Eskom	Standard	Technology

Title: **STANDARD FOR TERTIARY BAY REQUIREMENTS WHEN POWER TRANSFORMERS ARE USED TO SUPPLY STATION AUXILIARY LOADS AND RURAL SUPPLIES**

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Date: 20/06/2022

This document is **STABILISED.** The technical content in this document is not expected to change because the document covers: *(Tick applicable motivation)*

1	A specific plant, project or solution	
2	A mature and stable technical area/technology	
3	Established and accepted practices.	x

This letter is for multiple documents: N/A

PCM Reference: **240-53459042**
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Content

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1. Introduction

Power transformers supplied to Eskom are specified to have a tertiary winding in order to supply station auxiliaries. The delta tertiary winding also acts as a stabilising winding to suppress third harmonic voltages and influence zero sequence impedance.

In remote areas, in the absence of established networks, main coupling transformer tertiaries are also used to feed local reticulation networks. These relatively unimportant loads are, however, subject to high fault incidences and therefore place severe stress on the power transformer. It is therefore not recommended that tertiaries be used to supply rural loads.

When, however, geographic and economic conditions make alternative supplies impractical, it is acceptable to make use of the tertiary provided that the requirements set out in this document are implemented.

Two cases are considered, these being existing installations and new installations.

2. Supporting clauses

2.1 Scope

The document refers to AIS substations where either stranded flexible conductors or round tubular conductors are employed for busbars, equipment interconnections and connections between equipment and busbar conductors.

2.1.1 Purpose

The purpose of this document is to provide a standard for implementing rural supply connections where no other solution is practical.

2.1.2 Applicability

This document shall apply throughout Eskom Holdings Limited Divisions.

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] Pretorius R.E., Rosen, P.R., ”Neutral Earthing in High Voltage Industrial Power Systems – Current South African Practice and Recommended Standards”, Trans. SAIEE July 1983

[2] Substation Layout Design Guide.

2.2.2 Informative

None

2.3 Definitions

2.3.1 General

Definition	Description
Effectively earthed	A system in which the value of the phase to earth voltage of the healthy phases during an earth fault, never exceed 1.39 times the pre-fault phase to ground voltage is effectively earthed. In an effectively (solidly) earthed system, transformer neutrals are earthed directly to the earthmat.
IDMT relays	IDMT relays are protection relays. They are used on transmission lines to see to that the line current doesn't exceed safe values and if it does, triggers the circuit breaker. IDMT means inverse definite minimum time. So as the current keeps increases, the relay takes minimum time to trip the circuit. Inverse means "higher the current value, lesser the time taken for the relay to trip the circuit". Current in the line and the time taken for the relay to trip the circuit breaker follow an inverse proportionality.
INST relay	• Instantaneous overcurrent relay • Operates in a definite time when current exceeds its Pick-up value. • Its operation criterion is only current magnitude (*without time delay*). • Operating time is constant. • There is no intentional time delay. • Coordination of definite-current relays is based on the fact that the fault current varies with the position of the fault because of the difference in the impedance between the fault and the source • The relay located furthest from the source operate for a low current value • The operating currents are progressively increased for the other relays when moving towards the source. • It operates in 0.1s or less
Non-effectively earthed	In a non-effectively earthed system, transformer neutrals are earthed to the earthmat via impedance. This could be either resistive, inductive or a combination of the two.

2.3.2 Disclosure classification

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

2.4 Abbreviations

Abbreviation	Description
AUX	Auxiliary
CB	Circuit breaker
CT	Current transformer
Dist.	Distribution
FCLR	Fault current limiting reactor
HV	High voltage
IDMT	Inverse Definite Minimum Time

Abbreviation	Description
kA	Kilo-amperes
kV	Kilo-volts
kVAr	Kilo-volt-amperes reactive
LV	Low voltage
mH	Milli-henry
MTS	Main transmission system
MV	Medium voltage
MVA	Meg-volt-amperes
NECR	Neutral earthing compensator with neutral resistor
NER	Neutral earthing resistor
PVC	Poly-vinyl Chloride
SA	Surge arrester
TRFR	Transformer

2.5 Roles and responsibilities

Group lead engineers need to be fully briefed on the contents of this document. They will in turn be expected to instruct their direct reports in its use.

