supply for Oil Purification Plant		
6	160 A	Supply to TDB Type 2	1 × 70 mm^2	217 m
7	100 A	Spare	1 × 35 mm^2	261 m
8	160 A	Transformer cooler supply	1 × 70 mm^2	217 m
9	25 A	Tap change motor supply	1 × 4 mm^2	119 m

The maximum cable length calculation for circuit 4 of 4 is as follows:

Nominal voltage = 400 V

3,5% of 400V = 14 V

Three-phase voltage drop of 120 mm^2 cable = 0,348 (mV/A/m)

Current = 70% of 250 A = 175 A

0,348/1 000 × 175 × m = 14

m = 14 × 1 000/(0,348 × 175)

= 230 m

5 shows the maximum cable lengths for a TDB Type 2, using 70% MCCB/MCB loading. A 1,5% voltage drop is allowed on circuits 3, 4 and 6.

Table 5: Maximum cable lengths – TDB Type 2

Circuit	MCCB/Isolator	Destination	Cable size	Cable lengths (max.)
1	Supply 1 160 A	From TDB Type 1	1 × 70 mm^2	230 m
2	Supply 2 160 A	From TDB Type 1	1 × 70 mm^2	230 m
3	100 A	Spare	1 × 35 mm^2	78 m
4	80 A	Reactor cooler supply	1 × 25 mm^2	71 m
5	160	Oil purification	1 × 70 mm^2	
6	25 A	Tap change motor supply	1 × 4 mm^2	36 m

6 shows the maximum cable lengths for the AC Board Type 1, using 70% MCCB/MCB loading. A 1,5% voltage drop is allowed on feeder circuits for the AC Board Type 1. For the plug box ring circuit, 15 A was used to calculate the maximum cable length. This is due to the fact that only low wattage heaters are permanently connected on these circuits and a plug point is made available at each plug box. Panel AC cable lengths were calculated using 5 A. Panel plug circuit's cable lengths were calculated using 10 A. The maximum distance for the plug box ring can exceed the maximum length indicated in 6, where the circuit is protected by a 300 mA RCD.

Table 6: Maximum cable lengths – AC board type 1

Circuit	MCCB/MCB rating	Destination	Cable size	Cable lengths (max.)
1	Supply 1 Isolator 300 A	From TDB Type 1	1 × 120 mm^2	230 m
2	Supply 2 Isolator 300 A	From TDB Type 1	1 × 120 mm^2	230 m
3	160A (3P)	(Control Room DB & Lighting Board)	70 mm^2	93 m
4	160A (3P)	Spare	70 mm^2	93 m
5	100A (3P)	Control Room DB	35 mm^2	78 m
6	100A (3P)	Spare	35 mm^2	78 m
7	80A (3P) Curve D	220 V DC/110 V DC M1 Charger	25 mm^2	71 m
8	80A (3P) Curve D	220 V DC/110 V DC M2 Charger	25 mm^2	71 m
9	80A (3P) Curve D	50 V DC M1 Charger	25 mm^2	71 m
10	80A (3P) Curve D	50 V DC M2 Charger	25 mm^2	71 m
11	63A (4P) + 300 mA RCD	Plug Box Ring 1	25 mm^2	264 m

Circuit	MCCB/MCB rating	Destination	Cable size	Cable lengths (max.)
12	63A (4P) + 300 mA RCD	Plug Box Ring 1	25 mm^2	264 m
13	63A (4P) + 300 mA RCD	Plug Box Ring 2	25 mm^2	264 m
14	63A (4P) + 300 mA RCD	Plug Box Ring 2	25 mm^2	264 m
15	63A (4P) + 300 mA RCD	Spare	16 mm^2	
16	63A (4P) + 300 mA RCD	Spare	16 mm^2	
17	63A (3P)	Spare	16 mm^2	57 m
18	63A (3P)	Spare	16 mm^2	57 m
19	16A (1P)	Protection Panel AC	4 mm^2	108 m
20	16A (1P)	Protection Panel AC	4 mm^2	108 m
21	16A (1P)	Protection Panel AC	4 mm^2	108 m
22	16A (1P)	Protection Panel AC	4 mm^2	108 m
23	16A (1P)	Protection Panel AC	4 mm^2	108 m
24	16A (1P)	Protection Panel AC	4 mm^2	108 m
25	16A (1P)	Protection Panel AC	4 mm^2	108 m
26	16A (1P)	Protection Panel AC	4 mm^2	108 m
27	16A (1P)	Protection Panel AC	4 mm^2	108 m
28	16A (1P)	Protection Panel AC	4 mm^2	108 m
29	16A (1P)	Spare	4 mm^2	108 m
30	16A (1P)	Spare	4 mm^2	108 m
31	16A (1P)	Spare	4 mm^2	108 m
32	16A (1P)	Spare	4 mm^2	108 m
33	16A (1P)	Spare	4 mm^2	108 m
34	16A (1P)	Spare	4 mm^2	108 m
35	20A (2P) + E/L (20 mA)	Panel Plugs (loop)	4 mm^2	54 m
36	20A (2P) + E/L (20 mA)	Panel Plugs (loop)	4 mm^2	54 m

If the maximum allowed cable length exceeds the values in the preceding tables, then the cable size must be increased so that allowable volt drop is not exceeded. The following example shows the required cable size where the distance between the TDB Type 1 and the AC board is 400 m.

Nominal voltage	= 400 V
3,5% of 400V	= 14 V
Three-phase voltage drop of cable	= Y (mV/A/m)
Current = 70% of 250 A	= 175 A
Number of cables	= 2
$Y/2\,000 \times 175 \times 400$	= 14
Y	$= 14 \times 2\,000/(400 \times 175)$
	= 0,4 (mV/A/m)

From 3, the smallest cable with a three-phase mV/A/m < 0,4 is a 120 mm^2 cable. Therefore a double 120 mm^2 cable (2 × BVX4QCV) should be used between the TDB Type 1 and the AC board if the distance between them is 400 m. It can be noted that a single 120 mm^2 cable can be used between TDB Type 1 and the AC board if the distance between them is ≤ 230 m.

6.2 Fault levels

Two values of short-circuit currents are evaluated at each distribution board. The maximum short-circuit current is used to determine:

- the breaking capacity of the circuit-breakers; and
- the making capacity of the circuit-breakers.

It is generally accepted that a three-phase fault causes the highest fault current to flow in LV systems.

The minimum short-circuit current is used to determine whether the protective device will trip instantaneously. The minimum LV short-circuit current is a phase-to-phase fault. This fault current will be calculated using 90% of the no-load voltage. This coefficient takes account of voltage drops upstream of the point considered.

2 shows an AC Network with the maximum allowable distance between the Type 1 TDB and AC board Type 1, and between the AC boards Type 1 and the plug box.

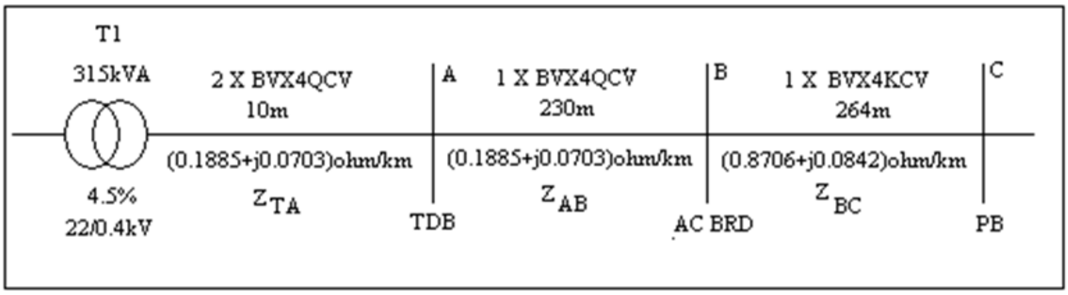


Figure 2: AC network (transmission substation)

Let MVA_{base} = 0,315 MVA

$$Z_b = \frac{kV^2}{MVA}$$

$$= \frac{0,4^2}{0,315}$$

$$= 0,508\ \Omega$$

$$Z_{T1_{actual}} = 0,508 \times 0,045$$

$$= 0,022857\ \Omega$$

$$Z_{TA} = (0,1885 + j0,0703)\frac{10}{2000}$$

$$= 0,000943 + j0,000352$$

$$Z_{AB} = (0,1885 + j0,0703)\frac{230}{1000}$$

$$= 0,043355 + j0,016169$$

$$Z_{BC} = (0,8706 + j0,0842)\frac{264}{1000}$$

$$= 0,229838 + j0,022229$$

$$I_{FA(MAX)} = \frac{400/\sqrt{3}}{j0{,}022857 + 0{,}000943 + j0{,}000352}$$

$$= 9{,}942 \text{ kA}$$

$$I_{FA(MIN)} = \frac{400 \times 0{,}9}{2 \times (j0{,}022857 + 0{,}000943 + j0{,}000352)}$$

$$= 7{,}75 \text{ kA}$$

$$I_{FB(MAX)} = \frac{400/\sqrt{3}}{j0{,}022857 + 0{,}000943 + j0{,}000352 + 0{,}043355 + j0{,}016169}$$

$$= 3{,}896 \text{ kA}$$

$$I_{FB(MIN)} = \frac{400 \times 0{,}9}{2 \times (j0{,}022857 + 0{,}000943 + j0{,}000352 + 0{,}043355 + j0{,}016169)}$$

$$= 3{,}037 \text{ kA}$$

$$I_{FC(MAX)} = \frac{400/\sqrt{3}}{j0{,}022857 + 0{,}000943 + j0{,}000352 + 0{,}043355 + j0{,}016169 + 0{,}229838 + j0{,}022229}$$

$$= 821{,}929 \text{ A}$$

$$I_{FC(MIN)} = \frac{400 \times 0{,}9}{2 \times (j0{,}022857 + 0{,}000943 + j0{,}000352 + 0{,}043355 + j0{,}016169 + 0{,}229838 + j0{,}022229)}$$

$$= 640{,}63 \text{ A}$$

From the preceding calculations, it is evident that the MCCB/MCBs at the TDB must have a short-circuit rating of at least 10 kA at 400 V. The minimum fault level is sufficient to trip a curve C type MCB protecting that particular circuit instantaneously. The cascading technique must be employed in order that both the AC Board Type 1 and the plug box are fitted with 6 kA circuit-breakers. This is due to the fact that if the AC Board is located < 150 m from the TDB, then the fault level at the AC Board will be > 6 kA.

