TRANSNET
freight rail

A Division of Transnet SOC Limited

RAIL NETWORK (TECHNICAL)
ELECTRICAL

MANUAL

Handbook for Testing and Calibration of Railway Electrical Protection Equipment

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SECTION 00: INTRODUCTION AND CONTENT

Commissioning and regular routine testing and calibration of protection equipment is required as an essential good practice to ensure that electrical equipment can be protected inherently in the event of abnormal conditions. It relies on sound calculations, appropriate device settings and effective earthing. Equipment that provides protection is installed in 3kV DC traction sub- & Tie stations, 25/50 kV AC Traction Substations, Distribution substations and Stepdown Signal supplies.

This handbook is a reference for testing of electrical equipment used in the railway electrification environment. It contains very important guidelines and procedures which should be followed during routine maintenance, commissioning and fault finding, and to ensure proper operation of protective devices. The intention of the manual is not to create a course in protection theory and design, but to serve as a practical guide for testing.

Testing entails different types of tests, whether routine calibration tests, conductivity earthing, commissioning, the test procedure on any piece of equipment is effectively the same. In this handbook special effort is directed towards

- a basic explanation of the function of each device in the electrical system;
- its principle of operation;
- basic precautions;
- types of the tests;
- test equipment used;
- the test circuit;
- the test procedure;
- documentation, i.e. test sheet(s) used;
- the range of acceptable test results;
- special pitfalls.
- annexures which provides broader background to the design and application of to the equipment.

Frequent reference is be made to the content of the publication “Substation Electrician’s Handbook”, latest edition being BBF8190, and no duplication will be made of material covered in that publication. It is assumed that the reader is familiar with the contents thereof.

All personnel involved in testing of electrical installations must be thoroughly acquainted with the contents of this handbook. Each Test Officer responsible for traction substation must be issued with his own personal copy of the handbook.

This handbook also provides a basis for training of Test Officers in the duties of traction substation maintenance.

Note that it is a dismissible offence to disable protection equipment and circuits in any way.

CONTENT

ACKNOWLEDGEMENTS

The contributions of Atholl Bruyns. Coert van Straaten, Pieter le Roux and others, who greatly contributed towards the compilation of this handbook through their knowledge and experience, is hereby acknowledged.

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SECTION 01

RESPONSIBILITY FOR TESTING AND CALIBRATION

1.1 GENERAL

1.1.1 Electrical Protection Staff must be appointed at various depots, to ensure the integrity of supply systems which include commissioning and routine testing of HV protection systems.

1.2 RESPONSIBILITY OF THE RESPONSIBLE ELECTRICAL ENGINEERING OFFICER

1.2.1 The responsible electrical engineering officer is responsible for:

1.2.1.1 The proper functioning of the Electrical Protection section in terms of facilities skilled manpower, facilities, vehicles and equipment. A schedule of test equipment is included in Annexure 1.1

1.2.1.2 Defining the duties to be performed and control the standard of work.

1.2.1.3 Maintaining a database of protection devices with associated calibration calculations for breakers ie circuits, along with loop impedance test results where available. A schedule of assets is included in Annexure 1.1

1.2.1.4 Calibration of test equipment.

1.2.1.5 Corrective action to exceptions.

1.2.1.6 Outsourcing the functions if responsibilities cannot be met with in-house staff, under strict controls of standards and work procedures.

1.3 DUTIES WITH RESPECT TO PROTECTION TESTING

1.3.1 Duties of the Electrical Protection Officer

1.3.1.1 Electrical Protection staff will be responsible for the routine testing and calibration of HV protective equipment in accordance with a routine program drawn up by the responsible electrical engineering officer. This program will be based on guidelines and a time cycle laid down by the Principal Electrical Engineer.

1.3.1.2 The settings for new equipment will be provided by the Technology Management section. Electrical Protection Officers may not change these settings.

1.3.1.3 Protection staff at depots will be responsible for maintaining a data base of all base loads and protection settings, and notifying the Manager (Resource optimisation) of any change in base loads or the protection settings.

1.3.1.5 When Infrastructure managers require special tests or assistance, the procedure to be followed are fully detailed in Engineering Instruction CEE-GI_045.

1.3.1.6 The management of protection settings is indicated in Appendix 1.

1.3.2 Duties of Substation Maintenance Electricians

1.3.2.1 The tasks with respect to substation protection and earthing safety systems is defined in the Technical Assistant Handbook EP001.

1.3.2.1 Electricians responsible for substation maintenance are not permitted to adjust or tamper with protection relays. They must however check all cable connections to the various components associated with DC and AC Earth Leakage protection as well as under-voltage on a routine basis, as well as after severe earth faults.

1.4 INSTRUMENTS

1.4.1 The responsible electrical engineering officer must provide the electrical protection staff with the instruments required to perform their normal duties. These tools are indicated in this handbook, for the specific equipment present in the section.

1.5 REPORTS AND TEST SHEETS

1.5.1 Protection staff at every depot shall submit copies of regular test reports to the Maintenance Manager (Electrical) concerned.

1.6 ASSOCIATED INSTRUCTION AND APPENDIX

1.6.1 CEE-GI_045: Management And Responsibilities of Infrastructure's Electrical Laboratory.

1.6.2 The following Appendix forms part of this instruction:-

Appendix 1: Protection setting data flow.

1.7 REFERENCES

- Electrical Safety Instructions (latest edition)
- Traction Substations Electricians' Handbook (BBF8190)
- Relevant Manufacturers Specifications And Manuals Of Substation Equipment
- Substation Wiring Diagrams
- Electrical Engineering Instructions: GI _012, S_013 & GI_029

1.8 COMPETENCY

1.8.1 Only persons authorised in terms of clauses 303.1.4.6 or 303.1.7.1 of the Electrical Safety Instructions (1999) shall be allowed to perform high voltage tests in the substations.

1.9 PREPARATION

- Ascertain that all required tools & equipment as per Appendix 1 are available.
- Obtain reference handbooks, engineering instructions and substation schematic diagrams.
- Arrange with the relevant depot staff for access to the substation or tie-stations for taking out the relevant work/test permits.
- Obtain copies of the previously completed test results and substation reports.
- Ensure that all relevant test sheets are available for testing.

Annexure 1.1

DATABASE PROFILE FOR ELECTRICAL PROTECTION ASSET REGISTER

	Aspect and technical reference	*file*	*Subsection*	*Detail*
1.1	*ELECTRICAL PROTECTION EQUIPMENT*	Inventory of Protection installed.	Substation site (50kV, 25kV or 3kV). (workload or Electrical Protection Officers)	Equipment detail per site: - Substations 3kV - Substations 25kV - Switching stations 25kV - Distributions subs - Distributions intake subs
1.2		*3kV HSCBs*	Inventory o HSCB's (workload or Substation electricians)	Substation site Reports sheet per equipment - HSCB type - Equipment detail per site. - HSCB Setting - Work procedure (TA Handbook, specific manufacturer instructions)
1.3		Protection calculations and settings	Equipment material per circuit.	- OHTE/Cable/Return material per circuit. - Loop-impedance calculations per circuit. (AC & DC). - Calculations
1.4			Substation protection settings per equipment	Per installation: - Types relays, CT ratios, - Schedule o testing. - PCB (Main transformer) - HSCB/Track breaker - AC Earth Leakage - DC Earth Leakage - Auxiliary Transformer OL - Battery Under-voltage - Substation Under-voltage (DC)
1.5			Commissioning test recordings & signos per sub	Commissioning sign-offs (3kV: BBC9921).
1.6			Test sheet per Sub	- Status o protection testing - DC Traction Substation: BBB0342, BBB0343 & BBB0344. - Traction Substation (Brown Boveri): BBB0345. - E L & P Substation

	Aspect and technical reference	*file*	*Subsection*	*Detail*
				BBB0346 - E L & P Intake Substation: BBB0348. - Sub defect report: BBB0347.
2.1	*PROTECTION MAINTENANCE RESOURCES*	Availability of test resources,	Skilled personnel in place	- Skilled personnel in place
2.2		Availability of test equipment	Schedule o test instruments and equipment	- 3 Phase Generator, Hand tools, Extension leads, Test Leads, - Water container and Petrol container - Null Balance Digital Earth Megger - 10kV Digital Megger - 4 kV DC Hi Pot Test Set - 25 kV AC Hi Pot Test Set - Primary Injection Test set variable 500/1000 Amps. - Secondary Injection Test set, variable from 0 to 100 Amps - AC / DC Injection Test Set, 200A, variable 0 to 250V - LCR Meter - Digital Millisecond Timer, 999 seconds - Multimeter Analog (A.V.O.) - 2 x Multimeters Digital (R.M.S.) - DC Milli-volt Injection Set, 100mV - Bucholtz Pump (air compressed pump or bicycle pump) - Heating Apparatus (Oil heating) - Thermometer - Emergency Lighting - Boom crane
2.3			Calibration of instruments	Calibration intervals - BBD 5294. Calibration certificates.
3.1	*PROTECTIVE DEVICES – LIGHTNING PROTECTION*	Inventory. Workload (of Electricians)	Equipment detail per site. Reports sheet per equipment	- Equipment location - Earth tests results - **BBD…(standard report sheet)**

	Aspect and technical reference	*file*	*Subsection*	*Detail*
3.2	*AC/DC PROTECTIVE DEVICES*	Inventory of devices (workload of Electricians)	Changeover sites	Equipment detail per site. - Reports sheet per equipment Location (e.g. Mast location) - Prescribed report sheet **(BBC…)**

SECTION 2

ROUTINE TESTING REQUIREMENTS

2.1 DC TRACTION SUBSTATIONS

2.1.1 The following routine testing must be performed

BBB0342 : Meters, Main & Aux. Overload relays, AC Earth Leakage & Transformer Protection

BBB0343: Earth and Insulation measurements, 3 kV & 110v Undervoltage -- & DC Earth leakage relays & Wave filter equipment

BBB0344 : Transformer / Rectifier protection Trafogaurd T100

BBB0345 : Transformer / Rectifier protection Brown Boveri

BBB0347 : Substation Defect Report

BBB0348 : Transformer Insulation & Ratio tests

BBB0349 : Insulation oil report

???0000 : Transformer / Rectifier protection Strike Technology

2.2 DC TRACTION TIESTATIONS

2.2.1 The following routine testing must be performed

????0000 Earth and Insulation measurements, 3 kV & 110v Undervoltage -- & DC Earth leakage relays,

BBB0347: Substation Defect Report

2.3 25KV TRACTION SUBSTATIONS

2.3.1 The following routine testing must be performed

???0000 Transformer: CT Mag Curves, IDMT Overload & Restricted Earth Fault relays, Buchholtz, Oil & Winding Temp. relays, Pressure Relief Device, Battery Undervoltage relay and Earth Measurements.

???0000 Incomer VCB: CT Mag Curves, Overload relay and meters.

???0000 Line feeder VCB's: CT Mag Curves, Instantaneous, Distance and Thermal Overload relays, Reclosing relay, and meters.

BBB0347: Substation Defect Report

2.4 DISTRIBUTION INTAKE SUBSTATIONS

2.4.1 The following routine testing must be performed

BBB0344 Transformer protection Trafogaurd T100

BBB0346 Electrical Light and Power

BBB0347 Substation Defect Report

BBB0348 Transformer Insulation & Ratio tests

2.5 DISTRIBUTION RING SUBSTATIONS

The following routine testing must be performed

BBB0344 Transformer protection Trafogaurd T100

BBB0346 Electrical Light and Power

BBB0347 Substation Defect Report

BBB0348 Transformer Insulation & Ratio tests

2.6 EQUIPMENT REQUIRING EARTHING TESTS

2.6.1 The following routine testing must be performed:

- Earth spike readings at transmission line terminations and stepdown points, according to Section 14.2.0 of the Technical Assistant Handbook EP001. This testing must be performed at 5-yearly intervals and proper records kept.
- Spark gap testing at all locations, excluding substations, where installed to provide a fault path between AC and DC negative return circuits.

???0000 Earth resistance Measurements

2.7 FREQUENCY OF TESTING

All Routine tests to be conducted as per 2 yearly time cycle are described below.

NOTE: All high voltage tests (>1000V) must be carried out in accordance with clause 609 of the Electrical Safety Instructions (1999)

2.8 ANNEXURES:

2.9 "ELECTRICAL TEST LABORATORY TEST SHEETS

BBB0342 : Meters, Main & Aux. Overload relays, AC Earth Leakage & Transformer Protection

BBB0343: Earth and Insulation measurements, 3 kV & 110v Undervoltage -- & DC Earth leakage relays & Wave filter equipment

BBB0344 : Transformer / Rectifier protection Trafogaurd T100

BBB0346 Electrical Light and Power

BBB0345 : Transformer / Rectifier protection Brown Boveri

???0000 : Transformer / Rectifier protection Strike Technology

BBB0347 : Substation Defect Report

BBB0348 : Transformer Insulation & Ratio tests

BBB0349 : Insulation oil report

????0000: Earth and Insulation measurements, 3 kV & 110v Undervoltage -- & DC Earth leakage relays,

???0000 Transformer: CT Mag Curves, IDMT Overload & Restricted Earth Fault relays, Buchholtz, Oil & Winding Temp. relays, Pressure Relief Device, Battery Undervoltage relay and Earth Measurements.

???0000 Incomer VCB: CT Mag Curves, Overload relay and meters.

???0000 Line feeder VCB's: CT Mag Curves, Instantaneous, Distance and Thermal Overload relays, Reclosing relay, and meters.

???0000 Earth resistance Measurements

Infrastructure (Maintenance) **BBB0342 Version 1**

Electrical Test Laboratory
Traction Substation
Test Sheet

TRANSNET freight rail

Location / Name:		
Date:	Nature:	Unit:

4 kA DC Ammeter			
Shunt:	A		mV
Indication	mV	Amps	% Error
500 A			
1 000 A			
2 000 A			
2 500 A			
3 000 A			

4 kV DC Voltmeter		
Indication	Sub standard	% Error
1000 V		
2 000 V		
2 500 V		
3 000 V		
3 500 V		
4 000 V		

AC Earth leakage	
CT Ratio:	
Volt	Amp

Main O/L:			
CT Ratio:			
V	R Amp	Y Amp	B Amp

Relay Make & Type: ______________
Full Load: = __________________ **A**

Thermal O/L.			
Relay was tested by prim. / sec. / Tw.			
Injection to operate at:			
x (FL) = Amp.			
Phase	R	Y	B
Time (sec)			
Current Set.			
Time Set.			

Instantaneous O/L.			
Relay was tested by prim. / sec. / Tw.			
Injection to operate at:			
x (FL) = Amp.			
Phase	R	Y	B
Time (sec)			
Current Set.			
Time Setting			
Relay Trip OCB			
Indication			

Bucholz Relay	cc
Relay trip, lock-out OCB:	
Indication:	

Aux. O/L:			
CT Ratio:			
V	R Amp	Y Amp	B Amp

Relay Make & Type: ______________
Full Load: = __________________ **A**

Thermal O/L.			
Relay was tested by prim. / sec. / Tw.			
Injection to operate at:			
x (FL) = Amp.			
Phase	R	Y	B
Time (sec)			
Current Set.			
Time Set.			

Instantaneous O/L.			
Relay was tested by prim. / sec. / Tw.			
Injection to operate at:			
x (FL) = Amp.			
Phase	R	Y	B
Time (sec)			
Current Set.			
Time Setting			
Relay Trip OCB			
Indication			

Bucholz Relay	cc
Relay trip, lock-out OCB:	
Indication:	

Temperature Relay			
Oil	°C	Winding	°C
Relay trip, lock-out OCB:	U/B	Relay trip, lock-out OCB:	U/B
Indication		Indication	

Relay Make & Type:
Relay set at:
Relay setting:
Relay checked for parallel path: Yes / No
Connect to AC E/L:
Main X/F tank:
OCB structure:
CT's structure:
Aux. X/F fence:
Relay trip and lock-out OCB: Yes / No
Indication: Yes / No

____
Tested By:

____
Approved By:

____
Date

Infrastructure (Maintenance) **BBB0343 Version 1**

Electrical Test Laboratory
Traction Substation
Test Sheet

TRANSNET freight rail

EARTH & INSULATION RESISTANCE		
EARTH RESISTANCE:	Measure	Acceptable
Test spike		<2000 Ω
Test spike - Sub earth		<5 Ω
Test spike - Rail		>5 Ω
Test spike - DC E/L		>25 Ω
Test spike - Neg. busbar		>3000 Ω
Test spike - RUA AC E/L		>10 Ω
Test spike - RUB AC E/L		>10 Ω
Test spike - RUC AC E/L		>10 Ω
Test spike - Track switch earth		<5 Ω
INSULATION RESISTANCE:		
DC. E/L – Sub. Earth		>25 Ω
DC. E/L – Neg. Busbar		>3000 Ω
DC. E/L – Rail		>30 Ω
DC. E/L – RUA AC E/L		>35 Ω
DC. E/L – RUB AC E/L		>35 Ω
DC. E/L – RUC AC E/L		>35 Ω
Sub. Earth – Neg. busbar		>3000 Ω
Sub. Earth - Rail		>5 Ω
Sub. Earth – RUA AC E/L		>10 Ω
Sub. Earth – RUB AC E/L		>10 Ω
Sub. Earth – RUC AC E/L		>10 Ω
Neg. Busbar - Rail		>3000 Ω
Neg. Busbar – RUA AC E/L		>3000 Ω
Neg. Busbar – RUB AC E/L		>3000 Ω
Neg. Busbar – RUC AC E/L		>3000 Ω
Rail – RUA AC E/L		>15 Ω
Rail – RUB AC E/L		>15 Ω
Rail – RUC AC E/L		>15 Ω
RUA AC E/L - RUB AC E/L		>20 Ω

NAME:			
DATE:			
NATURE:			
DC. EARTH LEAKAGE RELAY			
Make & Type:			
Relay operate at:			
Relay Setting:			
Checked for parallel path:			
Connected to DC. E/L	RUA	RUB	RUC
Rectifier frame			
Reactor frame			
Wall bushing plate			
Control panels			
Wavefilter room earth			
Aux. X/F starpoint			
Battery charger			
Telecontrol panel			
Undervoltage relay			
Track breaker cells			
Checker plates			
Tubing in sub.			
Operation of relay results in:			
Relay L/O. OCB.			
Relay L/O U/B.			
Relay L/O T/B.			
Fault indication			

3 kV DC UNDERVOLTAGE RELAY						110 V BATTERY UNDERVOLTAGE	
RUA			RUB				
Make &Type:			Make &Type:			Make &Type:	
Pick-Up:		V	Pick-Up:		V	Pick-Up:	V
Drop-Out:		V	Drop-Out:		V	Drop-Out:	V
Drop-Out delay:		Sec.	Drop-Out delay:		Sec.		
Relay drop-out results:			Relay drop-out results:			Relay drop-out results:	
Trip all T/B			Trip all T/B				
Counter operation			Counter operation			Trip and lock-out of OCB:	
Fault indication			Fault indication				

WAVE FILTER						Check zero voltage between:
RUA			RUB			
Harmonic	Cap (uf)	Induction(mH)	Harmonic	Cap (uf)	Induction(mH)	Battery positive - earth:
6			6			
12			12			Battery negative - earth:
18			18			
24			24			
DISCHARGE RESISTOR :			DISCHARGE RESISTOR :			
SERIES RESISTOR :			SERIES RESISTOR :			
FUSE TESTED :			FUSE TESTED :			

______________ TESTED BY

______________ APPROVED BY

______________ DATE

Infrastructure (Maintenance) BBB0344 Version 1

Electrical Test Laboratory
Traction Substation
Test Sheet

TRANSNET freight rail

SUBSTATION: **DATE:**

MAIN/AUX TRANSFORMER PROTECTION

TRAFOGAURD T100

LIST OF AVAILABLE ADJUSTMENTS
*SET NOMINAL TRFO CURRENT, ITN (30% - 100%) OF IN1 RATED CT PRIMARY CURRENT
*SET INSTANTANEOUS OVERCURRENT TRIP LEVEL, 1>> (200% - 500%) OF IT 400%
*SET INVERSE – TIME CURVE CURRENT THRESHOLD, 1> (100% - 400%) OF IT 200%
*SET INVERSE – TIME CURVE TIME MULT.KT (10MIN – 60MIN) NB: 30MIN

EXAMPLE:
CT RATIO 150/5
NOMINAL EXPECTED CT PRIMARY CURRENT ITN = 105AMP (FULL LOAD OF TRAFO)
THUS ITN/IN1 = 105/150
= 70%
ITN SETTING = 70%

NOTE: AFTER THE SYSTEM IS ENERGISED, 105 AMP IN THE CT PRIMARY CIRCUIT NOW CORRESPOND TO A 100% READING WHEN THE CONTINUOUS IT DISPLAY IS SELECTED. INDICATING FULL LOAD CURRENT.
200% WILL TRIP OCB/SF6 IN 1800 SEC
300% WILL TRIP OCB/SF6 IN 118 SEC
400% WILL TRIP OCB/SF6 IN 30 MILLISECONDS

TEST AND CALIBRATION OF TRAFOGAURD T100

CT RATIO	R PHASE	Y PHASE	B PHASE
MARKED			
MEAS.			

SETTINGS

KT = 30 MINUTES
I>> = 400%
I> = 200%

ITN SETTING

*FULL LOAD OF TRAFO = AMP
*CT RATIO =
*ITN = F/L DEVIDED BY CT PRIMARY TIMES 100%
THUS ITN= = %

BITT SWITCHES

1 = OFF
2 = OFF (STANDARD CURVE
3 = ON (30 MILLISECONDS)
4 – 8 = OFF

TEST RELAY BY PRIM/SEC INJECTION AS FOLLOWS:

300%	R PHASE	Y PHASE	B PHASE
TIME:	S	S	S
TRIP OCB			

400%	R PHASE	Y PHASE	B PHASE
TIME:	M/S	M/S	M/S
TRIP OCB			

TESTED BY: ____________________

Infrastructure (Maintenance) **BBB0345 Version 1**

TRANSNET freight rail

Electrical Test Laboratory
Traction Substation (Brown Boveri)
Test sheet

Name: ____________________________

Date: ____________________________

Nature: R/C ____________________________

Relay Type: **Red Phase: ________________** **Blue Phase: ________________**

Full Load Current: Primary: ________________ A Secondary: ________________ A

Current Transformer Ratio:

Relay Tested: Prim/ Sec/ TW Injection

Thermal O/L: Red Phase Setting: ___________

Preheat Relay At 2 X Full load = ___________ A to 22 °C

Inject 3 X Full load = _______A Relay Operate In _______ Seconds

Relay Trip OCB: Yes / No Relay Indication: Yes / No

Instantaneous O/L: Red Phase Setting: ___________

Inject 3,75 X Full load = ___________ A

Relay Trip OCB: Yes / No Relay Indication: Yes / No

Thermal O/L: Blue Phase Setting: ___________

Preheat Relay At 2 X Full load = ___________ A to 22 °C

Inject 3 X Full load = _______A Relay Operate In _______ Seconds

Relay Trip OCB: Yes / No Relay Indication: Yes / No

Instantaneous O/L: Blue Phase Setting: ___________

Inject 3,75 X Full load = ___________ A

Relay Trip OCB: Yes / No Relay Indication: Yes / No

Tested By: ____________________________ Date: ____________________

Approved By: ____________________________ Date: ____________________

Infrastructure (Maintenance) **BBB0346**

TRANSNET freight rail

Electrical Test Laboratory
E L & P Substation
Test Sheet

NAME :

DESIGNATION : OCB No. :

PANEL NO. : DATE : NATURE : R/C

D.M.I.T. RELAY.

CT RATIO :

V	R Amp	Y Amp	B Amp

POLARITIES :

O/L SETTING : A/% T.M.S. :

E/L SETTING : A/% T.M.S. :

RELAY TESTED PRIM/ SEC/ TW. INJECTION

MULTIPLE	O/L R ph.		O/L Y ph.		O/L B ph.		E/L	
Of P.C.S.	A	Sec	A	Sec	A	Sec	A	Sec
2								
4								
6								

INSTANTANEOUS RELAY

O/L Setting	E/L Setting
R ph. Trips at A	
Y ph. Trips at A	Relay trips at A
B ph. Trips at A	

BUCHOLZ RELAY cc

Relay trip & lock-out OCB. Give indication.

TEMPERATURE RELAY C

Relay trip OCB. Give indication.

FRAME LEAKAGE RELAY:

V	1 A	2 A	3 A	ZONE	1	2	3
				TYPE			
				PLUG			
				P / Amp			
				TRIPS			
				RATIO			
				TEST SPIKES : Ohm			
				EARTH MAT : Ohm			

SOLKOR R/TRANSLAY

CT RATIO :

V	R Amp	Y Amp	B Amp

PILOT CABLE

Loop resistance :

Insulation resistance :

T1 – E :

T2 – E :

T1 – T2 :

OVERALL FAULT SETTING

FAULT	T.W./ Sec. A	A mA	B mA	AC mA	OPERA-TION %
R – E					
Y – E					
B – E					
R – Y					
B – Y					
R - B					

CURRENT BETWEEN		RELAY OUTPUT
R – E	1.10A	V
Y – E	1.40A	V
B – E	2.00 A	V
R – Y	4.50 A	V
B – Y	4.50 A	V
R - B	2.25 A	V

RELAY TYPE :

SETTING :

RESISTANCE MEASUREMENTS

ZONE	1	2	3
E			
1			
2			

....

TESTED BY APPROVED BY DATE

Infrastructure (Maintenance) BBB0347 Version 1

Electrical Test Laboratory
SUB DEFECT REPORT

TRANSNET freight rail

GRADE: SENIOR ENGINEERING TECHNICIAN
ADDRESS:

TO: MAINTENANCE MANAGER
DEPOT:
DATE:

OUR REF.:

PROTECTION DEFECT REPORT	
The following DEFECTS were found during commissioning / routine testing:	
At :	E.L.&P. /TRACT. Sub-, Tie station:

TESTED BY : ____________________ SIGNATURE : ____________________

*Please attend to these defects and complete bottom portion of this form within two months after receiving report and send back to **TEST LAB**.*

TO: SENIOR ENGINEERING TECHNICIAN

FROM : MAINTENANCE MANAGER
DEPOT:

YOUR REF:

CORRECTION ACTION REPORT	
The following REPAIRS were done for :	
At :	E.L.&P. / TRACT. Sub-, Tie-station :

These defects were repaired by :

Technician : ____________________ Technical Supt. : ________________________
And reported to TECHNICAL MANAGER/SUPT.

Checked by
Date :________________________ Chief Eng. Technician : ____________________

If any assistance is needed to solve or repair a defect and re-testing is necessary, please contact Senior Engineering Technician. Before the Final correction report is sent through.
THANK YOU FOR YOUR CO-OPERATION.

Infrastructure (Maintenance) BBB0348 Version 1

Electrical Test Laboratory
Traction / E L & P Substation
Test Sheet

TRANSNET freight rail

SUBSTATION: ________________ **DATE:** __________

TRANSFORMER: ________________

MAKE: ________________ KVA : __________

SERIAL NO.: ________________ VOLTAGE: __________

DATE OF MANUFACTURE: ________________ VECTOR: __________

INSULATION RESISTANCE TEST: 2 500 V MEGGER (2 mΩ/kV = Good norm)

EARTH TO HT: ________________ HT TO LT1: __________

EARTH TO LT1: ________________ HT TO LT2: __________

EARTH TO LT2: ________________ HT TO AUX.: __________

EARTH TO AUX.: ________________ LT1 TO LT2: __________

LT2 TO AUX.: ________________ LT1 TO AUX.: __________

VOLTAGE RATIO TEST: 3 PHASE GENERATOR

SUPPLY VOLTAGE (3 phase) ________________V

	Primary	Secondary	TAP 1	TAP 2	TAP 3	TAP 4	TAP 5
LT1:			V	V	V	V	V
			V	V	V	V	V
			V	V	V	V	V
LT2:			V	V	V	V	V
			V	V	V	V	V
			V	V	V	V	V
AUXILIARY:			V	V	V	V	V
			V	V	V	V	V
			V	V	V	V	V

AT TAP No. 3: CALCULATED RATIO = HT/LT = _________ / _________ = _______

MEASURED VALUE = SUPPLY V / MEASURED V = _________ / _________ = _______

TESTED BY: ________________ DATE: __________

APPROVED BY: ________________ DATE: __________

Infrastructure (Maintenance) **BBB0349**

Electrical Test Laboratory
TEST CERTIFICATE

TRANSNET freight rail

SUBSTATION: ______________ **DATE:** __________

OIL TEST REPORT

	DESCRIPTION
SUBSTATION	
TRANSFORMER	
MAKE	
DATE OF MANUFACTURE	
SERIAL No.	
KVA RATING	
VOLTAGE HV/LV	
DATE OF SAMPLE	
OIL VOLUME GAL/LITRE	

	TEST RESULTS BOTTOM SAMPLE	ACTION REQUIRED
OIL TEMPERATURE DEG. C		
WATER CONTENT/KARL FISCHER (ppm)		
APPEARANCE/COLOUR OF OIL		
N.N. ACIDITY mg KOH/g OIL		
DIELELECTRIC BREAKDOWN STRENGTH AVR. (kV)		
RECOMMENDATION		

A THE SAMPLE COMPLIES WITH THE REQUIREMENTS.

