Eskom	Standard	Technology

Title: **Generation Auxiliary Plant Medium Voltage Protection Standard**

Unique Identifier:	**240-143485806**
Alternative Reference Number:	**N/A**
Area of Applicability:	**Engineering**
Documentation Type:	**Standard**
Revision:	**1**
Total Pages:	**72**
Next Review Date:	**January 2025**
Disclosure Classification:	**CONTROLLED DISCLOSURE**

APPROVED FOR AUTHORISATION
TECHNOLOGY ENGINEERING
DOCUMENT CENTRE ☎ X4962

Compiled by	**Approved by**	**Authorised by**
....	....	....
J.M. Jordaan	**P. Rakeketsi**	**P. Madiba**
Senior Engineer **PEI Electrical**	**Manager** **CoE Electrical plant**	**Senior Manager** **EC&I Engineering**
Date: 2019-12-17	Date: 2020-01-14	Date: 2020-01-14
		Supported by SCOT/SC/TC
		....
		A.Oommen
		PASC Chairperson
		Date: 16/01/2020

PCM Reference : **240-53459012 Perform Power Plant Electrical Engineering**
SCOT Study Committee Number/Name : **Protection and Automation Study Committee**

CONTENTS

FIGURES

TABLES

1. INTRODUCTION

Eskom Generation operates an extensive reticulation system within the power station confines. A big portion is located inside the power house and the remainder is in the so called common plant or outside plant area (also called balance of plant). Not all items within the power station confines have the same criticality. From a mechanical and process control point of view, redundancy has been designed into the operation of the station and the electrical reticulation needs to support that redundancy to the best of its ability. The same primary equipment is applied in a variety of applications and therefore an electrical protection philosophy is necessary to guide protection engineering practitioners and sometimes specifies how protection needs to be deployed. This documents doubles as a standard and a guide. It outlines the protection philosophies as used in Eskom Generation and gives guidance to engineering setting practitioners.

Standardisation leads to consistency in design approaches but may limit solutions. This document should rather be seen as a culmination of best practices and specific Eskom requirements and therefore should serve as a guideline to engineering practitioners performing medium voltage protection designs because a “one-size-fits-all” approach can lead to curtailment of ingenious design solutions. The document does not give carte blanche to designers and a rigorous review will still be required before a technical specification can be used as an inquiry document for new protection schemes. Neither regulatory nor safety related requirements can be ignored and every design needs to respect and conform to those requirements, where applicable.

2. SUPPORTING CLAUSES

2.1 SCOPE

This document presents the principles and philosophies of electrical protection applied to a multitude of power system elements in a power station reticulation environment on medium voltage level. It applies to the electrical power system elements inside the power house as well as the common plant circuits connected to medium voltage sources. It does not cover any part of the generating unit protection nor does it cover any low voltage protection requirements. Communication requirements to allow the IEDs to communicate with each other and the substation automation system are not part of this document although reference may be made to such communication that might be required to configure a fully functional protection system. It describes the general tripping and setting principles, the protection functions and associated aspects of the protection equipment. Process protection is excluded from this document, although any process trip to the MV switch gear will either be reordered or actually be tripped by the protection IED as an intermediary.

2.1.1 Purpose

This document describes the electrical protection functionality that is applicable to the various elements in the power station connected and operated at medium voltage level. Due to a multitude of applications and differences between the various types of plant this document purposely allows for enhancement and/or simplification of designs to result in fit-for-purpose designs.

The document specifies and references other documents which are imperative to complete the medium voltage protection in a power station. It shall be used as a reference document for any new medium voltage protection schemes to be installed on refurbished or new power plants. It assists and guides protection setting engineering practitioners with recommended or typical setting values.

2.1.2 Applicability

This document shall apply throughout Eskom Generation and allows for the different designs and protection approaches of the different configurations of primary plant layouts.

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] ISO 9001 Quality Management Systems.

[2] 240-53114002, Engineering Change Management Procedure

[3] 240-53114026, Project Engineering Change Management Procedure

[4] 240-53113685, Design Review Procedure

[5] 240-49104739, Registration Procedure for Engineering Work

[6] 240-53113953, Manage Engineering Accountability Procedure

[7] 32-644, Eskom Documentation Management Standard

[8] 240-50237146, Medium Voltage AC Variable Frequency Drives Standard

[9] 240-86973501, Engineering Drawing Standard – Common Requirements

[10] 0.00/10341, Eskom Generation MV & LV Switchgear lugs and terminations, pre-insulted lugs & sleeves, wiring and termination and circuit and function letters

[11] IEC 61800-4, Adjustable speed electrical power drive systems - Part 4

2.2.2 Informative

[12] 240-43327398, Engineering Policy

[13] 240-51093273, Process Control Manual (PCM) – Control Configuration Changes

[14] 240-59266984, Engineering Change Management Central Change Control Committee – Generation Terms of Reference

[15] 240-59266979, Engineering Change Management Site Change Control Committee – Generation Terms of Reference

[16] 240-53114078, Comment and Review form

[17] 240-64685228, Generic Specification for protective intelligent electronic devices (IEDs)

[18] 240-56227589, List of approved electronic devices to be used on Eskom power stations

[19] IEC 60050-448, International Electrotechnical Vocabulary Chapter 448: Power System Protection or the online edition at www.electropedia.org

[20] IEEE C57.13.3-2004, IEEE Guide for Grounding of Instrument Transformer Secondary Circuits and Cases

[21] 200-4190, The Application of KKS Plant Coding

[22] 240-56227573, Air-Insulated Withdrawable AC Metal-Enclosed Switchgear Control gear for 1kV to 52kV

[23] 240-82332407, Generation Fixed Pattern Gas Insulated Metal-Enclosed Indoor Primary Switchgear and Control gear Specification for Rated Voltages above 1kV up to and including 52kV

2.3 DEFINITIONS

Definition	Description
Back-up protection	Protection which is intended to operate when a system fault is not cleared, or abnormal condition not detected, in the required time because of failure or inability of other protection to operate or failure of the appropriate circuit-breaker(s) to trip. The term "backup protection" designates a form of protection that operates independently of specified devices in the main protection system. The backup protection may duplicate the main protection or may be intended to operate only if the main protection system fails or is temporarily out of service
Bright chop over	A bright chop over is the switching from one supply to another, by paralleling the two supplies for a short period, without interrupting the supply to the connected load.
Clean supply	This applies to 110V and 220V DC supplies and refers to the supply that is used to power electronic devices like protection IEDs and the associated switchgear control like close and trip coils. It is not used to power high power loads like motors.
Critical plant	Plant which, if tripped, could cause a multi-unit trip (MUT) or load loss. Also Plant (including LV motors >15kW) which, if tripped, could prevent continued operation of units or prevent prompt return to service
Dark chop over	A dark chop over is the switching from one supply to another by disconnecting a supply before closing onto the alternative supply. The connected load is therefore without a supply during the switching operation.
Dirty supply	This applies to 110V and 220V DC supplies in the power station which is defined by the DC standard as an essential emergency supply used for high power applications. In this context it is the DC supply that is used for spring rewind motors and motorised isolators in GIS switchgear. It is a supply that may be contaminated with voltage spikes and even ripple might be more that a clean supply. This supply are not be used for power electronic devices like protection IEDs or SAS network switches
Generating unit protection	Protection equipment used for protection of the generator, generator transformer and unit transformer/s
Main protection	Protection expected to have priority in initiating fault clearance or an action to terminate an abnormal condition in a power system.
Settings	All configurable parameters used to specify the behaviour of protection functions.
Standard	A document established by consensus to provide rules, definitions, limits, dimensions, tolerances or other characteristics for activities or their results, for common and repeated use. A standard is aimed at the achievement of the optimum degree of order in a given context. Compliance with a standard is mandatory in its area of applicability
Unit Type Protection	Protection equipment which protects a particular item/unit of primary

Definition	Description
	plant

2.3.1 Disclosure Classification

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

ABBREVIATIONS

Abbreviation	Description
A	Ampere
AC	Alternating current
AIS	Air insulated switchgear
AKZ	Anlagenkennzeichnung System
BPS	Boiler protection system
CBF	Circuit Breaker Failure
CoE	Centre of Excellence
CT	Current transformer
DC	Direct Current
DCS	Distributed Control System
DT	Definite Time
EOD	Electrical Operating Desk
FFFR	Fossil Fuel Firing Regulations
GIS	Gas Insulated Switchgear
GOOSE	Generic Object Oriented Substation Event
GUI	Graphical User Interface
HMI	Human Machine Interface
HV	High Voltage
Hz	Hertz
I/O	Input / Output (related to binary signals)
IDMT	Inverse Definite Minimum Time
IED	Intelligent Electronic Device
IPC	Interposing close (relay)
IPO	Interposing open (relay)
IPT	Interposing trip (relay)
kA	kilo Ampere
KKS	Kraftwerk Kennzeichen System

Abbreviation	Description
kV	kilo Volt
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LV	Low voltage (≤1000V AC)
MCB	Miniature Circuit Breaker
MUT	Multiple Unit Trip
MV	Medium voltage (>1000V and ≤15kV)
O/C	Over Current
OEM	Original Equipment Manufacturer
s	second
SAS	Substation Automation System
SME	Subject Matter Expert
V	Volt
VFD	Variable Frequency Drive
VSD	Variable Speed Drive (In the context of this document is refers to a VFD or VVVF and not any other form of speed control)
VT	Voltage transformer
VVVF	Variable Voltage Variable Frequency

2.4 ROLES AND RESPONSIBILITIES

- The Generation Electrical Plant CoE will ensure validity of the document over its lifespan and needs to amend, update, modify or retract this document if and when required.
- Protection engineering practitioners shall ensure compliance with the standard when new protection equipment is procured and ensure rigorous reviews are in place when this document allows for different application designs.
- Engineering protection setting practitioners will ensure that this standard is used as a guide when settings are calculated.

2.5 PROCESS FOR MONITORING

The document shall be updated in accordance with the Eskom document review process or as business needs change.

2.6 RELATED/SUPPORTING DOCUMENTS

The standard, 240-56357424, MV and LV Switchgear Protection Standard is partially superseded by this standard. All references in the mentioned standard to MV protection are superseded by this document.

3. ESKOM GENERATION AUXILIARY PLANT MEDIUM VOLTAGE PROTECTION PHILOSOPHY

The primary functions of electrical protection are:

- to prevent and/or minimise damage to the primary plant by disconnecting equipment as quickly as possible and in the safest manner possible in the event of a detected failure/fault,
- to prevent or minimize damage to healthy equipment that conduct fault current during fault conditions,
- and to respond to external inputs when disconnection of a part of the plant is required when other equipment is operated outside its specified limits.

The protection functions are considered adequate when the protection devices perform correctly in terms of:

- dependability;
- security;
- speed of operation;
- selectivity; and
- the single failure criterion.

Dependability:

The probability of not having a failure to operate under given conditions for a given time interval. [IEC 60050 - 448]

Security:

The probability of not having an unwanted operation under given conditions for a given time interval. [IEC 60050 - 448]

Speed of Operation:

The clearance of faults on the electrical systems in the shortest time is a fundamental requirement, but this must be seen in conjunction with the associated cost implications and the performance requirements for a specific application.

Selectivity (Discrimination):

The ability to detect a fault within a specified zone of a network and to trip the appropriate circuit breaker(s) to clear this fault with a minimum disturbance to the rest of that network.

Single failure criterion:

A protection design criterion whereby a protection system must not fail to operate even after one component fails to operate. With respect to the primary protection IED, the single failure criterion caters primarily for a failed or defective IED, and not a failure to operate as a result of a performance deficiency inherent within the design of the IED.

Having stated the primary requirements and defined the adequacy of protection, one has to take cognisance of two critical pillars of this protection philosophy:

- Each electrical fault in the power station medium voltage reticulation system must be detected by a main and at least one back-up protection function and clear the fault within the primary plant fault withstand capability. This does NOT require main and back-up protection with-in the same bay. Up-stream protection that can detect and safely trip for such a fault is adequate as back-up protection. It is with this design approach that protection designs should be carried out. The main and back-up protection shall be powered from two different DC supplies.
- Protection needs to operate for primary faults and should not operate when secondary faults can be unambiguously detected and this “secondary plant supervision functions” may be used to block

protection functions under these conditions. These supervision functions may include voltage and current supervision.

It has been a long standing practice to utilise voltage transformer failure detection to block all power and impedance functions. With the advent of new powerful numerical devices (IEDs) this supervision and blocking of functions may be introduced on current transformer circuits as well. Momentarily opening CT circuits can cause current differential to operate and if this unbalance can be detected unambiguously, it may be used to block current differential for instance, provided that the over current protection which could be seen as back-up, is not blocked at the same time. When blocking of protection functions are allowed for secondary faults it is imperative that:

- an alarm annunciate the situation to the appropriate control desk so that personnel can investigate and take the corrective actions and
- the disturbance recorder needs to be triggered to allow personnel to analyse the origin of the CT disturbance.

CTs going open circuit have been a source of serious damage to primary plant in the past. Although this standard cannot directly address the CTs as such, it is strongly advised that break over diodes of the correct rating be applied back-to-back as close to the CT terminals as possible to ensure no arcing takes place between terminal blocks or inside test blocks. The loss of such a current in the IEDs can then be dealt with as an alarm and appropriate actions can be devised based on the analysis.

3.1 PLANT CONFIGURATIONS, REQUIREMENTS AND IMPACTS ON A PROTECTION IED AND ITS FUNCTIONS

There are plant requirements, configurations and plant operating conditions that extend the role of the protection IED beyond that of just protection.

3.1.1 Impact of earthing arrangement

Most electrical faults are either earth faults or starts off as an earth fault before it develops into a phase to phase or three phase faults. It is therefore important to note that different earthing methods are used within the power station environment.

On the classical 1st level of reticulation (unit and station boards) which is either at 6.6kV, 11kV or 15kV, the earthing arrangements differ between the older power stations (pre 1980's) to the later power stations. The earthing on the unit transformers used to be a solid or effective connection to earth. Post 1980 most MV transformers (i.e. LV side within MV voltage range) in the power house are now using high resistance earthing. It is not in the scope of this document to elaborate on the reasons for this earthing arrangement but it suffices to say that three phase loads, like motors, are virtually undisturbed by earth faults on the reticulation system because the phase to phase voltage are not affected by such faults.

The same earthing arrangements are also found on service boards at 3.3kV and 6.6kV levels inside the power station.

The outside plant (common plant) is earthed differently. Solidly/effectively earthed systems are more the order of the day and trips are less likely to cause an immediate load loss or directly tripping a generating unit. There is normally a time buffer of several minutes before units are adversely affected by un-faulted plant that might have tripped unnecessarily due to earth fault protection operation. Reconfiguration of the plant by means of a different switching topology can normally reinstate unaffected plant within this time frame.

This earthing arrangement has a direct influence on the type of earth fault detection and protection philosophy that is deployed and how it is set to ensure proper co-ordination. A transformer in the power house and a transformer in the common plant will therefore have different protection philosophies and settings applied. The protection schemes and templates will therefore be different too for these applications.

Older power stations like Arnot, Hendrina, Grootvlei, Komati and Camden have solidly earthing arrangements on the LV side of the unit and boiler board transformers but the HV side neutral of these Y_Ny_n transformers are not earthed at all. This makes the calculation and prediction of earth fault currents in the power station reticulation extremely challenging as these earth fault currents are primarily determined by the zero sequence impedance of the supply transformers. This may vary from 200% to 800% of positive sequence impedance. It is unlikely that any new power station will adopt this earthing philosophy.

3.1.2 Synchronism check and chop-over

The primary plant is designed to have the correct phase angle displacement to allow certain parts of the plant to be energised from different sources without severe consequences for the energised plant when changing over from one source to another. These sources are non-rotating plant therefore the angle difference between two circuits can only be attributed to the loading on the respective sources of supply to the point of connection in question.

The only reason for having the synchronism check would then be to prevent paralleling of sources with a load angle that could produce large circulating reactive currents and phase shits in rotating plant like motors. The bigger the load angle, the larger the phase shift will be that the motors will experience and the larger the re-synchronising current would be following a voltage vector jump.

Sensitivity of VSDs to vector jumps of this nature is not well documented and synchronism might become more of a requirement if this is really an issue to the VSD monitoring equipment.

Chop-overs are required on a regular basis to change sources of supply especially during outages and start-ups after outages. In cases of certain plant failures the very concept of redundancy requires chop-overs to be executed to allow the redundancy built into the design to assist in unnecessary power output reduction or even plants to be shut down completely.

Chop-overs can happen between two incomers of a board or it could be a bus section closure. How this chop-over needs to be conducted and under what plant operating conditions will dictate if it will be a bright chop-over or a dark chop over.

A chop-over can be automatic where equipment monitors the busbar and cable voltages and act upon a certain predetermined operating philosophy and then act without operator intervention.

Manual initiation but automatic execution of the chop over action is also used on a large scale. This shall be the preferred chop-over system to prevent paralleling of source for long periods.

Manual chop overs are literally an operator action, required to open and close breakers in the correct sequence with perhaps some IED interlocking or trapped key system (also called Castell key system after its inventor James Harry Castell 1880-1953) to prevent incorrect switching. However this type of chop-over will allow breakers to remain closed indefinitely and thereby possibly paralleling supplies too.

The IEDs form part of the interlocking system and are reliant on a communication bus to distribute the relevant interlocking quantities or statuses. Any chop-over shall be blocked when:

- There is a protection unhealthy,
- switchgear unhealthy,
- any protection operated related to the chop over or
- any communication error/failure,

The latter leads to interlocking data not being reliable or not available at all and that is why all chop-overs must be blocked.

When this happens, operating personnel must have the facility to operate the plant without IED inter-communication. Such operating shall then bypass any inter-bay interlocking configured in the IED. All local bay interlocking shall remain active. This over-ride facility shall be captured by the local IED where any such switching or operating is carried out. Once local/manual/over-ride operating is selected a communication “error” must be signalled (published) by the local IED to all other IEDs in case the communication is restored while one breaker is selected to local/manual/over-ride mode. This will prevent any remote breaker to start an automated sequence (if configured to do so).

A second stage over-ride could be engineered where any operating of the breakers are done outside of the IED under emergency operating conditions. This is only required when emergency operating is required without a functional Substation Automation System and/or IEDs. This override should be controlled by locked operating interfaces or key switches or password override facilities. Any local bay interlocking is then bypassed under such second stage emergency operating conditions. Operating personnel then takes full control and responsibility of how the switching must be carried out.

3.1.3 Plant operations

It is not in the scope of this document to describe the requirements for remote operating capability of switching elements via a Substation Automation System. It is however sufficient to say that SAS are part of the Eskom Generation’s plant operating strategy and the protection IED needs to comply to the SAS requirements as the protection IED now fulfill an automation function as well.

Even local operation of a breaker takes places via the HMI or functions keys on the IED.

3.1.4 Voltage and current transformer supervision

Voltage supervision has always been a requirement for reliable under voltage protection. With the processing power available in IEDs, the protection functions are now extended to do a lot more with it regarding measurements, processing and functionality especially the utilisation of sequence component calculations. Extended and/or alternative methods to detect earth faults are for instance based on the sequence components of voltages. It might be unconventional but totally possible to utilise sequence component calculations to enhance protection reliability, even if protection operation is slowed down to allow conventional methods to detect and operate first.

Once such functions and philosophies are adopted, the required supervision must support the execution algorithms to maintain or increase the reliability of the protection.

Both current and voltage supervision functions are available from all OEMs. The exact functioning and utilisation of these supervision functions needs to be understood and evaluated so that critical functions, without back-up, are not blocked to operate. It is known that incorrect CT secondary wiring could block current differential to operate. Although such supervision is critical to prevent over functioning of protection functions, it must cater primarily for transient secondary measuring disturbances that cannot be substantiated by a supervision function. Only then does it need to block for a predetermined time e.g. for a couple of cycles and then release the function again. If the disturbance is then still present, tripping by the function must be released.

Although voltage and current supervision are not traditional protection functions, IEDs are equipped with it for a variety of applications. The use of these supervision functions needs to be carefully applied to assist the production capability of a plant too.

Any supervision function that operates shall initiate a local event and provide facility to annunciate the condition to a remote monitoring system as well.

3.1.5 Local Alarm and status indications

Protection IEDs also fulfill the requirements for local alarms and indications either via built-in LEDs or LCD displays.

3.1.6 Logics

IEDs have become very powerful and harvesting this processing power allows engineers to utilise software logic configuration to enhance a product's "fit-for-purpose" application. It allows for relatively inexpensive modifications to be carried out. It goes without saying that any change or modification still needs to comply with the proper engineering change process.

3.2 GENERAL REQUIREMENTS

3.2.1 Control circuit design philosophy

The standard circuit design shall facilitate the integration of signals from the CT's and VT's and the interface with circuit breakers to perform various functions such as protection, control, alarm and monitoring. An (IED) that can perform at least control, indication and protection functionalities shall be used. The IED shall also be linked to the circuit breakers and earth switches for inter-tripping and interlocking functions where required.

The typical design includes functions for Supply Point, Control Trip, Control Close and Indication and DC Fail (DCF) as shown in the figure below. Two very distinctly different approaches are followed with-in Eskom Generation. The one school of thought is based on fuses, the other using MCB's with auxiliary contacts. Both designs have their respective advantages and disadvantages. In the design application the interrupting components are simply not interchangeable. The complete design with it is associated monitoring and interlocking is dependent on the circuit interrupters that are used and will require in certain cases specific monitoring requirements in the IED logic while another design could have it embedded in the hardwiring.

3.2.1.1 DC control supply - Fuse application

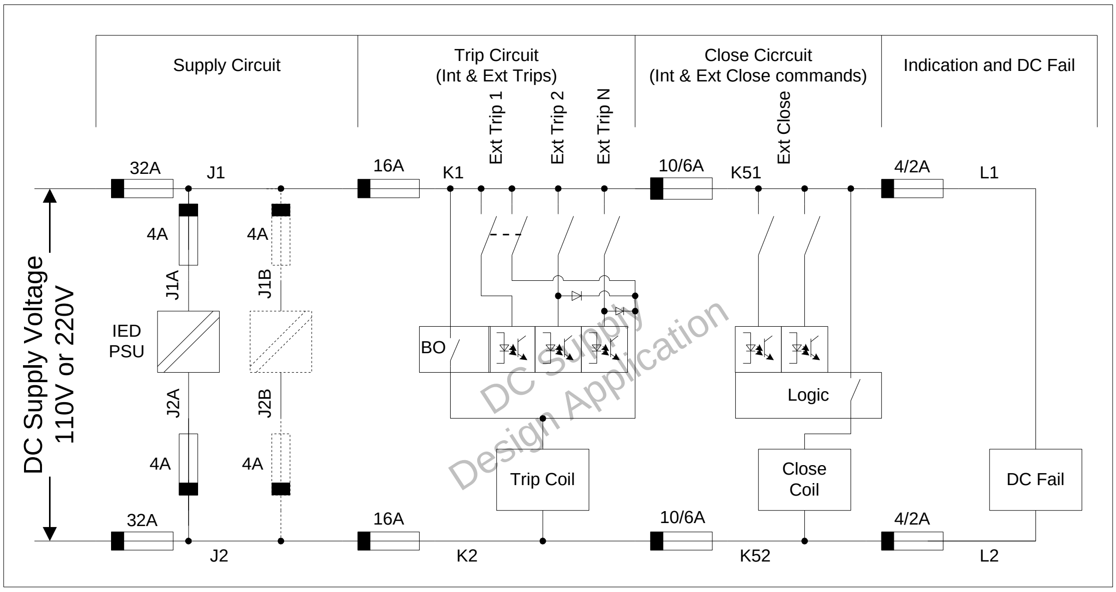

Figure 1: Typical DC Control circuit diagram - Fuse application

The DC control circuit design shall have the following functions as a minimum:

- Control Trip - Trip signal to circuit breaker (local and remote)
- Control Close - Close signal to circuit breaker (local and remote)
- Indication and DC Fail - Circuit breaker, earth switch and link indication as well as DC fail alarm.

The control circuit fuses shall have adequate co-ordination between them in the control circuit and also the feeder from the DC supply. Example of the graded system of the fuses used for the protection of the control circuit are as follows (as shown in Figure 1)

- Supply point = 32A.
- Control Trip = 16A.
- Control Close = 6A.
- Indication, spring charge and DC Fail = 2A.

Note: The protection IED shall be supplied by fuses connected between the 32A and 16A fuses.

The control circuits shall be designed to make allowance for the alarm signals to be send to the process control system.

The DC fail functions shall be separate no volt relays. The internal DC fail detection of the IEDs may not be used. This is to allow for standardisation when two or even three different DCs need to be monitored.

The IED failure contact shall be used to detect not only an internal IED failure but also the fuses that supplies it. The internal IED failure will then annunciate either an IED failure or loss of supply to the IED. Either way the IED is not functional in this scenario.

3.2.1.2 DC control supply - MCB application

The alternative approach is a set of MCBs in series/parallel with an important difference that the IED is supplied from the trip supply. So if the tripping supply MCB is open, the IED will be without power as well. Such arrangement is shown below.