6.3 MCB and cable selection for switch mode battery chargers

7 shows the various battery chargers and the recommended sizing of the supply MCB and cable.

Table 7: Miniature circuit-breaker and cable sizes for battery chargers

Output voltage	Output current	Input current/phase	MCB in charger	MCB in AC board	Cable size
50	100	44,5	63 A curve D	80 A curve D	25 mm^2
50	200	44,5	63 A curve D	80 A curve D	25 mm^2
50	300	44,5	63 A curve D	80 A curve D	25 mm^2
110	100	50,6	63 A curve D	80 A curve D	25 mm^2
110	200	50,6	63 A curve D	80 A curve D	25 mm^2
110	300	101,2	125 A curve D	160 A MCCB	70 mm^2
220	100	50,6	63 A curve D	80 A curve D	25 mm^2
220	200	101,2	125 A curve D	160 A MCCB	70 mm^2
220	300	126,5	160 A MCCB	160 A MCCB	95 mm^2

7. Breaker-and-a-half substations

7.1 Voltage drop and cable sizes

8, 9 and 10 show the maximum cables lengths that can be connected on the outdoor AC Boards located in breaker-and-a-half substations. These maximum lengths were calculated to ensure that the voltage drop does not exceed 5%. However, the cable sizes can be increased to 185 mm^2 for all MCCBs used on the outdoor AC Boards in breaker-and-a-half substations. All MCCBs and incomer circuits are equipped with busbar terminations.

Table 8: Maximum cable lengths – type 3A DB

Circuit	MCCB	Destination	Cable size (min.)	Cable lengths (max.)
ISOL 1	Supply 1	From Auxiliary Transformer	2×185 mm^2	
ISOL 2	Supply 2	From another DB Type 3A (Standby supply)	2×150 mm^2	295 m
MCB A	500 A	To another DB Type 3A	2×150 mm^2	295 m
MCB B	500 A	To Service Distribution Box (SDB) Type 1	2×150 mm^2	295 m
MCB C	500 A	To DB Type 4A	2×150 mm^2	295 m
MCB D	500 A	To DB Type 4A	2×150 mm^2	295 m
MCB E	200 A	Cooler Control (R, W & B)	1×120 mm^2	328 m
MCB F	350 A	Oil Purification		
MCB G	100 A	Spare/Flood Lighting	1×35 mm^2	
MCB H	125 A	Cooler Control (R)/Spare	1×50 mm^2	
MCB J	125 A	Cooler Control (W)/Spare	$1 \times 50mm^2$	
MCB K	125 A	Cooler Control (B)/Spare	1×50 mm^2	
MCB L	63 A	Three-phase welding socket		

Table 9: Maximum cable lengths – type 4A DB

Circuit	MCCB	Destination	Cable size (min.)	Cable lengths (max.)
ISOL 1	Supply 1	From DB Type 3A	2×150 mm^2	295 m
ISOL 2	Supply 2	From DB Type 3A	2×150 mm^2	295 m
MCB A	350 A	To another DB Type 4A	2×150 mm^2	295 m
MCB B	350 A	Oil Purification		
MCB C	160 A	Spare/Flood Lighting	$1 \times 70mm^2$	125 m
MCB D	100 A	Spare/Flood Lighting	1×35 mm^2	104 m
MCB E	63 A	Cooler Control (R, W & B)	1×16 mm^2	124 m
MCB F	16 A	Kelman (R, W & B)	1×4 mm^2	
MCB G	16 A	Dry Keep units (R, W & B)	1×4 mm^2	
MCB H	16 A	Spare	1×4 mm^2	
MCB J	63 A	Three-phase welding socket		

Table 10: Maximum cable lengths – SDB type 1

Circuit	MCCB	Destination	Cable size (min.)	Cable lengths (max.)
ISOL 1	Supply 1	From DB Type 3A	2×150 mm^2	295 m
ISOL 2	Supply 2	From DB Type 3A	2×150 mm^2	295 m
MCB A	160 A	380 V Control Room DB/Flood Lighting	1×70 mm^2	125 m
MCB B	100 A	Spare	1×35 mm^2	104 m
MCB C	80 A	230 V AC Distribution Board – Type 4	1×25 mm^2	95 m
MCB D	125 A	220 V DC MAIN 1 Battery Charger (200 A)	1×25 mm^2	95 m
MCB E	125 A	220 V DC MAIN 2 Battery Charger (200 A)	1×25 mm^2	95 m
MCB F	63 A	Diameter MA – DMK AC Board Type 1	1×70 mm^2	347 m
MCB G	63 A	Diameter MB – DMK AC Board Type 1	1×70 mm^2	347 m
MCB H	63 A	Diameter MC – DMK AC Board Type 1	1×70 mm^2	347 m
MCB J	63 A	Diameter MD – DMK AC Board Type 1	1×70 mm^2	347 m
MCB K	63 A	Diameter ME – DMK AC Board Type 1	1×70 mm^2	347 m
MCB L	63 A	Diameter MF – DMK AC Board Type 1	1×70 mm^2	347 m
MCB M	63 A	50 V DC MAIN 1 Battery Charger	1×16 mm^2	76 m
MCB N	63 A	50 V DC MAIN 2 Battery Charger	1×16 mm^2	76 m

7.2 DMK AC board application

11, 12 and 13 show the application circuits for the various types of diameters that exist in breaker-and-a-half substations. Circuits 6 to 10 supply the JB panels located within the Diameter Marshalling Kiosk (DMK). Circuits 11 to 45 supply heater circuits. The maximum distance between the DMK AC Board and the plug box (located within the same diameter) shall not exceed 126 m, due to the voltage drop, during maximum load conditions. However, because the circuit is protected by an earth leakage unit, tripping for earth faults is enhanced. The maximum distance for the heater circuits is 350 m. This distance will never be exceeded as long as the DMK AC Board is used to supply heater circuits within the same diameter.

Table 11: DMK AC board application – busbar reactor diameter

Destination	Circuit	Eskom cable specification	Notes
Station Distribution Board	1	BVX4NCV	Main Supply
Diameter Marshalling Kiosk 230 V DB	2	BVX4FCV	DMK DB AC Supply
Yard Plug Boxes	3	BVX2HCV	Plug box loop supply
Spare	4		Plug box loop supply
Diameter Marshalling Kiosk 220 V DC Board	5	BVX2ECV	DMK DC Board
Spare	6	BVX2ECV	Object (JB) Link to Bay 1
Bay 1 Junction Box Panel	7	BVX2ECV	Bay 1
Spare	8	BVX2ECV	Tie Bay
Bay 2 Junction Box Panel	9	BVX2ECV	Bay 2
Busbar Reactor # Reactor Junction Box Panel	10	BVX2ECV	Object (JB) Link to Bay 2

Destination	Circuit	Eskom cable specification	Notes
Spare	11	BVX2ECV	Object Linked to Bay 1
Spare	12	BVX2ECV	Object Linked to Bay 1
Spare	13	BVX2ECV	Object Linked to Bay 1
Spare	14	BVX2ECV	Object Linked to Bay 1
Spare	15	BVX2ECV	Object Linked to Bay 1
Spare	16	BVX2ECV	Object Linked to Bay 1
Busbar 1 Earth switch	17	BVX2ECV	Object Linked to Bay 1
Bay 1 Busbar 1 VTJB	18	BVX2ECV	Object Linked to Bay 1
Bay 1 Busbar 1 Isolator	19	BVX2ECV	Bay 1
Bay 1 Breaker Earth Switch Busbar 1 side	20	BVX2ECV	Bay 1
Bay 1 Breaker	21	BVX2ECV	Bay 1
Bay 1 Breaker Earth Switch Connector 1 side	22	BVX2ECV	Bay 1
Bay 1 Isolator Busbar 2 side	23	BVX2ECV	Bay 1
Connector 1 VTJB	24	BVX2ECV	Bay 1
Connector 1 Earth Switch	25	BVX2ECV	Bay 1
Spare	26	BVX2ECV	Tie Bay
Spare	27	BVX2ECV	Tie Bay
Spare	28	BVX2ECV	Tie Bay
Spare	29	BVX2ECV	Tie Bay
Spare	30	BVX2ECV	Tie Bay
Connector 2 Earth Switch	31	BVX2ECV	Tie Bay
Connector 2 VTJB	32	BVX2ECV	Tie Bay
Bay 2 Isolator Busbar 1 side	33	BVX2ECV	Bay 2
Bay 2 Breaker Earth Switch Connector 2 side	34	BVX2ECV	Bay 2
Bay 2 Breaker	35	BVX2ECV	Bay 2
Bay 2 Breaker Earth Switch Busbar 2 side	36	BVX2ECV	Bay 2
Bay 2 Busbar 2 Isolator	37	BVX2ECV	Bay 2
Bay 2 Busbar 2 VTJB	38	BVX2ECV	Object Linked to Bay 2
Busbar 2 Earth switch	39	BVX2ECV	Object Linked to Bay 2
Busbar Reactor # Connector 1 Isolator	40	BVX2ECV	Object Linked to Bay 2
Busbar Reactor # Transfer Busbar Earth Switch	41	BVX2ECV	Object Linked to Bay 2
Busbar Reactor # Isolator	42	BVX2ECV	Object Linked to Bay 2
B/B Reac # Breaker Earth Switch Trans Busbar side	43	BVX2ECV	Object Linked to Bay 2
Busbar Reactor Breaker	44	BVX2ECV	Object Linked to Bay 2
Busbar Reactor # Breaker Earth Switch Reactor side	45	BVX2ECV	Object Linked to Bay 2