B THE OIL MUST BE FILTERED IN ORDER TO IMPROVE ITS DIELELCTRIC BREAKDOWN STRENGTH.

C THE OIL MUST BE FILTERED WITH HEAT AND VACUUM IN ORDER TO REMOVE THE EXCESS MOISTURE.

D OIL MUST BE REGENERATED/REPLACED AND A SAMPLE SUBMITTED AFTER 6 MONTHS. (SHOULD THE ACIDITY HAVE INCREASE BY MORE THAN 0,03mg KOH/g OIL, THE TRANSFORMER SHALL BE DE-SLUDGED).

E A SLUDGE TEST MUST BE CARRIED OUT. PLEASE SUBMIT SAMPLE FOR TEST.

TESTED BY: ____________________

Rail Network (Maintenance) ????0000

Electrical Test Laboratory
Traction Tie station
Test Sheet

TRANSNET freight rail

EARTH & INSULATION RESISTANCE		
EARTH RESISTANCE:	Measure	Acceptable
Test spike		<2000 Ω
Test spike – Tiestation earth		<5 Ω
Test spike - Rail		>5 Ω
Test spike - DC E/L		>25 Ω
Test spike - Neg. busbar		>3000 Ω
Test spike - Track switch earth		<5 Ω
INSULATION RESISTANCE:		
DC. E/L – Sub. Earth		>25 Ω
DC. E/L – Neg. Busbar		>3000 Ω
DC. E/L – Rail		>30 Ω
Sub. Earth – Neg. busbar		>3000 Ω
Sub. Earth - Rail		>5 Ω
		>3000 Ω

NAME:	
DATE:	
NATURE:	
DC. EARTH LEAKAGE RELAY	
Make & Type:	
Relay operate at:	
Relay Setting:	
Checked for parallel path:	
Connected to DC. E/L	
Control panels	
Battery charger	
Telecontrol panel	
Undervoltage relay	
Track breaker cells	
Checker plates	
Tubing in sub.	
Operation of relay results in:	
Relay L/O T/B.	
Fault indication	

3 kV DC UNDERVOLTAGE RELAY		
Make &Type:		
Pick-Up:	V	
Drop-Out:	V	
Time delay	Sec	
Relay drop-out results		
Trip all T/B	Yes	No
Counter operation	Yes	No
Fault indication	Yes	No
Check zero voltage between:		
Battery positive - earth:		
Battery negative - earth:		

110 V BATTERY UNDERVOLTAGE		
Make &Type:		
Pick-Up:	V	
Drop-Out:	V	
Relay drop-out results		
Trip all T/B	Yes	No

Tested by: Name: _______________ Signature: __________________ Date:_____________

Approved: Name:________________ Signature:__________________ Date:_____________

Rail Network Maintenance	000???? Version 1

25 kV AC Traction Substations Test Sheet
Current Transformer Ratio and Mag. curves.
Incomer VCB Overload Protection
Line Feeder VCB's Instaneous , Thermal Overload & Distance Protection. Volt & Ammeters

TRANSNET freight rail

Substation: **Routine :** **Commissioning:**

Panel No						
CT Ratio Marked	1200/1		1200/1		1200/1	
CT Ratio Measured						
Magnetisation curves	Volts	mAmps	Volts	mAmps	Volts	mAmps
Instantaneous Overload Protection						
Relay Make & Type:	IDMT		CAG		CAG	
Overcurrent setting	1		1		1	
IDMT Time setting						
% Test current	200%	400%	200%		200%	
Injected current at test current % (Amps)	2	4	2		2	
Operating tripping times (sec)						
Thermal Overload Protection						
Relay Make & Type:			P&B Golds		P&B Golds	
Thermal current setting			1		1	
Time setting			120		120	
% Test current						
Operating tripping times (sec)						
All operations trip VCB's giving indication	Yes	No	Yes	No	Yes	No
Distance Protection						
Relay Make & Type:			YTG 14		YTG 14	
Relay Settings			K1=1 K2=3.5 K3=3.5 K4=1 K5=32 Q1=65 Q2=65 T(Z2)=0.1T(Z3)=0.5 Z2TDelayT=Out		K1=1 K2=3.5 K3=3.5 K4=1 K5=32 Q1=65 Q2=65 T(Z2)=0.1 T(Z3)=0.5 Z2T DelayT=Out K8=1	

		K8=1 K18= 1		K18= 2	
Operating % Calculated/Measured		Z1: 76-69		Z1: 76-69	
		Z2: 92-102		Z2: 92-102	
		Z3: 92-103		Z3: 92-103	
		Z3 Rev: 3		Z3 Rev: 3	
Indicating instruments					
Voltmeter @ Full Scale deflection					
Ammeters@ Full Scale deflection					
Max Demand Indicators					
Tested by: Name:	Signature			Date:	

SECTION 3

COMMISSIONING TESTING

3.1 COMMISSIONING PROCESS

3.1.1 The purpose of commissioning testing is to verify that the installation is complete, installed in terms of the specification and that all aspects are functioning correctly. It is a prerequisite for handing the equipment over to the maintenance section. The process of accepting new or repaired equipment into service is performed in terms of two engineering Instructions:

3.1.1.2 Engineering Instructions G.018: "Inspection and handing over of electrical equipment" according to which a handing over certificate guides the handshake process:

- Portion A: Description of equipment.
- Portion B: Preliminary inspection of the equipment.
- Portion C: Withdrawal of staff. (applicable to High Voltage equipment only).
- Portion D: Authority to commission equipment.
- Portion E: Acceptance of Equipment for Service and Maintenance.
- Portion F: Defects still requiring attention.

3.1.1.2 Engineering instructions G.019 "Procedures for energising / de-energising of high-voltage electrical equipment" stipulates the process for bringing the equipment on load after outage of new constructions, or removing it from service.

3.1.2 For minor alterations or additions to the installations the process laid down in engineering instruction G.013 "Safety precautions to be taken when minor alterations are carried out on electrification installations not covered by handing over certificates" must be followed. Testing may be required before energising or cancelling the work permit.

3.1.1 In case of repairs to equipment, testing may be required before energising or cancelling the work permit.

3.2 TRACTION SUBSTATION COMMISSIONING

3.2.1 TYPE TESTS

1.1 Where type tests are specified they shall be carried out in accordance with the recommended standards or specification referred to this specification.

1.2 Type tests certificates shall be submitted with tender documents and copies must be available on site with commissioning.

3.2.2 INITIAL FACTORY TESTS

2.1 The following initial factory tests shall be carried out on the completed switchgear or control gear at the manufacturers works prior to delivery. Test certificate for these tests shall be supplied.
2.2 The ratio, polarity and magnetization curve of each current transformer.
2.3 The characteristic curves of each protection relay where applicable.
2.4 On DC Traction rectifiers the operation of all fan control and diode indication circuits is to be tested.
2.5 The errors of all indicating instruments.
2.6 A functional test of the complete board including all protective relays by secondary injection. Test certificate for these shall be supplied.
2.7 Four copies of all approved factory test certificates shall be supplied, at the date nor later than the delivery date of the switchgear or control gear.
2.8 All testing shall be witnessed and inspection carried out by the Quality Assurance Section of Transnet Freight Rail's Technology Management.

3.2.2 FUNCTIONAL TESTS

1.1 Complete functional tests must be done according to **BBC9921 Version 2**

3.3 SIGNAL AND DISTRIBUTION SUPPLY SUBSTATION COMMISSIONING

3.3.1 TYPE TESTS

1.1 Where type tests are specified they shall be carried out in accordance with the recommended standards or specification referred to this specification.
1.2 Type tests certificates shall be submitted with tender documents.

3.3.2 INITIAL FACTORY TESTS

2.1 The following initial factory tests shall be carried out on the completed switchgear or control gear at the manufacturers works prior to delivery. Test certificate for these tests shall be supplied.
2.2 The ratio, polarity and magnetization curve of each current transformer after their installation in the board.
2.3 The characteristic curves of each protection relay where applicable.
2.4 The ratio of each voltage transformer.
2.5 The errors of all indicating instruments.
2.6 A functional test of the complete board including all protective relays by primary injection. Test certificate for these shall be supplied.
2.7 Breakers' opening times.
2.8 Four copies of all approved factory test certificates shall be supplied, at the date nor later than the delivery date of the switchgear or control gear.
2.9 All testing shall be witnessed and inspection carried out by the Quality Assurance Section of Transnet Freight Rail's Technology Management.

3.2.3 FUNCTIONAL TESTS

3.1 Complete functional tests must be done according to **BBB4182**

3.4 REFERENCES

- Engineering instruction G.018
- Engineering instruction G.013
- Engineering instruction G.019

3.5 ANNEXURES

3.5.1 BBC9921: "3kV Traction Substations: Commissioning tests by Contractor prior to final Commissioning by Transnet Freight Rail" (Pre-commissioning)

3.5.2 BBB4182: "EL&P Substations: Commissioning tests by Contractor prior to final Commissioning by Transnet Freight Rail" (Pre-commissioning)

TEST SHEET: TRACTION 3kV DC SUBSTATION

TRANSNET freight rail

COMMISSIONING TESTS BY CONTRACTOR PRIOR TO FINAL COMMISSIONING BY TRANSNET FREIGHT RAIL

CONTRACT NO:

SUBSTATION NAME	DEPOT	DATE

	FUNCTION	*COMPLY (YES/NO)*	*COMMENTS*
1.0	**FUNCTIONAL TESTS IN AC YARD**		
1.1	AC Disconnects to trip P.C.B when operating under load conditions		
1.2	Operation of Wave Filter Door switches to trip P.C.B		
1.3	Main Transformer Bucholz Relay to trip and lockout P.C.B giving indication		
1.4	Main Transformer Oil temp Relay to trip P.C.B giving indication		
1.5	Main Transformer Winding temp. Relay to trip and lockout P.C.B giving indication		
1.6	Winding and Oil Temp relays will only trip Unit Breaker if still in use.		
1.7	All lockout circuits will also trip the Unit Breaker with P.C.B if Unit Breakers are still in use		
1.8	Auxiliary Transformer Bucholz Relay to trip and lockout P.C.B giving indication		
1.9	P.C.B operation only when selector switch is in the Local position		
1.10	P.C.B to trip when 110V DC Supply is removed from the No Volt Coil		
1.11	All cables to Substation to be block jointed and covered with suitable heat shrink		
1.12	Operation of S.F.6 Low gas to trip and lockout P.C.B giving indication		
2.0	**FUNCTIONAL TESTS INSIDE SUBSTATION**		
2.1	Operation of P.C.B giving indication Spring Charged and Spring Discharged with selector switch in the Local position		
2.2	Check that P.C.B does not operate when Local/Remote switch is in the Remote position		
2.3	Operation of DC Earth Leakage relay to trip P.C.B as well as all Track Breakers giving lockout and Indication		
2.4	Operation of AC Earth Leakage relay to trip P.C.B giving lockout and indication		
2.5	Operation of all Track Breakers in Local position to close and drop out after delay period giving		

	FUNCTION	*COMPLY (YES/NO)*	*COMMENTS*
	indication		
2.6	Auxiliary Transformer protection relay operation to trip P.C.B giving indication – all phases		
2.7	Main Transformer protection relay operation to trip P.C.B giving indication – all phases		
2.8	Battery Under Voltage protection to trip G.C.B giving lockout and Indication		
2.9	3kV DC Under Voltage protection to Pick up and Drop out all Track Breakers		
2.10	Check direction of fans on Rectifier unit		
2.11	Operation of attenuation fail protection to trip and lockout P.C.B		
2.12	Operation of fan failure vane switches to trip and lockout P.C.B		
2.13	Operation of Current Monitor relay to start Rectifier fans for cooling		
2.14	Operation of Temp. Sensor to start Rectifier fans at 80 degrees C for cooling		
2.15	Operation of Over Temp. Sensor to Trip and lockout P.C.B giving indication		
2.16	Check that the key interlocking is in place and in the right sequence to enter Rectifier bay		
2.17	When Unit Breaker is still in use – Check intertripping between P.C.B and Unit Breaker		
2.18	Check Main Transformer Oil and Winding temp to trip Unit Breaker only, and to close again with temp normal		
2.19	Emergency Stop button to operate and give complete shutdown with latching device giving lockout		
2.20	Where telecontrolled devices have been replaced or repaired, the correct operation and indication must be checked with Control and Telecontrol.		

Contractor: ________________________

Name: ________________________

Signature: ________________________ **Date:** ____________________

Tests witnessed by: **Transnet Freight Rail**

Name: ________________________

Signature: ________________________ **Date:** ____________________

SECTION 4

CURRENT TRANSFORMERS

4.1 THE FUNCTION OF THE CURRENT TRANSFORMER IN THE ELECTRICAL SYSTEM.

Current transformers are installed to obtain a proportional value of the current which flows in the power circuit to drive measuring and protection equipment.

AC and DC Traction substations

Primary side: Free standing Current Transformers’ are connected in series between the AC disconnects and the transformer. The actual position varies depending on yard layout. The Current Transformers may thus be between the transformer and primary breaker or between the disconnects and primary circuitbreaker. The actual position varies depending on the outdoor yard layout.

Secondary side: Current Transformers’ are connected in series between the secondary side of the transformer and the rectifier in DC substations. In AC Traction Substations current transformers are installed in the roof bushings of VCB cubicles but the latter are being replaced with outdoor VCB’s with associated current transformer mounted on the extensions from the VCB support structure.

Alternatively the Current Transformers may be located in the transformer being fitted around the bottom of the HT (Primary) and LT (Secondary) bushings.

Signal and Distribution Substations

Similar installations are done for Signal and Power Supply Intake substations on the primary side. In Distribution substations (EL&P) current transformers are installed in the cable entry enclosures as part of the single or multi panel structure construction.

4.2 PRINCIPLE OF OPERATION.

Current transformers are graded according to the intended purpose, namely measurement of energy, metering instruments and protection in terms of:

- Current ratio   Accuracy   Ability to protect against high currents

Current Transformers consist of magnetically coupled primary and secondary windings, wound on a common iron core, the primary winding being connected in series with the network. The flow of current in the primary winding produces an alternating flux in the core and this flux induces an e.m.f in the secondary winding which results in the flow of secondary current when this winding is connected to an external closed circuit. For further information refer to Annexure 1: THEORY AND PRACTICE OF CURRENT TRANSFORMERS.

4,3 **BASIC PRECAUTIONS**.

Work to be done under the cover of a work permit. All possible sources of supply are to be isolated and earthed.

Current Transformers normally work at a low flux density and the core is made of high quality steel which has a low magnetising current. On open circuit (under load) the secondary impedance becomes infinite and the core saturates. This induces a very high voltage in the secondary winding and damage to insulation may occur as well as creating a serious electrical shock hazard.

4.5 CURRENT TRANSFORMER CONNECTIONS

In DC traction substations current transformers are connected from the outdoor equipment to the related protection/metering equipment via underground multicore cables through cable entries to the relevant connection terminals in the Control panel and this must be disconnected to facilitate testing.

In the case of AC Traction and Distribution substations current transformers are connected from outdoor or indoor equipment to the related protection/metering equipment via a standard test terminal block on the control panel to shown in fig 4,1 with the normal sequence of terminals as configured in Figure 4.2. This enables the connections from the current transformers to be either connected to the protection-/metering equipment or shorted to earth if required by changing the position of the links. Testing of current transformers and related equipment is more easily facilitated.

Figure 4.1

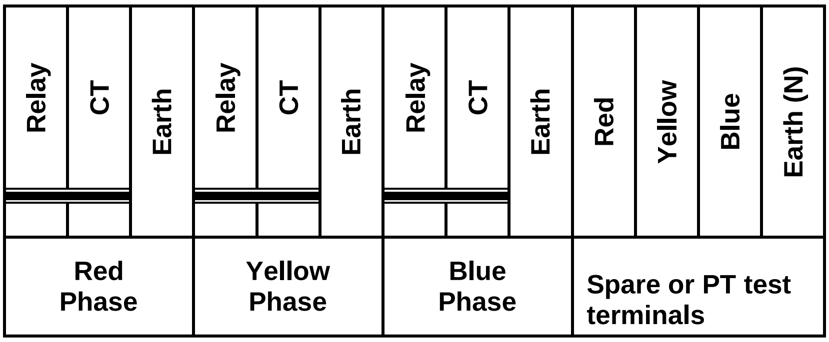


Figure 4.2

Figure 4.2 shows the positions of the links for normal operation.

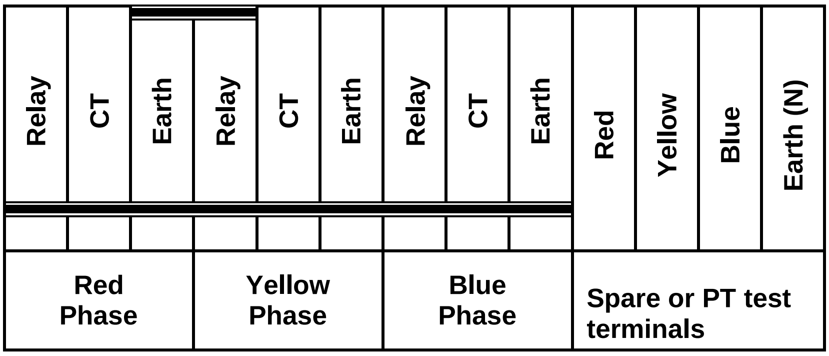


Figure 4.3

Figure 4.3 shows the positions of the links shorted out

4.5 **TESTING OF CURRENT TRANSFORMERS**

1 **Commissioning tests**:

1.1 Insulation test: To prove insulation levels between Primary to Secondary windings and to earth (Megger to 2 Megohms/kV).

1.2 Ratio test: To prove primary to secondary ratios by primary injection or by test winding as well as to verify the overall operation of the circuit usually during commissioning or after a major modification.

1**.3 Magnetization curve**: Drawn to ensure that magnetizing characteristics are correct. Comparison of magnetizing curves over time indicates a shift in performance of any defects present. **1.4 Polarity test**: Done on commissioning and when replacement of current transformer was done to ensure that the polarity of all current transformers are uniform.

2 Routine testing

2.1 Ratio test: To prove primary to secondary ratios by primary injection or by test winding

2.2 Magnetization curve: Drawn to ensure that magnetizing characteristics are correct. Comparison of magnetizing curves over time indicate a shift in performance of any defects present.

.

4.6 TEST EQUIPMENT

1.1 Insulation test: 2.5 kV -1000volt Megger

1.2 Ratio test: Variac 0-250 volt @ 8 Amps (Tesset)
Injection Transformer 0-50-100-200 amps
Multi ratio Lab CT with Ammeters 0-1-5 amps.
Set of heavy duty and light leads.

1.3 Magnetization curve: Variac 0-250 volt @ 8 Amps (Tesset)
Standard Voltmeter 0-250-1000v.
Ammeters 0-1000mA-1-5 Amps
Set of light leads.

1.4 Polarity test : Battery 9 volt. Analogue voltmeter on low scale or centre zero galvanometer Set of light leads

4.7 TEST CIRCUITS.AND PROCEDURES

1.1 Insulation test

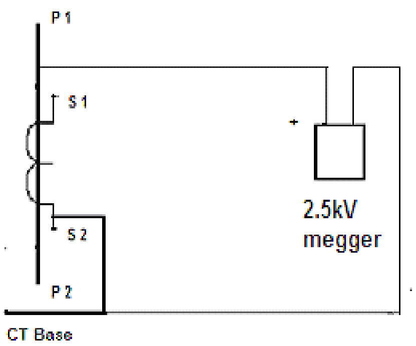


Figure 4.4

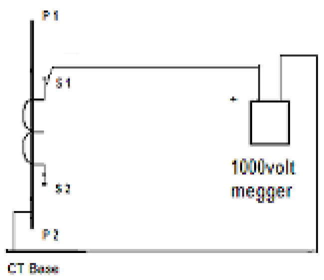


Figure 4.5

1.1 Connect the 2.5kV megger to the CT under test as shown in Figure 4.4 for testing the primary winding to the secondary winding plus earth.

1.2 Connect the 1000 V megger to the CT under test as shown in Figure 4.5 for testing the secondary winding to earth.

1.3 Record the values for each current transformer in the circuit on the relevant test sheet.

2 Range of acceptable results

2.1 Primary winding to Secondary winding and Earth > 2 megohms per kV
Secondary winding to Earth > 1 Megohm,

1.2 Ratio test

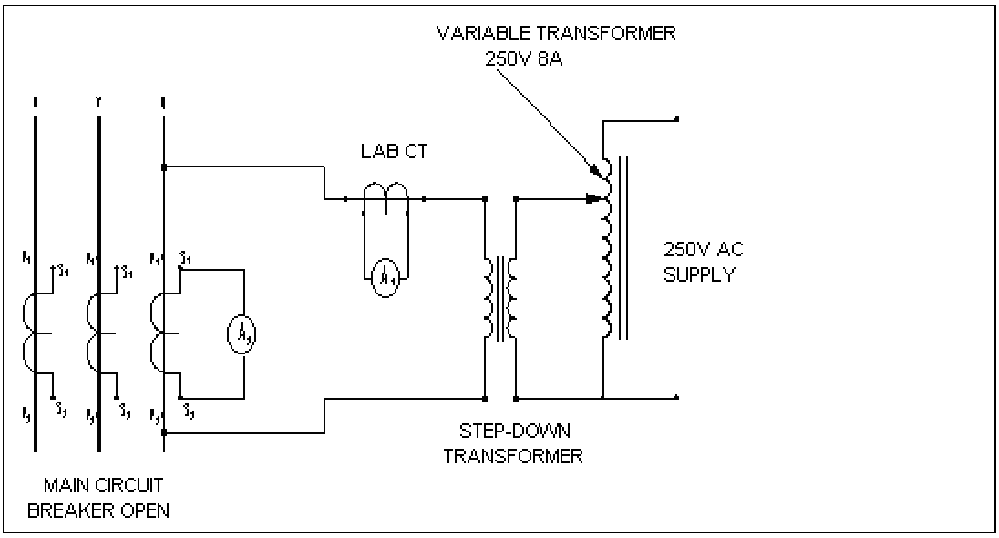


Figure 4.6: Test Circuit for Current Transformer Ratio test

The Test Procedure

.1 Primary injection

1.1 Isolate the current transformer form all sources of supply Remove all earth connections.

1.2 Connect the test equipment to the CT under test as shown in Figure 4.6 selecting a suitable Lab CT ratio

1.3 Slowly increase the injection current until the primary current (A1) corresponds with the CT rated current.

1.4 Record the readings from ammeters A1 (primary current) and A2 (secondary current).

1.5 Check that the ratio of the values, A1: A2 corresponds to the ratio on the current transformer (CT) nameplate.

.1.6 Test each CT individually and verify that the primary and secondary polarity markings are correct.

1.7 Record the values for each current transformer in the circuit on the relevant test sheet.

2 Range of acceptable results

2.1 The nameplate data on a current transformer indicates the tolerance applicable to that particular instrument for example 10P10 indicates that up to 10 times the full load current the accuracy is guaranteed to be within 10%.. At rated full load current as a rule of thumb a difference of 5% is acceptable.

1.3 Magnetization curve

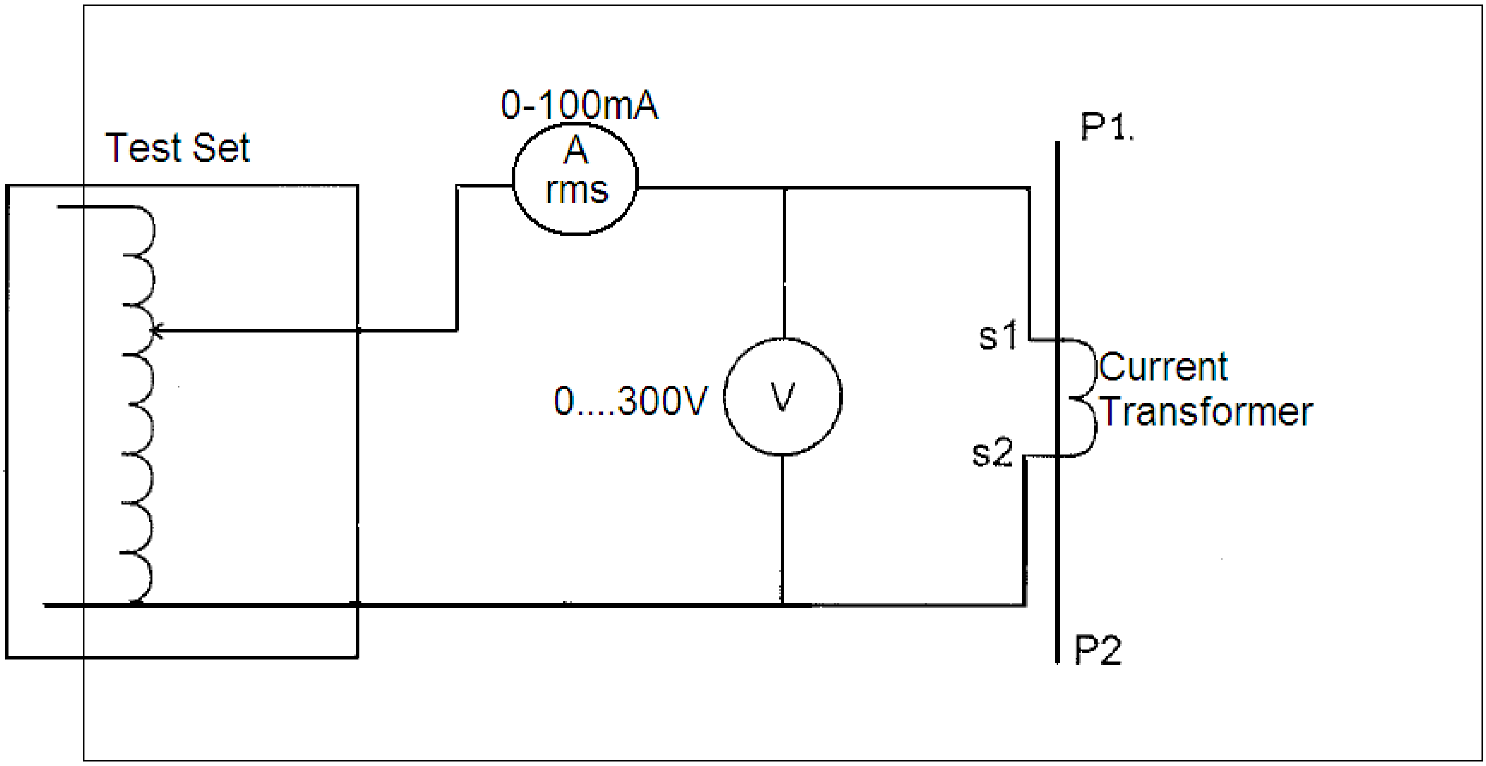


Figure 4.7: Connections for Magnetisation curve test.

1.1 Connect the test equipment to the CT under test as shown in Figure 4.7 selecting suitable scales on the volt and ammeter.

1.3 Slowly increase the injection voltage until the current reaches a value approximately equal to or just above to the rated full load current which will normally be the saturation point.

1.4 Record the values for each current transformer in the circuit on the relevant test sheet.

Saturation point occurs normally at a 10% increase in Voltage and 50% increase in Current. Record all measurements on the test sheet.

2 Range of acceptable results

2.1 The magnetization curve values are normally compared to the factory test results regarding the saturation point and with subsequent routine tests a history is built up that will indicate if any deteriation has taken place..