2.6 Process for monitoring

The document is to be updated from time to time as the technology develops.

2.7 Related/supporting documents

Not applicable.

3. Document content

3.1 Tertiaries supplying station auxiliaries

The recommended single line diagram arrangement is shown in Figure 1 below.

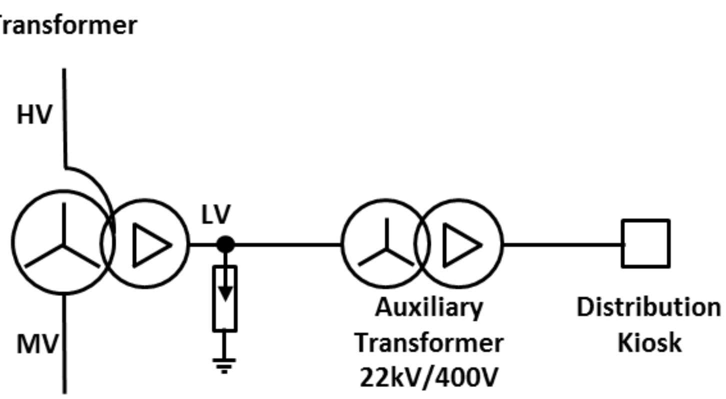

Figure 1: Auxiliary Transformer only Connected to Power Transformer

Figure 2 illustrates an elevation on a typical tertiary bay that supplies station auxiliaries.

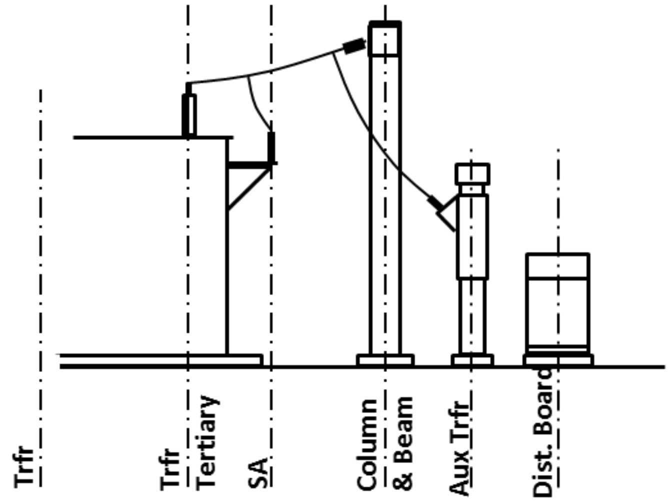

Figure 2: Standard Bay Layout: Auxiliary Supplies only

3.2 Tertiaries supplying station auxiliaries and rural loads

3.2.1 Insulation requirements to minimise fault occurrence in 22kV tertiary bays

The following philosophy is introduced to minimise the probability of close in faults which can produce the highest level of fault current. These requirements apply only to the 22kV tertiary bay and exclude the reticulation in the yard.

a) For 22kV systems, a minimum of 33kV insulation level is to be used.

b) General electrical clearances for a 33kV system should be used (430mm for phase-to-earth and 580mm for phase-to-phase). The current conductor phase spacing of 900mm for the standard steelwork is acceptable.

c) The conductors employed should be PVC insulated for additional protection against phase-to-phase faults caused by birds and vermin (PVC insulation to 22/√3kV ≈ 13kV). Provision for portable earths should be made by the removal of a ±100mm section of the insulation on each conductor as illustrated in Figre 3. These connection points should be staggered so as to reduced the possibility of short circuits occurring as a result of animal contact.