Table 12: DMK AC board application (transformer – feeder diameter)

Destination	Circuit	Cable Specification	Notes
Station Distribution Board	1	BVX4NCV	Main Supply
Diameter Marshalling Kiosk 230 V DB	2	BVX4FCV	DMK DB AC Supply
Yard Plug Boxes	3	BVX2HCV	Plug box loop supply
Spare	4		Plug box loop supply
Diameter Marshalling Kiosk 220 V DC Board	5	BVX2ECV	DMK DC Board
Transformer # Junction Box Panel	6	BVX2ECV	Object (JB) Link to Bay 1
Bay 1 Junction Box Panel	7	BVX2ECV	Bay 1
Tie Bay Junction Box Panel	8	BVX2ECV	Tie Bay
Bay 2 Junction Box Panel	9	BVX2ECV	Bay 2
Feeder # Reactor Reactor Junction Box Panel	10	BVX2ECV	Object (JB) Link to Bay 2
NECRT Breaker	11	BVX2ECV	NECRT
MV Busbar 1 VTJB	12	BVX2ECV	MV B/B 1 VTJB
MV Busbar 2 VTJB	13	BVX2ECV	MV B/B 2 VTJB
Spare	14		Object Linked to Bay 1
Spare	15		Object Linked to Bay 1
Transformer # MVVTJB	16	BVX2ECV	Object Linked to Bay 1
Transformer # Earth Switch	17	BVX2ECV	Object Linked to Bay 1
Transformer # HV Isolator	18	BVX2ECV	Object Linked to Bay 1
Bay 1 Busbar 1 Isolator	19	BVX2ECV	Bay 1
Bay 1 Breaker Earth Switch Busbar 1 side	20	BVX2ECV	Bay 1
Bay 1 Breaker	21	BVX2ECV	Bay 1
Bay 1 Breaker Earth Switch Connector 1 side	22	BVX2ECV	Bay 1
Bay 1 Isolator Busbar 2 side	23	BVX2ECV	Bay 1
Connector 1 VTJB	24	BVX2ECV	Bay 1
Connector 1 Earth Switch	25	BVX2ECV	Bay 1
Tie Bay Isolator Busbar 1 side	26	BVX2ECV	Tie Bay
Tie Bay Breaker Earth Switch Busbar I side	27	BVX2ECV	Tie Bay
Tie Bay Breaker	28	BVX2ECV	Tie Bay
Tie Bay Breaker Earth Switch Busbar 2 side	29	BVX2ECV	Tie Bay
Tie Bay Isolator Busbar 2 side	30	BVX2ECV	Tie Bay
Connector 2 Earth Switch	31	BVX2ECV	Tie Bay
Connector 2 VTJB	32	BVX2ECV	Tie Bay
Bay 2 Isolator Busbar 1 side	33	BVX2ECV	Bay 2
Bay 2 Breaker Earth Switch Connector 2 side	34	BVX2ECV	Bay 2
Bay 2 Breaker	35	BVX2ECV	Bay 2
Bay 2 Breaker Earth Switch Busbar 2 side	36	BVX2ECV	Bay 2

Destination	Circuit	Cable Specification	Notes
Bay 2 Busbar 2 Isolator	37	BVX2ECV	Bay 2
Feeder # VTJB	38	BVX2ECV	Object Linked to Bay 2
Feeder # Transfer Isolator	39	BVX2ECV	Object Linked to Bay 2
Feeder # Line Earth Switch	40	BVX2ECV	Object Linked to Bay 2
Feeder # Line Isolator	41	BVX2ECV	Object Linked to Bay 2
Feeder # Reactor Breaker Earth Switch Line side	42	BVX2ECV	Object Linked to Bay 2
Feeder # Reactor Breaker	43	BVX2ECV	Object Linked to Bay 2
Feeder # Reactor Isolator	44	BVX2ECV	Object Linked to Bay 2
Feeder # Reactor Breaker Earth Switch Reactor side	45	BVX2ECV	Object Linked to Bay 2

Table 13: DMK AC board application (feeder – feeder diameter)

Destination	Circuit	Eskom Cable Spec	Notes
Station Distribution Board	1	BVX4NCV	Main Supply
Diameter Marshalling Kiosk 230 V DB	2	BVX4FCV	DMK DB AC Supply
Yard Plug Boxes	3	BVX2HCV	Plug box loop supply
Spare	4		Plug box loop supply
Diameter Marshalling Kiosk 220 V DC Board	5	BVX2ECV	DMK DC Board
Feeder # Reactor Reactor Junction Box Panel	6	BVX2ECV	Object (JB) Link to Bay 1
Bay 1 Junction Box Panel	7	BVX2ECV	Bay 1
Tie Bay Junction Box Panel	8	BVX2ECV	Tie Bay
Bay 2 Junction Box Panel	9	BVX2ECV	Bay 2
Feeder # Reactor Reactor Junction Box Panel	10	BVX2ECV	Object (JB) Link to Bay 2
Feeder # Reactor Breaker Earth Switch Reactor side	11	BVX2ECV	Object Linked to Bay 1
Feeder # Reactor Isolator	12	BVX2ECV	Object Linked to Bay 1
Feeder # Reactor Breaker	13	BVX2ECV	Object Linked to Bay 1
Feeder # Reactor Breaker Earth Switch Line side	14	BVX2ECV	Object Linked to Bay 1
Feeder # Line Isolator	15	BVX2ECV	Object Linked to Bay 1
Feeder # Line Earth Switch	16	BVX2ECV	Object Linked to Bay 1
Feeder # Transfer Isolator	17	BVX2ECV	Object Linked to Bay 1
Feeder # VTJB	18	BVX2ECV	Object Linked to Bay 1
Bay 1 Busbar 1 Isolator	19	BVX2ECV	Bay 1
Bay 1 Breaker Earth Switch Busbar 1 side	20	BVX2ECV	Bay 1
Bay 1 Breaker	21	BVX2ECV	Bay 1
Bay 1 Breaker Earth Switch Connector 1 side	22	BVX2ECV	Bay 1
Bay 1 Isolator Busbar 2 side	23	BVX2ECV	Bay 1
Connector 1 VTJB	24	BVX2ECV	Bay 1

Destination	Circuit	Eskom Cable Spec	Notes
Connector 1 Earth Switch	25	BVX2ECV	Bay 1
Tie Bay Isolator Busbar 1 side	26	BVX2ECV	Tie Bay
Tie Bay Breaker Earth Switch Busbar I side	27	BVX2ECV	Tie Bay
Tie Bay Breaker	28	BVX2ECV	Tie Bay
Tie Bay Breaker Earth Switch Busbar 2 side	29	BVX2ECV	Tie Bay
Tie Bay Isolator Busbar 2 side	30	BVX2ECV	Tie Bay
Connector 2 Earth Switch	31	BVX2ECV	Tie Bay
Connector 2 VTJB	32	BVX2ECV	Tie Bay
Bay 2 Isolator Busbar 1 side	33	BVX2ECV	Bay 2
Bay 2 Breaker Earth Switch Connector 2 side	34	BVX2ECV	Bay 2
Bay 2 Breaker	35	BVX2ECV	Bay 2
Bay 2 Breaker Earth Switch Busbar 2 side	36	BVX2ECV	Bay 2
Bay 2 Busbar 2 Isolator	37	BVX2ECV	Bay 2
Feeder # VTJB	38	BVX2ECV	Object Linked to Bay 2
Feeder # Transfer Isolator	39	BVX2ECV	Object Linked to Bay 2
Feeder # Line Earth Switch	40	BVX2ECV	Object Linked to Bay 2
Feeder # Line Isolator	41	BVX2ECV	Object Linked to Bay 2
Feeder # Reactor Breaker Earth Switch Line side	42	BVX2ECV	Object Linked to Bay 2
Feeder # Reactor Breaker	43	BVX2ECV	Object Linked to Bay 2
Feeder # Reactor Isolator	44	BVX2ECV	Object Linked to Bay 2
Feeder # Reactor Breaker Earth Switch Reactor side	45	BVX2ECV	Object Linked to Bay 2

7.3 230 V control room AC board application

The 230 V Control Room AC Board consists of 36 single-phase circuits (MCB 1 to MCB 36) and 22 single-phase earth leakage circuits (MCB 37 to MCB 58). All plug points within the Diameter Interface panels, Disturbance Recorder panels, etc. are supplied from individual earth leakage units. The AC for each Diameter Interface panel has its own dedicated AC supply. 14 shows an application done for a substation consisting of four diameters.

Table 14: 230 V AC board application

Circuit	Destination	Circuit	Destination	Circuit	Destination
MCB 1	DMK MA TRF. 21 NECRT PNL	MCB 21		MCB 41	DMK MB INTERFACE PNL
MCB 2	DMK MA INTERFACE PNL	MCB 22		MCB 42	
MCB 3		MCB 23		MCB 43	DMK MC INTERFACE PNL
MCB 4		MCB 24		MCB 44	DMK MC B.B. REAC. 1 RP

Circuit	Destination	Circuit	Destination	Circuit	Destination
MCB 5	DMK MB INTERFACE PNL	MCB 25		MCB 45	
MCB 6		MCB 26		MCB 46	DMK MD FDR. 6 REAC. RP
MCB 7	DMK MC INTERFACE PNL	MCB 27		MCB 47	DMK MD INTERFACE PNL.
MCB 8	DMK MC B.B. REAC. 1 IP	MCB 28		MCB 48	DMK MD FDR. 3 REAC. RP
MCB 9		MCB 29		MCB 49	DIST. RECORDER PANEL 1
MCB 10	DMK MD FDR. 6 REAC. IP	MCB 30		MCB 50	DIST. RECORDER PANEL 2
MCB 11	DMK MD INTERFACE PNL	MCB 31		MCB 51	
MCB 12	DMK MD FDR. 3 REAC. IP	MCB 32		MCB 52	
MCB 13		MCB 33		MCB 53	PLC – FDR 3
MCB 14		MCB 34		MCB 54	PLC – FDR 6
MCB 15		MCB 35	ENGINEERING WORK STATION	MCB 55	PLC – FDR 1
MCB 16		MCB 36	BUS ZONE PANEL 1	MCB 56	TELECOMMS CABINET
MCB 17		MCB 37	DMK MA TRF. 21 NECRT PNL	MCB 57	D400 ERTU
MCB 18		MCB 38	DMK MA INTERFACE PNL	MCB 58	BME CABINET
MCB 19		MCB 39		MCB 59	PLUG MODULE 1
MCB 20		MCB 40		MCB 60	PLUG MODULE 2

7.4 Fault levels

3 shows an AC Network with the maximum allowable distances between the various distribution boards.