1.4 Polarity test

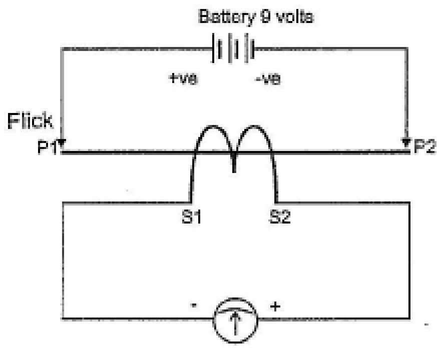


Fig. 4

1. Connect centre zero galvanometer across secondary of the current transformer.
2. Connect battery negative terminal to the current transformer P2 primary terminal.
3. Touch or flick the positive battery connection to the current transformer P1 primary terminal.
4. If the polarity of the current transformer is correct the galvanometer should flick in the positive direction.

4.8 RANGE OF ACCEPTABLE RESULTS

2.1 The polarity has to be correct according to the terminal markings as well as uniform for current transformers applied in multiphase systems.

4.9 SPECIAL PITFALLS.

1. When wound primary current transformer are tested an injection set with a high output voltage is to be used as the impedance will be too high for the normal low voltage high current injection set.

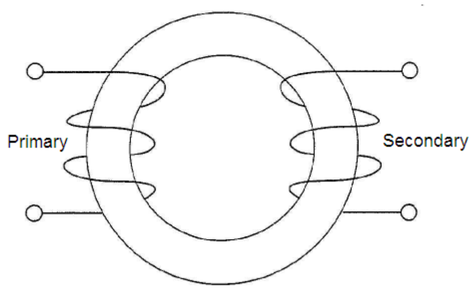
4.10 REFERENCES

- Les Hewitson Pr. Eng. PSP Training. “Power Protection course Version 3.01 May 1998, Commonwealth English Edition.
- IEC 60044 Current transformers

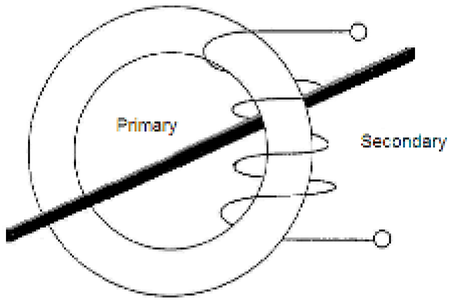
THEORY AND PRACTICE OF CURRENT TRANSFORMERS

All current transformers used in protection are basically similar in construction in that they consist of magnetically coupled primary and secondary windings, wound on a common iron core, the primary winding being connected in series with the network.

They must therefore withstand the networks short-circuit current.



Wound Primary



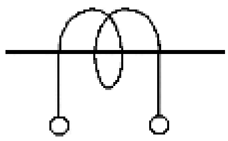
Bar Primary (Currents >100A)

The wound primary is used for the smaller currents, but it can only be applied on low fault level installations due to thermal limitations as well as structural requirements due to high magnetic forces.

If the secondary winding is evenly distributed around the complete iron core its leakage reactance is eliminated.

Protection CT's are most frequently of the bar primary, toroidal core with evenly distributed secondary winding type construction.

The standard symbol used to depict current transformers is as follows:



The basis of all transformers is that:

AMP TURNS on the Primary = AMP TURNS on the secondary

The primary current contains two components:

- An exciting current which magnetises the core and supplies the eddy current and hysteresis losses etc.
- A remaining primary current component which is available for transformation to secondary current in the inverse ratio of turns.

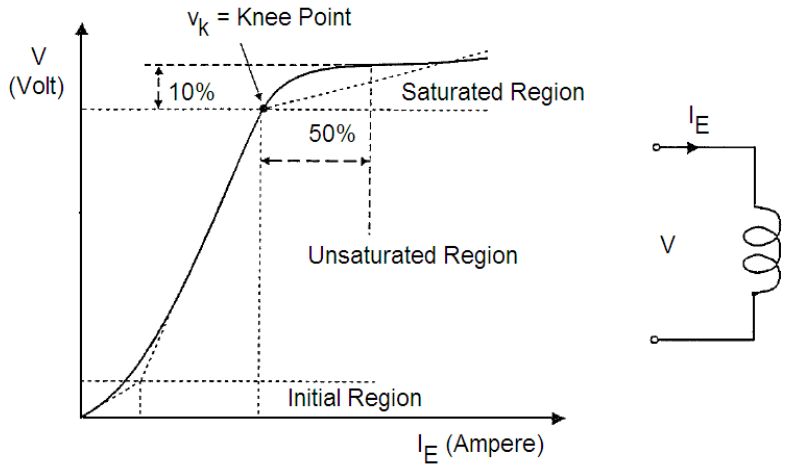
The exciting current is not transformed and is therefore the cause of transformer errors.

The amount of exciting current drawn by a C.T. depends upon the core material and the amount of flux that must be developed in the core to satisfy the output requirements of the CT. That is, to develop sufficient driving voltage required to push secondary current through its connected load or burden.

Magnetisation Curve

This curve is the best method of determining a CT's performance. It is a graph of the amount of magnetising current required to generate an open-circuit voltage at the terminals of the unit.

Due to the non-linearity of the core iron, it follows the B-H loop characteristic and comprises three regions, namely the initial region, unsaturated region and saturated region.



Knee-Point Voltage

The transition from the unsaturated to the saturated region of the open circuit excitation characteristic is a rather gradual process in most core materials. It is difficult to define this transition and use is made of the so-called "knee-point" voltage for this purpose.

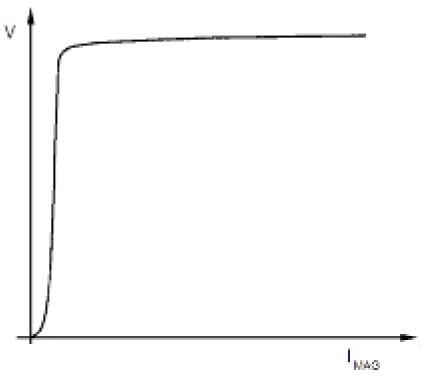
It is generally defined as the voltage at which a further 10% increase in volts will require a 50% increase in excitation current. For most applications, it means that current transformers can be considered as approximately linear up to this point.

Metering C.T.s

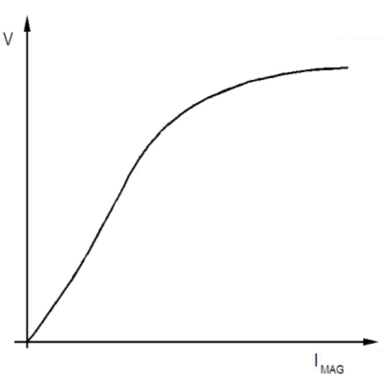
Instruments and meters are required to work accurately up to fill load current, but above this it is advantageous to saturate to protect the instruments under fault conditions. They therefore have a very sharp knee-point and a special nickel-alloy metal is used, having a very low magnetising current, in order to achieve the accuracy.

Protection C.T.s

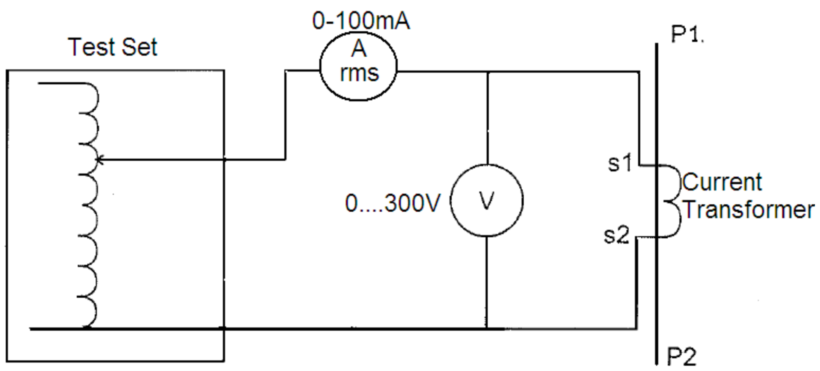
Protective gear, on the other hand, is concerned with a wide range of currents from fault settings to maximum fault currents many times normal rating. Larger errors may be permitted and it is important to ensure that saturation is avoided wherever possible to ensure positive operation of the relays.



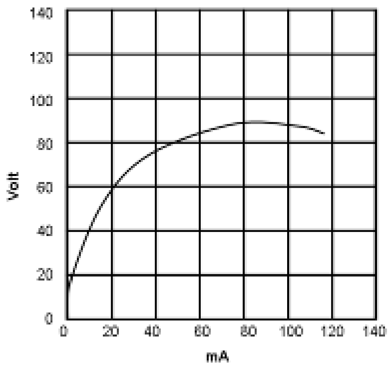
Metering Magnetizing curve



Protection Magnetizing curve



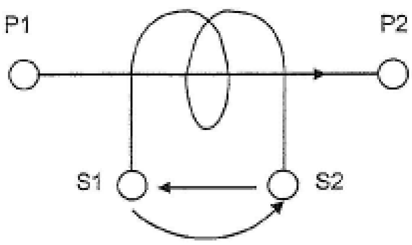
Magnetising curve test circuit



mA	V
5	16
10	37
16	53
20	60
27	67
35	72
40	75
52	79
66	80
81	85
95	86
104	84

Polarity

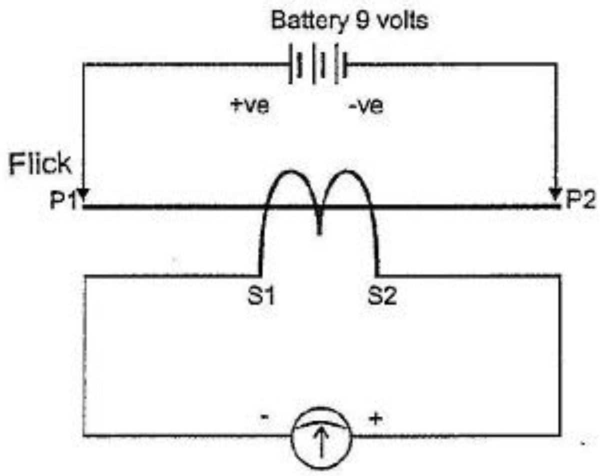
Polarity is very important when connecting relays as this will determine correct operation or not.



Polarity markings of a CT

B.S3938 states that at the instant when current is flowing from P1 to P2 in primary, then current in secondary must flow from SI to S2 through the external circuit.

To test the polarity of a C.T.:



Connect centre zero galvanometer across secondary of the current transformer. Connect battery negative terminal to the current transformer P2 primary terminal. Touch or flick the positive battery connection to the current transformer P1 primary terminal. If the polarity of the current transformer is correct the galvanometer should flick in the positive direction.

Secondary Resistance

The secondary resistance of a CT is an important factor as the CT has to develop enough voltage to push the secondary current through its own internal resistance as well as the connected external burden. This should always be kept as low as possible.

CT SPECIFICATION

CT Selection depends on:

For protection CTs:

CT Specification according to IEC has the following format:

- For OC&EF application,
- For Metering
- For differential protection

- the fault level. It must handle the fault level without saturating. A three phase fault is the highest possible condition.
- the full load current.

A 10P<u>10</u> current transformer can take 10X the primary rated current before saturating. A 10P<u>5</u> will saturate at 5X primary CT current.

.g. for a fault current of 20000A and 10P<u>10</u> CT with ratio 10:5, the CT will saturate because it is seeing 20000/5 = 4000 x primary current

You would actually require a ratio of

20000/10 : 5 = 2000:5 for a 10P10 CT, or

20000/5 : 5 = 4000:5 for a 10P5 CT

Overload rating

Secondary current rating

e.g. for a 10P5 CT 4000:5, the secondary current Is = 5 X 5 = 25A. If the burden is say 1Ω the voltage is 30V.

For a 10P5 CT 4000:1, Is = 5 X 1 = 5A, and V = 5V

Name Plate information and what you can derive

e.g. Class	10P10	10P	Accuracy Class = 10% error
		10	Accuracy Limit Factor (CT is not guaranteed beyond this value)
			Accuracy limit current = rated secondary current x ALF
			= 5 x 10 = 50 Amp
			V_{sec} = 50 x 0.6 (ignoring CT internal impedance)
Burden	15VA		Rated burden. 15VA can be supplied at 5A
			$Z_{burden} = VA/I^2 = 15/5^2 = 0.6\Omega$
			$V_{kneepoint} \approx 30V$
Ratio	2000/5		Ratio Secondary rated current is 5A

A current transformer is normally specified in terms of:

- A rated burden at rated current.
- An accuracy class.
- An upper limit beyond which accuracy is not guaranteed. (Known as the Accuracy Limit Factor, ALF).

In the relevant BSS 3938 the various accuracy classes are in accordance with the following tables:

Class	± percentage current (ratio) error at percentage of rated Current shown below			± phase displacement at percentage of rated current shown below					
				Minutes			Centiradians		
	10 up to but not incl. 20	20 up to but not incl. 100	100 up to 120	10 up to but not incl. 20	20 up to but not incl. 100	100 up to 120	10 up to but not incl. 20	20 up to but not incl. 100	100 up to 120
0.1	0.25	0.2	0.1	10	8	5	0.3	0.24	0.15
0.2	0.5	0.35	0.2	20	15	10	0.6	0.45	0.3
0.5	1.0	0.75	0.5	60	45	30	1.8	1.35	0.9
1	2.0	1.5	1.0	120	90	60	3.6	2.7	1.8

Limits of error for accuracy Classes 0.1 to 1 (Metering CT).

Accuracy class	Current error at rated primary current %	Phase displacement at rated primary current		Composite error at rated accuracy limited primary current %
		Minutes	centiradians	
5P 10P	± 1 ± 3	± 60	± 1.8	5 10

Limits of Error for accuracy Class 5P and Class 10P (Protection C.T.)

In terms of the specification a current transformer would, for example, be briefly referred to as 15VA 5P20 if it were a protection CT or 15VA Class 0.5 if it were a metering CT:

	Protection	Metering
Rated Burden	15VA	I 5VA
Accuracy Class	52	0,5
Accuracy Limit Factor	20	Class 1,0

(ALP is 20 x normal or rated current)

Class X Current Transformers

These are normally specified for special purpose applications such as busbar protection, where it is important that CTs have matching characteristics.

For this type of CT an exact point on the Magnetisation Curve is specified, e.g.

(1) Rated primary current

(2) Turns ratio

(3) Rated knee point e.m.f. at maximum secondary turns

(4) Maximum exciting current at rated knee point e.m.f,

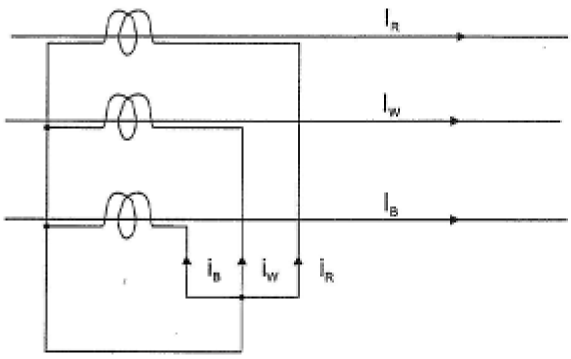
(5) Maximum resistance of secondary winding.

In addition, the error in the turns ratio shall not exceed ± 0.25%

Connection of Current Transformers

Current transformers for protection are normally provided in groups of three, one for each phase.

They are most frequently connected in "star" illustrated as follows:



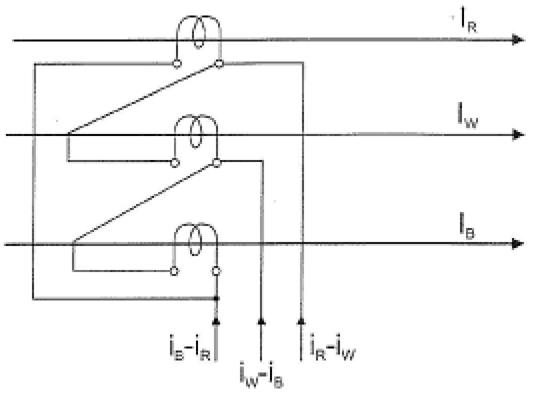
Star Connection of Current Transformers.

The secondary currents obtainable with this connection are the three individual phase currents and also the residual or neutral current.

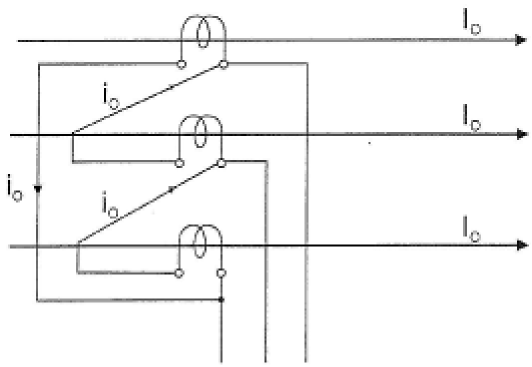
The residual is the vector sum of the three phase currents which under healthy conditions would be zero. Under earth fault conditions, this would be the secondary equivalent of the earth fault current in the primary circuit.

Sometimes, current transformers are connected in" delta". The reasons for adopting this connection are one or more of the following:

- To obtain the currents Ir-Tw, Iw-Ib, Ib-Ir.
- To eliminate the residual current from the relays.
- To introduce a phase-shift of 30º under balanced conditions, between primary and relay currents. -



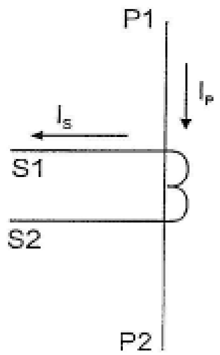
Delta connection of Current Transformers.



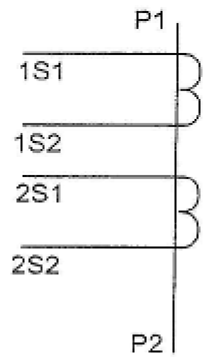
Current distribution under earth fault conditions (I, circulating inside the delta)

Terminal Designations for Current Transformers

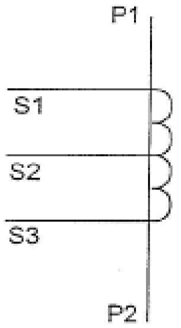
According to IEC Publication 185, the terminals are to be designated as shown in the following diagrams. All terminals that are marked P1, S1 and C1 are to have the same polarity.



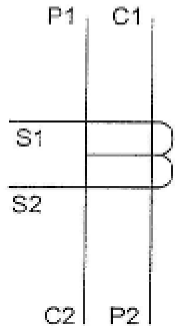
(a) One secondary winding



(b) Two secondary windings



c) One secondary winding which, has an extra tapping



(d) Two primary windings and one secondary winding.

Secondary Earthing of Current Transformers

To prevent the secondary circuits from attaining dangerously high potential to earth, these circuits are to be earthed. Connect either the S1 terminal or the S2 terminal to earth.

NOTE: Transnet substations often provide the metering CT to Eskom. Such metering CTs should not be earthed on the AC Earth Leakage busbar, since Eskom will earth the CTs on their side, thus short circuiting the earth leakage busbar.

For protective relays, earth the terminal that is nearest to the protected objects. For meters and instruments, terminal nearest to the consumer is earthed.

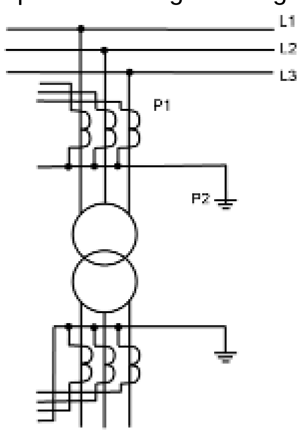
When metering instruments and protective relays are on the same winding, the protective relay determines the point to be earthed.

If there are taps on the secondary winding which are not used, then they must be left open.

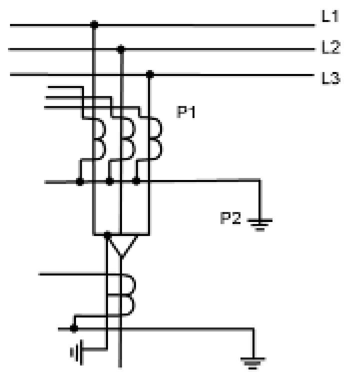
If more than one current transformer are galvanic connected together they shall be earthed at one point only (e.g. differential protection).

If the cores are not used in a current transformer they must be short-circuited between the highest ratio taps and shall be earthed.

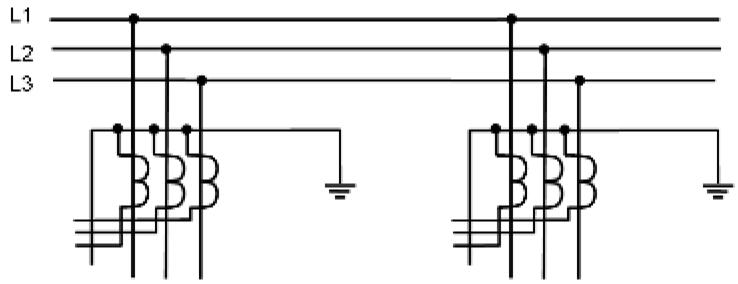
It is dangerous to open the secondary circuit when the CT is in operation. High voltage will be induced.



Connections for Transformer



Connections for cable



Connections for busbars

Test Windings

It is often necessary to carry out on-site testing of current transformers and the associated equipment but it is not always possible to do primary injection because of access of test sets not being large enough to deliver the high value of current required.

Additional test windings can be provided to make such tests easier. These windings are normally rated at 10 Amps and when injected with this value of current produce the same output as the rated primary current passed through the primary winding.

NOTE: When energizing the test winding, the normal primary winding should be open circuited, otherwise the CT will summate the effects of the primary and test currents.

Conversely, in normal operation the test winding should be left open-circuited.

Test windings do, however, occupy an appreciable amount of additional space and therefore increase the cost. Alternatively, for given dimensions they will restrict the size and hence the performance of the main current transformer.

Application of Current Transformers

In order to overcome the limitations as experienced by series trip coils, current transformers are used so that the high primary currents are transformed down to manageable levels that can be handled comfortably by protection equipment

A typical example would be Fused A.C. Trip Coils

These use current transformers which must be employed above certain limits i.e. when current rating and breaking capacity become excessively high. Some basic schemes are:-

Overcurrent

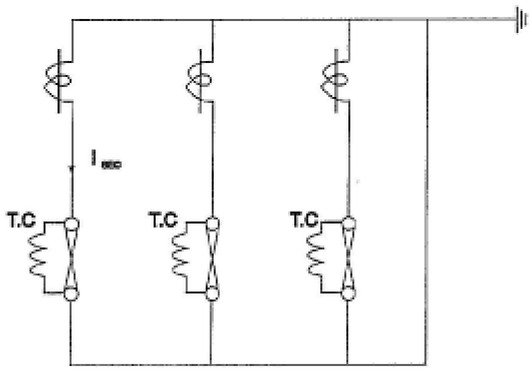
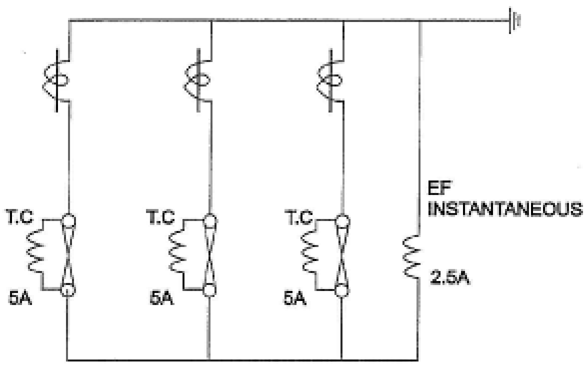


Figure 6.27
Overcurrent Use.

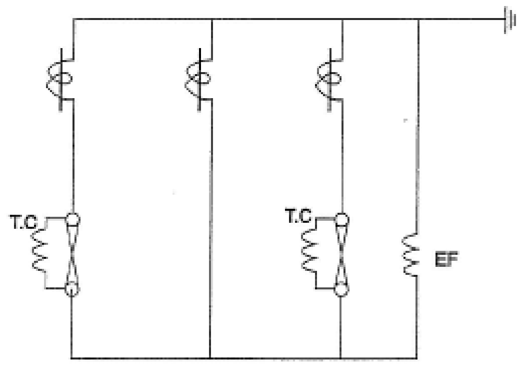
Overcurrent use

Under fault conditions, Isec having reached the value at which the fuse blows, operates trip coil IC to trip the circuit breaker. Characteristic of the fuse is inverse so a limited degree of grading is achieved.

<u>Overcurrent & Earth Fault</u>

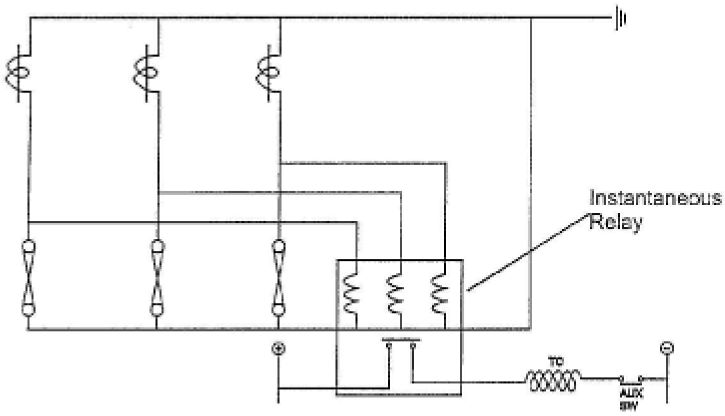


Overcurrent and Earth Fault use.

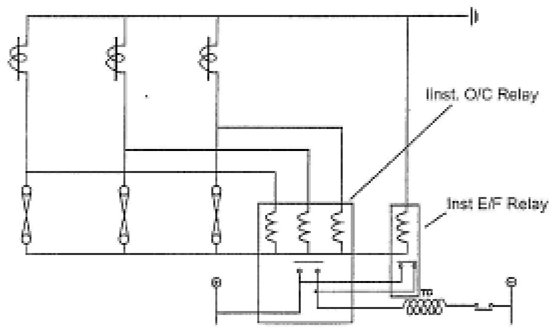


Economical use

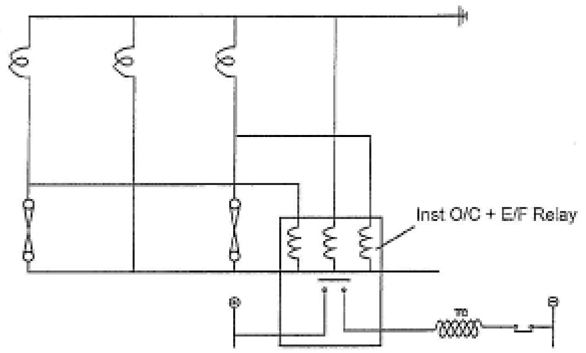
<u>Relays in Conjunction with Fuses</u>



Inverse Overcurrent Tripping Characteristic.

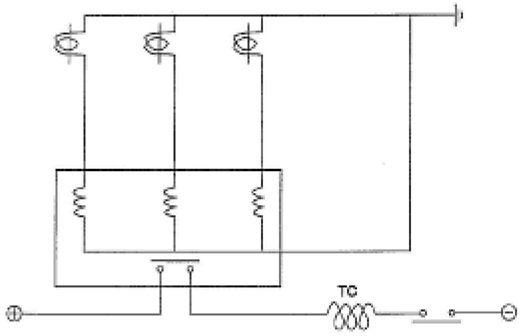


Inverse Over-current ± instantaneous earth fault

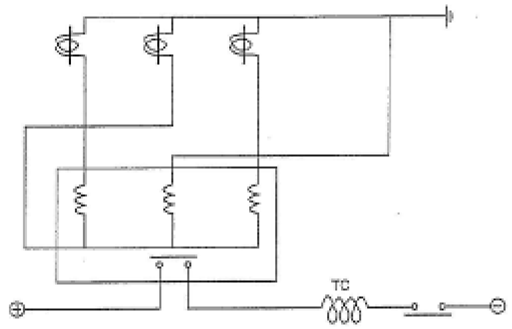


More Economic Method.