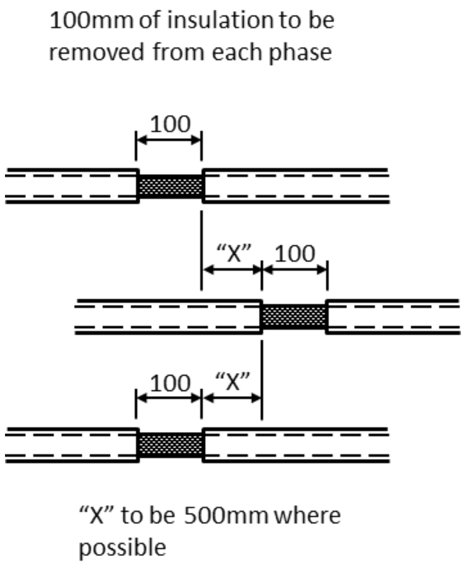

Figure 3: Staggering of Connection Points on PVC Insulated Conductor on Tertiary Bays

d) Bare metal clamps and terminals should be covered with acrylic covers according to Eskom Drg. No. 0.54/412 sheets 19-22, 46 and 47 (see Appendix A). These covers must be cut to suit the insulation so that they do not cover the sheds of the insulators. The alternative is to use pre-approved heat shrink insulation and BCIC covers. The latter is the preferred solution.

PVC taping is not recommended as it tends to unravel with time.

Note: The above requirements also apply to the first case where tertiary bays are used to supply station auxiliaries only.

3.2.2 Fault current limiting reactors to minimise stresses on transformer tertiary windings

3.2.2.1 New installations

For rural systems connected to tertiaries, a fault current limiting reactor (**FCLR**) sized to limit the symmetrical fault current to 70% of the declared transformer tertiary design capability is recommended.

This in addition to 3.1.1.1 is aimed at protecting the transformer against the unavoidably high incidence of line faults on rural systems.

This philosophy will reduce the short circuit forces by 50% of the specified value since:

$I_f = 0{,}7.\ I$

$F \propto I_f^2$

$= (0{,}7.\ I)^2$

$\approx 0{,}5.\ I^2$

Where:

I_f = Symmetrical fault current

I = Declared transformer tertiary design capability

F = Short circuit force

3.2.2.2 Existing installations

The philosophy outlined in 3.2.2.1 should also be applied to the upgrading of existing installations. With certain older designs, however, even though the three phase fault level may be within 70% of the specified design capability, further fault current limiting may be required due to the weakening effects of time and repeated faults. Transformer specialist staff will be required to ascertain these levels in conjunction with the manufacturers.

Reactor ratings cannot be standardised as every case needs to be considered on its own merits. Appendix A illustrates a study that was conducted for a number of stations and contains a table that shows examples of reactor ratings that were required.

3.2.3 Circuit breakers

Since it is completely unacceptable to use the HV and MV circuit breakers as the main backup for the rural line breaker, it is necessary that even in the case of a single rural line, an additional backup circuit breaker be provided as shown in the single line diagram below.

Due to the fault level rating, 22kV breakers are generally inadequate. It is therefore recommended that if a breaker of the required rupturing capacity cannot be sourced, that a 66kV circuit breaker with appropriated capacity be employed. The objective with the 66kV breaker would be to obtain suitable external electrical insulation due to the larger clearances.

It is essential to avoid tripping the power transformer for faults occuring in the rural network. The philosophy behind the placement of circuit breaker S1 in Figure 4 is therefore important.

The circuit breaker should be located on the load side of the fault current limiting reactor where a fault on the breaker will be less onerous due to reduced fault level.