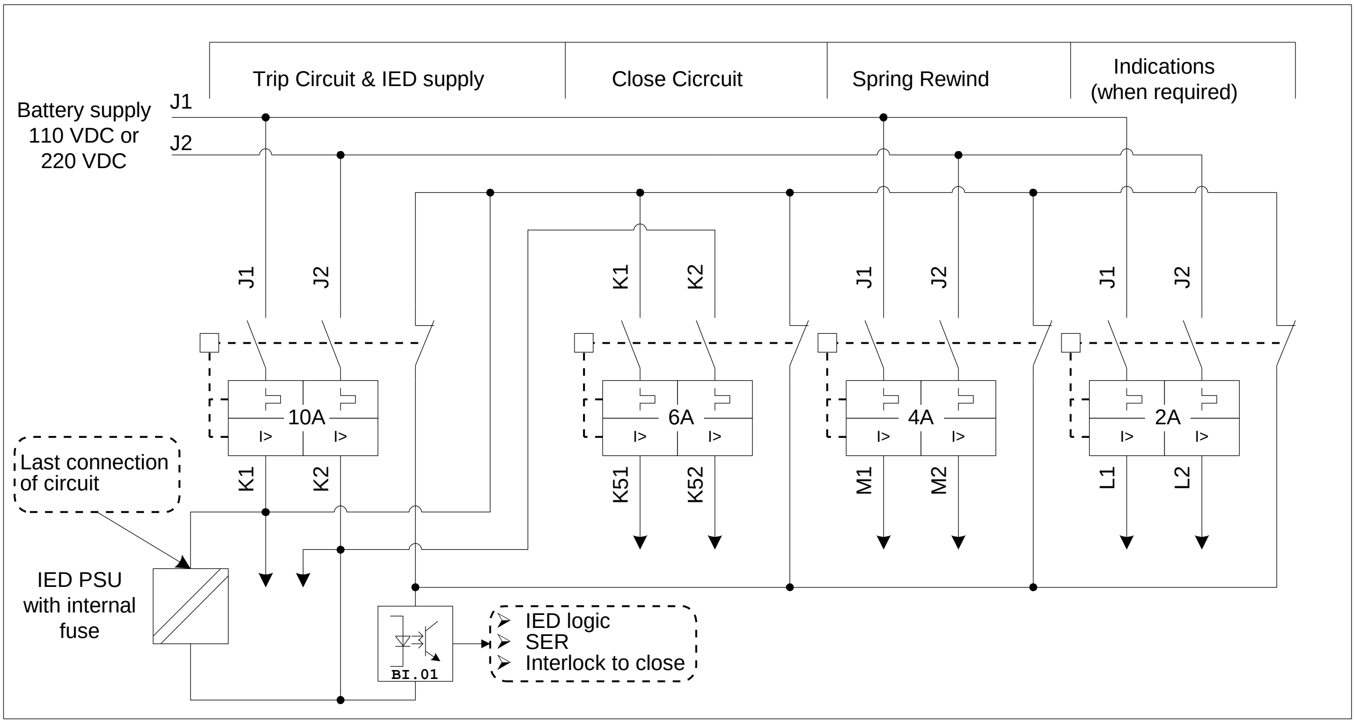

Figure 2: Typical DC Control circuit diagram - MCB application

When MCBs are used, their auxiliary contacts shall be monitored and be used with-in the IED logic as part of the close interlocking.

Note: MCBs used in DC circuits shall have the correct interrupting capability and where it is put in series; the required grading shall be proven. These MCBs should preferably be from the same supplier.

3.2.2 Redundancy

As per IEC 60050-448, redundancy is defined as the existence of more than one means of performing a required function. Redundancy covers a wide spectrum of elements within the MV protection system and includes but are not limited to the protection functional elements, trip coils and DC power sources used for supplying IEDs or trip coils.

3.2.2.1 Protection functions

Medium voltage protection needs to comply with the following:

Each electrical fault in the power station medium voltage reticulation system must be detected by a main and at least one back-up protection function and clear the fault within the primary plant fault withstand capability. The main and back-up protection shall be powered from two different DC supplies. This does NOT require main and back-up protection with-in the same bay. Up-stream protection that can detect and safely trip for such a fault is adequate back-up protection. It is with this design approach that protection designs should be carried out.

In contrast to generating unit protection, the protection on the medium voltage reticulation on a power station does not subscribe to the same redundancy aspects of Main 1 and Main 2. There are however certain redundant elements to enhance the dependability and there are elements to enhance safety.

When the criteria of back-up protection, as defined, needs to be fulfilled, it becomes impossible in some cases with traditional protection schemes as they are applied.

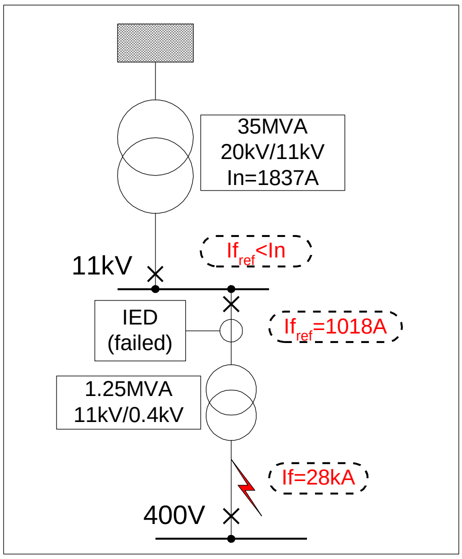

Figure 3: MV incomer protection not sensitive enough for certain LV faults

A classic example of this is if a typical LV transformer, supplied by a unit board develops a fault on the LV cabling before the LV switchgear and the LV CTs are part of the LV switchgear. This fault current, although often quite high on the LV side of the transformer, invariably is much lower on the HV side. It is in fact so small that it is less than the nominal rating of the unit board supply transformer (station or unit transformer). If the IED on that transformer feeder fails, neither a breaker trip nor a breaker fail can be initiated to clear the fault upstream. Therefore the traditional IDMT over current on the incomer does not even detect such a fault.

To overcome this obstacle and to comply with the back-up protection requirement, a redundant function (but not necessarily a duplicate function) needs to be implemented and a low impedance bus zone scheme is an ideal solution in this case. Low impedance bus zone on modern IEDs have more than one current element that can be set independently. If one of the time over current elements is set as a back-up for the main protection IED on the feeder, then a slightly delayed tripping of the incomer will occur but it would still be with-in the rating of the power system elements under stress for this fault i.e. HV cable to the transformer and the transformer itself.

3.2.2.2 Trip coils

The redundancy described in this paragraph does not apply to hydro, or pump-storage plants. Nu-clear plants may adopt the requirement although not governed by the FFFR.

Trip coil redundancy is required on a breaker that can be operated from different schemes (excluding bus zone and internal arc schemes). This is to enhance dependability and not to mix different DC sources. This applies to all unit transformer incomers and loop supply incomers on unit boards. The same applies to the station board supply breakers.

The boiler protection system requires a fail-safe tripping mechanism and the switchgear standard requires no-volt coils to allow tripping by the BPS. These no-volt coils will be energised by the BPS system. This shall be the standard interface with respect to tripping the required MV breakers by the BPS.

When electrical protection gets replaced and excludes the switchgear replacement, redundant trip coils shall be provided on the circuits described by the FFFR. It must be noted that the FFFR does not stipulate the use of dual trip coils, but under the circumstance as described, it is the best alternative to enhanced dependability. It is appreciated that this will lead to having three different trip circuit configurations.

Where redundancy is deployed on trip circuits and the conventional battery supply (110VDC or 220VDC) is used, the trip coils still needs to comply with the capacitive discharge test to ensure it does not operate spuriously for DC switching that could take place on the chargers for instance.

The typical trip coil application is further described under the interface requirement under paragraph 3.2.10.2 External breaker command.

All unit board incomers and all motors forming part of the draught groups and mill motors shall have two ways of tripping. Depending on the C&I capabilities, the trip coils forming part of the motors mentioned in the FFFR, shall as first option be no-volt coils energised by the boiler protection system. This supply from the BPS shall be monitored by the electrical protection scheme and its status shall be captured as a binary input into the associated IED.

3.2.2.3 DC supplies

The redundancy described in this paragraph does not apply to hydro, or pump-storage plants. Nu-clear plants may adopt the requirement.

Redundancy of DC supplies per IED is not required, however where main and back-up protection is concerned it shall not be supplied from the same DC. Dual DC is also required in a bay if that bay is equipped with two trip coils. Where more than one DC enters a board a four position selector switch (refer to Figure 4) shall be installed such that:

- Two sources coming in are distributed such that one source supplies the feeder IEDs and the other source supplies the incomer IED and bus zone IED (if installed).
- Any source can supply both the feeder and the incomer IEDs without connecting the sources together.
- The selector switch contacts shall be **break-before-make** to prevent DC supplies from being paralleled. These IEDs might reboot during this period and no trip output shall be energised during the switch-over or the re-booting process.

- Proper interface engineering needs to prevail to prevent the unit control system to act drastically to switchgear alarms that may be raised during these switching conditions. Alarms such as DC fail, and internal IED failure could potentially have the wrong knock-on effect on the process control side.

Where a bus zone scheme is installed, a similar DC selector switch, with only three positions needs to be provided such that:

- Any source can supply the bus zone IEDs without connecting the sources together.
- The selector switch contacts shall be **break-before-make** to prevent DC supplies from being paralleled. These IEDs might reboot during this period and no trip output shall be energised during the switch-over or the re-booting process.
- Bus zone DC fail would normally not interface with the unit process control system but, proper interface engineering needs to prevail to prevent the unit control system to act drastically to switchgear alarms that may be raised during these switching conditions. Alarms such as DC fail, and internal IED failure could potentially have the wrong knock-on effect on the process control side.

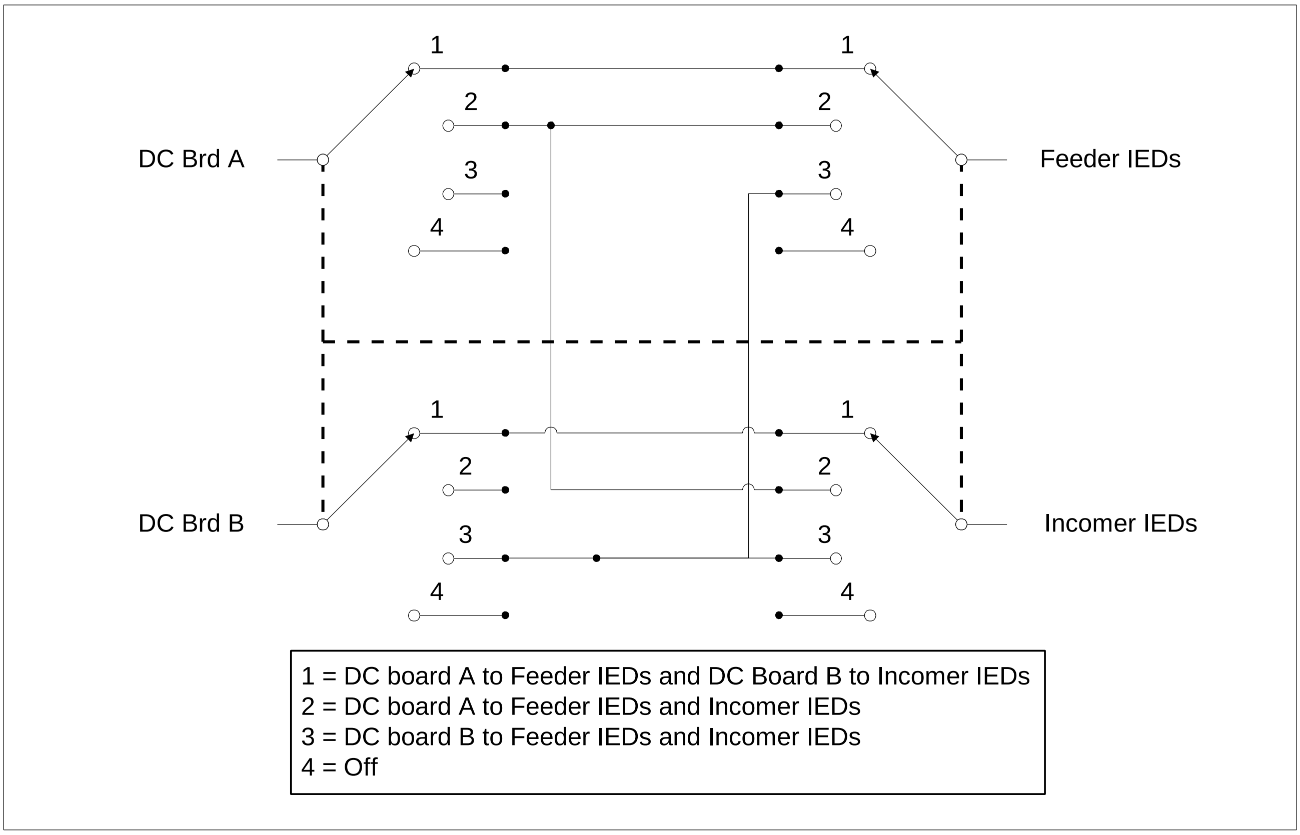

Figure 4: Simplified diagram of DC source selection for protection IEDs

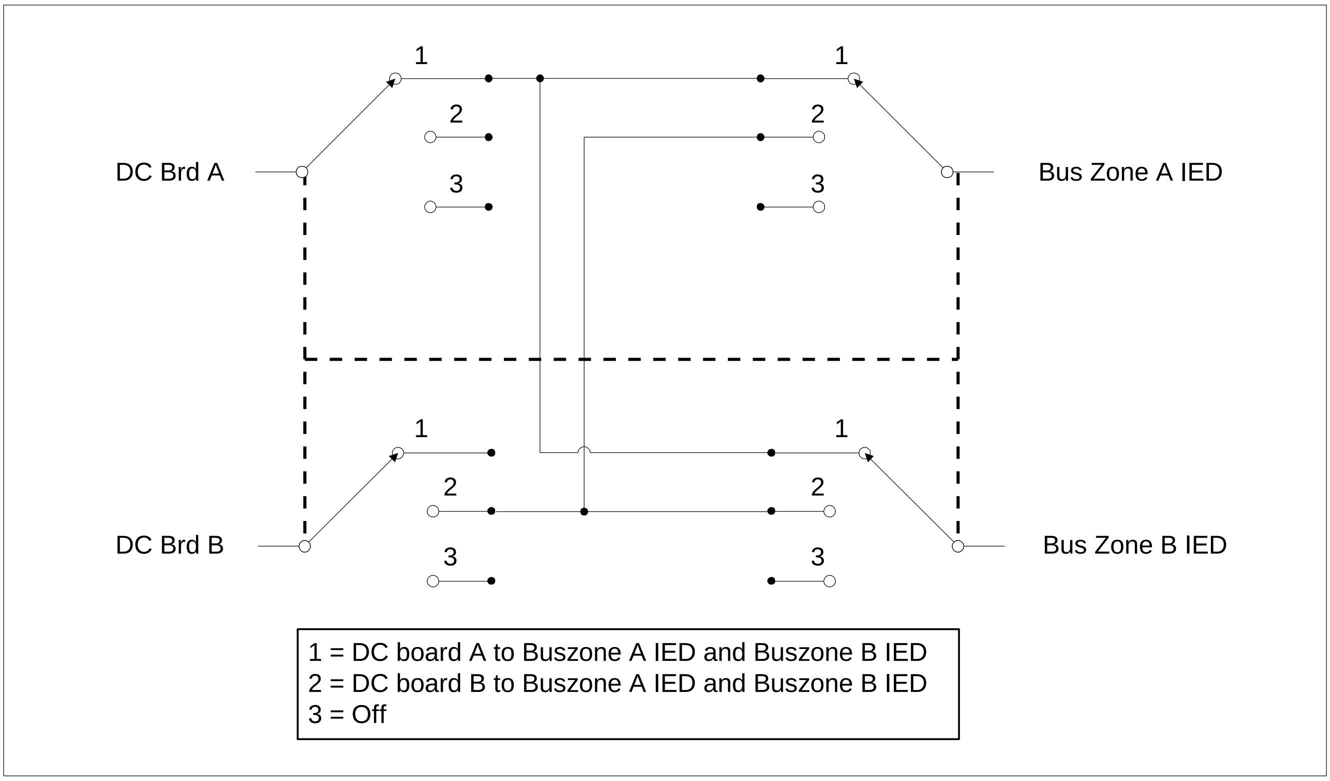

Figure 5: Simplified diagram of DC source selection for Buszone IEDs

3.2.3 Current transformers and measured quantities

Measuring transformers are required to transform the high power currents to safe and representative measurable values to enable protection devices to detect electrical faults or abnormal plant conditions. Various types, sizes and classes of current transformers are required to enable the protection to operate accurately and reliably to systems faults. This document does not prescribe type or size of any CT to be used because each application and each manufacturer might have their own current transformer requirements for a particular application.

The exception to rule is when a core balance CT is required as applied to motors, Eskom Generation has standardised on a 100/1, 5VA, class 5P10 CT, unless this requirement can be technically challenged and legitimate reasons found to deviate from the specified requirement.

It must be stressed that any current differential CT set shall have the same characteristic, including any parameters that can alter the time constants of the measurement to ensure differential integrity and stability. CTs with different parameters can easily comply with CT standards but as a set it might not be suitable for an application. Where CTs are required as a set, both criteria must be complied with.

3.2.4 Voltage transformers and measured quantities

Like CTs, VTs are also measuring transformers and in the typical three phase power system dealt with-in this context, the construction type of the VTs are important to fulfil the measuring and detection requirements of the protection functions. Where zero sequence voltage detection is required, it is important that the VT construction is either in the form of three single phase VTs or a 5-limb core three phase VT. A further requirement is that the VTs must have a minimum voltage factor of 1.9 where compensated earthing is applied.

The secondary circuits of VTs shall be protected with correctly sized and rated fuses or MCBs. Where three phase MCBs are used and allowed, MCB monitoring via an auxiliary contact is required. It is recommended to use single phase MCBs on VT circuits, each with it own auxiliary contact to assist in fault finding should the MCB trip due to overload.

Voltage transformers are not dedicated to protection devices but are shared amongst devices for measuring, protection and even interlocking of control. Voltage supervision functions will therefore be required in the IEDs. The voltage supervision function needs to be fast and accurate to detect voltage disturbances and to block associated voltage dependant functions from operation under momentary or permanent voltage disturbances and then alarm such a voltage disturbance correctly. Where MCB contact status is monitored it may be used to indicate loss of voltage and may be applied in the same way as the measured voltage principle.

3.2.5 DC supplies

3.2.5.1 Clean and Dirty supplies

Clean supplies shall be provided for electronic equipment and dirty supplies shall be provided for spring rewind motors and any other heavy powered DC operation equipment inside the switchgear control circuit.

- For **station** supplies, two DC boards, supplied from separate battery charger systems (including separate battery banks) shall be provided to power the station supplies.
- For **generating unit** supplies, two DC boards supplied from separate battery charger systems (including separate battery banks) shall be provided to power the unit supplies. At coal-fired power plants a third supply (C-board) is available and is provided to power the high power loads like spring rewind and motorised isolators on GIS switchgear for instance.
- **Common plant** boards might only have a total of two clean DC supplies. Spring rewind motors are normally supplied via power VTs. The DC standard requires the common plant chargers to cater for two AC inputs, one from each of the AC boards. The normal supply shall be from the A board for A board DC supply and vice versa.

There might be situations during refurbishment projects were only one clean DC and one dirty DC is available. The dirty DC may then be used to power IEDs but only if suitable filters are installed by the protection supplier to ensure that the AC ripple is within the specification as indicated below for clean supplies.

The Clean DC supply shall not exceed any of the supply parameter requirements:

- Nominal voltage U_n: 110VDC or 220VDC
- Permissible range: U_n ±20%
- AC Ripple peak to peak (IEC 60255-11) ≤12% of U_n
- Minimum of 4 hours standby time for unit supplies and 1 hours for common plant
- To enhance redundancy/availability a maintenance connector shall be provided between the two boards but kept in the normal open positions.

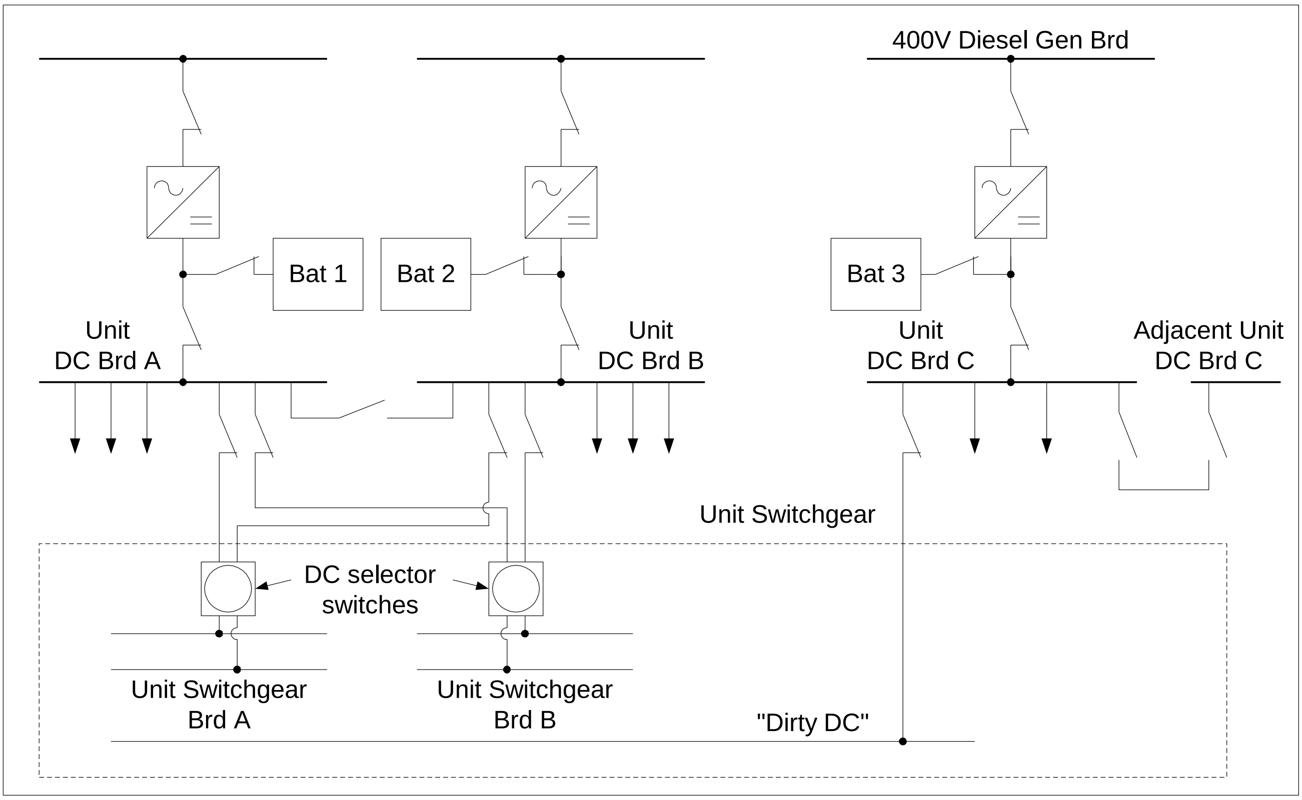

Figure 6: Simplified DC single line for Unit DC distribution to MV switchgear (coal-fired P/S)

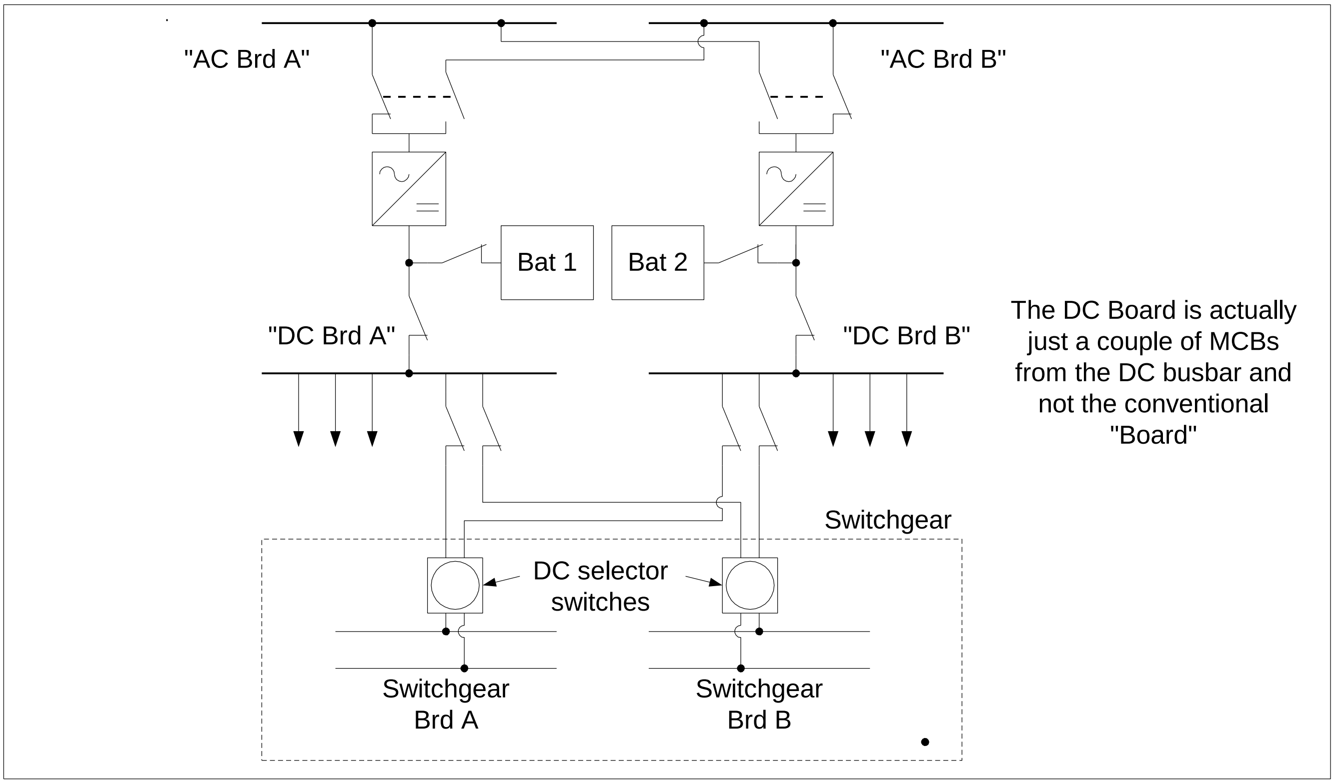

Figure 7: Simplified DC single line for common plant board DC distribution to MV switchgear (coal-fired P/S)

3.2.5.2 DC monitoring

3.2.5.2.1 DC Fail - Coal fired plant

All circuits shall have DC fail detection with indication of which DC has failed. DC fail functions shall be installed after the last required cascaded fuse or MCB and shall operate for either loss of positive or negative supply. All DC fail detections shall be done by separate no-volt relays to allow for standardisation in different circuits. The relay shall be energised all the time while DC is available and N/C contacts of the associated relay shall be used to relay the status to the protection IED as well as station control.