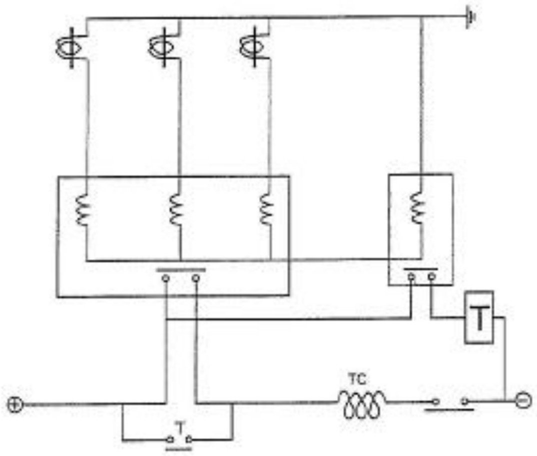
Inverse Definite Minimum Time Lag (IDMTL) Relay



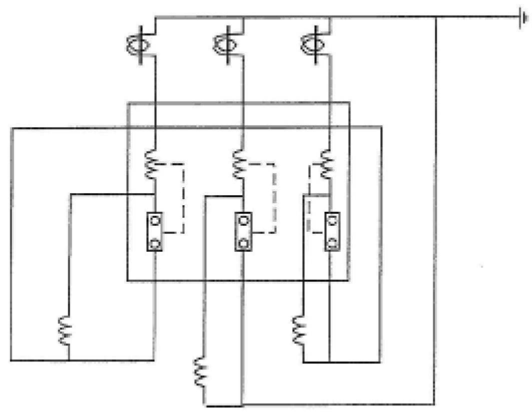
Overcurrent.



Overcurrent + Earth Fault



IDMTL Overcurrent + Time Lag Earth Fault



IDMTL OC+EF Relay with A C Trip Coils.

REFERENCE

Les Hewitson Pr. Eng. PSP Training. “Power Protection course Version 3.01 May 1998, Commonwealth English Edition.

SECTION 5

TRANSFORMERS

5.1 THE FUNCTION OF A TRANSFORMER IN THE ELECTRICAL SYSTEM

1 Transformers are designed to step down the supplier's EHV or HV to the specified system voltage required by the consumer. The design normally facilitates tap changing to adapt secondary voltage to suitable values due to supply voltage fluctuations. Rectifier Transformers are designed with multi secondary windings for smooth rectified outputs from DC traction substations.

2 Transformers use magnetic coupling between primary and secondary windings, in a step-down ratio to provide the desired load voltage in single, three or six phase configurations. Transformers are filled with oil to provide the required insulation as well as a cooling medium The type in use on Transnet are generally of the ONAN (**o**il **n**atural **a**ir **n**atural) cooling type.

5.2 PRINCIPLE OF OPERATION

.1 Transformers use magnetic coupling between primary and secondary windings, which are in a step-down ratio to provide the desired load voltage from that of the Eskom transmission voltage.

2 Transformers are designed to deliver specific secondary voltages on each tap setting. This is indicted on the Transformer Name Plate. The tap changers are connected to incremental windings on the primary side, which is connected on the autotransformer principle.

By reducing the tap setting to below 100% the secondary voltage is increased, and vice versa.

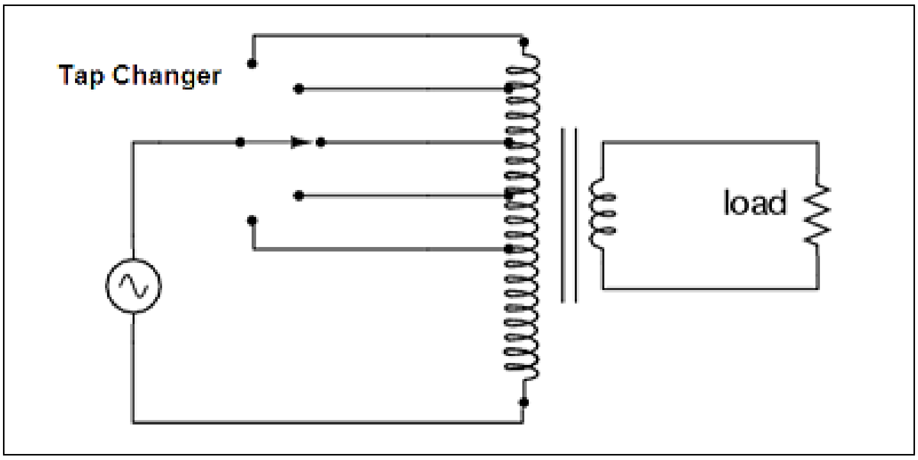


Figure 5.1

5.3 BASIC PRECAUTIONS

1 Main and Auxiliary Transformer must be completely disconnected and isolated from the network before tests can proceed. (primary and secondary connections).

2 The applied voltage ratio test must not be done from the secondary side since a high voltage according to the transformer ratio will be developed on the primary side, which will cause an electric shock hazard and damage to equipment

3 Testing is to be done under cover of a work permit.

5.4 TYPES OF TEST

1 Insulation test

2 Ratio test

3 Insulation oil test

This is done in order to confirm the condition of the transformer after the following events:

- The transformer has been damaged by lightning
- Internal damage such as a short circuit between windings or coil damage..
- The transformer has been transported.
- The transformer has been repaired (i.e. does it have the correct name plate on, and does the ratio correspond to the name plate, are all the tappings connected properly)
- The transformer has been maintained/overhauled, e.g. gaskets replaced, bushings removed, etc)

5.5 TEST EQUIPMENT USED

1 Megger 2.5 to 5 kV

2 Hi Pot set

3 AC generator/ 3 phase supply

4 Multimeter

Note: If with the applied voltage ratio test does not give acceptable results a high tech ratiometer test must be done by a reputable contractor.

5 Sample containers for taking oil samples to do routine or after breakdown gas analysis tests.

5.6.1 THE TEST CIRCUITS

1 Insulation test

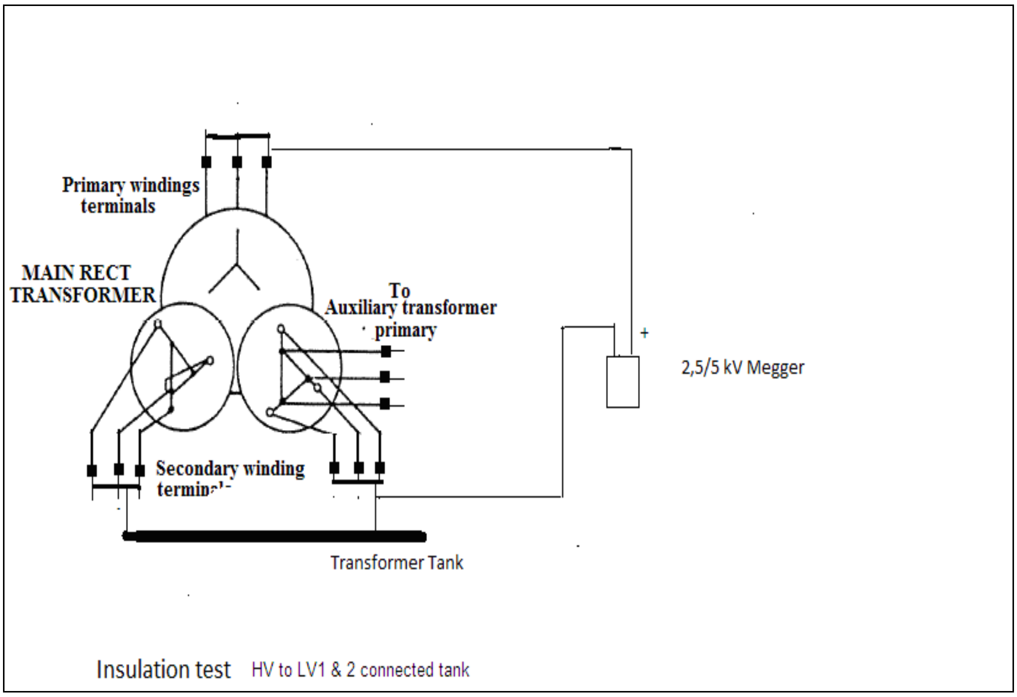


Figure 5.2: Insulation test HV to LV 1 & 2 & Earth

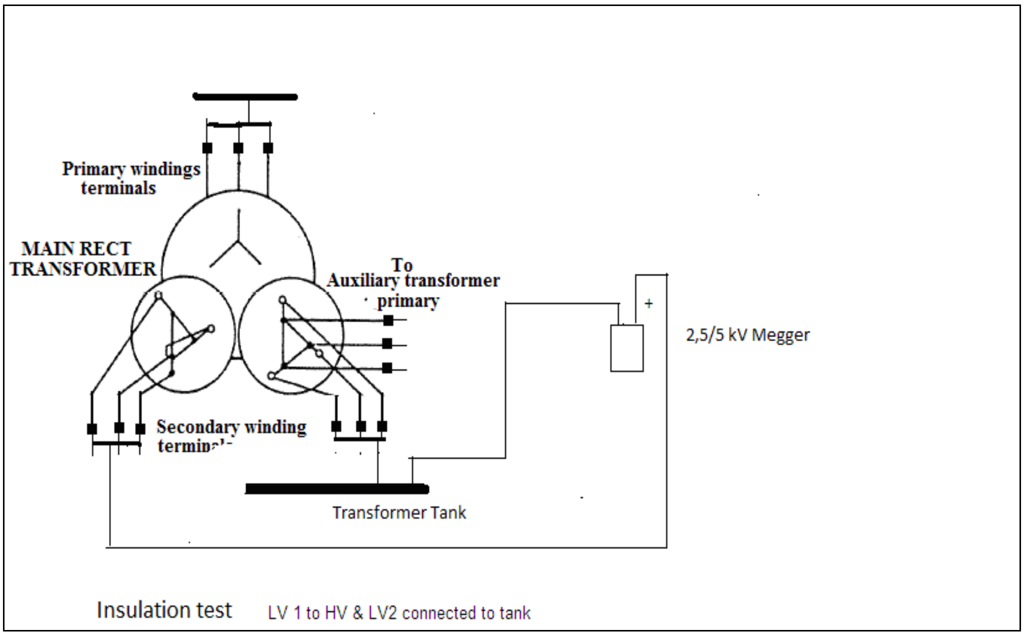


Figure 5.3: Insulation test LV1 to HV & LV 2 & Earth

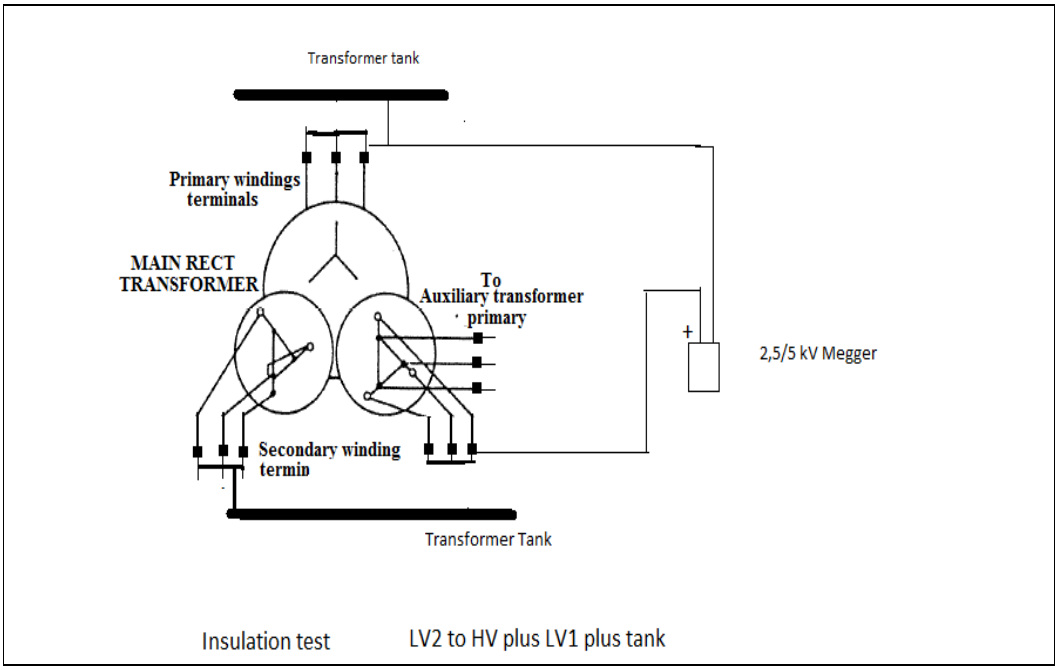


Figure 5.4: Insulation test LV 2 to HV & LV 1 & Earth

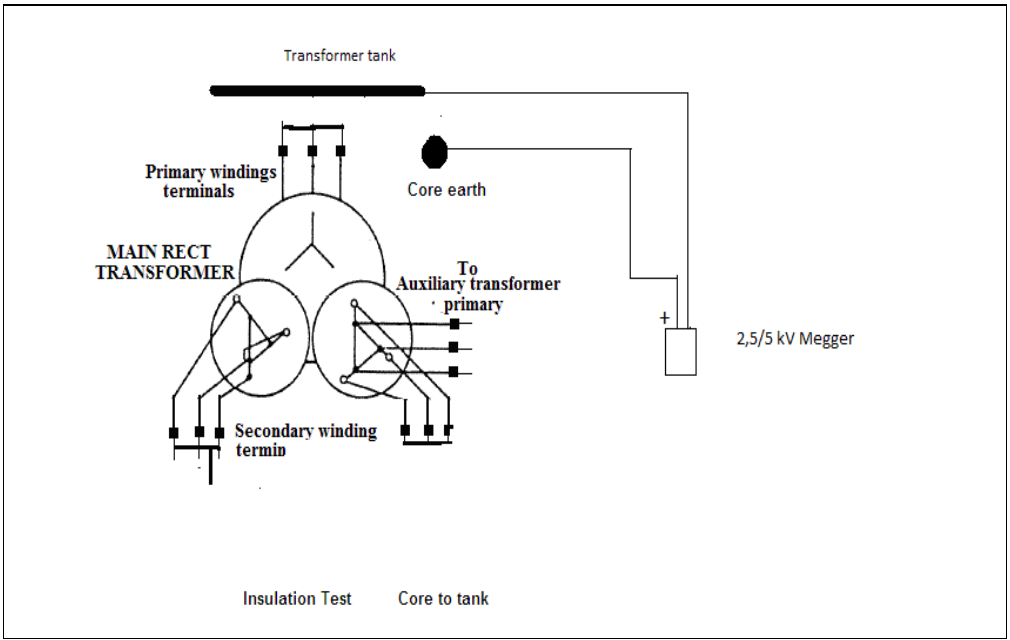


Figure 5.5 Insulation test Core to tank

5.7.1 TEST PROCEDURE

Figures 5.2, 5.3 , 5.4 & 5 shows the connections for testing a typical traction transformer. After confirming secure connections the test voltage is applied by cranking the handle of the analogue megger for at least 30 seconds. The reading will gradually increase to a point where it stabilises and that reading will be recorded. Electronic digital instruments will "charge" up the winding under test in a similar manner. The gradual "charging" rate is due to and depends on the impedance of the winding. The core earth has to be disconnected for the test to ensure that the core to tank insulation is intact.

5.6.2 TEST CIRCUIT

2 Ratio test by applied voltage method

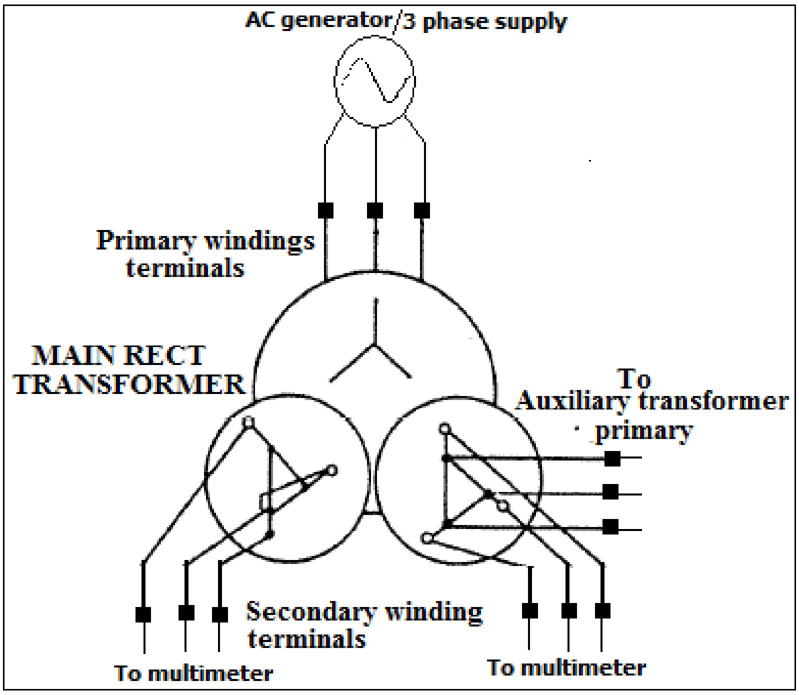


Figure 5.6: Connections for ratio test by applied voltage method

5.7.2 THE TEST PROCEDURE

2 Ratio test by applied voltage method

1 Do the necessary calculations on test sheet to determine the Transformer Ratio as well as the secondary voltage for tap no. 3 by using test sheet formula.

2 Apply three phase supply (380V) to the Primary side of the Transformer. Record all the secondary voltages on the test sheet. All the taps must be tested. i.e. tap 1 to 5, and recorded on the test sheet.

3 Prove that the transformer ratio is correct by comparing the secondary voltage to the calculated voltage on tap no. 3.

4 Record all measurements on the test sheet.

5.7.2 THE TEST PROCEDURE

3 Insulation oil test

1. Oil samples must be taken on a routine bases every two years as well as soon as possible after a breakdown and sent to a contractor for preferably a gas analysis test in which the following levels are determined (acceptable levels shown in brackets):

• moisture content expressed in mg/kg or parts/million	(Refer to Eng Instruction)
• Electric strength in kV	(> 30 kV)
• Acid in mg KOH /kg	(< 0.50 mg KOH/g)
• Hydrogen	(< 150 ppm)
• Oxygen)	(not specified for free)
• Nitrogen)	(breathing Xformers)
• Methane	(< 25 ppm)
• Carbon Monoxide	(< 500 ppm)
• Carbon dioxide	(<10000 ppm)
• Ethylene	(<20 ppm)
• Ethane	(< 10 ppm)
• Acetylene	(< 15 ppm)

5.8 DOCUMENTATION

1 The following documentation must be completed

Insulation and ratio test: **BBB 0348**

Insulating oil test report from contractor.
(Refer to Engineering Instruction GI 012 Issue 2)

5.9 ACCEPTABLE TEST RESULTS

1 Insulation values must be equal or above the level of 2 Megohms per KV. Core to tank reading must be at a minimum of 1 megohm for traction transformers

2 The ratio if measured compared to that calculated from the name place must correspond within 5 %.

3 The secondary voltage readings on every tap position must correlate to the calculated values for all tap positions.

4 Insulating oil test report from contractor.

5.10 SPECIAL PITFALLS.

1 Note that consistent measurements are dependent on a stable supply. If the applied voltage drifts (e.g. erratic generator) the measurements will not be consistent.

2 Ensure proper connections to the phases to prevent loose or weak connections. Jumper lead clamps are usually effective.

3 If the transformer was damaged by lightning, accurate test results is of great importance to take a decision whether the transformer can be repaired on site or has to be transported to a contractor's works at great cost. If required obtain a second opinion from a second reputable contractor.

SECTION 6
TRANSFORMER PROTECTION
OIL AND WINDING TEMPERATURE THERMOMETERRELAYS)

6.1 THE FUNCTION OF THE DEVICE IN THE ELECTRICAL SYSTEM

1 The Oil temperature thermometer monitor the temperature of the insulation oil in Traction and Distribution transformers by sampling the temperature and is set to trip the Primary Circuit Breaker if the preset "oil over temperature is reached. The Winding temperature thermometer monitor the temperature of the transformer windings mainly in Traction transformers by sampling the temperature which is superimposed onto the oil temperature by a heating resistor supplied from a current transformer. The current transformer is situated on the transformer winding connection and monitors the primary or secondary load current and the resultant temperature is set to trip the Primary Circuit Breaker if the preset "winding over temperature" is reached.

6.2 PRINCIPLE OF OPERATION

Refer to annexure 1 for further information.

1 The oil temperature thermometer device is in essence a closed system consisting of the sensing bulb connected by a capillary tube to a set of bellows filled with temperature sensitive fluid. Any temperature change expands or contracts this fluid in the capillary tube system and the movement is amplified by the bellows to result in the rotating movement of the indicator. Two sets of mercury tilt contacts are mounted on the dial mechanism to provide alarm and trip pulses at the predetermined settings. These contacts are normally wired in parallel to give alarm and trip pulses simultaneously to trip the Primary Circuit Breakers or Unit Breakers as applicable.

2 The winding temperature thermometer operates on the same principle but the indication is superimposed on the oil temperature by the heating resistor, being built in the bellows, as mentioned above. The indicated temperature is proportional to the square of voltage across the resistor which allows the resultant indication to be an accurate reflection of the winding temperature as "imaged" by the secondary current in the circuit induced by the primary load current in the main winding of the traction transformer. The time constant of the indicator at a sudden change of current is about 9 minutes, which is of the same magnitude as the time constant of the winding itself.

6.3 BASIC PRECAUTIONS

1 Work permit from AC Disconnects to the Positive Isolator which must be open and locked out.

2 The thermometer bulb must be withdrawn without having to drain the oil from the conservator.

6.4 TYPES OF THE TEST

1. Calibration and functional test by simulation of temperature increases.

6.5 TEST EQUIPMENT REQUIRED

1. Oil bath of approx. 1 to 2 litre capacity.
2. Heating apparatus (Electrical or gas flame)
3. Standard thermometers.
4. Rags and cleaning material.

6.6 THE TEST CIRCUIT

N/a

6.7 THE TEST PROCEDURE

1. The thermometer bulb is placed in an oil bath together with a control thermometer and container heated slowly by the electric element or gas flame. The bulbs of both thermometers should be placed close together and the oil is continually stirred to ensure proper heat distribution.
2. Compare the thermometer readings at 10 degree intervals up to approx 120 degrees, noting the operation of the operating temperatures of 90º C for the Oil Thermometer and 115º C for the Winding Thermometer as prescribed in the Engineering Instruction.

6.8 DOCUMENTATION

1 Complete the relevant test sheets BBB0342 for DC and ???0000 for AC substations

6.9 THE RANGE OF ACCEPTABLE TEST RESULTS

1 A tolerance of plus or minus 5 º C is allowed. Within this tolerance the pointer must be mechanically adjusted at the pivoting centre of the pointer with a screwdriver. If the error is greater than this, this may indicate leakage in the measuring system, in which case the instrument should be returned for repair or replacement.

For setting the winding temperature instrument, an adjustable shunt-resistor is provided, which can be adjusted to give a voltage across the heating resistor corresponding to the temperature rise of the winding hot spot above the top oil temperature. For further information, adjustments and calibration refer to the manufacturers' handbook.

2 When replacing the thermometer bulb in the pocket, check that the pocket is filled with oil to ensure good heat transfer from pocket to thermometer bulb to ensure indication of the correct temperature.

6.10 SPECIAL PITFALLS.

1 Check that the gasket between the cover and the housing of the relay is continuous and in good condition. Continual ingress of moisture causes the mechanical movement of the dial to rust and become faulty.

6.11 REFERENCES

1. Manufacturers manuals
2. Engineering Instructions.

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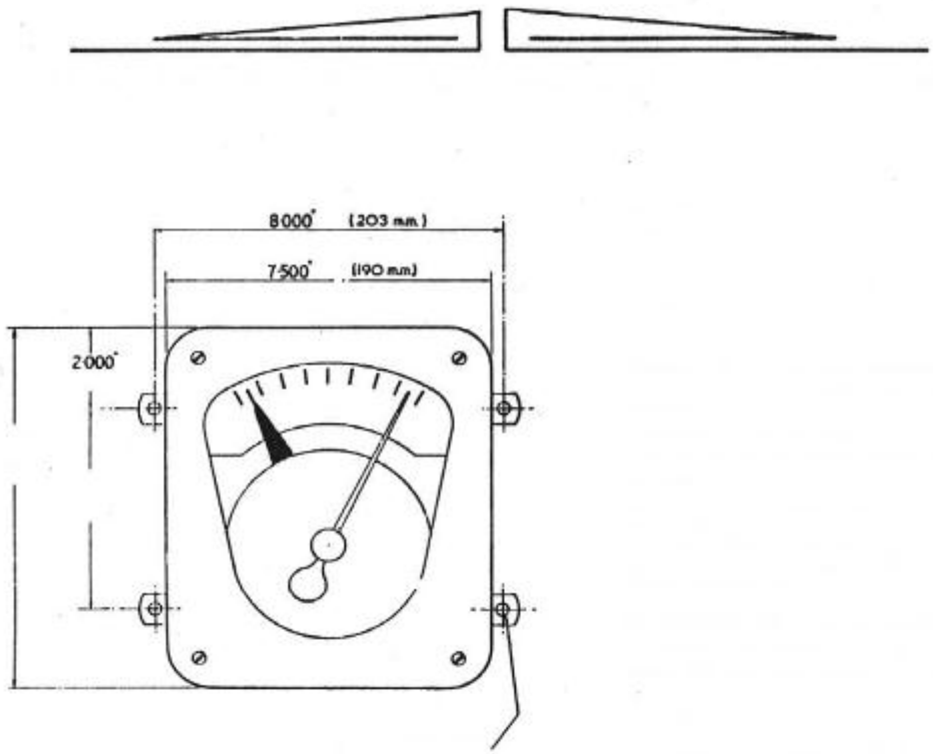
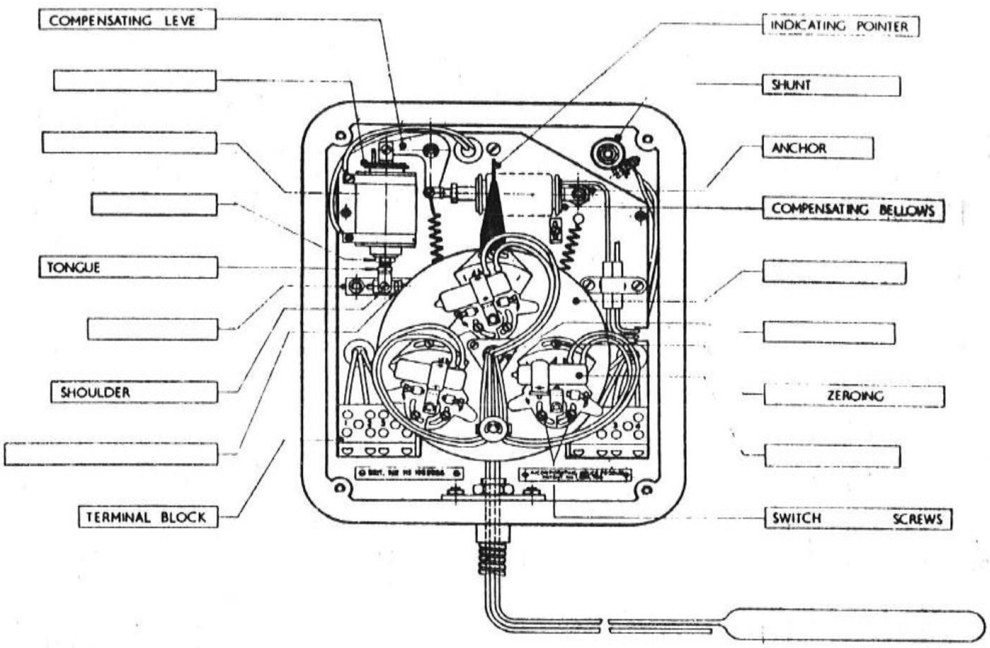


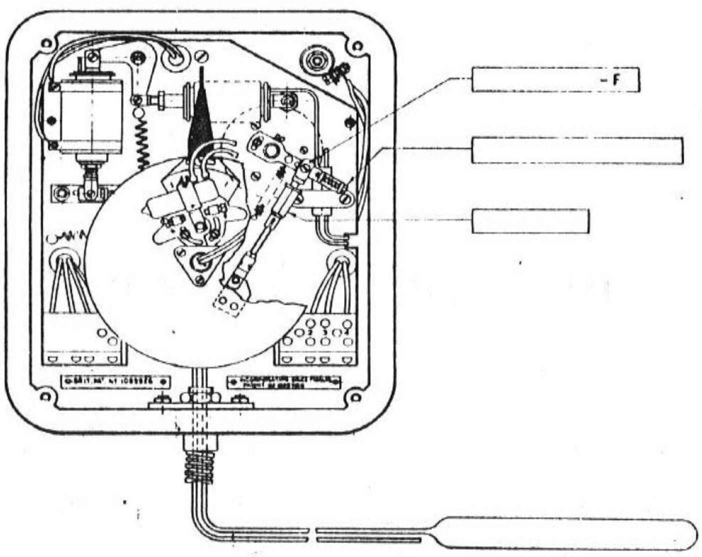
ler Model A131 which is being manufactured by Accurate Controls Ltd., Heath Works, Fordbridge Road, Sunbury-on-Thames, is designed for the protection of power transformers. The instrument is fully compensated for ambient temperature changes on capillary lines and case and operates in the following

bulb is similar to that of an ordinary distance reading thermometer and is connected to the head in the usual way by a capillary tube. A second capillary tube running parallel and close to the first is, however, provided; the two tubes being of the same bore and length. Neglecting the bulb, the twin systems are, therefore, alike and each contains the same

are, however, linked together via sating lever in such a manner volume changes are cancelled ou way affects the indication.

to the combined circular switch platform and indicating pointer. When the bulb is subjected to a rise in temperature, the bulb fluid capacity increases and this increase is transmitted to the operating bellows via the capillary tube. The operating bellows now moves downwards, since it is prevented from moving upwards by the compensating lever, the compensating bellows and the anchor





height between bulb and the head.
The fluid in system is practically compressible a the bellows will expa with a linear m n for a linear change

temperature. The power available from this type of system is more than adequate to operate up to four mercury switches of the dry electrode type to the C.E.G.B. specification, or three switches and a potentiometer without any visible detent. Diagram Fig. 2 shows a cutaway view through the circular switch platform to reveal the precision

The Temperature Indicator requires no maintenance but adjustment or replacement of switches and resetting of maximum pointer may become necessary.