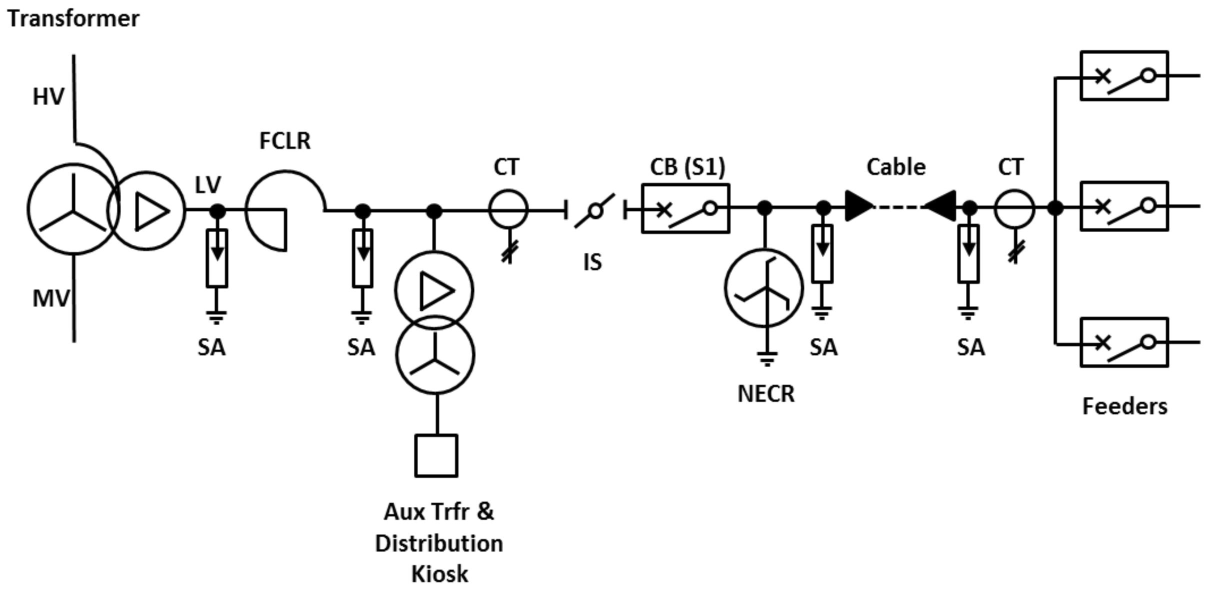

Figure 4: Equipment positioning for tertiary bays supplying rural loads

3.2.3.1 New and existing installations

The NECR unit is a possible source of faults and since it is critical for the operation of the main coupling transformer, it should be placed on the load side of the circuit breaker S1 where it can be isolated from the main transformer in the event of failure.

The auxiliary transformers should be placed on the transformer side of breaker S1 in order to prevent the loss of the station auxiliary supplies during a breaker trip condition.

Note: For maintenance purposes, it is recommended that circuit breaker S1 be considered as part of the Main Transmission System and having the same level of importance as the HV and MV circuit breakers.

3.2.4 Neutral earthing requirements

Neutral earthing requirements published by SAIEE [1] are based on the following objectives:

a) Stabilizing of phase-to-earth voltages. If the neutral is isolated, the system is in effect capacitively earthed (i.e. via cables, busbars, etc.) which can lead to high neutral voltages.

b) To divert a major portion of the fault current to the point of intentional earthing, where the current can be controlled and monitored.

c) Limiting of transient overvoltages and reducing damage at the point of the fault.

3.2.4.1 Effective earthing

The advantage of effective earthing is that during an earth fault, the phase-to-earth voltages of the healthy phases rise to only 80% of the line voltage.

Transient overvoltages are also limited to acceptable levels. However, the earth fault current is approximately equal to the three phase current levels.

3.2.4.2 Non-effective earthing (resistive earthing)

Resistive earthing provides a major reduction in earth fault current magnitudes and reduces associated transient overvoltages.

The main disadvantage is that the phase-to-phase earth voltage of the healthy phases may rise to full line voltage during the earth fault. This provides a particular problem for cables that are only rated for the normal phase-to-earth voltage.

In choosing the type of earthing to be used, it was concluded that the advantages of reduced fault currents (less damage to equipment and lower step and touch potentials) outweighed the cost of upgrading the system to withstand the higher levels during faults.

An earth fault level of 360A per earthing point was selected as a compromise between excessive damage being caused at the point of the fault and having too small an earth fault current at the extreme end of feeders to reasonably guarantee protection operation.

Eskom national contracts currently specify 360/720 ampere NECRs.

High fault resistances may reduce earth fault current. Relay settings should therefore be set as low as practically possible.

In cases where very long lines and high earth fault resistances could cause difficulty in protection discrimination, it is possible to use an NECR with a higher current rating. Values of 720A and 1200A, or any other value are possible using standard NEC's together with NER's.

Note: Where tertiary supplies are taken off more than one transformer, they should never be operated in parallel.

a) New installations

Where a system neutral is available, e.g. a voltage regulator, the required NER may be inserted between the neutral and earth.

Where a system neutral is not available, a standard 22kV 360A NECR should be used.