Dirty DC supplies shall be monitored by a separate DC fail relay. Where two clean DC supplies are used within the same bay, supplies shall be monitored individually and annunciate as such.

Where a DC fail condition needs to render the breaker inoperable to close from remote, the processed signal via the IED shall be used because the IED will prevent the **closing** of the breaker if any DC has failed. Because the cascaded DCs are not monitored separately, a DC fail should never prevent a remote trip to be executed. This is in-line with the direct tripping philosophy.

3.2.5.3 DC Fail - Hydro and pump-storage

In all the hydro and pump-storage power plants two DC supplies are provided per board A and B. These supplies are monitored by DC fail devices/functions where it enters the board. Individual circuits are monitored per bay by contacts and utilising the IED internal DC fail function.

3.2.5.3.1 DC supply selection monitoring

The DC supply selector switch position needs to be monitored with a separate contact/s and alarm the abnormal status (not in normal) to station control. This applies to all DC selector switches including bus zone panels where applicable.

3.2.5.4 DC earth fault monitoring

DC boards supplying any MV board in the plant shall be fitted with a DC earth fault monitoring device per circuit, situated at the respective DC board with annunciation to the Station Control (EOD) alarm system. The notorious practice of switching off DC circuits to locate an earth fault is very time consuming. By installing these earth fault detectors, the fault finding time will be drastically reduced as well as the time that protection might be solid. This is not in the scope of the protection supplier but a requirement that the DC supplier needs to comply with.

3.2.6 Trip circuit supervision

All circuit breakers shall have trip circuit supervision and it shall be operational in both the open and close positions.

Trip circuit supervision shall initiate a local as well as remote alarm.

An active trip circuit supervision alarm shall prevent a breaker to close. Where breakers form part of a chop-over scheme it shall form part of the interlocking criteria to disallow a chop-over or transfer to be initiated.

Trip circuit supervision shall be configured not to produce alarms when breaker switching takes place.

3.2.7 Close circuit supervision

Close circuit supervision is mandatory on coal-fired plant and optional on hydro and pump-storage plants

All circuit breakers shall have close circuit supervision and it shall be operational in both the open and close positions.

Close circuit supervision shall be configured not to produce alarms when breaker switching takes place.

Close circuit supervision shall initiate a local as well as remote alarm.

3.2.8 Breaker fail

Breaker fail functions are required on all MV switchgear and shall trip all sources of supply when required. A process control breaker open must not initiate a breaker fail, therefore the input for a trip and control open shall be treated differently.

3.2.8.1 Breaker fail protection requirements

Where breaker fail protection is installed, it shall adhere to the following principles:

- The breaker fail protection trip shall be routed to all sources of supply. In hardwired installations, bus wiring from the CBF contacts shall energise a latching master trip relay to eliminate the mixing of different DC supplies. Where bus zone protection is available it shall be used to trip the source/s of supply and its remote ends. If the board is not equipped with Bus Zone protection, tripping of all points of supply shall be implemented (incomers, bus section, etc.).
- Isolation of the breaker fail protection function shall be provided either through the installed Bus Zone to isolate tripping from the Bus Zone panel or in the IED/panel of the sources of supply. For boards not equipped with Bus Zone protection, breaker fail protection isolation switches shall be fitted to all panels of supply. These switching events shall be alarmed locally and to the EOD when this switch is selected to the off position and also activate an event in the IED event list.
- Any internal arc system shall be equipped with an isolation function for all trips and breaker fail trips.
- A test block contact, per bay, shall be wired in series between the IED breaker fail output contact and the circuit which is connected to the master trip relay or the Bus Zone protection relay input.
- A facility to disable the CBF output shall be provided in the IED, to enable the engineering practitioner to disable the function when required.
- A “Not in service” status from the breakers shall be utilised to isolate the relay breaker fail protection output.
- An “open” position breaker contact shall inhibit the relay breaker fail protection output circuit.
- Utilise the breaker fail function of the IED which was developed by the OEM for the application and do not create an application by adding logics to the IED.
- The process control stop function shall not initiate the CBF but the process control trip shall initiate the CBF.
- Current interlock pick-up = 20% of nominal current or object setting value.
- Standard breaker fail time = 150msec. CBF time shall be based on the breaker and IED performance and as a minimum the following shall be used:

  Function operating time + IED output contact operating time + any intermediate tripping relay + breaker operating time + 20% safety margin.

3.2.9 IED and / or auxiliary relay acceptance for use

Eskom Generation has a list of approved devices that is kept current. Before a protection IED or auxiliary relay for control or tripping may be used in Eskom Generation it needs to appear on this list as managed by *240-56227589 - List of Approved Electronic Devices to be used on Eskom Power Stations Standard*.

3.2.10 Interfaces

Standardised interfaces ease the implementation of different protection solutions to different switchgear and other systems like unit control/station control, boiler protection systems and measurement systems. Analog and binary data are required to be exchanged. This exchange can happen via hard wired interfacing or via communication bus with a protocol like IEC 61850. It is not in the scope of this standard to elaborate on the substation automation portion, but it suffices to say that a minimum number of signals need to be exchanged and this standard specifies the minimum requirements.

3.2.10.1 Analog inputs and outputs

3.2.10.1.1 Test blocks

The protection IEDs require current and/or voltage transformer inputs from the plant to measure analyse and react to abnormal conditions. To validate and verify the functionality and operation of an IED, it is required to test the IED with secondary injection equipment. A safe, non-intrusive method of injecting current and/or voltages shall be supplied in the form of approved test blocks. When injection needs to be done, it shall be possible to do so without disconnecting any wires or opening any links. Eskom generation has a standard governing the use of equipment to be used on generation plant. Only items from the LAP may be used and the use of sliding links in current and voltage transformers circuits are prohibited.

Current test blocks shall have the ability to short circuit the current transformer inputs and provide a safe injection point for testing personnel. Voltage test blocks on the other hand need to disconnect the voltage transformer quantities, leaving it open circuited for measuring purposes and provide an injection point for personnel to test the IED.

Maintenance and test procedures and practices differ. It is highly recommended that only test blocks with additional contacts to isolate trip circuits once a test handle is inserted may be used. When breakers are required to be racked out for testing and breaker fail is interlocked with the racked-in position, it is safe to test the circuit without additional breaker fail interlock to the bus zone or master trip functions. When breakers can be tested in any position, the breaker fail contact shall be wired in series with a contact on the test block to ensure that any trip testing initiating a breaker fail will not trip the bus zone or incomer, especially to up-stream circuits that may be alive.

Test blocks are installed such that test handles can be inserted without interference.

Bus zone circuits as well as measurement circuits shall be fitted with test blocks too.

3.2.10.2 External breaker commands

External inputs required to energise a trip coil or to de-energise a no-volt coil to cause direct trips shall be monitored in parallel as an input to the IED for event logging, possible local and remote indication and may be for “trip reinforcing”.

Inputs required to close the breaker do not have a multitude of sources but their operation still need to be monitored.

3.2.10.2.1 Energise to trip

All trip commands originating from outside the IED like, process control breaker trips, emergency push buttons or other protection IEDs operating shall be monitored. When no interposing relays are used for these inputs, diodes may be used to ensure that the IED monitors the energising or operation of the trip commands. When a local interposing relay is used, a contact from this relay shall be used by the IED to monitor its operation status.

Note: If indication or back-up tripping is needed, the use of diodes are permitted to identify each trip signal in the IED as described in § 3.2.11 Tripping and closing principles.

3.2.10.2.2 De-energise to trip (no-volt)

De-energise to trip signals like the "green wire" on conveyers and boiler protection trips requires no-volt coils to be installed on the breakers for opening the primary contacts. These inputs shall be monitored with approved relays. These relays shall have a mechanical cam to force the plunger to simulate an energised state. This is required for protection personnel to perform protection testing when the BPS might not be available during an outage. The monitoring of these de-energise to trip coils are used to detect operation of the inputs, be it a real trip, loss of DC or a wire break. The protection IED needs to log the event and use it to prevent a close command from either local or remote.

3.2.10.2.3 Energise to open

A process stop command is not regarded as a trip. This will be a locally energise-to-operate relay (IPO). The contact from this IPO will energise a binary input of the IED for logging and trip coil activation. This input will not start the breaker fail function but an unsuccessful execution of the command shall be alarmed to the unit control as "failed to open" alarm. Alternatively the process control signal must use breaker status feedback for its own "check-back" or "acknowledge" signal to indicate an unsuccessful opening of the breaker.

3.2.10.2.4 Energise to close

Remote breaker close commands will operate a local energise-to-operate relay (IPC). The contact from this IPC will energise a binary input of the IED for logging and close coil activation. An unsuccessful execution of the command shall be alarmed to the unit control as a "failed to close" alarm. Alternatively the process control signal must use breaker status feedback for its own "check-back" or "acknowledge" signal to indicate an unsuccessful closing of the breaker.

3.2.10.3 Binary Inputs and Outputs

Binary inputs are used for plant status detection, interlocking, control commands and for tripping purposes. Output contacts are used to drive statuses, alarms and trips. Ensure the IED in question is fit for purpose to handle all input- and output requirements for the application by adding it explicitly to schedule A of tender documents.

It is common practice (but do differ from plant to plant) where a transformer supplies a LV board that the LV disconnecting device can only interrupt fault current for a couple of times (quite a few manufactures specify three trips at rated fault breaking current) and then requires replacement. This requires I^2t monitoring with the possibility to block the close function to be configured on the LV disconnecting device. It also has a significant financial impact when such a device needs to be replaced. To overcome this burden of monitoring and supervision it is common practise that the LV IED does not trip the LV disconnecting device but rather trips the high voltage side breaker which does not suffer from the same limitation as described above.

In the common plant these transformers can be very long distances (hundreds of meters) away from the MV boards. Over and above any transformer protection like winding and oil temp that need to be relayed back the MV source IED, an extra trip command from the LV IED has to be provided too. These long distances are a major contributing factor towards induced noise that can operate the binary inputs on the MV IED. It is therefore required that cables carrying binary trip signals from the protected object or between IEDs not in the same bay, be screened twisted pairs. To reduce the chances of a false operation even further, IED inputs shall be desensitised against noise induced signals. Over and above the noise immunity requirements for an IED as per Eskom standard, Eskom Generation requires a capacitive discharge test to be performed on trip inputs. No change of state or any operation shall occur when a capacitor of capacitance shown below, charged to 1,5 × Vn volts, is connected between any combination of terminals and any combination of terminals and ground.

- Master trip circuits - 10 µF
- Other protection & control circuits - 2 µF

The IED supplier must demonstrate this capability prior to the acceptance of the device. External desensitising circuits will be allowed once proven to be effective.

3.2.10.4 Switchgear

The interfacing between a protection IED and its associated switchgear is vital for the correct control, operation, interlocking and annunciation of plant status on the local HMI and to any other systems reliant on these signals.

It is highly advised that all contacts used for interlocking to abide by the double bit principle and switch gear engineering practitioners must ensure that future requirements have this incorporated in the technical specifications. This applies to breaker positions, earth switch positions, rack in/out positions. All these contacts need to be wired from the switchgear to the IED via an interface terminal. No merging units are allowed. If the double bit principle cannot be applied, the best practice for validation of critical signals should be applied.

Only bi-stable relays are allowed for breaker contact multiplication for non-critical status indication.

3.2.10.5 Unit control (DCS process control and Boiler Protection for coal-fired P/S)

3.2.10.5.1 Inputs from Unit Control (Process and BPS)

The unit control system is by definition a process control system and therefore controls the process of starting and stopping certain motors as required. Interfacing with the unit control DCS is achieved via interposing 24VDC multi-contact relays with the number of contacts and rating as required by the technical specification document when MV protection is procured. At the time that this standard was published, the process control did not distinguish between a process trip and a process open/stop command and hence the MV protection IED will treat the single input to open the breaker as a breaker trip command. In future it could be spilt and then the breaker fail philosophy can be revised.

The BPS on the other hand is a protection system and tripping is cardinal to its functioning. Historical incidents and new functional safety requirements have forced electrical switch gear to start implementing “fail-safe” type tripping functionality. Due to the operating methodology of the primary control supply (110/220VDC) used by switch gear, a de-energise-to-trip functionality will cause numerous unwanted trips in the generation plant. To support the highly critical tripping requirement from the BPS, it was decided to use the 24VDC supply from the BPS as energising supply for the “de-energise-to-trip” coils in future designs.

Table 1: Inputs into motor protection from Unit control system

Signal	Source	Interface method
Process stop / trip (IPT)	Process Control stop command Cooling system failed (Aux fans/Water system) Aux oil pumps non operational Thermal exceeded (RTD) Vibrations exceeded Boiler capability (not BPS)	HW
Motor start (IPC)	Motor start command	HW

3.2.10.5.2 Outputs to Unit Control

Outputs to the unit control system need to be carefully engineered by the electrical and control system engineering practitioners. Signals generated by the protection IED based on abnormal conditions, need to be carefully grouped to prevent unnecessary automated actions by the control system. These actions could inter alia be to de-load the unit (operating the capability function) or switch from automatic control to manual control or even to prevent the DCS to operate the breaker. Such drastic consequences must be limited to the minimum. It is appreciated that these types of alarms and interfaces could vary between control systems but generally the following groups of alarms and or statuses are required.

Table 2: Outputs from motor protection scheme to unit control system

Signal	Source or description (comments)	Interface method
Start-up Block / Breaker close blocked	Number of starts exceeded Delay time after stop or trip command Thermal high alarm Close circuit unhealthy Trip circuit unhealthy SF_6 pressure low alarm (when applicable) DC Fail Any protection operation that has not reset Primary plant not selected or not switched to "normal state" IPT relay removed or permanently operated	HW
Over load alarm	Current high (90-100% of rated current) Thermally calculated alarm (I>100% and Θ_{alarm} activated)	HW
Motor thermal trip	Motor thermal trip (Auto reset)	HW
Protection unhealthy	Built-in IED failure	HW
Switchgear unhealthy	Trip circuit supervision unhealthy Close circuit supervision unhealthy DC Fail VT fuse fail/MCB Off SF6 low (switchgear dependant) Spring not charged Breaker racked out Circuit earthed (Switchgear dependant) Linked off (Switchgear dependant)	HW
Locked-out trip Protection operated	Any electrical trip from the IED excluding motor thermal	HW
LOR not in remote	LOR or LR not in remote, only if control is on the IED HMI. When LOR or LR is on the panel, it is wired directly from the switch.	HW
Protection blocked	Supervision function operated, blocking protection function	HW
Under voltage detected	An under voltage starter element that may be used by VSD restarting commands	HW

Plant interfacing, operating and interlocking differ quite radically from plant to plant. Equipment features and capability normally dictate the final operating philosophies. This standard can therefore not prescribe how the final design has to be done, but serves to guide engineering practitioners to design the plant to be safe and reliable. The electrical protection in conjunction with the MV switchgear must be designed to preferably never interlock any tripping, hence the reason for direct interfacing between the switchgear trip coils via the IPT from the DCS and BPS system.

The process control designer needs to take cognisance of the fact that no alarm generated by the MV switchgear and protection interface, requires blocking or interlocking of any process protection trip. Any trip must always have first priority.

During outages, when testing could be done uncoordinated, the personnel at the switchgear need to take the necessary precautions to isolate unwanted remote tripping from interfering with their testing. They have to re-instate these once testing has been completed. Finally remote testing needs to be conducted to ensure no inadvertent isolations still blocks any remote operation.

A plethora of conditions exist that must stop the breaker from being closed from an open state. From a plant safety and operating perspective it is therefore impossible to create a single signal that would block all breaker operations from remote. When an inhibition of breaker closing is generated by either switchgear or protection, it is important that the remote system (DCS/operators) is notified of such condition/s. The indication should be intuitive so that the operator would be able to carry out the correct alarm response procedure.

The interfacing of the systems mentioned is so critical in the process that both disciplines will have to jointly engineer and test the functions, once the vendor specific equipment has been secured, before a design can be authorised.

Breaker statuses to be used by the BPS and DCS shall not originate from a protection IED or flip-flop type relay. The switchgear is directly responsible for statuses related to the switch gear and these statuses are not relayed by the protection IED although the IED monitors them and do use the same information to formulate specific actions. The switchgear shall make available two normally open and two normally closed breaker auxiliary contacts, mechanically linked to the breaker. These contacts shall be used by the BPS and the DCS respectively. The recipients of these signals will have to use their own logic to solve the breaker state including any timers to cater for the state changes when an invalid state may be produced due to auxiliary contacts having inconsistent statuses during the transition period.

Table 3: Outputs from switchgear via LV compartment of a motor/drive bay including DC monitoring

Signal	**Source or description (comments)**	**Interface method**
Switchgear unhealthy	Spring not charged SF_6 pressure low Breaker status (Racking /Earth Switch /Link positions) LOR or LR not in remote	HW
Breaker close	Breaker closed status (may be used as check back to DCS) To Boiler Protection system (may be used for double bit logic)	HW
Breaker open	Breaker open status (may be used as check-back to DCS) To Boiler Protection System (may be sued fro double bit logic)	HW
DC Fail	Any DC fail	HW

The following diagram portrays a proposed interfacing between a motor protection IED and the DCS. The trip to the breaker trip coil is deliberately excluded due to the many different existing plant configurations at the moment. A future revision of this standard might seek a more standardised approach and may then be updated to include the interfacing with the trip coil. Certain aspects of tripping is captured in paragraph 3.2.11 Tripping and closing principles.

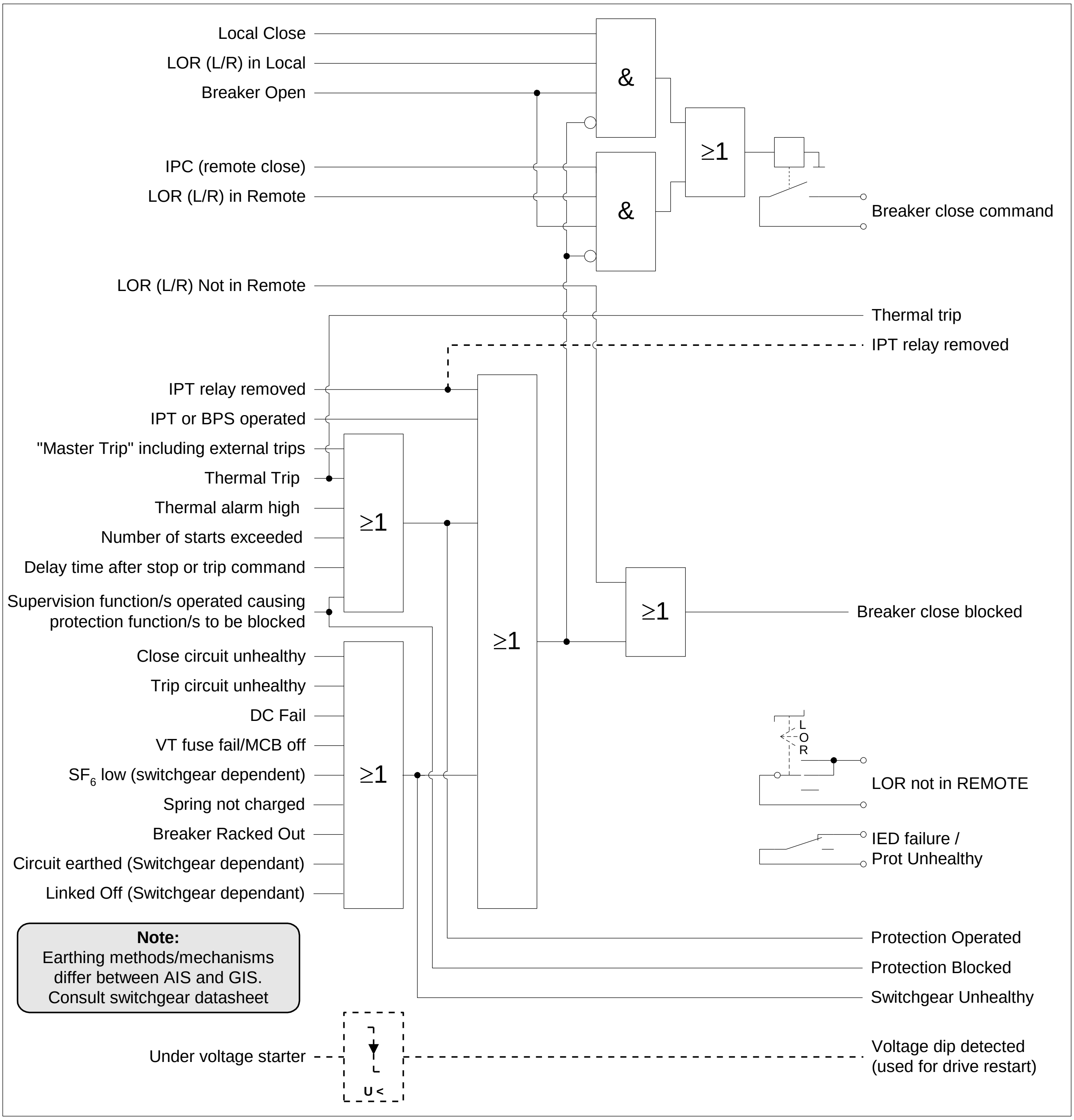

Figure 8: Grouping of alarms and statuses by motor protection IED

3.2.10.6 Station control

Station control is primarily responsible for the reticulation system. Signals to and from the switchgear are therefore required to convey statuses, alarms and breaker control commands.

3.2.10.6.1 Inputs from Station Control

Table 4: Input from station control to IED to control the breaker

Signal	Source	Interface method
Breaker close	Breaker close command	HW/Comms
Breaker open	Breaker open command	HW/Comms

3.2.10.6.2 Outputs to Station Control

The protection IED is required to send signal to Station Control for a detail overview of plant status and availability and to inform station control of any abnormal conditions that is within their mandate.

Table 5: Outputs from IED (excluding motors) to station control

Signal	Source	Interface method
Protection operated	Any electrical trip	HW/Comms
Switchgear unhealthy	Trip Circuit Supervision Close Circuit Supervision Spring not charged SF_6 pressure low Breaker status (Racking /Earth Switch /Link positions) Remote control not selected by IED (old LOR) DC Fail	HW/Comms
Breaker closed	Breaker status when closed	HW/Comms
Breaker open	Breaker status when open	HW/Comms
LOR	LOR switch position	HW/Comms

3.2.11 Tripping and closing principles

3.2.11.1 General principles

Generally, main protection is specific to a particular board, item of equipment or circuit. The protection shall trip that board or circuit only for a fault on that board or circuit. Back-up protection is achieved by means of current/voltage grading or time grading and may trip more than just the faulted plant.

At least one trip coil and one close coil per circuit shall be installed for each MV circuit. Trip circuit and close circuit supervision shall be provided as per paragraph 3.2.7 . Trip coil redundancy is required in special cases as per paragraph 3.2.2.2. Anti-pumping circuitry/logic is required by the IED only if the circuit breaker does not cater for it.

Trip counting and running hour functionality are part and parcel of new IEDs and may be enabled for MV circuits. Accumulative data must be transferable between devices upon replacement.

Differential protection, where applied, shall always provide overlapping with other differential protection ensuring that no part of the system is unprotected.

Trip signals from the protection IED to the circuit breaker trip coil shall be hard wired in the same bay and in the same board. It is not allowed that one IED trips another IED to trip primary plant. When more than one IED interfaces to a trip coil, each IED trip signal shall be hard wired to the circuit breaker trip coil/s.

An exception to the rule above is when internal arc is applied to a typical loop supply circuit. The internal arc protection will be required to trip breakers hundreds of meters away and direct hardwire interfacing could be problematic. Tripping via the cable protection IED on its proprietary communication hardware and protocol will be allowed under these circumstances.

Note: If indication or back-up tripping is needed, using diodes are permitted to identify each trip signal in the IED. Please note that only certain diodes have been approved for this application.