MOUNTING

Care must be taken to ensure that the instrument is mounted in a vertical position as errors, particularly in the horizontal plane will upset the zero of the mercury switch setting scales. The use of a spirit level, placed on top of the instrument case, will ensure correct operation.

Ordinary care is needed when running the capillary, and sharp bends should be avoided, particularly where it joins the instrument and the bulb. The capillary should be supported by suitable clips at intervals of 12 to 18 inches and a suitable length left so that the bulb may be freely installed or removed. The capillary line is fully compensated, so that normal variations in

The method of adjusting the from the diagram Fig. 1. The justable over the range of the scales and all switches are differential to the same scale.

Each switch is set by slackening the each arm and moving the left hand the required operating temperature nd pointer to the reset temperature a

obtained by closing the right hand pointer to the left hand pointer. A built-in stop automatically sets the minimum differential. When slackening or tightening the locking screws, steady the switch platform with the other hand to prevent undue strain on the mechanism. Care must also be taken that the dressing of the switch flexible leads are not disturbed. To obtain an accurate check on these settings the indicating pointer can be operated with the finger in a clock-wise direction to check the switch settings against the indicator dial. To obtain an accurate check on these settings the pointer must be moved slowly and steadily and must not be allowed to spring back quickly.

The mercury switches are conservatively rated and robust, but should one be damaged in any way, it may be unclipped from the switch carriage and the leads removed with a hot soldering iron. After resoldering the leads to a new switch and fitting back into the switch carriage, it may be necessary to re-balance the switch. Check that at the instant when the mercury flows to or away from the electrodes the switch topples in its carriage between the stop pins. If the switch does not topple correctly it can be adjusted by sliding it a small amount in the appropriate direction in the plastic

been balanced correctly the switch setting scale. ckening the screw at the o the required position.

No adjustments should normal temperature controller but if does not agree within ± 2% of reading on a certified N.P.L. stirred temperature bath, it may

se the instrument before checking th should be stirred ... the pointer

bath temperature within ± 2% it must be reset. Fit a 2.B.A. spanner on the hexagon tongue adjuster 'C' and slacken locknut 'D'. Turn 'C' to the left a small amount to move the pointer up scale and vice versa. The lock-nut 'D' should then be re-tightened. Now place the instrument bulb in the hot bath for 5 minutes and the pointer should indicate this new temperature. If the instrument indicates less than the correct temperature at the high end of the range, the pointer sweep is too short and may be increased by the range adjustment.

To lengthen the pointer sweep, slacken shoulder screw 'A', turn the hexagon range adjuster screw 'B' one half turn anti-clockwise and re-tighten shoulder screw 'A'. To shorten the pointer sweep, reverse the procedure. In either case the adjustment should be made carefully and by small increments, the shoulder screw being slackened half a turn or so but not removed. Repeat the tests in the cold and hot baths until the instrument reads within ± 2% of the dial range at both ends of the scale.

A bellows heater coil is shown in Fig. 1. The bellows type of heater coil was designed by Bruce Peebles Ltd. and is covered by their Patent No. 1025785. Connections are made to the terminal block within the instrument case. The heater current with this type of unit is small. To cover normal manufacturing tolerances some means of gradient adjustment must be available. In the case of the "ACCURATE" instrument an adjustable shunt resistance mounted inside the instrument case and shown in Fig. 1 can be supplied. Coils are wound to suit customers' requirements and the adjustable shunt resistance can be factory pre-set to give the required temperature gradient for a specified current.

the other lead. To increase the temperature gradient, reverse the procedure. The position of the centre band may be altered by slackening the small screw in the retaining clip and moving the band a small amount in the appropriate direction. The small screw must then be re-tightened. Replace the shunt, dial and instrument lid before checking the gradient setting. Place the instrument bulb in a well stirred, constant temperature bath, preferably at the mid-scale temperature of the instrument. After five minutes when the instrument has

Where transformer vibrat position it is essential vibration mountings are for projection mounted tested at frequencies and power transformers.

present at the mountin suitably selected ant These can be supplie ments and have bee udes applicable to larg

The instrument is case, aluminium al blue/grey outside included in the ca

SECTION 7

TRANSFORMER PROTECTION

GAS OPERATED (BUCHOLTZ) RELAY

7.1 THE FUNCTION OF THE DEVICE IN THE ELECTRICAL SYSTEM

1. The Buchholz relay is situated in the pipeline between the conservator tank and the main transformer tank.

2. The main functional parts of this relay consist of a housing, float, 2 mercury switches and a flap attached to one of the mercury switches.

3. In the latest types of relay installed, a permanent magnet and a dry reed switch replace the 2 mercury switches, which in conjunction with the two floats operate the respective reed switch contacts.

7.2 PRINCIPLE OF OPERATION

1 The presence of gas realised from an insulation breakdown between windings, or other electrical arcing in transformer is detected by the Bucholtz relay. Voltage free contact are made, which must trip and lock out the primary circuit breaker.

2 For a full description of Bucholtz operation and maintenance refer to the Publication EP001.

7.3 BASIC PRECAUTIONS

1 Substation condition prior to test: Work permit between AC Disconnects and Track Switches.

7.4 TYPES OF THE TEST

1 The Bucholtz relay is test operated by pumping air (simulating gas pressure) onto the relay chamber via the petcock fitted on the transformer in such a position that the testing can be done at ground level.

7.5 TEST EQUIPMENT USED

1 Buchholtz air injection pump or Compressed air device.

7.6 THE TEST CIRCUIT

1 Not applicable

7.7 THE TEST PROCEDURE

1 Connect a Bucholtz pump or Compressed air device to the petcock provided for testing the relay. Pump air into the relay chamber. The air pressure will force air into the Bucholz relay chamber and causes the 2 switches (alarm and trip) to operate and trip and lockout the Primary Circuit Breaker, giving fault indication.

2 Check that the indication on the control panel in the substation is detected and that the lockout circuit is energised.

3 Release the air through the gas release valve, allowing the chamber to refill with oil. Reset the lockout relay and all indication flags.

7.8 DOCUMENTATION.

1 Complete the BBB0342 by recording the volume of air in cc’s indicated on the sight glass of the relay during the test procedure.

7.9 THE RANGE OF ACCEPTABLE TEST RESULTS

1 The volume of air required to complete the test procedure will vary according to the size of the device (pipe diameter). Normally the float switches are set to half of the sight glass to achieve the required result i.e. approx. 250-300 cc for traction transformers and 150-200 cc for distribution units.

7.10 SPECIAL PITFALLS.

1 At times if a transformer has not tested at regular intervals, the float does not "fall" with the dropping of the oil level during the air injection process and then has to be tapped "free" by the tapping lightly on the body of the housing with a light hammer. If this action does not give results with two or three attempts the relay will have to be repaired or replaced.

2 If the control cables have been disconnected for any reason, malfunction can occur if wiring was not replaced correctly.

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SECTION 8

MAIN TRANSFORMER OVERLOAD AND FAULT PROTECTION

8.1 THE FUNCTION OF THE DEVICE IN THE ELECTRICAL SYSTEM.

1 The Main transformer is protected against overload and fault currents by Instantaneous and Thermal Overload Relays with Oil, Winding, Buchholtz, and Pressure Relief Device protection as discussed in other sections of the Handbook.

At A.C. traction substations Restricted Earth Fault and Biased Differential protection is installed as well.

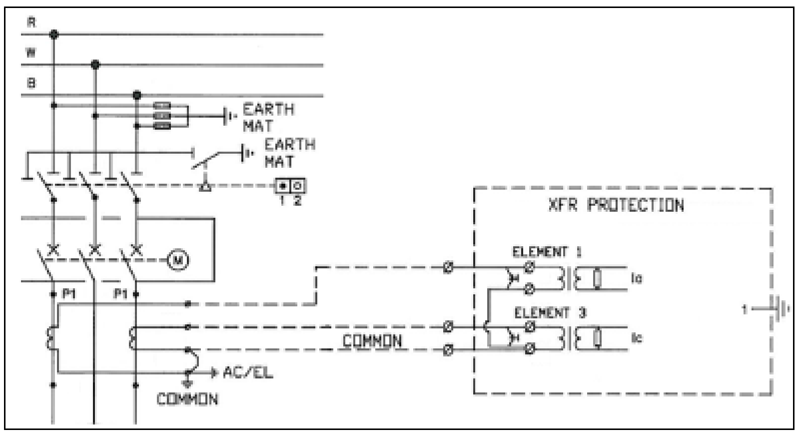

Figure 14.1 DC substation General Arrangement for Main Transformer Thermal and Instantaneous overload protection.

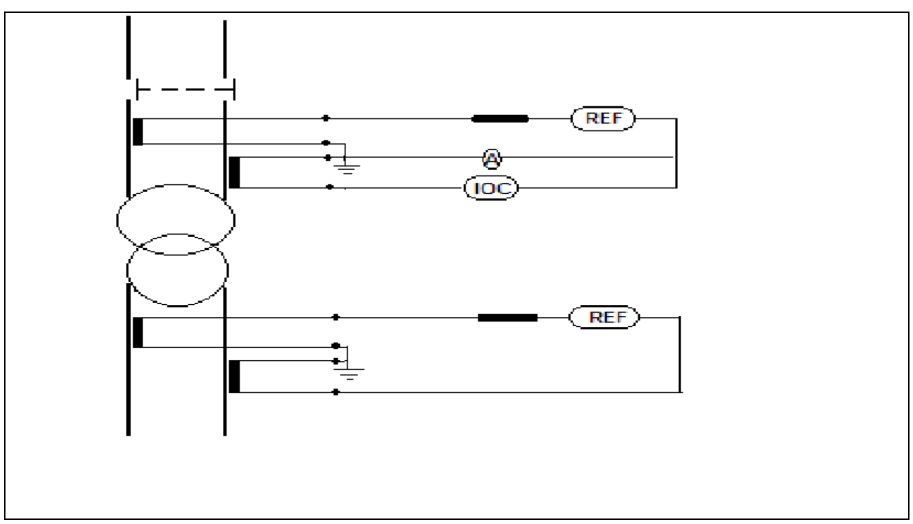

Figure 14.2: AC Substation General Arrangement for Main Transformer Restricted Earth Fault protection.

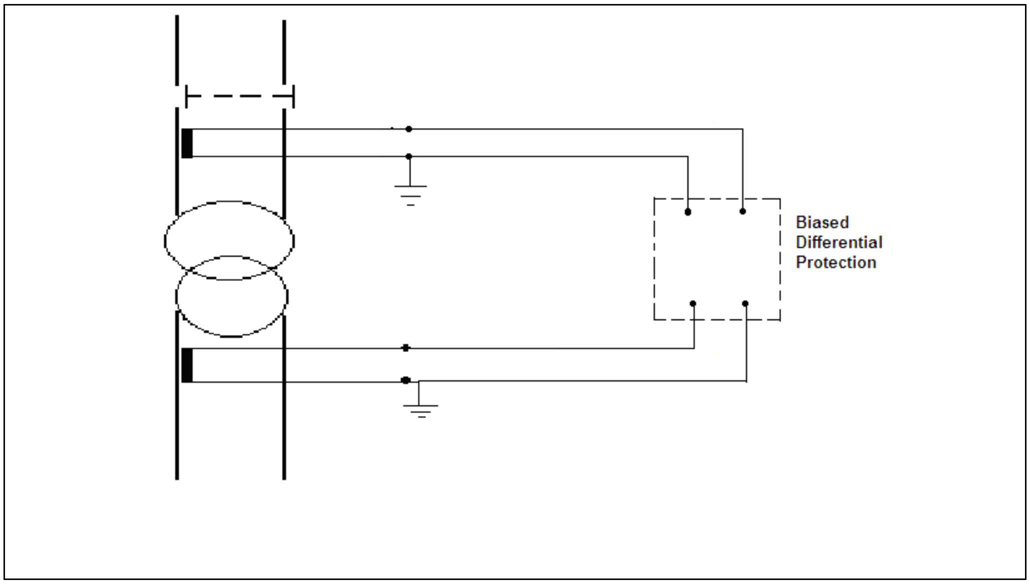

Figure 14.3: AC Substation General Arrangement for Main Transformer Biased Differential protection

8.2 PRINCIPLES OF OPERATION.

1 Loose standing or bushing current transformers is applied to drive the protection relays. A proportional component of the load or fault current passes through the sensing part of the relay. If the preset values are exceeded the trip contact is closed by the operational part to send a trip pulse to the primary circuit breaker.

For current operations, Instantaneous and Thermal elements are connected in series in electromechanical relays and in modern electronic type relays different elements are programmed to distinguish between fault and load currents.

For timing operations, magnetic disc and thermal bimetallic principles are used in electro mechanical types with timing elements in electronic relays. .

2 Restricted Earth Fault protection operates on a balanced current principle where the current flowing into the transformer winding is compared with the current flowing out of the winding. The two currents from the CT secondary windings are so connected that summary of the resultant current amount to zero. If a leakage through failure of insulation occurs the two currents will be different thus current will flow through the relay. A setting of 10% is normally applicable to both Primary and Secondary windings to allow for magnetization and inrush currents.

3 Biased Differential Protection operates on a similar balanced current principle where the current flowing into the transformer primary winding is compared with the current flowing out of the secondary winding. A setting of 20% is normally applicable to allow for magnetization and inrush currents.

8.3 BASIC PRECAUTIONS

1 All testing must be done under cover of a work permit.

2 Never disconnect any relay or current transformer under load.

8.4 TYPES OF TESTS

1. Magnetization curves and ratio tests (where possible) on Current Transformers.

2. Polarity tests must be done in both AC & DC substations on current transformers when control cables were disconnected or replacements of bushings were done.

3. Primary, secondary or test winding injection to test and set overload protection relays at predetermined typical values as below.

   Instantaneous overload relays in AC & DC traction substations are generally tested at 4 and 6 times full load to trip the PCB within 50 milliseconds. Other settings can be applicable depending on the type of substation.

   Thermal overload relays in AC and DC traction substations are generally tested at 2 and 3 times full load to trip the PCB within 30 minutes and 2-3 minutes respectively.

4. Restricted Earth Fault relays are tested by applying either a gradually increasing AC voltage (between 40-80 volts) across or current (typical 0.1 amps for a 1 amp secondary) through the relay to preset values tripping the PCB.

5. Biased Differential Protection relays are tested by applying a gradually increasing AC current through one of the relays (primary and secondary) at one time to preset values (typical 0.2 amp for a 1 amp secondary) tripping the PCB

8.5 TEST EQUIPMENT USED

1. Variable voltage injection test set.

2. Variable current injection test set with timing facility.

3. Voltmeter 0-300 v AC

4. Ammeters with Lab. current transformers.

5. Set of test leads.

8.6 THE TEST CIRCUIT

1. **Mag curves and Ratio of Current transformers**. Refer to Section 4 of the Manual

8.6 THE TEST CIRCUIT (cntd)

2 Instantaneous and thermal overload relay.

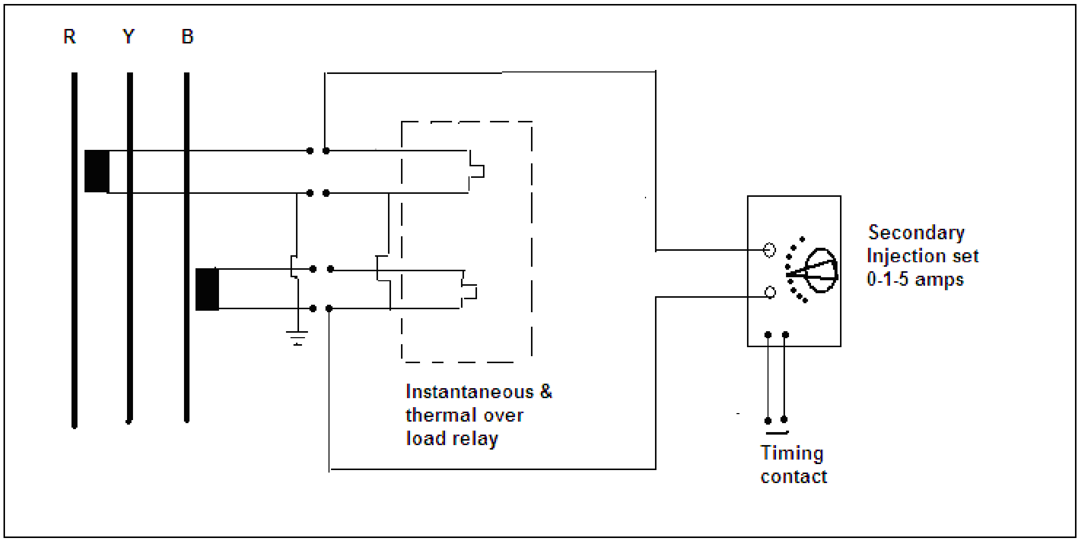

Figure 8.2: Connections for secondary injection test

Figure 8.2 shows the connections for secondary injection to test the relay connected to the red phase as well as a timing contact that can be connected to either a contact on the relay or across the poles of the relevant primary circuit breaker. For testing procedures the links must opened or wires disconnected on the relevant terminals as determined from the applicable circuit diagram.

3 Restricted Earth Fault relay

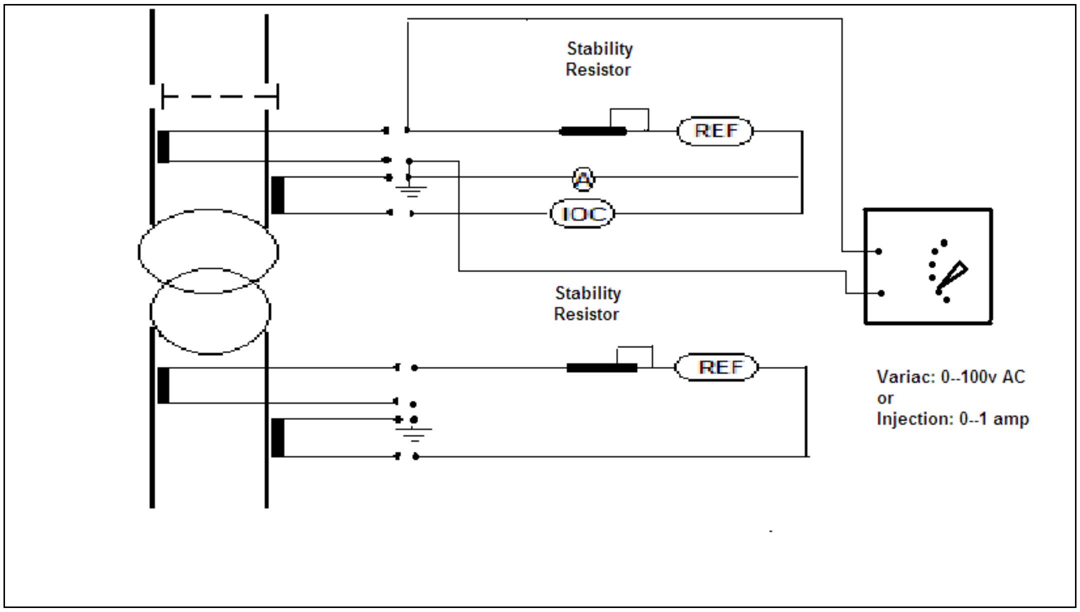

Figure 14.3: Connections for secondary injection

Figure 14.3 shows the connections for secondary injection to test the relay connected to the red phase as well as a timing contact that can be connected to either a contact on the relay or across the poles of the relevant primary circuit breaker The test must be repeated on the secondary side of the transformer to confirm operation from both sides.

8.6 THE TEST CIRCUIT (cntd)

4. Biased differential fault relay

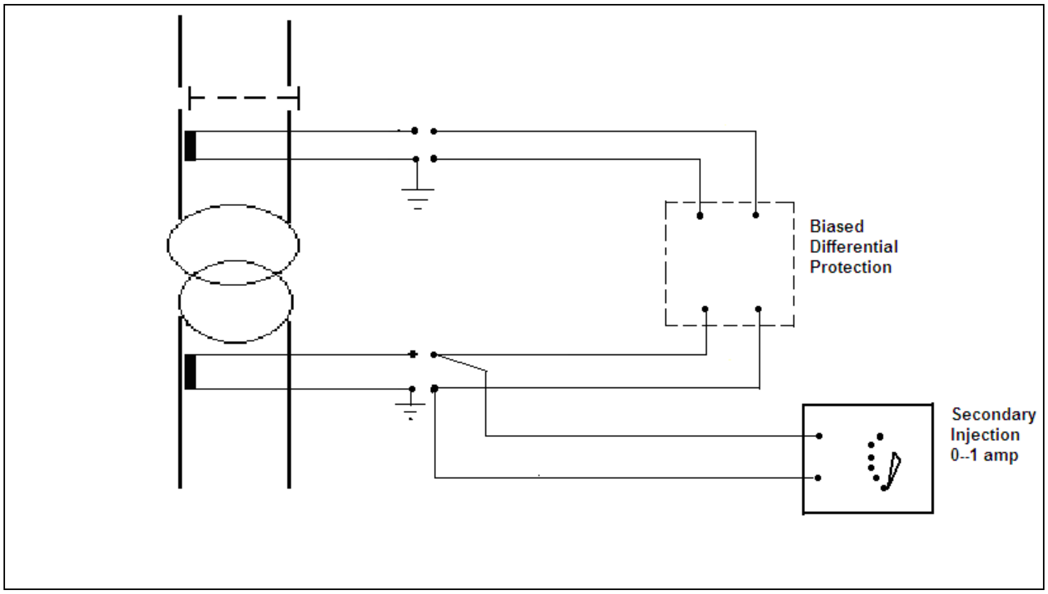

Figure 14.4: ***Connections for secondary injection***

Figure 14.2 shows the connections for secondary injection to test the biased differential protection relay connected to the secondary of the transformer. The test must be repeated on the primary side of the transformer to confirm operation from both sides.

8.7 THE TEST PROCEDURE

1 Determine the required settings for the instantaneous and thermal overload relays according to the type of relay and the rated full load current.

Refer to the substation manuals for information on relays in use.

The following annexures can be referred to for information electronic type relays

Annexure 1: FP 04 Strike Technologies

Annexure 2: Argus 7SR1102-1 Siemens

2 For first time settings e.g. after replacements or refurbishment set the different elements for instantaneous, thermal overloads with the relative Time Minimum Settings (T.M.S.).

3 Inject the required current for the different multiples of secondary current recording the respective times on the relevant test sheet.

4 Confirm the indications and tripping of the primary circuit breaker.

8.8 DOCUMENTATION.

1 Complete the relevant test sheet for the particular substation.

8.9 THE RANGE OF ACCEPTABLE TEST RESULTS

1 Tripping values of current and resultant times should fall within 5 % of the specified
. values for the particular relay allowing for differences in equipment and instruments used.

8.10 SPECIAL PITFALLS.

.

1 Care must be taken when setting up the required injecting current at multiples higher than 3 times full load current that the relay is not subjected to these higher currents for more than 5 seconds at any time as the relay is not rated to carry high currents for more than a few seconds.

2 Always confirm the injecting current reading the on Lab. instruments to be correct before applying it to the relay under test.

SECTION 09

AUXILIARY TRANSFORMER PROTECTION

9.1 THE FUNCTION OF THE DEVICE IN THE ELECTRICAL SYSTEM.

1 The Auxiliary transformer is used to supply a stepped down voltage to the auxiliary equipment in traction substations. In DC substations tertiary connections are tapped from one of the secondary windings and supplied to a three phase step down transformer at ratings of 50 to 150 KVA

In AC substations a single phase transformer at ratings of 16 to 50 KVA is employed.

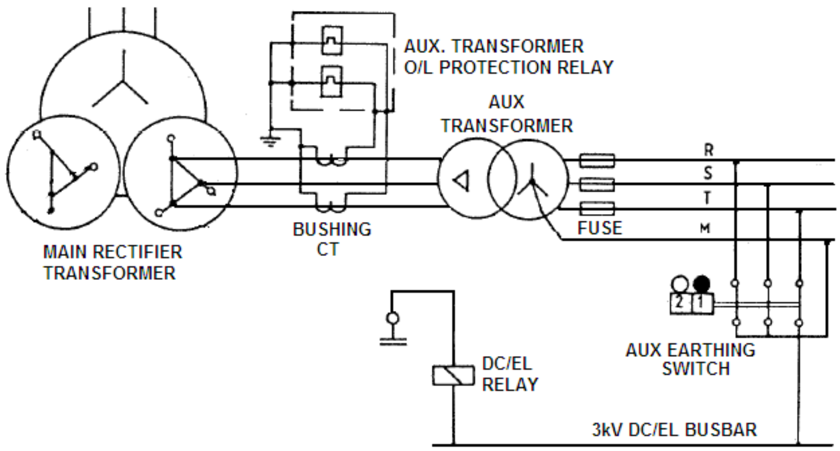

Figure 9.1: Typical connection for Auxiliary Transformer as arranged in Traction substations.

2 The Auxiliary transformer in traction substations is protected against overload and fault currents by Instantaneous and Thermal Overload Relays with Buchholtz relay protection as discussed in other sections of the Handbook.

9.2 PRINCIPLE OF OPERATION.

1 Bushing current transformers is applied to drive the protection relays. A proportional component of the load or fault current passes through the sensing part of the relay. If the preset values are exceeded the trip contact is closed by the operational part to send a trip pulse to the primary circuit breaker.

For current operations, Instantaneous and Thermal elements are connected in series in electromechanical relays and in modern electronic type relays different elements are programmed to distinguish between fault and load currents.

For timing operations, magnetic disc or thermal bimetallic principles are used in electro mechanical types with timing elements in electronic relays. .

9.3 BASIC PRECAUTIONS

1 All testing must be done under cover of a work permit.

2 Never disconnect any relay or current transformer under load.

9.4 TYPES OF THE TEST

1 Magnetization curves and ratio tests (where possible) on Current Transformers.

2 Primary, secondary or test winding injection to test and set overload protection relays.

Instantaneous overload relays in DC substations are generally tested at 4 and 6 times full load to trip the PCB within 500 and 300 milliseconds respectively. Other settings can be applicable depending on the type of substation.

Thermal overload relays in DC substations are generally tested at 3 times full load to trip the PCB and 2-3 minutes.

