Eskom	Standard	Technology

Title: **STANDARD PHILOSOPHY FOR THE BREAKER-AND-A-HALF LINE PROTECTION**

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1. Introduction

This document describes Eskom's Extra High-Voltage (EHV) breaker-and-a-half transmission line protection and control philosophy.

2. Supporting clauses

2.1 Scope

2.1.1 Purpose

The purpose of this standard is to describe Eskom's philosophy for breaker-and-a-half line protection schemes.

2.1.2 Applicability

This standard shall apply to PTM&C within Eskom Group Technology.

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] Cigré Working Group B5.27: Implications and Benefits of Standardised Protection and Control Schemes

[2] Cigre SC34: "Eskom's certification testing requirements for EHV numerical transmission line protection relays" 1999

[3] IEC 50: International Electrotechnical Vocabulary; Chapter 448 Power system protection

[4] Cigre SC34-WG04: Application Guide on protection of complex transmission network configurations

[5] Network Code: The South African Grid Code (Revision 8.0)

[6] TST41-689: Standard for the Protection and Control of Extra High Voltage Transmission Lines on the Eskom Power System

2.2.2 Informative

[7] 32-9: Definition of Eskom documents

[8] 32-644: Eskom documentation management standard

[9] 474-65: Operating manual of the Steering Committee of Technologies (SCOT)

2.3 Definitions

2.3.1 General

Definition	Description
Auxiliary functions	Non-measuring functions which augment the required tripping system capability.
Back-up protection	Protection functions which are called on to operate to ensure fault clearance as a result of failure of the primary protection or of circuit-breaker failure.
Dependability	The probability of not having a failure to operate under given conditions for a given time interval [IEC 50 - 448].
Duplication	Doubling-up of equipment to provide redundancy (local back-up). The equipment could be identical or diverse. Each would serve the same purpose and have the same level of importance.
Fault clearance system	The Fault Clearance System comprises the two Tripping Systems, plus the circuit-breaker.
Non-intrusive	Without intruding on, changing the properties of, or compromising the integrity of a piece of equipment, especially when testing such equipment.
Primary protection	The main element of the Tripping System which consists of primary protection functions and supplementary protection functions.
Primary protection function	The most important protection function within the primary protection. It operates in the fastest time possible, removes the least amount of equipment from service, and is expected to have priority over supplementary protection in initiating fault clearance.
Protection and control scheme	A composite arrangement of protection functions as well as control and information systems put together to isolate system disturbances and to minimise damage to items of plant. The Protection and Control Scheme is that portion of the Fault Clearance System, Bay Closing System, and Bay Management System housed within the suite of cubicles within the control room building or kiosk.
Protection function	The basic conceptual component of a Protection System
Protection system	The Protection System is that part of the Tripping System which provides the requisite primary, back-up, system and auxiliary protection functions.
Security	The probability of not having an unwanted operation under given conditions for a given time interval [IEC50-448].
Selectivity	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.

Definition	Description
Single failure criterion	A design criterion whereby a system must not fail to operate even if one component fails to operate. With respect to the primary protection relay, Eskom's interpretation of the single failure criterion caters primarily for a failed or defective relay, and not a failure to operate as a result of a performance deficiency inherent within the design of the protection device.
Supplementary protection function	A protection function which augments the primary protection function by enhancing dependability and/or security.
System protection	Protection which is required to respond to a system condition as opposed to a system fault e.g. overvoltage, underfrequency or power swing conditions.
Teleprotection dependability	The ability of the teleprotection system to issue a valid command in the presence of interference and/or noise (IEC 834-1)
Teleprotection security	The ability of the teleprotection system to prevent interference and noise from generating a command state at the receiving end when no command signal is transmitted (IEC 834-1).
Tripping system	A Tripping System comprises the Protection System, an independent d.c. source, a dedicated CT core, a separately fused input from a shared VT core (where applicable), dedicated teleprotection equipment, and dedicated trip-coil of the diameter circuit-breakers.

2.3.2 Disclosure classification

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

2.4 Abbreviations

Abbreviation	Description
52a	Breaker normally open auxiliary contact
52b	Breaker normally closed auxiliary contact
A	Ampere(s)
B#SIS	Bay 1/2 supervisory isolating switch
BB	Bay breaker
B-N	Blue to neutral
B-R	Blue to red
CALH	Alarm handling
CL	Closing
CSWI	Switch Controller
CT	Current transformer
CTTB	Current transformer test block
CVT	Capacitive voltage transformer
DC	Direct current
DCD	Diameter Control Device
DCI	Direct current isolation

Abbreviation	Description
DIP	Diameter interface panel
EHV	Extra high voltage
ETHSW	Ethernet switch
F	Frequency
FACTS	Flexible AC Transmission System
GGIO	Generic process Inputs/Outputs
GOOSE	Generic Object Oriented Substation Event
HMI	Human machine interface
Hz	Frequency
IDMT	Inverse definite minimum time
IEC	International Electrotechnical Committee
IED	Intelligent electronic device
IEEE	Institute of Electrical and Electronic Engineers
IHMI	Human machine interface
IND	Indication
JB	Junction box
JBNH	Junction box not healthy
KHTR	Cubicle heater
Km	Kilometre
kV	Kilo volt
M	Isolator normally open auxiliary contact
MCB	Miniature Circuit-Breaker
MMS	Manufacturing Message Specification
MMXU	Measurement
MPS	Model Power System Simulator Testing
ms	Millisecond
N	Isolator normally closed auxiliary contact
nm	Nano metre
P	Active power
PDIF	Differential protection
PDIR	Distance zone directional element
PDIS	Distance protection
PF	Power factor
PIOC	Instantaneous overcurrent
PIU	Process interface unit

Abbreviation	Description
POR	Permissive overreach
PSCH	Scheme communication
PSNH	Protection system not healthy
PTOC	Time overcurrent
PTOV	Overvoltage protection
PTRC	Trip conditioning
PTUC	Undercurrent
PTUV	Undervoltage
PUR	Permissive underreach
Q	Reactive power
R	Resistance
RADR	Disturbance recorder channel analogue
RBDR	Disturbance recorder channel binary
RBRF	Breaker failure protection
RDIR	Distance zone directional element
RDIS	Distance zone
RDRE	Disturbance recorder function
RFLO	Fault locator name
R-N	Red to neutral
RPSB	Power swing blocking
R-W	Red to white
SANS	South African National Standard
SCADA	Supervisory Control And Data Acquisition
SCD	Substation Configuration Description
SED	System Exchange Description
SIS	Supervisory Isolate Switch
SOTF	Switch-onto-fault
SS	Secure supply
TB	Tie bay
TBSIS	Tie bay supervisory isolating switch
TNS	Test Normal Selection
TPIS	Teleprotection isolating switch
TST	Transmission standard
V	Voltage
VAC	AC voltage

Abbreviation	Description
VDC	DC voltage
VT	Voltage transformer
VTTB	Voltage transformer test block
W-B	White to blue
W-N	White to neutral
XCBR	Circuit breaker
XSWI	Circuit switch

2.5 Roles and responsibilities

Protection technology and support shall utilise this document as basis for the breaker-and-a-half line protection specification.

2.6 Process for monitoring

The protection technology & support manager and the custodian will monitor the compliance to this standard.

2.7 Related/supporting documents

Not applicable.

3. Requirements

3.1 Introduction

The requirement is to have more cost effective Protection Systems, is to reduce the overall cost of the Protection Scheme. In any modern business environment, cost is a focal issue. In Eskom, business imperatives have, over time, been biased either towards engineering / superior performance issues, or towards financial issues. It has now become necessary to seek an optimal balance between the two, with equipment cost being a priority issue. It is now necessary to engineer schemes smarter by better understanding and designing for the associated risks, and by eliminating unnecessary cost premiums by applying suitable functionality and performance capability to meet the specific requirements.

3.1.1 General statement

Electrical protection of the Eskom EHV transmission lines is required in order that system disturbances due to network transmission line related faults are promptly disconnected from the system, thereby ensuring optimal quality of supply to customers, minimal damage to primary plant, and sustained stability and integrity of the power system.

a) Quality of supply to customers

The duration of the disturbance must be kept to a minimum, implying the necessity for rapid isolation of faults, and the extent of the disturbance must be minimised, implying the need for good selectivity.

b) Damage to primary plant

By minimising the fault duration, the damage to primary plant is limited and the reduction of the life of the plant is minimised.

c) Stability and integrity of the power system

The ability of the transmission system to transport power in a stable manner such that the integrity of the power system is not compromised.

The requirement is to have more cost effective Protection Systems to reduce the overall cost of the Protection Scheme. In any modern business environment, cost is a focal issue. In Eskom, business imperatives have, over time, been biased either towards engineering / superior performance issues, or towards financial issues. It has now become necessary to seek an optimal balance between the two, with equipment cost being a priority issue. It is now necessary to engineer schemes smarter by better understanding and designing for the associated risks, and by eliminating unnecessary cost premiums by applying suitable functionality and performance capability to meet the specific requirements.

3.1.2 Scope of application

Transmission lines used in the Eskom transmission system vary in length from a few kilometres to hundreds of kilometres. The range of breaker-and-a-half EHV transmission line protection schemes employed must be capable of protecting various transmission line arrangements which include:

- Single and multi-circuit lines;
- Long, medium an short two-terminal transmission lines;
- Transposed and untransposed lines;
- Radial feeders;
- Series compensated lines (end-point, mid-point or multiple series compensation, and over compensated lines), and on lines adjacent to series compensated lines;
- Single or parallel lines with high mutual coupling;
- Transformer feeders (line banks);
- Multi-terminal lines;

- Flexible AC Transmission System (FACTS) devices; and,
- Generator back-up protection.

The performance and complexity of each protection scheme is matched to customer requirements and/or the strategic importance of the protected line.

These schemes shall interface with the diameter interface solution to provide for the required protection and control of the diameter and the lines. The line protection scheme shall be capable of single pole tripping (bay breaker) and three pole tripping (bay breaker and tie bay breaker), auto-reclosing (single and three-pole for the bay breaker and three-pole for the tie bay breaker), manual closing and single pole trip testing. The scheme permutations shall cater for application to stations with a single station HMI and stations with a dual station HMI.

3.2 Composition

3.2.1 Philosophy

For all breaker-and-a-half EHV transmission line protection applications, the bay protection solution shall comprise of a Fault Clearance System.

The Fault Clearance System shall comprise two independent and galvanically isolated Tripping Systems, plus the bay circuit-breaker and tie bay circuit-breaker. Each Tripping System shall comprise a Protection System, supplied from an independent DC source, receive its analogue inputs from a separate CT core and a separately protected VT core (line VT), interface to its own dedicated teleprotection equipment, and be directly connected (via the process interface unit) to one trip-coil of the bay circuit-breaker and to one trip-coil of the tie bay circuit breaker. The two Tripping Systems shall operate in a one-out-of-two tripping mode.

Each Protection System shall provide the requisite primary, back-up, system and auxiliary protection functions. Within a single Protection System, all protection functions shall reside within a single hardware device. The Protection Scheme is that portion of the Fault Clearance System housed within a cubicle within the control room building. The Protection System shall interface with the diameter primary equipment through IEC61850 process interface units located in close proximity to the primary plant equipment. The Protection System shall interface with other diameter primary equipment through IEC61850 process interface units for the purpose of transferring tripping and status signals between primary plant object connected to different diameters.

The breaker-and-half line protection scheme shall have one IED with all the required protection (distance and current differential protection) functions integrated within the IED. A maximum of two line protection IEDs, where the distance based IED protection functionality is fully integrated within the one IED and the current differential based IED functionality is fully integrated within the second IED is permissible.

Process interface units (PIU) are required to interface (binary inputs and outputs) between the primary plant equipment and the line protection IEDs. The PIUs shall be located within the relevant JB(s). The circuit-breaker PIU (breaker, isolator and earth switches) shall be used to interface (IEC61850) with the protection IEDs.

The IEDs (protection and PIU) shall comply with the Generic Specification for Intelligent Electronic Devices (IEDs) Standard, Unique Identifier 240-64685228.

3.2.2 Rationale

Two independent and galvanically isolated Tripping Systems operating in a one-out-of-two tripping mode are required to satisfy the single failure criterion. Furthermore, the provision of two Tripping Systems allows routine maintenance and refurbishment to be carried out on one Protection System without taking the line or diameter out of service. When necessary, the relevant Protection System can be isolated, keeping the line and diameter in service with the other Protection System still operational.

To comply with the single failure criterion and maintenance requirement, each Protection System is therefore required to provide the requisite primary, back-up, system, and auxiliary protection functionality. This will cater for:

- clearance of all faults occurring on the protected line, or of any hazardous (e.g. overvoltage) condition for which the protected line is the cause, measured by the Protection System functions, even in the event of a failure to operate of one Tripping System, or a failure within the mechanism of the circuit-breaker;
- successful clearance of uncleared external faults within the measurement range of the Protection System functions, primarily uncleared faults on the remote adjacent busbar; and,
- clearance of system generated disturbances or deviations, by incorporating within the Protection System protection functions primarily intended to operate for these system generated disturbances or deviations and not for faults occurring on the protected line, or by providing for inputs to the Protection System from externally realised protection functions to effect the required action.

Fully integrating all protection functions for each Protection System into one hardware device is required as this does not compromise the expected reliability of the overall scheme design due to the dual Tripping System philosophy, and the fact that all the integrated protection functions are independent functions within their own right, and not back-up to each other within the same Protection System. Although primarily a back-up function, the circuit-breaker failure protection does not provide back-up to the primary protection function or other supplementary function(s). The residual overcurrent protection an directional earth fault comparison is not considered as a back-up protection function, but rather as a protection function that supplements the primary protection function by detecting and operating for those high resistance faults which are beyond the measurement capability of the primary function. The other functions, such as overvoltage / compensated overvoltage, transfer tripping, etc., also do not offer back-up to, and are independent of, the primary protection function. The Tripping Systems is biased towards dependability (dual one-out-of-two tripping mode of operation).

The Protection System interface with the primary plant equipment through the IEC61850 process interface units is to minimise copper interfacing between the relay room and the primary plant equipment, and between different protection systems within the relay room.

3.2.3 Design requirements

The breaker-and-a-half line protection scheme shall comprise all the required protection functions, MCBs, test blocks, switches, pushbuttons and indications. The IED(s), MCBs, switches, indications, test blocks, indications and pushbuttons shall be located at the front of the panel. All the equipment shall have the capability to be mounted in a flush mount 19" rack system. The breaker-and-a-half line protection system shall not adversely affect the availability and performance of any other in-service protection system.

All protection functions within a protection system shall be integrated within a single hardware device. This hardware device shall comprise the single node through which all tripping and closing device initiations shall occur for all internally generated commands, as well as through which all externally generated trip commands shall be routed.

The breaker-and-a-half line protection scheme shall be designed that the panel can be mounted on either the left hand or right hand or both sides of the diameter interface panel (6DIP-#100). The breaker-and-a-half line protection scheme shall be an independent design with an own set of scheme diagrams.

The breaker-and-a-half protection system shall include:

- Main # Primary Protection System Not Healthy Indication (230 VAC);
- Main # Primary protection Device with all the required protection functions integrated within a single hardware device;
- Main # Bay Breaker Current Transformer Test Block;
- Main # Tie Bay Breaker Current Transformer Test Block;
- Main # Bay Breaker Disturbance Recorder Current Transformer Test Block;
- Main # Tie Bay Breaker Disturbance Recorder Current Transformer Test Block;
- Main # Line Voltage Transformer Test Block;

- Test Normal selection push buttons (push buttons for the following selection: Normal, Test 1 and Test 2);
- Main # DC Isolating MCB;
- Main # Bay Breaker Tripping DC Isolating MCB;
- Main # Teleprotection Isolating Switch;
- Main # Teleprotection Interface (optional and free issued, not part of this enquiry);
- Main # Teleprotection DC Isolating MCB;
- Main # Teleprotection DC/DC Converter (110/48 VDC or 220/48 VDC);
- Opto-coupler unit for external Disturbance Recorder (bay breaker status (independent per phase) and tie bay breaker);
- Diode Units; and,
- Main # Test Points.

The breaker-and-a-half line protection device shall constitute a single node through which all protection tripping shall be routed (all internal protection functions; plus all trip commands from the external devices, routed to binary inputs of the primary protection device). All the protection functions of the protection system shall reside within the line protection device.

The breaker-and-a-half line protection scheme shall provide for the following DC voltage options to meet the station requirements:

- 110 VDC; and,
- 220 VDC.

The scheme solutions shall have the capability interface and integrate with legacy diameter interface solutions. A scheme permutation with dual main protection within a single panel shall also be designed and available as a contact item.

The process interface units, in close proximity to the primary plant equipment, shall include all the required IEC61850 logical nodes required to represent each item of primary plant equipment. Each of the breaker bays shall have two process interface units to interface the two independent Fault Clearance Systems and diameter interface systems.

A secure supply, derived from the main 1 and main 2 DC systems, shall be available to power the singular primary plant interface items.

3.3 Line protection device

3.3.1 Philosophy

The breaker-and-a-half protection scheme shall have all the required protection functions integrated within a single IED. Process interface units (PIU) are required to be located in close proximity to the primary plant equipment and to provide the interface (binary inputs and outputs via IEC61850) between the primary plant equipment and the protection IEDs.

The LPHD (Logical Physical Device Information) Logical Node models the common issues for physical devices (diameter control IED). This Logical Node and associated Data Attributes such as physical description, physical health, communications, and power supply, shall be available to the Eskom System Configurator for modelling issues.

All intelligent electronic devices shall have built-in self-monitoring features. The built-in self-monitoring features shall not in any way compromise the operational status of any one of the functions (logical nodes).

3.3.2 Rationale

For the protection system, maximum integration of functions within a single hardware device is required to reduce complexity, DC supply burden and to achieve the maximum cost benefit.

The PIUs located within the relevant breaker bay JB, shall broadcast and receive IEC61850 messages from the diameter control devices and the protection devices. The utilisation of IEC61850 minimise the copper interface between the control room equipment and the primary plant.

Self-monitoring functions in IEDs are provided to avoid and control internal failures that can occur in these devices. Self-monitoring improves the availability of the protection scheme and also enables the reduction of the frequency and duration of relay maintenance visits. This in turn enables a reduction in the overall life-cycle cost of the protection.

3.3.3 Design requirements

The LPHD (Logical Physical Device Information) detailed requirements are within document 240-42066934 section 6.2.

The circuit breaker PIUs (breaker, isolator and earth switches) are required as interface (IEC61850) between the primary plant equipment within the diameter and the protection IED.

3.3.3.1 Breaker-and-a-half line protection IED

The breaker-and-a-half line protection IED (single IED that include both distance protection and current differential protection for application to any line length) shall include the following protection functions:

	Function	**Logical Node**
1	Zone 1 protection	PDIS 1
2	Zone 2 protection	PDIS 2
3	Zone 2 accelerated trip	PDIS 2
4	Zone 3 protection	PDIS 3
5	Reverse Zone protection	PDIS 4
6	Phase selection	PDIS 5
7	Distance zone directional element	RDIR
8	Power swing blocking	RPSB
9	VT Fuse failure	
10	Direct transfer tripping	PSCH 3
11	Switch-onto-fault protection	PIOC 1
12	STUB protection	PIOC 2
13	Bay breaker trip circuit seal-in	PIOC 3
14	Tie bay breaker trip circuit seal-in	PIOC 4
15	IDMT earth fault protection	PTOC 1
16	Local overvoltage protection	PTOV 1
17	Bay breaker trip conditioning	PTRC 1
18	Tie Bay breaker trip conditioning	PTRC 2
19	Bay breaker failure protection	RBRF 1
20	Tie Bay breaker failure protection	RBRF 2
21	Disturbance recorder function	RDRE

	Function	**Logical Node**
22	Disturbance recorder channel analogue (per analogue quantity)	RADR
23	Disturbance recorder channel binary (per binary signal)	RBDR
24	Fault locator	RFLO
25	Alarm handling	CALH
26	Bay breaker status	CSWI 1
27	Bay breaker pole discrepancy	
28	Bay breaker red phase discrepancy	
29	Bay breaker white phase discrepancy	
30	Bay breaker blue phase discrepancy	
31	Tie bay breaker status	CSWI 2
32	Tie bay breaker pole discrepancy	
33	Tie bay breaker red phase discrepancy	
34	Tie bay breaker white phase discrepancy	
35	Tie bay breaker blue phase discrepancy	
36	Line isolator status	CSWI 3
37	Line isolator discrepancy	
38	Measurements	MMXU
39	Bay breaker red phase trip circuit supervision	
40	Bay breaker white phase trip circuit supervision	
41	Bay breaker blue phase trip circuit supervision	
42	Tie bay breaker red phase trip circuit supervision	
43	Tie bay breaker white phase trip circuit supervision	
44	Tie bay breaker blue phase trip circuit supervision	
45	Circuit-breaker monitoring	
46	DC supply monitoring	
47	GOOSE receive functional blocks	
48	GOOSE broadcast functional blocks	
49	GOOSE broadcast functional blocks	
50	Human machine interface	IHMI
51	Binary inputs (quantity as per the required scheme design)	
52	Binary outputs (quantity as per the required scheme design)	
53	Analogue inputs (quantity as per the required scheme design)	
54	Generic process I/O (per function that does not have a standard defined logical node)	GGIO
55	Line current differential protection	PDIF
56	Distance zone protection scheme communication	PSCH 1
57	Directional earth fault protection scheme communication	PSCH 2
58	Compensated overvoltage protection	PTOV 2

	Function	Logical Node
59	Transfer isolator status	CSWI 4
60	Transfer isolator discrepancy	

3.3.3.2 The breaker-and-a-half line impedance based protection IED

In the event that two products are offered, impedance based line protection IED and current differential based IED, the impedance based protection IEDs shall include the following protection functions:

	Function	Logical Node
1	Zone 1 protection	PDIS 1
2	Zone 2 protection	PDIS 2
3	Zone 2 accelerated trip	PDIS 2
4	Zone 3 protection	PDIS 3
5	Reverse Zone protection	PDIS 4
6	Phase selection	PDIS 5
7	Distance zone directional element	RDIR
8	Power swing blocking	RPSB
9	VT Fuse failure	
10	Direct transfer tripping	PSCH 3
11	Switch-onto-fault protection	PIOC 1
12	STUB protection	PIOC 2
13	Bay breaker trip circuit seal-in	PIOC 3
14	Tie bay breaker trip circuit seal-in	PIOC 4
15	IDMT earth fault protection	PTOC 1
16	Local overvoltage protection	PTOV 1
17	Bay breaker trip conditioning	PTRC 1
18	Tie Bay breaker trip conditioning	PTRC 2
19	Bay breaker failure protection	RBRF 1
20	Tie Bay breaker failure protection	RBRF 2
21	Disturbance recorder function	RDRE
22	Disturbance recorder channel analogue (per analogue quantity)	RADR
23	Disturbance recorder channel binary (per binary signal)	RBDR
24	Fault locator	RFLO
25	Alarm handling	CALH
26	Bay breaker status	CSWI 1
27	Bay breaker pole discrepancy	
28	Bay breaker red phase discrepancy	
29	Bay breaker white phase discrepancy	

	Function	**Logical Node**
30	Bay breaker blue phase discrepancy	
31	Tie bay breaker status	CSWI 2
32	Tie bay breaker pole discrepancy	
33	Tie bay breaker red phase discrepancy	
34	Tie bay breaker white phase discrepancy	
35	Tie bay breaker blue phase discrepancy	
36	Line isolator status	CSWI 3
37	Line isolator discrepancy	
38	Measurements	MMXU
39	Bay breaker red phase trip circuit supervision	
40	Bay breaker white phase trip circuit supervision	
41	Bay breaker blue phase trip circuit supervision	
42	Tie bay breaker red phase trip circuit supervision	
43	Tie bay breaker white phase trip circuit supervision	
44	Tie bay breaker blue phase trip circuit supervision	
45	Circuit-breaker monitoring	
46	DC supply monitoring	
47	GOOSE receive functional blocks	
48	GOOSE broadcast functional blocks	
49	GOOSE broadcast functional blocks	
50	Human machine interface	IHMI
51	Binary inputs (quantity as per the required scheme design)	
52	Binary outputs (quantity as per the required scheme design)	
53	Analogue inputs (quantity as per the required scheme design)	
54	Generic process I/O (per function that does not have a standard defined logical node)	GGIO
55	Distance zone protection scheme communication	PSCH 1
56	Directional earth fault protection scheme communication	PSCH 2
57	Compensated overvoltage protection	PTOV 2
58	Transfer isolator status	CSWI 4
59	Transfer isolator discrepancy	

3.3.3.3 The breaker-and-a-half line current differential based protection IED

In the event that two products are offered, impedance based line protection IED and current differential based IED, the current differential based IEDs shall include the following protection functions:

	Function	**Logical Node**

	Function	**Logical Node**
1	Zone 1 protection	PDIS 1
2	Zone 2 protection	PDIS 2
3	Zone 2 accelerated trip	PDIS 2
4	Zone 3 protection	PDIS 3
5	Reverse Zone protection	PDIS 4
6	Phase selection	PDIS 5
7	Distance zone directional element	RDIR
8	Power swing blocking	RPSB
9	VT Fuse failure	
10	Direct transfer tripping	PSCH 3
11	Switch-onto-fault protection	PIOC 1
12	STUB protection	PIOC 2
13	Bay breaker trip circuit seal-in	PIOC 3
14	Tie bay breaker trip circuit seal-in	PIOC 4
15	IDMT earth fault protection	PTOC 1
16	Local overvoltage protection	PTOV 1
17	Bay breaker trip conditioning	PTRC 1
18	Tie Bay breaker trip conditioning	PTRC 2
19	Bay breaker failure protection	RBRF 1
20	Tie Bay breaker failure protection	RBRF 2
21	Disturbance recorder function	RDRE
22	Disturbance recorder channel analogue (per analogue quantity)	RADR
23	Disturbance recorder channel binary (per binary signal)	RBDR
24	Fault locator	RFLO
25	Alarm handling	CALH
26	Bay breaker status	CSWI 1
27	Bay breaker pole discrepancy	
28	Bay breaker red phase discrepancy	
29	Bay breaker white phase discrepancy	
30	Bay breaker blue phase discrepancy	
31	Tie bay breaker status	CSWI 2
32	Tie bay breaker pole discrepancy	
33	Tie bay breaker red phase discrepancy	
34	Tie bay breaker white phase discrepancy	
35	Tie bay breaker blue phase discrepancy	

	Function	**Logical Node**
36	Line isolator status	CSWI 3
37	Line isolator discrepancy	
38	Measurements	MMXU
39	Bay breaker red phase trip circuit supervision	
40	Bay breaker white phase trip circuit supervision	
41	Bay breaker blue phase trip circuit supervision	
42	Tie bay breaker red phase trip circuit supervision	
43	Tie bay breaker white phase trip circuit supervision	
44	Tie bay breaker blue phase trip circuit supervision	
45	Circuit-breaker monitoring	
46	DC supply monitoring	
47	GOOSE receive functional blocks	
48	GOOSE broadcast functional blocks	
49	GOOSE broadcast functional blocks	
50	Human machine interface	IHMI
51	Binary inputs (quantity as per the required scheme design)	
52	Binary outputs (quantity as per the required scheme design)	
53	Analogue inputs (quantity as per the required scheme design)	
54	Generic process I/O (per function that does not have a standard defined logical node)	GGIO
55	Line current differential protection	PDIF

3.4 Sensitivity

3.4.1 Philosophy

Sensitivity is the measure of the ability of the relay to detect faults, either with low primary quantities, or with small deviations from the healthy state.

The Protection System is required to respond correctly, including correct phase selection, without and with pre-fault load flow, for faults down to zero infeed conditions at one line terminal.

Within the measurement capability of the relay, e.g. set reaches for high resistance faults, or down to the sensitivity thresholds, e.g. minimum current, minimum deviation from healthy state, voltage limit for accurate reach point measurement, the phase selection / directional determination must be assured, and the variation in relay performance (tripping time) must be in accordance with the given acceptable tripping profiles.

3.4.2 Rationale

Cases exist on the Eskom network where, depending on the location of the fault on the protected line, the level of infeed from one terminal can vary from well above the sensitivity threshold to below the sensitivity threshold. As correct operation is expected from the non-affected terminal, the affected terminal is also required to operate correctly, including correct phase selection / correct single pole tripping, over the full infeed range, with pre-fault load flow (and during the fault on the non-faulted phase(s)). The terminal to which this applies is normally the importing load terminal.

Failure to perform correct single pole tripping, or performing incorrect tripping due to wrong directional determination can have adverse effects to both Eskom and Eskom's customers in the areas of system integrity, load flow capability and supply continuity. Therefore, within the 'capability plain' of the Protection System, correct, positive, operation must result, beyond the limitations of the relay no operation must result, and no cases of incorrect operation must result for quantities within the vicinity of the sensitivity thresholds or approaching the boundaries of operation.

Eskom is contractually bound to deliver an agreed level of power quality to its customers. Of primary concern here is dip minimisation. Excessive prolonging of protection equipment performance as it approaches its sensitivity limits is therefore unacceptable.

3.4.3 Design requirements

Correct co-ordination of the various sensitivity thresholds within the relay to ensure correct operation (correct faulted loop(s) detection / selection, etc.) for input quantities approaching below the minimum quantity sensitivity threshold(s), with pre-fault load flow.

The sensitivity of the protection functions is the measure of the ability of the relay to detect faults, either with low primary quantities, or with small deviations from the healthy state.

The protection system is required to respond correctly, including correct phase selection, without and with pre-fault load flow, for faults down to zero infeed conditions.

Within the measurement capability of the IED, e.g. minimum current, minimum deviation from healthy state, voltage limit for accurate reach point measurement, the phase selection / directional determination shall be assured, and the variation in IED performance (tripping time) must be in accordance with the given acceptable tripping profiles.

3.5 Security

3.5.1 Philosophy

Security is defined as the probability of not having an unwanted operation under given conditions for a given time interval. The protection system should have as high a security as possible.

3.5.2 Rationale

Security of the tripping system is very important because overtripping may lead to increased system risk and deterioration of power quality. Poor security would manifest itself in tripping for a through fault. Because of the principle of applying duplicate tripping systems in a 1 out of 2 tripping arrangement security is adversely affected as poor security of any of the two systems will result in poor security of the whole scheme.

Tripping system security can be influenced by software, incorrect settings and failure of hardware e.g. VT secondary supply failure, etc.

3.5.3 Design requirements

A balance needs to be achieved between the protection system security, its speed of operation and sensitivity.

The security should not be compromised by conditions such as open pole, or current and voltage reversal on series compensated lines.

3.6 Dependability

3.6.1 Philosophy

Dependability is defined as the probability of not having a failure to operate under given conditions for a given time interval. The protection system should have as high a dependability as possible.

3.6.2 Rationale

Dependability of the tripping systems is very important because un-cleared system faults could threaten system stability and integrity. Because of the undesirable consequences of failure of protection to operate it is Eskom's philosophy to duplicate tripping systems in a 1 out of 2 tripping arrangement.

Tripping system dependability can be influenced by software (configuration), incorrect settings, IED availability, d.c. supply health and failure of hardware e.g. VT secondary supply failure, etc.

3.6.3 Design requirements

The dependability should not be compromised by conditions such as open pole, CVT transients, CT saturation, geomagnetic induced currents or current and voltage reversal on series compensated lines.

3.7 Directionality

3.7.1 Philosophy

Directionality is the ability of a protection relay to distinguish between forward and reverse fault conditions. The relay shall be capable of correctly determining directionality, without any added delay to the overall tripping time, for any fault occurring for any network condition.

Relays applied to series compensated lines or adjacent to series compensated lines shall also be capable of correctly determining directionality even under the circumstances of voltage and / or current reversal.

3.7.2 Rationale

To achieve the required levels of security and dependability, correct directional determination is imperative.

3.7.3 Design requirements

Correct directionality is required for, inter alia:

- zero voltage faults;
- for any possible transmission system source to line impedance ratios;
- no load to maximum possible load conditions;
- high resistance fault conditions (single ph-to-earth and two single ph-to-earth faults);
- open pole conditions;
- evolving faults (fault inception from abnormal pre-fault condition);
- intercircuit and cross country faults; and,
- current and voltage reversal on series compensated lines.

Directionality is the ability of a protection functions to distinguish between forward and reverse fault conditions, and in-zone and out of zone faults. The protection functions shall be capable of correctly determining the fault position, without any added delay to the overall tripping time, for any fault occurring and for any network condition.

3.8 Speed

3.8.1 Philosophy

Clearance of network faults in the shortest time is a fundamental requirement, but this must be seen in conjunction with performance requirements for the specific application. The Protection Systems applied throughout Eskom's system shall comply with the specified operating times. Speed shall not compromise dependability and security.

Eskom has established a standard trip time profile for broadband EHV applications. These applications exclude special applications, e.g. series compensated lines, and applications which require, or can permit, different operating times. The Protection Systems applied throughout Eskom's transmission system, excluding the special cases, shall operate in accordance with this profile, and will fulfil Eskom's standard EHV feeder protection performance requirement. The profile represents the entire performance spectrum required to accommodate the full range of conditions expected on Eskom's total transmission system.

3.8.2 Rationale

The high operating speed of line protection relays applied on the transmission system is required for reasons of power system stability, power quality, limiting damage, and safety to personnel.

Power system stability is adversely affected by faults on the power system, with multi-phase faults being more onerous than single-phase-to-ground faults. For this reason fast clearance, especially of multi-phase faults, is essential, especially at certain critical locations on the power system.

As a general rule, faults with high fault levels (low SIR) require faster operating speeds for reasons of system stability, and the higher possibility of damage to plant.

Power quality has significant impact on Eskom's customers. Power quality standards have been introduced by the National Electricity Regulator, with limits being specified in supply contracts, and measured by Eskom and customers.

3.8.3 Design requirements

Security must not be compromised in the quest to achieve better operating speed. The tripping time requirements is for the setup where the line protection device GOOSE the trip signals to the PIU and the PIU binary outputs are connected to the breaker trip coils. The tripping time measure is from fault inception (within the line protection device) and closure of the PIU binary output (GOOSE inclusive) the is connected to the bay and tie bay breaker trip coils.