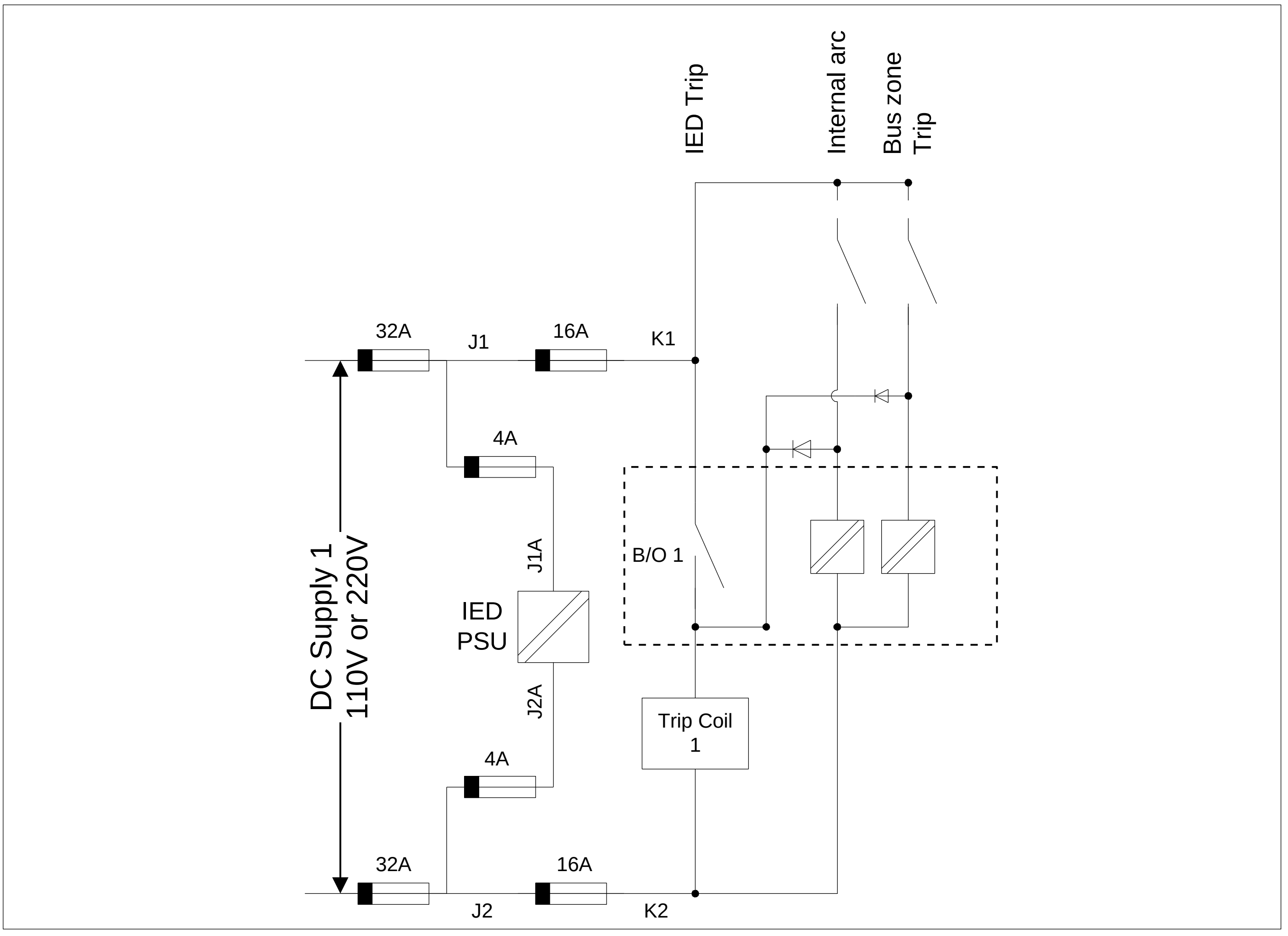

Figure 9: Example of using diodes instead of extra interposing relays to trip directly

IEC 61850 GOOSE tripping / closing signals and hardware tripping / closing signals may co-exist. This document advices to use hardwired tripping whenever possible. The rationale is purely based on Eskom Generation's past experience. The technology is not the issue, but the engineering applications. Each project will have to review the skills required to commission and maintain such protection schemes as part of a bigger SAS system. Where tripping via IEC 61850 protocol is not implemented, the signal may still be configured as a message to which subscribers to the GOOSE message can then record and alarm the state/condition. This will provide information to engineering practitioners and maintenance personnel and over time this may be used to upskill personnel and prove GOOSE reliability in a particular application.

GOOSE messaging for closing rotating plant (synchronising) shall not be allowed.

3.2.11.2 Safety tripping (coal-fired P/S)

Safe or safety related tripping will be done via de-energise to trip coils on draft group motors, mill motors and conveyor drive motors. For safe tripping from the BPS, a circuit representative of Figure 10 shall be used. To keep the breaker closed or allow it to be closed, the de-energise-to-trip circuit must be energised. Any loss of 24VDC at the terminations will de-energise the coil and the breaker will open if it was closed or will remain open if it was already open. Only two terminals are therefore available for the BPS trip interface. Feedback from a shunt relay will provide status locally to the IED and remotely to the DCS/BPS regarding the coil status. Breaker auxiliary contacts are also provided to the BPS and DCS separately to monitor the breaker status. This is not shown in the simplified diagrams below.

Conveyor circuits are also safety critical circuits and long line or green wire trips will also use the de-energise-to-trip coils as the primary safe shutdown methodology. The supply to the coil needs to come from the DCS control system or conveyor head units. An auxiliary contact shall be used to energise or de-energise a binary input of the IED to inform the IED of the external trip. A 220VDC fail is not required to cause a conveyor shutdown but must be alarmed by the local DC fail monitoring relay to allow corrective action. This will result in fewer trips of the conveyors when DC earth faults are investigated and DC supplies are switched off.

The figures below are typical representations of the tripping principles applied and do not constitute complete tripping schemes or tripping arrangements

In it simplest form the BPS tripping and IED trip interface will look like in Figure 10.

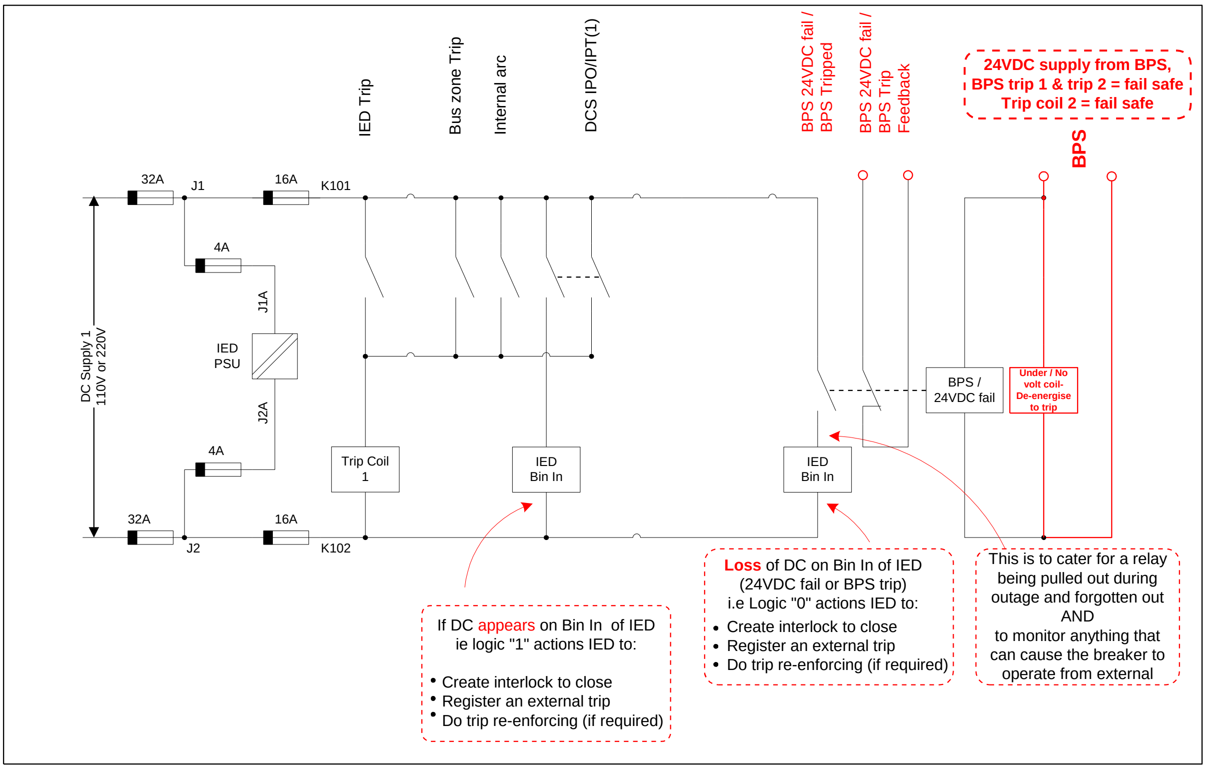

Figure 10: Simplified BPS-Switchgear interface via fail safe no-volt coil

When dual trip coils and dual DC supplies are deployed the circuit doubles up as depicted in Figure 11.

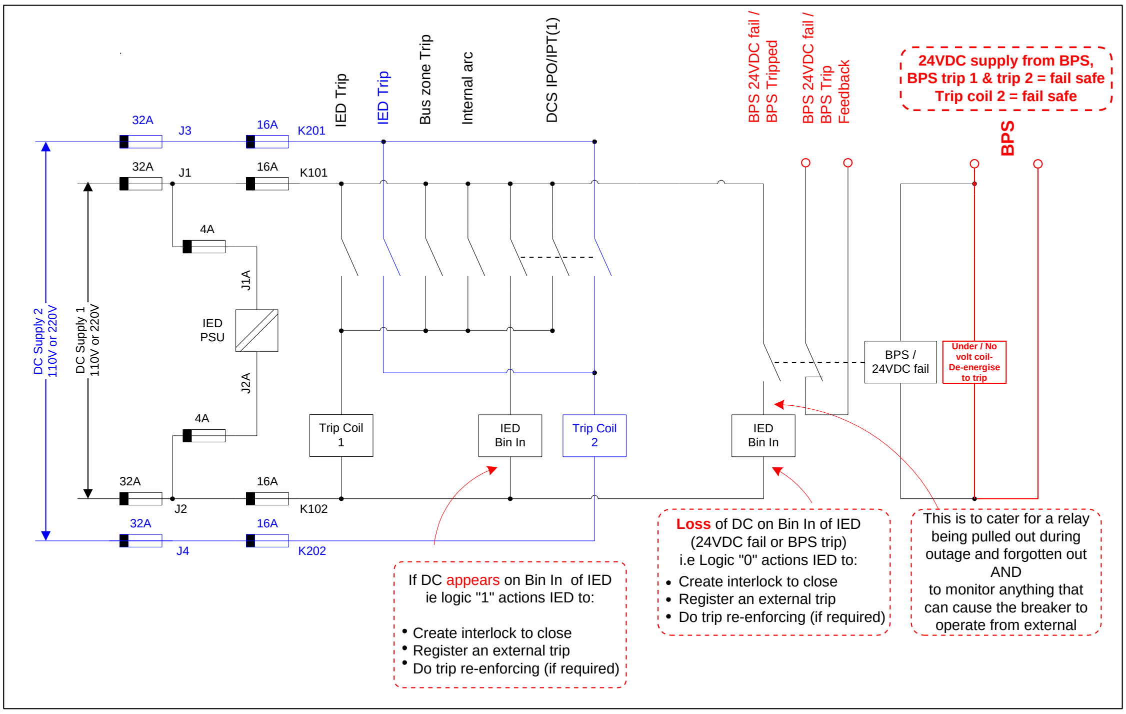

Figure 11: Simplified BPS-Switchgear interface via fail safe no-volt coil and Trip coil redundancy on DCS tripping input via IPT

To enhance DCS trip dependability a normally closed contact from the IPT may be added to the de-energise-to-trip circuit, making the use of a 2nd conventional trip coil virtually superfluous due to its inherent safe tripping characteristics and it does not rely on any of the MV circuit DC supplies.

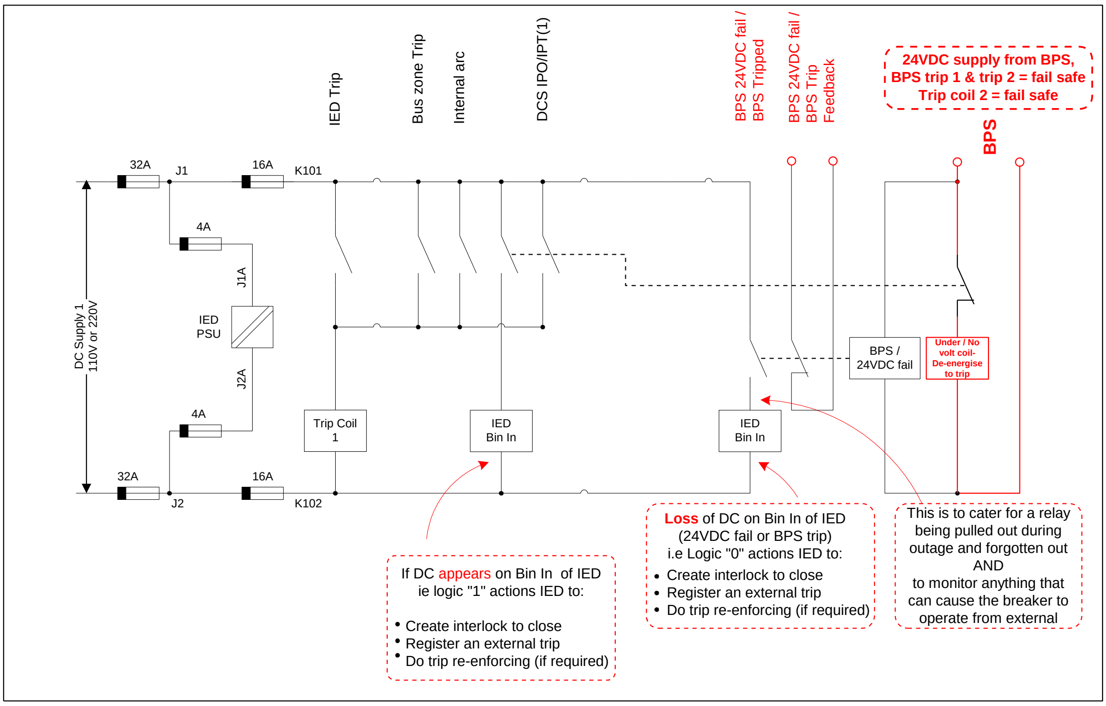

Figure 12: Simplified BPS-Switchgear interface via fail safe no-volt coil and DCS IPT also in no-volt coil circuit

3.2.11.3 BPS tripping when no-volt coil cannot be retrofitted to existing switch gear

It is foreseen that during refurbishment projects, phasing of projects will not coincide and there exists a real possibility that either the boiler protection or electrical protection or both could be replaced without the switch gear being replaced. If the existing switch gear cannot be economically modified during these replacement projects, an alternative solution is required. This solution entails the use of a de-energise-to-trip interposing relay (BPS IPT) which will still require the switch gear control DC to be available. To enhance the dependability of the boiler tripping requirement, two energise to trip coils will be used in the switch gear as most switch gear can accommodate a second trip coil. The two trip coils will be energised from two different DC sources as well.

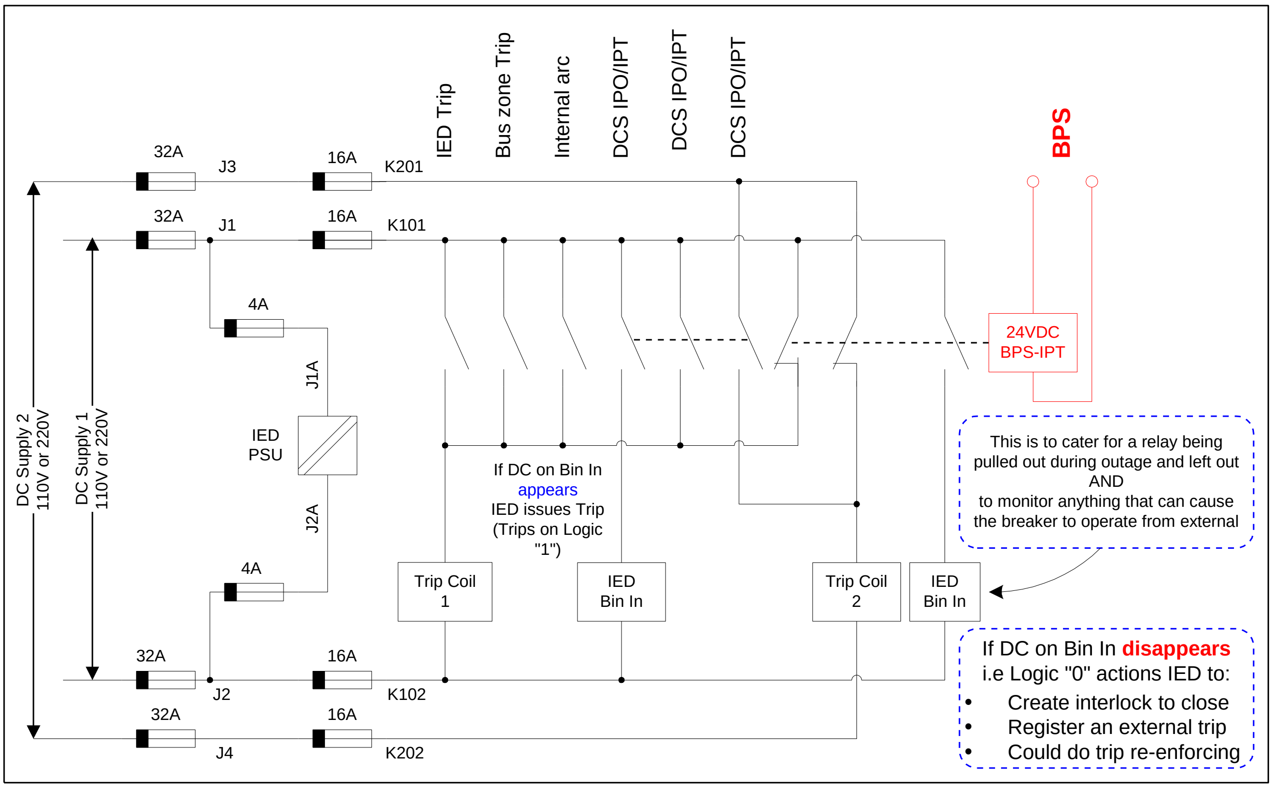

Figure 13: Simplified BPS-Switchgear interface (non-fail safe but redundant)

3.2.12 Interlocking principles

Electromechanical interlocking is integrated in the switchgear designs and resides within the primary and secondary plant. The switchgear is mechanically interlocked for safe operation as required in the MV switchgear standard, but for electrical interlocking, blocking magnets might be used (if provided) which are controlled by the IED within the same bay. The IED monitors the cable/busbar voltage and all other binaries e.g breaker status, earth switch status, isolator status etc, to ensure safe operating of the equipment is achieved at all times. When contacts of critical plant statuses are used, the double bit binary principle shall be applied where ever possible. Switch gear designs should cater for this requirement in future.

3.2.13 Setting principles

Before settings can be applied a proper power system analysis and modelling needs to be done. Fault calculations are done to:

- Establish adequate sizing of the operating and interruption parts;
- Define the thermal and mechanical stresses of the plant elements;

Once the primary plant has been selected the fault calculations are further used to:

- Calculate and select the protection system settings;
- Provide information for suitable protection for personnel and plant

Settings relates to all of the aspects of a well-engineered protection solution like:

- dependability,
- security,
- speed of operation and
- selectivity

Selectivity is probably top of the list when it comes to settings. This selectivity means that is has the ability to detect a fault within a specified zone of a network and to trip the appropriate circuit breaker(s) to clear the fault with a minimum disturbance to the rest of that network. By doing this it will ensure maximum availability of generating units while providing adequate protection against faults and/or abnormal conditions.

There are protection functions like under-voltage and frequency that are non-selective and their application needs to be considered carefully when applied to a protection scheme.

The security aspect is addressed by selecting setting values above the transient conditions which can occur in the network without requiring disconnection.

Settings shall take primary plant capabilities into considerations when calculations are performed. It is very important to protect an asset effectively and then look at selectivity and grading.

Alternative (adaptive) setting ranges can be considered if primary plant conditions can change.

The pre-fault voltage levels shall be considered when calculating protection settings. The effect of motors starting (including high efficient motors) shall be considered when calculating protection settings.

The basic and most wide spread setting principles are that of

- Definite Minimum Time over current
- Inverse Definite Minimum Time over current

These can be applied to directional and non-directional phase and earth fault protection. It may even apply to unit type protection and thermal protection in one way or the other. Both these principles tie into the two main criteria of time and current co-ordination or selectivity. Time to clear the fault current is crucial in correct protection co-ordination. Factors like CT inaccuracies, relay inaccuracies, breaker operating times, protection function pick-up and drop-off ratios and resetting times need to be considered to allow proper co-ordination to be achieved.

The golden rule to protection co-ordination is the bottom-up approach where the element furthest away from the source trips first and the protection at the source trips last. This has to be tested against the fault tolerance of any of the power elements in the circuit. The primary plant will always dictate if the protection may be applied as preferred. Protection engineering practitioners must never assume that the fault tolerance of primary plant has been chosen correctly. Always obtain the primary plant detail and cross check the data.

Other protection functions associated with voltage, frequency and temperature are used extensively too. With modern day processing power, the utilisation of sequence components, either as primary function or supervision function can be harvested to enhance the overall protection system. The use of this additional functionality normally does not require a lot of protection co-ordination and hence the focus in the next couple of sub paragraphs is on current functions.

3.2.13.1 DMT phase over current

DMT shall be set well above the absolute maximum current that may flow without any insulation breakdown but also less than minimum fault current that might flow with some high impedance fault. It is Eskom Generations philosophy to set DMT to 50% of prospective fault current for all circuits expect for motor circuits. A more conservative approach is followed in case of single motor feeders. The DMT is then set to 1.5 x maximum starting current to allow for inrush currents and this might even be delay for a couple of cycles.

3.2.13.2 IDMT phase over current

Inverse definite minimum time characteristics vary significantly. The most widely used in Eskom generation is the standard or normal inverse curve as defined by IEC 60255. It allows for a varying trip time depending on the magnitude of the current. Some advantages of using the inverse methodology is that plant faults could be detected sooner, it might clear faster than using definite time and it has some tolerance over transient conditions too.

IDMT is mostly used on transformer protection. It is a generally accepted norm to set the current pick-up of an IDMT function to between 1.5 and 2.0 times the rated current of the protected object. When used on a transformer where there is a direct online starting motor of significant size compared to that of the transformer, it might be required to change from one type of curve to another or even to introduce an additional definite time stage. It basically means that there is not a one size fits all approach that can be followed. This needs to be proven by superimposing the starting current of a motor on top of the base load current and compare that with the protection tripping curve/s.

To get proper co-ordination with downstream devices, a trip time margin of 250ms to 300ms is suggested and a minimum of 5% of rated current on the pick-up to be provided.

Care needs to be taken when definite time and IDMT are combined. Not all manufactures provides a minimum tripping time on the IDMT functions and then IDMT could operate faster than the definite time function.

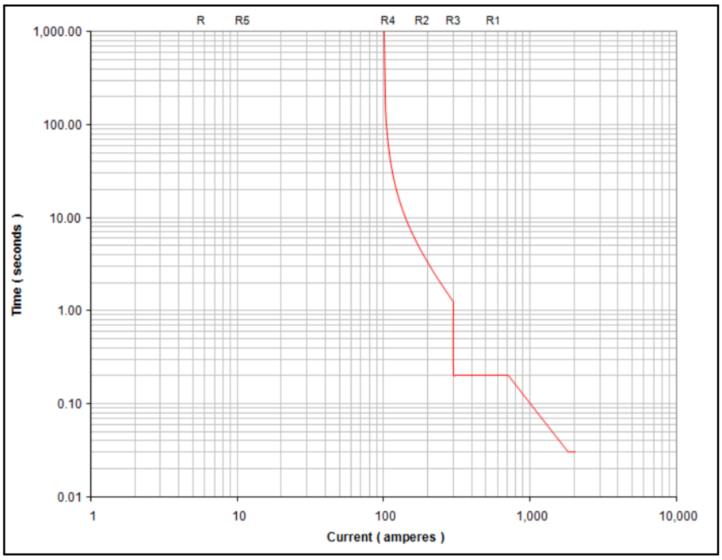

Figure 14: IDMT vs DT co-ordination without minimum tripping time set on the IDMT function

3.2.13.3 Definite time earth fault protection

In a power station no deliberate currents should flow in the earth mat of the power house because all loads are three phase balanced loads and all the star points of MV motors are floating. During phase to earth fault conditions, fault currents do flow though the earth connections back to the source transformers. There could be multiple paths for an earth fault current to flow back to the source. When the neutral is resistively earthed, the earth fault currents are typically limited to between 300A and 320A primary. This reduces the step and touches potentials significantly and reduces damage that can be caused in the plant and therefore the definite time approach is deployed here.

There is another school of thought that argues that single phase to earth faults develops into phase to phase faults or even three phase fault quite rapidly and the fault currents does not stay low for any significant length of time and therefore the tripping should not be delayed unnecessarily. The counter argument is that as soon as the earth fault develops into a multiphase fault the phase over current elements will detect it and trip faster than the original earth fault setting.

Protection operation thresholds for earth faults used to be set at 100A primary (<50% of prospective earth fault current) throughout the power plant and co-ordination was achieved through a pure time setting difference. The same approach still applies as it is believed that current produced by any of the MV voltage levels will reach maximum or close to maximum fault current virtually instantaneously.

In more recent times it was argued that some form of current co-ordination should be introduced because faults furthest away will have higher fault impedance due to cable lengths involved. This fact is acknowledged but it is still believed that the driving voltage is high enough to have negligible effect on the magnitude of the fault current far away from the source transformer compared to those faults close to the source.

To allow for some grading due to inaccuracies in measuring the earth fault currents, the protection operation thresholds may be set with some small current grading margin. These settings should never be below 20A to allow for any capacitive current from the extensive cable network to flow without disturbing the protection but at the same time it should not be set more than 50% of prospective fault current. Any earth fault current operating thresholds differences shall not exceed 10A primary from one setting to another.