All cables must be rated for $\sqrt{3} * E_{ph}$ phase-to-earth voltages and 100% surge arresters must be used.

b) Existing installations

A study of existing installations revealed that many were neither effectively nor resistively earthed. Appendix B, Table 2 shows fault current calculations and the value of resistance that was required to ensure resistive earthing.

The results illustrated that standard NER's could be used at the different voltages in order to obtain sufficient current limiting, together with the reduction of transient voltages.

Where resistive earthing is implemented, care must be taken to ensure cables can withstand the increased voltages experienced on the healthy phases during earth fault conditions.

4. Authorization

This document has been seen and accepted by:

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5. Revisions

Date	Rev	Compiler	Remarks
Nov 2016	1	AJS Groenewald	First Issue.

6. Development team

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

Braam Groenewald   Technology Group   Johannesburg

7. Acknowledgements

The following individuals should be acknowledged for setting up the original document:

- PV Goosen
- RJC Moore
- DW Hayes
- JM Theunissen

Annex A – Fault Current Limiting Reactors for Various Stations

Table 1 below illustrate examples of the reactors that were required at various stations. These values should be used as indicators only and should be verified case by case.

Table A.1: Fault Current Limiting Reactors

Station	Transformer Impedance			MVA Main/ Tertiary	Voltage (kV)	Fault Level Without Reactor (kA)	Fault Level With Reactor (kA)	Tertiary Fault Current Design Level	Fault Current Limiting Reactor			
	%Z1 H-L /Base MVA	%Z2 M-L /Base MVA	%Z3 H-M /Base MVA						Impedance			
									(%Z)	(Oh ms)	L (mH)	Rating (KVAr)
Acornhoek	56,34 75	43,14 75	11,33 75	75/ 12,5	275/ 132/22	3,4		6,6	Reactor not required*			
Bloedrivier	40,9 160	26,0 160	12,9 160	160/20	275/ 88/22	12,61	4,26	17,8	Reactor not required*			
Everest	28,3 150	18,4 150	7,61 150	150/50	275/ 132/42	9,42	7,31	10,4	6,3	0,74	2,37	350
Foskor	63,3 250	49,7 250	11,7 250	250/40	275/ 132/22	11,1	9,25	13,2	11,6	0,225	0,715	248
Helios	7,29 10			75/10	400/22	3,6		5,8	Reactor not required*			
Juno	7,28 75			75/10	400/22	3,6		6,6	Reactor not required*			
Komatipoort	54,9 75	43,3 75	11,37 75	75/12,5	275/ 132/22	3,4		6,6	Reactor not required*			
Marathon	63,4 250	49,5 250	11,6 250	250/40	275/ 132/22	11,5	9,95	14,2	8,84	0,17	0,54	187
Nama	31,94 80	19,94 80	11,31 80	80/10	220/ 66/22	10,4	3,6	5,2	37,85	2,29	7,31	158
Perseus	3,85 5	3,89 5	11,33 400	400/5	400/ 275/22	3,2		5,4	Reactor not required*			
Pluto	89,9 750	96,0 750	10,5 750	750/40	21,4	2,73	3,9	628,9	4,059	12,92	4472, 6	
Sol	44,9 500	32,2 500	14,03 500	500/40	400/ 132/22	37	26	37	15,26	0,148	0,47	163

* These values were according to the original design level. If for any reason a further reduction in fault current is necessary due to age, weakening, etc., the further evaluation will be required.

Annex B – Neutral Earthing Requirements for Various Stations

Table B.1: Neutral Earthing Requirements

Station	3-PH Fault I	1-PH Fault I	3Rn (300A) NER	Vdc	Vbc NER	kV	No. Trfrs	No. NERs	Total E/F Current	R_0/X_0 (≥ 2)	Connect Point
Acornhoek	Tertiaries to be used as standby only										
Bloedrivier	4268,05	655,29	111,92	1,6	1,738	22	2	2	600	2,144	NEC
Everest	9420,7	2611,2	235,2	1,30	1,787	42	5	2	600	13,4	Vreg
Foskor	11066,7	3183,3	125,8	1,192	1,766	22	2	2	600	19,2	Vreg
Grassridge	Tertiaries to be removed										
Komatipoort	Tertiaries to be used as standby only										
Marathon	11496,2	2328,7	125,8	1,36	1,755	22	2	2	600	10,998	Vreg
Merensky	Tertiaries to be removed										
Perseus	3412,98	654,29	112,5	1,57	1,737	22	2	2	600	2,215	NEC
Pluto	21414,9	856,8	59,691	1,17	1,78	11	2	2	600	4,52	TRFR
Scafell	Tertiaries to be removed										
Sol	Tertiaries to be removed										
Umfolozi	No tertiary load										