3.8.4 Tripping time profile

The operating time performance is specified in terms of an operating time standard. The profile consists of a curve, with a value for variable 'n'. Values for 'n' are specified according to defined categories. Category definition is based on line length, SIR, and fault position (as a percentage of set reach). The specified value for 'n' for a given category, positions the curve in the time domain, and in so doing prescribes the operating time performance requirement for the relay for the parameters which define the category. For a broad sample of faults within a given category, the minimum number (%) of operating times which are required to be less than 'n' ms is specified. The curve provides an operating time specification/evaluation reference for the operating time greater than, or equal to, 'n' ms. The shape of the curve is defined by assigning the number (%) of operating times at each millisecond from 'n' ms to the maximum operating time limit. Any given curve does not represent the acceptable spread for any repeated fault condition, but rather depicts the acceptable profile and maximum operating time for a representative sample of faults within a given category.

The protection device shall operate in accordance with the prescribed performance requirements irrespective of the number of functions enabled within the device. The tripping time is measured between fault inception (faulted phase(s)) and closure of the trip output contract to the breaker trip coil.

The trip time profiles below do not represent the acceptable spread for any repeated fault condition, but rather the acceptable profiles and maximum tripping times for a sample encompassing the full range of conditions one would expect to encounter on Eskom's total transmission system.

Included within the trip time profiles are any factors which may cause slower relay operating speed, such as transients present in the input quantities. Furthermore, the trip time profiles reflect the total operating time of the relay, including the output contacts and the GOOSE time.

The graphs depict the profiles of acceptable tripping times with respect to the number of trips at 'n' msec. For any given sample covering a broad representative set of conditions expected on Eskom's transmission system, for the trip time profile. A minimum of 80% of trips should yield operating times less than 'n' ms; and the profile is drawn with the number of trips at 'n' ms equal to 10%, with 10% in the range 'n+1' to 'n+6' ms. Figure 1 depicts the tripping time profile. Table 1 specifies the values for 'n' (in ms).

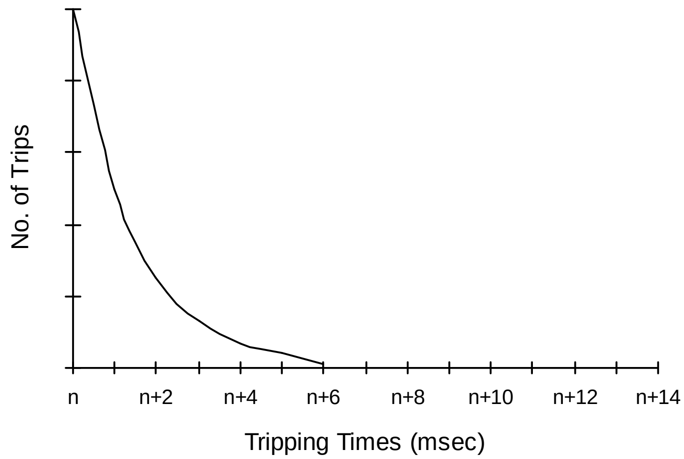


Figure 1: Tripping time profile

In order to meet the requirement that, for certain specific conditions, the relay must operate consistently within a prescribed subset of the quoted trip time profile, the following graph is also applicable, where the required operating times for conditions below the graph must be ≤ n msec.

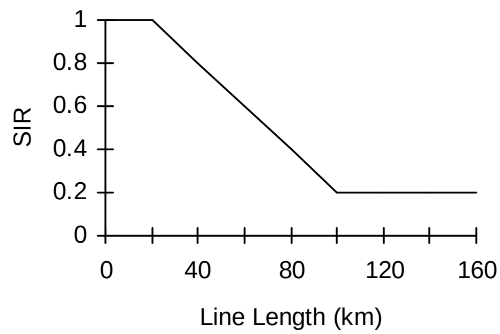


Figure 2: Line Length

Table 1: Underreaching Zone Operating Time Performance

Line length	**Fault position (% of Zone 1 set reach)**								
	0 – 20%			**21 – 60%**			**61 – 90%**		
	SIR≤1	**1<SIR≤6**	**6<SIR≤30**	**SIR≤1**	**1<SIR≤6**	**6<SIR≤30**	**SIR≤1**	**1<SIR≤6**	**6<SIR≤30**
Long line (>100km)	20	21	23	21	22	24	23	24	26

Medium line (20 – 100km)	21	22	24	22	23	25	24	25	27
Short line (< 20km)	23	24	26	24	25	27	26	27	29

The delays that could be introduced due to CVT transients, CT saturation and GOOSE transmission time is included within the required operating times.

3.8.4.1 Moderated trip time limits for conditions other than basic single faults

Fault scenario	**Tripping time**
High resistance faults (see 4.6.4) (for the measured impedance up to 80% of the zone boundary)	n'= n + 5
Evolving faults – from single-phase-to-ground to phase-to-phase-to-ground or three-phase (-to-ground) (from the point of change)	n'= n + 3
Faults during open pole conditions	n'= n + 3
Sequential tripping (following opening of the remote-end circuit-breaker)	n'= n + 3
Faults occurring ≤ 100 ms after clearance of parallel line fault (with possible current reversal)	n'= n + 3
Faults occurring > 100 ms after clearance of parallel line fault	1

NOTE: n' is the relaxed value of n as defined in 1 and 1

3.8.4.2 Moderated trip time limits for spark gap protected series compensated lines

Fault scenario	**Tripping time**
Faults between CVT and capacitor	n' = n + 0
Faults with capacitor between CVT and fault • capacitor gaps did not flash; or • capacitor gaps flashed (≤ 5 ms) on faulted phase/s only; or • capacitor gaps delayed flash (> 5 ms) or flashed asymmetrically	n' = n + 10

NOTE: n' is the relaxed value of n as defined in 1 and 1

3.8.4.3 Moderated trip time limits for MOV protected series compensated lines

Fault scenario	**Tripping time**
Faults between CVT and capacitor	n' = n + 0

Faults with capacitor between CVT and fault • MOV energy or temperature levels not exceeded (minimum current through MOV); or, • Minimum MOV resistance in parallel with capacitor (maximum current through MOV).	n' = n + 5

Note: n' is the relaxed value of n as defined in 1 and 1

3.8.4.4 Moderated trip times for switch-on-to-fault conditions

Fault scenario	Tripping time
Loose-in faults with current greater than hi-set SOTF current threshold	≤ 20 ms,
Remote faults with current less than hi-set SOTF current threshold	≤ 30 ms,

3.9 Accuracy

3.9.1 Philosophy

IED accuracy is a measure of an IED's ability to conform to its applied settings within a specified level of tolerance (excluding any errors introduced by current and voltage transformers). IED functions applied on EHV transmission line breaker-and-a-half protection schemes shall conform to the specified accuracy levels under all system operating scenarios.

3.9.2 Rationale

In EHV breaker-and-a-half protection applications IED accuracy is important to ensure no incorrect protection operations, over or under tripping occur due to measurement and/or timing errors. Accuracy is therefore closely coupled to the security, dependability, selectivity, sensitivity and directionality of all the protection functions within the tripping systems that make up the IED.

3.9.3 Design Requirements

Overall protection accuracy needs to take into account the accuracy of the current and voltage transformers used.

3.10 Single pole tripping

3.10.1 Philosophy

All primary protection IEDs shall be capable of performing single- and three-pole tripping and reclose initiation of the bay breaker and three-pole tripping and reclose initiation of the tie bay breaker.

Non-evolving, non-switch-onto-fault, single-phase-to-ground faults occurring on the protected line, which are cleared instantaneously, are required to be able to be cleared by tripping the relevant phase of the bay circuit-breaker and all three phases of the tie bay circuit-breaker.

All faults catered for by the protection including single-phase-to-ground faults (for which single-pole tripping may not be required under certain circumstances) are required to be able to be cleared by tripping all three phases of the bay circuit-breaker and all three phases of the tie bay circuit-breaker.

3.10.2 Rationale

On the Eskom transmission network, 85 % of all faults are single-phase-to-ground faults. Single pole tripping improves power transfer capability and increases the reliability of a mesh transmission system on a second or third contingency basis. From a utility customer perspective, single pole tripping also improves the availability of supply. Other considerations that support the use of single pole tripping and reclosing include, inter alia,

3.10.3 Design Requirements

The following design requirements should be considered:

- single pole tripping of the bay breaker;
- three pole tripping of the tie bay breaker also in the event that the bay breaker was already in the open position at the time of the fault;
- correct handling of a second fault during the one pole open condition;
- correct handling of evolving and cross-country faults; and,
- correct display of faulted phase information.

The success of single pole tripping schemes relies on the ability of the IEDs employed to have accurate phase selection capability (see section on Phase Selection).

3.11 Back-up philosophy

3.11.1 Philosophy

3.11.1.1 Faults on the protected line

The back-up philosophy adopted to ensure the dependable clearance of faults occurring on the protected line is one of local back-up. The required level of local back-up is accomplished by employing fully duplicated Tripping Systems, independent and galvanically isolated, operating in a one-out-of-two tripping arrangement, with the Protection System within each Tripping System incorporating bay circuit-breaker failure protection and tie bay circuit-breaker failure protection. The tripping system of the tie bay circuit-breaker is independent and galvanically isolated from the bay circuit-breaker tripping system. The tie bay breaker tripping system within the two object protection systems will share a common dc supply and connected to the same tie bay circuit-breaker trip coil per main protection system.

3.11.1.2 Faults not on the protected line

The feeder protection scheme is required to provide remote back-up protection to the remote-end busbar protection, as well as, in special circumstances, to the protection up to one busbar away from the remote-end busbar. This remote back-up shall be provided by overreaching, time-delayed, impedance elements, and not just IDMT or other overcurrent protection functions. There is no firm requirement for the provision of back-up to the busbar protection on the immediately adjacent reverse busbar, or to the protection up to one busbar away from the reverse busbar, though if the applied feeder protection is capable of providing this to the benefit of the system performance, it may be implemented.

The provision of remote back-up by both Tripping Systems (Protection Systems) is not a firm requirement, whereas it is a firm requirement that at least one of the Tripping Systems (Protection Systems) must provide this. This opens the way to apply, for example, a cost effective unit-type protection without impedance elements within one Tripping System, but not both Tripping Systems. When selecting the Tripping Systems for any application, cognisance must be taken not only of the requirements for the protected line, but of the remote back-up requirements as well.

3.11.2 Rationale

3.11.2.1 Faults on the protected line

The required level of dependability for the clearance of faults occurring on the protected line cannot be achieved by employing a single Tripping System, as it cannot be guaranteed that the elements within the Tripping System will never fail. For this reason dual Tripping Systems are required, whereby each Tripping System will provide local back-up to the other. The two Tripping System are required to be independent and galvanically isolated to reduce the possible points of common failure, thereby ensuring that no single failure will result in failure of the overall Fault Clearance System, and similarly to ensure that no failure within a single Tripping System will result in failure of the overall Fault Clearance System.

To achieve the increased dependability afforded by employing dual Tripping Systems, they must be configured in a one-out-of-two tripping arrangement.

The additional cost of employing dual Tripping Systems is justified by the high cost of the installed primary equipment, and the consequences to Eskom and its customers of the failure of the Fault Clearance System to successfully disconnect the faulted line.

Employing dual Tripping Systems does not cater for simultaneous failures within both Tripping Systems, or failures within the circuit-breaker, excluding the trip-coils, which form part of the Tripping Systems. The most likely cause of failure to clear faults not catered for by employing dual Tripping Systems is as a result of failures within the circuit-breaker. Simultaneous failures within both Tripping Systems rendering the Fault Clearance System inoperative are extremely unlikely and therefore not catered for in the back-up protection requirements. In order to cater for circuit-breaker failures, additional back-up protection over and above the local back-up afforded by employing dual Tripping Systems is required. This additional back-up protection can either be afforded by protection on circuits adjacent to the faulted line (remote back-up) or by local circuit-breaker failure protection (local back-up).

A remote back-up philosophy would cater for both causes of failure to clear protected line faults not catered for by the dual Tripping System / single failure criterion approach. To achieve adequate back-up, the Protection Systems at the remote-end of all adjacent feeders would need to provide a ‘third’ zone facility (zone 3 on impedance protection, or an equivalent overreaching zone on unit-type protection) which would cover the full length of the protected line. This cannot always be achieved in Eskom due to a scenario of long lines requiring extensive reach settings, and is exacerbated by the effects of remote infeed and the limitations imposed by load encroachment. Furthermore, due to the size of the third zone which is sometimes required to achieve the necessary back-up coverage, there is an increased sensitivity, resulting in a reduced security.

A local back-up philosophy based on circuit-breaker failure protection would cater only for those cases where the fault was not cleared as a result of a failure of the circuit-breaker. This is acceptable as a simultaneous failure within both Tripping Systems is a double contingency, the probability of which is extremely unlikely, particularly with the self-checking features presently incorporated within protection relays.

Following from the above, the adopted back-up philosophy for faults occurring on the protected line is one of local back-up. The associated benefits are the following:

- in the event of component failure within one Tripping System, clearing of the fault by opening only the intended line circuit-breaker without an added time delay will still be effected via the other Tripping System;
- following a failure to open of the circuit-breaker, circuit-breaker failure protection will effect fault clearance after a short, limited, fixed, time-delay, by initiating the tripping of adjacent circuit-breakers, within the same substation, and connected to the same zone as the failed circuit-breaker;
- the reduced security resulting from the requirements placed on the extent of the ‘third’ zone coverage can be eliminated;
- the clearing of faults by means of remote back-up protection operation can only occur after an extended time delay, and would result in widespread disruption due to the opening of the remote circuit-breakers on all connected circuits; and,

- a remote back-up protection philosophy would require the Protection Systems on the circuits adjacent to the faulted feeder to provide the required remote back-up protection; conversely, the Protection Systems associated with the protected feeder would need to include adequate protection functionality to afford the appropriate level of remote back-up protection to its adjacent circuits.

As tripping is effected via the one-out-of-two principle, it follows that the probability of a trip signal not being issued to the circuit-breaker is extremely small. Correct operation of any one of the two Tripping Systems is sufficient to effect tripping of the circuit-breaker. The most probable cause of uncleared faults is, therefore, a failed circuit-breaker For this reason all protection tripping functions within each Tripping System should initiate the circuit-breaker failure protection.

The only question is whether to duplicate the circuit-breaker failure protection or not. The factors to consider are:

- the expected number of circuit-breaker failures; and,
- the consequences of a circuit-breaker failure, bearing in mind that with the adopted local back-up philosophy, no reliance can be placed on ‘third’ zone assistance, versus the up-front cost of installing the circuit-breaker failure protection.

It can be argued that the dependability of the circuit-breaker failure function must be consistent with that of the protection functions, and that to cater for a single component failure, dual circuit-breaker failure protection is required, i.e. it must be included within each Protection System, operating in a one-out-of-two arrangement for bus-stripping. Ideally, therefore, guaranteed circuit-breaker failure initiation is required every time a protection initiated trip signal is issued to the circuit-breaker. The probability of this not occurring is very low if dual circuit-breaker failure is implemented, i.e. one per Protection System, but would be the most costly, and require a higher degree of justification, if stand-alone units were to be employed. Circuit-breaker failure initiation cannot be guaranteed if, to effect a cost reduction, a single stand-alone circuit-breaker failure is implemented, as this unit could fail with one, or both, of the protection (tripping) units still fully operational. The argument which ultimately decides the issue is Eskom’s acceptance of the integration of all protection functions within each Protection System into a single hardware device. This affords the most cost effective solution to employing dual circuit-breaker failure protection, with the guarantee that circuit-breaker failure will be initiated for every trip output, as the protection and circuit-breaker failure are integrated within the same hardware device, and this is not expected to be partially operational. It is not acceptable to include a single circuit-breaker failure function integrated within one Protection System, as a failure of that system would mean no circuit-breaker failure initiation for a trip issued by the healthy Protection System.

Little increase in overall dependability would be achieved by initiating each circuit-breaker failure protection from the protection function within each Tripping System. Therefore, for this reason, and to ensure maximum security against human errors, each Protection System should initiate only the circuit-breaker failure protection included within the same Protection System.

3.11.2.2 Faults not on the protected line

The busbar protection is not duplicated, and essentially there are no local back-up functions incorporated within the busbar protection. For this reason it is necessary for the line protection to provide remote back-up protection to the remote-end busbar protection.

For line protection incorporating impedance protection, remote back-up to the remote-end busbar protection is easily achieved by means of the first overreaching zone (zone 2). Even with a line protection philosophy of local back-up, zone 2 is provided to cover the remote-end of the line beyond zone 1 coverage, and will therefore cover the remote-end busbar. It is the smallest of the overreaching zones, with the shortest tripping delay, and is therefore eminently suited to provide this remote back-up.

For line protection incorporating unit-type protection, the required remote back-up to the remote-end busbar protection can only be achieved if the unit-type protection relay incorporates overreaching impedance elements.

Impedance-type protection functions are required to provide the remote back-up. IDMT or other overcurrent protection functions are not acceptable for the following reasons: IDMT overcurrent functions do not provide fixed, pre-determined tripping time delays whereas impedance protection tripping time delays can be set fairly short without resulting in co-ordination problems. Furthermore, the reach of IDMT or other overcurrent functions is also affected by the fault current level.

To cater for the possibility that one Tripping System may be out of service, the preference is that both Tripping Systems should be capable of providing the remote back-up. However, if this is not possible, e.g. due, following careful consideration, to the application of a unit-type protection scheme without overreaching impedance elements, the required back-up may be provided by one Tripping System only. The reasoning for accepting this is the following: The protection on the protected line, designed to satisfy the single failure criterion, will affect successful fault clearance even if one Tripping System fails. However, if one Tripping System has failed or is out of service (e.g. on test) full reliance is placed on the remaining in-service tripping system. Following the same reasoning, if the busbar protection fails to operate, successful fault clearance need be reliant on only one other protection system (per connected circuit). Although it is acceptable to reduce the provision of the remote back-up to one Tripping System, it is not acceptable to do away with the remote back-up altogether by employing two unit-type protections without overreaching impedance elements.

Circumstances can occur on the power system where remote busbars, one busbar away from the remote-end feeder busbar, do not have adequate back-up protection coverage, other than that which can be provided by the protected line protection, e.g. when transformer protection is unable to provide adequate back-up to the MV busbar protection due to a scenario of low fault levels and high load. To cater for these particular circumstances, the feeder protection should be equipped with a 'third' impedance zone capability. The 'third' zone back-up should only be implemented when required by the particular circumstances.

An argument for the provision of either local or remote back-up may be made by stating that as long as adequate back-up for the busbar protection is provided by correctly applied distance elements, it is immaterial whether this is provided locally (reverse reaching elements) or remotely (forward overreaching elements). In the interests of a standard back-up philosophy, remote back-up is the chosen standard, and as a minimum a 'second' zone impedance function shall be provided. It is not possible to base the standard philosophy on the provision of local back-up as not all protection relays have the necessary reverse elements capable of providing this.

3.11.3 Design requirements

None

3.12 Duplication

3.12.1 Philosophy

For all EHV breaker-and-a-half applications, the Fault Clearance System shall incorporate two Tripping Systems, each of which shall contain a Protection System. The preferred practice for all Eskom EHV breaker-and-a-half applications is for:

- two identical impedance Protection Systems;
- combined main 1 current differential protection system and main 2 impedance protection system; or,
- two identical current differential protection systems.

A dual identical or non-identical unit-type Protection System without overreaching elements is not acceptable.

3.12.2 Rationale

In order to satisfy the single failure criterion, dual Tripping Systems are employed. However, Eskom makes a distinction between a failure to operate as a result of a failed or defective Protection System, and a failure to operate as a result of a performance deficiency inherent within the design of the Protection System. Eskom's interpretation of the single failure criterion is that it shall cater for a failed component within one Tripping System (Protection System), and not a performance deficiency. Eskom does not, therefore, stipulate that the two Protection Systems should use different relays with similar, or different, measuring principles. In fact, Eskom believes that no compromise in dependability is incurred by employing carefully selected and tested identical Protection Systems, and that employing identical Protection Systems can yield a more secure solution than non-identical. Experience has also taught Eskom that the probability of overtripping is larger than that for undertripping, further strengthening the argument for identical Protection Systems. A further argument is that in certain applications a particular Protection System may offer a better performance than the other alternatives, thereby making no sense to employ non-identical Protection Systems.

The Eskom transmission system, with a predominance of long lines, is eminently suitable for the application of impedance protection. The advantages of impedance protection include favourable operating times, limited dependence on teleprotection signalling to provide direct tripping, and no essential requirement for inter-substation digital communications. It also offers the highest compatibility with the existing installed base, requiring for the remote-end protection nothing more than a similar impedance protection scheme operating with the same (Eskom standard) teleprotection philosophy. Unit-type protection requires a digital communications link, as well as identical Protection Systems at both ends of the line, both requirements having significant cost implications.

For certain applications (very short lines, predominance of high resistance faults, etc.) impedance protection does not provide the best solution, and unit-type protection should be applied. However, when applying unit-type protection, cognisance must be taken of the requirement for the feeder protection to provide back-up to the remote-end busbar protection. For this reason, dual identical unit-type Protection Systems can only be applied if they incorporate overreaching impedance elements which are continuously in-service.

The communications philosophy requires two totally diverse routes for the two Main Protection Systems. However, for dual unit-type Protection System applications, to cater for the possibility of a common mode failure whereby both Main Protection Systems simultaneously experience communications channel failure, direct tripping underreaching impedance elements, in addition to the overreaching elements, and which at minimum are switched-in on communications channel failure, must be incorporated within at least one of the Protection Systems. This ensures the provision of at least one Main stepped-distance scheme to provide non time-delayed clearance without communications for faults occurring on the major portion of the line. For schemes comprising one unit-type Protection System and one impedance Protection System, there is no firm requirement that the unit-type Protection System has any impedance elements, as the impedance Protection System fulfils the requirement of providing at least one Main stepped-distance scheme, as well as the required provision of remote back-up to the busbar protection by one Main Protection System.

Preference for short lines is to be protected with dual current differential protection, with the required local and remote back-up functions.

3.12.3 Design requirements

None

3.13 Analogue processing

3.13.1 Philosophy

The breaker-and-a-half line protection IED shall have the ability to independently interface with both the bay CTs (3 phases and neutral) and tie bay CTs (3 phases and neutral). The bay CT and tie bay CT quantities shall be independently and summated available, within the protection IED, for the required protection functions. The independent and summated CT quantities are also required to be connected to the internal disturbance recorder.

The breaker-and-a-half protection IED shall interface with the line CVT (3 phases), on the line side of the line isolator.

The analogue quantities for the line protection functions and stub protection shall be controlled by the line isolator status and with no line isolator discrepancy condition.

All the analogue quantities shall be synchronised within the IED as not to influence the measured accuracy and dependability of the protection functions.

3.13.2 Rationale

The independent CT quantities are required for the bay and tie bay breaker failure protection and trip circuit seal-in. The summated current quantities are required for the line protection functions.

Internal summation of the CTs is required to prevent magnetisation of a disconnected CT in the event of external summation.

The connection to the line side CVT is to cater for end line series compensation where the CVT is required to be on the line side of the series capacitor bank. The connection to the line side CVT, on the line side of the line trap, is also required for the power line carrier equipment.

The control of the line protection functions by the line isolator is necessary as to disable these functions when the line isolator is open and without a line isolator discrepancy condition. The line protection functions is connected to the line side CVT and with the line isolator open the line CVT is disconnected from the diameter and cannot be relied upon to provide credible quantities to the line protection functions. The stub protection is therefore required to be activated as to provide instantaneous protection of the stub between the bay breaker, tie bay breaker and line isolator, when the line isolator is open and with no discrepancy condition.

3.13.3 Design Requirements

The line isolator open and no line isolator discrepancy shall be combined to disable and enable protection functions and tripping inputs. All protection functions shall be active when the line isolator is open and with the presence of a line isolator discrepancy condition.

3.14 Binary information processing

3.14.1 Philosophy

The primary protection device shall constitute a single node through which all protection tripping shall be routed (all internal protection functions, plus all trip commands from the external devices, and teleprotection signals that are routed to binary inputs or received GOOSE messages).

The GOOSE data shall be utilised to communicate plant information and protection information between IEDs (and test equipment). IEC 61850 shall be implemented as “purely” as possible (e.g. defined logical node names and data attributes).

3.14.2 Rationale

The single node requirement for the primary protection device provides for:

- Trip circuit seal-in;
- Breaker fail initiation;
- Auto-reclose initiation;
- Teleprotection interface; and,
- Local and remote reporting.

The GOOSE data usage reduce the hardwire interfacing between IEDs within the bay, the primary plant equipment and interfacing with other bays.

3.14.3 Design Requirements

The vendor shall comply with the IEC61850 standards and Eskom's requirements as per document 240-42066934.

GOOSE data communication shall be between the primary protection device and:

- Diameter control device;
- Other main diameter control device;
- Other object protection system;
- Bay breaker process interface unit;
- Tie bay breaker process interface unit;
- Teleprotection equipment failed to the other main protection system;
- Line reactor protection system;
- Line reactor breaker process interface unit;
- Busbar reactor protection system;
- Busbar reactor breaker process interface unit;
- Teleprotection equipment; and,
- Busbar protection system.

3.15 Local controls

3.15.1 Philosophy

Protection system test and normal mode control and teleprotection on and off controls shall be made available locally, on a real time basis.

3.15.2 Rationale

Protection system test and normal mode control and teleprotection on and off controls are required by the protection field staff and site operators to facilitate safe testing of the protection system and teleprotection equipment.

3.15.3 Design Requirements

Protection system mode control shall be utilised to control the trip signals to the bay and tie bay breakers, busbar protection system and the series capacitor bank protection system (when applicable).

The teleprotection mode controls shall be utilised to control the teleprotection signals to and from the teleprotection equipment.

The preferred method of providing local controls is via integrated programmable push buttons on IEDs, as an alternative, dedicated local control LCD/LED screen HMI. The required local controls:

- TNS Normal selection;
- TNS Test 1 selection; and,
- TNS Test 2 selection.

The following shall be a dedicated device and independent from the IED HMI:

- TPIS Switch.

3.15.3.1 Supervisory Isolating Switches

The Bay Supervisory Isolating Switch (B#SIS) and the Tie Bay Supervisory Isolating Switch (TBSIS) is located on the diameter interface panel and provides for the selection between local (OFF selected), remote (ON selected) controls and maintenance mode (breaker fail isolated). The Bay Supervisory Isolating Switch (B#SIS) maintenance mode selection shall be wired from the diameter interface panel to the main # protection device to block the bay breaker fail function. The Tie Bay Supervisory Isolating Switch (TBSIS) maintenance mode selection shall be wired from the diameter interface panel to the main # protection device to block the tie bay breaker fail function.

3.15.3.2 Test Normal selection

The Test Normal selection (TNS) provides for the isolation of trip outputs, isolation the bay breaker fail outputs and selection for auto-reclose initiation. The TNS selections shall be done via the IED HMI or alternatively by use on push buttons with indications on the front of the panel. The TNS selection shall be latched within the IED and shall retain the selection when the IED powers down and back up again. The enabling and disabling of the relevant functions, as per the below, shall be done within the IED. The TNS selection shall not be selectable from remote (Station HMI and Control centre). The selected TNS position shall be clearly displayed (illuminated) on the HMI or on the panel. The TEST 1 and TEST 2 selections shall be remotely reported (station HMI and control centre).

The following is the controlled by the TNS selections:

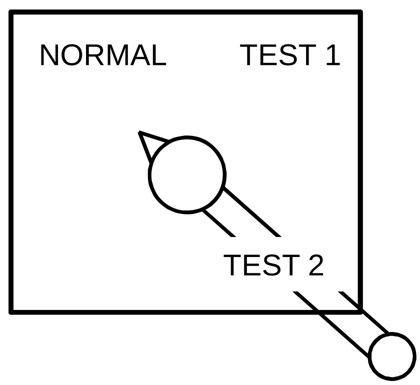
Description	Selection of the desired test option for the protection tripping, breaker failure signal and auto-reclose initiations.
NORMAL	Enable: • Main # red phase trip to the bay breaker Main # red phase trip-coil; • Main # white phase trip to the bay breaker Main # white phase trip-coil; • Main # blue phase trip to the bay breaker Main # blue phase trip-coil; • Main # red phase trip to the tie bay breaker Main # red phase trip-coil; • Main # white phase trip to the tie bay breaker Main # white phase trip-coil; • Main # blue phase trip to the tie bay breaker Main # blue phase trip-coil; • Bay breaker one-pole auto reclose initiation; • Bay breaker three-pole auto reclose initiation; • Bay breaker auto reclose block; • Tie bay breaker three-pole auto reclose initiation; • Tie bay breaker auto reclose block; • Bay breaker three-pole trip selected from the auto-reclose function; • Bay breaker one-pole auto reclose in progress from the bay closing device; • Bay breaker red phase trip counter; • Bay breaker white phase trip counter; • Bay breaker blue phase trip counter; • Tie bay breaker three phase trip counter; • Main # bay breaker fail to the busbar protection scheme (own zone); • Main # bay breaker fail to the busbar protection scheme (other zone);

	• Main # tie bay breaker fail to the other object Main # protection; • Main # red phase trip to the series capacitor bank; • Main # white phase trip to the series capacitor bank; • Main # blue phase trip to the series capacitor bank; and, • Reverse zone trip.
TEST1	Enable: • Main # red phase trip to the bay breaker Main # red phase trip-coil; • Main # white phase trip to the bay breaker Main # white phase trip-coil; • Main # blue phase trip to the bay breaker Main # blue phase trip-coil; • Main # red phase trip to the tie bay breaker Main # red phase trip-coil; • Main # white phase trip to the tie bay breaker Main # white phase trip-coil; • Main # blue phase trip to the tie bay breaker Main # blue phase trip-coil; • Bay breaker one-pole auto reclose initiation; • Bay breaker three-pole auto reclose initiation; • Bay breaker auto reclose block; • Tie bay breaker three-pole auto reclose initiation; • Tie bay breaker auto reclose block; • Bay breaker three-pole trip selected from the auto-reclose function; and, • Bay breaker one-pole auto reclose in progress from the bay closing device. Disable: • Main # bay breaker fail to the busbar protection scheme (own zone); • Main # bay breaker fail to the busbar protection scheme (other zone); • Main # tie bay breaker fail to the other object Main # protection; • Main # red phase trip to the series capacitor bank; • Main # white phase trip to the series capacitor bank; • Main # blue phase trip to the series capacitor bank; • Reverse zone trip; • Bay breaker red phase trip counter; • Bay breaker white phase trip counter; • Bay breaker blue phase trip counter; and, • Tie bay breaker three phase trip counter.
TEST2	Disable: • Main # red phase trip to the bay breaker Main # red phase trip-coil; • Main # white phase trip to the bay breaker Main # white phase trip-coil; • Main # blue phase trip to the bay breaker Main # blue phase trip-coil;

	• Main # red phase trip to the tie bay breaker Main # red phase trip-coil; • Main # white phase trip to the tie bay breaker Main # white phase trip-coil; • Main # blue phase trip to the tie bay breaker Main # blue phase trip-coil; • Bay breaker one-pole auto reclose initiation; • Bay breaker three-pole auto reclose initiation; • Bay breaker auto reclose block; • Tie bay breaker three-pole auto reclose initiation; • Tie bay breaker auto reclose block; • Bay breaker three-pole trip selected from the auto-reclose function; • Bay breaker one-pole auto reclose in progress from the bay closing device; • Bay breaker red phase trip counter; • Bay breaker white phase trip counter; • Bay breaker blue phase trip counter; • Tie bay breaker three phase trip counter; • Main # bay breaker fail to the busbar protection scheme (own zone); • Main # bay breaker fail to the busbar protection scheme (other zone); • Main # tie bay breaker fail to the other object Main # protection; • Main # red phase trip to the series capacitor bank; • Main # white phase trip to the series capacitor bank; • Main # blue phase trip to the series capacitor bank; and, • Reverse zone trip.

The following functions shall be independent on the TNS selection:

- Main # Buszone trip input (own zone);
- Main # Buszone trip input (other zone); and,
- Main # tie bay breaker fail from the other object Main # protection.



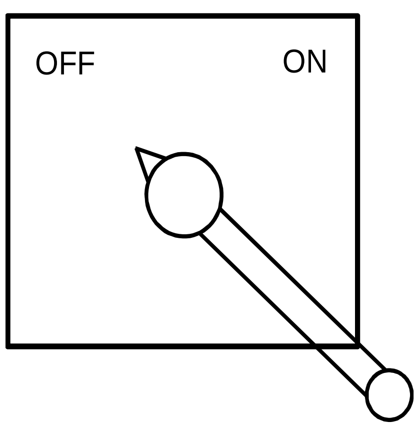
NOTE:

- Rotational direction: NORMAL ⇨ TEST 1 ⇨ TEST 2
- Rotational direction: TEST 2 ⇨ TEST 1 ⇨ NORMAL

3.15.3.3 Teleprotection Isolating Switch

The Teleprotection isolating switch (TPIS) provides isolation of the main # 48 VDC teleprotection supply to the teleprotection circuits. The enabling and disabling of the relevant functions, as per the below, shall be done external to the IED. The OFF selection shall be remotely reported (station HMI and control centre).

Description	Selection of the Main # 48 VDC teleprotection supply to the teleprotection circuitry.
OFF	De-energise the Main # 48 VDC teleprotection circuitry thereby disabling: • Permissive send; • Permissive receive; • Directional earth fault comparison permissive send; • Directional earth fault comparison permissive receive; • Direct transfer trip send; and, • Direct transfer trip receive.
ON	Energise the Main # 48 V DC teleprotection circuitry thereby enabling: • Permissive send; • Permissive receive; • Directional earth fault comparison permissive send; • Directional earth fault comparison permissive receive; • Direct transfer trip send; and, • Direct transfer trip receive.



NOTE:

- Rotational direction: OFF ⇨ ON

- Rotational direction: ON ⇨ OFF

3.16 Local indications

3.16.1 Philosophy

The IED mimic shall have a single line diagram representing the applicable bay, with the required controls, indications and display of analogue quantities. The IED HMI shall reflect the true status being selected, the most resent protection operational indications and the real time analogue quantities. The selected modes shall continuously be illuminated and health verified with the lamp check function.