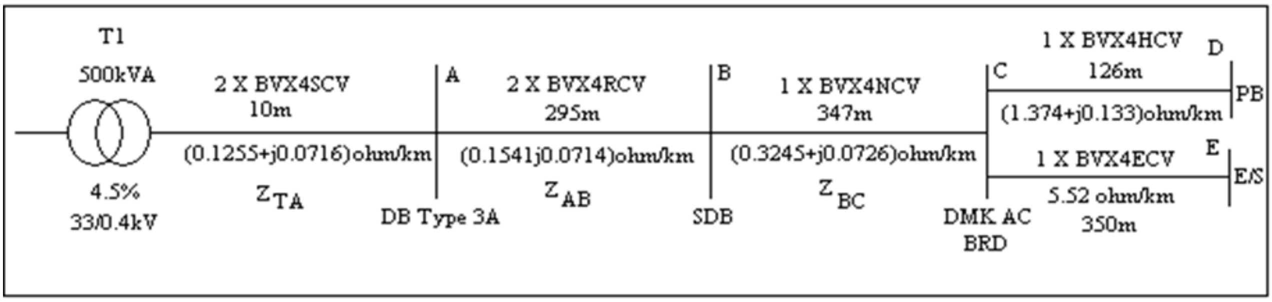


Figure 3: AC Network (breaker-and-a-half substation)

Let MVA_{base} = 0,5 MVA

$$Z_b = \frac{kV^2}{MVA}$$

$$= \frac{0{,}4^2}{0{,}5}$$

$$= 0{,}32\ \Omega$$

$$Z_{T1_{actual}} = 0{,}32 \times 0{,}045$$

$$= 0{,}0144\ \Omega$$

$$Z_{TA} = (0{,}1255 + j0{,}0716)\frac{10}{2000}$$

$$= 0{,}000628 + j0{,}000358$$

$$Z_{AB} = (0{,}1541 + j0{,}0714)\frac{295}{2000}$$

$$= 0{,}022730 + j0{,}010532$$

$$Z_{BC} = (0{,}3245 + j0{,}0726)\frac{347}{1000}$$

$$= 0{,}112602 + j0{,}025192$$

$$Z_{CD} = (0{,}1374 + j0{,}133)\frac{126}{1000}$$

$$= 0{,}017312 + j0{,}016758$$

$$Z_{CE} = (5{,}52)\frac{350}{1000}$$

$$= 1{,}932$$

$$I_{FA(MAX)} = \frac{400/\sqrt{3}}{j0{,}0144 + 0{,}000628 + j0{,}000358}$$

$$= 15{,}63\ \text{kA}$$

$$I_{FA(MIN)} = \frac{400 \times 0{,}9}{2 \times (j0{,}0144 + 0{,}000628 + j0{,}000358)}$$

$$= 12{,}19\ \text{kA}$$

$$I_{FB(MAX)} = \frac{400/\sqrt{3}}{(j0{,}0144 + 0{,}000628 + j0{,}000358 + 0{,}022730 + j0{,}010532)}$$

$$= 6{,}71\ \text{kA}$$

$$I_{FB(MIN)} = \frac{400 \times 0{,}9}{2 \times (j0{,}0144 + 0{,}000628 + j0{,}000358 + 0{,}022730 + j0{,}010532)}$$

$$= 5{,}23\ \text{kA}$$

$$I_{FC(MAX)} = \frac{400/\sqrt{3}}{(j0{,}0144 + 0{,}000628 + j0{,}000358 + 0{,}022730 + j0{,}010532 + 0{,}112602 + j0{,}025192)}$$

$$= 1{,}592\ \text{kA}$$

$$I_{FC(MIN)} = \frac{400 \times 0{,}9}{2 \times (j0{,}0144 + 0{,}000628 + j0{,}000358 + 0{,}022730 + j0{,}010532 + 0{,}112602 + j0{,}025192)}$$

$$= 1{,}24\ \text{kA}$$

$$I_{FD(MAX)} = \frac{400/\sqrt{3}}{(j0{,}0144 + 0{,}000628 + j0{,}000358 + 0{,}022730 + j0{,}010532 + 0{,}112602 + j0{,}025192 + 0{,}017312 + j0{,}016758)}$$

$$= 1{,}38\ \text{kA}$$

$$I_{FD(MIN)} = \frac{400 \times 0{,}9}{2 \times (j0{,}0144 + 0{,}000628 + j0{,}000358 + 0{,}022730 + j0{,}010532 + 0{,}112602 + j0{,}025192 + 0{,}017312 + j0{,}016758)}$$

$$= 1{,}075\ \text{kA}$$

$$I_{FE(MAX)} = \frac{400/\sqrt{3}}{(j0{,}0144 + 0{,}000628 + j0{,}000358 + 0{,}022730 + j0{,}010532 + 0{,}112602 + j0{,}025192 + 1{,}932)}$$

$$= 111{,}64\ \text{A}$$

$$I_{FE(MIN)} = \frac{400 \times 0{,}9}{2 \times (j0{,}0144 + 0{,}000628 + j0{,}000358 + 0{,}022730 + j0{,}010532 + 0{,}112602 + j0{,}025192 + 1{,}932)}$$

$$= 87\ \text{A}$$

The preceding calculations prove that the fault level is at least five times higher than the rating of the MCB protecting that particular circuit, provided that the maximum cable lengths are adhered to.

8. Distribution substations

8.1 Transformer cooling fans

In the design, it is assumed that a maximum number of eight (2,8 kW) fan motors are used for cooling the transformers. It is further assumed that the cooling fans are switched on sequentially in pairs (two at a time). Cooling fans are normally used on transformers with a rating of ≥ 40 MVA.

8.2 Floodlights

Floodlight design parameters: a maximum number of 12 × 400 W lights are allowed for in the design.

The floodlights are controlled by two-way switches, which shall be located on the inside of the substation gate and at the relay house entrance. The floodlights are energized by these two floodlight switches through a contactor in the Yard AC Distribution Panel. The floodlight supply circuit is a looped supply, which in the case of large yards, should be balanced from a three-phase looped supply. The supply to the floodlights may be split so that only some lights are switched on from the remote switch while the rest are switched on at the light.

8.3 Cabling

8.3.1 Standard cable sizes

Table 15: Cable size for panels that require AC and DC supplies

Cores	Dimensions	Destination
4	4 mm^2	Two cores for AC and two cores (one core per polarity) for DC.
	4 mm^2	Separate AC and DC supply cables.
4	16 mm^2	AC supply from the auxiliary transformer to the fan motors.
4	16 mm^2	AC supply from the Yard AC board to the relay house board.
4	25 mm^2	AC supply from the auxiliary transformer to the Yard AC board.
4	2,5 mm^2	AC supply from the Yard AC board to the floodlights and OLTC motors.
2	2,5 mm^2	A. supply from the Yard AC board to the heaters, floodlights control switch.
4	4 mm^2	AC supply from the relay-house AC/DC board to the domestic distribution in the relay house.
2	4 mm^2	AC supply from the relay house AC/DC board to the 50 V and 110 V, single-phase battery chargers.
2 $\times$ 2	16 mm^2	Supply cable from battery to battery protection device (one cable per polarity).

8.3.2 Cable sizing

8.3.2.1 Introduction

The following voltage drop and fault level analysis is for a typical substation. All new designs or refurbishments must be taken on their own merit, as there is a lot of variety in modern designs.

8.3.2.2 Load analysis

Table 16 and 17 show the typical equipment in a substation with typical maximum load currents.

Note: These tables also show the preferred phase connections to the loads in order to get a good balancing of load currents.

Table 16: Typical yard AC distribution loads

Yard AC loads	Phase currents (A)			
	Red	White	Blue	Neutral
OLTC – motor 1	2	2	2	0
OLTC – motor 2	2	2	2	0
OLTC – motor 3	2	2	2	0
OLTC – motor 4	2	2	2	0
Heaters	5	0	0	5
Floodlights	7	7	7	0
Floodlights control	0	2	0	2
Test socket	16	16	16	0
Total yard current	**36**	**33**	**31**	**4,36**

Table 17: Typical relay-house AC distribution loads

Relay house loads	Phase currents (A)			
	Red	White	Blue	Neutral
TRFR/OLTC Panel 1	1	0	0	1
TRFR/OLTC Panel 2	0	1	0	1
TRFR/OLTC Panel 3	0	0	1	1
TRFR/OLTC Panel 4	1	0	0	1
HV Feeder Panel 1	0	1	0	1
HV Feeder Panel 2	0	0	1	1
MV Feeder Panel 1	1	0	0	1
MV Feeder Panel 2	0	1	0	1
MV Feeder Panel 3	0	0	1	1
MV Feeder Panel 4	1	0	0	1
Buszone Panel	0	1	0	1
UFL Panel	0	0	1	1
Measurements Panel	1	0	0	1
110 V, 20 A Charger	0	0	10	10
50 V Charger	0	0	0	0
Test socket	16	16	16	0
Domestic Distribution AC-DB	30	30	30	0
Total relay-house current	**51**	**50**	**60**	**9,54**

The neutral currents in Table 16 and 17were calculated using the following formula:

$$I_{neutral} = \sqrt{R^2 + W^2 + B^2 - (R \times W) - (R \times B) - (B \times W)}$$

The total load currents per phase with all the loads operating (worst case) are:

- Red Phase = 87 A
- White Phase = 83 A
- Blue Phase = 91 A
- Neutral = 13,898 A

8.3.2.3 Voltage drops

4 is a single-line diagram indicating circuits that may be sensitive to voltage drops.