Key:

3-PH Fault	Three phase fault current at the tertiary of the transformer
1-PH Fault	Single phase fault current at the LV busbars (without NER)
3Rn (300A)	Three times the neutral resistance required to achieve 300A earth fault current
Vbc	Voltage on healthy phases during earth fault (without NER)
Vbc NER	Maximum voltage on healthy phases during earth fault (with NER)
KV	System voltage to which NER is connected
No. Trfrs	Number of transformers in parallel
No. NERs	Number of NERs to be installed
Total E/F	Total earth fault current at LV busbars
R_0/X_0	Ratio of zero sequence resistance to reactance (must be ≥ 2 in order to reduce transient overvoltages)
Connect Point	Equipment to which NER is connected

Annex C – Protection

C1. New installations

For a new installation of an auto transformer circuit, where the tertiary may be used for purposes other than supplying subatation auxiliaries, the following is recommended:

1) The transformer differential protection that is installed, should be of the three winding type, i.e. differential protection CT's connected to the HV, MV and LV sides of the transformer, and should be applied to include the reactor within the protected zone.

2) The settings of the instantaneous and IDMT overcurrent elements located in the tertiary delta winding, should be adjusted such that the instantaneous element covers faults from the transformer LV bushings to past the midpoint of the reactor windings (it should not reach past the remote terminals of the reactor) and the IDMT element provides backup, time delayed protection for faults within the LV network past the reactor. The IDMT element should discriminate with other time based relays further down stream.

3) The IDMT element should trip the LV circuit breaker and initiate LV breaker fail protection. It should also trip the main transformer HV and MV breakers after a further time delay of 500ms if the overcurrent condition is sustained.

4) The LV breaker fail relay should be added off the same CT core as the tertiary overcurrent relay. This relay acts as breaker fail protection for the LV circuit breaker. Initiation of this function should be from the tertiary overcurrent (IDMT and INST), the biased differential, the restricted earth fault and backup earth fault protection functions. The breaker fail output should trip the main transformer HV and MV breakers.

5) A biased differential relay should be added off the same CT core as the tertiary overcurrent relay and should be applied to cover the LV reactor, circuit breaker, surge arresters, NECR/auxiliary transformer and respective cabling. This relay should trip the LV circuit breaker and initiate the LV breaker fail protection.

6) In order to protect the NECRT, a restricted earth fault relay should be applied by using a post type CT on the outgoing tertiary circuit and a CT in the neutral path of the NECR. This relay should trip the LV circuit breaker and initiate the LV breaker fail protection.

7) A separate backup IDMT earth fault relay may optionally form part of the reactor and LV system protection. This relay would provide backup protection for reactor earth connected off a CT core in the neutral circuit of the NECR. The backup earth fault relay should trip the LV circuit breaker and initiate the LV breaker fail protection. It should also trip the main transformer HV and MV breakers after a further time delay of 500ms if the earth fault condition is sustained.

8) An LV bus protection scheme using the reverse blocking principle should be applied which makes use of the tertiary IDMT overcurrent relay start contact.

C2. Existing installations

For existing installations where the tertiary circuits are to be modified to fulfil purposes other than supplying substation auxiliaries, the following is recommended:

1) The existing differential protection of the coupling transformer should be extended to include the series reactor within the protection zone. Depending on the installed transformer protection scheme, this will imply:

   - A suitable type of CT is required on the outgoing side of the series reactor where the ratio and specification is dependent on the individual application
   - Recommendation of the tertiary circuit of the differential protection to the load side of the reactor (if the existing protection is of a three winding type) or replacement of existing two winding type differential protection (usually only found when the tertiary supplies station auxiliaries only) with three winding type differential protection.