3.16.2 Rationale

The IED information is required by the protection field staff and site operators to visually verify control selections, protection operation information for post fault analysis and analogue quantities.

3.16.3 Design Requirements

The required indications and selection statuses shall be displayed in real time on the IED HMI with the option to latch the indications.

The following IED HMI indications are required:

- TNS selection;
- TPIS selection;
- Non time delayed trip;
- Time delayed trip;
- Bay breaker trip signals;
- Tie bay breaker trip signals;
- Buszone trip;
- Breaker fail;
- Bay breaker 3 pole trip selected
- External trip;
- Carrier channel A transmitted;
- Carrier channel A received;
- Carrier channel B transmitted;
- Carrier channel B received;
- Carrier channel C transmitted;
- Carrier channel C received;
- Line VT fuse failure;
- Bay Breaker pole and phase discrepancy;
- Tie bay Breaker pole and phase discrepancy;
- Isolator discrepancy;
- Teleprotection equipment or Current Differential communications failed;
- IEC61850 communications failure that affects the GOOSE signals; and,

- Bay Breaker Trip Circuit supervision alarm.

The following indications shall be available on the IED HMI or on the LCD/LED screen HMI:

- TNS Normal selected;
- TNS Test 1 selected;
- TNS Test 2 selected; and,
- Protection System Not Healthy Indication.

All indications shall be visible by default, that is, no external influence shall be required to view any indication. Indication lamp colours shall be as follows:

- Red: Trip conditions, not healthy conditions; and
- Amber: Alarm conditions.
- White (or Amber): Earth applied, Automatic Voltage Control on Manual (DIP only)

The protection IED HMI shall be equipped with light emitting diodes for local reporting purposes. The following conditions shall be reported separately via IED indications and shall not activate the M#PSNH alarm:

Indication	Description	Mode
1	Non time delayed trip • Zone 1 trip; • Weak infeed trip; • Trip during a power swing; • Permissive trip; • Directional earth fault comparison trip; • Switch-onto-fault trip; and, • Stub protection trip.	Latched - reset via Push Button
2	Time delayed trip • Zone 2 trip; • Reverse zone trip; • Zone 3 trip; • Zone 2 accelerated trip when both main 1 & 2 teleprotection equipment has failed; • IDMT earth fault trip; • Local overvoltage trip – blocked with the line/busbar reactor isolator open and with no discrepancy; and, • Compensated overvoltage trip.	Latched - reset via Push Button
3	Bay breaker trip signals • Red phase trip; • White phase trip; and, • Blue phase trip.	Latched - reset via Push Button
4	Tie Bay breaker trip signal • Three pole trip.	Latched - reset via Push Button
5	Buszone trip • Buszone trip from own zone; and, • Buszone trip from other zone in the event that the	Latched - reset via Push Button

	other object is not present (only 1 object on that diameter).	
6	Breaker fail • Bay breaker fail; and, • Tie bay breaker fail.	Latched - reset via Push Button
7	Bay breaker 3 pole trip selected • Bay breaker 1-pole trip enable signal (supervised by TNS selected to Test 2. Remove the 3-pole trip selected when on test 2 to permit 1-pole tripping for testing purposes); • Trip during power swing – to force a 3 pole trip for this condition; • Busbar reactor diameter application selected; and, • IEC61850 communications failure that effects the GOOSE signals – disabled when the TNS is selected to test 2.	Latched - reset via Push Button

Indication	Description	Mode
8	External trip • Out-of-step trip input – disabled with the line/busbar reactor isolator and no discrepancy; • External 3-pole trip without auto-reclose – disabled with the line/busbar reactor isolator and no discrepancy; • External 3-pole trip without auto-reclose; • Simultaneous trip by the line protection and line reactor protection trip input; • Simultaneous trip by the line protection and busbar reactor protection trip input; • Series capacitor bank breaker failure to close trip input; • Connected line reactor breaker fail trip; • Connected busbar reactor breaker fail trip; and, • Other object on the diameter tie bay breaker fail.	Latched - reset via Push Button
9	Carrier channel A transmitted • Directional earth fault comparison carrier send.	Latched - reset via Push Button
10	Carrier channel A received • Directional earth fault comparison carrier received.	Latched - reset via Push Button
11	Carrier channel B transmitted • Permissive carrier send – this channel is also triggered by the direct transfer trip send signal.	Latched - reset via Push Button
12	Carrier channel B received • Permissive carrier received – this channel is also triggered by the direct transfer trip received signal.	Latched - reset via Push Button

13	Carrier channel C transmitted • Direct transfer trip carrier send – this signal also trigger channel B transmit.	Latched - reset via Push Button
14	Carrier channel C received • Direct transfer trip carrier received – this signal also trigger channel B receive.	Latched - reset via Push Button
15	Line VT fuse failure (delayed as to prevent unnecessary alarming).	Follow the condition
16	Bay Breaker pole and phase discrepancy.	Latched - reset via Push Button
17	Tie Bay Breaker pole and phase discrepancy.	Latched - reset via Push Button

Indication	Description	Mode
18	Isolator discrepancy • Line isolator; and, • Transfer isolator.	Latched - reset via Push Button
19	Teleprotection equipment or Current Differential communications failed	Follow the condition
20	IEC61850 communications failure that affects the GOOSE signals.	Follow the condition
21	Bay Breaker Trip Circuit supervision alarm.	Follow the condition

3.17 Remote indications, info and status to be reported

3.17.1 Philosophy

The IED shall report all the active protection indications and alarms, when operated to the client(s). The indications and alarms shall be time stamped at the IED. The detailed functional specifications will include the list of MMS data points (Logical nodes and data attributes) for vertical communication. The vendors shall use IEC 61850 as “purely” as possible (e.g. defined logical node names and data attributes). Remote information reporting are required for all protection mode selections, supply health, equipment health and protection operations.

3.17.2 Rationale

The IED protection indications and alarms are required by the control centre staff and site operators to manage the network effectively by restoring tripped lines to service. The IED protection indications and alarms are logged at the station HMI for post fault analysis.

3.17.3 Design Requirements

The indications and alarms of the required protection functions shall comply with the IEC61850 standards and Eskom’s mandatory requirements as per document 240-42066934. The detailed functional specifications shall include the list of MMS data points (Logical nodes and data attributes) for vertical communication.

The IED shall report the protection operation and unhealthy conditions per data attribute and as grouped alarms.

The CAHL logical node shall be used for the creation of group alarms and group events. This logical node shall be used to calculate new data out of individual data from different logical nodes. The following grouped alarms are required for remote reporting purposes:

Grouped Alarm	**Individual data points within grouped alarm**
Protection operated	Trip During Power Swing Detection Switch-Onto-Fault Trip – Three pole Switch-Onto-Fault Trip – Single pole STUB Trip Weak Infeed Trip - Red Phase Weak Infeed Trip - White Phase Weak Infeed Trip - Blue Phase Permissive Trip - Red Phase Permissive Trip - White Phase Permissive Trip - Blue Phase Zone 2 Trip - Both TPE Failed Directional Earth Fault Comparison Trip Directional Earth Fault Comparison Trip - Red Phase Directional Earth Fault Comparison Trip - White Phase Directional Earth Fault Comparison Trip - Blue Phase Directional Earth Fault Comparison 3 Pole Trip Line Protection Trip and Line Reactor Trip (Simultaneous) Line Protection Trip and Busbar Reactor Trip (Simultaneous) External Three Pole Trip No ARC
Breaker fail operated	Line Reactor Breaker Fail Trip Busbar Reactor Breaker Fail Trip Bay Breaker Fail Operated Tie Bay Breaker Fail Operated Tie Breaker Fail Trip From Other Object Protection
Non unit protection operated	IDMT Earth Fault Trip

Grouped Alarm	**Individual data points within grouped alarm**
	Local Overvoltage Trip Compensated Overvoltage Trip

Breaker Phase Discrepancy Trip	Bay Breaker Phase Discrepancy Trip
	Bay Breaker Phase Discrepancy Trip - Red Phase
	Bay Breaker Phase Discrepancy Trip - White Phase
	Bay Breaker Phase Discrepancy Trip - Blue Phase
	Tie Breaker Phase Discrepancy
	Tie Breaker Phase Discrepancy Trip -Red Phase
	Tie Breaker Phase Discrepancy Trip -White Phase
	Tie Breaker Phase Discrepancy Trip - Blue Phase
Breaker Pole Discrepancy Trip	Bay Breaker Pole Discrepancy Trip
	Tie Bay Breaker Pole Discrepancy Trip
Direct Transfer Trip	Direct Transfer Trip Send
	Direct Transfer Trip Receive
Bus Zone Trip	Buszone Trip from Own Zone
	Buszone Trip from Other Zone
Main # DC Fail	Main # Protection DC Supply Failed
	Main # Bay Breaker Tripping DC Supply Failed
IEC61850 Communication Failed	IEC61850 Communication to the DCD Failed
	IEC61850 Communication to the Main # PIU Failed
	IEC61850 Communication to the Line Reactor PIU Failed
	IEC61850 Communication to the Busbar Reactor PIU Failed
Protection Abnormal	TNS Test 1 Selected
	TNS Test 2 Selected
	TPIS OFF Selected
Protection Unhealthy	VT Fuse Failed
	VT Supply MCBs Tripped (All three Single Phase MCBs Tripped)
Teleprotection Unhealthy	Own Main Teleprotection Equipment Failed
	Other Main Teleprotection Equipment Failed
	Main # Teleprotection DC Supply Failed

3.18 GOOSE data for testing

3.18.1 Philosophy

The IED(s) shall be configured with GOOSE data to verify each setting within the IED. The test equipment will also simulate test points for verification and fault playback purposes. The simulated GOOSE signals shall be enabled and disabled within the IED. All the protection functions to be tested shall be enabled and the bay breaker three pole trip selected condition removed from PTRC1 when selected to the test mode.

3.18.2 Rationale

The utilisation of GOOSE data for testing eliminates the need to switch off (disable) any function within the IED (non-intrusive testing).

The GOOSE testing information is required by the protection field staff to verify all the applied setting during commissioning and maintenance activities. The test equipment will subscribe to the GOOSE data being broadcasted by the IED under test to interrupt the test quantities for the function under test. The test equipment simulated GOOSE data attributes are required for verification and fault playback purposes. The simulated GOOSE signals shall be enabled and disabled within the IED, when selected to the test mode, to prevent any simulated GOOSE signal to remain high and hence adversely affect the in-service performance of the IED. The bay breaker three pole trip selected condition are required to be removed from PTRC1, when selected to the test mode, to enable verification of single pole tripping.

3.18.3 Design Requirements

The GOOSE data attributes required for testing shall comply with the IEC61850 standards and Eskom's mandatory requirements as per document 240-42066934. The detailed functional specifications shall include the list of the GOOSE data testing points (Logical nodes and data attributes).

3.19 Secondary injection testing test aids

3.19.1 Philosophy

Current and voltage testing facilities shall be available between the current & voltage transformers and the IED.

3.19.2 Rationale

The current and voltage testing facilities are required to isolate the interfaces between the current & voltage transformers and the IED. The testing facilities shall provide for:

- Automatic short circuiting of the incoming current transformer circuits;
- Measurement of the current in the incoming current transformer circuit of all three phases and the neutral individually;
- Measurement of the voltage in the incoming voltage transformer circuit of all three phases and the neutral individually; and,
- Injection of test currents and voltages into the panel circuits on all three phases and the neutral individually 9with the bay in, or out of service).

3.19.3 Design Requirements

Current transformer test interface shall be fitted with shorting strips to prevent open circuiting of current transformer secondary circuits when the IED is under test or out of service.

The current and voltage transformer circuit's connections to test facilities shall be consistent with legacy arrangements.

The testing interfaces shall be located on the front of the panel and be clearly labelled.

3.20 Line current differential protection: PDIF

3.20.1 Philosophy

The line current differential function shall compare the currents, on a per phase basis, entering and leaving the protected line and shall provide phase selection information for single-pole tripping. The current differential function shall be sufficiently sensitive to detect in-zone high resistance faults (no additional protection function shall be necessary to cater for high resistance faults).

The current differential protection shall provide immunity to CT saturation and to inrush currents, and shall provide compensation for transmission line charging current. The measurement algorithm shall ensure immunity to DC offset, harmonics, high frequency components and sub-fundamental frequency reactor ring down. A CT failure or current unbalance alarm shall be provided and shall not operate during the open pole period and shall not increase the overall tripping time. The operation of the current differential protection shall be independent of the real-time clock.

The current differential protection device shall provide for a direct communication link to the remote current differential protection device via a dedicated fibre optic link. The integrated optic transmitter shall transmit at 1310 nm over a distance of up to 30 km. An embedded direct transfer trip function shall be provided for.

The communication channel shall be continuously monitored and failure of the channel shall result in an alarm. The current differential measurement shall automatically compensate for any communication channel delay (caused for example by automatic network route switching). The alarm is to be activated after a settable time as to avoid nuisance alarms. The impedance zones shall be independent on the health of the communications channel. The current differential measurement shall accommodate a telecommunications propagation delay time of 10 ms or more and shall automatically compensate for deviations (caused for example by automatic network route switching) of up to 3 ms either side of the propagation delay time setting. The current differential function shall have a user definable address for the identification of current differential pairs via the telecommunications network.

The current differential function shall have the capability to interface with a current differential function at the remote end where the busbar layout can be either breaker-and-a-half (2 CT inputs) or double busbar (single CT input).

The selection of the local or remote test facilities shall disable both the local and remote current differential functions. Any current differential communications failure shall disable both the local and remote current differential functions.

The current differential protection system shall cater for single- and three-pole switch-onto-fault conditions (three-pole manual close or three-pole auto-reclose at one line-end only, single-pole auto-reclose at both line-ends simultaneously). All switch-onto-fault tripping shall be three-pole. Tripping for a switch-onto-fault must occur via the switch-onto-fault logic for a fixed (settable) switch-onto-fault time duration following closure of the circuit-breaker (single- or three-pole).

The current differential protection system shall remain secure for a reversal of current on the protected line following unequal circuit-breaker opening on the faulted parallel line. Security shall also be maintained for current reversal conditions with a simultaneous change in current magnitude.

For the conditions of a strong infeed to a fault on the protected line from one terminal, and a weak/zero infeed from the other, the current differential protection system shall be capable of issuing a trip output at both the strong and weak/zero infeed ends without any significant added time delay at the weak/zero infeed end.

The current differential protection function shall remain stable during power swings on the power system. Notwithstanding the varying conditions experienced during power swing conditions, correct operation shall occur for a protected line fault that occurs during the power swing.

3.20.2 Rationale

The requirement for the current differential protection is to ensure non time delayed protection can be effected over the entire line length for any fault type and position on the protected line. Phase selective tripping is required to trip for only the faulted phase and to maintain connection and hence power transfer between the two stations on either side of the protected line. The current differential protection shall remain stable for any fault outside of the protected zone and for any network, primary plant or instrument transformer phenomena.

Communication verification is to prevent unwanted/over tripping in the event of a communications failure of extensive communications delay between the line ends.

3.20.3 Design Requirements

Current transformer test interface shall be fitted with shorting strips to prevent open circuiting of current.

The current differential function shall make provision to be blocked (communications failures and test mode selections) to be immune to specific conditions thereby prevent overtripping.

3.21 Distance protection zones

3.21.1 Philosophy

The minimum requirement for the protection of the protected line is three forward zones, one underreaching zone, and two overreaching zones. However, to cater for special circumstances over and above the protection requirements for the protected line, a fourth reverse reaching zone is also required.

The three forward reaching zones shall have the capability of issuing a trip command after its associated time delay, or with the time delay bypassed in accordance with the chosen teleprotection aided logic. The fourth reverse reaching zone shall have the capability of issuing a trip command after its associated time delay to intertrip another circuit-breaker within the station.

All zones shall be capable of being set independently with respect to reach, trip delay time, direction (third and fourth zones only) and IN / OUT selection. The trip delay time shall be settable from zero.

3.21.2 Rationale

The requirement for three forward zones of protection for the protected line is so that the first and second zones of protection will ensure non time delayed protection can be effected over the entire line length, and the third zone of protection to provide remote back-up to uncleared busbar faults one busbar away. Although this could be achieved with only a single overreaching zone, faults occurring anywhere along the entire line length from any given line-end would be reliant on the chosen teleprotection aided tripping logic to effect non time delayed tripping. By incorporating a direct tripping underreaching zone, dependence on the teleprotection aided tripping logic from any given line-end to effect non time delayed tripping is limited to a small remote segment of the line.

Three forward zones of protection supports the adopted philosophy on the Eskom transmission system of local back-up protection, i.e. back-up provided by circuit-breaker failure protection. Furthermore, the overreaching zone provides the required back-up to the remote-end busbar protection.

In order to cater for circumstances which can occur whereby the protection on adjacent equipment to the protected line cannot adequately cover its remote busbar, the line protection, one busbar back from the adjacent equipment, can provide for this by incorporating a third zone. For this reason, impedance protection shall include a third zone. However, this third zone back-up should only be implemented when required by the particular circumstances.

Independently settable reach settings for all zones are required to permit optimal reaches for each zone to be set in all circumstances, e.g. for a short line followed by long lines, where optimal reach settings for the overreaching zone may not be possible if the reach settings are interdependent, i.e. a multiple of the shortest reach (underreaching zone) or of a common base. Independent time delay settings for each zone are required to ensure that no delay set on any given zone affects any other zone or any logic, e.g. permissive tripping logic, associated with any other zone.

Independent zone IN / OUT selection is required for the following reasons:

- it provides the facility to select the direct tripping first (underreaching) zone out for very short line and overcompensated series compensated line applications, i.e. if the first zone either cannot be, or is chosen not to be, selected as the teleprotection aided overreaching zone;
- it provides the facility to select the second zone out if so desired whenever the first zone is selected as the first overreaching zone;and,
- it provides the facility to select the third and fourth zones out when it is not required.

3.21.3 Design requirements

The start signals (signal starting the zone time delay) from the first forward overreaching zone and the fourth reverse reaching zone shall be available for the current reversal guard functionality.

The start signal (signal starting the zone time delay) from the first forward overreaching zone shall be available for the switch-onto-fault function.

The fourth reverse reaching zone tripping output shall be independently selectable ON/OFF as to have the start always available for current reversal guard in the event where tripping is not required from the fourth zone. The fourth zone trip signal shall be available on potential free contacts as to be wired into another scheme and DC tripping supply.

The distance protection is a non-unit protection whose operation and selectivity depend on local measurement of electrical quantities from which the equivalent distance to the fault is evaluated by comparing with zone settings with a time interval between the instant when the characteristic quantity of a measuring relay in reset condition is changed, under specified conditions, and the instant when the distance protection function operates.

The distance protection zones shall make provision to be blocked by other functions to be immune to specific conditions thereby prevent overtripping or undertripping.

3.21.3.1 Additional influencing functions/conditions

The following conditions will affect the behaviour of the distance protection function. These conditions can be detected by additional function elements which then interact with the distance protection functions through external inputs or signals from internal functional elements in pre-defined ways. The distance protection zones shall make provision to be blocked by other functions or to be immune specific conditions to prevent overtripping or undertripping:

- Inrush currents due to power transformer switching shall not generate unwanted starting or operate signals by the distance protection functions;
- System emergency conditions and black start conditions it is important that the performance of the distance function is not compromised when the frequency is outside of the operating range; and,
- The distance zone measurement shall not incorrectly operate for, or following a trip output remain sealed-in for, frequency variations (e.g. reactor ringdown conditions).

3.21.3.2 Effect on reach measurement accuracy

Reach measurement accuracy (overreaching or underreaching) shall not be adversely affected for:

- faults during high import and export of load;
- evolving faults;

- faults during an open pole condition;
- switch-onto-fault conditions;
- cross-country faults;
- high fault resistance faults;
- weak system conditions;
- series compensation (end, multiple end, off-set and mid);
- high mutual coupling; and,
- untransposed lines.

3.21.3.3 Distance zones element input and output requirements

The distance zones shall have the following input signals available for use within the integrated IED:

- 3 phase analogue voltages;
- 3 phase and neutral analogue currents (internally summated bay and tie bay currents);
- phase selection;
- directionality; and,
- distance zone blocking (VT fuse fail detection, power swing blocking & line isolator open without a discrepancy). It is permissible to also control the analogue quantities by enabling and disabling of the quantities to the zone functional blocks.

The distance zones shall have the following output signals available for use within the integrated IED:

- general start forward;
- general start reverse;
- general start non-directional;
- general trip;
- phase A trip;
- phase B trip; and,
- phase C trip.

3.21.3.4 Zone 1 protection: PDIS 1

The first forward zone shall have the capability of issuing a trip command after the associated zone 1 time delay. In the majority of applications, the function of the first zone shall be to provide a direct tripping underreaching zone of protection. The delay time for the first zone shall therefore be settable down to zero.

The zone 1 distance protection function shall:

- Trip the bay breaker single pole for single line to ground faults and three pole for multi-phase faults (PTRC1 - with trip seal-in in accordance with the trip seal-in logic). Three pole trip selection for all fault types shall be done within the PTRC1. The outputs from PTRC1 shall trip the bay breaker and initiate the bay breaker's breaker fail function;
- Trip the tie bay breaker three pole for single line to ground faults and multi-phase faults (PTRC2 - with trip seal-in in accordance with the trip seal-in logic). The outputs from PTRC2 shall trip the tie bay breaker and initiate the tie bay breaker's breaker fail function;
- Initiate the bay breaker single pole auto-reclose cycle for single line to ground faults and three pole auto-reclose cycle for multi-phase faults (the permitted auto-reclose cycle and sequence will be determined by the auto-reclose function);

- Initiate the tie bay breaker three pole auto-reclose cycle for single line to ground faults and for multi-phase faults (the permitted auto-reclose cycle and sequence will be determined by the auto-reclose function);
- Initiate teleprotection permissive transmit for both PUR and POR modes;
- Phase segregated tripping shall be connected to the IED internal disturbance recorder function (RBDR); and,
- Phase segregated tripping shall be reported to the gateway and station HMI.

3.21.3.5 Zone 2 protection: PDIS 2

The second forward zone shall provide the (first) overreaching zone of protection, with time delayed tripping. The second zone shall protect 100% of the protected line including the remote end busbar. Tripping of the bay breaker and the tie bay breaker by the second zone, after the zone delay time, shall be three pole and auto-reclosing shall be blocked.

The second forward zone shall be implemented within the required teleprotection aided tripping logic. It shall be possible to implement the second zone within the teleprotection logic with the zone time delayed tripping either enabled or disabled. Phase segregated information is required to

The second forward zone start signal shall be used to trigger the permissive carrier transmit channel when in the permissive overreach mode and to issue a trip (single or three pole) on receipt of a permissive receive signal in both the permissive overreach and permissive underreach modes.

The zone 2 distance protection function shall:

- Trip the bay breaker three pole, after the zone delay time, for single line to ground faults and multi-phase faults (PTRC1 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC1 shall trip the bay breaker and initiate the bay breaker's breaker fail function;
- Trip the tie bay breaker three pole, after the zone delay time, for single line to ground faults and multi-phase faults (PTRC2 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC2 shall trip the tie bay breaker and initiate the tie bay breaker's breaker fail function;
- Initiate teleprotection permissive transmit for the POR mode;
- Phase segregated zone starting signals are required for permissive tripping of the bay breaker. Single pole for single line to ground faults and three pole for multi-phase faults. The single phase permissive trip signals shall initiate the bay breaker single pole auto-reclose cycle and the multi-phase permissive trip signals shall initiate the bay breaker three pole auto-reclose cycle (the permitted auto-reclose cycle and sequence will be determined by the auto-reclose function);
- Phase segregated zone starting signals are required for permissive tripping of the tie bay breaker. Three pole for single line to ground faults and multi-phase faults. The single phase permissive trip signals and the multi-phase permissive trip signals shall initiate the tie bay breaker three pole auto-reclose cycle (the permitted auto-reclose cycle and sequence will be determined by the auto-reclose function);
- When the fault is detected in the forward direction, the current reversal guard function shall be blocked even in the event that the fault current would then reverse due to opening one of the parallel faulted line breakers. Once current reversal is established, subsequent operation of the zone 2 start function shall permit the current reversal guard timer to time out;
- Block the weak infeed function. The blocking of the weak infeed function shall remain active after opening of the last breaker to prevent unwanted tripping due to the presence of a permissive receive signal;
- Block the permissive echo function;

- Provide for a general forward start input to the switch-onto-fault function to ensure instantaneous remote end fault clearance when charging the line from the local end;
- Block directional earth fault comparison Comp;
- Provide for a general forward start input to the zone 2 accelerated tip function;
- Zone forward start shall be connected to the IED internal disturbance recorder function (RBDR);
- Phase segregated permissive tripping shall be connected to the IED internal disturbance recorder function (RBDR);
- Zone tripping, after the zone delay time, shall be connected to the IED internal disturbance recorder function (RBDR); and,
- Zone phase segregated tripping shall be reported to the gateway and station HMI.

3.21.3.6 Zone 2 accelerated trip

The zone 2 accelerated trip function shall trip both the bay breaker and tie bay breaker when both main protection teleprotection channels have failed with the presence of a zone 2 forward start detection, after a set delay. This time delay shall be independently settable from the zone 2 tipping time delay.

The zone 2 accelerated tripping function shall:

- Trip the bay breaker three pole, after the accelerated delay time, for single line to ground faults and multi-phase faults (PTRC1 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC1 shall trip the bay breaker and initiate the bay breaker's breaker fail function;
- Trip the tie bay breaker three pole, after the accelerated delay time, for single line to ground faults and multi-phase faults (PTRC2 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC2 shall trip the tie bay breaker and initiate the tie bay breaker's breaker fail function;
- Zone accelerated tripping, after the accelerated delay time, shall be connected to the IED internal disturbance recorder function (RBDR); and,
- Zone accelerated tripping shall be reported to the gateway and station HMI.

3.21.3.7 Zone 3 protection: PDIS 3

The third forward zone shall be used to provide remote time-delayed back-up with a zone reach setting greater than that of the second zone.

The zone 3 distance protection function shall:

- Trip the bay breaker three pole, after the zone delay time, for single line to ground faults and multi-phase faults (PTRC1 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC1 shall trip the bay breaker and initiate the bay breaker's breaker fail function;
- Trip the tie bay breaker three pole, after the zone delay time, for single line to ground faults and multi-phase faults (PTRC2 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC2 shall trip the tie bay breaker and initiate the tie bay breaker's breaker fail function;.
- Zone forward start shall be connected to the IED internal disturbance recorder function (RBDR);
- Zone tripping, after the zone delay time, shall be connected to the IED internal disturbance recorder function (RBDR); and,
- Zone tripping shall be reported to the gateway and station HMI.

3.21.3.8 Reverse Zone protection: PDIS 4

The reverse zone shall be used to provide local time delayed back-up with a zone reach setting greater than that of the remote end second zone reach.

The reverse zone distance protection function shall:

- Trip the bay breaker, user selectable, three pole, after the zone delay time, for single line to ground faults and multi-phase faults (PTRC1 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC1 shall trip, user selectable, the bay breaker and initiate the bay breaker's breaker fail function and/or, user selectable, other breaker(s) within the substation;
- Trip the tie bay breaker, user selectable, three pole, after the zone delay time, for single line to ground faults and multi-phase faults (PTRC2 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC2 shall trip, user selectable, the tie bay breaker and initiate the tie bay breaker's breaker fail function and/or, user selectable, other breaker(s) within the substation;
- Trip other breaker(s), user selectable, within the substation;
- The reverse zone start condition shall be used to activate the current reversal guard logic;
- The reverse zone start condition shall be used to block weak end infeed tripping;
- The reverse zone start condition shall be used to block permissive carrier echo;
- Zone reverse start shall be connected to the IED internal disturbance recorder function (RBDR);
- Zone tripping, after the zone delay time, shall be connected to the IED internal disturbance recorder function (RBDR); and,
- Zone tripping shall be reported to the gateway and station HMI.

3.21.3.9 Distance zone directional element: RDIR

The distance zone directional element (RDIR) is a dedicated logical node and shall present all the directional protection activation information to the distance zones (PDIS) logical node(s).

The directional element shall have the ability to distinguish between forward and reverse fault conditions, and in-zone and out of zone faults. The directional element shall be capable of correctly determining the fault direction, without any added delay to the overall tripping time, for any fault occurring and for any network condition.

The directional element activation information shall not be adversely affected for series compensated line applications (protected line or adjacent to a series compensated line) for voltage reversals caused by series compensated lines.

3.21.3.10 Fault locator: RFLO

The fault locator shall calculate from the protection information (for example the fault impedance of the LN distance function) the location of the fault in km. The distance to fault in Km shall be displayed on the IED HMI and shall be easily accessible to the operating staff. The distance to fault location shall not be adversely affected for series compensated line applications.

3.21.3.11 Auto reclose bay initiation

The main protection device shall provide for the suitable initiation of the bay breaker and the tie bay breaker auto-reclose functionality within the diameter control device. Reclose initiation shall take the form of separate signals for single- and three-pole reclose initiates for the bay breaker and three-pole reclose initiates for the tie bay breaker. The bay breaker and tie bay breaker auto-reclose block shall be initiated for all functions (protection device tripping functions) and commands (breaker fail command and all external trip commands) which are not permitted to initiate a reclosing cycle. The bay breaker and the tie bay breaker reclose initiation and reclose block signals to the auto-reclose functions shall be dependent on the TNS selection (permitted when selected to 'Normal' or 'Test 1'). The bay breaker single- and three-pole auto-reclose initiate signals and the tie bay breaker three-pole auto-reclose initiate signal shall not be slower than the trip signals to the breakers as to ensure the successful start of an auto-reclose cycle. The auto-reclose initiate and block signals shall be send via GOOSE to the diameter control device that is housing the auto-reclose functionality.

3.22 Distance protection characteristic

3.22.1 Philosophy

The distance measurement function shall have an operating characteristic which shall operate inside a characteristic boundary. The operating characteristics shall be referred to the distance protection function impedance setting(s) for a radial feeder with no superimposed load. The operating characteristic shall make provision for measures against load encroachment and to maximise fault resistance coverage. The operating characteristics shall have a settable minimum enabling current and residual current from a parallel line. The distance zone shall have phase segregated zone start and zone trip signals available for tripping and for use by other related protection functions (e.g. Teleprotection accelerated tripping, weak-end infer tripping, current reversal guard, switch-onto-fault, etc.).

3.22.2 Rationale

The quadrilateral characteristic is the required distance characteristic, the distance zone(s) within the integrated IED shall meet the specified performance requirements with respect to: operating times, phase selection, directional determination, reach measurement accuracy for the specified range of line lengths, fault resistance coverage, and load flow conditions. The impedance measurement shall not incorrectly operate for, or following a trip output remain sealed-in for, sub-fundamental frequency reactor ringdown conditions [Note: the line reactor is connected on the line side of the CTs within the diameter, hence the line reactor is in the forward direction of the distance zones].

3.22.3 Design requirements

The protection IED shall be equipped with four zones of protection. Three of these shall be in the forward direction and the fourth in the reverse direction. For each zone, all 6 fault loops shall be independently measured. All zones shall operate, and hence be settable, independently of each other. Independent zone settings shall include: reach, time delay and IN/OUT selection.

3.23 Distance protection phase selection

3.23.1 Philosophy

All EHV relays shall correctly determine the faulted phase(s) under all fault conditions and operating scenarios.

3.23.2 Rationale

To enable correct single pole tripping of the bay breaker on all single pole tripping applications and to correctly indicate faulted phase information for all tripping conditions.

3.23.3 Design Requirements

The correct phase selection shall correctly operate for, inter alia:

- weak in-feed conditions;
- switch-onto-fault conditions;
- evolving faults;
- cross country faults;
- high resistance faults (single ph-to-earth faults and two single ph-to-earth faults);
- Single or parallel lines with high mutual coupling;
- open pole conditions (both on the protected line and in the source);
- Multi-terminal lines;
- Transformer feeders (line banks); and,
- single or three pole bypass of own or adjacent line series capacitor bank (end-point, mid-point or multiple series compensation, and over compensated lines).

Correct operation should not be compromised by adverse pre-fault conditions and correct operation should be ensured for single-, double- and multi-circuit transmission line applications.

Faulted phase identification is required to enable appropriate distance loops and inhibit the other loops in order to maintain dependability and security. The distance protection phase selection shall detect and indicate the appropriate faulted phases and also indicate if earth is involved in the fault (for single phase to earth and phase-phase to earth faults).

Faulted phase identification is also essential for correct fault location, teleprotection, single phase tripping and reclosing. Faulted phase identification will be challenged under some fault conditions including evolving faults, cross-country faults, high fault resistance faults and weak system conditions.

3.24 Distance zone timers

3.24.1 Philosophy

The distance zones shall, apart from the zone reach settings, have the following settings:

- ON/OFF selection;
- Current supervision (settable); and,
- Settable zone tripping delay time.

3.24.2 Rationale

To enable correct coordination with adjacent line faults en hence prevent overtripping of own line for adjacent line faults.

3.24.3 Design Requirements

The ON/OFF selection shall only disable the trip signals (input to the distance zone timer) and not the start signals.

The zone timer shall be restarted when the fault evolve from a single-line to ground fault to a multi-phase fault. The zone timer shall be restarted for any fault type during and open-pole condition.

The distance protection function shall have a settable current supervision for:

- Minimum operating current condition that will select between distance zone measurement and weak-end-infeed detection; and,

- Operating current condition that will release the distance zone on series compensation lines after bypassing of the series capacitor bank(s).

3.25 Switch-onto-fault protection: PIOC 1

3.25.1 Philosophy

The switch-on-to-fault protection shall cater for single- and three-pole switch-on-to-fault conditions, single- and three-pole open pole conditions, and shall cover the full line length. All switch-on-to-fault tripping shall be three-pole. Switch-on-to-fault tripping shall be effected via a high-set overcurrent threshold and/or the first overreaching zone in the forward direction.

Tripping via the switch-on-to-fault logic shall only occur for the duration of the switch-on-to-fault window, and then only for faults that occur on a phase that was open. The switch-on-to-fault window shall be a settable fixed value, and not be reset on detection of healthy line voltage.