The total load currents are used to calculate the voltage drop along the different cable routes.

Note: Throughout the calculations, the letters R, W, B and N denote the red, white, blue and neutral conductors respectively. The starting currents (5,3 × I_{nom}) are used to calculate the voltage drops for motors.

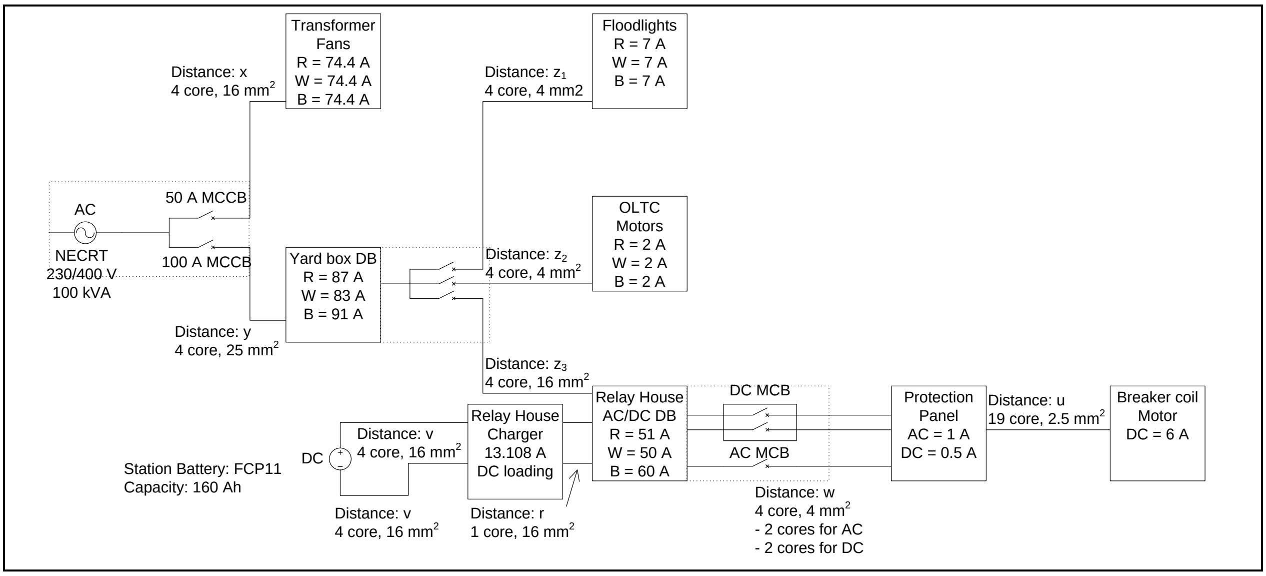


Figure 4: Single-line diagram indicating circuits that may be sensitive to voltage drops

The cable typically used for the auxiliary supply to the yard box is a four- core, 25 mm^2 cable. The worst case current rating is 96 A installed in ducts. The impedance is 0,8749 Ω/km and the voltage drop is 1,515 mV/A/m.

Total currents at this point: R = 87 A

W = 83 A

B = 91 A

N = 13,898 A

This data is from Table 16 and 17. Using this, the maximum cable length for the allowed 5% voltage drop as per [6] SANS 10142-1 can be worked out. Using the blue phase current, since this phase is loaded the most, the voltage drop is calculated as follows:

$$\%V_{drop} = \frac{V_{drop}}{V_{\varphi-n}} \cdot 100$$

$$V_{drop} = \frac{\%V_{drop} \cdot V_{\varphi-n}}{100}$$

$$= \frac{5 \times 230}{100}$$

$$= 11,5\,V$$

$$
\begin{aligned}
Z_{cable} &= \frac{V_{drop}}{I|_{bluephase}} \\
&= \frac{11 \times 5}{91} \\
&= 0{,}1264\,\Omega
\end{aligned}
$$

$$
\begin{aligned}
L_{cable} &= \frac{Z_{cable}}{Z_{\Omega/km}} \cdot 1000 \\
&= \frac{0{,}1264}{0{,}8749} \cdot 1000 \\
&= 144{,}44\,m
\end{aligned}
$$

The maximum cable length allowed load is therefore 144,44 m. If the yard box is installed further than this, a larger cable will be required.

Using the follow data, the rest of the cable lengths can be computed:

- Four core, 16 mm^2. The impedance is 1,38 Ω/km as per manufacturer's data.
- Four core, 4 mm^2. The impedance is 5,52 Ω/km as per manufacturer's data.

Table 18: Maximum cable lengths (Distribution substation)

Route	Maximum cable length
Auxiliary supply MCBs to Yard Box (y)	144,44 m
Auxiliary supply MCBs to Cooling Fans (x)	85,034 m
Yard DB to Relay-house AC/DC panel (z_3)	138,889 m
Yard DB to Floodlights (z_1)	297,619 m
Yard DB to OLTC motors (z_2)	1 041,667 m

5 shows a graph with the current vs distance for a 5% voltage drop in the four main size cables used. They are 25 mm^2, 16 mm^2, 4 mm^2 and 2,5 mm^2 cables. The maximum current used for the auxiliary supply MCBs to the yard box and from the Yard DB to the Relay-house AC/DC panel as taken from Table 16 and 17 are more than the rated current for the cable. This current is a maximum current and will never be drawn for long periods of time, and the MCB will protect the cable from damage. The following calculations are for a moment in time and the maximum current.

This gives the designer an idea of how long the cables can be, but it is not the full picture. The 5% voltage drop is from the source to the load. The length must thus be from the auxiliary supply to the relay house DB, for instance. To demonstrate this better, average distances are chosen between boards for x, y, z_1, z_2 and z_3. Refer to 18. With these values, the reverse of the preceding method will be followed and the actual voltage drop is computed to verify if it is within specifications.

Distances are: x = 20 m

y = 20 m

z_1 = 60 m

z_2 = 30 m

z_3 = 60 m

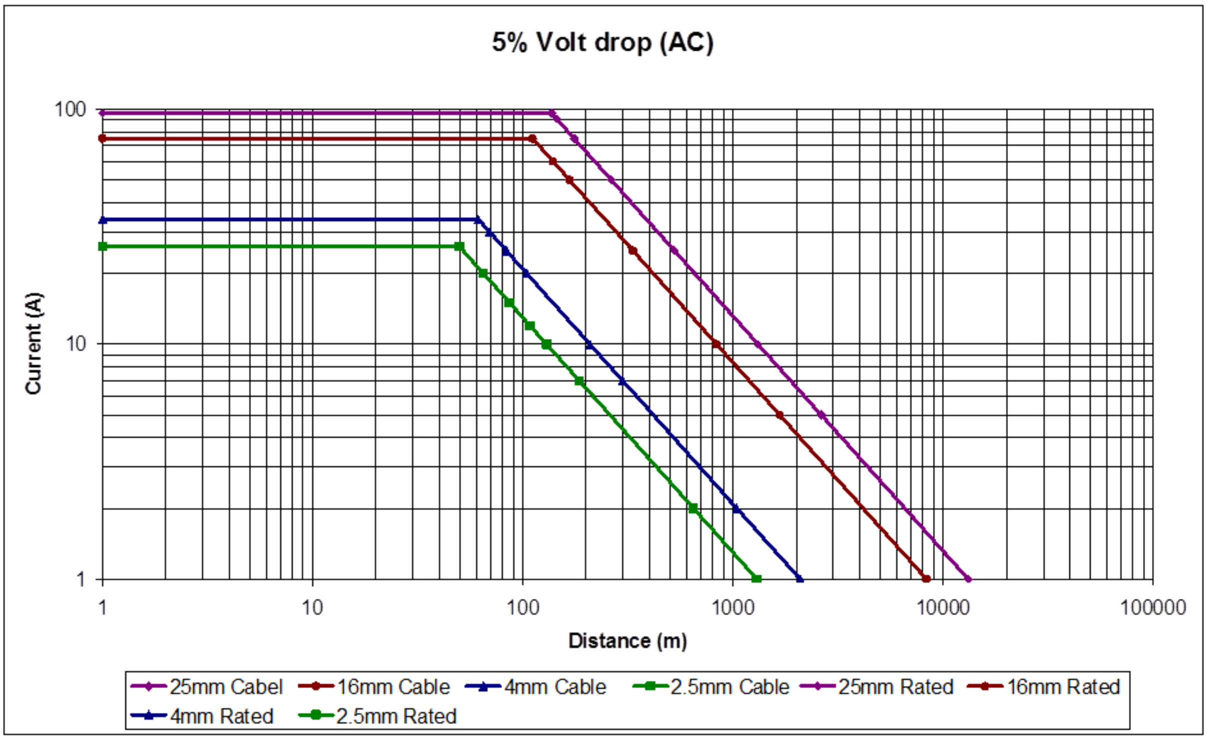


Figure 5: Current vs distance for a 5% voltage drop in 25 mm², 16 mm², 4 mm² and 2,5 mm² cable

First, calculate the voltage drop for the 20 m section from the auxiliary supply to the yard box.

$$Z_{\text{cable}}\big|_{20\text{m}} = 0{,}8749 \times \frac{20}{1000}$$
$$= 0{,}017\Omega$$

The voltage drop along the blue phase will be:

$$V_{drop}\big|_{bluephase} = Z_{cable}\big|_{20m} \times I_{bluephase}$$
$$= 0{,}017 \cdot 91$$
$$= 1{,}592\,V$$

The voltage drops for the other phases are worked out in the same way as explained above.