9.5 TEST EQUIPMENT USED

1 Variable voltage injection test set.

2 Variable current injection test set with timing facility.

3 Voltmeter 0-300 v AC

4 Ammeters with Lab. current transformers.

5 Set of test leads.

9.6 THE TEST CIRCUIT

1 Mag curves and Ratio of Current transformer. Refer to Section 4 of the Manual

2 Instantaneous and thermal overload relay.

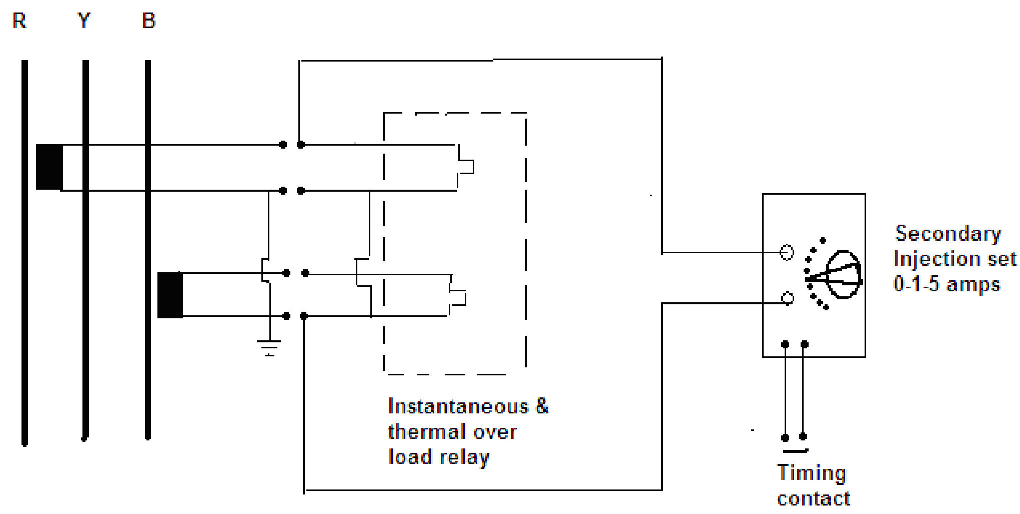

Figure 14.2

3 Figure 14.2 shows the connections for secondary injection to test the relay connected to the red phase as well as a timing contact that can be connected to either a contact on the relay or across the poles of the relevant primary circuit breaker. For testing procedures the links must opened or wires disconnected on the relevant terminals as determined from the applicable circuit diagram.

9.7 THE TEST PROCEDURE

1 Determine the required settings for the instantaneous and thermal overload relays according to the type of relay and the rated full load current.

2 For first time settings e.g. after replacements or refurbishment set the different elements for instantaneous, thermal overloads with the relative Time Minimum Setting (T.M.S.).

The following annexures can be referred to for information electronic type relays

Annexure 1: FP 04 Strike Technologies

Annexure 2: Argus 7SR1102-1 Siemens

3 Inject the required current for the different multiples of secondary current recording the respective times on the relevant test sheet.

4 Confirm the indications and tripping of the primary circuit breaker.

9.8 DOCUMENTATION.

1 Complete the relevant test sheet for the particular substation.

9.9 THE RANGE OF ACCEPTABLE TEST RESULTS

1 Tripping values of current and resultant times should fall within 10 % of the specified values for the particular relay allowing for differences in equipment and instruments used.

9.10 SPECIAL PITFALLS.

1 Care must be taken when setting up the required injecting current at multiples higher than 3 times full load current that the relay is not subjected to these higher currents for more than 5 seconds at any time as the relay is not rated to carry high currents for more than a few seconds.

2 Always confirm the injecting current reading the on Lab. instruments to be correct before applying it to the relay under test.

SECTION 10

AC EARTH LEAKAGE SYSTEM

10.1 THE FUNCTION OF THE DEVICE IN THE ELECTRICAL SYSTEM;

1 An AC earth leakage (E/L) system is provided to protect against flashovers on the HV outdoor yard equipment. Outdoor steelwork of equipment which support the Eskom supply voltage is insulated from the earth mat and connected in parallel through a current transformer to the earth mat. The CT is connected to an AC Earth Leakage relay.

2 Operation of the relay trips and locks out the primary circuit breaker.

3 Note that this arrangement can only isolate a fault occurring on the load side of the PCB. A fault on the supply side will still trip the PCB, but the fault must be interrupted by Eskom. If Eskom does not trip the current can cause serious damage at the substation. The same can happen if a fault on the Eskom transmission line earth, which is connected to the substation earth, is not cleared quickly.

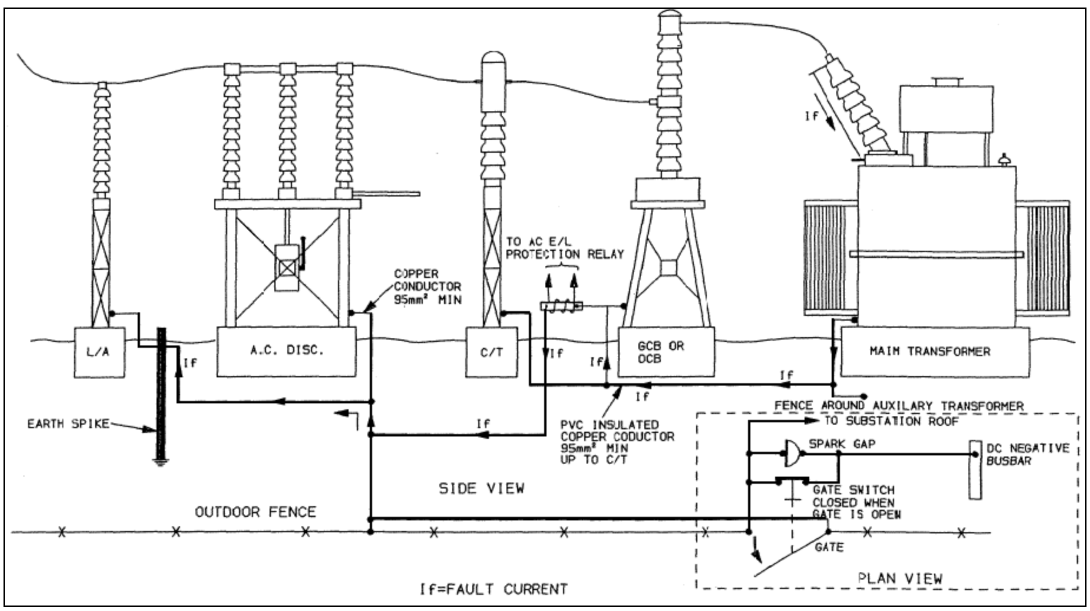

Figure 6.1: Typical layout of the earthing of the equipment in the outdoor yard

The equipment in the outdoor yard is insulated from substation earth mat and is connected in parallel through a 250-50:5 current transformers to earth mat. The minimum resistance between the parallel connected equipment and earth mat is 10 Ohm.

The output of the CT (which is mounted on the primary circuit breaker support frame) is fed into an earth leakage relay which is normally set to operate between 50A and 100A of primary current.

10.2 PRINCIPLE OF OPERATION;

1 The Current Transformer output (250-50:5) is fed to an AC Earth Leakage Relay which is normally set in the range of 50 to 100A of the primary current.

2 Figure 4.1 shows a typical layout of the earthing of the equipment in the outdoor yard, including the position of the AC earth Leakage Relay on the primary circuit breaker support frame. The current path of a fault on the main transformer is indicated by means of arrows.

3 An AC Earth Leakage operation must trip and lockout the Primary Circuit Breaker.

10.3 BASIC PRECAUTIONS

1 The CT may under no circumstances be open circuited when the substation is on load.

10.4 TYPES OF THE TEST

1 Injection test

2 Trip test to verify the functional operation of the substation.

10.5 TEST EQUIPMENT USED

1 Injection set,

Lab CT at 100/200 amps Lab ammeters to 5 amp scale or clamp on Ammeter

Set of Heavy duty leads

10.6 THE TEST CIRCUIT

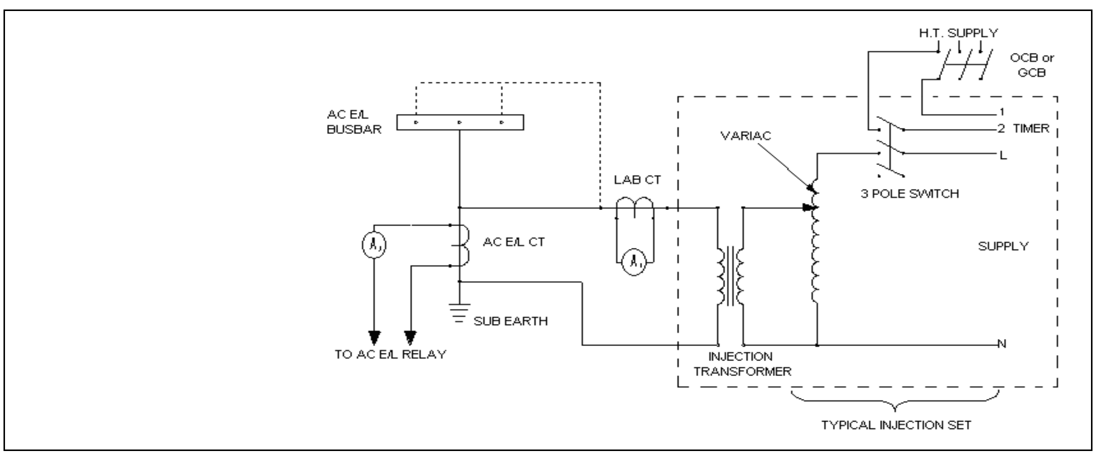

Figure 6.2: Circuit Diagram for Testing AC E/L Protection

10.7 THE TEST PROCEDURE

(1) Inject alternating current through the A.C. earth leakage current transformer as shown in Figure 4.2, using a 250 Amp AC Injection Test Set.

(2) Note the primary and secondary currents A1 and A2. The relay trip setting must correspond with the prescribed primary current A1 (as per test sheet BBB0342).

(3) Check that the primary circuit breaker trips and that the trip & lockout condition is indicated on the A/C control panel.

(4) Remove the primary injection cable from the A.C. earth leakage busbar side of current transformer and inject (flash test) through the metal parts of the following equipment, one by one, to ensure that all equipment is properly connected to the A.C. Earth leakage busbar; :

- main current transformer structure;
- primary circuit breaker structure;
- main transformer tank and
- auxiliary transformer screen.

(5) Check that the relay operates in each case.

(6) NOTE: When injecting through the various equipment, the test voltage should be increased to account for the increase in resistance in the circuit to obtain the tripping current.

(7) Record all measurements on the test sheet BBB0342.

10.8 DOCUMENTATION,

1 Complete the BBB 0342 test sheet.

10.9 ACCEPTABLE TEST RESULTS

1 Relay operates at a current of 50-100 A, tripping the PCB to lockout. The minimum resistance between equipment and earth mat is 10 Ω.

10.10 SPECIAL PITFALLS.

1 Resistance between AC earth Leakage busbar to Earth mat below 10 ohms due to parallel paths formed by insulation failure between transformer and skid rails or control cables exits and entries not block jointed.

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SECTION 11

TRACTION RECTIFIER

11.1 THE FUNCTION OF THE DEVICE IN THE ELECTRICAL SYSTEM

1 The function of the rectifier is to convert AC input power to DC input power suitable for 3kV DC traction. Typical connection of transformer/rectifier unit is shown below:

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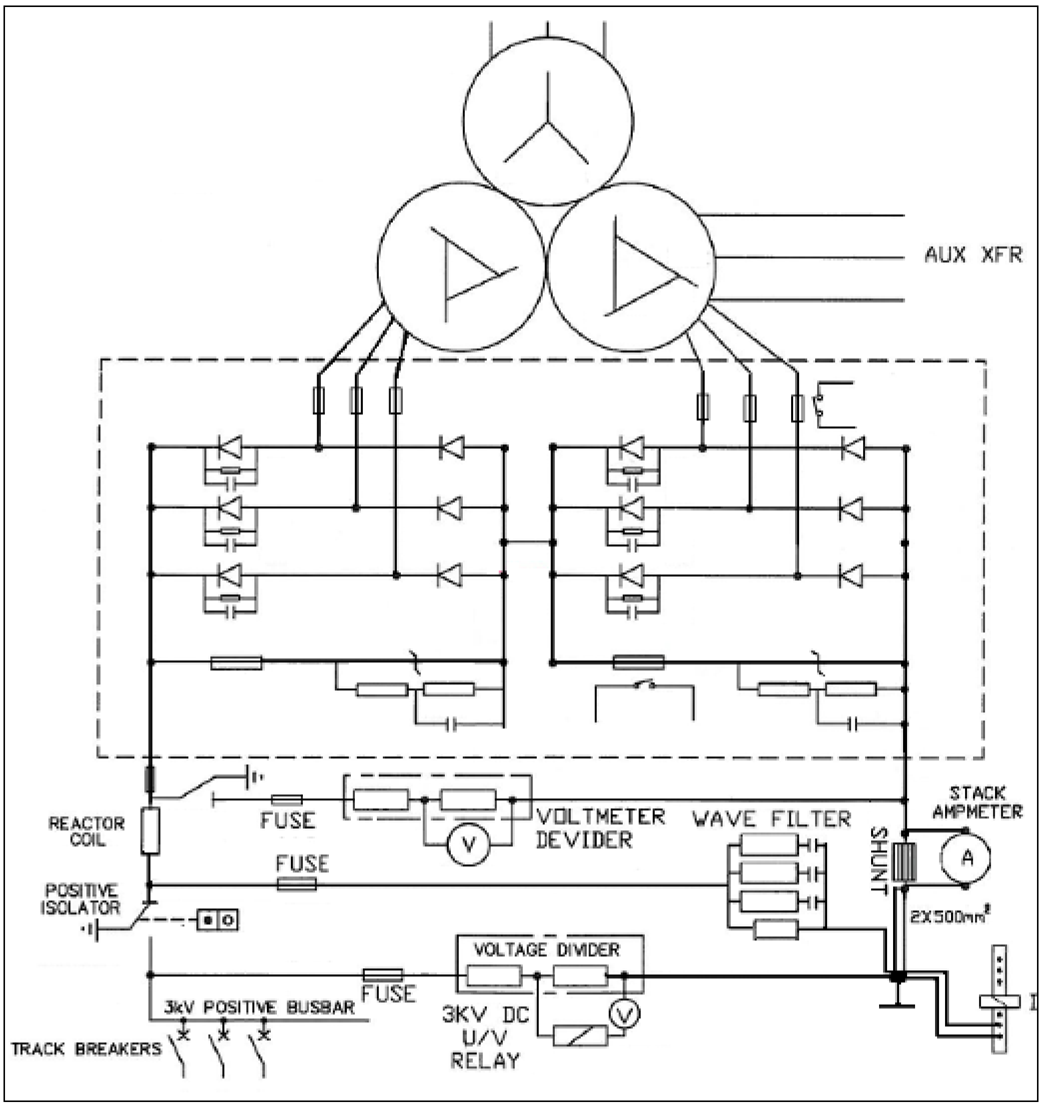


Fig 7.1: General arrangement for traction rectifier connections.

11.2 PRINCIPLE OF OPERATION

1 The Rectifier Unit

Rectifiers used are either full wave three phase units converting to 3kV 6-pulse DC from a 2450 or 1220 V three supply, or a 12-pulse rectifier configured as two full wave rectifiers in series, each producing a pulsating 1,5kV DC with 6 pulses per cycle. In this case the two 6-phase components are phase shifted by 30 degrees to produce an overall 3kV DC with 12 pulses per cycle.

The rectifier is connected in series between the traction transformer and the reactor coil and in parallel with a wave filter, which is designed to smooth the 12-pulse harmonic components.

2 Diodes

The diodes are connected in series and parallel to achieve the current and reverse voltage levels required. The voltage distribution between series connected diodes is controlled statically with RC components. Each diode is monitored with a diode monitoring circuit.

Capacitors ensure that diodes switch on and off more or less simultaneously to prevent any one diode from receiving the full inverse voltage. Resistors ensure an even distribution of voltage across each diode in a series bank.

The loss of one diode failing to short circuit causes:

- The reverse voltage rating or peak inverse voltage (PIV) of series diodes can be exceeded by line surges or over temperatures and cause failure thereof to a short circuit between two of the 3-phases feeding that bridge rectifier (which will result in a high fault current with operation of the overload relay).
- Full 3kV DC from the line side is placed over one half string of the bridge rectifier which can exceed the reverse voltage rating of the string.

The loss of one diode failing to open circuit causes one of the 6 pulses to be absent, which results in pulsating DC with a large harmonic component which the wave filter equipment cannot neutralise.

3 Diode monitoring

Diode monitoring equipment is installed to monitor the condition of every diode. A LED indication is provided on the display panel. Any diode going faulty must trip and lock out the unit.

> *Fault finding hint*: Defects of the DMS can usually be traced to the power supply which is derived from the 110V of the substation as the 110V supply may contain high switching surges as a result of the reactive load from the contactors on the High Speed Circuit Breakers.

6 Fuse protection

The latest generation rectifiers are supplied with striker pin fuse protection on the incoming phases, which must lock out the unit in the event of operation.

4 Cooling

Rectifiers' temperatures are mostly controlled by forced air cooling The cooling fan is activated by a current monitoring relay which detects load current through a shunt resistor or to switch on at 700Amps**.** The rectifier is protected by two over-temperature sensors which is set at 50º for the cooling fan switch on and 80ºC.for the PCB to trip.

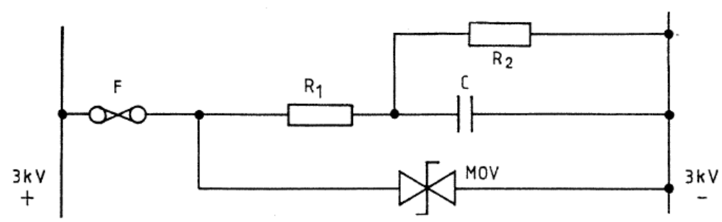
Fan failure is detected with a vane which is kept open when the fan blows. At initial power up of the rectifier, a short time delay overrides the fan-fail while the blower gathers speed.

A fan failure must trip and lock out the Primary Circuit Breaker with indication on the Control panel.

A fan test switch is provided on the Control Panel.

5 Attenuation

An attenuation circuit is installed across the output of the rectifier to suppress and absorb short surge voltages on the load side. The over-voltages should be reduced to around 6kV by the protective devices at the track switch.



The main energy absorbing component is the capacitor C. When it charges via R2 to a level higher than the surge, it will discharge through the resistor. If the surge is of too high magnitude the MOV will trigger. If the MOV cannot discharge the surge, the fuse will operate. A striker pin fuse operation activates a tripping and locks out the PCB and all HSCB's to prevent damage.

11.3 BASIC PRECAUTIONS

1 Work permit on rectifier unit under test

11.4 TYPES OF THE TEST

1. **Factory tests**
2. **Commissioning or after Major repair tests.**
3. **Operation of Diodes**

11.4 TYPES OF THE TEST (cntd)

1. Factory tests

A new rectifier must have the following tests performed at the supplier's test facility before delivery to site:

- Insulations tests
- Light load test
- Functional tests on the associated control equipment and circuitry of the rectifier
- Temperature rise test i.e. temperature measurements on diode heat sink temperature rise which must not exceed 75ºC
- Checking of auxiliary and protective devices and control equipment
- Rated output test with measurement of output voltage
- Over-current capacity test
- Power loss determination

2 Commissioning or after Major repair tests.

Insulation Test

Equipment Required: Hi pot test set 0-25-30 kV AC.

Testing Procedure:

- Disconnect all busbar connections to and from the rectifier with adequate insulation inserted where required.
- Short out all diode circuits and busbars by means of binding wire.
- Remove fuse from Attenuation Circuit.
- Connect High tension lead from test set to shorted busbars.
- Connect earth lead from test set to metal frame of rectifier.
- Raise test voltage to 10.5 kV AC for one minute.
- Reduce voltage gradually
- Remove shorting connections and reconnect all busbars.
- Replace fuse in attenuation circuit.

Rectifier temperature control tests:

Equipment Required: Optic fibre simulation equipment.
Millivolt injection set.

Testing procedure:

- Simulate fan operation at 50º C and/or 600-700 amps by mvolt injection.
- Simulate Primary Circuit Breaker trip at 80º C. with indication.

Diode monitoring equipment test

- Simulate Diode failure on random circuits to trip Primary Circuit Breaker. with indication.

Indicating instrument tests

Equipment Required: Hi pot test set 0-4 kV DC
Millivolt injection set.

Testing procedure:

- Calibrate DC volt- and ammeters on rectifier.

11.4 TYPES OF THE TEST (cntd)

Load test

Testing procedure

- Energise rectifier with HSCB's open for approx.10 minutes noting no-load voltage.
- Close HSCB's noting On-load voltage to be stable and current to have an even rate of rise.

3. Operation of diodes

With new hitech rectifier designs with diode monitoring systems, faulty diodes can easily be identified. The following procedures below can be applied to confirm any indications or diodes in the process of failing.

Equipment Required: 3 Phase Generator.
Multimeter
Set of light leads.
0-4 kV DC Injection set

Voltdrop test: (*see Figure 11.2*)

Testing procedure

- Disconnect all AC & DC Busbar connections.
- Connect 3 Phase supply to each rectifier bank in turn.
- Measure voltdrop across each diode noting readings.
- If voltage reading is low or zero diode is faulty
- Variation in voltage readings can be caused by RC commutation circuits

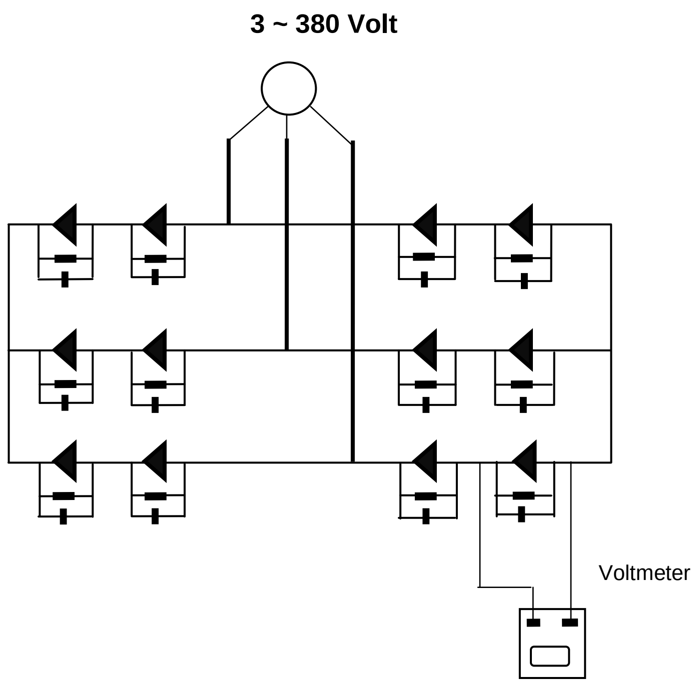


Figure 11.2: *Connections for voltdrop test on rectifier bank*

11.4 TYPES OF THE TEST (cntd)

3. Operation of diodes

Peak Inverse Voltage test:

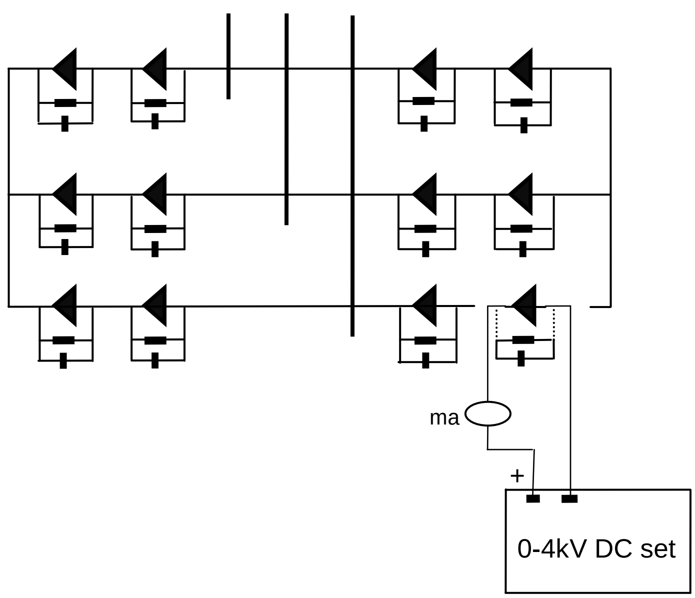


Figure 11.3: Connections for Peak Inverse Voltage test.

Testing procedure

- Disconnect/remove suspect diodes from rectifier bank.
- From the DC Hipot apply a reverse voltage of 50 % of the diode rated PIV across the diode. (Typically in the order of 1500 volts DC)
- The reverse current in micro/milliamps must conform to the diode specified rating curve to identify “soft” diodes.

11.8 DOCUMENTATION

Complete the applicable test sheets.

11.9 THE RANGE OF ACCEPTABLE TEST RESULTS

Insulation test: At 10.5 kV the leakage current should be less than 5 mA

Functional tests:

- All temperature tests shall be within 5 % with required indications .
- All meters within 5 %
- Load tests: No load and full load voltage within 10 % of 3,300 volts.
- Diode Test: Voltdrop across diode to be within 5 % of average value.

11.10 SPECIAL PITFALLS.

On testing diodes a faulty diode will only break down at higher voltages.

end

SECTION 12

WAVE FILTER EQUIPMENT

12.1 THE FUNCTION OF THE WAVE FILTER EQUIPMENT IN THE ELECTRICAL SYSTEM

1 The rectifier in most DC substations is a 12 pulse rectifier, which generate harmonic frequencies (the 6th, 12th, 18th and 24th harmonics). This can cause interference on communication and train authorisation systems.

The circuit and output voltage waveform is as follows:

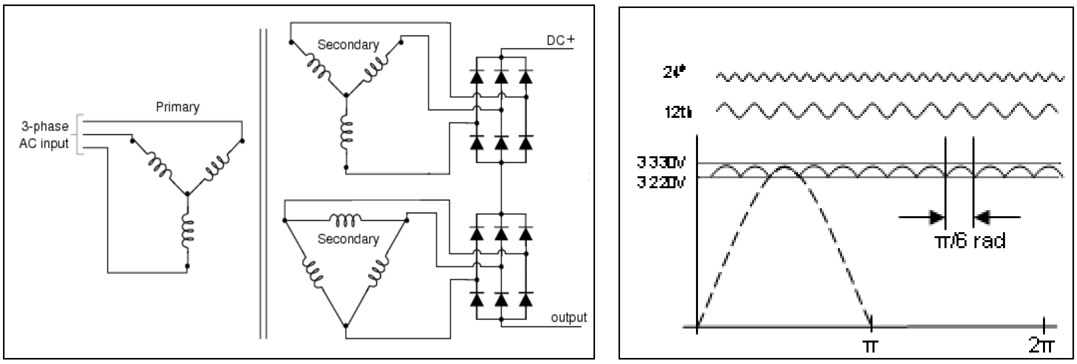


Fig 8.1 : 12 pulse rectifier and ripple waveforms

2 The Wave filter is connected on the load side of the main reactor. It is protected with a fuse. There are a number of arrangements for this equipment:

3 In some substations the wave filter is interlocked with the positive isolator such that the capacitors are earthed / discharged when the rectifier bay needs to be entered.

4 Some subs have a separate wave filter room (old mercury arc converted subs), in which case the wave filter has to be earthed by a special mechanism on the access door (ensure its is connected in the capacitor side of the fuse!). These access doors should also be mechanically interlocked with the positive isolator.

5 Since this equipment must be disconnected to test it, the substation circuit must be studied beforehand. Where automatic earthing is not provided the capacitors must be discharged manually first.

12.2 PRINCIPLE OF OPERATION

The connection in the circuit is as follows:

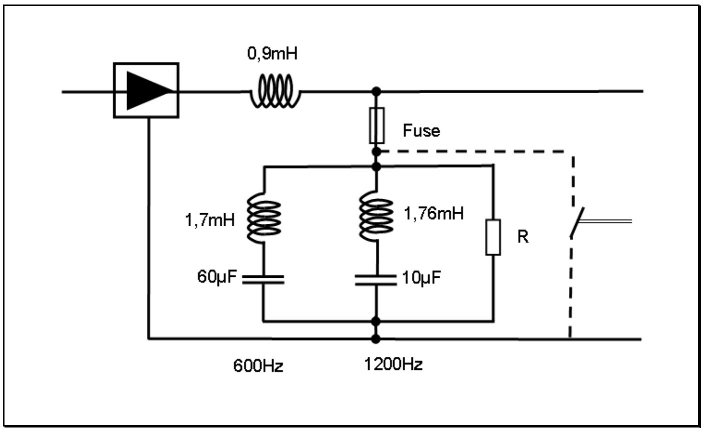


Fig 12.2 12th and 24th harmonic filter for a 12 pulse rectifier

1. Wave filters are designed to remove or reduce the ripple resulting from the rectification process. Frequencies in multiples of 300Hz or 600Hz are generated on the output of the rectifier depending on whether 6-pulse or 12-pulse rectification are applicable. The system is installed mainly for no- or light load conditions as it must be born in mind that the harmonic content of the output waveform increases in proportion to the load current.
2. The Wave Filter equipment consists of tuning coils and capacitors. The capacitors are normally rated at 100µF, 60µF, 20µF, and 10µF for the 6th, 12th, 18th and 24th harmonics respectively. The tuning coil and capacitor must be in resonance to achieve the best filtration.
3. To set the wave filter frequency, the capacitance must be measured and the formula is used to calculate the inductance in milli-Henry for each harmonic frequency:

   X_L: Inductance = $2\pi fL$

   X_C: Capacitance = $\frac{1}{2\pi fC}$

   $X_L = X_C$ for the resonance condition.