On motor circuits the use of core balance CTs have allowed setting engineering practitioners to reduce the earth fault tripping times from typically 1.5s to 100ms and the sensitivity of the protection operation to as low as 5% of the protected object's nominal current, even for small motors. Core balance CTs only produces an output if the flux produced by the primary currents does not add to zero at any given point in time. When using the Holmgren connection method, "apparent earth fault currents" could be created due to CT performance inequalities such as different saturation levels and different secondary time constants. With a single core balance CT this is not the case anymore.

In the figure below a recording of a perfectly healthy motor under start-up conditions shows the summated phase currents compared to a single core balance CT output. Scales needs to be observed to appreciate the real difference between the signals. All signals are referred to primary values including the core balance signal.

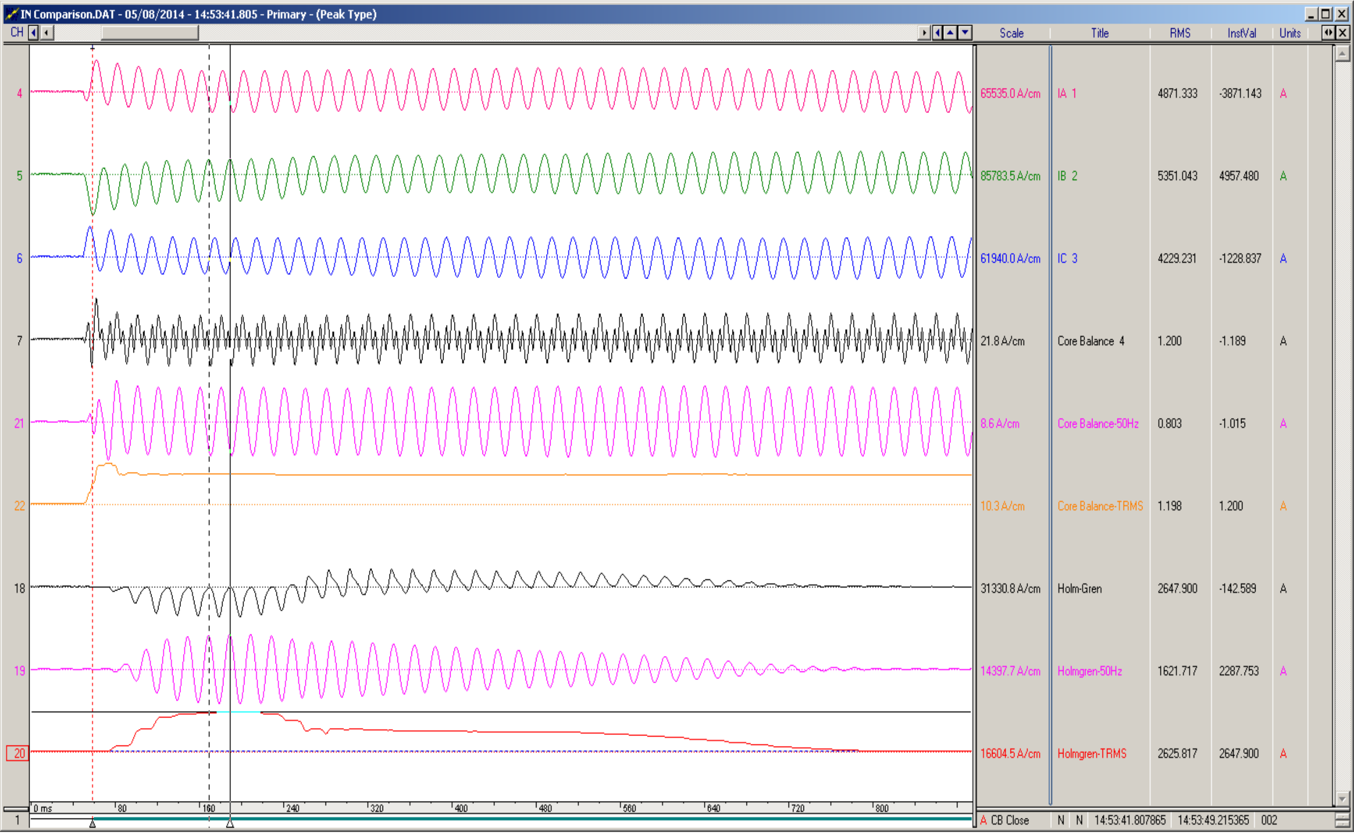

Figure 15: Holmgren vs core balance CT performance

Core balance CTs comes in all shapes and size and cater for most installations.

Figure 16: Samples of core balance CTs

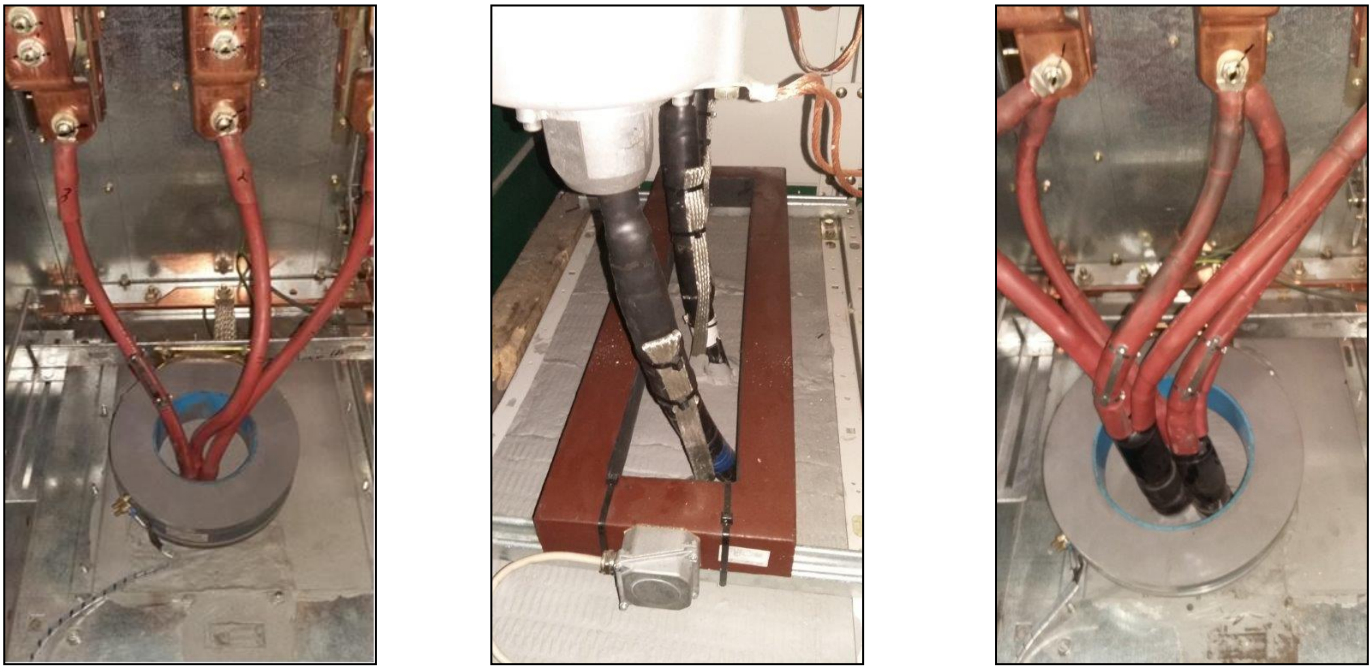

Figure 17: Examples of correctly installed core balance CTs

Figure 18: Example of INCORRECTLY installed core balance CT

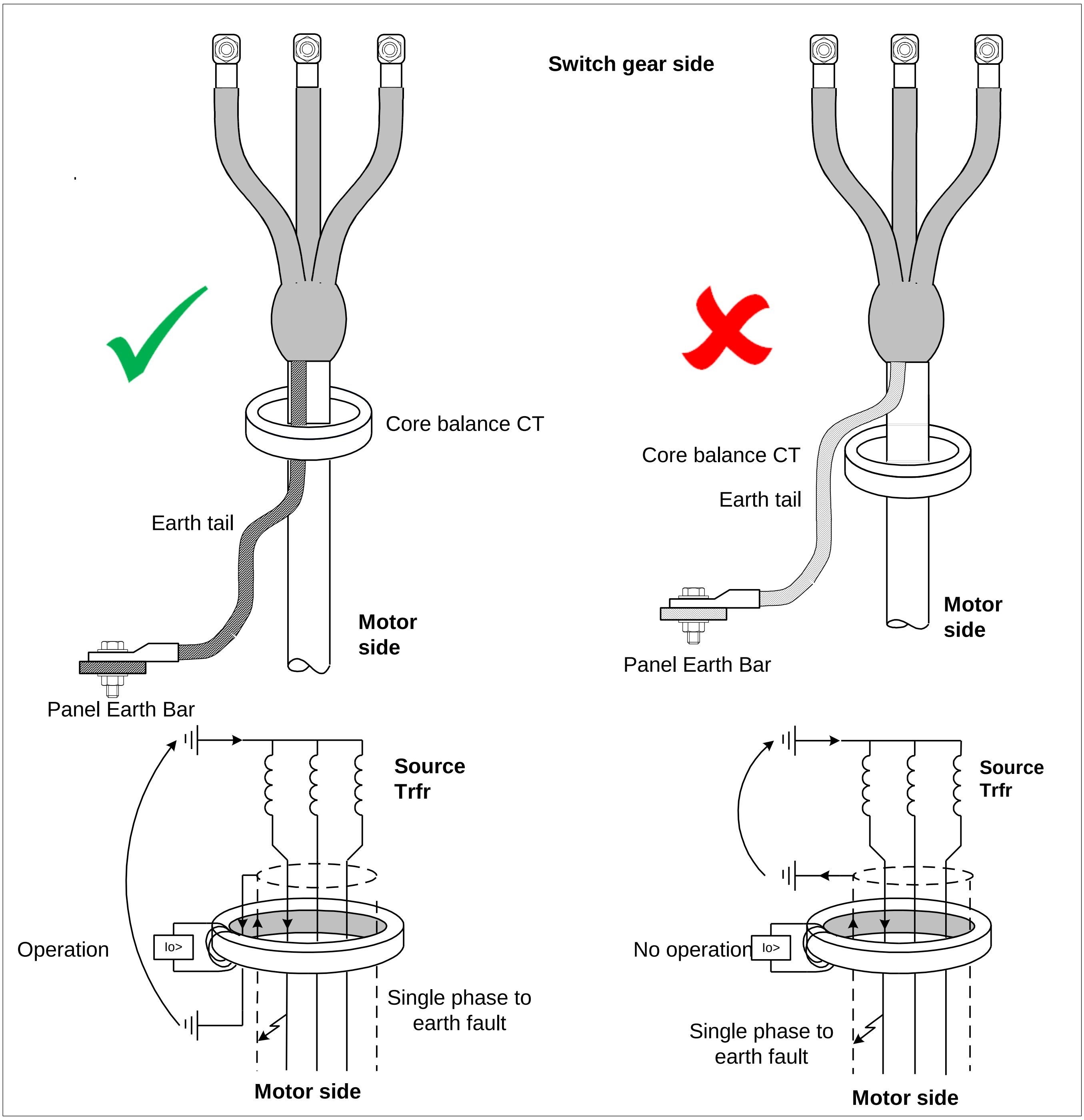

Figure 19: Core balance CT earth tail connection

When there are multiple loads supplied by a single transformer, as is the case in virtually all installations, an earth fault on one circuit can cause an earth fault trip on an adjacent circuit when the core balance CT is incorrectly earthed at the switchgear. This is due to current distribution that could take place in the sheathing of multiple cables and earth paths that are created. The return paths are not predefined routes as any and all conductors between the faulted point and the source can carry some current and the impedance of each path will determine how much current will flow in any branch. Therefore if the phase currents do not support the earth fault trip, it is very likely that the cable passing though the core balance is not correctly earthed at the switchgear.

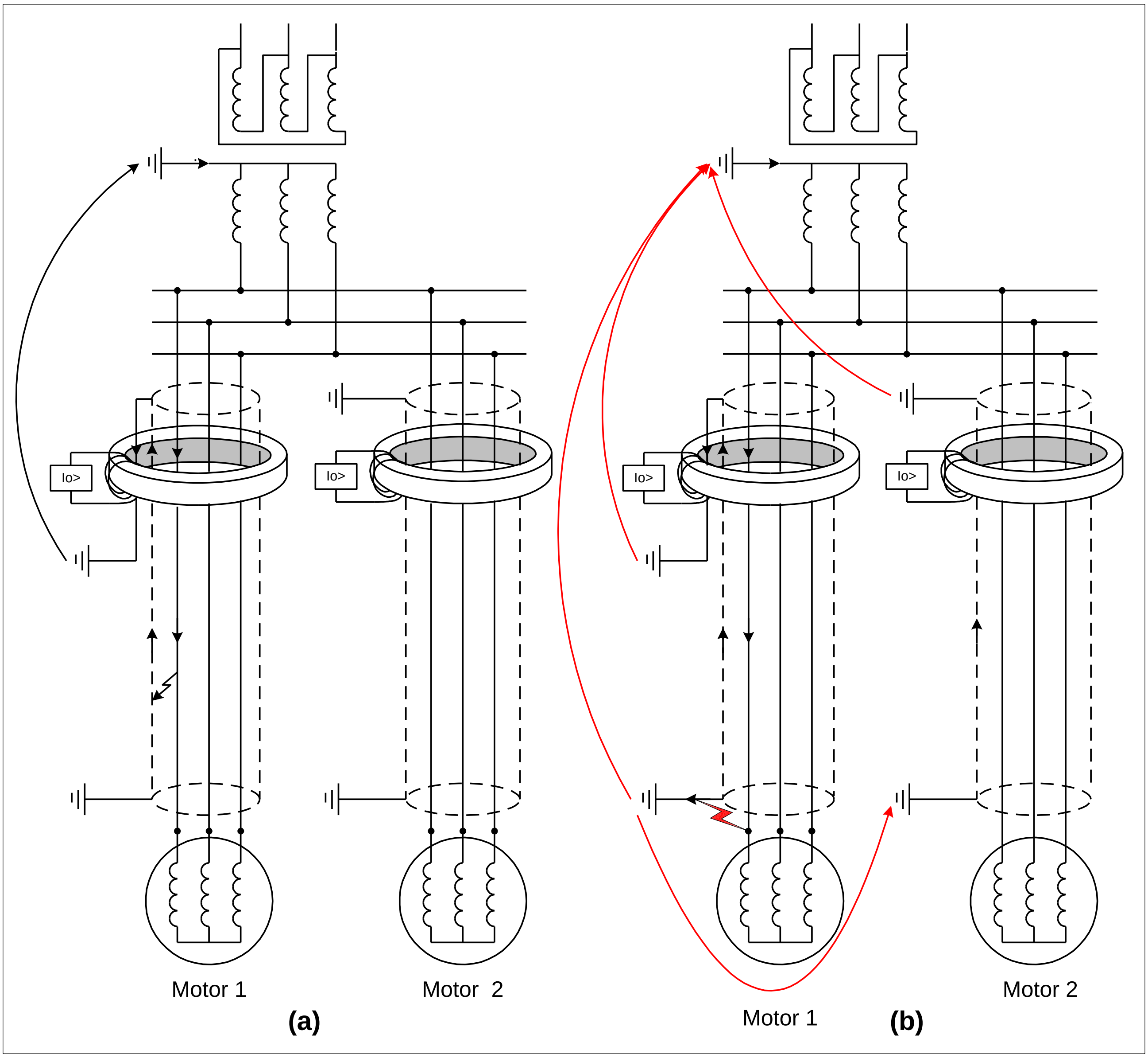

Figure 20: Earth current distribution for different faults

In the example above there are two motors supplied by a single transformer, both fitted with core balance CTs. The one cable is correctly earthed at the switchgear, the other not.

In Figure 20 (a) there is a fault between one phase and the sheath or armouring of a cable but not to ground. There is a well-defined path back to the source transformer and in this case the cable sheath is correctly connected at the core balance CT in the switchgear.

In Figure 20 (b) however a phase to earth fault occurs at the motor terminations and now current distribution takes place. Some current will flow back through the cable armouring or sheath, some current will flow through the earth mat back to the transformer and some current might flow through the earth mat to the adjacent cable's earth at the un-faulted motor and then through the cable sheath or armouring towards the switchgear and from there back to the source transformer. Both earth fault detectors could operate in such a scenario because of the incorrectly earthed cable at the switchgear of the un-faulted motor. Disturbance recording analysis is of the utmost importance to determine the correct/incorrect behaviour of the protection and the incorrect operation of the un-faulted motor protection due to the earthing error of the un-faulted motor.

3.2.13.4 IDMT earth fault protection

IDMT functions are applied to earth fault protection on systems with an effective (solid) earth connection. Current pick-up may vary between 10% to 100% of protected object's rated current but to remain below 50% of the minimum prospective fault level. Normal inverse curves shall be used except in exceptional circumstances. The extreme downstream circuit shall be set to 50ms. Grading margin shall be 250ms for numerical type equipment and 300-400ms for other types.

3.2.13.5 Earth fault protection using zero sequence voltage

A reticulation system, supplied by a single transformer with its neutral point earthed via a high resistance, demarcates an area in the power system and links it to that specific supply transformer. Should an earth fault occur with-in this demarcated area, the neutral displacement voltage will be practically the same anywhere within this area. The consequence is that the neutral over voltage (U_o>) detected by VTs anywhere with-in this area can only act as a general indication of an earth fault on its own. This is the same as the neutral over current element at the earthing point. It can detect the earth fault but cannot pinpoint its location. Obviously the U_o function can still detect an earth fault even without any zero sequence current flowing due to an earth connection forgotten after an outage or even due to copper theft.

Zero sequence over voltage functions has however several applications such as:

- Overall (area wide) earth fault protection (delayed)
- It could be used for blocking over current or can be used for directional functions
- It could be set to act as super sensitive high resistance fault detection
- It can be used as busbar protection where earth faults might not be high enough to operate a high impedance busbar scheme
- And it can be used as back-up protection for feeder protection functions

Zero sequence over voltage can be set quite sensitive in high resistance earthed systems. Literature sources indicate successful levels as low as 3%. Eskom Generation requires the setting to be a minimum of 5% and less than 30%. The time for it to operate will depend if it is used for alarming or for back-up protection.

3.2.14 Wiring and wiring identification requirements

Wiring and wiring identification shall be accordance to Eskom standard drawing 0.00/10341.

Alphanumeric ferrule codes are to be provided on all wires. Wires are marked on both ends with the same number. A wire adopting its termination point in a terminal rail as its wire number is not acceptable. When one wire has to move from one terminal to another the complete philosophy fails.

Ferrules with wire identification numbers read from left to right (the right way up) on vertical terminal strips and from top to bottom.

For control wiring, each wire tail is of sufficient length to reach the allocated apparatus plus an additional length of 500mm to facilitate changes in wiring. The slack appears as close as possible to the component in the form of a loop.

Wiring presents a neat appearance and is braced and placed in PVC trunking to prevent vibration and the possibility of forces being exerted on termination arrangements, no stick on plastic bracing supports are allowed.

Wires to plant and material on swing doors are so arranged as to give a twisting motion and not a bending motion to wires. It is required that robust wiring looms at doors are used with clamps on both ends (Clamp on the door and a clamp inside the panel.

Where this wiring is connected to current transformers, protection of the terminations is provided.

Control and power panel wiring sheaths are coloured as follows:

- Black for single phase AC circuits.
- Grey for DC circuits.
- CT and VT wiring are colour coded as per the phase - red, white, blue and black (neutral).
- Power 3 phase AC circuit wiring is colour coded as per the phase - red, white, blue and black (neutral).

Panel wire terminations to electronic cards from the back are permissible.

All cables cores are terminated on a terminal strip with panel wiring completing the circuit to the relevant interface.

Wiring in trunking occupies no more than 75% of the cross sectional area of the trunking.

Any wiring connected to AC and DC busbars has an insulation withstand capability of 10 times the rated voltage with a minimum of 2.5 kV over one minute.

There are specific rules governing the ferrule numbers for wires. A comprehensive list is available on Eskom drawing 0.00/10341 sheet 4. When dual DCs are involved the Main 1/Main 2 numbering principle shall apply.

3.2.15 Drawings

All drawings are created electronically and 100% compatible with Microstation software, the version will be stated in a technical schedule and must be in a DGN file format. All drawings are signed and the revisions noted as per Eskom specifications. The electronic file conforms to the requirements of Eskom Standard 240-86973501.

All drawings have the pre-approved title blocks and borders as provided by the Eskom standard 240-86973501, Engineering Drawing Standard – Common Requirements.

Graphical symbols used are in accordance with Eskom standard 36-946.

The set of drawings contain the following types of drawings:

- Cover sheet with legends, descriptions of equipment, etc.
- Index sheet
- General layout drawing of the panels and floor plan
- Single line diagram
- AC - schematic
- DC - trip schematics
- DC - close schematics
- Control schematics
- Completed cabling diagram with termination point
- Completed Bus wiring diagram
- IEC 61850 alarm/status/trip signals
- Panel internal wiring drawings, including cross referencing and wire numbers
- Cable block diagrams with both ends indicated
- Functional logic diagrams

Note: All spare inputs, outputs or any contact or spare hardware functionality (i.e. communication interface, etc.) to be shown on the drawings.

3.3 PROTECTION FUNCTIONS OVERVIEW

Table 6: Summary of Protection functions

	Sync Check	BKR Fail	IDMT O/C	DT O/C	IDMT E/F &/or DT E/F	DIFF Prot	REF	U/V	Motor Prot	Thermal O/L	Field Inputs	Bus zone	Internal Arc	DT U/C	Trfr Prot	Capacitor
	⑦	⑤	-	❶	-	❷		-	❼	-	❸	⑥	❻	③	①	④
MV Board		-	-	-	-	-		-	-	-	-	x	x	-	-	-
Unit brd incomer	x	x		x				-	-	-	-	-	-	-	-	-
Other MV incomer		x	x	x	x											
Loop type inc (0900)		x	x	x	x	x										
MV Maint isol(1400)	x	-	-	-	-	-		-	-	-	-	-	-	-	-	-
MV Bus sec (1400A) ❹	x															
MV brd trfr (0700)		x	x	x	x	x	x	-	-	-	x	-	-	-	x	-
MV brd trfr (1000)		x	x	x	x	-		-	-	-	x	-	-	-	x	-
MV brd motor <1MW		x	-	x	x	-		x	x	x	x	-	-	x	-	-
MV brd motor ≥1MW		x	-	x	x	x		x	x	x	x	-	-	x	-	-
MV brd to MV brd cable(0800) ❺	x	x	x	x	x	x		-	-	-	-	-	-	-	-	-
MV brd capacitor		x	-	-	-	-		-	-	-	-	-	-	-	-	x
Earthing resistor/trfr ②		-	-	-	-	-		-	-	x	x	-	-	-	-	-

NOTES:

❶ DT / Instantaneous over current is used on dedicated circuits and for bus zone and internal arc interlocking.

❷ Differential protection installed on incomers is the one side of pilot wire or transformer differential protection

❸ Thermistor type heat detectors are installed in MV motors and should be connected to the C&I (Control & Instrumentation) system for protection purposes.

❹ For the purpose of change over and alarming only i.e. interlocking or chop-over or indication

❺ Supply cable between MV boards and cables between the outside plant ring. Board to board feeders.

❻ Selective tripping is not necessary for Outside Plant and Common Plant boards. Installation of this protection is not compulsory for refurbishment projects but bus zone protection must then be installed as minimum depending on design of existing plant

❼ Protection includes as a minimum the following: Thermal overload, negative phase sequence, start-up supervision, stall (locked rotor)

➀ Power transformer protection includes as a minimum: Buchholz, PRD, oil and/or winding temperature devices

➁ Oil temperature protection on oil filled equipment only, thermal as part of transformer protection

➂ Motors for pumps and conveyers when applicable

➃ Protection includes as a minimum: Unbalance, cascading failure, instantaneous & definite time over current & earth fault, under current, over & under voltage and overload.

➄ As described in 4.1 and 4.2.2

➅ Switchgear type dependent. GIS and AIS might or might not require bus zone protection.

➆ Only if boards can be paralleled.

3.4 STANDARD PROTECTION SCHEMES

Protection schemes have been identified by an alphanumeric identification numbering system. This numbering system is a general scheme number and does not identify a manufacturer or any specific variation of particular scheme. It does not identify the IED nor does it prescribe how many IEDs are to be used to realise the scheme it describes. There are some schemes that require more than one IED to realise a fully functional protection scheme.

Table 7: MV protection scheme numbers

Alphanumeric number	Application
PA0100	Motor protection with current differential
PA0200	Transformer/Motor combination
PA0300	Power Drive System protection (VFD with transformer)
PA0400	Motor protection without current differential
PA0500	Power Drive System protection (VFD with transformer) and current diff
PA0700	Transformer protection with current differential
PA0800	Cable protection (end-to-end)
PA0900	Multi-point cable protection
PA1000	Transformer protection without current differential
PA1200	Incoming circuit protection
PA1400	Maintenance isolator
PA1400A	Bus section
PA1500	Diesel generator
PA1600	Biased Differential (Low Impedance) Buszone
PA1700	Busbar blocking

3.4.1 Busbar protection

Faults on a node within power systems subject the associated equipment to high fault currents, busbars to high mechanical stresses and it suppress the supply voltage to all feeders. It is therefore important to clear faults with-in the shortest possible time to reduce the risk to personnel and to reduce the damage to equipment in the switchgear arrangement.