3.25.2 Rationale

Switch-on-to-fault is required for all three-pole breaker closures (manual closures and auto-reclosures) to ensure tripping following closure onto a fault where there is a possibility of no pre-fault voltage.

In addition switch-on-to-fault is also required for single-pole auto-reclosures to improve the fault clearance time, as the system may not have fully recovered from the initial disturbance.

To provide accelerated tripping for switching onto remote faults, the switch-on-to-fault function is required to cover the full line length. Fast tripping can be effected via high-set overcurrent for close-in faults. However, to preserve discriminative tripping, it is not possible to cater for remote-end faults in this way. Remote-end faults shall therefore be catered for by the release of an overreaching (to ensure coverage of entire line) element, with the timing bypassed, for the duration of the switch-on-to-fault window.

Often following closure, and in particular auto-reclosure, healthy voltage is established for a few cycles before breakdown to a short-circuited fault condition. For this reason reset of the switch-on-to-fault window should not be reset by detection of healthy line voltage, but should be maintained for a fixed, settable, time duration. In this way recurring faults after a small number of cycles of healthy voltage (delayed re-strike of the original fault) will still be fast cleared via the switch-on-to-fault logic, and not via the normal impedance tripping logic. As the fixed window will enable the switch-on-to-fault logic for a longer duration than a window reset by detection of healthy voltage, there is a slightly higher risk of over-tripping for an adjacent line fault. To minimise this risk, the impedance element released for switch-on-to-fault tripping should be the first forward directional overreaching zone, and not a higher zone or non-directional element, or a starting element / fault detector.

3.25.3 Design requirements

The required outputs for a single-pole switch-on-to-fault are:

- Three-pole trip,
- breaker fail initiation,
- three-pole auto-reclose initiate (or block, selectable),
- teleprotection permissive signal send (selectable). The selectable teleprotection signal send is to cater for cases of weak infeed switch-on-to-fault at the remote terminal.
- switch-on-to-fault trip alarm.

The required outputs for a three-pole switch-onto-fault are:

- Three-pole trip,
- breaker fail initiate,
- three-pole auto-reclose block,

- direct transfer trip send,
- switch-on-to-fault trip alarm.

The VT supply used shall be the line VTs. The SOTF function shall be blocked with the line isolator in the open position and with no line isolator discrepancy condition.

A switch-on-to-fault (line check) function is required for all single and three-pole closures of the circuit-breaker (manual closures as well as automatic reclosures). All switch-on-to-fault tripping shall be three-pole. Switch-on-to-fault tripping shall only occur for faults occurring on a switched (from open to closed) phase. For three-pole closures (manual or automatic) a fault on any phase(s) shall result in switch-on-to-fault tripping as all phases will have been switched. However, for single-pole reclosures, switch-on-to-fault tripping shall only occur if the fault includes the switched phase.

Switch-on-to-fault tripping shall not occur when energising transformers/line reactors. Furthermore, switch-on-to-fault tripping logic shall not be spuriously armed, but shall only be armed for actual circuit-breaker open/line (phase) discharged conditions. This condition shall be determined by measurement, and not by the status of the circuit-breaker auxiliary contact(s). Activation of the switch-on-to-fault function shall be done after successful fault clearance and resetting of the protection elements and current detection that did operate during the fault. Tripping by way of the switch-on-to-fault logic shall only occur within the switch-on-to-fault window. The switch-on-to-fault window shall commence timing on detection, by measurement, that the pole(s) of the circuit-breaker are no longer open, or that the line (phase) is no longer discharged. The switch-on-to-fault window shall be a settable fixed value, and shall not be reset on detection of healthy line voltage.

The switch-on-to-fault function shall cover the full line length. Switch-on-to-fault tripping of close-in faults shall be effected by way of a high-set overcurrent element, and of remote faults by way of the release (timing bypassed) of the second zone (first overreaching zone, forward direction only). The requirement for the release of this zone, and not a farther reaching or starting/fault detector zone, which may also be non-directional, is due to the switch-on-to-fault window being a fixed value.

Switch-on-to-fault protection function shall following a three pole closure (manual or auto-reclose):

- Trip the bay breaker three pole for single line to ground faults and multi-phase faults (PTRC1 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC1 shall trip the bay breaker and initiate the bay breaker’s breaker fail function;
- Trip the tie bay breaker three pole for single line to ground faults and multi-phase faults (PTRC2 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC2 shall trip the tie bay breaker and initiate the tie bay breaker’s breaker fail function;
- Three phase switch-on-to-fault trip signal shall be connected to the IED internal disturbance recorder function (RBDR); and,
- Three phase switch-on-to-fault tripping shall be reported to the gateway and station HMI.

Switch-on-to-fault protection function shall following a single pole closure (single pole auto-reclose):

- Trip the bay breaker three pole for single line to ground faults and multi-phase faults (PTRC1) and initiate three pole auto-reclosing (or block auto-reclosing, user selectable). The outputs from PTRC1 shall trip the bay breaker and initiate the bay breaker’s breaker fail function;
- Trip the tie bay breaker three pole for single line to ground faults and multi-phase faults (PTRC2) and initiate three pole auto-reclosing (or block auto-reclosing, user selectable). The outputs from PTRC2 shall trip the tie bay breaker and initiate the tie bay breaker’s breaker fail function;
- Initiate teleprotection permissive transmit, user selectable;
- Single phase switch-on-to-fault trip signal shall be connected to the IED internal disturbance recorder function (RBDR); and,
- Single phase switch-on-to-fault tripping shall be reported to the gateway and station HMI.

3.26 STUB protection: PIOC 2

3.26.1 Philosophy

The STUB protection function shall be used to provide instantaneous protection for the STUB between the bay breaker, tie bay breaker and line isolator in the event that the line isolator is in the open position and without a line isolator discrepancy condition.

3.26.2 Rationale

The STUB protection is required due to the absence of a line VT quantity that is located on the line side of the line isolator and outside the zone of the STUB protection.

3.26.3 Design Requirements

The STUB protection function shall:

- Trip the bay breaker three pole for single line to ground faults and multi-phase faults (PTRC1 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC1 shall trip the bay breaker and initiate the bay breaker's breaker fail function;
- Trip the tie bay breaker three pole for single line to ground faults and multi-phase faults (PTRC2 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC2 shall trip the tie bay breaker and initiate the tie bay breaker's breaker fail function;
- STUB trip signal shall be connected to the IED internal disturbance recorder function (RBDR); and,
- STUB tripping shall be reported to the gateway and station HMI.

3.27 Bay breaker trip circuit seal-in: PIOC 3

3.27.1 Philosophy

The Protection System shall include trip-circuit seal-in capability which shall operate for all possible primary system conditions prevailing at the time of issuing the trip, i.e. seal-in of the trip-circuit to occur irrespective of the flow or not of primary system current. The trip-circuit seal-in logic should seal-in not only the trip-circuit, but also the relevant scheme functionality, e.g. circuit-breaker failure initiate inputs, recloser initiate inputs, and alarm outputs.

If, at the time the Protection System makes the decision to issue a trip output, primary system current flow above a threshold is detected by the relay, the seal-in must be based on the flow of this current. This must be applied for the full duration of the fault event, and must not revert to the no current seal-in on successful opening of the circuit-breaker.

If no primary current is detected at the time of making the decision to issue a trip, the seal-in shall be based on settable (fixed once set) time delays, which shall be separately settable for single-pole and three-pole tripping.

The following illustrates more clearly the above points:

	Faulted phase/s I> Unfaulted phase/s I>	**Faulted phase/s I> Unfaulted phase/s I<**	**Faulted phase/s I< Unfaulted phase/s I>**	**Faulted phase/s I< Unfaulted phase/s I<**
Single-phase fault, single-pole trip	Faulted phase I seal-in, reset when faulted phase I reset	Faulted phase I seal-in, reset when faulted phase I reset	Faulted phase 1 pole timer seal-in, reset when time elapsed	Faulted phase 1 pole timer seal-in, reset when time elapsed

	Faulted phase/s I> Unfaulted phase/s I>	**Faulted phase/s I> Unfaulted phase/s I<**	**Faulted phase/s I< Unfaulted phase/s I>**	**Faulted phase/s I< Unfaulted phase/s I<**
Single-phase fault, three-pole trip	I seal-in all phases, reset when last phase I reset	Faulted phase I seal-in all phases, reset when faulted phase I reset	3 pole timer seal-in all phases, reset when time elapsed	3 pole timer seal-in all phases, reset when time elapsed
Two-phase fault, three-pole trip	I seal-in all phases, reset when last phase I reset	Faulted phases I seal-in all phases, reset when last faulted phase I reset	3 pole timer seal-in all phases, reset when time elapsed	3 pole timer seal-in all phases, reset when time elapsed
Three-phase fault, three-pole trip	I seal-in all phases, reset when last phase I reset	I seal-in all phases, reset when last phase I reset	3 pole timer seal-in all phases, reset when time elapsed	3 pole timer seal-in all phases, reset when time elapsed

The Protection System must make the decision to seal-in via current or the timers (no current) irrespective of whether the decision to issue a trip originates from a protection function (measurement) within the Protection System, or whether it originates from an external source with tripping effected via the Protection System.

The required seal-in shall be via detection of the flow of primary system ac current, or the time delays, and shall not be based solely on measurement of the dc trip-coil current. However, if the flow of trip-coil current has not ceased after a prescribed time, an alternate method shall be provided to safely interrupt this circuit.

3.27.2 Rationale

Trip-circuit seal-in is required to preserve the trip relay output contacts which are not rated to interrupt the trip-circuit current, i.e. the trip-circuit is sealed-in to ensure that the trip-coil path is open-circuited by the circuit-breaker auxiliary contacts when the circuit-breaker opens. Seal-in must occur whether primary current is present or not in order to cater for weak / zero infeed tripping, etc. The reason for requiring outputs other than the trip-circuit to be sealed-in is to ensure that the input signals, e.g. to the circuit-breaker failure protection and recloser, are maintained to ensure correct operation of these functions.

Seal-in via current detection provides for optimal seal-in, as the seal-in is broken immediately on opening of the circuit-breaker, with the subsequent resetting of all other sealed-in outputs. Although acceptable, fixed time-delay seal-in must only occur for no detectable flow of primary system current. For this reason conversion of current seal-in to timer (no current) seal-in must not occur on successful opening of the circuit-breaker.

The requirement for separately settable single-pole and three-pole seal-in time-delays is to accommodate possible differences in the circuit-breaker failure time-delays for single- and three-pole tripping.

As the Protection System provides a single node via which all tripping is routed, the seal-in logic must reside within this device, irrespective of whether the trip decision originates from within this device or external to it.

It is not acceptable to base the trip-circuit seal-in solely on the measurement of trip-circuit dc current, as the possibility exists that the trip-coil may burn-out before, e.g. the circuit-breaker failure bus-strip time delay. However, if the flow of dc current has not ceased after a prescribed time delay (greater than circuit-breaker failure bus-strip time, but less than the bus-strip time plus the circuit-breaker opening time plus the Protection System current seal-in reset time (or less than the timer seal-in delay)), the trip-coil circuit should be interrupted, as sustained trip-coil current flow would lead to either destruction of the associated trip coil(s), or damage to the tripping output contacts when the seal-in drops-off (current reset following bus-strip operation, or seal-in timer elapsed).

3.27.3 Design requirements

3.27.3.1 Bay breaker trip-circuit seal-in: PIOC 3

Bay breaker trip-circuit seal-in is required for all trip outputs, irrespective of the magnitude of the interrupted current. The trip-circuit seal-in logic shall not only seal-in the trip output(s), but also the relevant initiation signals to other scheme functions, (e.g. initiate signals to the circuit-breaker failure function and the auto-reclose fuctions), and the alarm output signals.

Two methods of seal-in are required, one based on the measurement of a.c. current, catering for those circumstances for which the interrupted current is above a set threshold, and one based on a fixed time duration, catering for those circumstances for which the interrupted current is small (below the current set threshold).

- For current seal-in, the seal-in shall be maintained until the circuit-breaker opens, at which time the seal-in shall reset (as the current drops below the threshold level). On detecting the current to be below the threshold level, the seal-in shall not now revert from the current seal-in to the fixed time duration seal-in; and,
- For the fixed time duration seal-in, the seal-in shall be maintained for the set time duration. This time duration shall be independently settable for single- and three-pole tripping.

Seal-in by way of current or by way of the fixed duration timer shall occur irrespective of whether the trip command originates from within the main protection IED itself (from any of the internal protection functions), or from an external device with its trip output routed through the protection IED for tripping.

Trip-circuit seal-in shall not take place under sub-harmonic conditions (e.g. reactor ringdown).

3.27.3.2 Tie bay breaker trip circuit seal-in: PIOC 4

Tie bay breaker trip-circuit seal-in is required for all trip outputs, irrespective of the magnitude of the interrupted current. The trip-circuit seal-in logic shall not only seal-in the trip output(s), but also the relevant initiation signals to other scheme functions, (e.g. initiate signals to the circuit-breaker failure function and bay closing system), and the alarm output signals.

Two methods of seal-in are required, one based on the measurement of a.c. current, catering for those circumstances for which the interrupted current is above a set threshold, and one based on a fixed time duration, catering for those circumstances for which the interrupted current is small (below the set threshold).

- For current seal-in, the seal-in shall be maintained until the circuit-breaker opens, at which time the seal-in shall reset (as the current drops below the threshold level). On detecting the current to be below the threshold level, the seal-in shall not now revert from the current seal-in to the fixed time duration seal-in.
- For the fixed time duration seal-in, the seal-in shall be maintained for the set time duration. This time duration shall be settable for three-pole tripping.

Seal-in by way of current or by way of the fixed duration timer shall occur irrespective of whether the trip command originates from within the main protection device itself (from any of the internal protection functions), or from an external device with its trip output routed through the main protection device for tripping.

Trip-circuit seal-in shall not take place under sub-harmonic conditions (e.g. reactor ringdown).

3.28 Distance zone protection scheme communication: PSCH 1

3.28.1 Philosophy

To combine the different PDIS zones a protection scheme represented by the logical node PSCH is needed. The PSCH is required to achieve instantaneous fault clearance for all line faults.

The PSCH for the distance zones shall include the following functions:

- Tele-protection functions and conditions for line protection schemes (PUR & POR);
- Carrier echo to accelerate tripping at the strong infeed end for faults beyond the underreaching zone;
- Weak-infeed tripping to accelerate single and three pole tripping for weak/zero infeed conditions; and,
- The protection system shall include current reversal guard (CRG) to ensure that the protection will remain secure for any fault on a parallel line resulting in a current reversal on the protected line.

3.28.2 Rationale

The instantaneous fault clearance is achieved with both the permissive underreach and permissive overreach teleprotection modes. The permissive underreach mode of operation utilise the distance underreaching zone for teleprotection transmission and any one of the distance overreaching zones to issue tripping on receipt of a teleprotection signal. The permissive overreach mode of operation utilise the first distance overreaching zone for teleprotection transmission and also the first distance overreaching zone to issue tripping on receipt of a teleprotection signal. Distance zone permissive trip send and receive signals shall be blocked in the event that the line isolator is in the open position and without a line isolator discrepancy condition.

3.28.2.1 Permissive Underreach (PUR)

The teleprotection permissive signal shall be sent by the first zone (underreaching zone). The permissive tripping shall be effected by pickup of an overreaching zone (second zone, third zone, or even starter/fault detector zone) element, and receipt of the permissive teleprotection signal. The zone used need not be forward directional only, as confirmation of the fault being on the protected line is ensured by the forward directional underreaching zone sending the teleprotection signal. The permissive underreach tripping signal shall, in combination with the different PDIS zones, be single phase for single line to ground faults and three phase for a multi-phase faults.

3.28.2.2 Permissive Overreach (POR)

The teleprotection permissive signal shall be sent by the second zone (first overreaching zone). The permissive tripping shall be effected by the pickup of a second zone element (overreaching/forward directional) and receipt of the permissive teleprotection signal. The permissive overreach tripping signal shall, in combination with the different PDIS zones, be single phase for single line to ground faults and three phase for a multi-phase faults.

If the line is too short for secure operation of the direct tripping underreaching zone, the following two options shall be possible:

- Switch the first zone out, and operate with the second zone as the first overreaching time delayed zone and the permissive zone; or,
- Operate with the first zone as the first overreaching time delayed tripping zone, and the second zone as the permissive zone.

Permissive tripping shall be blocked by: current reversal guard, VT fuse fail detection, power swing blocking & line isolator open without a discrepancy).

The permissive tripping function within the scheme communication function shall:

- Trip the bay breaker single pole for single line to ground faults and three pole for multi-phase faults (PTRC1 - with trip seal-in in accordance with the trip seal-in logic). Three pole trip selection for all fault types shall be done within the PTRC1. The outputs from PTRC1 shall trip the bay breaker and initiate the bay breaker's breaker fail function;
- Trip the tie bay breaker three pole for single line to ground faults and multi-phase faults (PTRC2 - with trip seal-in in accordance with the trip seal-in logic). The outputs from PTRC2 shall trip the tie bay breaker and initiate the tie bay breaker's breaker fail function;
- Initiate the bay breaker single pole auto-reclose cycle for single line to ground faults and three pole auto-reclose cycle for multi-phase faults (the permitted auto-reclose cycle and sequence will be determined by the auto-reclose function);
- Initiate the tie bay breaker three pole auto-reclose cycle for single line to ground faults and for multi-phase faults (the permitted auto-reclose cycle and sequence will be determined by the auto-reclose function);
- Phase segregated permissive trip signal shall be connected to the IED internal disturbance recorder function (RBDR);
- Permissive transmit signal shall be connected to the IED internal disturbance recorder function (RBDR);
- Permissive receive signal shall be connected to the IED internal disturbance recorder function (RBDR); and,
- Phase segregated permissive tripping shall be reported to the gateway and station HMI.

3.28.2.3 Echo function

If, for the POR mode of operation, the permissive signal from the remote-end is received with no pickup of the local permissive send zone, the local end shall send (echo) a permissive signal back to the remote-end provided that the local end has not detected the fault (seen by the remote end) to be an external fault in its reverse direction. The means shall be provided by which the reverse fault detection sensitivity at the local-end can be set to co-ordinate with the forward fault detection sensitivity at the remote-end, thereby ensuring that no incorrect operation can result as the result of an incorrectly echoed signal. As the echoing of the permissive signal between the remote/local ends shall not continue indefinitely, provision shall be made to limit the echo duration to a pre-determined fixed value. This echo function shall be selectable ON/OFF. It shall cater for both weak and zero (both bay and tie bay breakers three pole open) infeed conditions. No echo of the permissive teleprotection signal shall be possible for a period immediately following impedance tripping. This is required to prevent any maloperations which may result due to echoing of the permissive teleprotection signal due to, for example, slower fault clearance at the remote end.

The teleprotection aided tripping logic shall contain all the required features to cater for the different application requirements, e.g. signal send extension, signal receive extension, security against spurious operation, etc.

The carrier echo signal shall have a selection between: carrier echo independent of the breaker position and echo only when all three poles of the bay breaker and the tie bay breaker are open. The breaker three pole open condition (both bay breaker and the tie bay breaker open) recognition shall be settable (time delayed) ensuring that no incorrect operation can result as the result of an incorrectly echoed signal.

3.28.2.4 Weak infeed tripping function

Accelerated tripping is required for weak or zero infeed conditions in order to minimise the voltage dip duration by minimising tripping times, thereby enhancing the power quality, rather than relying upon sequential tripping to clear the fault.

Weak infeed tripping logic is required to cater for those cases where the current infeed to a line fault is too low to be detected by the impedance function. The weak infeed tripping logic shall therefore cater for conditions from zero current infeed up to the threshold current which supervises the impedance function detection/operation i.e. the threshold current at which the impedance function detection/operation is released for further processing within the relay logic.

3.28.2.5 Current reversal guard function

Current reversal guard is required to uphold the security of the protection system on the protected line. For a fault on a parallel line resulting in a reversal of current on the healthy line due to unequal circuit-breaker opening on the faulted line (parallel line), the protection on the healthy line can overtrip if operating in a permissive overreaching mode due to the overlap of protection / teleprotection signal timing.

3.28.3 Design requirements

3.28.3.1 Weak infeed tripping

Weak infeed tripping logic shall correctly phase select the faulted phase(s), and shall correctly trip one- or three-pole respectively for single-phase-to-ground or multi-phase faults. Three-pole tripping for all fault types shall only occur if three-pole only tripping is selected.

The delay to issuing an output from the weak infeed tripping logic shall be minimised, being limited to only those measures that are necessary to ensure no spurious operation can occur. Pick-up of an unfaulted loop as a result of pre-fault load flow must not cause failure of the weak infeed logic to operate for an actual weak infeed fault condition.

Weak infeed tripping shall result following receipt of the teleprotection signal from the remote-end plus fault confirmation by way of under voltage (and under current) detection. The undervoltage detection (all three phase measured to be below the undervoltage detection setting) shall be time delayed as to prevent over operation of the weak infeed functions following a successful clearance of a line fault by the other protection functions. A trip output from the weak infeed tripping logic shall, after impedance tripping of the line and reset of the fault detector, be prevented for sustained/prolonged receipt of the teleprotection signal, e.g. due to slower fault clearance at the remote-end.

The weak infeed tripping function shall be disabled (blocked) for the following conditions:

- operation of the first overreaching forward distance zone (permissive tripping zone) to prevent unwanted operation of the weak infeed tripping logic as a result of unequal circuit-breaker opening times at the two ends of the line.;
- operation of the reverse reaching distance zone (no reverse fault detection);
- directional earth fault comparison trip;
- VT supply fuse fail detection;
- power swing blocking;
- breaker(s) three pole open (time delayed); and,
- line isolator open (breaker-and-a-half applications).

Correct operation shall be ensured for a differently detected fault i.e. where the current for the subsequent fault condition traverses the supervising current threshold of the impedance measurement output, e.g. initial single-phase-to-ground fault detected by impedance function, but infeed when evolved to phase-to-phase-to-ground fault below impedance function threshold (or vice versa); and initial single-phase-to-ground fault detected by impedance function, but infeed to subsequent fault on other phase(s) during pole open period below impedance function threshold (or vice versa).

Unwanted tripping and initiation of the recloser for an open circuit-breaker (both bay and tie bay breakers 3 pole open) by the weak infeed tripping logic shall be prevented.

After an initial single-line-to-ground fault, the weak infeed logic must operate correctly for an evolving fault to ensure correct three-pole tripping.

Should a second fault develop during an open pole condition, the weak infeed logic must operate correctly to ensure correct three-pole tripping.

Following a single-pole automatic reclosure, the weak infeed logic shall operate correctly for a switch-on-to-a weak infeed fault to ensure three-pole tripping occurs.

Pickup of the fault detector of an unfaulted loop as a result of pre-fault load flow shall not cause failure of the weak infeed logic to operate for an actual weak infeed fault condition.

Under weak infeed conditions, correct three-pole tripping shall result for:

- an initial single-phase-to-ground fault evolving to a multi-phase fault; and,
- a second fault occurring during single pole open conditions.

The weak infeed tripping function shall be disabled (blocked) for the following conditions:

- operation of the first overreaching forward distance zone (permissive tripping zone);
- operation of the reverse reaching distance zone (no reverse fault detection);
- directional earth fault comparison trip;
- VT supply fuse fail detection;
- power swing blocking;
- breaker(s) three pole open (time delayed); and,
- line isolator open (breaker-and-a-half applications).

The weak infeed tripping function shall be selectable IN/OUT.

The weak infeed tripping within the scheme communication function shall:

- Trip the bay breaker single pole for single line to ground faults and three pole for multi-phase faults (PTRC1 - with trip seal-in in accordance with the trip seal-in logic). Three pole trip selection for all fault types shall be done within the PTRC1. The outputs from PTRC1 shall trip the bay breaker and initiate the bay breaker's breaker fail function;
- Trip the tie bay breaker three pole for single line to ground faults and multi-phase faults (PTRC2 - with trip seal-in in accordance with the trip seal-in logic). The outputs from PTRC2 shall trip the tie bay breaker and initiate the tie bay breaker's breaker fail function;
- Initiate the bay breaker single pole auto-reclose cycle for single line to ground faults and three pole auto-reclose cycle for multi-phase faults (the permitted auto-reclose cycle and sequence will be determined by the auto-reclose function);
- Initiate the tie bay breaker three pole auto-reclose cycle for single line to ground faults and for multi-phase faults (the permitted auto-reclose cycle and sequence will be determined by the auto-reclose function);
- Phase segregated weak infeed trip signals shall be connected to the IED internal disturbance recorder function (RBDR); and,
- Phase segregated permissive tripping shall be reported to the gateway and station HMI.

3.28.3.2 Current reversal guard

Zone 1 operation and its associated permissive teleprotection signal does not form part of the current reversal guard logic and shall always be permitted.

In order to ensure the quickest permissive tripping for a fault on the protected line once blocking has been established following a parallel line fault, any signal received must be logically extended to ensure that the receive logic is valid when the blocking time resets.

The current reversal guard logic shall be activated at the line terminal which initially detects the parallel line fault as being in the reverse direction, i.e. the line terminal for which the direction of current flow is from the line to the busbar, and which receives the teleprotection signal from the remote terminal, which initially detects the fault to be within the reach of its permissive overreaching zone. The duration for which the current reversal guard logic is activated shall be settable. For the duration that the logic is activated, the release for tripping by the permissive overreaching zone on receipt of the teleprotection signal shall be blocked, and the sending of a teleprotection signal shall be blocked.

To ensure fastest possible tripping for protected line faults during the duration of the current reversal guard blocking following a parallel line fault, the ability of the first (underreaching) zone to execute its normal functions shall not be influenced by the current reversal guard logic, i.e. pickup of the first zone shall still directly trip the circuit-breaker, and shall still send the teleprotection signal. To ensure the quickest permissive tripping for a fault on the protected line once blocking has been established following a parallel line fault, any teleprotection signal received shall be logically extended to ensure that the receive logic is still valid when the blocking time resets. Apart from a general extension set for the receive signal, it shall be possible to set an extension that is applicable only during current reversal guard conditions.

Restoration of a VT secondary supply failure to the current reversal guard blocking shall be delayed as to prevent unwanted blocking of permissive tripping by the current reversal guard function.

Establishment of the current reversal guard function shall be connected to the IED internal disturbance recorder function (RBDR).

3.29 Directional earth fault protection scheme communication: PSCH 2

3.29.1 Philosophy

To combine the directional earth fault directionality and teleprotection interface a protection scheme represented by the logical node PSCH is needed. The PSCH is required to achieve instantaneous fault clearance for all high resistance faults not detected and cleared by the distance zones. The directional earth fault comparison protection shall have a dedicated teleprotection channel (independent from the distance teleprotection channels).

The PSCH for the directional earth fault shall include the following functions (independent from the distance teleprotection interface and functions):

- Tele-protection functions and conditions for line protection schemes (POR);
- Carrier echo to accelerate tripping at the strong infeed end for any high resistance line fault; and,
- The protection system shall include current reversal guard (CRG) to ensure that the protection will remain secure for any fault on a parallel line resulting in a current reversal on the protected line.

3.29.2 Rationale

The instantaneous fault clearance is achieved with the permissive overreach teleprotection mode. The permissive overreach mode of operation utilise the directional earth fault forward direction detection for teleprotection transmission and also the directional earth fault forward direction detection to issue tripping on receipt of a teleprotection signal. Directional earth fault forward direction detection trip send and receive signals shall be blocked in the event that the line isolator is in the open position and without a line isolator discrepancy condition.

3.29.2.1 Permissive Overreach (POR)

The teleprotection signal shall be sent by the forward directional earth fault element. Directional earth fault comparison tripping shall be effected by the pickup of the forward directional element and receipt of the directional earth fault permissive signal. Faulted phase identification is essential for single phase tripping and reclosing. Faulted phase identification will be challenged under some fault conditions including evolving faults, cross-country faults, high fault resistance faults and weak system conditions. The directional earth fault permissive communications channel shall be independent from the distance zone communications channel.

3.29.2.2 Current reversal guard

Current reversal guard is required for parallel line applications in the POR mode to ensure that the directional earth fault comparison overreach tripping function remains secure for a parallel line fault, the clearing of which causes a current reversal on the healthy line due to unequal opening of the circuit-breakers on the faulted line.

The directional earth fault comparison current reversal guard logic shall be activated at the line terminal which initially detects the parallel line earth fault as being in the reverse direction, i.e. the line terminal for which the direction of current flow is from the line to the busbar, and which receives the directional earth fault comparison teleprotection signal from the remote terminal, which initially detects the fault to be within the directional earth fault comparison forward reach. The duration for which the current reversal guard logic is activated shall be settable. For the duration that the logic is activated, the release for tripping by the directional earth fault comparison on receipt of the teleprotection signal shall be blocked, and the sending of a directional earth fault comparison teleprotection signal shall be blocked.

To ensure the quickest directional earth fault comparison tripping for a fault on the protected line once blocking has been established following a parallel line fault, the directional earth fault comparison teleprotection signal received shall be logically extended to ensure that the receive logic is still valid when the blocking time resets. Apart from a general extension set for the receive signal, it shall be possible to set an extension that is applicable only during current reversal guard conditions.

Establishment of the current reversal guard function shall be connected to the IED internal disturbance recorder function (RBDR).

3.29.3 Design requirements

The directional earth fault comparison function shall be disabled (blocked) for the following conditions:

- Distance zone underreach and permissive tripping signals;
- Current reversal guard (directional earth fault comparison);
- VT supply fuse fail detection;
- Bay breaker pole discrepancy with the tie bay breaker not three pole closed;
- Tie breaker pole discrepancy with the bay breaker not three pole closed; and,
- The line isolator is in the open position and without a line isolator discrepancy condition.

The directional earth fault comparison tripping within the scheme communication function shall:

- Trip the bay breaker single pole for single line to ground faults (PTRC1 - with trip seal-in in accordance with the trip seal-in logic). Three pole trip selection for all fault types shall be done within the PTRC1. The outputs from PTRC1 shall trip the bay breaker and initiate the bay breaker's breaker fail function;
- Trip the tie bay breaker three pole for single line to ground faults (PTRC2 - with trip seal-in in accordance with the trip seal-in logic). The outputs from PTRC2 shall trip the tie bay breaker and initiate the tie bay breaker's breaker fail function;
- Initiate the bay breaker single pole auto-reclose cycle for single line to ground faults (the permitted auto-reclose cycle and sequence will be determined by the auto-reclose function);
- Initiate the tie bay breaker three pole auto-reclose cycle for single line to ground faults (the permitted auto-reclose cycle and sequence will be determined by the auto-reclose function);
- Directional earth fault trip signal shall be connected to the IED internal disturbance recorder function (RBDR);
- Directional earth fault carrier transmit signal shall be connected to the IED internal disturbance recorder function (RBDR);

- Directional earth fault carrier receive signal shall be connected to the IED internal disturbance recorder function (RBDR); and,
- Directional earth fault tripping shall be reported to the gateway and station HMI.

3.29.3.1 Current reversal guard

In order to ensure the quickest directional earth fault tripping for a fault on the protected line once blocking has been established following a parallel line fault, any signal received must be logically extended to ensure that the receive logic is valid when the blocking time resets.

The current reversal guard logic shall be activated at the line terminal which initially detects the parallel line fault as being in the reverse direction, i.e. the line terminal for which the direction of current flow is from the line to the busbar, and which receives the teleprotection signal from the remote terminal, which initially detects the fault to be within the forward direction. The duration for which the current reversal guard logic is activated shall be settable. For the duration that the logic is activated, the release for tripping by the directional earth fault on receipt of the teleprotection signal shall be blocked, and the sending of a teleprotection signal shall be blocked.

Restoration of a VT secondary supply failure to the current reversal guard blocking shall be delayed as to prevent unwanted blocking of the directional earth fault function by the current reversal guard function.

Establishment of the current reversal guard function shall be connected to the IED internal disturbance recorder function (RBDR).

3.30 Teleprotection channels

3.30.1 Philosophy

With respect to the dual Protection Systems contained within the EHV feeder scheme, three possible combinations exist:

- dual impedance;
- one impedance and one unit-type; and,
- dual unit-type.

Concerning the types of teleprotection channels, three exist:

- power line carrier (PLC);
- bandwidth management equipment (BME); and.
- dark fibre.

The primary criterion is that teleprotection for the Main 1 and Main 2 Protection Systems should be routed via diverse routes. The exception to this is where the teleprotection for both Main Protection Systems is via PLC, as common points exist.

For channel routing via BME, teleprotection circuits must be afforded the highest priority rating.

The following indicates the different combinations of feeder schemes, with the combinations of teleprotection channel types able to be used.