   The frequencies for the different harmonics for a 12 pulse rectifier are as follows:

   6th = 300 Hz

   12th = 600 Hz

   18th = 900 Hz

   24th = 1200 Hz.

12.3 BASIC PRECAUTIONS

1 In the past some wave filter capacitors used PCB (Poly-Chlorinated Biphenyl) insulating oils. These should all have been exchanged by now, but due care is required. PBC's are very toxic and require special specialist companies to handle such contaminated equipment. (See CEE.0094.86 & CEE.GI.009)

2 Testing to be done under a work permit between the AC Disconnects and the Track switches or unit breaker if one is installed as applicable.

3 All capacitors must be shorted out before any measurements. Even though there is a resistor connected in parallel with the capacitor when the fuse is drawn, the discharge rate may be slow. Damage will occur to the measuring instrument if connected to a capacitor that has not been discharged.

Verify first the earthing arrangement as stated above. In a multiple unit substation, all the units must be de-energised.

12.4 TYPES OF THE TESTING

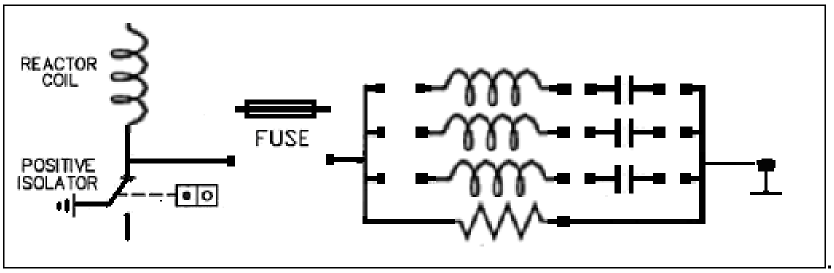
1 **Value test**

Capacitors and inductors are individually tested by establishing the values with an LCR-meter, with each component disconnected from the circuit. The values are recorded and compared to the design values.

12.5 TEST EQUIPMENT USED

1 The test equipment required for this test is a LCR Meter.

12.6 THE TEST CIRCUIT



12.7 THE TEST PROCEDURE

- Disconnect Caps and Coils. Short out capacitors prior to measuring capacitance. Measure the capacitance of each capacitor and record the values.
- Measure the inductance of each coil (the wave filter coils must be disconnected when conducting this test).
- Adjust the tuning coils if necessary by moving it closer or further apart to set the coils to the correct value of inductance. (calculated milli-Henry)
- Check the 100amp HRC fuse that protects the Wave Filter equipment in the event of capacitor failure, or in the event of the filters passing excessive current
- Measure the resistance of the discharge resistor (75k Ohm) connected in parallel with the resonant shunts, to discharge the capacitors when the rectifier is switched off for maintenance purposes.
- Measure the resistance of the series resistor, if provided. (± 0.68 ohm.)
- Record all measured values and reconnect all leads to wave filter equipment

12.8 DOCUMENTATION,

1 Complete the relevant test sheet BBB0342

12.9 ACCEPTABLE TEST RESULTS

1 6 pulse:

Harmonic	L	C
6th = 300 Hz		
12th = 600 Hz	1,173	60µF
18th = 900 Hz		
24th = 1200 Hz	1.759	10µF

2 12 pulse

Harmonic	L	C
6th = 300 Hz	2.814 mh	100µF
12th = 600 Hz	1.173 mh	60µF
18th = 900 Hz	1.564 mh	20µF
24th = 1200 Hz	1.759 mh	10µF

12.10 SPECIAL PITFALLS.

1 Ensure that the inductor coils are properly fastened on the mounting frames as surge currents caused by lightning and switches through the capacitors will cause movement due the magnetic fields present and thereby causing the set values to be out of specifications.

12.11 REFERENCES.

1 Specification CEE.0094.86 “Retro-filling PCB filled transformers and disposal of (Poly-Chlorinated Biphenyl)

Engineering Instruction CEE.GI.009: “Electrical Equipment containing Askarels (Poly-Chlorinated Biphenyl)

SECTION 13

DC EARTH LEAKAGE PROTECTION

13.1 THE FUNCTION OF THE DEVICE IN THE ELECTRICAL SYSTEM;

1 A DC earth leakage system is provided in order to detect 3kV insulation failure and flash-over in the substation. All steelwork, control panels and the auxiliary supply neutral installed in a DC substation are bonded to a DC Earth Leakage busbar, which is insulated from earth mat (minimum resistance 25 Ohm). This busbar is connected to the substation negative busbar through the DC earth Leakage relay.

2 Each item in the earth leakage circuit is connected in a ring and each ring is connected the DC earth leakage busbar via two cables to ensure continuity in the even of a break in the circuit.

3 When this relay operates as a result of a current flowing through the relay, it ensures that all incoming 3kV supplies from the line are interrupted by opening the HSCB's, and that the supply/supplies to the rectifier is interrupted by isolating and locking out the primary circuit breaker(s).

4 The equipment connected to the DC earth Leakage busbar system are shown in Figure 9.1 below:

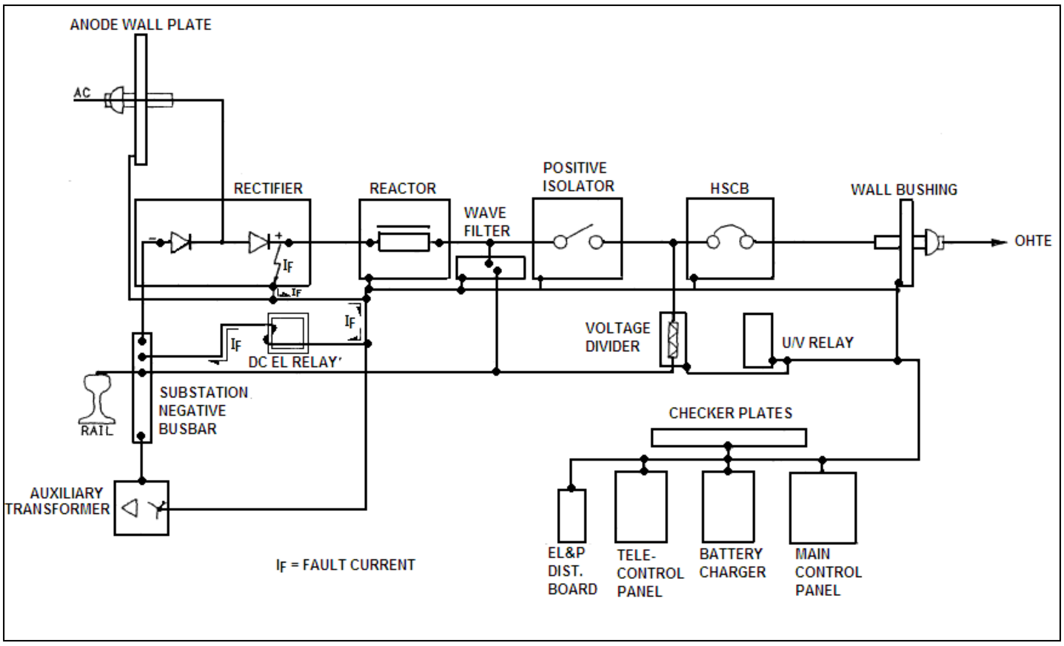


Figure 9.1

13.2 PRINCIPLE OF OPERATION;

1 In the event of a failure of the 3kV insulation, the fault current flows to the negative busbar via the DC Earth Leakage relay and the thereby causes the operation of the relay. The relay is normally of the attracted armature type, operating on the magnetic field set up by the fault current passing through the busbar or cable through the relay..

2 The DC Earth Leakage relay is generally calibrated to trip at a value as low as possible but not higher than 250 Ampere.

3 Operation of the DC Earth Leakage relay must isolate the complete substation from all sources of supply and must lock out the Primary Circuit Breaker and all 3kV high speed circuit breakers

13.3 BASIC PRECAUTIONS

1 Testing requires a work permit across the complete substation**.**

13.4 TYPES OF THE TEST

1 DC Injecting test to establish operation of the DC Earth Leakage relay

2 "Flash" test: Confirming that all connected equipment operates the relay.

13.5 TEST EQUIPMENT USED

1 Injection Set

2 DC metering equipment

3 Set of heavy test leads.

13.6 THE TEST CIRCUIT

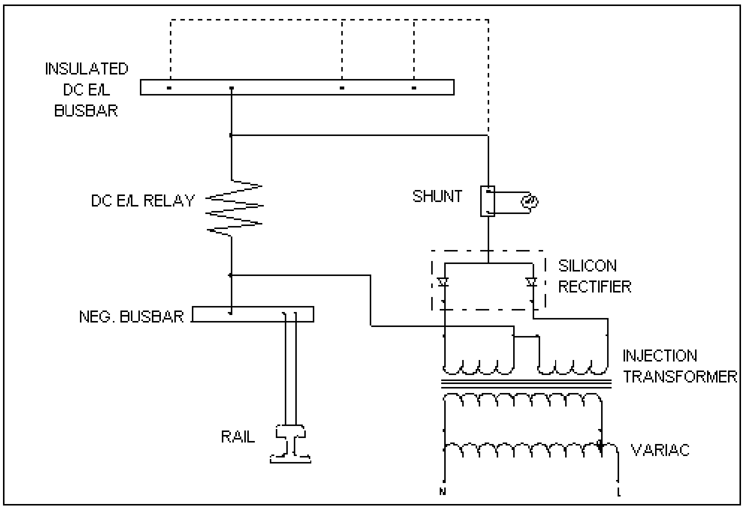


Figure 9.2: Circuit Diagram for Testing DC E/L Protection

13.7 THE TEST PROCEDURE

1 Inject DC current through the DC earth leakage relay as shown in Figure 9.2 by using a 250 Volt AC / DC Injection Test Set and slowly increasing the current from zero. Note the setting and trip current.

2 The relay should be set to trip at the value as per the previous test, but not higher than the rating of the relay, or 200 Amps (Traction Substations Technical Assistant Handbook EP.001 Issues 1 indicates 250 A), whichever is the highest.

4 Remove the injection cable from earth leakage busbar side of the relay and inject ("flash" test) through the metal parts of all the equipment that is connected to the DC earth leakage busbar as indicated in Engineering Instruction S.013. The relay must operate in each case.

5 When injecting through the various equipment, the test voltage should be increased to account for the increase in resistance in the circuit to obtain the tripping current.

6 Confirm that Primary Circuit Breaker as well as all 3 kV High Speed Circuit Breakers trips, and that the trip & lockout condition is indicated on the A/C control panel. (The DC/EL operation should isolate the substation from all sources of supply)

13.8 DOCUMENTATION

1 Record results on the relevant test sheet The following documentation must be completed:

BBB0343

13.9 ACCEPTABLE TEST RESULTS

1 DC/EL relay should trip at currents of values of lower than 250 A.

2 DC/EL relay operation must isolate the substation from all sources of supply and lock out the Primary Circuit Breaker as well as all 3 kV High Speed Circuit Breakers.

13.10 SPECIAL PITFALLS.

1 Parallel paths can be formed by modifications to control cables and leakage paths formed in the low voltage power and lighting systems in substation.

References Substations Electricians Handbook

Engineering Instruction S.013.

SECTION 14

CONDUCTIVITY (EARTH) MEASUREMENTS

14.1 THE FUNCTION OF CONDUCTIVITY SYSTEMS.

1 The conductivity systems of any electrical installation is required to

- provide a return circuit for normal power transfer.
- complete the electrical circuit for all high voltage components to provide an conductivity/earth return path in the event of electrical insulation failure.
- to provide a safe step voltage for normal access in railway electrified areas such as substations and the permanent way.
- For surge protection a good earth is required to discharge the large currents associated with lightning and other surges.

2 Conductivity installations are arranged in the railway electrification systems as follows:

For 3kV DC Traction,

- The rail return circuit is insulated from “mass earth”. The insulation must be of such a value to prevent or limit DC stray currents from flowing through any other services such as pipelines, fences, steel structures or power supply systems. The resistance value from the rail return to earth is normally in the order of more than 5 ohms.

For 3 kV traction substations:

The following 5 distinctive "Earth" systems are in place:

- **The outdoor Earth system** consisting of the bare copper earth mat or spike to which the steel structures before the Primary Circuit breaker is connected i.e. AC disconnects, HV lightning arrestors, Current transformers (where installed) and substation fencing.
- **The AC Earth Leakage system** consisting of all outdoor equipment support structures i.e. Current transformers (where installed), Primary Circuit Breakers, Main transformer (being insulated from the substation earth) and Auxiliary Transformer barrier fencing.
- **The DC Earth Leakage system** consisting of all indoor equipment subjected to possible HV DC flashover structures i.e. Anode wall plates, Rectifier frames, Reactor base, Wave filter equipment, Positive isolator, 3kv DC undervoltage relay and potential divider support frame, High Speed Circuit Breakers, Auxiliary transformer starpoint, Main control panel, Battery charger, Telecontrol equipment and Low voltage distribution board.
- **The Substation Negative Busbar** to which the following is connected: the DC Earth leakage system is coupled via the DC EL Relay, the gate earth switch, the 3 kV undervoltage relay negative, wave filter equipment negative, auxiliary transformer tank and the rail return connections.
- **The Rail return Connections** which is connected to the negative return rail via the rail connection cubicle next to the rail.

For 25 and 50 kV AC Traction

- For 25kV and 50kV the return is common with mass earth. A good earthing installation has less than 5-Ohm resistance between the return circuits and substation "earth" which comprises of bare copper conductors buried in the outdoor yard of the substation with one or more spikes..

For 11 and 6,6 kV Signal and distribution

- For Distribution and Signal power supplies, a return leg is required to complete the circuit to its source. In the case of a star connected transformer the star point serves as the neutral being earthed at the transformer. The substation has the associated protection to react to a phase/earth fault. Distribution substations require a good earth mat, and minisubs, H-masts and transformer step-downs require a star point connection to an earth electrode which can be an earth Spike or Trench Earths. The Earth reading must be below 5 ohms.

14.2 PRINCIPLE OF OPERATION.

1 DC Traction Substations

The principle of the distinctive separate earth systems is to ensure that fault currents during insulation failures are forced to flow to its source via a dedicated shortest route to operate dedicated protective devices effectively in the shortest possible time.

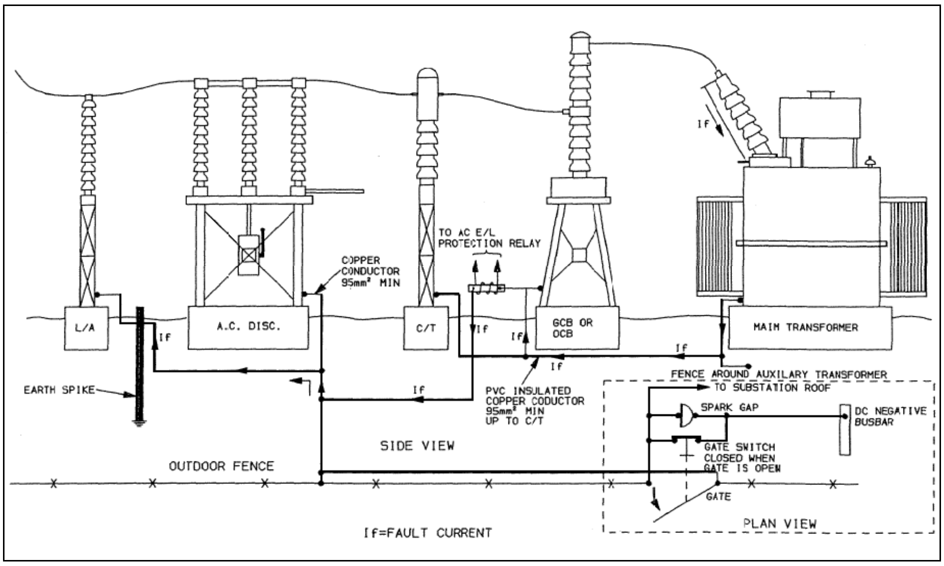


Figure 9.1:Typical AC Earth leakage protection systems.

Figure 9.1 shows the typical AC connections where fault current flows from the transformer HV side to earth via the AC earth Leakage system operating the required protection to isolate the supply. Note that the lightning arrestors and AC disconnects are connected directly to earth.

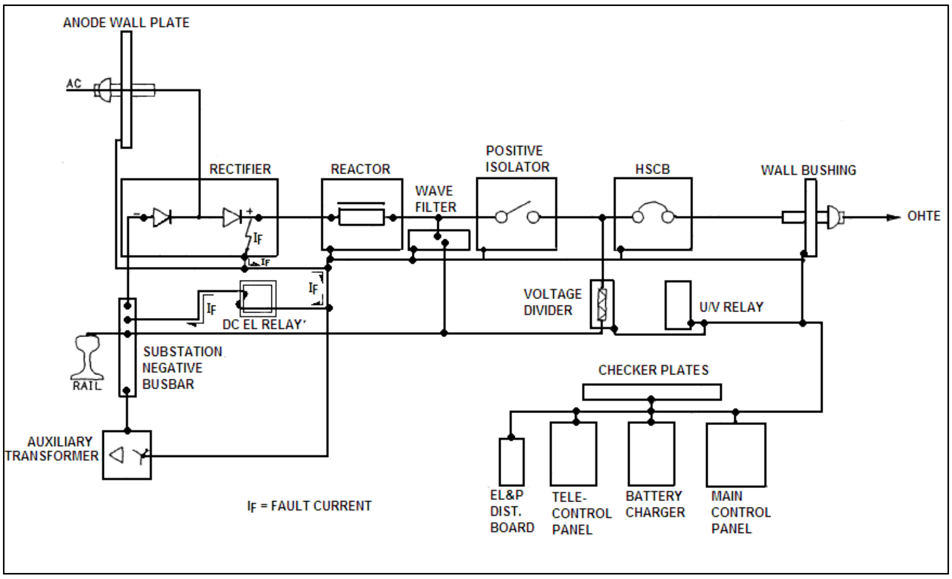


Figure 14.2 Typical AC Earth leakage protection systems.

Figure 14.2 shows the typical DC connections where fault current flows from the rectifier to negative via the DC earth Leakage system operating the required protection to isolate the supply.

2. **AC traction Substations**

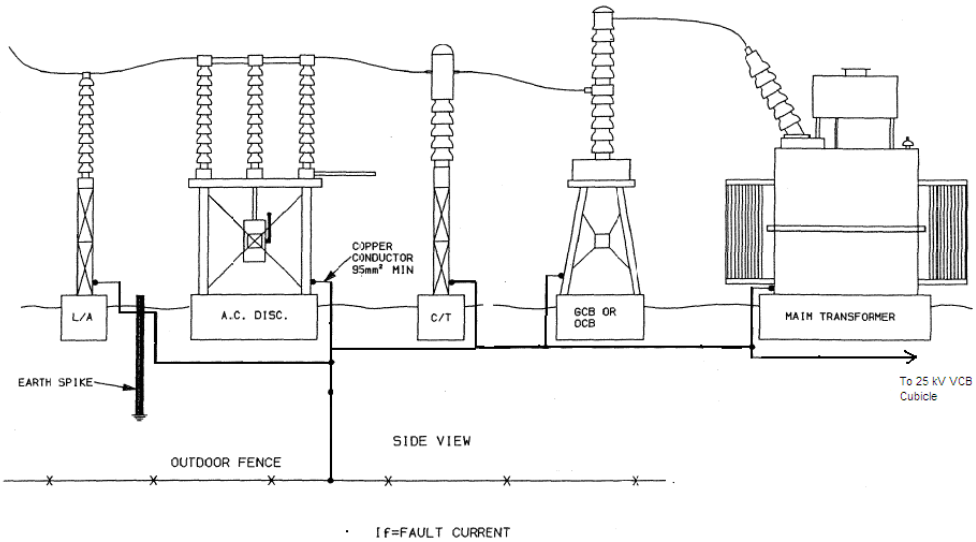


Figure 14.3

Figure 9.3 shows a typical AC traction substation earth layout where all primary fault currents will flow to common mass earth to which all equipment is connected relying on Eskom protection for equipment before the PCB and the transformer protection for equipment after the PCB.

3 11 kV and 6,6 kV Signal and Distribution

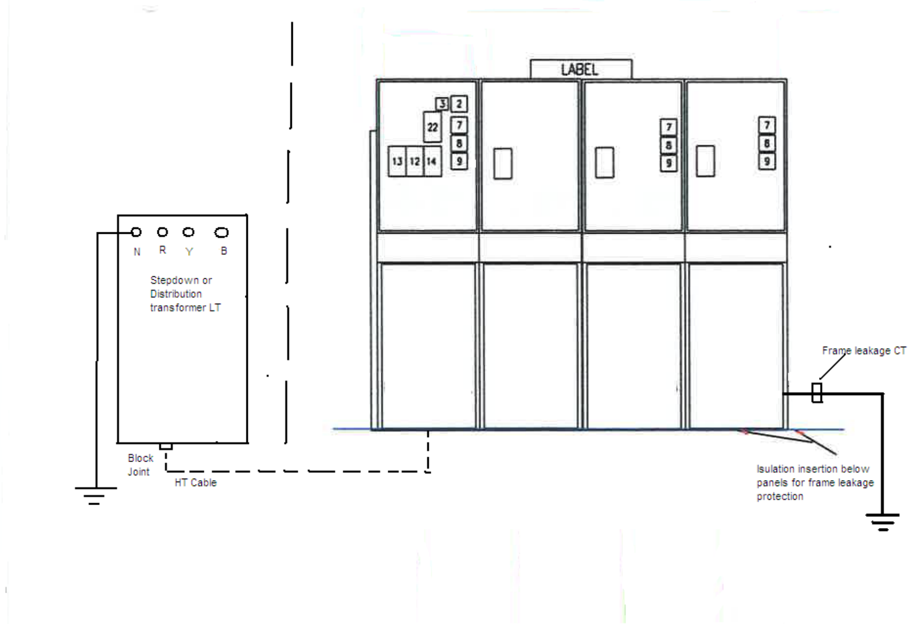


Figure 14.4: Typical distribution earth system

Figure 14.4 shows a typical distribution substation earth system where all equipment is earthed to a common earth mat or spike. Where frame leakage protection is installed, the HV panels are insulated from the floor and the earth fault current will flow from the panels through the frame leakage current transformer to operate the applicable protection.

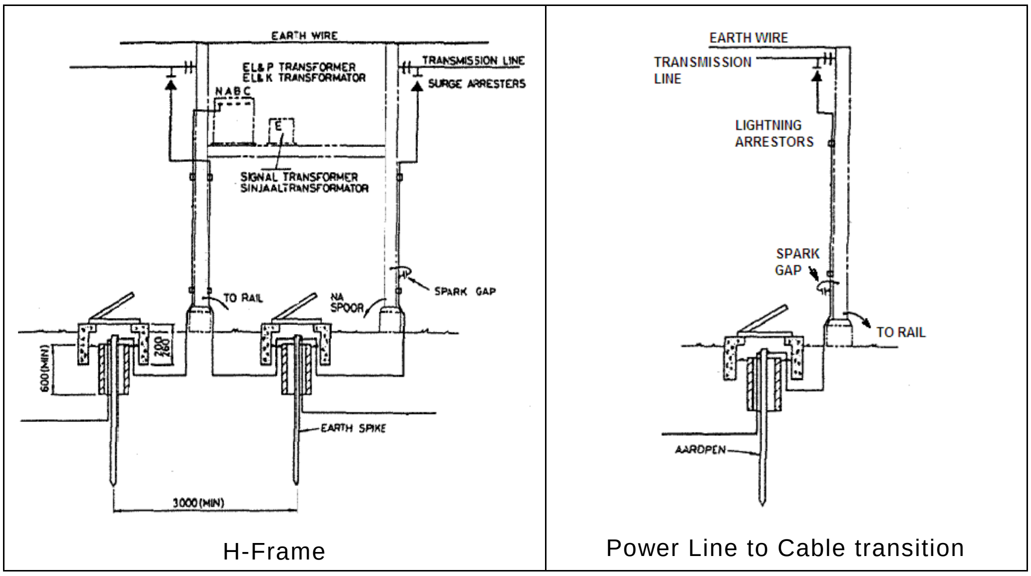


Figure 14.5: Typical H Frame stepdown point earthing arrangement

Figure 9.5 shows typical transmission line stepdown point earth arrangement. Note the separation distance of 3m between the earth spike for the transformer neutral point and the spike for the surge arrestor earth connections. This ensures that high surge currents from lightning strikes do not affect the neutral point of the transformer

14.3 BASIC PRECAUTIONS

1. Trace all underground cable routes before hitting in a earth test spike.
2. When testing an earth electrode the equipment that it protects must be is temporarily taken out of service.
3. Be aware of lightning activity in the area (up to 10km).

14.4 TYPES OF THE TESTS

1. Earth resistance test.
2. Insulation resistance test
3. Test for deterioration of earth mat at DC substations
4. Earth Resistivity test (See Code of practice)

14.5 EARTH RESISTANCE TEST

Test equipment used

1. Null balance megger with four terminals
2. Two metal test earth spikes
3. Three insulated light leads
   - Current Lead 1(+/- 50m long)
   - Potential Lead 2 (+/- 25m long)
   - Test Lead 3 to connect the Megger to the spike under test ((max 2 m long)

14.6 THE TEST CIRCUIT

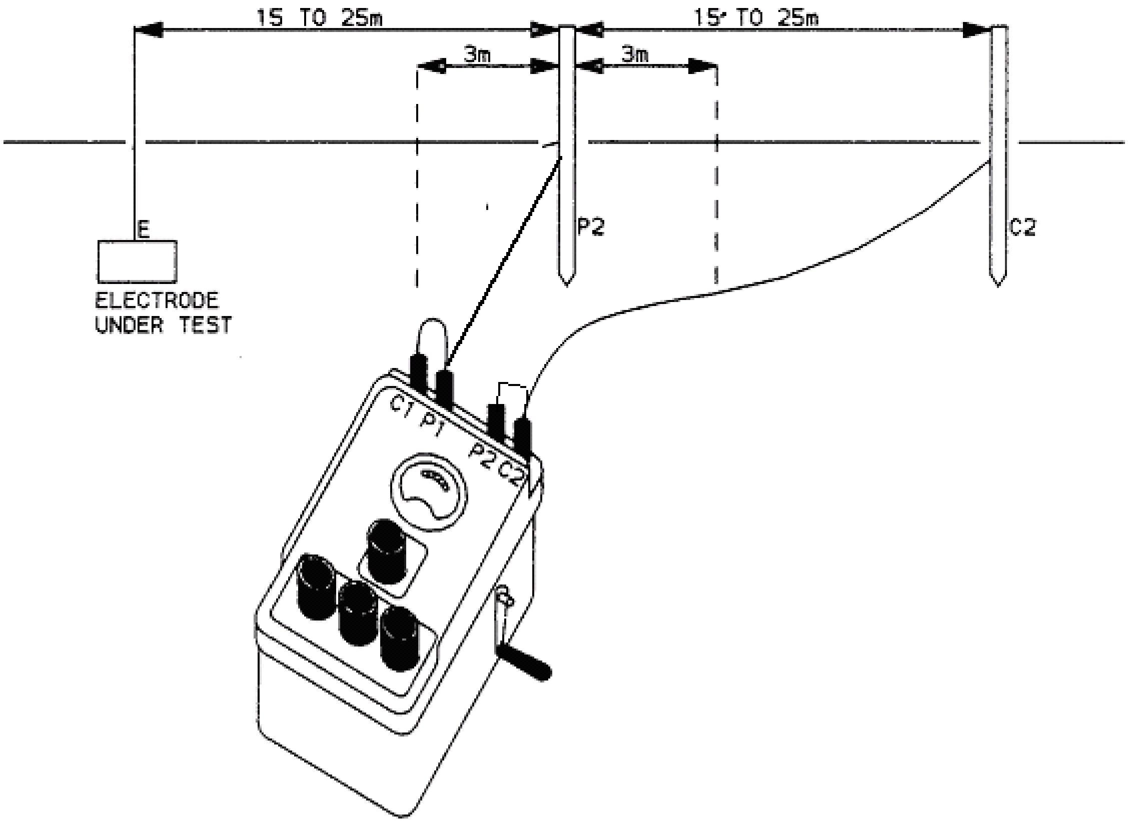


Figure 14.6: Connections for testing resistance between the current and potential spikes

14.6 THE TEST PROCEDURE

1. Set up the two spikes (current spike, C2 and potential spike, P2), in a straight line and as far as possible from the earth electrode under test / test spike. Connect the earth megger as shown in figure 9.6

2. Follow the test procedure given in the instruction handbook for the earth megger to determine the true soil resistivity between the potential, P2 and current, C2 spikes. This value should be in the order of 500-1000 ohm.