Voltage drops: R = 1,522 V

W = 1,452 V

B = 1,592 V

N = 0,243 V

The percentage voltage drop at this point can be calculated as follows:

$$\%V_{drop} = \frac{V_{drop}}{V_{\phi-n}} \cdot 100$$
$$= \frac{1{,}592}{230} \cdot 100$$
$$= 0{,}692\%$$

Table 19: AC voltage drops along the cables in 5

Route	Red phase	White phase	Blue phase	Neutral
Aux. TRFR – Yard DB	1,52	1,45	1,59	0,24
Yard DB – Relay house DB	4,22	4,14	4,97	0,79
Aux. TRFR – Relay house DB	5,75	5,59	6,56	1,03
Yard DB – Floodlights	2,32	2,32	2,32	0,00
Aux. TRFR – Floodlights	3,84	3,77	3,91	0,24
Yard DB – OLTC motors	0,33	0,33	0,33	0,00
Aux. TRFR – OLTC motors	1,85	1,78	1,92	0,24
Relay house DB – Control Plant Panel (single phase)			0,33	0,33
Aux. TRFR – Control Plant Panel (single phase)			6,89	1,36

Table 20: Percentage AC voltage drops along the cables in 5

Route	Red phase	White phase	Blue phase	Neutral
Aux. TRFR – Yard DB	0,66	0,63	0,69	0,11
Yard DB – Relay-house DB	1,84	1,80	2,16	0,34
Aux. TRFR – Relay-house DB	2,50	2,43	2,85	0,45
Yard DB –Floodlights	1,01	1,01	1,01	0,00
Aux. TRFR – Floodlights	1,67	1,64	1,70	0,11
Yard DB – OLTC motors	0,14	0,14	0,14	0,00
Aux. TRFR – OLTC motors	0,81	0,78	0,84	0,11
Relay-house DB – Control Plant Panel (single phase)	0,00	0,00	0,14	0,14
Aux. TRFR – Control Plant Panel (single phase)	0,00	0,00	3,00	0,59

The four-core, 16 mm^2 cables that are supplying the cooling fans of the main transformer have the following voltage drops, if we assume that a total of eight 1,5 kW fan motors are started in a sequence of pairs (two at a time). When the last two motors (7 and 8) are started, the total current at this time will amount to 74,4 A. This value was worked out by using the following information that was obtained from a typical fan motor data sheet, as shown in Annex C:

- Power output : 1,5 kW
- Rated voltage : 380 V
- Rated current : 4,48 A
- LR amperes : 23,7 A (start-up current)
- I_l/I_n : 5,3

6 illustrates the start-up of the fans. At time period 1, fans 1 and 2 start up. The current peaks at 47,5 A and returns to the rated 8,96 A for the two fans. We assume that the fan is a 100% load on the motor. At time period 3, fans 3 and 4 start up. The peak current is now 47,5 A plus the rated current of fans 1 and 2. The current then returns to the rated current of four fan motors. The current continues to rise like this until all the fans are running.

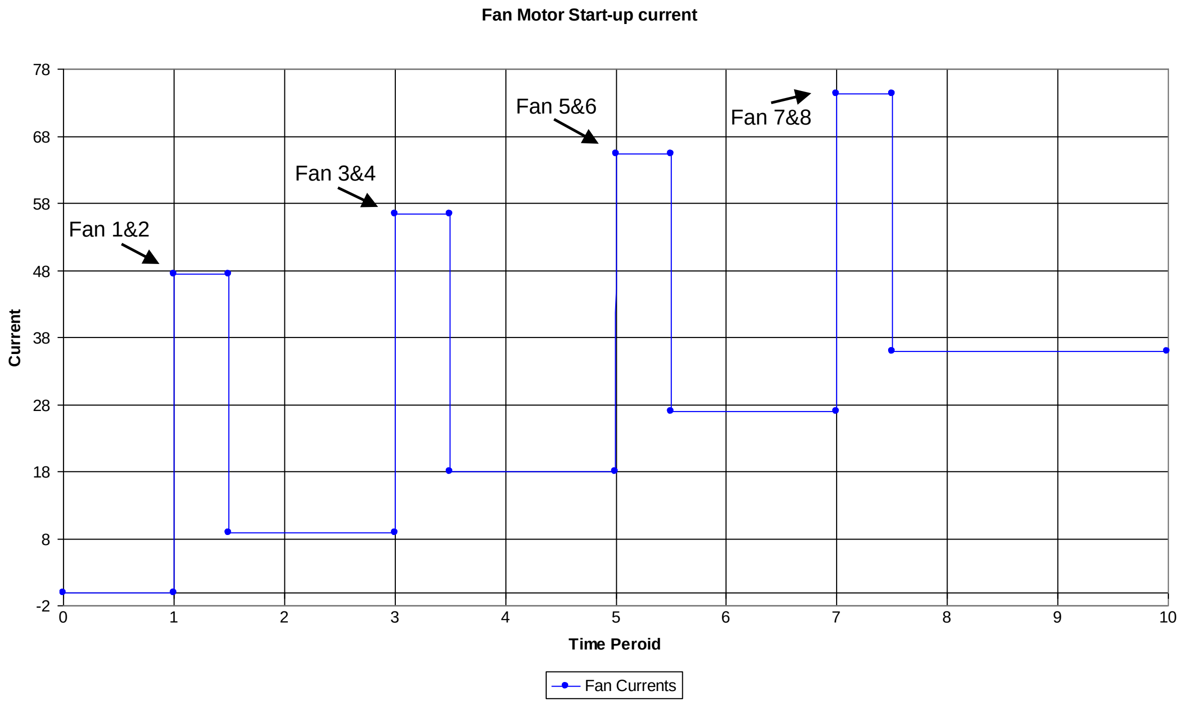


Figure 6: Start-up currents of transformer cooling fans

$$V_{drop} = I_{start} \times Z_{cable}\big|_{20m}$$

$$= 74{,}4 \times \frac{1m38}{1000} \times 20$$

$$= 2{,}1V$$

$$\Rightarrow \%V_{drop} = \frac{2{,}1}{230} \times 100$$

$$= 0{,}89\%$$

From the preceding tables and calculations, it can be seen that the voltage drops for this worst-case scenario are within 5% of the nominal phase-to-neutral voltage of 230 V.

8.3.2.4 Fault level analysis

a) NECRT/auxiliary transformer (auxiliary supply)

In this clause, the fault level at the secondary side of the Neutral Earthing Coupling Resistor with Auxiliary Transformer (NECRT) will be considered; refer to 7. Most of Distribution's substations are equipped with 100 kVA NECRTs, but a few require 300 kVA. The average Z% for these transformers is 4,5%.

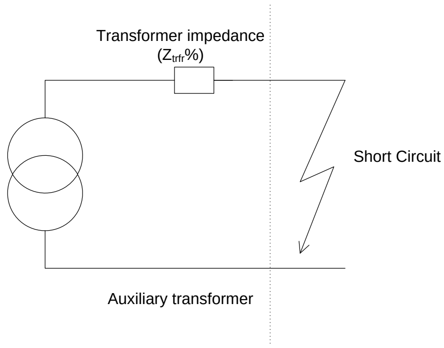


Figure 7: Auxiliary transformer Z%

The output voltage is 400 VLL. Calculation of the fault current on the LV terminals of the NECRT is as follows:

$$I_{fault} = I_{nom} \times {}^{1}\!/_{Z_{trfr}\%}$$

$$= \frac{S_{trfr}}{\sqrt{3} \cdot V} \times \frac{100}{Z_{trfr}\%}$$

$$I_{fault100} = \frac{100}{\sqrt{3} \cdot 400} \times \frac{100}{4{,}5}$$

$$= 3{,}2\,kA$$

$$or$$

$$I_{fault300} = \frac{300}{\sqrt{3} \cdot 400} \times \frac{100}{4{,}5}$$

$$= 9{,}6\,kA$$

Where:

- $Z_{trfr}\%$ = Transformer's percentage impedance
- I_{nom} = Nominal current
- $I_{fault100}$ = Short-circuit current with a 100 kVA auxiliary transformer
- $I_{fault300}$ = Short-circuit current with a 300 kVA auxiliary transformer
- S_{trfr} = Transformer's rated power

Another method to calculate the fault level is to make use of the per-unit system and use a standard MVA base of S_{base} = 100 MVA. The auxiliary transformer has a percentage impedance of typically 4,5%. Due to this, the per-unit impedance of the source is negligible in comparison to the per-unit impedance of the auxiliary transformer, and is therefore omitted from the fault calculation:

$$Z_{trfr} = \frac{S_{base}[MVA] \cdot Z_{trfr}\%}{S_{trfr}[MVA]}$$

$$= \frac{100}{0{,}1} \times 0{,}045$$

$$= 45\ pu$$

$$S_{faultlevel} = \frac{S_{base}}{Z_{trfr}}[MVA]$$
$$= \frac{100}{45}$$
$$= 2{,}2MVA$$
$$\Rightarrow I_{fault100} = \frac{S_{faultlevel}[MVA]}{\sqrt{3} \cdot V}$$
$$= \frac{2{,}2 \times 1000000}{\sqrt{3} \cdot 400}$$
$$= 3{,}2\,kA$$

Where:

- S_{base} = Rated power used as base for per-unit calculations
- $S_{faultlevel}$ = The rated power during a fault with respect to S_{base}

The same can be done for the 300 kVA auxiliary transformer.

This indicates that if the MCB located in the NECRT has a short-circuit rating of 10 kA, it will be able to be used in both 100 kVA and 300 kVA auxiliary transformers. The norm is to use a 100 kVA transformer, thus all other fault level calculations will be done using the 100 kVA auxiliary transformer. Care should be taken when the 300 kVA auxiliary transformer is utilized. One must ensure that the cable and MCB sizing are correct for the higher fault level.

b) Fault level at yard box

The auxiliary transformer usually feeds a yard box. The yard box usually supplies the On-load Tap Changer (OLTC) motors, floodlights and the relay house (AC/DC panel). It is proven that the shortest cable length will provide the highest fault level at the end of that cable. The shortest length between the auxiliary transformer's MCBs and the yard box will be when the yard box is placed next to the transformer. This length is approximately 5 m. The cable used for this connection is a four-core, 25 mm^2 cable. Refer to 8.