	(i) PLC + PLC	**(ii) PLC + BME**	**(iii) PLC + Dark Fibre**	**(iv) BME + BME**	**(v) BME + Dark Fibre**	**(vi) Dark Fibre + Dark Fibre**
(A) Dual impedance	✓	✓	✓	✓	✓	✓
(B) One impedance + one unit-type	X	✓	✓	✓	✓	✓
(C) Dual unit-type	X	X	X	✓	✓	✓

The actual allocation of channels and specific requirements which apply shall be as follows:

(NMTI = Network Management Terminal Interface)

				Comments
(A) + (i)	identical relays	Main 1	PLC	
		Main 2	PLC	
	non-identical relays	Main 1	PLC	
		Main 2	PLC	
(A) + (ii)	identical relays	Main 1	BME	NMTI set-up, no re-route
		Main 2	PLC	
	non-identical relays	Main 1	BME	Superior relay NMTI set-up, no re-route
		Main 2	PLC	Lesser relay
(A) + (iii)	identical relays	Main 1	Dark Fibre	
		Main 2	PLC	
	non-identical relays	Main 1	Dark Fibre	Superior relay
		Main 2	PLC	Lesser relay
(A) + (iv)	identical relays	Main 1	BME	NMTI set-up, no re-route Most direct route
		Main 2	BME	NMTI set-up, no re-route Separate BME, diverse route
	non-identical relays	Main 1	BME	Superior relay NMTI set-up, no re-route

				Most direct route
		Main 2	BME	Lesser relay NMTI set-up, no re-route Separate BME, diverse route
(A) + (v)	identical relays	Main 1	Dark Fibre	
		Main 2	BME	NMTI set-up, no re-route Diverse route from fibre route
	non-identical relays	Main 1	Dark Fibre	Superior relay
		Main 2	BME	Lesser relay NMTI set-up, no re-route Diverse route from fibre route
(A) + (vi)	identical relays	Main 1	Dark Fibre	Most direct fibre route
		Main 2	Dark Fibre	Diverse route
	non-identical relays	Main 1	Dark Fibre	Superior relay Most direct fibre route
		Main 2	Dark Fibre	Lesser relay Diverse route
(B) + (ii)	Main 1	unit-type	BME	NMTI set-up, no re-route
	Main 2	impedance	PLC	
(B) + (iii)	Main 1	unit-type	Dark Fibre	
	Main 2	impedance	PLC	
(B) + (iv)	Main 1	unit-type	BME	NMTI set-up, no re-route Most direct route
	Main 2	impedance	BME	NMTI set-up, no re-route Separate BME, diverse route
(B) + (v)	Main 1	unit-type	Dark Fibre	
	Main 2	impedance	BME	NMTI set-up, no re-route Diverse route from fibre route
(B) + (vi)	Main 1	unit-type	Dark Fibre	Most direct fibre route
	Main 2	impedance	Dark Fibre	Diverse route
(C) + (iv)	identical relays	Main 1	BME	NMTI set-up, no re-route Most direct route
		Main 2	BME	NMTI set-up, no re-route Separate BME, diverse route
	non-identical relays	Main 1	BME	Superior relay NMTI set-up, no re-route Most direct route

		Main 2	BME	Lesser relay NMTI set-up, no re-route Separate BME, diverse route
(C) + (v)	identical relays	Main 1	Dark Fibre	
		Main 2	BME	NMTI set-up, no re-route Diverse route from fibre route
	non-identical relays	Main 1	Dark Fibre	Superior relay
		Main 2	BME	Lesser relay NMTI set-up, no re-route Diverse route from fibre route
(C) + (vi)	identical relays	Main 1	Dark Fibre	Most direct fibre route
		Main 2	Dark Fibre	Diverse route
	non-identical relays	Main 1	Dark Fibre	Superior relay Most direct fibre route
		Main 2	Dark Fibre	Lesser relay Diverse route

3.30.2 Rationale

The requirement for teleprotection diverse routing is to satisfy the single failure criterion, which aims to eliminate all possible points of common failure, thereby ensuring that no single failure will result in the failure of both teleprotection links. Therefore,

- where the teleprotection links for both Main Protection Systems are via BME, no sharing of a single BME is permitted, the requirement being two separate BMEs via totally diverse routing;
- where the teleprotection links for both Main Protection Systems are via Dark Fibre, the requirement for diverse routing implies that the fibres may not be in the same cable, or even the same cable duct; and,
- where the teleprotection link for one Main Protection System is via Dark Fibre and for the other Main Protection System via BME, the requirement for diverse routing implies that the BME route must be diverse from the fibre route.

Availability of the teleprotection channels are imperative for the correct operation of the protection, which impacts directly on the integrity of and safe operation of the power system. Therefore, for channel routing via BMEs, teleprotection circuits must be afforded the highest priority.

An NMTI session is required to set-up the BME routes to ensure routing is manually allocated, and is therefore via the best pre-determined route, which is then known and fixed.

The allocation of channels was done in accordance with the following:

- the types of teleprotection channels were rated from best to worst in the following order: Dark Fibre, BME, PLC
- for non-identical impedance or unit-type protection relays, the chosen standard was always to allocate the superior relay to Main 1, therefore
  - o where different types of channel are employed, the superior channel was always allocated to the Main 1 Protection System

    - where the same channel type is employed for both Main Protection Systems, the one with the most direct route was allocated to the Main 1 Protection System

- in accordance with the above standard of allocating the superior channel type to the Main 1 Protection System, for one impedance one unit-type protection schemes, the unit-type Protection System was allocated to Main 1

For teleprotection via BME, no re-routing is to be employed. This is primarily for reasons of cost, but is also to ensure that when in-service, the channel is always the known best pre-determined route, and not an unknown, probably less direct route, and is also known to be diverse from the route for the other Main Protection System if also via BME.

For impedance protection, channel failure will result in the scheme reverting to a plain stepped-distance mode of operation. This is acceptable without requiring re-routing for the expected non-availability of the channel, as the Protection System remains in-service with non time-delayed tripping for most of the line, with the other Main Protection System still fully operational. Unit-type protection requires the channel to be in-service to be fully operational. However, due to the applied channel diversity to eliminate common points of failure, i.e. to eliminate simultaneous failure of the teleprotection channels of both Main Protection Systems, the cost of an alternate prescribed re-route is not justified. On the failure of one teleprotection channel, total reliance is therefore placed on the other Main Protection System, which may be unit-type as well, or impedance.

3.30.3 Design requirements

For impedance based protection the telecommunications interface shall be provided by means of the conventional potential-free contact as well as by means of a digital communications port (X.21 interface capable of operating over a standard 64 kilobit/sec digital communications channel).

A channel used for permissive tripping purposes shall be biased towards speed and dependability as the primary aim is to clear the fault, with the necessary security provided by the protection relay.

A channel used for direct transfer tripping purposes shall be biased towards security as the protection does not provide any security enhancement on receipt of a transfer trip command.

For unit-type protection the telecommunications interface shall be provided by means of a digital communications port (X.21 interface capable of operating over a standard 64 kilobit/sec digital communications channel). The unit-type protection must exhibit the required level of security to ensure no maloperation can occur on channel failure (corrupted data).

The teleprotection channels are allocated as follow:

- Channel A - Directional earth fault comparison;
- Channel B - Distance zone permissive function (this channel shall also be triggered by the direct transfer trip function;
- Channel C - Direct transfer trip function; and,
- Dedicated channel for out-of-step-tripping.

The main protection device shall provide for a permissive channel send function and a permissive channel receive function. The permissive channel receive function (channel B receive) shall be operated by the teleprotection equipment on receipt of a permissive channel receive signal when the TPIS(M#) is in the ‘On’ position. The permissive channel send function shall trigger the permissive transmit channel (channel B send) of the teleprotection equipment when the TPIS(M#) is in the ‘On’ position. The distance zone permissive send, directional earth fault comparison send and direct transfer trip send signals shall be of the same duration as for the trigger condition. A sustained condition shall have a settable maximum transmit duration.

The current differential protection device shall make provision for a fibre optic communications interface for interconnecting to the remote protection system device. Interconnection shall be via a dedicated fibre, transmitting at 1300nm (single mode). The direct transfer trip signals shall also be routed via the current differential communications fibre.

The protection IED shall have the capability to interface with the teleprotection equipment via hardwire (binary input and binary outputs) and via GOOSE messaging. The failure of both main protection teleprotection interfaces shall be routed to both main protection IEDs.

3.30.3.1 Out-of-step-tripping channel

Out-of-step protection is employed at strategic locations on the power system to detect, and operate for, out-of-step conditions. As the best location to trip circuit-breakers may not be at the measurement location, an additional transfer trip teleprotection channel is required to accommodate transfer tripping from the measurement location to assigned tripping locations.

3.31 Teleprotection end-to-end compatibility

3.31.1 Philosophy

For impedance-based protection, the telecommunications system shall provide the facility for a channel biased towards dependability and a second channel biased towards security. The dependable channel will be utilised for the permissive function and a combination of the two channels for the transfer trip function.

3.31.2 Rationale

The implementation of a bi-directional telecommunication channel provides the medium to achieve 'unitised' impedance protection which provides non time-delayed tripping covering the entire length of the transmission line. This channel is required to be fast and dependable to ensure assured fast permissive tripping. The reduced security requirement is due to the fact that all permissive tripping is verified within the receiving protection system by the pick-up of the required permissive zone impedance elements.

For transfer tripping the emphasis is on security as receipt of this signal is a direct instruction to trip without supervision by any picked-up element. The combination of the permissive and direct transfer tripping channels is to obtain enhanced security for the direct transfer tripping function.

3.31.3 Design requirements

For impedance-based protection the telecommunications interface shall be realised by way of the conventional potential-free contact.

In addition to the output contact, the telecommunications interface can be via a digital communications port which complies with X.21 sync at 64 kilobits/sec as per ITU-T Rec.

At the sending end both the permissive and transfer trip channels must be triggered by the direct transfer tripping function, and at the receiving end both channels must be received simultaneously to provide the direct transfer tripping output.

3.31.3.1 Teleprotection communication failure

The teleprotection equipment and communications failed condition shall be monitored by the line protection device and:

- Reported locally to the main # protection system unhealthy indication;
- Reported remotely via the gateway;
- Reported to the station HMI; and,
- GOOSED to the other main protection device (required for accelerated tripping of the first overreaching zone in the event that both teleprotection devices has failed).

The current differential (PDIF) communications failed condition shall be monitored by the line protection device and:

- Reported locally at the line protection IED HMI;

- Reported locally to the main # protection system unhealthy indication;
- Reported remotely via the gateway;
- Reported to the station HMI; and,
- GOOSED to the other main protection device (required for accelerated tripping of the first overreaching zone in the event that both main protection's communications has failed).

3.32 Unit protection communications

3.32.1 Philosophy

The unit-type protection inter relay/s data communications interface shall be in accordance with the current Eskom teleprotection communications interface standard.

The unit-type protection shall be capable of automatic transmission time correction to accommodate varying transmission time delays of up to 30 ms.

For unit-type protection systems, a second channel for transfer tripping is not required. The transfer trip command shall be included within the data package communicated from the one protection system to its recipient protection system(s). The digital communications link must therefore possess the required levels of security and dependability. On receipt of the transfer trip signal, the unit-type protection system must issue a three-pole trip and auto-reclose block.

3.32.2 Rationale

Unit-type protection requires the real time exchange of primary quantities between line terminals to facilitate the protection measurement. The communications channel must therefore exhibit the required level of data integrity and error checking to ensure that no maloperation can occur by way of corrupted data, including the transfer trip command.

Unit-type protection systems require real-time continuous information on primary system quantities for correct operation. If, in future, automatic re-routing is required, the unit-type protection system must remain stable while re-adjusting to the transmission delay of the new route. For this reason the relay must be capable of automatic transmission time correction. The 30 ms requirement is to cater for the worst possible scenario.

On receipt of a transfer trip command, three-pole tripping without auto-reclose is required in accordance with conventional transfer tripping, which may be triggered by any one of the following:

- a fault between the CT and the circuit-breaker,
- a local overvoltage condition, and;
- an external direct transfer trip input, e.g. due to a line reactor trip or bus zone trip.

3.32.3 Design requirements

The digital communications port shall comply with X.21 sync at 64 kilobits/sec as per ITU-T Rec.

3.33 Unit protection communication failure

3.33.1 Philosophy

The Protection System shall implement blocking of the unit-type protection function when a communications failure is detected including, inter alia, when the data transmission is interrupted or when the automatic transmission time correction is exceeded. The unit-type protection function shall be automatically restored when the communication system is restored.

It is not a requirement that a unit-type Protection System applied without concurrently active overreaching impedance elements should have the capability of switching-in such elements on communications failure. However, for unit-type Protection Systems incorporating concurrently active overreaching impedance elements, such elements must remain active during a communications failure and not be blocked along with the unit-type protection functions. A direct tripping underreaching zone concurrently active with the unit-type protection function is not prescribed, but should be included to be switched-in on communications failure.

3.33.2 Rationale

When a communications failure occurs, the unit-type protection function can no longer perform a valid measurement, and therefore to enhance the security, the unit-type protection measurement must be blocked. Self restoration of the unit-type protection function is required to ensure full protection functionality is restored as soon as is possible without reliance on human intervention.

The design philosophy is in accordance with the single failure criterion. This is realised practically by employing dual Tripping Systems, each with its own independent communications channel via a diverse route to that of the other Tripping System. The single failure criterion allows for any failure within a single Tripping System which would render that Tripping System non functional, and hence place total reliance on the other Tripping System for the period of failure. Therefore, unit-type protection applied in conjunction with impedance protection does not require additional protection functions to be switched-in on communications failure.

For those unit-type Protection Systems incorporating impedance elements, no blocking of these elements should occur with the unit-type functions as, over and above the single failure criterion design philosophy, no more than the affected functionality should ever be lost.

The requirement for underreaching elements to be switched-in on communications failure is based on the reasoning that direct, communications independent, tripping is always available irrespective of which main Protection System experiences the communications failure.

This rationale is more fully explained in the following table.

Protection Systems	Protection System communications failure	Protection in service
One unit-type (without impedance elements), one impedance	(i) Unit-type Protection System	Fully operational impedance protection, including underreaching and overreaching zones, and teleprotection aided tripping; stepped distance protection including underreaching and overreaching zones for simultaneous second channel failure
	(ii) Impedance Protection System	Fully operational unit-type protection plus stepped distance protection including underreaching and overreaching zones; stepped distance protection including underreaching and overreaching zones for simultaneous second channel failure
Dual unit-type, one with impedance elements, the other without	(iii) Unit-type Protection System (with impedance elements)	Impedance protection comprising underreaching and overreaching zones plus fully operational unit-type protection; impedance protection comprising underreaching and overreaching zones for second channel failure
	(iv) Unit-type Protection System (without impedance elements)	Fully operational unit-type protection including impedance protection overreaching zone; impedance protection underreaching and overreaching zones for simultaneous second channel failure

For (i) and (ii), irrespective which Protection System experiences the communications failure, direct, communications independent tripping is available via the impedance Protection System. For (iii), direct, communications independent tripping is only available if the unit-type Protection System with impedance elements switches-in direct tripping underreaching elements on communications failure. For (iv), no direct tripping underreaching elements are immediately available, or required, on channel failure, but will become available on the loss of both communications channels should this ever occur.

3.33.3 Design requirements

The communications channels must be diverse to ensure as far as possible that no common mode failure can occur which can simultaneously affect the operation of both main Protection Systems.

The signal transmission time from one line-end to the other must be dynamically compensated within the Protection System to accommodate transmission time variances due to channel re-routing should this become a future requirement.

3.34 Direct transfer tripping

3.34.1 Philosophy

For all EHV breaker-and-a-half line protection applications, each of the tripping systems shall provide a direct transfer tripping facility with inputs derived from within the scheme or external to the scheme.

Operation of the external trip input to the scheme shall initiate 3-pole tripping without auto-reclose and shall initiate the circuit-breaker failure protection and when selected, trigger the direct transfer trip send function.

3.34.2 Rationale

Direct transfer tripping is required in order to provide enhanced tripping for the following conditions:

- a fault between the CT and the circuit-breaker, selectable, to ensure fast tripping of the remote end;
    - external inputs, e.g. line reactor breaker fail trip, other object tie breaker fail trip;
    - simultaneous tripping of the line protection and the connected line/busbar reactor protection;
    - circuit-breaker fail protection;
    - local overvoltage protection;
    - series cap bank breaker failure to close;
    - circuit-breaker pole discrepancy trip (bay breaker pole discrepancy trip with tie bay breaker open, tie bay breaker pole discrepancy trip with the bay breaker open);
    - circuit-breaker phase discrepancy trip (bay breaker phase discrepancy trip with tie bay breaker open, tie bay breaker phase discrepancy trip with the bay breaker open);
    - external out-of-step trip input; and,
    - switch-onto-fault protection.

No auto-reclose is desirable as controlled, manually executed restoration is necessary.

3.34.3 Design Requirements

The teleprotection direct transfer trip receive input shall be capable of accepting a dc 50 V signal.

The IED direct transfer trip send input shall be capable of accepting a dc 110 VDC 220 VDC and/or 50 VDC signals.

The protection IED and teleprotection IED shall have the capability of interchanging direct transfer trip signals via IEC61850.

The main protection device shall provide for a direct transfer trip send and a direct transfer trip receive function. The direct transfer trip receive function (channel C receive) shall be operated by the teleprotection equipment on receipt of a direct transfer trip receive signal (channel C receive) when the TPIS(M#), for protection system # is in the 'On' position. Direct transfer trip send and receive shall be blocked in the event that the line isolator is in the open position and without a line isolator discrepancy condition.

The direct transfer trip send function shall trigger the direct transfer trip channel (channel C) and the permissive transmit channel (channel B) of the teleprotection equipment when the TPIS(M#) for protection system # is in the 'On' position. The direct transfer trip sent signal duration shall be user settable.

The direct transfer tripping function shall incorporate a send function to the remote-end for inputs derived from within the scheme (own protection system) or from devices external to the scheme, and a receive function, for which a three-pole trip output, with no further supervision, shall be initiated. A block automatic reclosing output shall be issued. The direct transfer trip function shall be disabled when the line isolator is open and with no discrepancy.

For current differential devices, communicating device-to-device via the digital communications network, the direct transfer trip command shall be embedded within the transmitted data message. This applies in the same way to impedance devices, connected device-to-device, via a built-in relay communications port and the communications network, rather than via contact outputs/binary inputs and the conventional teleprotection channels.

The direct transfer trip receive function shall:

- Trip the bay breaker three pole (PTRC1 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC1 shall trip the bay breaker and initiate the bay breaker's breaker fail function;
- Trip the tie bay breaker three pole (PTRC2 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC2 shall trip the tie bay breaker and initiate the tie bay breaker's breaker fail function;
- Direct transfer trip transmit signal shall be connected to the IED internal disturbance recorder function (RBDR);
- Direct transfer trip receive signal shall be connected to the IED internal disturbance recorder function (RBDR);
- Direct transfer trip signal shall be connected to the IED internal disturbance recorder function (RBDR); and,
- Direct transfer tripping shall be reported to the gateway and station HMI.

3.35 IDMT earth fault protection: PTOC 1

3.35.1 Philosophy

The main protection device shall include a supplementary earth fault function. The earth fault protection function shall comprise an Inverse Definite Minimum Time (IDMT) overcurrent function (IEC 60255-3 normal inverse) connected in the zero sequence current path of the current transformer. Directional selection for the IDMT earth fault function shall be available, forward, reverse and non-directional. This protection function shall be integrated into the same hardware unit as the impedance protection function.

3.35.2 Rationale

Historically IDMT residual overcurrent protection relays were included in feeder protection schemes to cater for a failure to operate of the primary relay. Their inclusion was justified on the basis of the fact that earth faults are the predominant fault type and because of the immunity of the zero sequence measurement to load. The benefit of the IDMT residual overcurrent protection relay as a high resistance fault detector was realised later.

The role of the IDMT residual overcurrent protection as a high resistance fault detector, is not required if the primary protection function is current differential, as this type of protection is more sensitive than distance protection. If the primary protection function is impedance based, the IDMT residual overcurrent protection role is supplementary to the distance protection function. Furthermore, the IDMT 'relay' is not expected to perform the function of local back-up for a primary protection function failure. There is a second primary protection relay for this purpose. For the aforementioned two reasons it is acceptable for the IDMT 'relay' to be integrated within the primary protection function. Although the acceptance of the integration of this function within the primary relay is based on a re-definition of its role, it additionally benefits the aim of more cost effective EHV transmission line protection schemes.

As primarily a supplementary protection, and bearing in mind one of the primary protection relays could be out of service, the IDMT function should be duplicated.

3.35.3 Design requirements

The IDMT earth fault function shall:

- Make provision for the earth fault start forward and start reverse signals for use within the directional earth fault comparison function. The directionality shall be independent from the IDMT earth fault directional selection;
- Trip the bay breaker three pole (PTRC1 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC1 shall trip the bay breaker and initiate the bay breaker’s breaker fail function;
- Trip the tie bay breaker three pole (PTRC2 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC2 shall trip the tie bay breaker and initiate the tie bay breaker’s breaker fail function;
- IDMT earth fault start signal shall be connected to the IED internal disturbance recorder function (RBDR);
- IDMT earth fault trip signal shall be connected to the IED internal disturbance recorder function (RBDR); and,
- IDMT earth fault tripping shall be reported to the gateway and station HMI.

3.36 Local overvoltage protection: PTOV 1

3.36.1 Philosophy

Local overvoltage protection shall be applied to disconnect the transmission line to remove a local overvoltage condition. The overvoltage function shall be duplicated and be integrated into the primary protection hardware.

The type of voltage measurement used shall match the characteristic EHV equipment withstand capability to temporary overvoltages (refer to Cigré SC33.paper, “Temporary overvoltages: causes, effects and evaluation” presented at the Paris 1990 session).

Each of the tripping systems shall contain overvoltage tripping input arrangements suitable for accepting input signals derived locally.

3.36.2 Rationale

The purpose of the local overvoltage function is to disconnect the protected transmission line for a local overvoltage condition. The overvoltage function is therefore required to make a local ‘measurement’ and then to trip the local circuit-breakers. The measurement voltage shall be positive sequence (V1). The local overvoltage function shall have a threshold setting and a definite time delay setting.

Station connected equipment can be damaged due to prolonged power frequency overvoltages. Consequently, protection must be provided to cater for such overvoltage conditions.

As the main purpose of the protection is to protect station-connected equipment against temporary power frequency overvoltages, the characteristic of the protection should match the capability of EHV equipment. This implies an inverse voltage versus time characteristic.

No auto-reclose is desirable as controlled, manually executed restoration is necessary.

3.36.3 Design Requirements

The local overvoltage function shall:

- Trip the bay breaker three pole (PTRC1 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC1 shall trip the bay breaker and initiate the bay breaker's breaker fail function;
- Trip the tie bay breaker three pole (PTRC2 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC2 shall trip the tie bay breaker and initiate the tie bay breaker's breaker fail function;
- Local overvoltage trip signal shall trigger the direct transfer trip send function;
- Local overvoltage start signal shall be connected to the IED internal disturbance recorder function (RBDR);
- Local overvoltage trip signal shall be connected to the IED internal disturbance recorder function (RBDR); and,
- Local overvoltage tripping shall be reported to the gateway and station HMI.

3.37 Compensated overvoltage protection

3.37.1 Philosophy

Overvoltage protection shall be applied to disconnect the transmission line to remove an overvoltage condition for cases when the protected line is the source of the overvoltage condition.

The overvoltage function shall be duplicated and may be integrated into the primary protection hardware.

Overvoltage protection is not prescribed but will be provided as an option for application on lines where it can be determined that the Ferranti effect on the line can cause a voltage rise greater than 5 % of the sending end voltage.

The type of voltage measurement used shall match the characteristic EHV equipment withstand capability to temporary overvoltages (refer to Cigré SC33.paper, "Temporary overvoltages: causes, effects and evaluation" presented at the Paris 1990 session).

Protection against local (substation) overvoltages is not considered to be the domain of the transmission line protection as the required action may require more than opening a circuit-breaker and needs to be co-ordinated on a substation basis.

3.37.2 Rationale

On all EHV transmission line applications excessive power frequency voltage rises are possible either due to the Ferranti effect as a result of the line being open ended or due to the line loading being well below the surge impedance loading.

Line connected equipment can be damaged due to prolonged power frequency overvoltages. Consequently, protection must be provided for such overvoltage conditions.

The purpose of the compensated overvoltage function is to disconnect the protected transmission line for those circumstances where it can be determined that the transmission line itself is the cause of the overvoltage condition on the line. This condition occurs primarily when a long line, for whatever reason, is open at one end only or lightly loaded, such that the voltage rise along the line is significant.

The overvoltage function is therefore required to make a local 'measurement' of the voltage at the remote end of the line, and then to trip the local circuit-breakers for a remote-end overvoltage. It is not specified whether the measured voltage shall be positive sequence (V1) or phase-to-neutral (Vph-n). Whatever the measurement principle, no incorrect operation shall result for heavy Var flows on an otherwise healthy system. The compensated overvoltage function shall have a threshold setting and a definite time delay setting.

The compensated overvoltage function is not required for all applications and shall be user selectable ON/OFF. The compensated overvoltage function shall be selectable to ON for application on lines where it can be determined that the effective remote-end voltage, due to the sending-end voltage and the Ferranti rise, could be such to warrant the need for overvoltage protection.

In accordance with the requirement of providing fully duplicated protection at the EHV level, the overvoltage function shall also be duplicated. The function shall be integrated within the primary protection hardware.

Not all EHV transmission lines suffer the effect of significant Ferranti voltage rise, especially when the lines are short or the line loading is much greater than the surge impedance loading. For this reason, the overvoltage function is required as an option which will only be utilised on those applications where temporary power frequency overvoltages are of concern.

The compensated overvoltage protection function is not required for the current differential protection IED.

3.37.3 Design Requirements

Line overvoltage conditions can be detected either by:

- measuring the actual voltage and issuing a local trip as well as an intertrip to the other line end; and,
- issuing a local trip for a calculated overvoltage of the remote line end.

The following points regarding the design of the compensated overvoltage function should be noted:

- Local relaying may be out of service when the line breaker is open;
- Corona noise is proportional to the line voltage. Excessive corona noise can adversely affect PLC signals;
- The overvoltage measurement location, accuracy, quantity and drop-out to pick-up ratio should be carefully evaluated;
- The damaging effect of overvoltages is a function of the magnitude and duration of the overvoltage;
- Precision of the measurement;
- The overvoltage measurement should be validated for 90o leading current (phase based measurement);
- Line reactors are in some cases switchable to line- or bus- side (relevant to compensated measurement); and,
- Ensure, in circumstances of excessive Var flow, that overvoltage measurement is correct.

The compensated overvoltage function shall:

- Trip the bay breaker three pole (PTRC1 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC1 shall trip the bay breaker and initiate the bay breaker's breaker fail function;
- Trip the tie bay breaker three pole (PTRC2 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC2 shall trip the tie bay breaker and initiate the tie bay breaker's breaker fail function;
- Compensated overvoltage start signal shall be connected to the IED internal disturbance recorder function (RBDR);

- Compensated overvoltage trip signal shall be connected to the IED internal disturbance recorder function (RBDR); and,
- Compensated overvoltage tripping shall be reported to the gateway and station HMI.

3.38 Tripping logic

3.38.1 Philosophy

The breaker-and-a-half line protection IED shall have the ability to independently interface with the bay circuit-breaker, tie bay circuit-breaker, busbar protection zone(s) and adjacent object protection systems.

3.38.2 Rationale

The independent interfacing is required to effectively manage the and to ensure trip each for the bay and tie bay breaker failure protection and trip circuit seal-in, and the summated quantity is required for the line protection functions.

3.38.3 Design Requirements

The following functions shall be disabled when the line isolator is open and with the absence of a line isolator discrepancy condition:

- Phase selection;
- Power swing blocking;
- All impedance zones;
- Switch-onto-fault protection;
- Weak-infeed protection;
- IDMT earth fault protection;
- Directional earth fault comparison protection;
- Directional earth fault comparison phase selection;
- Local overvoltage protection trip;
- Compensated overvoltage protection;
- Fuse fail detection;
- Direct transfer trip send (excluding local overvoltage protection to DTTS);
- Direct transfer trip receive;
- Series cap bank breaker failure to close trip input;
- Out-of-step external trip input;
- External 3 pole trip without auto-reclose input; and,
- Busbar reactor breaker fail trip input.

The following functions shall be enabled when the line isolator is open and with the absence of a line isolator discrepancy condition:

- Stub protection.

The following functions shall always be enabled independent on the line isolator position or line isolator discrepancy condition:

- Bay circuit-breaker fail protection;

- Tie bay circuit-breaker fail protection;
- Trip circuit seal-in;
- Bay breaker tripping;
- Tie bay breaker tripping;
- Direct transfer trip send by the local overvoltage protection; and,
- Line reactor breaker fail trip input (disabled when IED is selected for a busbar reactor diameter application).

3.39 Trip command routing

3.39.1 Philosophy

The minimum amount of circuit-breakers shall be tripped to isolate a fault condition and to auto-reclose for supply restoration.

The main # protection device shall trip (on a per phase basis) the bay main # trip coil of the bay circuit-breaker and the tie bay main # trip coil of the tie bay circuit-breaker through the trip-duty rated output contacts of the main # protection when the TNS(M#) is in the 'Normal' or 'Test 1' position. Tripping shall be routed via the breaker PIU.

All the protection functions (internal to the protection IED and external trip inputs to the protections IED) shall initiate the bay breaker fail function and the tie bay breaker fail function (excluding the bay pole discrepancy and the tie bay pole discrepancy functions).

The busstrip command from the bay breaker fail function shall issue a busstrip command to trip the adjacent circuit-breakers:

- Buszone protection scheme (own zone) with the TNS selected to the 'Normal' position; and,
- Remote line end with the relevant TPIS selected to the 'On' position.

The busstrip command from the tie bay breaker fail function shall issue a busstrip command to trip the adjacent circuit-breakers:

- Other object protection scheme with the TNS selected to the 'Normal' position;
- Buszone protection scheme (other zone) with the TNS selected to the 'Normal' position (when the other object is non-existent); and,
- Remote line end with the relevant TPIS selected to the 'On' position.

3.39.2 Rationale

Tripping via the process interface units (GOOSE) is to reduce wiring between the control room and the primary plant equipment. The overall tripping time is measured from fault inception until closure of the trip duty contact on the process interface unit (GOOSE time included) and shall comply with the tripping time requirements within this document.

Two fundamental methods of routing Protection System output trip commands to trip-coils are practised, namely:

- segregated trip command routing; and,
- consolidated trip command routing.

It is Eskom's philosophy to employ the consolidated trip command routing approach. The main reasons behind this decision are:

- to reduce scheme costs by employing only one set of high grade trip-duty contacts for tripping;
- to consolidate the trip-circuit seal-in design within the scheme;

- to provide a common node for the initiation of circuit-breaker failure protection and the Closing Control System; and,
- to provide a centralised node for event logging within each Protection System.

In addition to the above reasons, new protection technology provides a much higher level of functional integration than in the past. This implies that functions previously separate from the main Protection System hardware device are now incorporated within the same device. Furthermore, any additional delay caused by this approach will not adversely affect the overall fault clearance time associated with the externally initiated trip inputs.

3.39.3 Design Requirements

The approach of routing all tripping through the main Protection System hardware device and the process interface units shall not compromise the internal functions, including the primary protection function, within the hardware device in terms of speed of operation.

External tripping inputs should invoke the same trip-circuit seal-in action as internally generated tripping signals.

3.39.3.1 Bay breaker trip conditioning: PTRC 1

The main # protection IED shall trip, on a per phase basis, the main # trip coil of the bay circuit-breaker through the trip-duty rated output contacts on the process interface unit when the TNS(M#) switch is in the 'Normal' or 'Test 1' position. The protection trips internal to the IED and the external trip inputs to the IED shall be routed via the PTRC1 to bay breaker.

PTRC1 shall:

- Trip the bay breaker single pole for single line to ground faults and three pole for multi-phase faults (with trip seal-in in accordance with the trip seal-in logic). Three pole trip selection for all fault types shall be done within the PTRC1. The outputs from PTRC1 shall trip the bay breaker and initiate the bay breaker's breaker fail function;
- Initiate the bay breaker single pole auto-reclose cycle for single line to ground faults and three pole auto-reclose cycle for multi-phase faults and auto-reclose block (the permitted auto-reclose cycle and sequence will be determined by the auto-reclose function). The PTRC1 trip outputs will be combined with the protection functions that will determine, single pole auto-reclose initiation, three pole auto-reclose initiation and auto-reclose block;
- Phase segregated trip signal shall be connected to the IED internal disturbance recorder function (RBDR); and,
- Phase segregated tripping shall be reported to the gateway and station HMI.

3.39.3.2 Bay breaker three pole trip selected

The protection IED PTRC1 shall provide for a three-pole trip only facility with an input derived from the bay breaker closing functionality when the TNS(M#) switch is in the 'Normal' or 'Test 1' positions. When the three pole trip select input is energised, PTRC1 shall perform only three-pole tripping irrespective of the type of fault or operating protection function. Initiation of the circuit-breaker failure function shall be for three-pole tripping, and initiation of automatic reclosing (if required) shall be three-pole.

The PTRC1 three pole trip selected signal from the bay breaker auto-reclose function shall be supervised by the TNS selected to test 2 (to remove the 3-pole trip selected when on test 2 to permit 1-pole tripping for testing purposes).

IEC61850 communications failure that affects the auto-reclose GOOSE signals, shall also select PTRC1 for three pole tripping only. The IEC61850 communications failure the affects three pole tripping only shall be disabled when the TNS is selected to test 2 (to remove the 3-pole trip selected when on test 2 to permit 1-pole tripping for testing purposes).

3.39.3.3 Tie Bay breaker trip conditioning: PTRC 2

The main # protection IED shall trip, on a per phase basis, the main # trip coil of the tie bay circuit-breaker through the trip-duty rated output contacts when the TNS(M#) switch is in the 'Normal' or 'Test 1' position. The protection trips internal to the IED and the external trip inputs to the IED shall be routed via the PTRC2 to bay breaker. PTRC2 shall:

- Trip the tie bay breaker three pole for single line to ground faults and multi-phase faults (with trip seal-in in accordance with the trip seal-in logic). The outputs from PTRC2 shall trip the tie bay breaker and initiate the tie bay breaker's breaker fail function;
- Initiate the tie bay breaker three pole auto-reclose cycle for single line to ground faults and multi-phase faults and auto-reclose block (the permitted auto-reclose cycle and sequence will be determined by the auto-reclose function). The PTRC1 trip outputs will be combined with the protection functions that will determine, three pole auto-reclose initiation and auto-reclose block;
- Three phase trip signal shall be connected to the IED internal disturbance recorder function (RBDR); and,
- Three phase trip signal shall be reported to the gateway and station HMI.

3.40 Disturbance recorder function: RDRE

3.40.1 Philosophy

The disturbance recorder function, at bay level, described as a requirement in IEC 61850-5 is decomposed into one LN class for analogue channels (RADR) and another LN class for binary channels (RBDR). The output refers to the "IEEE Standard Format for Transient Data Exchange (COMTRADE) for Power Systems" (IEC 60255-24). Disturbance recorders are logical devices built up with one instance of LN RADR or LN RBDR per channel.

The main protection device internal disturbance recorder shall have the capability to record the listed analogue and binary signals. The analogue traces and binary event information shall be displayed within a single window when the data is uploaded to the device's operating and analysis software for post fault analysis purposes.