2) The setting of the instantaneous and IDMT overcurrent elements, located in the tertiary delta winding, should be adjusted as in a) ii. above.

3) Additional protection should be incorporated as per a) iii. to vii above and should be fitted in the main transformer protection scheme, space permitting, or alternatively in a separate panel.

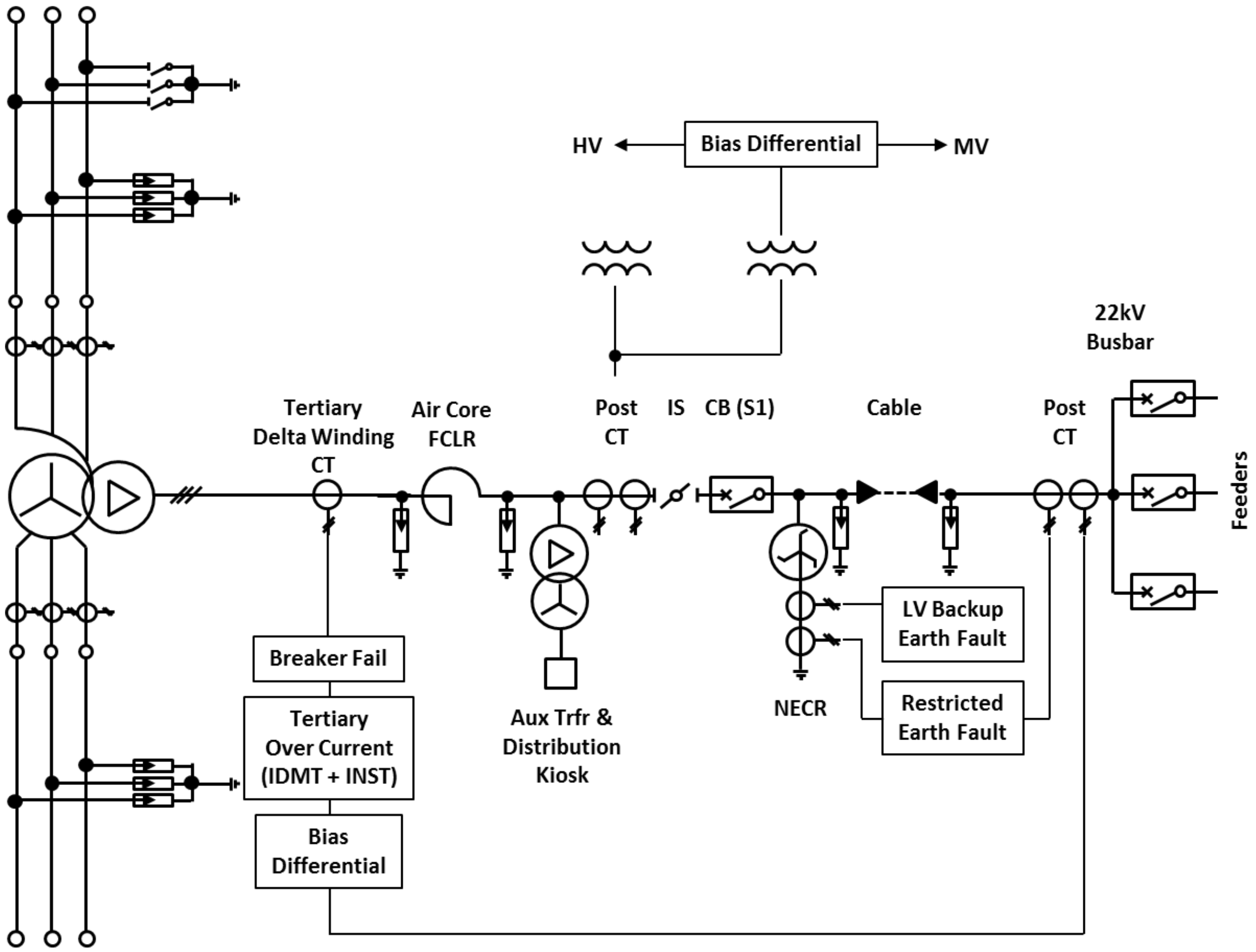

Figure C.1: Protection Block Diagram for a Series Reactor in the Tertiary Circuit