Busbar protection can be achieved with bus zone or busbar blocking arrangements. Bus zone protection can be sub divided into high impedance or biased differential (low impedance) scheme. Each arrangement has its own limitations.

Bus zone protection is based on current differential measurement while a busbar blocking scheme requires a feeder to detect an over current (through fault) to block the incomer from operating. A lack of any feeder detecting an over current will lead to the incomer definite time to operate and to trip the incomer. If there are more than one point of supply like a “normal” incomer and bus section, the correct selectivity for detection and tripping needs to be carried out.

3.4.1.1 Bus zone (*PA1600)

Bus zone protection shall be provided on all MV Unit boards, Service boards, Station boards, Main outside plant/common plant ring boards and any board that could be critical to the power station operation. A fault level of more than 10kA may be used as guide to motivate the use of a buszone scheme. Installation of this protection is also dependent on switchgear plant design parameters, configuration and type tests which might include GIS applications too.

To comply with a basic, but very important protection principle i.e:

Each electrical fault in the power station medium voltage reticulation system must be detected by a main and at least one back-up protection function and clear the fault within the primary plant fault withstand capability.

Eskom Generation has decided to implement biased current differential (low impedance) bus zone schemes on any new plant or where switchgear and protection are replaced on existing installations. This shall be a fit for purpose device with inherent check zone capability.

The primary function of the bus zone scheme is busbar protection. It shall have no explicit time delay and shall operate within the designed parameters. Bus zone differential shall be deemed inadequate if protection operating times extend beyond 40 ms.

The secondary function of the bus zone schemes is to act as back-up protection to any feeder protection scheme for over current conditions. Modern bus zone IEDs have more than one DT over current function and these can be individually set to act as back-up protection for every feeder. This is especially useful where high ratio transformers are connected to the MV bus and their respective LV fault current, when referred to the HV side, does not even exceed nominal current of the associated main reticulation supply transformer.

E.g. for a three phase fault on the LV side of a 1600kVA, 11kV/400V, 5%Z, Dyn transformer , the referred fault on the 11kV side will only be 1680A maximum. This is within the load range of a typical 35MVA unit transformer with a LV nominal current of 1837A. If an IED on this particular feeder is non-operational, then there is no other protection that will detect this fault and catastrophic failures can happen. This is even worse for earth faults on the LV side when the HV side currents are only 57% of the current on LV side.

Consult the IED manufacturer for CT requirements/stipulation before CTs are ordered and installed in the switchgear.

3.4.1.2 Busbar blocking (*PA1700)

Busbar blocking schemes have been used for decades on non-critical substations in the industry. It is regarded as a cost effective solution providing accelerated tripping times compared to traditional time delayed trips. It behaves almost like a permissive scheme. It trips slower than dedicated busbar protection schemes due to the deliberate delays that are introduced on the incomer devices. It does however trip much faster than IDMT functions of incomers or upstream first line back-up protection.

Typical generation substations consist of two boards, each with its own incomer and then a bus section between the boards to enhance redundancy. Each board typically has many radial feeders. Generation substations are never operated with both the incomers and the bus section closed. The normal scenario is that each board is alive from its own incomer. If all the feeder circuits are equipped with over current devices, faults on the feeders can be detected milliseconds after fault inception. These over current detectors or starter elements then send a “block” signal to the incomer IED and blocks its definite time over current element which needs to be delayed long enough to allow starter pick-ups to relay the message to the incomer to prevent tripping of the incomer for “through faults”.

In principle it is a very simple scheme but the moment there are more than one source, a directional over current element needs to be installed on the bus section device at least. Once you have directional elements you need to have VT supervision too and then logic needs to be configured to block the busbar protection if the VT circuit is unhealthy. Directional elements are inherently slower than a simple current starter element and therefore the incomer over current element will required a slightly longer time delay before it can trip. The existing 4PA1400/schemes do not provide for any current measurements or protection requirements. New IED requirements for the 4PA1400 schemes will have to be compiled to deliver this functionality.

In the figure below the busbar blocking arrangement is graphically depicted. Zone 1 & 2 will be stable for faults A and C. Zone 1 will be stable for faults A, B and C. Zone 2 will trip the bus section for fault B.

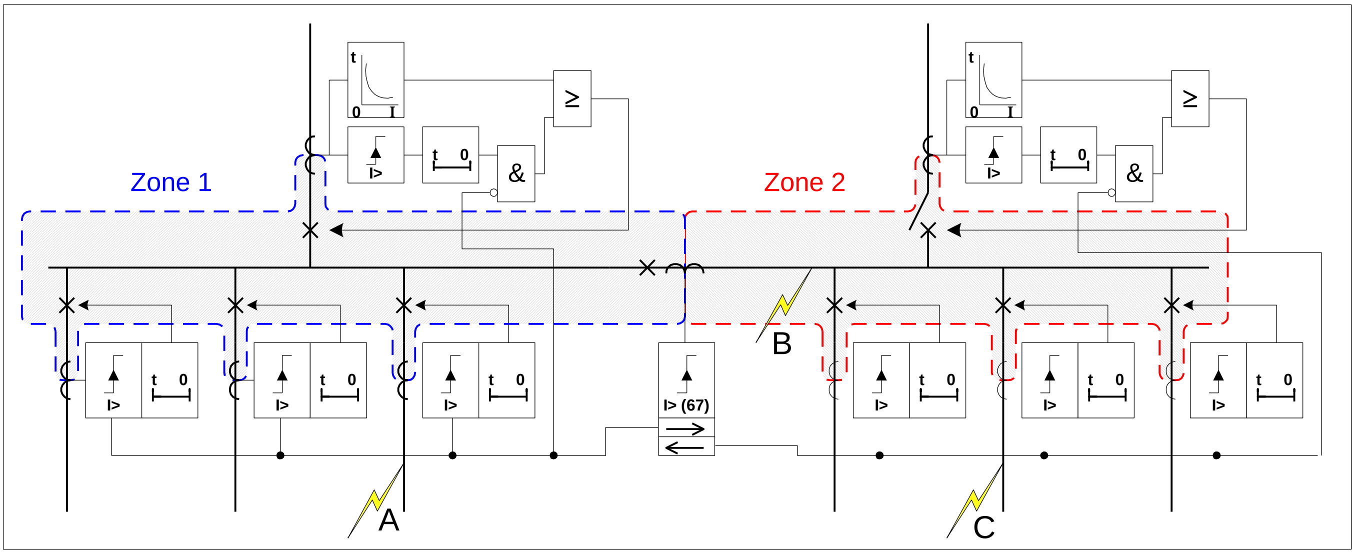

Figure 21: Typical busbar blocking protection scheme

Typical settings:

The setting for the over current pick-up on the incomer must be set to:

- I>> = max board load - biggest motor rated current + biggest motor starting current + margin.
- A short time delay on the incomer needs to be introduced to allow the feeder over current to pick-up and block the incomer before its time expires.

3.4.2 Arc protection

This is not necessarily a scheme on its own but is sometimes integrated in local IEDs. The function of the arc protection system is to perform the detection and high speed tripping of the supply circuit breaker in the event of a fault which is associated with an arc or a flash. The protection system protects the segregated sections which are the breaker, busbar and cable chambers/compartments. The arc protection also assists in localisation of faults associated with arcing in the conventional bus zone area.

This is unit type protection, instantaneous in operation, covering the breaker, busbar and cable compartments for arcing due to flashovers.

Arc detection is performed with light sensitive sensors located in the respective switchgear chambers installed to completely cover the protected area. The light sensors are installed in such a way that they are not triggered by external light sources such as camera flashes or welding arcs. The sensors are fitted to enable normal routine maintenance thereof as required. The installation also allows for routine switchgear maintenance without damaging the sensors.

Application of internal arc protection can be selective or non-selective and both can be current supervised or not. In Eskom Generation the internal arc protection system uses light sensitive arc sensors input and an over and/or earth fault current input from the board incomer or upstream current transformers to provide a two-out-of-two protection operation philosophy. Earth fault supervision may come from transformer neutral CTs. No operation is obtained if only the over current or the light detection input is received. This methodology, albeit noble, makes implementation extremely difficult if not almost impossible in the complicated loop supply topologies deployed at new power stations with multiple maintenance isolation boards.

Selective and non-selective tripping refers to the way tripping is executed based on light sensor information received.

In selective tripping, the sensors in the cable feeder compartments communicate an arc within its detection area and then a local unit to that panel will trip only that feeder, provided that an over current message from the incomer has been received as well.

In non-selective tripping any sensor detecting an arc will send this information to the IED on the incomer and trip the incomer if an over current had been detected too.

The internal arc protection system contains a self-diagnostic function that prevents the IEDs from operating if a relay/system fault is detected (including arc sensors input that are sustained) and clearly indicates with an alarm indicator the fault and the location thereof.

The trip relay output contacts shall latch after an operation until the reset function is operated

CT positioning for the current interlocking must be selected such that is does not to impair negatively on the functionality of the interlock, i.e. when upstream CT on the other side of a power transformer is utilised the vector group and earthing method must be considered.

The arc detection protection shall utilise breaker fail functionality.

NOTE: Selective tripping is not necessary for Outside Plant or Common Plant boards unless it can be motivated to reduce the risk of either a multiple unit trip, severe production losses or is a safety related case.

Typical settings:

- Over current check = Pickup level shall be set to 1.1 x highest prospective load current. This shall include motor starting current
- Earth fault check = 0.2 - 0.5 x fault level for high resistance earthed systems
  1 x rated current for solidly earthed systems
- Circuit breaker fail = 0.15 s

3.4.3 MV incomer (*PA1200)

MV incomers are minimalistic with respect to protection functions. It basically requires over current and earth fault protection from a protection detection perspective. It goes without saying that breaker-fail and trip circuit supervision needs to be included too. As part of the extended functions as discussed earlier in this document, the incomer IED also needs to be able to perform synch check to facilitate the chop over functionality. Three phase voltage measurement is therefore required to be used for chop-over/synch check/transfer schemes and as $3I_o$ supervision and back-up protection when a primary earth is not connected to the transformer. The latter is highly recommended due to increasing copper theft of transformer earths. The same scheme could be required to participate in a busbar blocking scheme and the number of over current elements needs to be confirmed to comply with a particular design.

3.4.3.1 Phase over current

Phase over current is divided in short time definite over current and inverse definite minimum time over current protection.

Over current protection is required to isolate the busbar and/or the incomer breaker in the event of severe overloading due to a downstream fault. It could also serve as a back-up for busbar protection in the case of a busbar fault, should the bus zone protection or arc protection fails. This protection is classified as back-up protection and shall be of the inverse definite minimum type characteristic. Normal IDMT (IEC60255) shall be selected as the preferred characteristic unless healthy plant operation requires this characteristic to be different, like EFP starting. Such big motors might require trip times longer than the general philosophy requires. It might even be required to make use of an extra definite time characteristic to protect the plant better. Protection settings shall be based on transformer through fault capabilities and consider busbar and breaker ratings too. The type of transformer will also dictate, from a damaging curve perspective, how the settings shall be applied. Because IDMT over current is not an overload type protection but used for faulted conditions, the pick-up shall not be set less than 1.5 pu of transformer rating but also not more than 2.0 pu of transformer rating. Deviation from this setting range must be properly motivated and their impact and transformer life clearly indicated.

Instantaneous (short time definite time) over current is NOT generally used for tripping, but may be utilised for busbar protection over current check if required or where a busbar blocking scheme is used. It could however be used with caution to augment the protection performance when very high starting current motors are used and additional steps in the grading curve will allow the motor to start but also trips in an acceptable time when there is a fault. To achieve this goal, the over current function shall have an adjustable minimum tripping time setting. Without this minimum tripping time setting, additional logic will have to be compiled and this is not ideal.

The figures below indicate how additional definite time over current functions can improve the tripping characteristic for a unit board incomer with a large DOL starting motor.

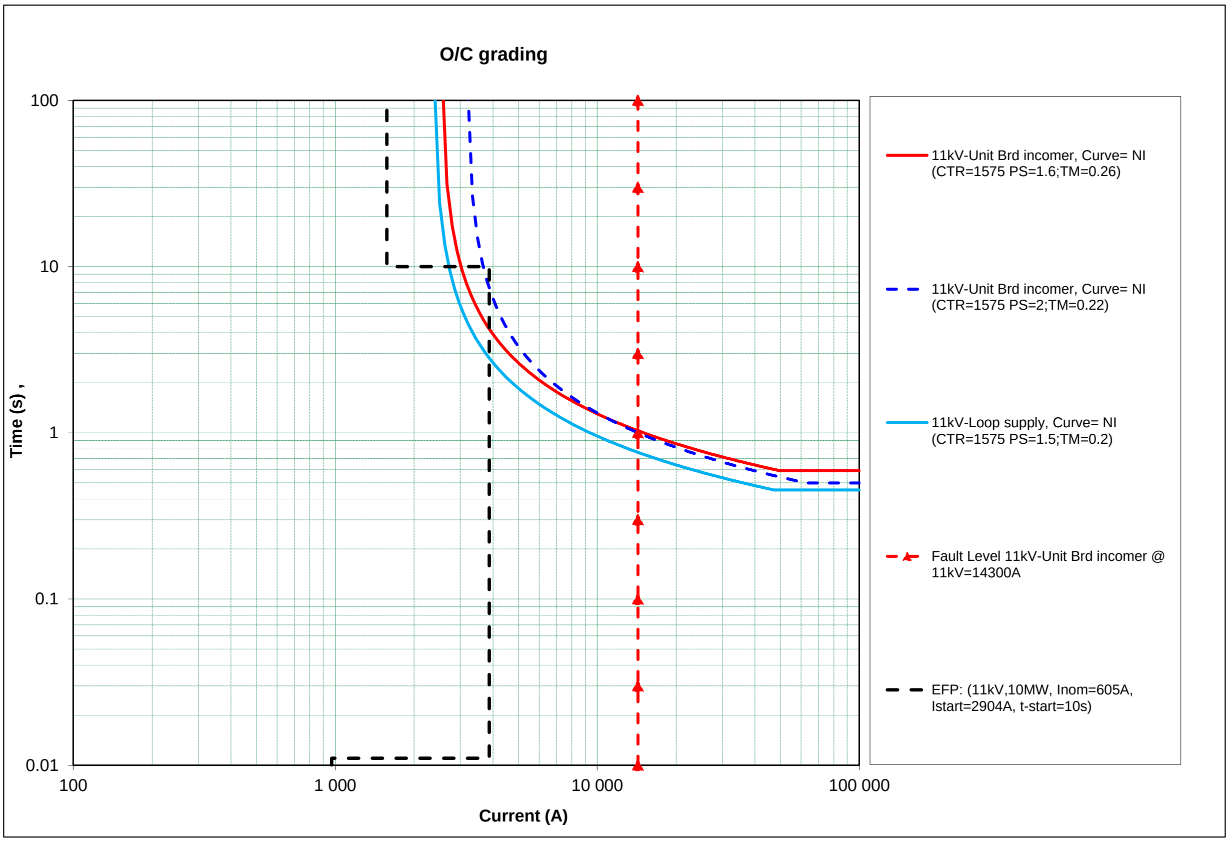

Figure 22: IDMT alone inadequate for grading

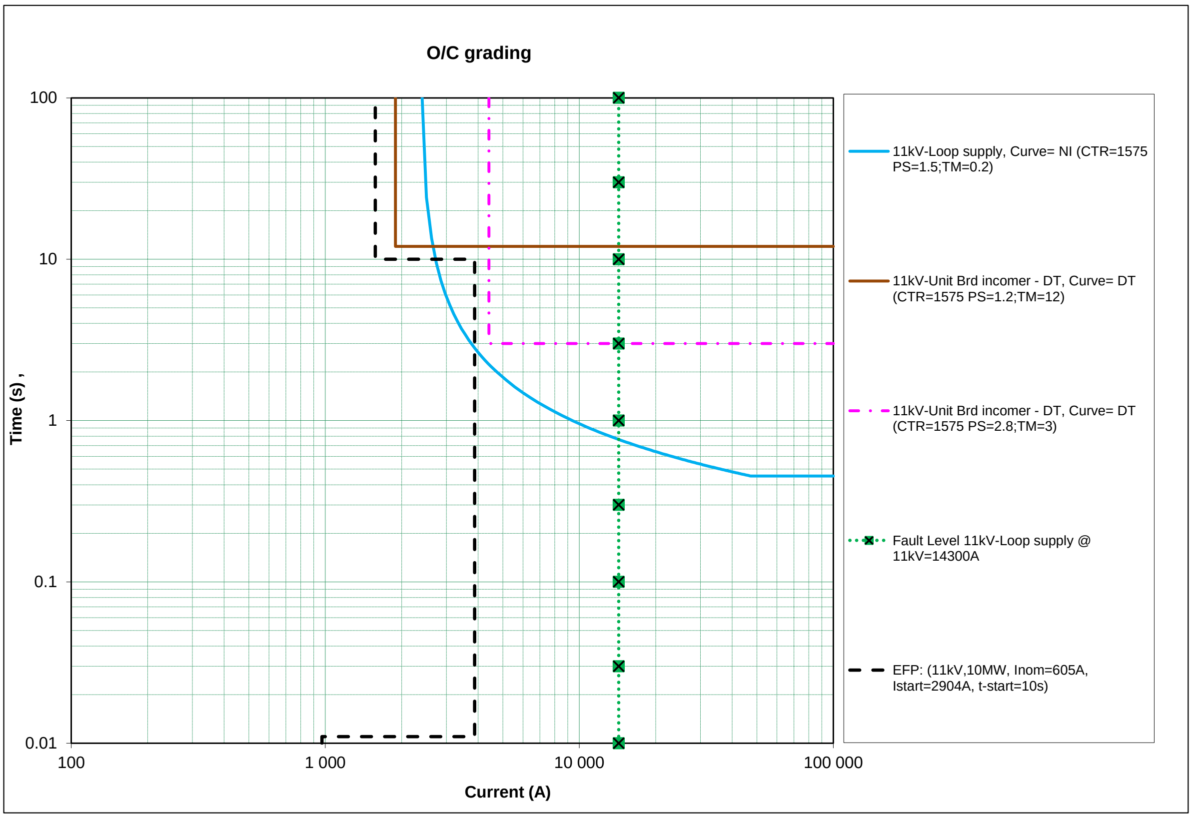

Figure 23: DT alone can achieve grading but not best protection

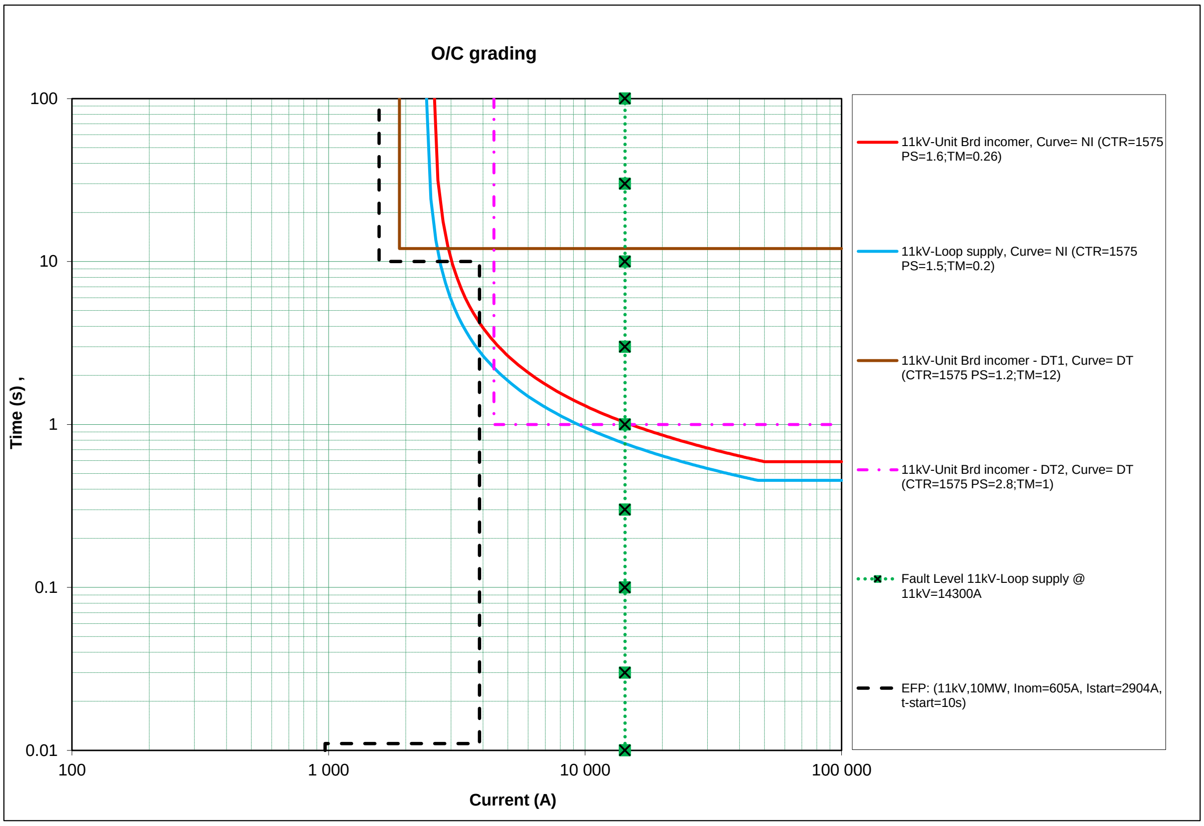

Figure 24: IDMT combined with DT achieve best outcome

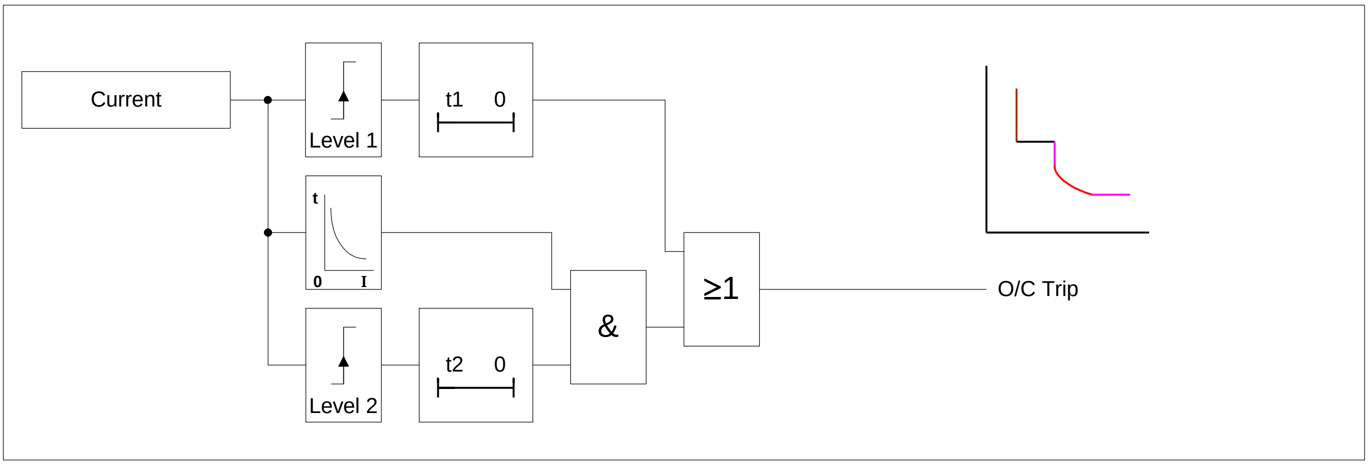

Figure 25: Logic to combine IDMT with DT

Note: Phase over current protection on unit board unit transformers incomers may be disabled when two winding unit transformers are used because the generator protection uses the unit transformers' HV CTs as back-up and there is a full Main 1 and Main 2 applied. If it is to remain on these circuits, no additional current or time grading are required between the incomer and the generator protection.

3.4.3.2 Earth fault protection

Earth fault protection is required to isolate the busbar and or the incomer breaker in the event of phase to ground faults.

Two types of characteristics are used:

- Definite time for resistive (compensated) earthing.
- IDMT (normal inverse) for solidly earthed systems

Where high resistance earthing is used on the transformer neutral, a neutral CT is normally used for earth fault detection. The neutral CT is normally wired to the supply side IED of the transformer and not the load side where the *PA1200 scheme is used. To enhance protection redundancy, the incomer CTs utilises the Holmgren connection principle at the incomer IED. As described earlier, the Holmgren connection has proven problematic on high resistance earthing circuits during transformer energising or motor starting. To safe guard against unnecessary trips due to an unbalance in the primary supply currents or due to CT performance, the $3I_o$/4th wire measuring methods shall be supervised with a U_o measurement. U_o measurement is dependent on the type of VTs. It must either be a 5-limb VT or three single phase VTs. Correct earthing of the VTs is essential for correct zero sequence voltage supervision. The alternative is the use core balance CTs.

When the primary earth connection is interrupted (copper stolen or not connected after an outage) neither of the current measurement techniques can detect an earth fault due to a lack of a current path. This condition however does raise the voltage on the un-faulted phases with √3 between phase and earth. Another earth fault on a second phase will then lead to a phase-to-phase fault. Using the zero sequence calculated voltage; a delayed trip can be applied as back-up protection and may safely disconnect the plant before any subsequent fault can develop.

To circumvent the Holmgren connection causing false trips for resistor flashovers and giving rise to high earth fault currents, the IDMT principle may be applied.