3.40.2 Rationale

The internal disturbance recorder function is required to record all analogue traces and binaries for the purpose of post fault analysis and to export in the recordings in comtrade format for fault play back purposes.

3.40.3 Design Requirements

The main protection device shall perform all the sequence of events and analogue event recording for that main protection system. When the protection device has detected a fault condition (operation of any one of the protection functions or an external trip input), causing the relay to close any one of its trip output contacts, the sequence of events (time on and time off) shall be logged, time stamped (to 1 millisecond resolution) and stored.

Any protection device failure or abnormality shall also be stored and accessible. The presentation of the sequence of events, device failure or device abnormality information shall be such that an inexperienced person can access and evaluate it easily. The analogue traces and sequence of events shall be displayed within a single window when the data is uploaded to the device's operating and analysis software for post fault analysis purposes.

The pre-fault, fault and post-fault durations shall be independently selectable and the set duration shall be sufficient to record an auto-reclose cycle.

3.40.3.1 Disturbance recorder analogue channels: RADR

In addition to the channel number, all attributes needed for the COMTRADE file shall be provided for by data from the measured values. The "circuit component" and "phase identification" is provided by the instance identification of the LN RADR. Channels "1" to "n" are created by "1" to "n" instances.

Triggering by an analogue channel shall be independently selectable per channel. The triggering levels for (High/Low) for analogue quantities shall be independently selectable and also selectable to OFF (not permitted to trigger). All analogue channels shall be recorded independent on the trigger mode. Only the allocated (used) analogue channel shall be recorded. All the input analogue channels (per channel) and the measured analogue channels (e.g. summated current per phase, differential current per phase, bias current per phase, etc.) shall be available to be recorded.

3.40.3.2 Disturbance recorder binary channels: RBDR

In addition to the channel number, all attributes needed for the COMTRADE file are provided by attributes of the binary input (subscribed from another LN). The "circuit component" and "phase identification" is provided by the instance identification of the LN RBDR. Channels "1" to "n" are created by "1" to "n" instances.

The main protection device internal disturbance recorder shall have the capability to record the listed binary signals. The analogue traces and binary event information shall be displayed within a single window when the data is uploaded to the device's operating and analysis software for post fault analysis purposes.

Triggering by a binary channel shall be independently selectable per channel. Triggering shall be selectable between a change from a logical 0 to a logical 1, logical 1 to a logical 0 and OFF (not permitted to trigger). All binary channels shall be recorded independent on the trigger mode. All binary channels shall be recorded independent on the triggering selection. Only the allocated (used) binary channel shall be recorded. All binary information that is required for post fault analysis shall be available to be recorded.

3.40.3.3 External disturbance recorder

The external disturbance recorder is a separate device (not in the scope of this philosophy and housed separately). Alarms shall be routed from the line protection scheme to the external disturbance recorder. The external disturbance recorder will provide the interrogation supply (common positive) for the alarms.

When any one of the functions within the primary protection device asserts, the external disturbance recorder alarm contact outputs shall follow the operation of the protection function.

3.41 Breaker failure protection

3.41.1 Philosophy

Each Protection System shall include a circuit-breaker failure protection function, which shall be integrated within the same hardware device as the primary line protection functions. The circuit-breaker failure protection is required for both single- and three-pole tripping.

The circuit-breaker failure logic shall ensure that for all fault types (single- and three-pole tripping) the time delay to issuing a bus-strip shall be able to be set no longer than that which is required to perform successful fault clearance, plus a safety margin. This delay may be independently settable for single- and three-pole tripping, with the smallest possible delay settable in each case. It should not be a requirement of the logic that either delay setting should be significantly longer than the other.

The circuit-breaker failure protection shall not rely on the resetting of the initiate input signal to conclude successful opening of the circuit-breaker, but shall incorporate a high speed resetting capability on drop-off of current.

The circuit-breaker failure protection shall issue a trip signal to the circuit-breaker before issuing a bus-strip command with sufficient margin such that successful opening of the circuit-breaker will prevent a bus-strip. This trip signal may be for three-pole tripping only, there being no firm requirement in this circumstance for phase selective single-pole tripping. If integrated within the same hardware device as the primary protection functions, this trip signal should be issued via separate trip output contacts to those via which the primary protection issues its trip output.

Circuit-breaker failure operation is required for current and no (low) current conditions (for single- and three-pole tripping), with the no (low) current supervision being a selectable option. If current is detectable on initiation, the current supervision must be applied for the full duration of the fault event, and not switched to circuit-breaker auxiliary contact detection on successful opening of the circuit-breaker (this is to prevent an unwanted breaker fail in the event of a failed breaker auxiliary contact, the breaker did successfully open, with currect, to clear the fault condition). Alternatively, if insufficient current is present on initiation, the no (low) current supervision shall be activated, i.e. monitoring of the circuit-breaker auxiliary contacts.

For single-pole tripping, the circuit-breaker failure logic shall monitor the current or circuit-breaker status of only the pole to be tripped.

For three-pole tripping:

- with the current above the current threshold in all phases, the circuit-breaker failure logic shall monitor the current status of all poles;
- with the current above the current threshold only in the faulted phase/s, the circuit-breaker failure logic shall monitor the current status of the faulted pole/s, with pole discrepancy detection resulting if the unfaulted pole/s failed to open; and,
- with the current below the current threshold in the faulted phase/s, the circuit-breaker failure logic shall monitor the circuit-breaker status of all poles.

The following illustrates more clearly the above points:

	Faulted phase/s I> Unfaulted phase/s I>	**Faulted phase/s I> Unfaulted phase/s I<**	**Faulted phase/s I< Unfaulted phase/s I>**	**Faulted phase/s I< Unfaulted phase/s I<**
Single-phase fault, single-pole trip	Faulted phase I measurement, reset when faulted pole opened and I reset	Faulted phase I measurement, reset when faulted pole opened and I reset	Faulted phase auxiliary contact detection, reset when faulted pole detected open	Faulted phase auxiliary contact detection, reset when faulted pole detected open
Single-phase fault, three-pole trip	I measurement all phases, reset when three poles opened and last phase I reset	Faulted phase I measurement, reset when faulted pole opened and I reset - PD detection if unfaulted pole/s failed to open	Auxiliary contact detection all phases, reset when all three poles detected open	Auxiliary contact detection all phases, reset when all three poles detected open
Two-phase fault, three-pole trip	I measurement all phases, reset when three poles	Faulted phases I measurement, reset when	Auxiliary contact detection all phases, reset	Auxiliary contact detection all phases, reset

	opened and last phase I reset	faulted poles opened and last I reset - PD detection if unfaulted pole failed to open	when all three poles detected open	when all three poles detected open
Three-phase fault, three-pole trip	I measurement all phases, reset when three poles opened and last phase I reset	I measurement all phases, reset when three poles opened and last phase I reset	Auxiliary contact detection all phases, reset when all three poles detected open	Auxiliary contact detection all phases, reset when all three poles detected open

3.41.2 Rationale

Circuit-breaker failure protection provides a fundamental component of the local back-up protection. It was argued previously that in order to ensure initiation of circuit-breaker failure protection every time a trip signal is issued to the circuit-breaker, the circuit-breaker failure protection must also be duplicated, one per Protection System. The circuit-breaker failure protection shall be integrated within the same hardware device as the primary protection functions.

Single- and three-pole circuit-breaker failure functionality is required as single- and three-pole tripping is effected on Eskom’s transmission system.

It is important that minimum bus-strip time-delay settings, but which do not jeopardise the correct operation or reduce the security of the circuit-breaker failure, can be applied for all fault types (single- and three-pole tripping) for reasons of system stability, limitation of damage, and particularly of quality of supply (dip duration). The requirement for a high-speed resetting capability on drop-off of current is consistent with ensuring minimum bus-strip time-delay settings.

Due to its severity, a bus-strip must only be performed if absolutely necessary. Every effort must first be made to trip the offending circuit-breaker. Therefore, with sufficient margin before issuing a bus-strip, the circuit-breaker failure protection should issue a trip to the circuit-breaker. The requirement for separate trip output contacts for this purpose is to achieve a limited degree of diversity in the trip route to the circuit-breaker. This feature of providing a trip from the circuit-breaker failure protection before a bus-strip also guards against human errors, as the consequences of tripping one circuit-breaker in error are significantly less severe than performing a bus-strip.

The no (low) current requirement is to cater for those conditions where a trip signal is issued to the circuit-breaker with current flow below the circuit-breaker failure current detection threshold, e.g. weak / zero infeed trips, possible for overvoltage trips, etc. Current supervision is by far the most secure and reliable method of detecting successful opening of the circuit-breaker, and is definitely Eskom’s preferred method. Although required, acceptance of circuit-breaker auxiliary contact supervision is only granted in those cases where the current is below the set threshold. It is expected that, for all trip outputs from the protection that initiate the circuit-breaker failure protection, the circuit-breaker failure protection must determine the presence of or lack of current. If current is present, current supervision must be applied for the full duration of the fault event. If the logic were to revert to circuit-breaker auxiliary supervision on successful opening of the circuit-breaker (drop-off of current), this would amount to no more than doing away with the current supervision and employing only circuit-breaker auxiliary contact supervision.

The requirement for the no (low) current using circuit-breaker auxiliary contact supervision to be a selectable option is the following:

- if, for a particular application, no low current faults are expected (or possible), this setting can be used as an additional safeguard; and,
- if, for a particular reason, bus-stripping is not required for no (low) current tripping, this setting can be used to disable bus-stripping.

3.41.3 Design Requirements

The circuit-breaker failure protection shall be able to evolve from single-pole logic to three-pole logic for evolving faults, i.e. for a single-pole trip evolving to a three-pole trip as the result of a single-phase fault evolving to a multi-phase fault. In essence this means also that the circuit-breaker failure protection must be secure against issuing an unnecessary and unwanted bus-strip command following an evolving fault.

3.41.3.1 Bay breaker failure protection: RBRF 1

The bay breaker failure function is required to trip the neighbouring breakers in the case that the fault is not cleared. The main protection device shall include a bay breaker failure protection function. The tripping functions within each main protection system shall initiate only the bay breaker failure function within the same main protection device. The bay breaker current transformer inputs (prior summation with the tie bay breaker currents) shall be utilised for the bay breaker fail function.

Initiation of the bay breaker failure function shall occur, for both single- and three-pole tripping, for all protection tripping of the bay circuit-breaker, with the exception of bay breaker pole discrepancy tripping function. The initiation shall be phase segregated (tripped phase) for single-pole tripping, and all phases (or a single three-phase initiation) for three-pole tripping. A settable bay breaker fail timer shall commence timing on initiation of the bay breaker failure function for both single-pole and three-pole tripping. Successful opening of the bay breaker (fault cleared) shall immediately stop the timer. Failure of the bay breaker to open by expiry of the timer shall result in closure of the bay breaker fail binary output contact(s).

Successful opening of the bay breaker shall be determined by the drop-off of current (by way of a high speed resetting capability), or on detection of change of status (closed to open) of the bay breaker auxiliary contacts, and shall not rely solely on the resetting of the initiating signal. This is required to allow the setting on the bay breaker timer to be set no longer than is necessary (maximum bay breaker opening time, plus a small margin). For single- and three-pole tripping, verification of successful opening of the bay breaker shall be by way of:

- current drop-off (current through the bay breaker) shall occur whenever current (above a settable threshold) is present on initiation of the bay breaker failure function (this verification of bay breaker opening by way of current measurement shall co-ordinate with the trip-circuit seal-in by way of current measurement); and,
- bay breaker auxiliary contacts shall occur for no (low) current conditions (current through the bay breaker below the settable threshold) on initiation (this verification of bay breaker opening by way of the bay breaker auxiliary contacts shall co-ordinate with the trip-circuit seal-in by way of a fixed duration timer). The no (low) current verification by way of the bay breaker auxiliary contacts shall be a selectable option.

If the bay breaker failure protection detects current on initiation, verification of successful opening of the bay breaker by way of current shall be maintained for the full duration of the fault event, i.e. when the current drops-off following successful opening of the bay breaker, the bay breaker failure function shall not now convert to the monitoring of the bay breaker auxiliary contact status for the no current condition.

For single-pole tripping, the bay breaker failure logic shall monitor the current or bay breaker status of only the pole to which the trip command was issued. The timing of the bay breaker fail timer shall, respectively, be stopped when the tripped phase current is detected to be below the threshold level, or the bay breaker auxiliary contacts of the tripped phase indicate that the pole have opened.

For three-pole tripping:

- with the current above the threshold level in all phases, irrespective of which are the actual faulted phase(s), the bay breaker failure logic shall monitor the current status of all poles, and shall stop the timing of the bay breaker fail timer when all phase currents are detected to be below the threshold level;

- with the current above the threshold level in only the faulted phase(s), the bay breaker failure logic shall monitor the current status of all poles, and shall stop the timing of the bay breaker fail timer when all phase currents are detected to be below the threshold level (bay breaker pole discrepancy detection shall result if the unfaulted pole(s) fails to open); and,
- with the current below the threshold level in the faulted phase(s), irrespective of the current level in the unfaulted phase(s), the bay breaker failure logic shall monitor the bay breaker auxiliary contact status of all poles, and shall stop the timing of the bay breaker fail timer when the bay breaker auxiliary contacts indicate that all poles have opened.

It must be ensured that the bay breaker failure protection cannot issue an unnecessary and unwanted breaker fail command for evolving faults, i.e. for single-pole trips evolving to three-pole trips as the result of single-phase faults evolving to multi-phase faults.

The bay breaker fail function shall:

- Issue a bay breaker fail command to the buszone protection scheme with the TNS selected to the ‘Normal’ position and the bay SIS not selected to the ‘Maintenance’ position;
- Issue a bay breaker fail command to trip the tie bay breaker and to block the tie bay breaker auto-reclose function with the TNS selected to the ‘Normal’ position and the bay SIS not selected to the ‘Maintenance’ position;
- Issue a bay breaker fail command to the remote end breaker(s) via the direct transfer trip function;
- Block the bay breaker auto-reclosing function;
- Bay breaker fail start signal shall be connected to the IED internal disturbance recorder function (RBDR);
- Bay breaker fail trip signal shall be connected to the IED internal disturbance recorder function (RBDR); and,
- Bay breaker fail shall be reported to the gateway and station HMI.

Manual opening (local and remote) and trip testing of the bay breaker shall not initiate the bay breaker failure protection function.

3.41.3.2 Tie Bay breaker failure protection: RBRF 2

The tie bay breaker failure function is required to trip the neighbouring breakers in the case that the fault is not cleared. The main protection device shall include a tie bay breaker failure protection function. The tripping functions within each main protection system shall initiate only the tie bay breaker failure function within the same main protection device. The tie bay breaker current transformer inputs (prior summation with the bay breaker currents) shall be utilised for the tie bay breaker fail function.

Initiation of the tie bay breaker failure function shall occur, for three-pole tripping, for all protection tripping of the tie bay circuit-breaker, with the exception of the tie bay breaker pole discrepancy tripping function. The initiation shall be all phases for three-pole tripping. A settable tie bay breaker fail timer shall commence timing on initiation of the tie bay breaker failure function for three-pole tripping. Successful opening of the tie bay breaker (fault cleared) shall immediately stop the timer. Failure of the tie bay breaker to open by expiry of the timer shall result in closure of the tie bay breaker fail binary output contact(s).

Successful opening of the tie bay breaker shall be determined by the drop-off of current (by way of a high speed resetting capability), or on detection of change of status (closed to open) of the tie bay breaker auxiliary contacts, and shall not rely solely on the resetting of the initiating signal. This is required to allow the setting on the tie bay breaker timer to be set no longer than is necessary (maximum bay breaker opening time, plus a small margin). Verification of successful opening of the tie bay breaker shall be by way of:

- current drop-off (current through the tie bay breaker) shall occur whenever current (above a settable threshold) is present on initiation of the bay breaker failure function (this verification of tie bay breaker opening by way of current measurement shall co-ordinate with the trip-circuit seal-in by way of current measurement); and,

- tie bay breaker auxiliary contacts shall occur for no (low) current conditions (current through the bay breaker below the settable threshold) on initiation (this verification of tie bay breaker opening by way of the tie bay breaker auxiliary contacts shall co-ordinate with the trip-circuit seal-in by way of a fixed duration timer). The no (low) current verification by way of the tie bay breaker auxiliary contacts shall be a selectable option.

If the tie bay breaker failure protection detects current on initiation, verification of successful opening of the tie bay breaker by way of current shall be maintained for the full duration of the fault event, i.e. when the current drops-off following successful opening of the tie bay breaker, the tie bay breaker failure function shall not now convert to the monitoring of the tie bay breaker auxiliary contact status for the no current condition.

For three-pole tripping:

- with the current above the threshold level in all phases, irrespective of which are the actual faulted phase(s), the tie bay breaker failure logic shall monitor the current status of all poles, and shall stop the timing of the tie bay breaker fail timer when all phase currents are detected to be below the threshold level;
- with the current above the threshold level in only the faulted phase(s), the tie bay breaker failure logic shall monitor the current status of all poles, and shall stop the timing of the tie bay breaker fail timer when all phase currents are detected to be below the threshold level (tie bay breaker pole discrepancy detection shall result if the unfaulted pole(s) fails to open); and,
- with the current below the threshold level in the faulted phase(s), irrespective of the current level in the unfaulted phase(s), the bay breaker failure logic shall monitor the tie bay breaker auxiliary contact status of all poles, and shall stop the timing of the bay breaker fail timer when the tie bay breaker auxiliary contacts indicate that all poles have opened.

The tie bay breaker fail function shall:

- Issue a tie bay breaker fail command to the other object protection scheme and in the event that the other object is not present then to the buszone protection scheme (other zone) with the TNS selected to the 'Normal' position and the tie bay SIS not selected to the 'Maintenance' position;
- Issue a tie bay breaker fail command to trip the bay breaker and to block the bay breaker auto-reclose function with the TNS selected to the 'Normal' position and the bay SIS not selected to the 'Maintenance' position; and;
- Issue a tie bay breaker fail command to the remote end breaker(s) via the direct transfer trip function;
- Block the tie bay breaker auto-reclosing function;
- Tie bay breaker fail start signal shall be connected to the IED internal disturbance recorder function (RBDR);
- Tie bay breaker fail trip signal shall be connected to the IED internal disturbance recorder function (RBDR); and,
- Tie bay breaker fail shall be reported to the gateway and station HMI.
- Manual opening (local and remote) and trip testing of the tie bay breaker shall not initiate the tie bay breaker failure protection function.

3.42 Power swing blocking: RPSB

3.42.1 Philosophy

Power swing measurement shall be an integral part of the IED and shall correctly determine the existence of a power swing condition under all system operating conditions.

Impedance-based relaying systems shall have the capability of providing the selective blocking of the individual zones of protection, auto-reclose initiation, weak infeed, teleprotection send and receive for detected power swing conditions.

The IED shall have the capability of issuing a trip command during an established power swing condition for faults on the protected line.

3.42.2 Rationale

Transmission lines on the Eskom network are susceptible to power swings and out-of-step conditions, due to the spread of generation in some areas of the network. Eskom's current out-of-step protection philosophy is to employ dedicated out-of-step tripping relays at strategic locations in the network. Upon detection of an out-of step condition, the out-of-step tripping system issues trip command signals to pre-determined circuit-breakers to separate the system into two islands. Therefore, impedance relays on the network are required to have the capability of being blocked under power swing conditions to prevent unwanted, fragmented tripping of the network.

Selective blocking of the various zones of protection is required for flexibility and optimisation of applications (studies are run to determine where the impedance locus can be expected).

Blocking of the weak infeed trip / echo is required to cover for contingencies where at one line end the locus has entered the teleprotection send zone without detection of the swing, while at the other line end the swing has been detected, but has not entered any of the relay zone characteristics, thereby preventing weak infeed tripping and echo. Blocking of the echo will prevent accelerated permissive tripping at the sending end.

Blocking of the carrier send signal [assuming measurement is not blocked] is required to cover for the contingency where one end detects a swing (and the swing locus enters the carrier send zone) with no swing detected by the other end and:

- there is no zone detection (in this case the aim is to prevent weak infeed tripping); or,
- there is a permissive zone detection (in this case the aim is to prevent accelerated permissive tripping)

Blocking of the carrier receive signal is required to cover for the contingency where the swing locus has entered the carrier send / permissive zone at both ends with detection of the swing at one end only (or detection at other end as well, but with the affected zone not selected for blocking). This requirement is to prevent accelerated permissive tripping at the end where the swing was detected with blocking enabled.

Blocking of ARC initiation is required to cater for three scenarios:

- the zones are not blocked and no ARC is desired;
- a fault occurs after blocking is established. Even if the relay can distinguish the 2nd disturbance as a fault, it will be undesirable to reclose as this would be a second system disturbance; and
- a zone is re-enabled after a fixed blocking duration and no ARC is desired.

3.42.3 Design requirements

Power swing detection with blocking is required to prevent tripping by the impedance function during power swing conditions. It shall be possible to detect, and block, for power swings up to 7 Hz.

Power swing detection shall cater for the impedance vector entering the power swing detection characteristic at any point, or at any angle. Power swing detection shall commence as the impedance vector passes the power swing detection characteristic, which shall be outside the fault detection characteristic(s). If a power swing is concluded, blocking shall be established. The blocking shall remain effective until the impedance vector leaves the power swing characteristic, a fault occurs, or a set timer has expired.

If a fault occurs on the protected line following power swing detection, with blocking established the blocking shall be released to allow normal operation of the impedance function. All tripping, in any zone, for faults following power swing detection, without the impedance vector having exited the power characteristic, shall be three-pole only.

When blocking is established, a timer (settable) shall commence timing. If the impedance vector has not exited the power swing characteristic by the time this timer expires, the blocking shall be released and normal operation of the impedance function allowed. All tripping, in any zone, resulting from the blocking release shall be three-pole.

Following power swing detection, it shall be possible to individually select each zone to be blocked, or not. It shall also be possible to select to block, or not, the teleprotection send and echo functions, the teleprotection permissive receive signal from influencing the permissive tripping logic, and the weak infeed tripping logic. If, following establishment of the power swing blocking, it is released for a subsequent fault, it shall be possible to select to allow (in accordance with normal restrictions), or block, automatic reclosing.

Correct power swing detection and blocking shall be possible during single-pole open conditions on the protected line, on a parallel line, or in either source. If power swing has been detected, and blocking established, during single-pole open conditions on the protected line, the blocking shall be released to allow normal operation of the impedance function for evolving faults.

Power swing blocking:

- Measurement technique needs to be sound;
- Single-pole blocking (one phase open on parallel line);
- If blocking has been established, blocking is required to be removed if a fault is subsequently detected. The occurrence of a system fault shall take priority over the power swing blocking. In this case a three-pole trip command must be issued (without reclosure) by the protection on the faulted line. A power swing blocking action time is required to unblock/release the protection functions during sustained power swings to allow tripping;
- All tripping following power swing detection, including tripping issued from non-blocked zones, tripping due to a fault after blocking has been established, or tripping for a fault occurring within a re-enabled zone after a fixed blocking duration, shall be three-pole;
- The power swing detection measurement must work correctly for the given maximum swing frequency and for the given maximum swing locus ohms/sec;
- If blocking has been established, the blocking is required to be removed if not automatically reset after a fixed (settable) time duration. Continuous pick-up of the power swing blocking might not mean the swing locus is continuously inside the characteristic, but that it exits and enters again before reset; and,
- Tripping for faults on the protected line during an established power swing shall be at a minimum time delay and the tripping shall be 3-pole without auto-reclose at both line ends.

3.43 VT Fuse failure

3.43.1 Philosophy

The primary protection function shall not operate incorrectly for the loss of any number of VT inputs. No alternative tripping logic is required on detection of the loss of the VT input quantities.

3.43.2 Rationale

VT input failure logic is required to prevent unnecessary tripping of a healthy line as a result of the loss of one or more VT inputs, both for load conditions and adjacent line fault conditions.

Alternative tripping logic is not required for the following reasons:

- it affects only one relay at one line-end; and,
- it is alarmed and can be restored timeously.

3.43.3 Design requirements

The detection of the loss of any VT input and any associated blocking actions shall be automatically reset once the VT supply is restored. The restoration of the current reversal guard blocking an weak-infeed tripping logic shall be delayed as to prevent overtripping.

Consideration must also be given to all other voltage dependent functions.

The VT secondary supply failure detection shall only operate for a genuine loss of VT input quantities, and not for open pole conditions or faults on adjacent networks.

The voltage transformer (CVT) secondary supply failure alarm must be delayed as to prevent unnecessary alarming due to unequal three pole opening of the circuit breaker.

The VT secondary supply failure function shall blocked by the trip signal to prevent unwanted operation of the fuse fail function during unequal opening of the circuit-breaker phases.

The failure of one or more fuses (or single phase MCBs) will affect the behaviour of the voltage dependent protection function. This condition shall be detected by and additional functional element which then interacts with all the voltage dependent protection functions to effect blocking of these protection functions for loss of voltage.

Monitoring for VT supply failure conditions, plus the associated supply failure logic, is required to ensure that the distance and other voltage function remains secure, i.e. that it does not misoperate, either for load conditions or adjacent line fault conditions, for the loss of any number of VT inputs.

To prevent a misoperation, blocking of all the voltage dependent measuring functions (e.g. impedance and other voltage dependent functions) shall occur immediately on detection of a supply failure condition by the supply failure monitor. Establishment of supply failure (one, two or three phase supplies) shall only occur for genuine supply failure conditions, and not for open pole conditions (one- or three-pole), or for faults on the protected line (weak infeed), or for faults on adjacent networks. A time delay may therefore be necessary before establishment of supply failure. This time delay shall be no longer than that required to ascertain a supply failure condition. Subsequent current detection within the time window following detection of the supply failure condition, but before establishment of supply failure, shall release the blocking of the voltage dependent measuring functions, allowing their operation. Establishment of supply failure shall occur if the detected supply failure condition persists for the duration of the time delay. Once established, supply failure shall be sealed-in, and blocking of the voltage dependent measuring functions shall not be released, until the supply is restored. Reset of the supply failure shall occur automatically with restoration of the VT supply.

On blocking of the distance function following the detection of a supply failure condition, or establishment of supply failure, it is not a requirement that the relay shall switch to an alternate function.

The VT fuse failure alarm (local and remote) shall be delayed as to prevent unnecessary alarming due to unequal operation of the circuit-breaker poles.

3.44 External inputs from other protection schemes

3.44.1 Philosophy

The primary protection IED shall make provision (via GOOSE) to receive trip and primary plant status inputs from other protection schemes.

3.44.2 Rationale

The trip inputs are required to the connected circuit-breakers within this protection scheme, as the second set of circuit-breakers to clear a network fault.

The external primary plant inputs are required to set this protection IED to reactor on trip information received from the other protection schemes.

3.44.3 Design requirements

3.44.3.1 Buszone trip input from own zone

The main protection devices shall provide for a buszone trip input function derived from the buszone protection scheme (connected zone). The interface between the line protection scheme and the busbar protection scheme (own zone) shall be a hardwire interface.

The connected zone buszone trip input shall:

- Trip the bay breaker trip coils directly. This tripping shall be independent on the TNS selection;
- Initiate the direct transfer trip send function (user selectable);
- Trip the bay breaker three pole via the line protection IED (PTRC1 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC1 shall trip the bay breaker and initiate the bay breaker's breaker fail function;
- Buszone (own zone) trip signal shall be connected to the IED internal disturbance recorder function (RBDR); and,
- Buszone (own zone) tripping shall be reported to the gateway and station HMI.

3.44.3.2 Buszone trip input from other zone

The main protection devices shall provide for a buszone trip input function derived from the buszone protection scheme (other zone). The buszone trip input from the other zone is required in the event that the other object is not present (only 1 object on that diameter). The interface between the line protection scheme and the busbar protection scheme (other zone) shall be a hardwire interface.

The other zone buszone trip input shall:

- Trip the tie bay breaker trip coils directly. This tripping shall be independent on the TNS selection;
- Initiate the direct transfer trip send function (user selectable);
- Trip the tie bay breaker three pole via the line protection IED (PTRC2 - with trip seal-in in accordance with the trip seal-in logic) and block the tie bay breaker auto-reclosing. The outputs from PTRC2 shall trip the tie bay breaker and initiate the tie bay breaker's breaker fail function;
- Buszone (other zone) trip signal shall be connected to the IED internal disturbance recorder function (RBDR); and,
- Buszone (other zone) tripping shall be reported to the gateway and station HMI.

3.44.3.3 Connected line reactor breaker fail protection trip input

For all breaker-and-a-half line protection applications, each of the tripping systems shall provide a line and busbar reactor tripping and breaker fail inputs derived from within the line and busbar reactor schemes.

Operation of the line reactor trip input to the scheme shall initiate 3-pole tripping without auto-reclose to both the bay 1/2 and tie bay breakers, shall initiate the bay 1/2 and tie bay circuit-breaker failure protection and trigger the direct transfer trip send function when this input and the line protection trip signal is simultaneously high.

Operation of the line reactor breaker fail input to the scheme shall initiate 3-pole tripping without auto-reclose to both the bay 1/2 and tie bay breakers, shall initiate the bay 1/2 and tie bay circuit-breaker failure protection and trigger the direct transfer trip send function when this input and the line protection trip signal is simultaneously high.

Operation of the busbar reactor trip input to the scheme and with the reactor transfer isolator in the close position, shall initiate 3-pole tripping without auto-reclose to both the bay 1/2 and tie bay breakers, shall initiate the bay 1/2 and tie bay circuit-breaker failure protection and trigger the direct transfer trip send function.

Operation of the reactor breaker fail input to the scheme and with the reactor transfer isolator in the close position, shall initiate 3-pole tripping without auto-reclose to both the bay 1/2 and tie bay breakers, shall initiate the bay 1/2 and tie bay circuit-breaker failure protection and trigger the direct transfer trip send function.

The line need to be tripped 3-pole without auto-reclose, both ends, as to prevent auto-reclosure for the condition where line protection and the reactor protection operate at the same time. This is to prevent auto-reclosure of the when the line protection operate for a fault on the reactor and the reactor protection also operate and remove the reactor from service.

Line reactor interfacing requirements:

- Line reactor trip signal; and,
- Line reactor breaker fail signal.

Busbar reactor interfacing requirements:

- Busbar reactor trip signal;
- Busbar reactor breaker fail signal; and,
- Transfer isolator close status.

The connected line reactor breaker fail protection trip input shall trip both the local bay and tie bay breakers and the remote end breaker(s). The connected line reactor breaker fail trip signal to the line protection scheme is supervised within the line reactor protection scheme. The interface between the line protection scheme and the line reactor protection scheme shall be a hardwire interface.

The connected line reactor breaker fail trip input shall:

- Trip the bay breaker three pole (PTRC1 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC1 shall trip the bay breaker and initiate the bay breaker's breaker fail function;
- Trip the tie bay breaker three pole (PTRC2 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC2 shall trip the tie bay breaker and initiate the tie bay breaker's breaker fail function;
- Initiate the direct transfer trip send function. Direct transfer trip send shall be disabled when the line isolator is open in the open position and with no discrepancy;
- Line reactor breaker fail protection trip shall be connected to the IED internal disturbance recorder function (RBDR); and,
- Line reactor breaker fail protection trip shall be reported to the gateway and station HMI.

3.44.3.4 Connected line reactor trip input

The connected line reactor is in the forward direction of the distance zones. A fault within the line reactor protection zone of operation will also be detected by the distance zones if the fault impedance is within the first overreaching zone. Auto-reclose shall not be permitted in the event that the line reactor breaker, the bay breaker and tie bay breakers are simultaneously tripped. The connected line reactor trip signal to the line protection scheme is supervised within the line reactor protection scheme. The interface between the line protection scheme and the line reactor protection scheme shall be a hardwire interface.

Simultaneous operation of the connected line reactor protection and the line protection shall:

- Trip the bay breaker three pole (PTRC1 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC1 shall trip the bay breaker and initiate the bay breaker's breaker fail function;
- Trip the tie bay breaker three pole (PTRC2 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC2 shall trip the tie bay breaker and initiate the tie bay breaker's breaker fail function;

- Initiate the direct transfer trip send function. Direct transfer trip send shall be disabled when the line isolator is open in the open position and with no discrepancy;
- Line reactor protection trip shall be connected to the IED internal disturbance recorder function (RBDR); and
- Line reactor protection trip shall be reported to the gateway and station HMI.

3.44.3.5 Connected busbar reactor breaker fail protection trip input

The connected busbar reactor breaker fail protection trip input (when connected to the protected line and operated as a line reactor) shall trip both the local bay and tie bay breakers and the remote end breaker(s). The connected busbar reactor breaker fail trip signal to the line protection scheme shall be supervised within the line protection scheme. The interface between the line protection scheme and the busbar reactor protection scheme shall be a hardwire interface.

The connected busbar reactor breaker fail trip input shall:

- Trip the bay breaker three pole (PTRC1 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC1 shall trip the bay breaker and initiate the bay breaker's breaker fail function;
- Trip the tie bay breaker three pole (PTRC2 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC2 shall trip the tie bay breaker and initiate the tie bay breaker's breaker fail function;
- Initiate the direct transfer trip send function. Direct transfer trip send shall be disabled when the line isolator is open in the open position and with no discrepancy;
- Busbar reactor breaker fail protection trip shall be connected to the IED internal disturbance recorder function (RBDR); and,
- Line reactor breaker fail protection trip shall be reported to the gateway and station HMI.

3.44.3.6 Connected busbar reactor trip input

The connected busbar reactor is in the forward direction of the distance zones. A fault within the busbar reactor protection zone of operation will also be detected by the distance zones if the fault impedance is within the first overreaching zone. Auto-reclose shall not be permitted in the event that the busbar reactor breaker, the bay breaker and tie bay breakers are simultaneously tripped. The connected busbar reactor breaker fail trip signal to the line protection scheme shall be supervised within the line protection scheme. The interface between the line protection scheme and the busbar reactor protection scheme shall be a hardwire interface.