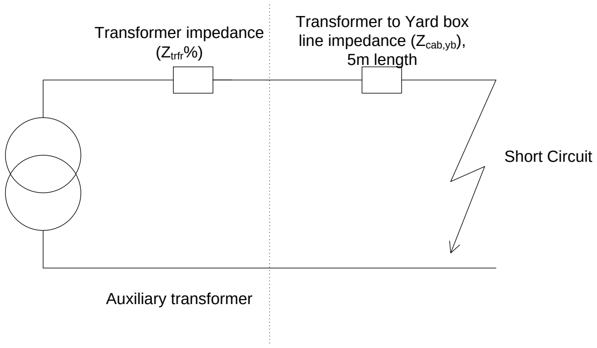


Figure 8: Auxiliary transformer Z% plus cable impedance to yard box

The worst-case current rating is 101 A installed in ducts. The impedance is 0,8749 Ω/km, the voltage drop is 1,515 mV/A/m and the 1 s short-circuit rating is 2,87 kA as per manufacturer's data.

This means that the total impedance for the cable is:

$$Z_{cab,yb} = 0{,}005 \times 0{,}8749$$
$$= 0{,}004375\,\Omega$$
$$= 4{,}375\,m\Omega$$

The maximum fault level at the yard box is calculated as follows:

$$Z_{trfr+cab,yb} = \frac{S_{base}[MVA]\cdot(Z_{trfr}\% + Z_{cab,yb})}{S_{trfr}[MVA]}$$
$$= \frac{100}{0{,}1}\cdot(0.045 + 0.004375)$$
$$= 49{,}375\,pu$$
$$S_{faultlevel} = \frac{S_{base}}{Z_{trfr}}[MVA]$$
$$= \frac{100}{49{,}375}$$
$$= 2{,}025\,MVA$$
$$\Rightarrow I_{fault100} = \frac{S_{faultlevel}[MVA]}{\sqrt{3}\cdot V}$$
$$= \frac{2{,}025\cdot 1000000}{\sqrt{3}\cdot 400}$$
$$= 2{,}923\,kA \approx 3\,kA$$

As is shown here, a breaking capacity of 3 kA or higher will be needed. The breaking capacity of the MCBs in the yard box is therefore selected to be 5 kA.

c) Fault level at AC/DC panel

As stated in b), the yard box usually supplies the OLTC motors, floodlights and the relay house (AC/DC panel). The shortest length of cable between the yard box and relay house (AC/DC panel) is approximately 10 m. The cable usually used for this application is a four-core, 16 mm^2 cable. Refer to 9.

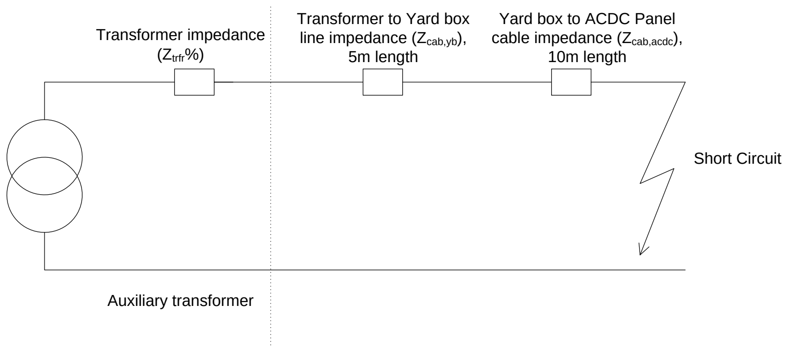


Figure 9: Auxiliary transformer Z% plus cable impedance to yard box and AC/DC panel

Again, the worst-case current rating of 67 A is for when the cable is installed in ducts. The impedance is 1,38 Ω/km, the voltage drop is 2,39 mV/A/m and the 1 s short-circuit rating is 1,84 kA as per manufacturer's data.

The impedance for the cable from the yard box to the AC/DC panel is:

$$Z_{cab,acdc} = 0{,}01 \times 1{,}38$$
$$= 0{,}0138\,\Omega$$
$$= 13{,}8\,m\Omega$$

Again, using the same method as above and using the transformer's impedance and the impedances of both sections of cable in series, the fault level at the AC/DC panel can be obtained.

$$Z_{trfr+cab,yb+cab,acdc} = \frac{S_{base}[MVA] \cdot (Z_{trfr}\% + Z_{cab,yb} + Z_{cab,acdc})}{S_{trfr}[MVA]}$$
$$= \frac{100}{0{,}1} \cdot (0;045 + 0;004375 + 0{,}0138)$$
$$= 63{,}175\,pu$$
$$S_{faultlevel} = \frac{S_{base}}{Z_{trfr}}[MVA]$$
$$= \frac{100}{63{,}175}$$
$$= 1{,}58\,MVA$$
$$\Rightarrow I_{fault100} = \frac{S_{faultlevel}[MVA]}{\sqrt{3} \cdot V}$$
$$= \frac{1{,}58 \cdot 1000000}{\sqrt{3} \cdot 400}$$
$$= 2{,}285\,kA \approx 2{,}3\,kA$$

From the preceding calculation, it is evident that MCBs with a breaking capacity of 2,3 kA or higher must be used. MCBs installed in the AC/DC panel must have a rated breaking capacity of 5 kA.

d) Fault level at the protection panel

The AC/DC panel supplies all the other control plant panels in the relay house. The shortest length of cable between the AC/DC panel and any other control plant panel is approximately 5 m. The cable usually used for this application is a four-core, 4 mm^2 cable. Refer to 10.

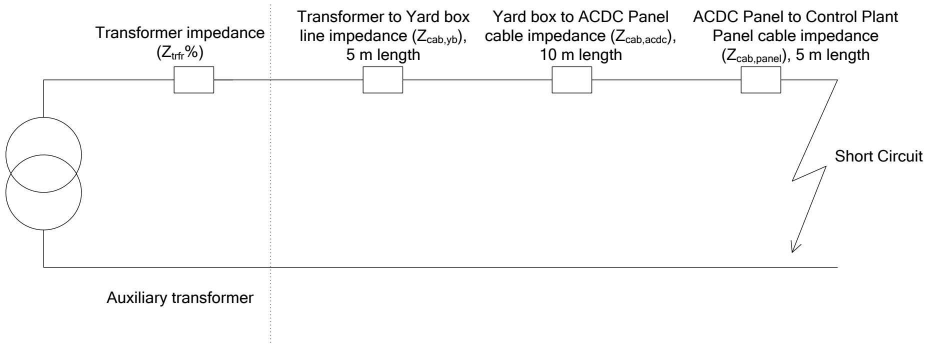


Figure 10: Auxiliary transformer Z% plus cable impedance to yard box, AC/DC panel and control plant panel

Again, the worst-case current rating of 34 A is for when the cable installed in ducts. The impedance is 5,52 Ω/km, the voltage drop is 9,561 mV/A/m and the 1 s short-circuit rating is 0,46 kA as per manufacturer's data.

The impedance for the cable from the AC/DC panel to control plant panel is:

$$Z_{cab,panel} = 0{,}005 \times 5{,}52$$
$$= 0{,}0276\ \Omega$$
$$= 27{,}6\, m\Omega$$

Again, using the same method as above and using the transformer's impedance and the impedances of both sections of cable in series, the fault level at the AC/DC panel can be obtained:

$$Z_{trfr+cab,yb+cab,acdc} = \frac{S_{base}[MVA] \cdot (Z_{trfr}\% + Z_{cab,yb} + Z_{cab,acdc} + Z_{cab,panel})}{S_{trfr}[MVA]}$$
$$= \frac{100}{0{,}1} \cdot (0{,}045 + 0{,}004375 + 0{,}0138 + 0{,}0276)$$
$$= 90{,}775\, pu$$
$$S_{faultlevel} = \frac{S_{base}}{Z_{trfr}}[MVA]$$
$$= \frac{100}{90{,}775}$$
$$= 1{,}1\, MVA$$
$$\Rightarrow I_{fault100} = \frac{S_{faultlevel}[MVA]}{\sqrt{3} \cdot V}$$
$$= \frac{1{,}1 \times 1000000}{\sqrt{3} \cdot 400}$$
$$= 1{,}59\, kA \approx 1{,}6\, kA$$

From the preceding calculation, it is evident that MCBs with a breaking capacity of 1,6 kA or higher must be used. MCBs installed in protection panels must have a rated breaking capacity of 5 kA.

9. Authorization

This document has been seen and accepted by:

Name and surname	Designation
R McCurrach	PTM&C Senior Manager
D Van Rooi	Metering, DC and Security Technologies Manager (Acting)
G Topham	Corporate Specialist (Engineering Protection)
L Kotze	Senior Consultant (Protection)
K Jagdaw	DC and Auxiliary Supplies Chairperson
C van Schalkwyk	DC Technology Engineer

10. Revisions

Date	Rev	Compiler	Remarks
April 2018	2	AN Majozi	Format changed to SCOT Template
March 2013	1	K Naicker	First issue

11. Development team

The following people were involved in the development of this document:

- Alpheus Majozi

12. Acknowledgements

Christine Van Schalkwyk and Kuben Naicker for compiling the original document that this Guideline is based on.

Annex A – Impact assessment

(Normative – for Eskom internal use only)

1) Guidelines

- All comments must be completed.
- Motivate why items are not applicable (n/a).
- Indicate actions to be taken, persons or organizations responsible for actions and deadline for action.
- Change control committees to discuss the impact assessment and, if necessary, give feedback to the compiler regarding any omissions or errors.

2) Critical points

2.1 Importance of this document, e.g. is implementation required due to safety deficiencies, statutory requirements, technology changes, document revisions, improved service quality, improved service performance, optimized costs.

Comment: New document.

2.2 If the document to be released impacts on statutory or legal compliance, this needs to be very clearly stated and so highlighted.

Comment: No impact.

2.3 Impact on stock holding and depletion of existing stock prior to switch over.

Comment: No impact.