Typical settings:

- When compensated earthing is used, grading is predominately based on time only although it is good practice to allow about 10A primary grading between two sets of protection settings to cater for CT and IED accuracies.
- Due to the large number of board-to-board feeders in the common plant area, care should be taken not to exceed 50% of prospective earth fault current at the last protection IED before the transformer. Time grading shall be based on the type of measurement of the earth fault currents.
- Because the 4^{th} wire connection and the $3I_o$ calculated value configurations are prone to exhibit higher and longer than actual zero sequence currents under transients when transformers or motors are energised, it is suggested to have time grading of 500ms between protection IEDs.
- When a solidly earthed system is used to supply the load, the IDMT pick shall be 20% of full load current of the supply transformer and a time grading of 250ms shall be allowed between two sets of IEDs
- High set over current (compensated earth) = 2 x restricted fault current (Protection in the case of resistor flashover)
- Time delay for I>> = 0.05 when supervised else 250ms
- Zero sequence over voltage > = 5% to 30%
- Time delays for Uo> trip (as back-up) = 5s
- IDMT pick-up for resistor flash-over = 50% of In of transformer
- IDMT trip time = 100ms to 250ms at maximum prospective fault current

Note: Earth fault protection on unit board unit transformer incomers may be disabled when two winding unit transformers are used because the generator protection uses the neutral CT already and there is a full Main 1 and Main 2 applied. The neutral CT quantity is required when internal arc is installed on high resistance earthed systems. This will require CT cabling to be rerouted though the unit board before going to the generator protection.

3.4.3.3 Synchronism check

The primary plant is designed to have the correct phase angle displacement to allow certain parts of the plant to be energised from different sources without severe consequences for the energised plant when changing over from one source to another. These sources are non-rotating plant so the angle difference between two circuits can only be attributed to the loading on the respective sources of supply to the point of connection in question.

The only reason for having the synchronism check would then be to prevent paralleling of sources with a load angle that could produce large circulating reactive current and phase shifts in rotating plant like motors. The bigger the load angle, the larger the phase shift will be that the motors will experience and the larger the re-synchronising current would be.

Sensitivity of VSDs to vector jumps of this nature is not well documented and synchronism might become more of a requirement if this is really an issue to the VSD monitoring.

Synchronism check functions built into the IEDs invariable has additional benefits like dead bus charging, dead line charging etc. These come in very handy to ensure safe chop overs can take place.

Typical settings:

- Paralleling time = 1s

Depending on the protection supplied with diesel generators certain incomer protection might require not only synchronism check but a synchroniser as well. Each project shall cater for these requirements via the technical specification.

3.4.4 MV Bus Section (*PA1400)

The Bus section shall be equipped with a bay controller for controlling both bus sections and for software interlocking between a bus section and the two incomers.

A synchronism check facility is required on the Unit boards as described in paragraph 3.1.2.

Hydro and pump-storage plants use under voltage as part of the auto-change over, load shedding and diesel generator/rural supply applications during blackouts.

3.4.5 Maintenance Isolator (*PA1400A) (where applied)

The Maintenance isolators shall be equipped with a bay controller for controlling the maintenance isolator breaker and software interlocking.

No synchronism check facility is required.

3.4.6 MV motor protection

Eskom Generation has taken a decision to add current differential protection on motors of 1MW and larger. This is the only protection function that is additional to other motor protection schemes.

3.4.6.1 Motor protection (*PA0400)

3.4.6.1.1 Over current protection

This protection shall be provided on all MV motors.

Over current protection shall be applied irrespective of size and earthing arrangement and is restricted to definite minimum time functions. At least two such functions need to be provided to allow once stage to be used for motor over current protection and the second one as part of the busbar blocking arrangement (if required).

On motors, over current protection operates for phase-to-phase faults. This is a high set definite time function in the IED. It has to be set higher than the starting current of the motor under highest voltage conditions and any inrush currents and the time longer than the transients of such a starting condition. The IED has to have two DT over current functions.

The practice of using settings below starting currents, due to the start current modifier parameter facility in some motor protection schemes, is to be discontinued on motors with high inertia loads, e.g. motor driving big fans. This is due to the fact that these motors draw very large currents caused by transient slips during generator load rejection or under large phase shift conditions related to bright chop overs.

Typical settings:

- Over current pick-up 1 = 1.5 × starting current
- t1>> = 0.1 s
- Over current pick-up 2 = 2.0 × starting current
- t_2>> = 0.02 s

3.4.6.1.2 Earth fault protection

This protection shall be provided on all motors

On motors, earth fault protection operates for single phase to earth faults. This protection does not have to grade with anything but normally has a short time delay to prevent mal-operation due to third harmonics during motor starting and even CT performance creating a virtual zero sequence component. On resistance earthed systems the earth fault currents are limited to typical values of 300A but on solidly earthed systems on the common plant area this can be many thousands of amps. On traditional residual connections (Holmgren-connection) a stabilising resistor was installed to dampen the effect described above. This was more prevalent on high resistance earthed systems. The use of the same resistor damping (stabilising) circuit on solidly earthed systems could lead to lethal voltages building up at the back of an IED and are not practised anymore.

To overcome all the issues described above, Eskom Generation has decided to use core balance CTs on motor circuits.

Typical settings:

On solidly earthed systems without core balance CT:

- IDMT current pick-up = 0.1 to 0.4 x rated current of protected object
- Trip time = 0.1 s

On resistance earthed systems without core balance CT:

- DT Current pick-up = 0.1 to 0.4 x fault current
- Time delay = 0.5 s

With core balance CTs installed, the earthing method does not play a role in the type of protection (IDMT or DT) as in the past. Only DT shall be used with following settings:

- DT current pick-up = (Min of 10A primary on compensated earthed systems and not more than 20% of rated current of the protected object
- Trip time = 0.1 s

3.4.6.1.3 Thermal protection

This protection shall be provided for all motors.

Thermal over load protects the motor from overheating which could lead to premature insulation ageing and even breakdown of insulation. This is not only for the winding but also for the lamination insulation.

Thermal overload protection function monitors the currents flowing into the motor. Based on these currents, the protection, in its simplest form, models the temperature inside the motor. The maximum thermal capacity of a motor is expressed as 100% in such a thermal calculation. Once it reaches this limit, the motor protection will issue a trip. It must be stressed that this calculation is based on current measurement and not the actual temperature of the motor. If the motors are provided with extra separately supplied cooling fans, additional protection must be enabled to cater for loss of external cooling. The default cooling for large motors used in industry (power stations too) is by means of shaft mounted fans and therefore only provides "forced cooling" when the shaft is turning.

Motor full load current is invariably rated at an ambient of 40^{o}C. If a motor therefore operates at elevated temperatures the motor needs to be de-rated accordingly. The opposite is also true.

IEDs available today can do the appropriate temperature compensation when an external temperature sensor is connected. Eskom generation do not make use of these external sensors due to reliability issues. A minimum ambient temperature of 40^{o}C will therefore always apply and if ambient exceed 40^{o}C, conscious upfront intervention through the calculations needs to be taken.

Thermal algorithms differ quite radically from OEM to OEM and therefore the settings shall be calculated based on the OEM application notes. One example is the inclusion of NPS into the thermal algorithm. The thermal calculations not only base its outcome then on the simple current magnitude but can also add any negative phase sequence component to it. This is the preferred way for all motors regardless of the fact that there might be a separate NPS functions in the scheme too.

The thermal protection shall include a value to alter the service factor of the motor too as this influences the thermal pick up of the protection function.

As an early warning to an operator the thermal function shall have a current setting to warn an operator of an imminent thermal trip. It might be in the operator’s control to reduce the mechanical load and therefore prevent a thermal trip. Although these kinds of alarms appear quite useful and legitimate, they can cause unnecessary actions on the automated control system side. Both electrical and control system engineering practitioners need to ensure that some “innocent” alarms does not have a ripple effect of switching the automated system to manual control.

Typical settings:

- Thermal overload = 1.05 to 1.15 x full load current. (Guided by motor service factor and IED algorithm)
- Number of starts per hour = 2 or 3 (OEM data)
- Cooling time constant = 4 to 20 x heating time constant.
- Starting time = 1.1 x measured starting time under low voltage conditions
- Prior thermal alarm = 0.95 pu (unless the motor really operate at or close to 1pu of its rated value - plant specific)

Note: Thermal trip has to be set to auto reset.

3.4.6.1.4 Negative phase sequence protection

This protection shall be provided on all motors.

Negative phase sequence currents result from asymmetrical faults or unbalanced system conditions. The worst and the most common cause of negative phase sequence is the disconnection of one phase (single phasing).

Negative phase sequence protection safeguards the motor rotor against overheating caused by the induced double frequency (100 Hz) currents when negative phase sequence currents are present in the stator.

The negative phase protection has an inverse time characteristic as well as a definite time characteristic for single phasing.

Negative phase sequence protection on motors must be graded with the generator negative phase sequence protection and for this reason current unbalance shall not be considered. It is important in protection schemes, that supervises motors and are part of the unit auxiliaries, that there is grading between the generator and the motors. The motors should never trip faster than the generator for NPS current imposed by the external network. Generally the maximum continuous NPS current that an induction motor can tolerate exceeds that of a synchronous generator by far.

Eskom Generation philosophy requires an inverse curve.

Typical settings:

- I2 IDMT current pick up = 0.1 to 0.3 x full load current (OEM)
- Motor NPS time constant = 0.1 to 0.5
- Single phasing time = 1.0 s
- Maximum trip time = more than generator time
- Minimum trip time = 3.0 s

3.4.6.1.5 Locked rotor / Stall protection

This protection shall be provided on all motors.

Locked rotor condition occurs when voltage is applied to the stator and the rotor remains stationary. This is sufficient when the maximum stall time is larger than the starting time of the motor. When large inertia loads are driven by motors there are numerous cases where the starting time exceeds the stall time of the motor. If the locked-rotor/start-up supervision is than based only on the stall time it will lead to premature tripping. Due to the fact that the rotor is connected to a cooling fan, the motor is actually cooled by the fan and hence can tolerate a starting time longer than stall time. When this motor is however in a real locked rotor condition the motor can thermally be damaged before the protection trips. A speed switch is then required to “override” the possible premature tripping based on a time only (I^2t) function.

Typical settings:

- Current pick-up = $\frac{\text{Lock rotor current} - \text{Rated current}}{2}$
- Time delay = Stall time of the motor

3.4.6.1.6 Start-up supervision/Cumulative Start-ups (Number of starts)

This protection shall be provided on all motors.

There are different definitions for start-up supervision but this document distinguishes between locked rotor and cumulative start-up supervision. Cumulative start-up supervision shall protect the motor against exceeding the number of starts it can tolerate. It shall take into consideration the motor’s immediate loading history when calculating the thermal image. Factors influencing this are, motor currents before shutdown and whether the cooling fan is shaft mounted or separately driven for instance. The algorithm shall then predict if more starts can be tolerated without exceeding the thermal capability of the motor. Not all algorithms in the industry has been developed the same. Those that take rotor local over heating into consideration shall be given preference to ones that don’t.

Cumulative start-up supervision shall have the capability to set a minimum time before a motor can be re-started regardless of its thermal capability to allow the back emf on large inertia load connected motors to subside below a threshold that is safe for the motor to be re-started. If the back emf is still large, excessive currents can be produced upon restart causing possible mechanical damage to the motor or its coupling.

Cumulative start-up supervision shall not be configured as a trip but act as an interlock in the close command logic i.e. when it exceeds its threshold it will only block the next start-up and shall not cause a trip.

Typical settings:

- Minimum time between starts: 10s to 20min
- Maximum number of starts: As per motor OEM / Eskom motor standard

3.4.6.1.7 Load/mechanical jam

This protection shall be provided on all motors.

The load jam protection does not protect against locked rotor conditions during starting but rather when the motor is forced to an abrupt halt due to a mechanical failure of the driven component. It can be an impeller blade that had broken off and caused a sudden stop of the motor etc. It is therefore required that this protection be blocked during start-up.

Care should be exercised when applying a time setting. High inertia loads can take a considerable time to track the generator frequency following a load rejection, and under these conditions starting current might be drawn by the motor. This needs to be set less than the hot locked rotor time.

Typical settings:

- Current pick-up = $\frac{\text{Lock rotor current under minimum voltage condtions} - \text{Rated current}}{2}$
- Trip time = 3.0 s, provided that it is less than hot stall time

3.4.6.1.8 Phase rotation detection

This function shall be provided on all motors on coal-fired plant. Where reversing motors are installed, like on some hydro/pump-storage plant, this function is not required because direction checking is done elsewhere.

Phase reversal function is primarily used to protect the driven load from damage due to incorrect shaft rotation. Shaft mounted fans are also designed to rotate in a specific direction and if the shaft turns the wrong way, the cooling of the motor can be jeopardised. Phase reversal can happen if the phases of a cable supplying a board or connection at the motor had been swapped around.

Because most IEDs only have current as a measuring quantity for the phase rotation function, it will be the default technique to trip the motor to prevent any possible damage. Where possible, phase rotation may be supplemented with a busbar voltage measurement and can then be used as an interlock to close.

Typical settings:

- Time delay (current) = 0.5s

3.4.6.1.9 Under voltage

This protection shall be provided on all motors.

Three phase under voltage protection connected to the busbar VT shall trip all motor feeder circuits if an under voltage condition occurs. Voltage transformer supervision protection shall be provided to block a under voltage tripping if ***any*** number of phases are lost due to secondary circuit errors.

Under voltage is required to prevent re-energisation of motors while still running down and causing shaft line overstressing. The under voltage is required to detect a “dead” busbar (all three phases below set threshold) to trip all the motors on the board. This will prevent overloading and tripping of upstream circuits due to multiple motors re-accelerating simultaneously.

A three phase fault will trigger the under voltage but due to the definite time delay setting that is longer than the longest anticipated fault clearance time it will not trip during three phase faulted conditions.

Voltage connections shall be phase to neutral connection to enable more distinctive measuring of phase quantities and fault recorder analysis. The HV and LV neutrals of the VTs shall be earthed and the voltage factor shall conform to a minimum of 1.9.

Power stations fitted with variable speed drives may require an under voltage starter element to be made available to the unit control. The unit control on power stations fitted with drives requires this “Voltage dip detected” to enable drive restarts under momentary voltage dip conditions.

Hydro and pump-storage schemes use under voltage as part of their change-over functionality and more than one set of timers might be required to allow for fast supply restoration.

Typical settings:

- Under voltage = 0.7 x nominal phase-neutral voltage
- Time delay = 3.0 seconds. (Peaking plant to be set to application requirement)

3.4.6.2 Motor protection (P≥1MW) (*PA0100)

The *PA0100 scheme comprises of the exactly the same functionality as the *PA0400 with the addition of current differential across the motor for motors of 1MW and larger. The *PA0100 scheme may consist of one or two IEDs.

3.4.6.2.1 Motor current differential

This is unit type biased differential protection, with no deliberate time delay in operation, protecting the motor and its connecting cables for phase-to-phase faults between the switchgear and the star point of the motor. Operating times longer than 40ms shall be deemed inadequate and not be allowed.

Typical settings

- Motor differential = 0.1 to 0.5 × full load current

3.4.6.3 Transformer/Motor combination (*PA0200)

There are a number of installations in Eskom Generation where a single DOL motor is connected to a single transformer. This is predominantly to minimise voltage drop over long cable runs and to reduce the size of cabling required. The protection used for this configuration is a combination of conventional motor protection and that of a transformer protection. The scheme is then configured with any number of IEDs to provide proper motor protection as per *PA0100/0400 **and** proper transformer protection as per *PA1000/0700. The newly created scheme could then either be a combination of a *PA0400/1000 or even a *PA0100/0700. The size of the motor and/or transformer will dictate which combination will be required. This could be a single or dual IED installation. The requirements and settings are as per standard motor and transformer protection schemes.

3.4.6.4 Motors fitted with electrical variable speed controllers (*PA0300)

Variable Speed Drives (VSDs), also known as Variable Frequency Drives (VFDs) or Variable Voltage Variable Frequency (VVVF) drives, are gaining popularity to control the speed of shafts in a variety of processes. This could be applied to fans and pumps alike.

The entire configuration constituting a total variable speed drive system is defined as a power drive system and is functionally depicted below in Figure 26 and it is redrawn from IEC 61800-4, Adjustable speed electrical power drive systems - Part 4[11].

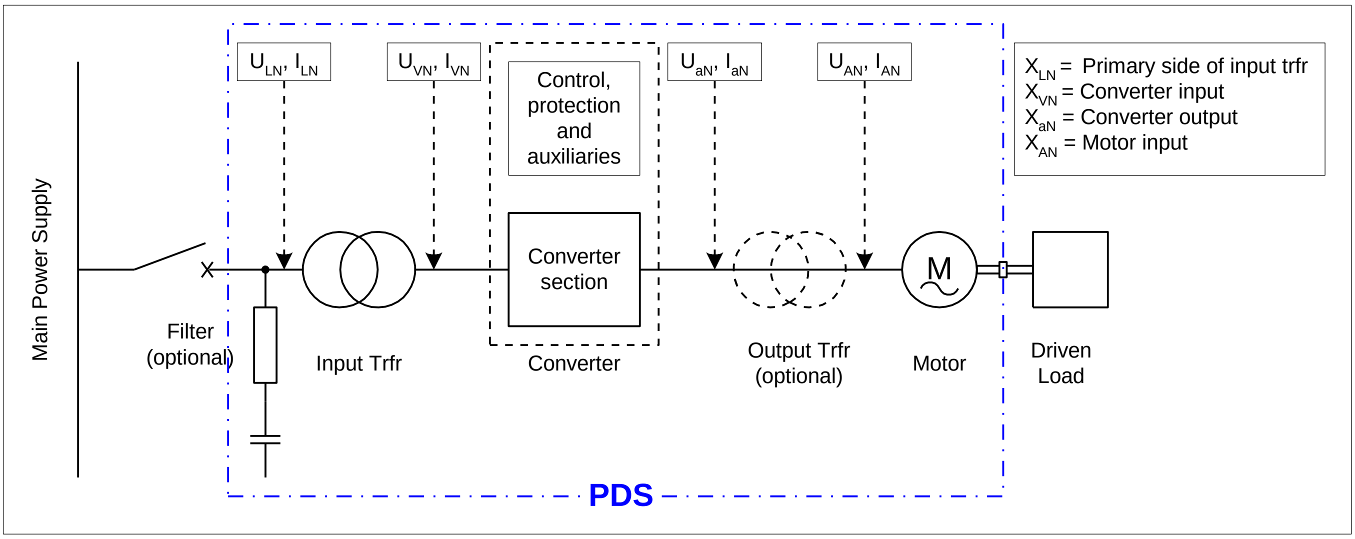

Figure 26: Functional diagram of an AC adjustable speed power drive system

The focus of this paragraph is that of the protection and it is appropriate to mention the difficulties to protect some of the PDS components. At the output of the converter the effective supply frequency of the motor supply varies over a large range, effectively from 0Hz to 100Hz in some case.

This poses a real challenge to convectional protection devices which uses CTs and VTs designed for power frequency applications and even the protection algorithms are tuned around the common power frequencies. Typical residual current type ground fault detectors cannot detect low-frequency or DC ground faults - they are insensitive to frequencies below 20 or 30 Hz. The protection scheme of the PDS should include fault detectors capable of low-frequency and DC fault detection. Specialised current operated IEDs using specialised current transformers are available to perform such functions.

Over and above the effective supply frequency, the modulation frequency has it is own challenges with higher frequencies causing higher capacitive currents to flow to ground.

The transformer/s and motor in a PDS needs to be protected in the same way as these power elements are protected as described elsewhere in this document. Eskom's VFD standard (240-50237146, Medium Voltage AC Variable Frequency Drives Standard) refers to the IEC 61800-4, Adjustable speed electrical power drive systems - Part 4. This standard covers the protection requirements for the total power drive system.

From the switchgear side the PDS appears as a simple transformer feeder and hence the applicable transformer type protection shall be provided as a minimum regardless of the PDS protection. Transformer thermal protection based on current or actual temperature sensing devices might be used within the protection of the PDS.

This IEC standard is however not as exhaustive for motor protection as the industry norm and Eskom's own motor protection requirements.

The latest published IEC standard lists a table with all the protection requirements. Notably missing in this table when compared to motor protection requirements of Eskom are:

- Earth fault
- Locked rotor
- Current differential

- NPS

It is therefore required that the protection be available on/in/at the switchgear mounted IED. This might require two IEDs being installed on the switchgear to cater for all the protection requirements especially if there is current differential on the motor. Most IEDs used for motor protection only cater for six current inputs and this might be the restriction to do all the protection in one IED.

Earth fault detection on the motor side is impossible by means of conventional/traditional methods because the VFD with its isolating transformer/s effectively decouples the motor from the grounded/earthed source transformer. It is almost the equivalent of a rotor of synchronous machine, it is basically a floating system. Some special means are required to detect earth faults in a floating system.

Certain VFD manufacturers make provision for earth fault detection, not only on the DC link but the motor side as well. Irrespective of the drive protection capability the MV protection shall be equipped with zero sequence voltage detection and protection algorithm to cater for earth faults on the motor side of the drive. This will require single phase voltage transformers to be installed on the motor side. These VTs shall be connected in star with both the HV and LV star connections connected to earth.

Some drives require that the drive needs to be switched off first before the source gets tripped. The MV protection shall make provision for this requirement and there shall be inputs to detect a drive “stop” command as well as a drive “trip” command. The opposite is also true, when the MV protection detects a fault and needs to trip, it needs to give a stop command first and then after suitable time delay the breaker may be tripped. These delays needs to be carefully selected not to cause breaker failure protection to operate prematurely and it could even impact on the upstream time grading.

The VFD LV compartment has an emergency pushbutton which requires the supply breaker to be tripped directly when activated. In-line with the external trips described in § 3.2.10.2 , this trip shall be monitored by the IED at the supply breaker.

According to Eskom’s VFD standard a bypass system, both for starting and continues operation of DOL motors, might be required. This necessitates the protection to be adaptive too, which will require at least two sets of protection settings. These settings groups shall be selected based on the mode of operation. A binary input shall be made available for this requirement and can also be used when scheme testing is required.

Typical settings:

- Motor protection: = Apply as per *PA0100/0400 schemes
- Transformer protection: = Apply as per *PA1000/0700 schemes

3.4.6.5 Dual drive conveyer motor protection

Eskom Generation regularly makes use of more than one motor to drive one conveyer belt or system. In most cases the two motors are fitted with couplings of different designs, one being a slow activating coupling and the second with a quicker activating coupling since the belts is already partially in motion. Since the two motors are used to drive one conveyor belt, the standard motor protection and tripping philosophy for one motor cannot be applied to trip or start one motor only.

Even though it might be considered as a DSC function to detect incorrect starting and stopping the DCS will only response will only be reactive and damaged to the equipment might occur.

The motor protection tripping and starting philosophy of multiple motors should consider the application and should not initiate abnormal plant conditions to happen.

To prevent abnormal plant operating conditions both primary and secondary motors for a dual drive conveyor must be tripped by the protection in the event of an abnormal motor protection on any one of the two motors. This will require some form of signal transfer between the IEDs. This could be IEDs in different geographical locations and a means of reliable signal transfer must be provided. Additionally motors start-up inhibits must be block on both primary and secondary motors.

Motor undercurrent protection on dual drive conveyors should be considered as serious equipment damaged can result from a mechanical failure like a shaft or a coupling failure should one motor remain in service without support of the second motor. Even though this is not considered to be a motor protection function but rather a mechanical protection function, most motor protection relays are equipped with the an under-current function. Care needs to be taken when applying settings for under current as the number of poles of a motor influence the no load current dramatically and it might cause nuisance tripping. Conveyor drive motors are also invariably over-sized for their application, which compounds the difficulty of utilising the under current function. The scheme needs to be revised and more research is required before a fixed philosophy can be stipulated. It suffices to say that a lot more thought need to go into protecting motors for this configuration.

3.4.7 Transformer protection

Oil type and dry type transformers have different requirements when it comes to monitoring and protection. Winding temperature might be required on both types whereas oil temperature obviously is only required on oil cooled transformers. The same holds for Buchholz protection. IEDs used for transformer protection needs to have their I/O counts correctly specified.

Although the unit transformers and station transformers forms part of the power station reticulation, the protection of these transformers is explicitly excluded from this standard. The unit transformers are covered by the generator protection system and the station transformers are normally protected by a protection scheme coming from the Eskom Transmission range of TM protection schemes for power transformers.

3.4.7.1 Transformer protection (*PA1000)

The *PA1000 scheme is applied to power transformers <10MVA. This explicitly excludes excitation transformers of any size because excitation transformers has a vector group of Yd_x and their application and settings deviate from normal power transformers as used in the general power station environment. *PA1000 schemes may be permanently installed on excitation transformer test circuits on MV boards (where provided) and even in these situations the excitation standard needs to be consulted for configuration and setting requirements.

3.4.7.1.1 Over current

This protection shall be provided on all transformers connected to any MV source.

The over current protection requires a minimum of two independent settable functions. One is a definite time and the other an IDMT function. The IDMT in turn shall be selectable between the IEC 60255 curves. In most case the Normal IDMT curves is used but in some case other curves might be required especially to grade with LV fuses for instance.

The high set definite time is regarded as main protection on transformers and is set to detect faults in the transformer or on the HV cable. The IDMT is classified as back-up to clear LV faults outside the transformer or that has not been cleared by the downstream protection. Protection co-ordination between the HV side IDMT and the downstream protection is required, both in current pick up and time to trip. This protection is co-ordinated with the transformer short time and continuous ratings.

When busbar blocking schemes are used on transformers, a second definite time over current might be required if the HV side of the transformer are the preferred isolating point.