Simultaneous operation of the connected busbar reactor protection and the line protection shall:

- Trip the bay breaker three pole (PTRC1 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC1 shall trip the bay breaker and initiate the bay breaker's breaker fail function;
- Trip the tie bay breaker three pole (PTRC2 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC2 shall trip the tie bay breaker and initiate the tie bay breaker's breaker fail function;
- Initiate the direct transfer trip send function. Direct transfer trip send shall be disabled when the line isolator is open in the open position and with no discrepancy;
- Busbar reactor protection trip shall be connected to the IED internal disturbance recorder function (RBDR); and,
- Busbar reactor protection trip shall be reported to the gateway and station HMI.

3.44.3.7 External out-of-step trip input

Out-of-step protection is employed at strategic locations on the power system to detect, and operate for, out-of-step conditions. As the best location to trip circuit-breakers may not be at the measurement location, an additional transfer trip teleprotection channel is required to accommodate transfer tripping from the measurement location to assigned tripping locations.

The line protection device shall provide for an external out-of-step trip binary input. The external out-of step trip function shall be operated by an out-of-step trip signal generated external (local or remote) to the line protection scheme. The purpose of the external out-of-step trip input is to disconnect the protected transmission line during an out-of-step condition.

The external out-of-step trip input shall:

- Trip the bay breaker three pole (PTRC1 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC1 shall trip the bay breaker and initiate the bay breaker's breaker fail function;
- Trip the tie bay breaker three pole (PTRC2 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC2 shall trip the tie bay breaker and initiate the tie bay breaker's breaker fail function;
- External out-of-step trip signal shall trigger the direct transfer trip send function (user selectable);
- External out-of-step trip signal shall be connected to the IED internal disturbance recorder function (RBDR); and,
- External out-of-step trip shall be reported to the gateway and station HMI.

3.44.3.8 External three pole trip input

The line protection device shall provide for an external three pole trip binary input. The external three pole trip function shall be operated by a trip signal generated external to the line protection scheme. The purpose of the external three pole trip input is to disconnect the protected transmission line for a given condition.

The external three pole trip input shall:

- Trip the bay breaker three pole (PTRC1 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC1 shall trip the bay breaker and initiate the bay breaker's breaker fail function;
- Trip the tie bay breaker three pole (PTRC2 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC2 shall trip the tie bay breaker and initiate the tie bay breaker's breaker fail function;
- External three pole trip signal shall trigger the direct transfer trip send function (user selectable);
- External three pole trip signal shall be connected to the IED internal disturbance recorder function (RBDR); and,
- External three pole trip shall be reported to the gateway and station HMI.

3.44.3.9 Other object tie bay breaker fail trip input

The line protection device shall provide for a tie bay breaker fail external trip input. The purpose of the tie bay breaker fail trip input is to disconnect the protected transmission line (local and remote) for a tie bay breaker failure condition detected within the other object protection scheme.

The tie bay breaker fail external trip input shall:

- Trip the bay breaker three pole (PTRC1 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC1 shall trip the bay breaker and initiate the bay breaker's breaker fail function;
- Trigger the direct transfer trip send function;

- Tie bay breaker fail external trip signal shall be connected to the IED internal disturbance recorder function (RBDR);
- Tie bay breaker fail external trip shall be reported to the gateway and station HMI; and,
- Displayed on the line protection IED.

3.44.3.10 Series capacitor bank breaker failure to close trip input

The line protection device shall provide for a series capacitor bank breaker failure to close three pole trip binary input. This external three pole trip function shall be operated by a trip signal generated external to the line protection scheme. The purpose of the series capacitor bank breaker failure trip input is to disconnect the protected transmission line from the network and hence disconnecting the failed series capacitor bank from the network.

The series capacitor bank breaker failure to close three pole trip input shall:

- Trip the bay breaker three pole (PTRC1 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC1 shall trip the bay breaker and initiate the bay breaker's breaker fail function;
- Trip the tie bay breaker three pole (PTRC2 - with trip seal-in in accordance with the trip seal-in logic) and block auto-reclosing. The outputs from PTRC2 shall trip the tie bay breaker and initiate the tie bay breaker's breaker fail function;
- Trigger the direct transfer trip send function;
- Series capacitor bank breaker failure to close three pole trip signal shall be connected to the IED internal disturbance recorder function (RBDR); and,
- Series capacitor bank breaker failure to close three pole trip shall be reported to the gateway and station HMI.

3.45 Primary plant inputs

3.45.1 Philosophy

The primary protection IED shall make provision (via GOOSE) to receive primary plant status inputs from the PIUs.

3.45.2 Rationale

The primary plant status inputs are required within this protection IED, for protection and recording purposes.

3.45.3 Design requirements

3.45.3.1 Bay breaker status: XCBR

The LN "circuit breaker" covers the circuit breakers, i.e. switches able to interrupt short circuits. An AC circuit breaker is a device that is used to close and interrupt an AC power circuit under normal conditions or to interrupt this circuit under fault or emergency conditions (IEEE C37.2-1996). If there is a single-phase breaker, this LN has an instance per phase. These three instances may be allocated to three physical devices mounted in the switchgear.

The protection device shall subscribe to the following XCBR data, the XCBR logical node shall be within the breaker PIU:

	Bay Breaker PIU - Data Broadcast	**Logical Node**	**240-42066934**	**Subscriber (IED)**
1	Bay Breaker Red Phase Status (Open & Close status)	XCBR	6.11.1	Protection IED and Diameter control device
2	Bay Breaker White Phase Status (Open & Close status)	XCBR	6.11.1	Protection IED and Diameter control device
3	Bay Breaker Blue Phase Status (Open & Close status)	XCBR	6.11.1	Protection IED and Diameter control device
4	Bay Breaker Red Phase Status (2nd CB) (Open & Close status)	XCBR	6.11.1	Protection IED and Diameter control device
5	Bay Breaker White Phase Status (2nd CB) (Open & Close status)	XCBR	6.11.1	Protection IED and Diameter control device
6	Bay Breaker Blue Phase Status (2nd CB) (Open & Close status)	XCBR	6.11.1	Protection IED and Diameter control device

The bay breaker status is required within the main protection device. The bay breaker statuses (52a and 52b contacts) information shall be received via GOOSE data from the specific main protection PIU.

The following bay breaker status GOOSE data shall be subscribed to:

- Bay breaker red phase normally open (52a) auxiliary contact;
- Bay breaker red phase normally closed (52b) auxiliary contact;
- Bay breaker white phase normally open (52a) auxiliary contact;
- Bay breaker white phase normally closed (52b) auxiliary contact;
- Bay breaker blue phase normally open (52a) auxiliary contact; and,
- Bay breaker blue phase normally closed (52b) auxiliary contact.

The required bay breaker auxiliary contact information is required to fulfil the following functions, implemented within the line protection device:

- Bay breaker pole discrepancy;
- Bay breaker failure protection;
- Bay breaker internal event recording (open status per phase);
- External disturbance recorder (open status per phase);
- Blocking of the directional earth fault comparison function (relationship between the bay breaker and the tie bay); and,
- Teleprotection carrier echo.

For applications with two breaker per phase (six breakers per bay), phase segregated bay breaker statuses (52a and 52b contacts) information shall be received via GOOSE data from the specific main protection PIU.

The following bay breaker status GOOSE data shall be subscribed to:

- Bay breaker red phase pole 1 normally open (52a) auxiliary contact;
- Bay breaker red phase pole 1 normally closed (52b) auxiliary contact;
- Bay breaker white phase pole 1 normally open (52a) auxiliary contact;
- Bay breaker white phase pole 1 normally closed (52b) auxiliary contact;
- Bay breaker blue phase pole 1 normally open (52a) auxiliary contact;
- Bay breaker blue phase pole 1 normally closed (52b) auxiliary contact;
- Bay breaker red phase pole 2 normally open (52a) auxiliary contact;
- Bay breaker red phase pole 2 normally closed (52b) auxiliary contact;
- Bay breaker white phase pole 2 normally open (52a) auxiliary contact;
- Bay breaker white phase pole 2 normally closed (52b) auxiliary contact;
- Bay breaker blue phase pole 2 normally open (52a) auxiliary contact; and,
- Bay breaker blue phase pole 2 normally closed (52b) auxiliary contact.

The bay breaker pole 1 and pole 2 52a and 52b auxiliary contacts shall be available in a serial and parallel combination on a per phase basis. The required bay breaker serial auxiliary contact information per phase is required to fulfil the following functions, implemented within the line protection device:

- Bay breaker pole discrepancy;
- Bay breaker phase discrepancy (per phase);
- Bay breaker internal disturbance recording (open status per phase);
- External disturbance recorder (open status per phase);
- Blocking of the directional earth fault comparison function (relationship between the bay breaker and the tie bay); and,
- Teleprotection carrier echo.

The required bay breaker parallel auxiliary contact information per phase is required to fulfil the following functions, implemented within the line protection device:

- Bay breaker fail protection.

3.45.3.2 Tie bay breaker status: XCBR

The LN “circuit breaker” covers the circuit breakers, i.e. switches able to interrupt short circuits. An AC circuit breaker is a device that is used to close and interrupt an AC power circuit under normal conditions or to interrupt this circuit under fault or emergency conditions (IEEE C37.2-1996). If there is a single-phase breaker, this LN has an instance per phase. These three instances may be allocated to three physical devices mounted in the switchgear.

The protection device shall subscribe to the following XCBR data, the XCBR logical node shall be within the breaker PIU:

	Tie Bay Breaker PIU - Data Broadcast	**Logical Node**	**240-42066934**	**Subscriber (IED)**
1	Tie Bay Breaker Red Phase Status (Open & Close status)	XCBR	6.11.1	Protection IED and Diameter control device
2	Tie Bay Breaker White Phase Status (Open & Close status)	XCBR	6.11.1	Protection IED and Diameter control device

	Tie Bay Breaker PIU - Data Broadcast	**Logical Node**	**240-42066934**	**Subscriber (IED)**
3	Tie Bay Breaker Blue Phase Status (Open & Close status)	XCBR	6.11.1	Protection IED and Diameter control device
4	Tie Bay Breaker Red Phase Status (2nd CB) (Open & Close status)	XCBR	6.11.1	Protection IED and Diameter control device
5	Tie Bay Breaker White Phase Status (2nd CB) (Open & Close status)	XCBR	6.11.1	Protection IED and Diameter control device
6	Tie Bay Breaker Blue Phase Status (2nd CB) (Open & Close status)	XCBR	6.11.1	Protection IED and Diameter control device

The tie bay breaker status is required within the main protection device. The tie bay breaker statuses (52a and 52b contacts) information shall be received via GOOSE data from the specific main protection PIU.

The following tie bay breaker status GOOSE data shall be subscribed to:

- Tie bay breaker red phase normally open (52a) auxiliary contact;
- Tie bay breaker red phase normally closed (52b) auxiliary contact;
- Tie bay breaker white phase normally open (52a) auxiliary contact;
- Tie bay breaker white phase normally closed (52b) auxiliary contact;
- Tie bay breaker blue phase normally open (52a) auxiliary contact; and,
- Tie bay breaker blue phase normally closed (52b) auxiliary contact.

The required tie bay breaker auxiliary contact information is required to fulfil the following functions, implemented within the line protection device:

- Tie bay breaker pole discrepancy;
- Tie bay breaker failure protection;
- Tie bay breaker internal event recording (open status per phase);
- External disturbance recorder (open status per phase);
- Blocking of the directional earth fault comparison function (relationship between the bay breaker and the tie bay); and,
- Teleprotection carrier echo.

For applications with two breaker per phase (six breakers per bay), phase segregated tie bay breaker statuses (52a and 52b contacts) information shall be received via GOOSE data from the specific main protection PIU.

The following tie bay breaker status GOOSE data shall be subscribed to:

- Tie bay breaker red phase pole 1 normally open (52a) auxiliary contact;
- Tie bay breaker red phase pole 1 normally closed (52b) auxiliary contact;
- Tie bay breaker white phase pole 1 normally open (52a) auxiliary contact;
- Tie bay breaker white phase pole 1 normally closed (52b) auxiliary contact;
- Tie bay breaker blue phase pole 1 normally open (52a) auxiliary contact;
- Tie bay breaker blue phase pole 1 normally closed (52b) auxiliary contact;
- Tie bay breaker red phase pole 2 normally open (52a) auxiliary contact;

- Tie bay breaker red phase pole 2 normally closed (52b) auxiliary contact;
- Tie bay breaker white phase pole 2 normally open (52a) auxiliary contact;
- Tie bay breaker white phase pole 2 normally closed (52b) auxiliary contact;
- Tie bay breaker blue phase pole 2 normally open (52a) auxiliary contact; and,
- Tie bay breaker blue phase pole 2 normally closed (52b) auxiliary contact.

The tie bay breaker pole 1 and pole 2 52a and 52b auxiliary contacts shall be available in a serial and parallel combination on a per phase basis. The required tie bay breaker serial auxiliary contact information per phase is required to fulfil the following functions, implemented within the line protection device:

- Tie bay breaker pole discrepancy;
- Tie bay breaker phase discrepancy (per phase);
- Tie bay breaker internal disturbance recording (open status per phase);
- External disturbance recorder (open status per phase);
- Blocking of the directional earth fault comparison function (relationship between the bay breaker and the tie bay); and,
- Teleprotection carrier echo.

The required tie bay breaker parallel auxiliary contact information per phase is required to fulfil the following functions, implemented within the line protection device:

- Tie bay breaker fail protection.

3.45.3.3 Line isolator status: XSWI

The LN "switch" covers the switching devices not able to switch short circuits. Line switch is a switch used as a disconnecting, load-interrupter, or isolating switch on an AC or DC power circuit (IEEE C37.2-1996). If there is a single-phase switch, this LN has an instance per phase. These three instances may be allocated to three physical devices mounted in the switchgear.

The protection device shall subscribe to the following XSWI data, the XSWI logical node shall be within the breaker PIU:

	Bay Breaker PIU - Data Broadcast	Logical Node	240-42066934	Subscriber (IED)
1	Line Isolator Red Phase Status (Open & Close status)	XSWI	6.11.2	Protection IED
2	Line Isolator White Phase Status (Open & Close status)	XSWI	6.11.2	Protection IED
3	Line Isolator Blue Phase Status (Open & Close status)	XSWI	6.11.2	Protection IED

The line isolator status is required within the main protection device. The line isolator statuses (M and N contacts) information shall be received via GOOSE data from the specific main protection PIU. The following line isolator status GOOSE data shall be subscribed to:

- Line isolator red phase normally open (M) auxiliary contact;
- Line isolator red phase normally closed (N) auxiliary contact;
- Line isolator white phase normally open (M) auxiliary contact;
- Line isolator white phase normally closed (N) auxiliary contact;
- Line isolator blue phase normally open (M) auxiliary contact; and,
- Line isolator blue phase normally closed (N) auxiliary contact.

The line isolator M auxiliary contacts shall be available in a serial combination (M contacts of the three phases in series) and the N auxiliary contacts shall be available in a serial combination (N contacts of the three phases in series). The required line isolator auxiliary contact information is required to fulfil the following functions, implemented within the line protection device:

- Line isolator discrepancy;
- Control of the direct transfer trip function; and,
- Control of the voltage dependent functions and the STUB protection.

3.45.3.4 Transfer isolator status: XSWI

The LN "switch" covers the switching devices not able to switch short circuits. Line switch is a switch used as a disconnecting, load-interrupter, or isolating switch on an AC or DC power circuit (IEEE C37.2-1996). If there is a single-phase switch, this LN has an instance per phase. These three instances may be allocated to three physical devices mounted in the switchgear.

The protection device shall subscribe to the following XSWI data, the XSWI logical node shall be within the breaker PIU:

	Bay Breaker PIU - Data Broadcast	**Logical Node**	**240-42066934**	**Subscriber (IED)**
1	Transfer Isolator Red Phase Status (Open & Close status)	XSWI	6.11.2	Protection IED
2	Transfer Isolator White Phase Status (Open & Close status)	XSWI	6.11.2	Protection IED
3	Transfer Isolator Blue Phase Status (Open & Close status)	XSWI	6.11.2	Protection IED

The transfer isolator status is required within the main protection device. The transfer isolator statuses (M and N contacts) information shall be received via GOOSE data from the specific main protection PIU. The following transfer isolator status GOOSE data shall be subscribed to:

- Transfer isolator red phase normally open (M) auxiliary contact;
- Transfer isolator red phase normally closed (N) auxiliary contact;
- Transfer isolator white phase normally open (M) auxiliary contact;
- Transfer isolator white phase normally closed (N) auxiliary contact;
- Transfer isolator blue phase normally open (M) auxiliary contact; and,
- Transfer isolator blue phase normally closed (N) auxiliary contact.

The transfer isolator M auxiliary contacts shall be available in a serial combination (M contacts of the three phases in series) and the N auxiliary contacts shall be available in a serial combination (N contacts of the three phases in series). The required transfer isolator auxiliary contact information is required to fulfil the following functions, implemented within the line protection device:

- Transfer isolator discrepancy;
- Control of the busbar reactor trip input; and,
- Control of the busbar reactor breaker fail trip input.

3.46 Bay breaker pole discrepancy

3.46.1 Philosophy

Circuit-breaker pole discrepancy detection shall be included within each Protection System, for both the bay and tie bay circuit-breakers, to detect a discrepancy between the phases of circuit-breakers having three mechanisms, i.e. two phases open and one closed, or vice versa. The pole discrepancy detection shall cater for a circuit-breaker pole discrepancy following any of the actions listed below:

- manually initiated close (local or from remote);
- auto-reclose;
- manually initiated open (local or from remote);
- trip-test; and,
- protection tripping.

The pole discrepancy detection shall produce a trip output whenever the states of the three poles of the circuit-breaker are different for a pre-determined period of time.

3.46.2 Rationale

Failure can occur in a circuit-breaker, either in the form of a mechanical failure, or in the form of an electrical failure, e.g. open-circuited trip- or close-coils, dirty auxiliary contacts, etc. The power system should not be exposed to a situation where, with either the bay or tie bay circuit-breaker is in the open position, the circuit-breaker poles are not in the same position for longer than a pre-determined period of time. This is due to the unbalance in the current flow which would occur during this period. During the 'unbalance' time, currents would flow in the neutral and could cause spurious operation of the residual overcurrent protection. The voltage distribution in the system would also be distorted while the poles, and thus the current flows, are not symmetrical, a phenomenon which could have a deleterious effect on connected customer loads, e.g. motors.

Pole discrepancy is required for all manually initiated opening of the circuit-breaker, including trip-testing, and all closing (manual and auto-reclosing) as, for these operations, no other protection function exists to remove a pole discrepancy from the system. For tripping of the circuit-breaker initiated by the protection, any resultant discrepancy in the poles of the circuit-breaker , i.e. one (or more) poles failing to open, would be dealt with via the circuit-breaker failure protection first, followed by pole discrepancy detection for any resultant unequal pole status.

Details of the different scenarios are:

(i)	start condition	bay circuit-breaker all three poles open, tie bay circuit-breaker all three poles open
	action	issue manual close command or auto-reclose command of the bay circuit-breaker
	result	failure of one (or two) of the bay circuit-breaker poles to close
	consequence	operation of the bay circuit-breaker pole discrepancy protection
	outcome	issue trip command to effect tripping of the bay circuit-breaker closed pole/s
(ii)	start condition	bay circuit-breaker all three poles close, tie bay circuit-breaker all three poles open
	action	issue manual open command (to only one trip-coil per phase) of the bay circuit-breaker

	result	failure of one (or two) of the bay circuit-breaker poles to open
	consequence	operation of the bay circuit-breaker pole discrepancy protection
	outcome	issue trip command (to both trip-coils per phase) to effect tripping of the bay circuit-breaker closed pole/s
	result	* successful opening of the bay circuit-breaker pole/s
		* failure of the bay circuit-breaker pole/s to open
(iii)	start condition	bay circuit-breaker all three poles close, tie bay circuit-breaker all three poles close
	action	issue manual close command or auto-reclose command of the bay circuit-breaker
	result	failure of one (or two) of the bay circuit-breaker poles to open
	consequence	operation of the bay circuit-breaker pole discrepancy protection
	outcome	issue trip command (to both trip-coils per phase) to effect tripping of the bay circuit-breaker closed pole/s
	result	* successful opening of the bay circuit-breaker pole/s
		* failure of the bay circuit-breaker pole/s to open
	*start condition	bay circuit-breaker in pole discrepancy condition
	*action	issue manual open command of the tie bay circuit-breaker
	*consequence	direct transfer trip to the remote line end
(iv)	start condition	tie bay circuit-breaker all three poles open, bay circuit-breaker all three poles open
	action	issue manual close command or auto-reclose command of the bay circuit-breaker
	result	failure of one (or two) of the bay circuit-breaker poles to open
	consequence	operation of the bay circuit-breaker pole discrepancy protection
	outcome	issue trip command to effect tripping of the tie bay circuit-breaker closed pole/s
(v)	start condition	tie bay circuit-breaker all three poles close, bay circuit-breaker all three poles open
	action	issue manual open command (to only one trip-coil per phase)
	result	failure of one (or two) poles to open
	consequence	operation of pole discrepancy protection
	outcome	issue trip command (to both trip-coils per phase) to effect tripping of the tie bay circuit-breaker closed pole/s
	result	* successful opening of pole/s
		* failure of pole/s to open

(vi)	start condition	tie bay circuit-breaker all three poles close, bay circuit-breaker all three poles close
	action	issue manual open command (to only one trip-coil per phase) to the tie bay circuit-breaker
	result	failure of one (or two) poles of the tie bay circuit-breaker to open
	consequence	operation of to the tie bay circuit-breaker pole discrepancy protection
	outcome	issue trip command (to both trip-coils per phase) to effect tripping of the bay circuit-breaker closed pole/s
	result	* successful opening of pole/s
		* failure of pole/s to open
	*start condition	tie bay circuit-breaker in pole discrepancy condition
	*action	issue manual open command of the bay circuit-breaker
	*consequence	direct transfer trip to the remote line end
(vii)	start condition	bay circuit-breaker all three poles closed and tie bay circuit-breaker all three poles open or close
	action	issue trip command (to both trip-coils per phase) to the bay circuit-breaker due to protection operation
	result	failure of any number of the bay circuit-breaker poles to open
	consequence	commence the bay circuit-breaker circuit-breaker failure protection timing
	outcome	▪ the bay circuit-breaker failure protection issues bus-strip command o to the connected busbar protection zone, o to the tie bay circuit-breaker, o direct transfer trip to the remote line end, o auto-reclose block of both the bay and tie bay circuit-breakers ▪ later operation of the bay circuit-breaker pole discrepancy protection
(viii)	start condition	tie bay circuit-breaker all three poles closed and bay circuit-breaker all three poles open or close
	action	issue trip command (to both trip-coils per phase) to the tie bay circuit-breaker due to protection operation
	result	failure of any number of the tie bay circuit-breaker poles to open
	consequence	commence the tie bay circuit-breaker circuit-breaker failure protection timing
	outcome	• the tie bay circuit-breaker failure protection issues bus-strip command o to the connected busbar protection zone, where there is no other bay breaker, o to the bay 1 circuit-breaker, o to the bay 2 circuit-breaker, o direct transfer trip to the remote line end, o direct transfer trip to the adjacent object's remote line end,

		and if the next object is a transformer, to the MV side circuit-breakers. o auto-reclose block of the bay 1, bay 2 and tie bay circuit-breakers if the adjacent object is a line • later operation of the tie bay circuit-breaker pole discrepancy protection

Tripping following detection of a pole discrepancy cannot occur instantaneously, but only after a pre-determined time-delay for the following reasons:

- for three-pole only tripping schemes, the lower limit for the permissible time for tripping following pole discrepancy detection is based on the time variations inherent within the mechanical systems, while the upper limit is based on co-ordination with the residual overcurrent protection and the three-pole auto-reclose dead-time settings; and,
- for single-pole tripping schemes, the lower limit for the permissible time for tripping following pole discrepancy detection is based on the single-pole auto-reclose dead-time setting, while the upper limit is based on co-ordination with the residual overcurrent protection.

Initiation of the circuit-breaker failure protection by the pole discrepancy function must not occur as this could lead to a bus-strip following a manual operation, or following failure to open for a protection operation of an unfaulted phase(s) whose current is below the circuit-breaker failure current threshold. For the latter condition auto-reclose must be blocked to prevent closure of the local circuit-breaker with a known failure of a pole(s) to open. Transfer tripping to the remote end is required to ensure that the remote end circuit-breaker does not close with a partially closed local circuit-breaker.

3.46.3 Design requirements

3.46.3.1 Bay breaker pole discrepancy

The bay breaker pole discrepancy function shall be able to cater for both three-phase only tripping and auto-reclosing schemes, and single- and three-phase tripping and auto-reclosing schemes.

The bay breaker pole discrepancy functions shall be included within the main protection device to detect a discrepancy between the poles of the bay breaker. Detection of a pole discrepancy condition shall be by way of the bay breaker auxiliary contacts, and shall be independent of the action from which it resulted. The bay breaker pole discrepancy shall be derived from the bay breaker statuses (52a and 52b contacts) information received via GOOSE from the specific main protection PIU. The bay breaker pole discrepancy trip delay shall make provision for a successful single pole auto-reclose cycle.

The bay breaker pole discrepancy trip (settable time delay) and with the tie bay breaker closed, shall:

- Trip the bay breaker three pole via the line protection IED (PTRC1 - with trip seal-in in accordance with the trip seal-in logic) and block bay breaker auto-reclosing.
- Not initiate the bay breaker fail function;
- With the tie bay breaker not three pole closed, block the directional earth fault comparison function;
- Connected to the IED internal disturbance recorder function (RBDR);
- Reported to the gateway and station HMI; and,
- Displayed on the line protection IED.

The bay breaker pole discrepancy trip (after a set time delay) shall be sustained and the following actions are required with the opening or tripping of the tie bay breaker:

- Initiate the direct transfer trip send function;
- Block the tie bay breaker auto-reclose function;
- Shall not initiate the bay breaker fail function;

- Shall not initiate the tie bay breaker fail function;
- Connected to the IED internal disturbance recorder function (RBDR); and,
- Reported to the gateway and station HMI.

3.46.3.2 Tie Bay breaker pole discrepancy

The tie bay breaker pole discrepancy function shall be included within the main protection device to detect a discrepancy between the poles of the tie bay breaker. Detection of a pole discrepancy condition shall be by way of the tie bay breaker auxiliary contacts, and shall be independent of the action from which it resulted. The tie bay breaker pole discrepancy shall be derived from the tie bay breaker statuses (52a and 52b contacts) information received via GOOSE from the specific main protection PIU. The tie bay breaker pole discrepancy trip delay shall make provision for a successful single pole auto-reclose cycle (trip testing).

The tie bay breaker pole discrepancy trip (settable time delay) and with the bay breaker closed, shall:

- Trip the tie bay breaker three pole via the line protection IED (PTRC2 - with trip seal-in in accordance with the trip seal-in logic) and block bay breaker auto-reclosing.
- Not initiate the tie bay breaker fail function;
- With the bay breaker not three pole closed, block the directional earth fault comparison function;
- Connected to the IED internal disturbance recorder function (RBDR);
- Reported to the gateway and station HMI; and
- Displayed on the line protection IED.

The tie bay breaker pole discrepancy trip (after a set time delay) shall be sustained and the following actions are required with the opening or tripping of the bay breaker:

- Initiate the direct transfer trip send function;
- Block the bay breaker auto-reclose function;
- Shall not initiate the bay breaker fail function;
- Shall not initiate the tie bay breaker fail function;
- Connected to the IED internal disturbance recorder function (RBDR); and,
- Reported to the gateway and station HMI.

3.46.3.3 Bay breaker phase discrepancy

The bay breaker phase discrepancy function shall be included within the main protection device to detect a discrepancy, on a per phase basis, between the phases of the bay breaker. Detection of a phase discrepancy condition shall be by way of the bay breaker auxiliary contacts, and shall be independent of the action from which it resulted. The bay breaker phase discrepancy shall be derived from the bay breaker statuses (52a and 52b contacts) information received via GOOSE from the specific main protection PIU. The bay breaker phase discrepancy trip delay shall make provision for a successful single pole auto-reclose cycle. The bay breaker phase discrepancy shall be selectable IN/OUT.

The bay breaker any phase discrepancy trip (settable time delay) and with the tie bay breaker closed, shall:

- Trip the bay breaker three pole via the line protection IED (PTRC1 - with trip seal-in in accordance with the trip seal-in logic) and block bay breaker auto-reclosing.
- Not initiate the bay breaker fail function;
- Connected to the IED internal disturbance recorder function (RBDR);
- Reported to the gateway and station HMI; and
- Displayed on the line protection IED.

The bay breaker any phase discrepancy trip (after a set time delay) shall be sustained and the following actions are required with the opening or tripping of the tie bay breaker:

- Initiate the direct transfer trip send function;
- Block the tie bay breaker auto-reclose function;
- Initiate the bay breaker fail function (user selectable);
- Initiate the tie bay breaker fail function (user selectable);
- Connected to the IED internal disturbance recorder function (RBDR); and,
- Reported to the gateway and station HMI.

3.46.3.4 Tie Bay breaker phase discrepancy

The tie bay breaker phase discrepancy function shall be included within the main protection device to detect a discrepancy, on a per phase basis, between the phases of the tie bay breaker. Detection of a phase discrepancy condition shall be by way of the tie bay breaker auxiliary contacts, and shall be independent of the action from which it resulted. The tie bay breaker phase discrepancy shall be derived from the tie bay breaker statuses (52a and 52b contacts) information received via GOOSE from the specific main protection PIU. The tie bay breaker phase discrepancy trip delay shall make provision for a successful single pole auto-reclose cycle. The tie bay breaker phase discrepancy shall be selectable IN/OUT.

The tie bay breaker any phase discrepancy trip (settable time delay) and with the bay breaker closed, shall:

- Trip the tie bay breaker three pole via the line protection IED (PTRC2 - with trip seal-in in accordance with the trip seal-in logic) and block bay breaker auto-reclosing.
- Not initiate the tie bay breaker fail function;
- Connected to the IED internal disturbance recorder function (RBDR);
- Reported to the gateway and station HMI; and,
- Displayed on the line protection IED.

The tie bay breaker any phase discrepancy trip (after a set time delay) shall be sustained and the following actions are required with the opening or tripping of the bay breaker:

- Initiate the direct transfer trip send function;
- Block the bay breaker auto-reclose function;
- Initiate the bay breaker fail function (user selectable);
- Initiate the tie bay breaker fail function (user selectable);
- Connected to the IED internal disturbance recorder function (RBDR); and,
- Reported to the gateway and station HMI.

3.46.3.5 Line isolator discrepancy

The line isolator discrepancy function shall be included within the main protection device to detect a discrepancy between the phases of the line isolator. Detection of a line isolator discrepancy condition shall be by way of the line isolator auxiliary contacts, and shall be independent of the action from which it resulted. The line isolator discrepancy shall be derived from the line isolator statuses information received via GOOSE from the specific main protection PIU. The line isolator shall consist of three (one per phase) normally open line isolator auxiliary contacts in parallel with three (one per phase) normally closed auxiliary contacts, with this parallel arrangement of contacts. The line isolator discrepancy shall be a drop-off time delay and shall be settable to accommodate the maximum normal discrepancy between the phases during open and close operations. This timer shall be normally picked-up, and shall only drop-off, and issue a line discrepancy alarm, for a line discrepancy condition which persists beyond the normal limits (timer setting). The line isolator discrepancy function shall be user selectable IN/OUT.

The line isolator discrepancy condition (settable time delay), shall:

- Combined to validate the open and closed statuses of the line isolator;
- Connected to the IED internal disturbance recorder function (RBDR);
- Reported to the gateway and station HMI; and,
- Displayed on the line protection IED.

3.46.3.6 Transfer isolator discrepancy

The transfer isolator discrepancy function shall be included within the main protection device to detect a discrepancy between the phases of the transfer isolator. Detection of a transfer isolator discrepancy condition shall be by way of the transfer isolator auxiliary contacts, and shall be independent of the action from which it resulted. The transfer isolator discrepancy shall be derived from the transfer isolator statuses information received via GOOSE from the specific main protection PIU. The transfer isolator shall consist of three (one per phase) normally open transfer isolator auxiliary contacts in parallel with three (one per phase) normally closed auxiliary contacts, with this parallel arrangement of contacts. The transfer isolator discrepancy shall be a drop-off time delay and shall be settable to accommodate the maximum normal discrepancy between the phases during open and close operations. This timer shall be normally picked-up, and shall only drop-off, and issue a transfer discrepancy alarm, for a transfer discrepancy condition which persists beyond the normal limits (timer setting). The transfer isolator discrepancy function shall be user selectable IN/OUT.

The transfer isolator discrepancy condition (settable time delay), shall:

- Combined to validate the open and closed statuses of the transfer isolator;
- Connected to the IED internal disturbance recorder function (RBDR);
- Reported to the gateway and station HMI; and,
- Displayed on the line protection IED.

3.47 Supervision and Monitoring functions

3.47.1 Philosophy

The primary protection device shall have the capability to supervise and monitor conditions and health that will adversely affect the operation and/or availability of the protection system.

3.47.2 Rationale

The capability to supervise and monitor conditions and health is required to be reported locally and remotely for actions to restore the protection system back to normal.

3.47.3 Design requirements

Following is the supervision, monitoring health monitoring requirements.

3.47.3.1 Trip circuit supervision

Trip circuit supervision shall continuously monitor each phase of the trip circuit of the bay breaker. The trip circuit shall be supervised with the bay breaker in the close and open positions. The trip circuit supervision shall be integrated within the protection IED. The trip circuit supervision shall not adversely affect the dependability and security of the trip circuit. Trip circuit supervision shall:

- Monitor each phase of the bay breaker trip circuit independently;
- Reported locally at the line protection IED HMI;
- Reported locally to the main # protection system unhealthy indication; and,

- Reported remotely via the gateway; and,
- Reported to the station HMI.

3.47.3.2 Circuit-breaker monitoring

The protection IED shall have the ability to summate the switched currents (per phase). The summated quantities shall be independent per breaker (bay breaker and tie bay breaker). The summed values shall be reported both local and remote. These summed values shall be resettable from the protection IED HMI. The summation shall only be permitted with the TNS selected to the 'Normal' position.