2.4 When will new stock be available?

Comment: n/a

2.5 Has the interchangeability of the product or item been verified, i.e. when it fails, is a straight swap possible with a competitor's product?

Comment: Yes.

2.6 Identify and provide details of other critical (items required for the successful implementation of this document) points to be considered in the implementation of this document.

Comment: None.

2.7 Provide details of any comments made by the Regions regarding the implementation of this document.

Comment: (n/a during commenting phase).

3) Implementation time frame

3.1 Time period for implementation of requirements.

Comment: ASAP.

3.2 Deadline for changeover to new item and personnel to be informed of DX wide changeover.

Comment: None.

4) Buyer's guide and power office

4.1 Does the Buyer's Guide or Buyer's List need updating?

Comment: No.

4.2 What Buyer's Guides or items have been created?

Comment: None.

4.3 List all assembly drawing changes that have been revised in conjunction with this document.

Comment: None.

4.4 If the implementation of this document requires assessment by CAP, provide details under 5).

4.5 Which Power Office packages have been created, modified or removed?

Comment: n/a

5) CAP/LAP pre-qualification process-related impacts

5.1 Is an ad hoc re-evaluation of all currently accepted suppliers required as a result of implementation of this document?

Comment: n/a

5.2 If NO, provide motivation for issuing this specification before Acceptance Cycle Expiry date.

Comment: n/a

5.3 Are ALL suppliers (currently accepted per LAP) aware of the nature of changes contained in this document? n/a

Comment: n/a

5.4 Is implementation of the provisions of this document required during the current supplier qualification period?

Comment: n/a

5.5 If Yes to 0, what date has been set for all currently accepted suppliers to comply fully?

Comment: n/a

5.6 If Yes to 0, have all currently accepted suppliers been sent a prior formal notification informing them of Eskom's expectations, including the implementation date deadline?

Comment: n/a

5.7 Can the changes made, potentially impact upon the purchase price of the material/equipment?

Comment: Yes.

5.8 Material group(s) affected by specification (refer to Pre-qualification invitation schedule for list of material groups).

Comment: n/a

6) Training or communication

6.1 Is training required?

Comment: No.

6.2 State the level of training required to implement this document (e.g. awareness training, practical/on job, module).

Comment: n/a

6.3 State designations of personnel that will require training.

Comment: n/a

6.4 Is the training material available? Identify person responsible for the development of training material.

Comment: n/a

6.5 If applicable, provide details of training that will take place (e.g. sponsor, costs, trainer, schedule of training, course material availability, training in erection/use of new equipment, maintenance training).

Comment: n/a

6.6 Was Technical Training Section consulted regarding module development process?

Comment: n/a

6.7 State communications channels to be used to inform target audience.

Comment: Email.

7) Special tools, equipment, software

7.1 What special tools, equipment, software, etc. will need to be purchased by the Region to effectively implement?

Comment: n/a

7.2 Are stock numbers available for the new equipment?

Comment: n/a

7.3 What will be the cost of these special tools, equipment, software?

Comment: n/a

8) Finances

8.1 What total costs would the Regions be required to incur in implementing this document? Identify all cost activities associated with implementation, e.g. labour, training, tooling, stock, obsolescence.

Comment: n/a

Impact assessment completed by:

Name: Alpheus Majozi

Designation: Senior Advisor

Annex B – MCB type C tripping curve

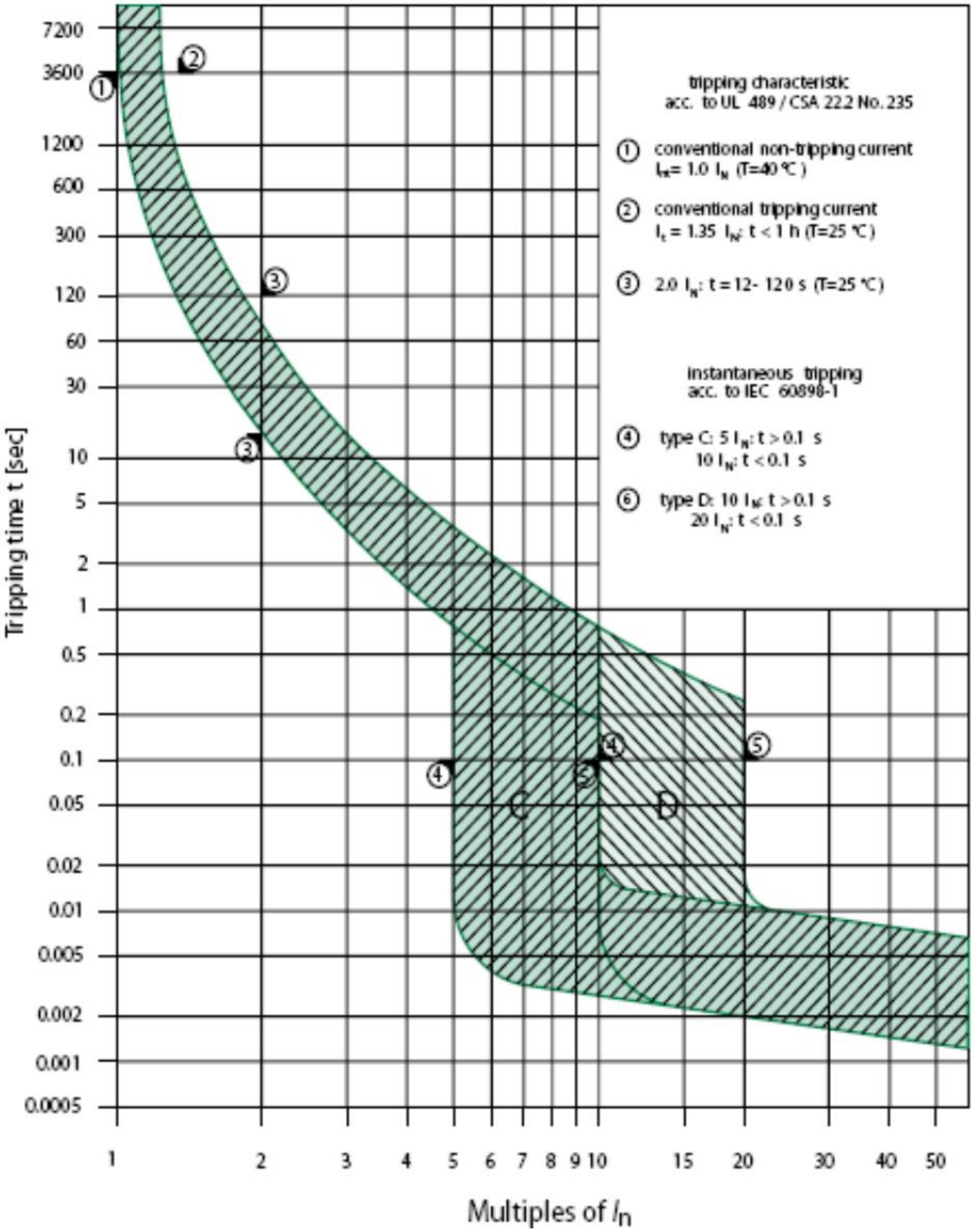


Figure B.1: Miniature circuit breaker type C tripping curve

Annex C – Transformer fan data sheet

ZEST ELECTRIC MOTORS

Nr.:

Date: 11/26/2009

DATA SHEET
Three-phase Induction Motor - Squirrel Cage

Customer :

Product line : Low Voltage Motors - IEC General Purpose - W21 - Cast Iron Frame - Standard Efficiency EFF2 - Multivoltage

Frame	: 132M
Output	: 1.5 kW
Frequency	: 50 Hz
Poles	: 10
Rated speed	: 570
Slip	: 5.00
Rated voltage	: 380/660 V
Rated current	: 4.48/2.58 A
L. R. Amperes	: 23.7/13.7 A
Il/In	: 5.3
No load current	: 2.65/1.53 A
Rated torque	: 25.14 Nm
Locked rotor torque	: 170 %
Breakdown torque	: 200 %
Design	: N
Insulation class	: F
Locked rotor time	: 39 s (hot)

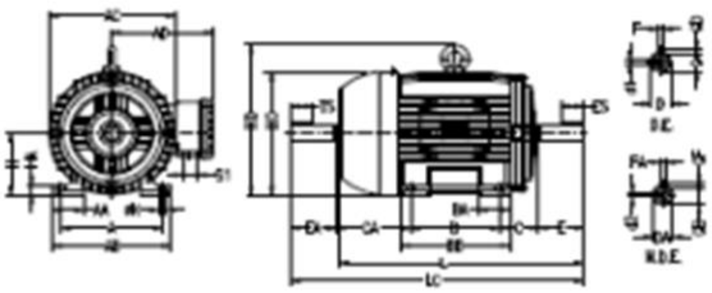
Service factor	: 1.00
Duty cycle	: S1
Ambient temperature	: -20°C - +40°C
Altitude	: 1000 m.a.s.l
Enclosure	: IP55
Aprox. weight	: 70.0 kg
Moment of inertia	: 0.07397 kgm²
Sound Pressure Level	: 48 db(A)

	Front	Rear
Bearing	6308 ZZ	6207 ZZ
Regreasing int.	—	—
Grease amount	—	—

PERFORMANCE UNDER LOAD

Load	Power factor	Efficiency (%)
100%	0.67	76.0
75%	0.59	75.5
50%	0.47	72.5

Notes:



A 216	AA 51	AB 248	AC 270	AD 212	B 178	BA 55	BB 225
C 89	CA 150	D 38k6	E 80	ES 63	F 10	G 33	GD 8
DA 28j6	EA 60	TS 45	FA 8	GB 24	GF 7	H 132	HA 20
HC 274	HD 319	K 12	L 490	LC 557	S1 2XM25X1.5	d1 DM12	d2 DM10

Performed: Checked:

*The values shown are subject to change without prior notice. Noise level with tolerance of +3 dB(A). Version 6.0.12

Figure C.1: Transformer fan data sheet