Typical settings:

- High-set over current pick-up 1 = 1.5 to 2.0 x LV fault level referred to HV side and 0.5 to 0.8 off minimum fault current on HV side
- Time delay 1 = 0.05s

- High-set over current pick-up 2 = Max LV board load - Biggest motor FLA + Motor start current + margin, referred to HV side (used for busbar blocking)
- Time delay 2 = 0.1s to 0.15s
- IDMT over current pick-up = 1.5 to 2.0 x full load current
- Time delay = 0.25s-0.3 s longer than the trip time of the downstream protection

When there are big motors connected to the transformer the pick-up and trip times need to be tested against the start-up current and times of the motors with simple superposition methodology. Practical preloading needs to be considered to prevent unnecessary high pick-up and trip times. When load flows studies are performed the most logical and practical loads have to be modelled to assist setting engineering practitioners to provide optimal settings for the transformer.

3.4.7.1.2 Earth fault protection

This protection shall be provided on all transformers connected to any MV source.

On solidly earthed systems, IDMT protection is used.

On resistive earthed systems, DT protection is used with instantaneous OC for resistor flashover (NOTE: only if neutral CT is used). Instances where the fourth (neutral) wire is used, an IDMT element must be used on resistive earthed systems for resistor flashover.

When boards are equipped with five limb VT's or three single phase VT's, a zero sequence voltage measurement and a Uo over voltage, it is recommended that voltage functions be used as back-up to the current protection (i.e. when copper earths are not in tact).

Typical settings

- IDMT earth fault pick-up = 0.1-0.5 x prospective fault level.
- Time delay = 0.25-0.3s longer than the trip time of the downstream circuit breaker
- DT earth fault pick-up = 0.2-0.5 anticipated fault level.
- Time delay = 0.25s-0.5s longer than the trip time of the downstream circuit breaker
- High set over current = 2 x fault current (Protection in the case of resistor flashover)

(NOTE: If an IDMT element is used, it must be time graded with the upstream protection)

- Zero sequence voltage p/u = 50% of phase value (incomers only)
- Time delay (zero seq volt) = Solidly earthed: up to 300msec above normal E/F trip time and resistive earthed: up to 3 sec above normal time E/F trip time.

3.4.7.1.3 Buchholz

This protection shall be provided on all oil filled transformers.

The Buchholz relay is a hydraulic device installed in the pipe between the transformer tank and the conservator. It operates on the principle that internal faults in oil-immersed transformers are associated with the production of gas and/or a surge of oil.

The relay collects the oil vapour or gas in a vessel. This vessel is normally full of oil and is fitted with a top and bottom float. Each float can operate a micro switch. The sequential displacement of each of the floats, due to the presence of gas, closes the micro switch contacts to give an alarm and then trip.

A second micro switch can be operated by a surge of oil from the transformer tank to the conservator.

3.4.7.1.4 Pressure Relief Device (PRD)

This protection shall be provided on oil filled transformers.

The PRD operates on the principle that a severe fault within the transformer produces a sudden overpressure inside the transformer tank.

The PRD is a mechanical device installed in the wall of the transformer tank. It contains a diaphragm which displaces under pressure. The PRD opens to relieve the pressure inside the tank and operates a micro switch trip facility.

3.4.7.1.5 Transformer Oil and Winding Temperature

Oil temperature and/or winding temperature monitoring devices are fitted on large transformers. High oil or winding temperature is a result of overloading, high ambient temperature or a failure in the cooling system. These devices can be thermocouples located in the oil, winding or core of the transformer. On dry transformers only winding temperature monitoring devices are fitted.

Typical settings

- Oil temperature alarm = 85°C
- Oil temperature trip = 100°C
- Winding temperature alarm = 100°C
- Winding temperature trip = 120°C

Note: Consult the OEM recommended settings. Apply the OEM setting if it is more restrictive. If the OEM recommendation is less restrictive, the application and environment must be considered before exceeding the value listed above.

Note: All temperature trip inputs shall be delayed between 1-5 seconds to enhance security.

3.4.7.2 Transformer protection (*PA0700)

This scheme uses of all the protection functions of the 4PA1000 scheme with the addition of current differential.

3.4.7.2.1 Transformer current differential protection

This protection shall be provided on transformers of 10MVA and larger or where the criticality warrants the use of differential protection it may be applied to transformers <10MVA.

This is unit type protection, instantaneous in operation, covering the transformers for phase-to-phase faults. Transformer differential protection is a biased differential with the functionality to restrain for second and fifth harmonic preventing inadvertent operation due to current inrush when energised. Transformer differential protection overlaps with other differential protection if applicable.

Typical settings

- Transformer differential = 0.1 to 0.3 x rated current of protected object

3.4.8 Cable protection (*PA0800 and *PA0900)

Critical cables in the power station are protected by dedicated cable protection schemes. The *PA0800 is a two terminal cable protection scheme while the *PA0900 is multi terminal cable protection scheme. In essence they function on the same principles and these functional requirements are listed below.

3.4.8.1 Current differential using pilot wire or fibre optic

Current differential protection is based on the Kirchhoff's first law i.e. the sum of currents into a node must be equal to zero. This protection shall be provided on cables that have a high fault level (≥10kA) and/or cables that are important to the operation of the station. It shall be provided on cables which connect boards that have bus zone protection.

Cable current differential protection is a unit type protection and operates without any additional time delay other than what the algorithm uses to produce a trip output. It is primarily for phase-to-phase faults (earthing dependent).

Each end of the protected cable has a protection IED with inter-bay communication between them using a propriety communication channel for this purpose. These are connected via pilot wires/fibre optics which completes the differential circuit of the CTs.

Differential protection overlaps at each end with bus zone protection if applicable.

The differential function should be set in line with the manufacturer's recommendations to ensure maximum sensitivity while maintaining stability for through-faults and load conditions. Capacitive charging current of the cable is a critical parameter to consider when applying the settings to a cable differential scheme.

Typical settings

- Cable current differential = 0.1 to 0.5 x rated current of cable or calculated load
- Time delay = no explicit time delay other than what the algorithm needs to take produce an output

Note: Cable current differential shall be deemed inadequate if operating times extend beyond 50 ms.

3.4.8.2 Over current

Cables with current differential protection require IDMT O/C protection as back-up protection on the installed circuit and for the downstream circuits. This protection is current graded to allow the downstream protection time to operate first.

On cables without current differential protection, IDMT O/C protection is the main protection on the installed circuit and back-up protection for downstream circuits. This protection is current graded to allow the downstream protection time to operate first.

NOTE: Where over current protection is used without current differential protection; care should be taken that the cable fault current time rating is not exceeded. Tripping times for fault levels at cable remote ends must be checked to be within the cable specifications.

Typical settings

- IDMT over current pick up = 1.2 x rated current
- Time delay = 0.25 s longer than the trip time of the down-stream circuit-breaker

3.4.8.3 Earth fault protection

On cables, earth fault protection is sometimes the main protection on the installed circuit and back-up protection for downstream circuits when cable current differential is deployed due to current pick-up values being higher than maximum fault currents on compensated earthing systems.

On solidly earthed systems this protection is current graded to allow the downstream protection time to operate first. The earth sheath rating shall be considered.

On resistance earthed systems this protection is time graded to allow the downstream protection time to operate first.

Typical settings:

On solidly earthed systems:

- IDMT earth fault pick up = 0.1 to 0.4 × full load current

- Time delay = 0.25 seconds longer than the trip time of the downstream circuit-breaker (provided that the earth sheath rating is not exceeded)

On resistance earthed systems:

- Earth fault pick up = 0.1 to 0.4 × fault current
- Time delay = 0.25 seconds longer than the trip time of the downstream circuit-breaker (provided that the earth sheath rating is not exceeded)

3.4.8.4 Synchronism check

A synchronism check facility is required during changing of supplies on a MV board, (where applicable) which is feeding from different sources by using the voltage elements supplied from the cable and busbar voltage transformers.

Different parameter sets are required:

- The synchronism check facility measures the single-phase voltage quantities from the cable and busbar VT's. Once the voltages are the same, in phase, magnitude and phase rotation, a control closing signal is given to the MV supply breaker and a trip signal after approximately 100 ms to the other supply breaker (selected breaker) and vice versa. (Live chop-over)
- Close the supply breaker (with unit supply cable VT alive) to energize the busbar (busbar VT dead and other supply breaker opened with cable VT dead). (Live line, dead bus charge) vice versa is also applicable.
- Close the unit loop supply breaker (with unit loop supply cable VT dead and busbar VT and unit supply VT alive) to energize the loop supply cable to the next unit. (Live bus, dead line charge)

Typical settings:

Paralleling time = 1s

3.4.8.5 Thermal protection

Traditionally the typical loop supply cables were adequately sized to cater for the worst case loading scenarios. Lately a different approach on primary cabling has lead to conditions that can cause a cable thermal rating to be exceeded due to inappropriate loading conditions. Cable thermal protection has to be enabled for these scenarios. Cable installations need to be considered by setting engineering practitioners to apply the correct derating factors and over load factors for any given installation. It is therefore a requirement that any cable differential scheme has to have thermal protection as part of its repertoire.

Typical settings:

Consult cable data sheets and physical installations for correct setting application.

3.4.8.6 Phase comparison differential

Phase Comparison Differential is not an acceptable option.

3.4.9 Diesel generator protection (*PA1500)

At the time of publications it was not finalised as yet if diesel generator protection needs to form part of this standard or if it should be incorporated in a standard related to black-start and standby generation. Diesel generators are also differently applied at different power stations. In some cases the point of connection is on LV level and it other cases it is on MV level.

Regardless of the position of the diesel generator or where the protection functionality will be described in future, some basic principles are enforced by this standard.

Diesel generator protection shall have two or more sets of setting and/or configurations. The selection of these will be decided if the generator is on a maintenance run or if it is running due to an emergency that caused it to start.

At the point of connection the IED shall have a synch check function to be used with the diesel gen synchronising equipment. A protection/interlock bypass function needs to be designed to allow a diesel generator to do dead bus charging as well as manual synchronising. To assist the operator with the manual synchronising a robust synchroscope shall be provided. The operating of the diesel generators needs to be clearly described in the works information. Selection of maintenance runs, automated run-up and synchronising and emergency operating condition needs to be well documented to allow the diesel generator to fulfil its duty of an emergency power source.

Under emergency running conditions, the diesel generator almost becomes a sacrificial component. Protection of the generator should be focused on severe electrical malfunctioning that can cause the generator to become a danger to personnel and the plant. Exceeding the normal operating envelope of the generator should be tolerated to a large extent.

If the generator size warrants it, current differential may be added as part of the electrical protection by the IED/scheme installed at the point of connection.

Diesel generator controllers have evolved in the recent past and these controllers shall be tested to enable them to be put on the list of approved devices. These controllers come with a plethora of electrical protection functions and should be adequate for the electrical protection requirements.

Diesel generator boards require a chop-over control scheme built into the Diesel Gen IED and it shall comply with the following:

- Connected to a source for normal conditions
- If the NORMAL supply fails it needs to chop to a STANDBY supply
- If the STANDBY fails it must chop to the DIESEL
- If the NORMAL supply returns, human intervention is required to perform a bright chop-over back to the NORMAL (preferred) supply

3.4.10 Earthing Resistor Protection

3.4.10.1 Oil temperature protection

Earthing resistor oil temperature monitoring devices are fitted to oil filled resistors. It creates a much more compact enclosure because the oil not only serves as coolant but also as insulation between the resistor layers. Even though the oil may act as an indication and protection, its time constant could be much longer than the short time rating of the resistor and damage to the resistor may well occur long before the oil temperature has had time to operate. The only advantage of the oil temp supervision is that it inherently compensates for ambient temperature.

Two different temperature levels shall be provided, the lower level for an alarm and the higher level for tripping. One new installation only the alarm function is required.

Typical settings:

- Oil temperature alarm level = 85 °C.
- Oil temperature trip level = 100°C.

Note: All oil temperature trip to be delayed with a minimum of 1-5 seconds to enhance security.

3.4.10.2 Earthing resistor thermal protection

With dry type earthing resistors the only protection that can be added is a thermal characteristic based on the current passing through the resistor. If the resistor is not protected it may be destroyed and then the system could be operated without an earth point and none of the current based earth fault protection functions would be able to operate. The sensitive earth fault protection does act partially to protect the resistor but there is large range of earth fault current that can flow without any protection picking up, especially if the "standard" 100A primary current pick-up is deployed. Most resistors have a continuous rating of 10A. That means that with a fault current more than 10A and less than 100A, the resistor is at risk of being damaged if nothing protects it. If a simple square law capability is deducted from the short time rating, then the standard IEC 60255-8 thermal curve which is available in some form or another in virtually all IEDs, can be applied. This could be supplemented with definite time "long time". Due to the very long time delay required this timer might not have the required range within a standard earth fault function but all IEDs allow for additional logics to be added to a scheme and these timers can be set up to hours if required. A time of 60 minutes and longer might be required.

This function is well suited for any type of resistor and therefore shall be installed on new installations to replace the oil temperature trip functions as described in the previous paragraph.

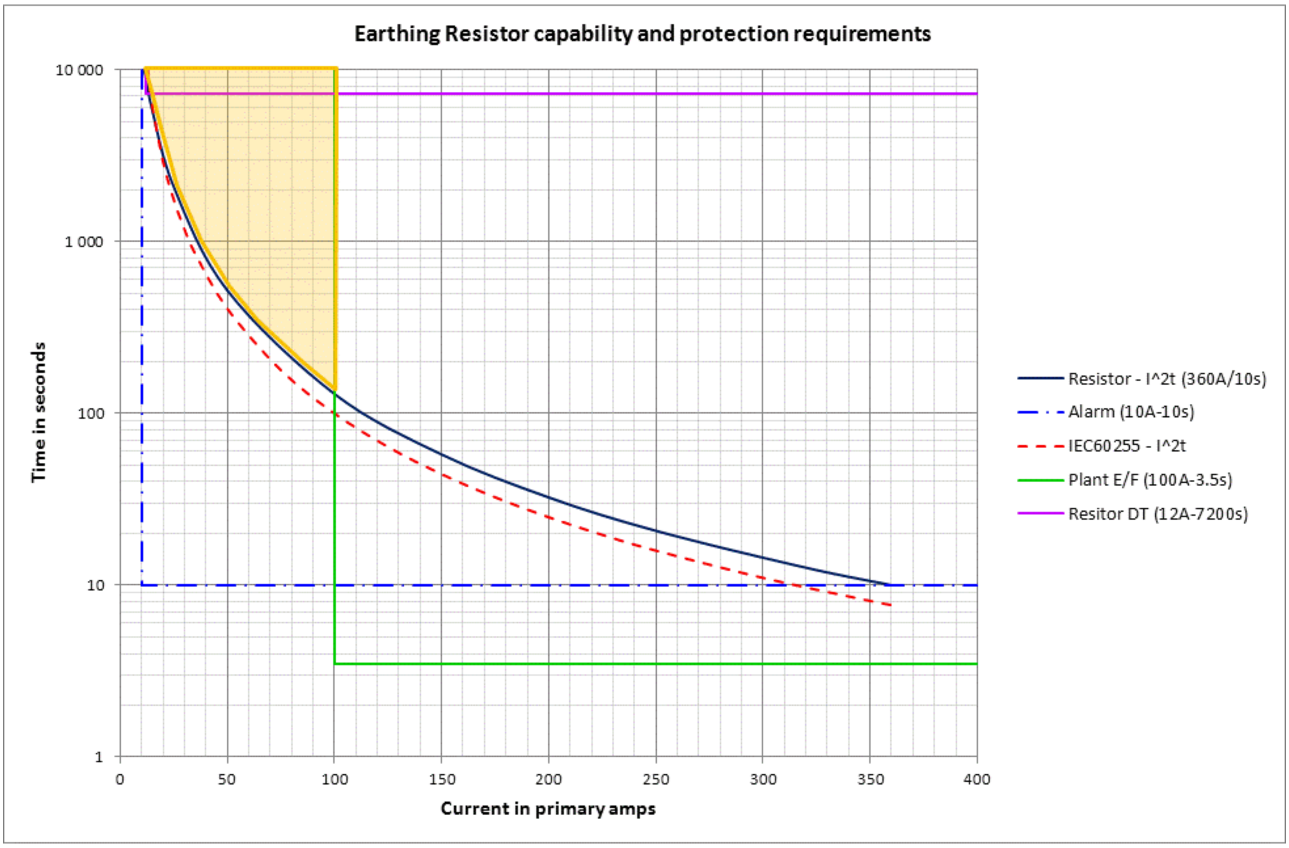

Figure 27: Typical earthing resistor capability and required protection

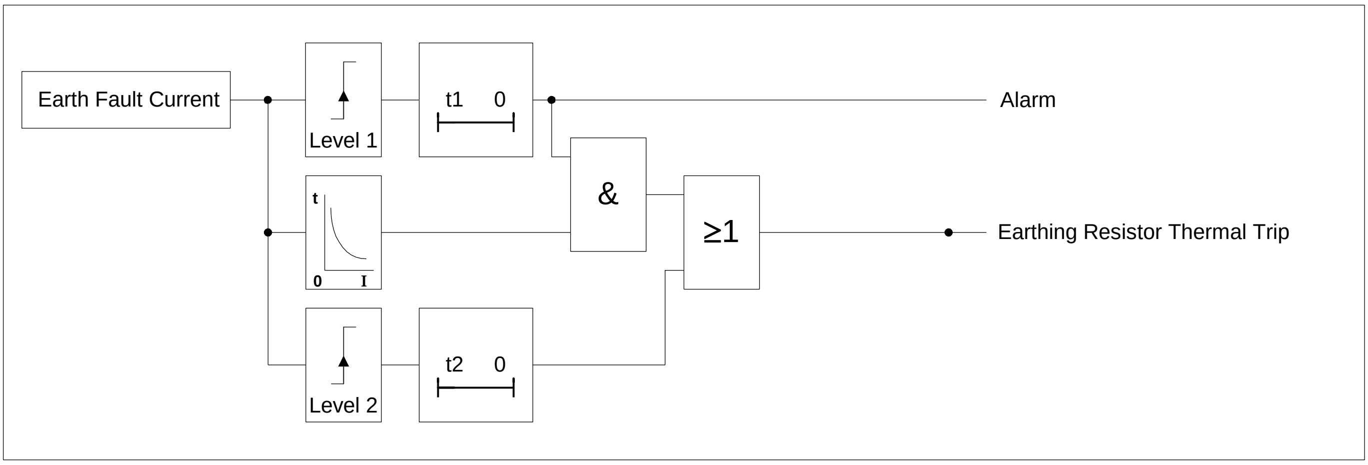

Figure 28: Earthing resistor temperature logic

Typical settings:

- Earth fault current level 1 = Continuous rating of resistor (typically 10A)
- Earth fault I2t pick-up = Level 1(I2t typically only picks up at 110% of setting)
- Earth fault current level 2 = 120 - 150% of Continuous rating of resistor (typically 12-15A)
- Timer t1 = Short time rating of resistor (typically 10s)
- Timer t2 = To be derived from resistor ratings (typically 2 hours)

3.4.11 Shunt capacitor bank protection (*PA1800)

Shunt capacitor banks are very seldom used in Eskom generation. Large motor control centres in the industry use capacitors for power factor correction and is also installed on the some of the generation water pump stations like the Komati water scheme. The only main capacitor bank at the time when this standard was compiled was installed at Kendal's black start gas turbines to supply reactive power under large motor stating conditions and to act as a filter for harmonics being generated by the electric boiler feed pump motors. As a minimum the functions as described below shall be used. Capacitor bank manufactures needs to be consulted if and when such banks are installed.

3.4.11.1 Unbalance protection

The capacitor shall be switched out when the voltage across any capacitor element or capacitor exceeds 110% of the rated voltage thereof. This may be a result of a blown fuse or capacitor fault. The unbalance protection can be achieved through current measurement or voltage measurement.

Typical settings

- Alarm pick-up = 50 - 80% of trip value
- Alarm pick-up time = 2 - 10 seconds
- Trip pick-up = 110% of rated voltage
- Trip pick-up time = 0.2 - 0.5 seconds

3.4.11.2 Cascading Failure Protection

One instantaneous or extremely inverse element in the split-phase neutral connection can serve as a back-up function to the unbalance protection as well as a fast cascading failure protection. Cascading failure of capacitor elements or units may result under conditions of sustained over voltages across remaining healthy elements of units or due parallel energy discharge of parallel elements or units under conditions where the unbalance relaying is not fast enough in disconnecting the bank.

Typical settings

- I pick-up = 120% of unbalance protection trip setting plus inherent unbalance of the bank
- Trip pick-up time = Instantaneous (should be stable during transient conditions)

3.4.11.3 DT Phase Over current Protection

Over current protection operates for phase-to-phase faults and phase to earth faults. The DT current elements provide limited thermal and unbalance protection. Instantaneous current elements should be insensitive to harmonics but the DT current elements should be harmonic sensitive.

Typical settings

- I pick-up (instantaneous) = 300 - 400% of rated bank current (single bank)
- I pick-up (instantaneous) = 400 - 600% of rated bank current (multiple bank)
- I pick-up (DT) = 150 - 180% of rated bank current
- I pick-up time (DT) = 0.2 s

3.4.11.4 DT/IDMT Earth Fault Protection

Earth fault protection operates for phase to earth faults. The DT earth fault current elements should be used for unearthed banks and the IDMT earth fault elements for the earthed banks.

Typical settings

- I pick-up (instantaneous) = 300 – 600% of rated bank current
- I pick-up (DT) = 20 – 40% of rated bank current
- I pick-up time (DT) = 0.2 – 0.5 s
- I pick-up time (IDMT) = to grade with other earth fault protection

3.4.11.5 Under Current Protection

Undercurrent protection shall be applied to provide protection for single phase open conditions due to the failure of jumpers between the busbar and the bank or connections between capacitor cans.

Typical settings

- I pick-up = 5 - 10% below rated bank current
- I pick-up time = 0.2 – 0.5 s

3.4.11.6 Over voltage and Under voltage Protection

Over voltage contributes to the ageing of the capacitor dielectric. Under voltage monitoring is necessary to prevent excessive over voltage on capacitors during re-closing following a system fault.

Typical settings

- O/V pick-up = 112 - 115% of system voltage
- O/V pick-up timer = 0.1 – 0.2 s
- U/V pick-up = 10% below the value that requires the bank to be switched in
- U/V pick-up timer = 0.2 – 0.5 s

3.4.11.7 Overload Protection

Settings applied to protect the banks from being operated continuously under heavily loaded conditions. Alarm to be set to a value 10 – 30% lower than the thermal setting.

Typical settings

- I pick-up = 150 – 180% of rated bank current
- I pick-up time (DT) = 0.2 – 0.5 s

4. AUTHORISATION

This document has been seen and accepted by:

Name & Surname	Designation
Machiel Viljoen	Senior Manager - Production Engineering Integration (Acting)
Ashwin Pillay	Senior Manager - PTM (Witbank)
Phera Rakeketsi	Middle Manager Engineering - Electrical Plant CoE
Lungile Malaza	Middle Manager Electrical Design Application CoE
Gert Brink	Electrical Engineering Manager - Arnot Power Station
Steyn Drotsky	Electrical Engineering Manager - Camden Power Station
Andile Nqayane	Electrical Engineering Manager - Duvha Power Station
Bawinile Malope	Electrical Engineering Manager - Grootvlei Power Station
Aluwani Mutsilanwana	Electrical Engineering Manager - Hendrina Power Station
Keabetswe Senosi	Electrical Engineering Manager - Kendal Power Station
Zieyaad Isaacs	Electrical Engineering Manager - Koeberg Power Station
Tsumza Tsumane	Electrical Engineering Manager - Kriel Power Station
Samuel Chembe	Electrical Engineering Manager - Komati Power Station
Mohapi Mphirime	Electrical Engineering Manager - Kusile Power Station
Theko Shete	Electrical Engineering Manager - Lethabo Power Station
Thabile Modungwa	Electrical Engineering Manager - Tutuka Power Station
Kefuoe Sejosing	Electrical Engineering Manager - Majuba Power Station
Louisa Bamuza	Electrical Engineering Manager - Matimba Power Station
Nkosinathi Maseko	Electrical Engineering Manager - Matla Power Station
Derrick Chauke	Electrical Engineering Manager - Medupi Power Station
Shivana Maharaj	Electrical Engineering Manager - Peaking Power Stations

5. REVISIONS

Date	Rev.	Compiler	Remarks
Nov 2018	0.1	JM Jordaan	• Autonomous MV protection standard drafted based on the previous MV & LV protection standard. • Basic Diesel generator protection added when POC is on MV • VSD protection added with reference to the VSD and

Date	Rev.	Compiler	Remarks
			SANS/IEC standards • Earthing resistor thermal protection based on current measurement added. • Cable thermal protection added. • Zero sequence over voltage added as long time back-up to earth fault protection and supervision for notoriously false operations when Holmgren connections on high resistance earthed circuits are used. • CT supervision added as a block to protection functions. • Biased differential (Low impedance) buszone added, and its additional, but very important benefit as back protection described. • Busbar blocking scheme added
Feb 2019	0.2	JM Jordaan	Updated draft after Care Group and CoE comments
May 2019	0.3	JM Jordaan	Updated draft after C&I interface discussions
June 2019	0.4	JM Jordaan	Updated draft after Study Committee comments
Nov 2019	0.5	JM Jordaan	Updated draft after Business review comments
Dec 2019	1	JM Jordaan	Final document for Authorisation and Publication

6. DEVELOPMENT TEAM

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

- Raosetene Mahlaku
- Jacques Strydom
- Makgatle Lentsoane
- Schalk van Staden
- Murray van Niekerk
- Martin Visser
- Chris Herbst (until his resignation)
- Kobus Stols (until his resignation)

7. ACKNOWLEDGEMENTS

- John Russell and Jacques Strydom have maintained the base document over many years and laid the platform for the new standard.
- Anthony Fassbender for providing insight in the peculiar applications on peaking sites.