3.47.3.3 Main # Protection system Not Healthy indication

The main # protection system not healthy lamp is an alarm condition that indicates that the scheme is in an abnormal state. The following conditions shall activate the M#PSNH alarm:

- DCF(M#) - Main # Protection DC supply failed (MCB switched Off or tripped, and open circuit in DC supply rail wiring loops);
- DCF(BB)(M#) - Main # Bay breaker tripping DC supply failed (MCB switched Off or tripped, and open circuit in DC supply rail wiring loops);
- Main # teleprotection 48 VDC supply failed;
- Main # Protection IED failed;
- Main # teleprotection equipment failed;
- TNS(M#) - Test 1 and Test 2 selections;
- TPIS(M#) - Off position;
- Bay supervisory isolating switch (located on the 6DIP-#100) selected to the Maintenance position. This position selection, when selected, disables the bay breaker failure function;
- Tie bay supervisory isolating switch (located on the 6DIP-#100) selected to the Maintenance position. This position selection, when selected, disables the tie bay breaker failure function; and,
- Lamp Check - Lamp check push button to test the lamp health.

The main # protection system not healthy lamp (M#PSNH) indication shall be provided external to the protection IED. The M#PSNH lamp shall be positioned on the top left hand side of the panel. The M#PSNH lamp shall be red and supplied by 230 VAC from the 6DIP-#100.

3.47.3.4 DC supply monitoring

Each DC supply rail shall be monitored and reported (local and remote). Each monitoring device shall be energised upon application of the DC supply it is monitoring, with its associated DC fail normally closed alarm contacts being maintained in an open circuit condition. In the event of a DC supply failure, or the switching to the 'Off' position of the relevant DC MCB, the DC fail monitoring device shall be de-energised, resulting in the closing of the alarm contacts. The DC supply fail monitoring device shall be connected to the last loop of the supply being monitored. Each supply rail controlled by an MCB shall be monitored.

The following DC rail monitoring is required:

- Main # protection supply rail;
- Main # teleprotection supply rail; and,
- Main # bay breaker tripping supply rail.

The following equipment failure alarms are required:

- Main # protection device failed; and,
- Main # teleprotection device failed.

3.47.3.5 IEC61850 communications failure

IEC61850 communications failure that affects the GOOSE signals shall be monitored by the line protection device and:

- Reported locally at the line protection IED HMI;
- Reported locally to the main # protection system unhealthy indication;
- Shall select three pole tripping (TNS 'Normal' and 'Test 1');
- Shall not cause failure of any protection function to trip when called upon to do so;
- Shall not cause an unwanted or overtrip; and,
- Reported remotely and to the station HMI.

3.48 Measurements

3.48.1 Philosophy

The line protection device shall display locally (IED HMI) measurements quantities, on a real time basis, without human intervention to view the values. The measurement for each quantity shall be measured separately and continuously.

3.48.2 Rationale

Local measurements quantities are required for visual verification during testing, primary plant injection testing and for operational purposes.

3.48.3 Design requirements

The line protection IED HMI shall display the analogue quantities continuously. The measured value is reported if the time integral of all changes exceeds a pre-set limit. A minimum settable value shall be possible for all the measured quantities, typical 5% for currents, active power, reactive power and apparent power, and 3% for voltage and frequency.

All measurements quantities shall be visible by default, that is, no external influence shall be required to view any quantity.

The IED HMI shall display the following measurements quantities:

- Active Power (P);
- Reactive Power (Q);
- Power factor (PF);
- Frequency (F);
- Measured impedance (R-W, W-B, B-R, R-N, W-N and B-N);
- Directionality (R-W, W-B, B-R, R-N, W-N and B-N);
- Phase-phase voltages (R-W, W-B and B-R);
- Bay currents (R-N, W-N and B-N);
- Tie bay currents (R-N, W-N and B-N);
- Line (summated) currents (R-N, W-N and B-N); and,
- Differential currents (PDIF) (red phase, white phase and blue phase).

3.49 Ethernet switches and communications architecture

3.49.1 Philosophy

The breaker-and-a half line protection IED shall connect to the diameter interface panel ethernet switch via a 100 Megabit Multi-mode optical interface. The IEDs within the diameter shall connect to the ethernet switch within that diameter interface panel in a star topology. The connections between the ethernet switch and the IEDs shall be multi-mode fibre.

3.49.2 Rationale

The optical ethernet interface is required for the GOOSE data between IEDs and the MMS data to the required clients.

3.49.3 Design requirements

The IEDs and PIUs fibre connection requirements shall comply with the Generic Specification for Intelligent Electronic Devices (IEDs) Standard, Unique Identifier 240-64685228. The ethernet switch, per bay, shall interface with the substation automation network topology as per the Substation Automation Network Architecture Standard, Unique Identifier TST 41-1077.

The breaker-and-a half line protection panel shall include fibre patch panels to interface between the fibre cables entering the panel to the current differential protection IED and between the protection IED and the PIU. The fibre patch panels shall be fitted FC fibre connections and shall include pigtails and midcouplers. The fibre patch panel shall make provision for the required number of fibre connections including 2 spares.

3.50 Busbar Reactor Transfer Functionality

3.50.1 Philosophy

The breaker-and-a-half line protection scheme shall have the capability to interface with either its own line reactor or the busbar reactor.

3.50.2 Rationale

High transmission line availability is achieved by providing transfer of the busbar reactor to any connected line, which enables the connected line reactor to be taken out of service for maintenance, testing and/or repairs.

3.50.3 Design requirements

3.50.3.1 Line Reactor Interface

The following functions are sent from the line reactor protection scheme to the breaker-and-a-half line protection scheme, these signals are supervised within the line reactor protection scheme by the line reactor isolator (when in the open position these signals shall be blocked as to prevent unwanted tripping of the bay and the tie bay breakers). The breaker-and-a-half line protection scheme shall make provision for the following inputs from the line reactor protection scheme:

- Main # line reactor trip; and,
- Main # line reactor breaker fail signal.

The line reactor trip signal, when simultaneously high with the line protection trip signal, shall:

- Trip the bay and tie bay breakers three pole;
- Block bay breaker and tie bay breaker auto-reclosing; and,
- Send a direct transfer trip send signal to the remote line end. This signal shall be disabled with the line isolator is open and with no line isolator discrepancy.

3.50.3.2 Busbar Reactor Interface

The following functions are sent from the busbar reactor protection scheme to the breaker-and-a-half line protection scheme when the busbar reactor transfer isolator is in the close position (busbar reactor connected to the protected line), these signals shall be supervised within the breaker-and-a-half line protection IED by the reactor transfer isolator (these signals shall be blocked when the transfer isolator is in the open position and with no discrepancy as to prevent unwanted tripping of the bay and the tie bay breakers). The breaker-and-a-half line protection scheme shall make provision for the following inputs from the busbar reactor protection scheme:

- Main # busbar reactor trip; and,
- Main # busbar reactor breaker fail signal.

The breaker-and-a-half line protection scheme shall make provision for the following inputs from the bay process interface unit:

- Transfer isolator open status; and,
- Transfer isolator closed status.

The busbar reactor trip signal, when simultaneously high with the line protection trip signal, shall:

- Trip the bay and tie bay breakers three pole;
- Block bay breaker and tie bay breaker auto-reclosing; and,
- Send a direct transfer trip send signal to the remote line end. This signal shall be disabled with the transfer isolator open and with no line isolator discrepancy.

3.51 Model power system simulator testing

3.51.1 Philosophy

In order to prove the operation of the protection scheme it is required that extensive model power system simulator testing of the protection and closing control devices be done.

3.51.2 Rationale

Eskom's main reason for including simulator testing as a certification requirement is to acquire sufficient confidence in the relay's performance that it may be applied on Eskom's transmission system. At the end of the simulator testing, Eskom will be in possession of a set of results against which a full evaluation of the relay can be made with respect to:

- the performance of the measurement algorithms, which encompasses the operating times, dependability/security, selectivity, and phase selection; and
- the logic functionality.

A relay's speed of operation is a fundamental performance issue, and to a large degree it is what differentiates the different classes of relays. Evaluation of operating speed therefore constitutes one of the primary aims of the simulator testing. There are definite system requirements on the speed of operation for issues of system stability, power quality to customers, limitation of damage, and safety to personnel.

A relay's dependability and security are, respectively, measures of its ability to operate when required to, and to restrain when required to. Its dependability/security performance therefore impacts directly on the sustained good performance of the system. Evaluation of the relay's dependability and security is achieved, respectively, by subjecting it to internal (line) faults (for which operation is required) and external faults (for which no operation is required).

A relay's selectivity is a measure of its ability to detect faults to be within a specified zone of network, and it therefore influences both the dependability and security. To ensure optimum system performance, only the faulted item must be removed. Selectivity as applicable to impedance protection includes the relay's directional determination capability (correct determination of forward faults as forward, and reverse faults as reverse), and reach accuracy capability (correct determination of fault location, i.e. no over- or under-reaching). Evaluation of the relay's selectivity is achieved by incorporating close-in forward and reverse faults to determine directional capability (no inadvertent tripping of the line for reverse faults or failure to trip for forward line faults), and remote-end forward faults to verify satisfactory reach discrimination (no inadvertent tripping of the line due to pick-up of the underreaching zone, and no failure to pick-up of the first (permissive) overreaching zone).

3.51.3 Design requirements

The tests shall be carried out by the tenderers in conjunction with the Purchaser's engineers at the tenderer's principal works on their model power system simulator. The purchaser will supply source and line data for the simulations as well as a list of the required tests and test scenarios during the product development phase. The protection equipment must not only be subjected to the list of required tests provided by the purchaser. The successful tenderers shall be responsible for the provision of all the equipment and protection/closing devices required, to conduct the MPS tests. All preparation shall be finalised before arrival of the purchaser's project engineers. The device settings shall be the responsibility of the tenderers, and shall be submitted to the identified purchaser's settings engineer for sanctioning prior commencement of the model power system simulator testing.

It is expected that any failures/shortcomings in the devices, identified during the above tests, shall immediately be noted and resolved by the tenderer's design engineers. The tenderers shall provide solution(s) to the identified failure(s)/shortcoming(s). The solution(s) shall be implemented to the device(s) in question and the tests that have highlighted the failure(s)/shortcoming(s) shall be repeated to confirm the solution(s). In the event that fundamental solution(s) are implemented, all the specified tests shall be repeated. The nature of the failure(s)/shortcoming(s) shall dictate whether or not the remainder of the tests shall be concluded before implementation of the solution(s). Should a further round of simulator testing be necessary this shall be at the supplier's cost. Additional and/or different tests/test scenarios may be prescribed for any subsequent rounds of testing.

The tenderers are required to provide full details of his "power system simulator", including its ranges of simulation and capabilities, with the offer.

Eskom requires that:

- the test set-up incorporates two relays, one at each end of the line (left and right), interconnected via a teleprotection link exhibiting characteristics (e.g. end-to-end delay time) that are representative of the systems that exist in reality. The relays are set to operate in a protection mode that is typical of that intended for operation on Eskom's transmission system.
- an independent disturbance recorder(s) is used to capture analogue and digital information from each line-end. The captured records are saved, and printed for immediate analysis purposes. In parallel, each relay event record is also saved and printed for analysis purposes.
- the performance of the relays is recorded on a standard summary sheet, one for each relay, alongside details of the fault and system parameters, plus any comments pertinent to the performance of the relay for that fault. The information gathered from the internally generated event records is also recorded on a summary sheet, again with any pertinent comments. In this way, the performance of the relays is thoroughly analysed for each fault, with a summary for quick reference and for later sample analysis.

When devising the scope of tests to be performed, it is not sufficient to adopt just a single set of system parameters (line, left and right source impedances, etc.) on which to apply a range of faults as this does not adequately represent the diverse system conditions, or cover the performance spectrum of the relay, which is not consistent over a broad spectrum of system conditions. The challenge is therefore to devise the best sample of tests, taking into account the constraints of time, simulator capability, etc., but at the same time achieving a sample which is representative of the diversity of the system, and brings out the full spectrum of the relay's performance.

When analysing the tests, the issues of dependability, security, selectivity, and phase selection are readily determined from the actual tests. The results can be viewed altogether, or within the different categories. The relay's performance either meets the set criteria, or it does not. The broad spectrum of test cases, spread over the different categories, allows the relay's performance and/or any weaknesses within the defined boundaries to be clearly determined.

To obtain the actual operating time profiles, the measured operating times can be plotted. These can be plotted by category, or even broken down further into the different types of faults.

3.52 In-service experience requirements

3.52.1 Philosophy

Eskom will use primary protection relays which satisfy the following six conditions:

- Are available 'off-the-shelf';
- Have a proven track record in terms of an acceptable in-service record on networks of greater than 200 kV in utilities world wide;
- Have a minimum in-service experience of 50 relay-years with at least 25 relays having an in-service record of more than 6 months. This must apply to the same or similar production unit version of relay that Eskom would employ;
- Successfully pass required simulator testing; and,
- Successfully pass all specified environmental tests.

The product(s) offered by the tenders shall comply with these requirements at the tender submission (closing) date.

3.52.2 Rationale

The successful implementation of a new protection relay product on a system is critical for the sustained good performance of protection of the network. Manufacturers are continually developing new relay products. The new numerical relays have two fundamental components, namely hardware and software, the integrity of both being vitally important to the performance of the product. It is therefore of paramount importance that all aspects of a new relay product are proven to the satisfaction of the utility purchasing the product, in order that the relay can be successfully applied with confidence and without 'teething' problems. It is on this basis that the above philosophy statement has been developed, whereby each important aspect of the new relay is carefully evaluated and/or tested.

The following rationale points cover the individual elements of the philosophy statement:

- Development of products in conjunction with manufacturers is time consuming and expensive. A preferred approach is to enter into 'partnerships' with manufacturers thereby influencing their product designs on an ongoing basis. Relays can then be purchased as standard products rather than as 'specials';
- It is preferred that relay products purchased have been in service elsewhere on similar network voltage levels. This would provide some confidence as to the soundness of design and reduction of possible 'teething' problems;

- The reasoning behind the requirement for the 'piggy-back' mode is to allow Eskom personnel the opportunity to become familiar with the relay product and also to 'soak' test such components as power supplies that have, in the past, been areas of concern;
- Simulator testing tests the design and capabilities of the product with the tender specification serving as the basis for evaluation. This is a type test which provides the opportunity for extensively evaluating the relay's performance in terms of its designed functions (also security, speed, dependability and selectivity); and,
- Electrical environmental tests are required to verify the capability of the relay to survive the harsh substation environment.

3.52.3 Design requirements

The tenderers shall provide details of their device's operating record and installation details with their offers. The tenderers shall also provide details on all offered IEDs, the firmware upgrades made in the past 3 years. The Purchaser will use protection devices that satisfy the following conditions:

- Available 'off-the-shelf';
- Have a proven track record in terms of an acceptable in-service record on networks of greater than 200kV in utilities world-wide and representative to the Eskom network. The tenderers shall provide proof of track record by documentation and reference to buyers and/or utilities world-wide;
- Have a minimum in-service experience of 50 equipment-years, at time of tender closure, with at least 25 devices/relays having an in-service record of more than 12 months. This shall apply to the same or similar production unit version of device/relay that the Purchaser would employ;
- The offered IEDs shall not be scheduled for discontinuation or major changes within the first 4 years of the production phase;
- The vendor shall notify Eskom well in advance regarding any discontinuation, major hardware and firmware changes of the offered IEDs;
- Successfully pass required model power system simulator testing;
- Successfully pass all functional testing; and,
- Successfully pass all specified environmental type tests.

Cumulative years of service are only based on an in-service period of identical hardware and firmware versions.

3.53 Warrantees, spares and support

3.53.1 Warrantees

The supplier shall provide a minimum of a 10 year warrantee on the protective IEDs provided in the scheme. The warranty shall include the repair of all failures due to latent defects (i.e. excluding failure due to mishandling or misuse of the equipment by Eskom or Eskom appointed representatives). Any charges associated with the repair/replacements and shipping of the defective equipment from the local supplier's office to and from the works of the overseas principal shall be for the supplier's expense.

The supplier of IEDs for protection schemes shall undertake, in writing, to support each product for a minimum period of 15 years from the date of contract signature. Product support shall include services to repair or replace any damaged or failed IED that falls outside the terms of the abovementioned warrantee. Eskom shall be liable for all costs associated with these services. Replacement IEDs shall preferably be of the same type, model number and firmware as the failed IED, but alternative products of substantially similar physical dimensions and terminal layouts offering the same or increased functionality shall be accepted in fulfilment of this requirement.

The supplier shall notify Eskom of the planned discontinuation of any IED used in a current or previous national contract.

3.53.2 Spares

The Supplier shall supply a comprehensive list of spares that shall, at minimum, include one of the devices/relays used, as well as MCB's, switches, lamps, empty sub-racks and any consumable items. The Supplier shall also include on the list of spares any other recommended spares necessary for the proper maintenance of the protection scheme. The spares items shall be priced individually and the list shall include a description of the item, a reference number, the pricing details and the guaranteed delivery time. All spares shall be delivered in approved cases suitable for storing such parts over a period of 10 years without damage or deterioration.

Spare devices shall be available from the tenderers for a period of at least 10 years subsequent to the expiry of the contract. Spares shall be carried at the tenderers's local works according to the following amount of schemes in service:

Table 2: Spares requirements

Number of schemes in service	Available immediately (within 24 hours of order)	Additionally available on demand within 72 hours
1 to 20 schemes	2 spare of each device	A maximum of 3 spares of each device
21 schemes and more	3 spares of each device	A maximum of 4 spares of each device

The successful *tenderers* shall maintain an up-to-date register of at least three contact persons who may be contacted regarding spares. This information shall be communicated to the *purchaser* when any of the details contained therein are altered.

The *purchaser* shall annually audit the spares holding as per the requirements of this specification.

3.53.3 Repairs

The tenderers shall provide a schedule detailing the guaranteed turnaround time for the repair of faulty equipment. The turnaround time shall include any international transport and customs clearance times as applicable. If the turnaround times differ for different equipment, the schedule shall include these details. The tenderers shall also state the extent to which repairs can be effected at the tenderers's local works, including the capability and equipment that the tenderers possesses in order to effect such repairs. The tenderers shall, for all repair work, inform the purchaser of the exact nature of the failure, how such failure was remedied and how these failures, and other similar failures, can be prevented. The solutions to the identified failures/deficiencies shall also be implemented to all the in-service and spare devices and shall be for the cost of the tenderers. The implementation will be governed by the availability of the devices due to power network constraints.

3.53.4 Support

The purchaser requires a maximum transfer of technology from the supplier's principals to enhance the local support capabilities. The tenderers shall indicate in his offer how he intends committing to this requirement.

The transfer of technology shall include, but not be limited to:

- Operating and analysis software;
- IED functions (detailed description and explanations); and,
- Compilation of standard IED (Eskom) templates that also include the IEC61850 engineering.

The vendor shall have at least more than one local skill with specialist knowledge. The specialist knowledge shall include but not be limited to the overall life cycle of the solutions, including:

- Ordering options;
- Configurations and settings; and,
- Commissioning and maintenance.

3.54 Documentation

3.54.1 Scheme manual requirements

The required documentation shall include a full description of the scheme including the detailed information/manuals on all scheme components and devices. Also required are the complete drawings for each of the scheme permutations. The scheme manual shall include the product configuration and a hard copy of the scheme drawings. All documentation called for shall be finalised and approved before the engineering/development phase ends and awarding of production contract phase.

The documentation shall be clear, concise and to the point. The supplier shall compile all documentation and a complete documentation set (printed and bounded and in electronic format *.doc(x)) shall be submitted to the purchaser on conclusion of the engineering/development phase.

The scheme manual shall have as a minimum the following chapters:

Chapter 1 **General Description**

1.1 Basic description of the scheme and devices

1.2 Intended area of application

1.3 Brief description of the protection and closing functions

1.4 Contract/agreement data

1.5 Device configuration (logic diagrams)

1.6 Drawing set (scheme)

Chapter 2 **Mechanical Construction**

2.1 Mechanical drawings

2.2 Construction details

Chapter 3 **Controls, Indications and Test Facilities**

3.1 List of controls and indications

3.2 Detailed description of functions

3.3 General operational data

3.4 Test facilities

Chapter 4 **Protection Functionality**

4.1 Detailed description of the diameter control functions

4.2 Scheme control philosophy

4.3 Scheme logic

4.4 Application guidance

4.5 Burdens

Chapter 5 **Substation automation integration**

5.1 MMS data sets with data attributes (also the subscribers to the data)

5.2 GOOSE data sets with data attributes (also the subscribers to the data)

Chapter 6 **Installation, Commissioning and Testing**

6.1 Installation procedure/requirements

6.2 Commissioning guidelines

6.3 Routing testing guidelines

Chapter 7 **Maintenance**

7.1 Maintenance requirements

7.2 Recommended "In-service" checks

7.3 Cross-referencing to relay manual

7.4 Audit intervals and scope

7.5 Physical replacement / refurbishment procedure

Chapter 8 **Parts List**

8.1 Parts list (Bill of material)

Chapter 9 **Associated Publications**

9.1 Information about all equipment used in scheme

Chapter 10 **Document Control**

10.1 Revision control

Chapter 11 **Software and firmware**

11.1 Hardware, firmware and software version control procedure

11.2 History of updates (Include ordering codes)

11.3 Upgrade procedure

11.4 Communication software

11.5 IED to Data Communications Equipment protocol

Chapter 12 **Peripheral Equipment**

12.1 IED to PC requirements (port, cable, etc.)

12.2 IED to Data Communications Equipment requirements (port, cable, etc.)

12.3 Printer requirements

12.4 PC requirements

3.54.2 Settings guide

The settings guide shall include a comprehensive set of blank and example setting details to cover all user settable functions in the scheme and devices shall be provided. A list of the settings, as set by the supplier prior to shipment of the scheme, shall also be provided to the *purchaser*. The supplier shall provide the recommended setting limits to ensure that the required protection performance is obtained. A list of settings (including the Eskom default settings) and settings guidelines shall be provided for all functional elements and shall indicate any setting limitation and any possible conflict with any other setting.

The settings guide (printed and bounded and in electronic format *.doc(x)) shall be finalised, approved and submitted to the *purchaser* before the engineering/development phase ends and awarding of production contract phase.

3.54.3 Scheme selection and application guide

The scheme selection and application guide shall include a complete description of the different scheme permutations and selection thereof for specific applications. The application section of the guide shall include a full description and the physical interfacing of the scheme with components external to the scheme (e.g. DC board, CTs, VTs, JB, substation automation, etc.).

The scheme selection and guide (printed and bounded and in electronic format *.doc(x)) shall be finalised, approved and submitted to the *purchaser* before the engineering/development phase ends and awarding of production contract phase.

3.54.4 Scheme drawings

The scheme drawings shall be as per the drawing standard 6DIP - #100. The supplier shall be accountable for the compilation of drawing for all scheme/module permutations.

3.54.5 Documentation handover requirements

The supplier shall be accountable, on completion of engineering/development phase to handover the following documentation to the Eskom's responsible engineer. The documentation format shall be printed and bounded and in electronic format *.doc(x), vendor specific documentation shall be in Acrobat format.

- Scheme manual (section 7.1);
- Settings guide (section 7.2);
- Scheme selection and application guide (section 7.3);
- Scheme drawings in Microstation format (section 7.4);
- Factory acceptance testing report;
- Type test report;
- MPS test report (where applicable);
- Scheme and spares lists for codification;
- Final PS5 price schedules; and,
- Equipment/IED manuals.

3.55 Training

The tenderer shall include proposals for the training of Eskom personnel. The following item shall be quoted:

- The local specialised training of selected Purchaser protection engineers (not more than 20) by an expert(s) from the tenderer's principal works. The price shall be quoted on a per week basis. Details of the specialised training will be negotiated during the development phase of the contract. The required training shall include, but not be limited to, an in-depth working knowledge of all devices and products (hardware, firmware and software functionality), the relay operating and analysis software, setting and application, commissioning, maintenance and first-line fault finding.
- The Grid staff training at the tenderer's local works (not more than 8). The price shall be quoted on a per week basis. Details of the training will be negotiated during the development phase of the contract. The required training shall include, but not be limited to, a working knowledge of all devices and products (hardware, firmware and software functionality), the relay operating and analysis software, setting and application, commissioning, maintenance and first-line fault finding.

3.56 IEC 61850 Engineering tools

The need for the engineering tools has developed as the technology has been and is being installed and commissioned in Eskom substations. At present, the required tools can be broadly categorised into:

- Configuration tools;
- Simulation tools; and,
- Communication Analysis tools.

3.56.1 Configuration tools

The configuration tool shall have the capability to assemble individual device configuration files (known as CID files) into the substation-wide configuration files (known as SCD files) and inter substation configuration files (known as SED files). This tool shall therefore be used to configure and have the ability to validate the configured files, hence ensuring the integrity of the configuration files as per the IEC 61850 standard.

3.56.2 Simulation tools

The simulation tools are essential to perform system-wide testing in a simulation environment using actual SCD file configurations.

3.56.2.1 Vertical communications

This tool shall have the ability to test the "vertical" communication of the IEDs to the substation gateway. The tool is required to simulate every IED described in the SCD file. Each IED should respond using its configured IP address and OSI addressing parameters. Each virtualized IED is further required to allow the data simulation of any data attribute of any attribute described within the file. The tool should optionally allow the setting of "invalid" data values for a data attribute in order to verify the correct operation of the gateway. The simulator shall respond to read requests and shall also generate information reports where the data attributes are allocated to datasets referred to by Report Control Blocks (RCBs). The tool is also required to simulate multiple data attributes concurrently and as such some form of scripting would be required. In such a "bulk data simulation" mode, the tool is expected to stress test the gateway for extreme conditions.

3.56.2.2 Horizontal communications

This tool shall have the ability to test the "horizontal" communication of the IEDs using GOOSE messaging. The purpose behind this simulation mode is to test one or more physical IEDs within the context of the full substation automation system. The tool should therefore allow the enabling of individual IEDs within the simulation environment. It shall be possible to simulate the values of data attributes corresponding to dataset "elements" associated with GOOSE Control Blocks (GCBs). The tool is also required to simulate multiple data attributes concurrently and as such some form of scripting would be required.

The final simulation purpose of the tool is to test the "horizontal" communication of the IEDs using Sampled Values. The purpose behind this simulation mode is to test one or more physical IEDs within the context of the full substation automation system. The tool should therefore allow the simulation of individual IEDs and/or merging units within the simulation environment. It shall be possible to simulate the values of data attributes corresponding to dataset "elements" associated with Sampled Value Control Blocks (SVCBs). The tool is also required to simulate multiple data attributes concurrently and as such some form of scripting would be required.

3.56.2.3 Communication analysis tools

The fundamental infrastructure required for IEC 61850 substation automation systems is a high-speed industrial Ethernet network. The inter-device communication often needs to be verified and in some cases detailed analysis is required to isolate problems and to troubleshoot commissioning issues. A tool that can analyse traffic patterns, performance and detailed message analysis is required to facilitate this requirement.

4. Authorization

This document has been seen and accepted by:

Name and surname	Designation
Ian Worthington	Middle Manager – Secondary Plant (Grid – South)
Paul Grobler	Chief Engineer
Jan Cronje	Chief Technologist
Anita Oommen	Middle Manager
Paul Keller	Chief Technologist
Anura Perera	Chief Engineer
Vincent Jansen van Rensburg	Chief Technologist
Bongani Qwabe	Chief Technologist

5. Revisions

Date	Rev	Compiler	Remarks
Sept 2015	1	T Bower	First issue.

6. Development team

This document was developed by Thys Bower.

7. Acknowledgements

Not applicable

Annex A – Impact Assessment

Impact assessment form to be completed for all documents.

1 Guidelines

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

2 Critical points

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

Comment: This standard is required to document the breaker-and-a-half diameter interface requirements for Transmission protection & control schemes.

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

Comment: No statutory or legal compliance required.

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

Comment: No impact.

2.4 When will new stock be available?

Comment: Not applicable.

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

Comment: Not interchangeable.

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

Comment: This document must be used as reference when compiling the bay specific protection & control scheme standards for application to Transmission stations.

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

Comment: (N/A during commenting phase)

3 Implementation timeframe

A3.1 Time period for implementation of requirements.

Comment: The breaker-and-a-half diameter interface requirements will be implemented during the product development phase.

A3.2 Deadline for changeover to new item and personnel to be informed of DX wide change-over.

Comment: No changeover required, new standard.

4 Buyers Guide and Power Office

A4.1 Does the Buyers Guide or Buyers List need updating?

Comment: No.

A4.2 What Buyer's Guides or items have been created?

Comment: N/A

A4.3 List all assembly drawing changes that have been revised in conjunction with this document.

Comment: N/A

A4.4 If the implementation of this document requires assessment by CAP, provide details under 5

A4.5 Which Power Office packages have been created, modified or removed?

Comment: N/A

5 CAP / LAP Pre-Qualification Process related impacts

A5.1 Is an ad-hoc re-evaluation of all currently accepted suppliers required as a result of implementation of this document?

Comment: N/A

A5.2 If NO, provide motivation for issuing this specification before Acceptance Cycle Expiry date.

Comment: N/A

A5.3 Are ALL suppliers (currently accepted per LAP), aware of the nature of changes contained in this document?

Comment: N/A

A5.4 Is implementation of the provisions of this document required during the current supplier qualification period?

Comment: N/A

A5.5 If Yes to 5.4, what date has been set for all currently accepted suppliers to comply fully?

Comment: N/A

A5.6 If Yes to 5.4, have all currently accepted suppliers been sent a prior formal notification informing them of Eskom's expectations, including the implementation date deadline?

Comment: N/A

A5.7 Can the changes made, potentially impact upon the purchase price of the material/equipment?

Comment: N/A

A5.8 Material group(s) affected by specification: (Refer to Pre-Qualification invitation schedule for list of material groups)

Comment: N/A

6 Training or communication

6.1 Is training required?

Comment: No

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

Comment: N/A

6.3 State designations of personnel that will require training.

Comment: N/A

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

Comment: N/A

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

Comment: N/A

6.6 Was Technical Training Section consulted w.r.t module development process?

Comment: N/A

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

Comment: N/A

7 Special tools, equipment, software

A7.9 What special tools, equipment, software, etc will need to be purchased by the Region to effectively implement?

Comment: N/A

A7.10 Are there stock numbers available for the new equipment?

Comment: N/A

A7.11 What will be the costs of these special tools, equipment, software?

8 Finances

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

Comment: N/A

Impact assessment completed by:

Name: Thys Bower

Designation: Senior Consultant

Annex B – Performance Questions

(Normative)

Tenderers are required to submit in writing, with their offer, answers to performance questions. Any technical documentation which might assist the answers must be provided. The answers to the questions will be taken into account in evaluating the offers. The performance questions, as applicable, shall be answered for each protection device offered. Actual performance to be stated and not general information on a product *range, but specific to the offered product.*

C1 Fault scenarios

C1.1 With regard to the distance elements, how is proper security provided for zero voltage faults in the reverse direction? This is especially critical for single line to ground faults where the distance function may operate on the unfaulted phases if a strong unbalance in the zero sequence to positive sequence source impedances exists at the line ends.

C1.2 What is the arc resistance capability of the distance functions for single line to ground faults, especially near-zero voltage faults? How is the required arc resistance coverage achieved?

C1.3 How is the performance of the scheme affected by mutual induction, especially with the parallel line out of service and earthed? What means are employed to accommodate large Zom/Z1 ratios?

C1.4 How do the distance zones perform for a zero voltage fault in in the forward direction?

C1.5 How is the impedance reach for single line to ground faults unaffected by infeed in a meshed network?

C1.6 How do the distance elements perform when the protected line or adjacent lines are "end-line" series compensated to 75%? How is correct directionality maintained when the so-called voltage reversal takes place?

C1.7 How is correct phase selection for inter-circuit faults ensured?

C1.8 What is done to prevent slow resetting on CT secondary current decay especially for the circuit-breaker failure current elements?

C1.9 How is the single line to ground fault differentiated from a double line to ground fault, at the end of the line, under extreme system conditions (strong zero sequence source at end near fault).

C1.10 What means is used to prevent incorrect operation of the distance zones, in particular the phase selectors during a one pole open condition?

C1.11 If the IED is capable of being applied to teed-feeders, explain how this is achieved.

C1.12 How does the current differential element remain stable (bias maximised) for close-up out-of-zone faults?

C2 Filtering

C2.1 What is the effect of transformer magnetising inrush and shunt reactor ringdown on the distance measurement?

C2.2 What is the delay in distance zone operation caused by CVT transients and CT saturation? How are these problems overcome in the design?

C3 Measurement algorithm(s)

C3.1 How is overreaching on double line to ground faults controlled, in particular with varying degrees of load flow?

C3.2 What is the maximum arc resistance coverage provided by the distance zone elements and what are the limitations of the distance measurement technique to provide additional arc resistance coverage.

C3.3 Describe the phase selection method used. Under what fault scenarios and/or system conditions could the phase selection algorithm not operate correctly?

C3.4 Provide details of how the distance functions for a ph-to-ph-gnd fault composed of two ph-gnd faults, and in particular, how overreaching is prevented under these scenarios.

C3.5 How is distance zone's reach measurements accuracy achieved with the presence of maximum load, export and import?

C4 Setting 'limitations'

C4.1 Are any plausibility checks performed on the IED settings before these are allowed to be activated? If yes, what checks are done and are setting conflicts detected and the operator informed of such problems?

C5 Power swing

C5.1 What power swing detection method is employed? Does this method cater for any angle of entry of the swing locus trajectory without affecting the required performance?

C5.2 What method is employed to ensure fast tripping for own line faults that occur after establishment of a power swing condition (all three breaker poles closed and during an open-pole condition)?

C6 Series compensated lines

C6.1 How does the IED provide for zone 1 clearance of faults on "end-line" series compensated transmission lines?

C6.2 How do the distance zones perform when the protected line or adjacent lines are "end-line" series compensated to 75%? How is the distance zone's correct operation ensured when voltage reversal takes place?

C7 Non-transposed lines

C7.1 Is the performance of the distance zones in any way affected when applied to long non-transposed transmission lines?

C8 General

C8.1 How does the IED(s) Logical physical device (LPHD) report the physical health information to the clients?