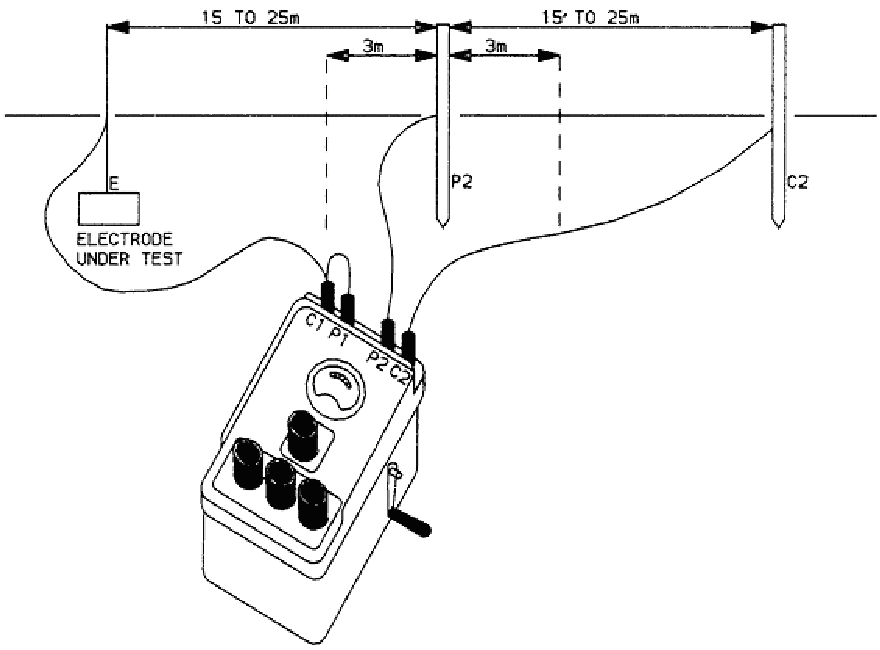


Figure 14.7: Connections for testing resistance between spike under test the current and potential spikes.

1 Follow the test procedure given in the instruction handbook for the earth megger to determine the true resistance of the earth spike/mat to earth. The value is to be below 5 ohms.

Equivalent circuit of earth test procedure.

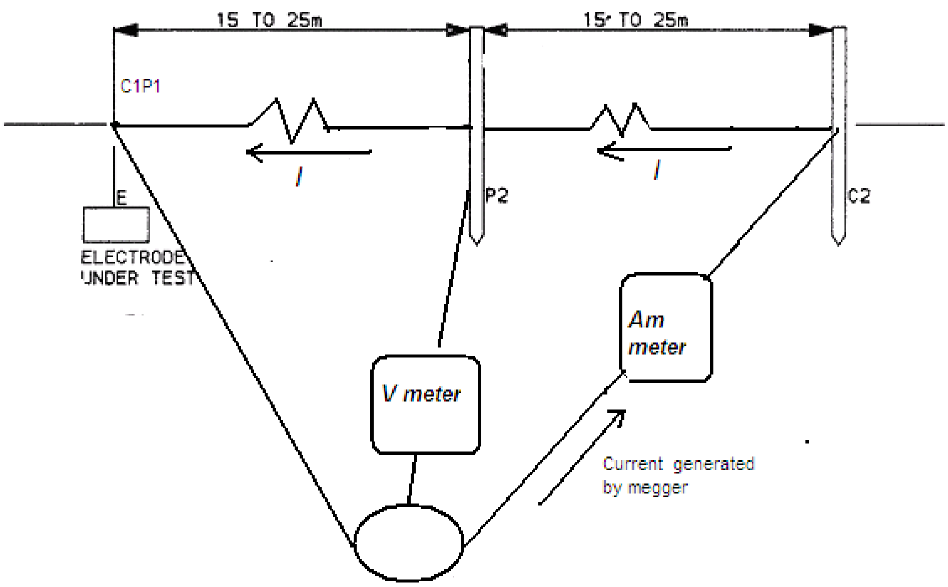


Figure 14.8: Equivalent circuit of earth test procedure.

2 Figure 9.8 shows the equivalent circuit for the test.

The earth megger generates an alternating voltage which sets up a current ***(I)*** flowing from the C2 spike through earth mass to spike C1. The voltdrop ***(V)*** across the earth resistance from spike P1 to spike P2 is measured by the internal voltmeter and integrated with the current (***I***) by the principle of Ohm's Law internally by the instrument as demonstrated below.

3 Resistance of the earth spike = V/I where:

V = voltmeter reading in Volts

I = current injected in Amps.

4 In the case where more detail readings are required the test must be repeated by moving the spikes in a straight line to 5 meters from the original positions

5 Take repeat readings to obtain a mean or average value.

14.7 INSULATION RESISTANCE TESTS

For DC Traction Substations it is required to test the resistance values between the separate " earth" systems for reasons mentioned above. Use the earth megger as an insulation tester with terminals P1-C1 and P2-C2 shorted respectively and follow process is laid down below:

1 Disconnect the DC earth leakage relay and the rail connections from the negative busbar (Rail) in the outdoor yard.

2 Disconnect the spark-gap at the yard gate switch or place a wedge between the contacts.

3 For convenience run three leads from the negative busbar, the DC earth leakage shunt and the rail connection to a suitable position in the outdoor yard.

4 Disconnect the earth lead from the AC earth leakage CT and run a lead from the CT to the same position as the other leads.

5 Run a lead from the substation earth spike to the same position as above.

6 With the leads from spikes, rail, DC earth leakage bar, negative busbar, AC earth leakage CT and substation earth spike carefully marked, measure all earth and insulation measurements according to test sheets BBB 0343 and record the results.

7 On completion replace all connections that were removed from equipment.

14.8 DOCUMENTATION

1 Record all measurements on the test sheet BBB 0343

14.9 RANGE OF ACCEPTABLE RESULTS

1 The acceptable values are laid down in the relevant document being **BBB 0343**

14.10 SPECIAL PITFALLS.

1 Earth mat: A high reading above 5 ohms. Possible causes include:
1) Dry soil condition
2) High resistance connections due to corrosion.
3) Underground bare connecting conductors corroded away due to electrolysis and acidic soil conditions.

2 AC earth leakage: Low reading to substation earth mat. Possible causes include:
(1) Low Resistivity of concrete bases for main transformer, CT or PCB structure;
(2) Waterlogged ground condition
(3) The insulation on the skid-rails under main transformer and skid-rails is not installed or has deteriated

3 AC earth leakage: Zero reading to substation earth mat. Possible causes include:
(1) Faulty or no block-joint between cables and equipment
(2) "Double-starring" of metering current transformers by ESKOM.

4 DC earth leakage: Very low or zero reading to substation earth mat.
(1) A possible cause is a faulty or no block-joint between control cables and equipment.
(2) Substation lighting circuit conduit passing through walls making contact with reinforcing or metal in contact with roof structure, which is bonded to earth.
3) Control cables not block jointed

.5 DC negative busbar: Very low reading to substation earth mat.
(1) Auxiliary transformer standing on low resistivity concrete base or very wet concrete base.
(2) Punctured dielectric in yard gate spark-gap if the spark gap has not been isolated for this test**.**

6 Rail: Technically insulated from earth, the resistance value may be low due to ballast fouling. The ballast is therefore a "leaky insulation".

7 Magnetic metals which fully surround the earth conductor. Such metallic path form a CT around the earth conductor which will block lightning and other high currents, thus making the earth electrode ineffective. A typical example is a cable cleat. Report such installations as a defect.

14.9 TEST FOR DETERIORATION OF EARTH MAT AT AC AND DC SUBSTATIONS

1 **Test equipment used**

Welder with secondary current rating 100 to 150 Ampere

Clamp on type ammeter with suitable range.

2 **The test circuit**

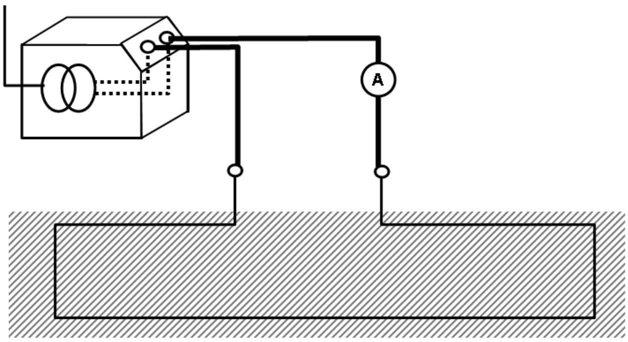


Figure 14:9 Earth connection tests

3 **The test procedure**

- Inject a current into the wires by means of a 100 to 150 ampere portable welding set connected to both ends of each conductor in turn. An ammeter is to be connected in series.
- The test current shall be allowed to flow for a minimum of five minutes where after the test is completed.

4 **Documentation, i.e. test sheet(s) used**

- The information must be entered in the substation report for routine maintenance.

5 **The range of acceptable test results**

6 A, unstable (varying) current indicates that the earth conductor may be open circuit underground due to corrosion or electrolysis and the soil itself is part of the circuit. A steady current is indicative of a good electrical circuit.

7 Provided that the current injected reaches a value in the order of the rating of the machine and can be maintained at that value during the full test period the conductor may be considered to be in a sound condition.

14.10 REFERENCES

1 "Code of Practice: Earthing Practice for Electrical Light and Power and Traction installations". CEE 0177.86

2 Engineering Instruction CEE T.004: Testing of outdoor yard earthing systems for corrosion: 3kV DC traction substations

SECTION 15

PANEL METERS

15.1 THE FUNCTION OF PANEL METERS IN THE ELECTRICAL SYSTEM;

1 Meters are the window to the electrical system, which cannot be safely sensed in any other way to monitor the system performance. Meters used are:

- Voltmeters – Indicates voltage at the connection point of the voltmeter or its transducer;
- Ammeters – Indicates the current at the connection point of the CT or transducer;
- kW-h meters. Energy Meters are used for billing purposes and for energy management purposes where they are connected.

15 2 PRINCIPLE OF OPERATION;

1 Voltmeters

- DC Traction Substations: Voltmeters are connected from a potential devider on the rectifier or the 3kV Undervoltage relay depending on the substation situation
- AC Traction Substations: Directly onto a VT supply, either indoor or outdoor.
- Signal supply and Distribution substations: The incoming feeder may be provided with a VT, or a VT by be connected onto the busbar.
- Battery voltmeters are connected onto the output of the battery supply.

. 2 Ammeters:

- DC Traction Substations: Derived from high current DC shunts supplying millivolts to a DC ammeter calibrated to read 4 kAmps.
- AC Traction Substations: Directly from a CT supply, either indoor or outdoor.
- Signal supply and Distribution substations: From a CT supply normally in series with other equipment.
-

15.3 BASIC PRECAUTIONS

1 All testing or calibration to be done under work permit conditions..

2 Remove voltage transformer LV fuses and open test links for Ammeters.

15.4 TYPES OF THE TEST

1 Comparison tests

15.5 TEST EQUIPMENT USED

1 Voltage, current and millivolt injection sets.

15.6 THE TEST CIRCUIT

1 DC Traction Substations:

- Voltmeters: Refer to Section 16 for the connections for primary injection onto the potential devider or inject the required voltage as per nameplate data directly onto the meter

- Ammeter:

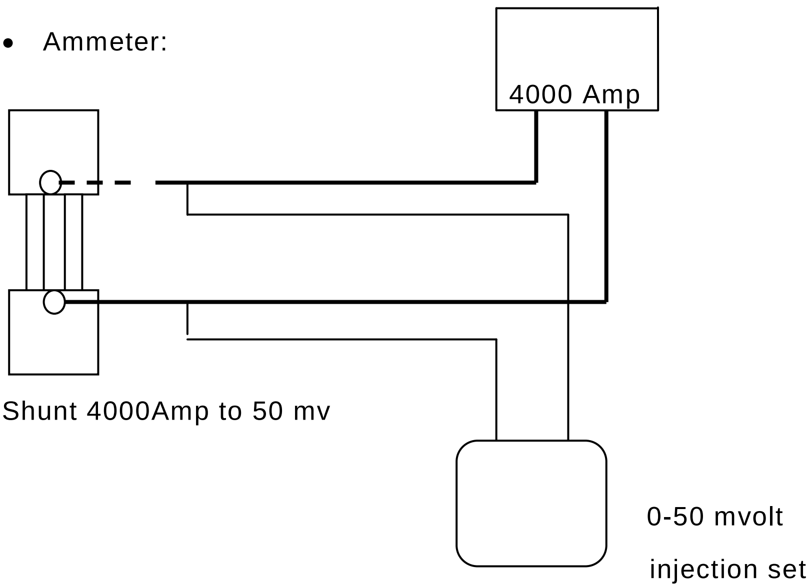


Figure 15:1 Connections for testing DC Kilo Ammeter.

AC Traction substations and Signal supply and Distribution substations

- : Voltmeters: The nominal voltage normally stepped down by the Voltage transformer is at 110 volts usually supplied through 1/ 2 Amp HRC fuses or MCB's.

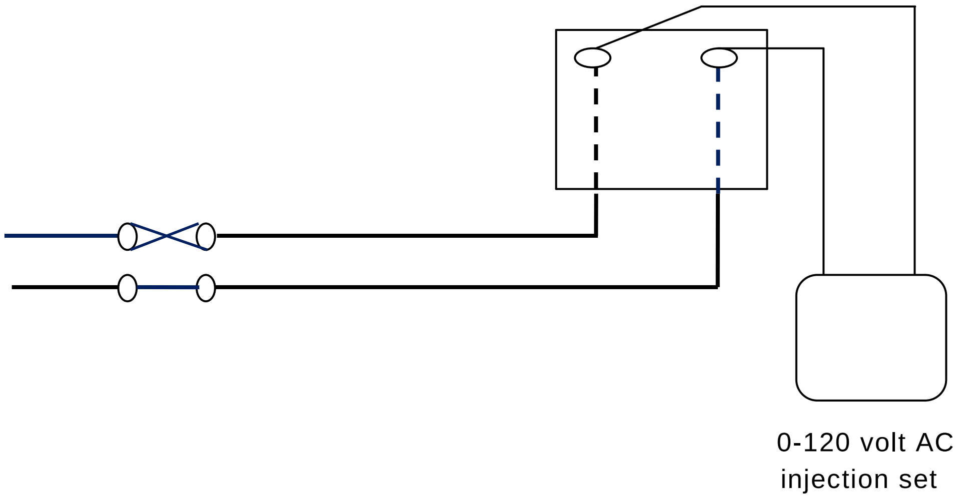


Figure 15:2 Connections for testing AC Voltmeter.

Ammeter. The nominal current normally stepped down by the current transformer is at 1or 5 amps usually supplied through the test block

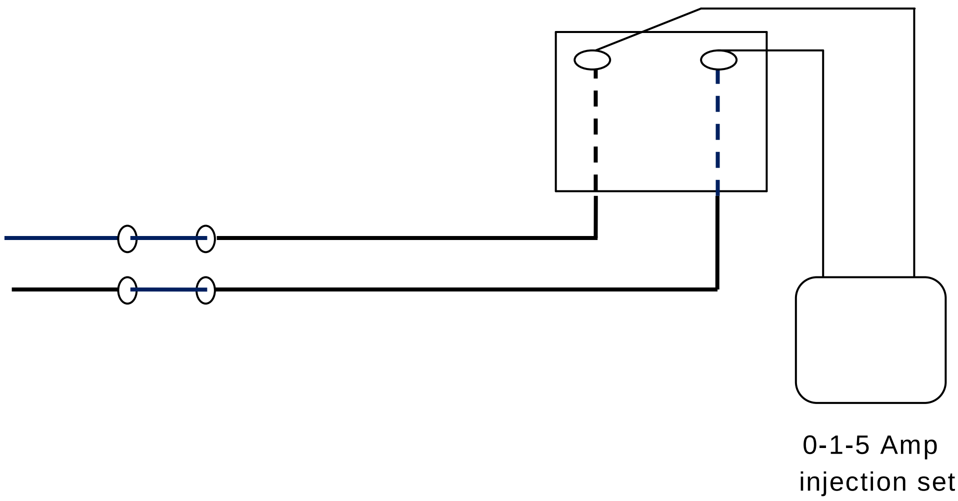


Figure 15:3 Connections for testing AC Ammeter.

15.7 THE TEST PROCEDURE

DC Traction Substations:

- Voltmeters: Refer to Section 16 for the connections for primary injection onto the potential devider or inject the required voltage as per nameplate data directly onto the meter
- Ammeter: Inject the required millivolts onto the shunt connections the latter being disconnected.

AC Traction substations and Signal supply and Distribution substations

- Voltmeters :Inject the required voltage as per nameplate data directly onto the meter being disconnected as per *Figure 15:2*
- Ammeter: Inject the required current onto the ammeter being disconnected or via the test block terminals as per nameplate data as per *Figure 15:2.*.

15.8 DOCUMENTATION.

1 The relevant test sheet must be complete, eg

BBB 0342 - Traction Substation Test Sheet

15.9 THE RANGE OF ACCEPTABLE TEST RESULTS

1 All the measurements must be accurate to within 5% error.

15.10 SPECIAL PITFALLS.

1 Nil.

SECTION 16

3KV DC UNDER-VOLTAGE PROTECTION

16.1 THE FUNCTION OF THE DEVICE IN THE ELECTRICAL SYSTEM;

1 DC traction systems supplies power to locomotives at high current values, typical current values according to HSCB setting can be in the order of 4000 amps. Applying Ohms Law in it is evident that the inherent resistance of the OHTE, (which increases with distance), causes the supply voltage to drop to a value which will bring about a "stale" condition. Referring to CEE S004 in this "stale" condition the train can be at an “offload substation” at a distance of e.g. 11 km from the next substation attempting to get moving drawing a high value of current from this next substation causing a large voltdrop. The high current being drawn for a considerable time can then cause high temperature rises in the OHTE .Annealing of the copper wires can take place which then have to be replaced at very high costs,. The Under-voltage relay is installed to detect the voltdrop at the busbar of the “off load” substation or the Tie station protecting OHTE the system against high currents at low voltages in case where a substation is off load or HSCB's has tripped. Since the DC busbar is the connection point of various supplies, the detection of under-voltage at the busbar must trip the all supplies associated with the relay.

2 The under-voltage setting is the highest voltage (that means the lowest voltage drop) which can occur on the busbar under the crippled network conditions; i.e. with the substation off load, while taking a safety factor into consideration.

16.2 PRINCIPLE OF OPERATION;

1 The Under-voltage relay monitors the 3kV DC busbar voltage by comparing a portion of the voltage stepped down by the potential divider to a pre-set minimum “Drop-out” value within the relay and interrupts the holding coil supply of all HSCB’s. The setting is normally in the order 2 250 Volt.

2 For calculation purposes of the “Drop-out” value, it is normally assumed that the relevant substation is off load, with the HSCB’s and all power routes are available.

3 To enable the 3kV busbar to be re-energised from the “line” side after all the HSCB’s have tripped, and to test whether the line voltage is greater than the “Pick-up” voltage of the relay, a set of by-pass timed contacts are provided in the relay which allows the relay to “read” the busbar voltage with one HSCB reclosing. If the voltage exceeds the “Pick-up” voltage the HSCB will stay closed and allow the reclosing of the remaining HSCB’s.

4 The relay is made inoperative with the substation on load by a set of “by pass” normally closed contacts which will open when the substation is off load.

The relay is connected in the circuit as follows:

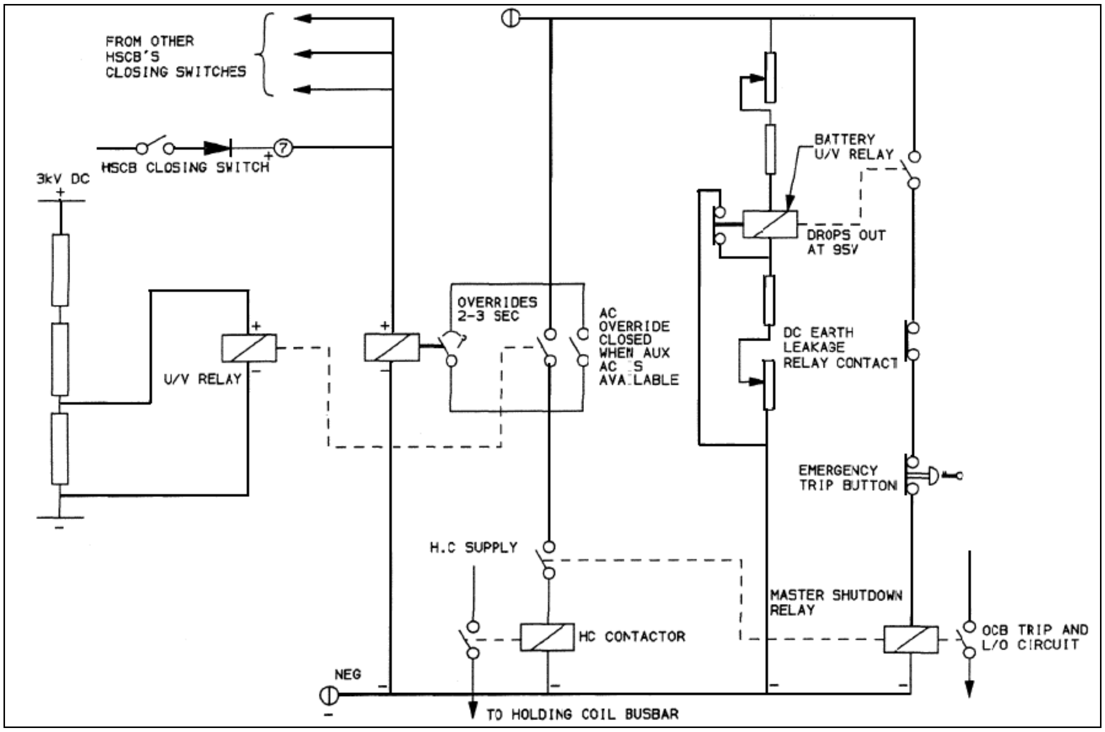


Figure 16.1: Schematic layout of 3 kV DC Undervoltage relay

16.3 BASIC PRECAUTIONS

1 All tests do be done under cover of a workpermit

2 The 3kV DC Under-voltage relay must be tested in accordance with clause 609 "Conditions governing High Voltage Power Testing" of the Electrical Safety Instructions (1999).

16.4 TYPES OF THE TEST

1 The Relay is tested by applying a variable HV DC test voltage across the potential divider.

16.5 TEST EQUIPMENT USED

1 The main instrument or test equipment required for this test is a 3 / 4kV DC Hi Pot set or calibration set.

16.6 THE TEST CIRCUIT

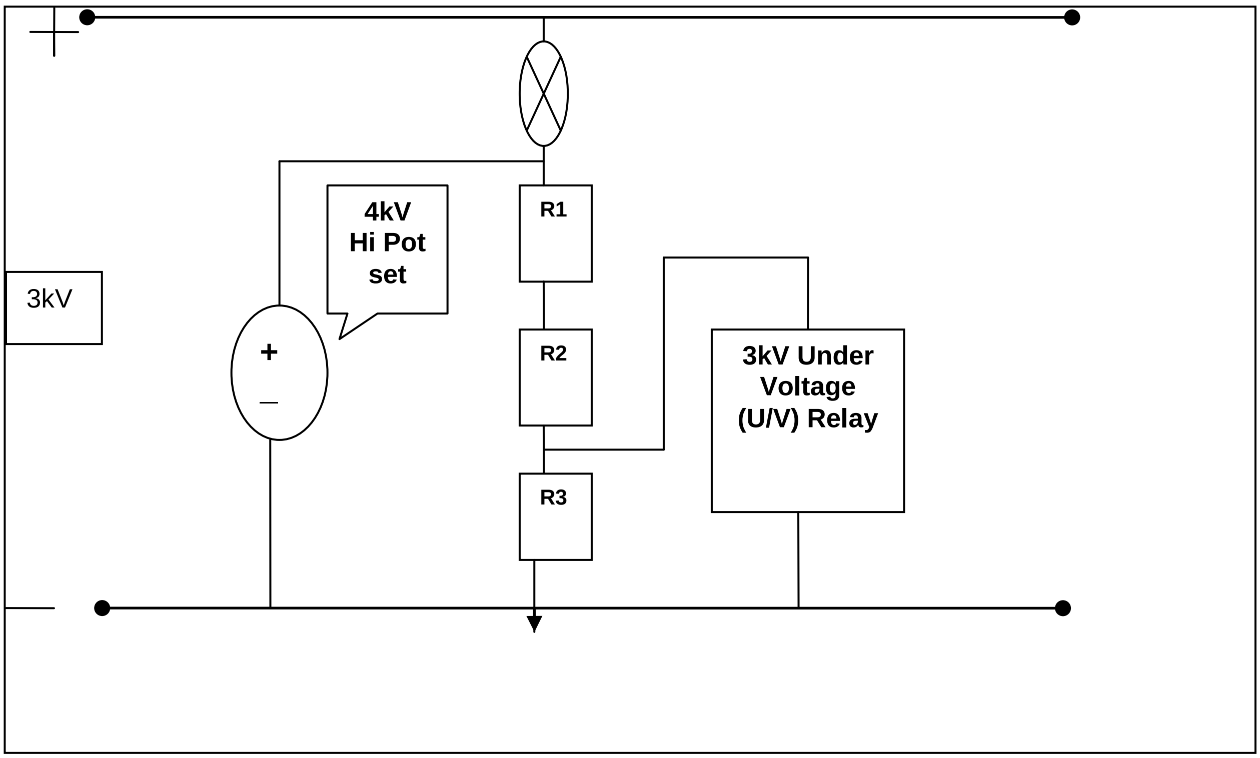


Figure 16.2: Test connections for testing 3kV DC Undervoltage relay

16.7 THE TEST PROCEDURE

(1) Remove the fuse from the potential divider.

(2) Connect the 4kV DC Hi Pot set on the potential divider, the Positive (+) lead to the bottom of the fuse holder and the Negative (-) lead to the Negative Busbar.

(3) Adjust the test voltage upwards from zero.

(4) When the pick-up voltage (as prescribed for the specific substation) is reached, the Under-voltage relay will be activated and the HSCB holding coil contactor will close.

(5) Close all HSCB’s manually.

(6) Slowly decrease the voltage until the dropout voltage is reached and all HSCB’s will open.

(7) The pick-up and dropout voltages should correspond to the values prescribed (obtained in most recent test sheet).

(8) If necessary, adjusted the values with the variable potentiometers on the Under-voltage relay, and the final values recorded on the test sheet. Check that when the relay operates on the dropout value that all track breakers trip after ±2 seconds, giving a counter operation and a fault indication on the control panel.

(9) Should the Under-voltage relay not operate correctly, the resistors on the potential divider, or the relay must be checked and report the faulty component to the technician.

(10) Test the fuse before being replaced into the holder..

16.8 DOCUMENTATION

1 The following documentation must be completed: BBB 0343

16.9 ACCEPTABLE TEST RESULTS

1 The relay operates on the "Dropout" value so that all track breakers trip after ±2 seconds, giving a counter operation and a fault indication on the control panel.

2 With the relay in the Dropout state, close one of the HSCB's the latter must stay closed for approximately 3 seconds and then fall out again to confirm the overriding facility of the relay.

3 The relay operates on the "Pickup" value in the order of 200 volts above the "Dropout" value reclosing the holding coil contactor and resetting the indication on the control panel.

16.10 COMPLICATIONS AND PITFALLS.

1 Ensure that the negative connection of the voltage divider is connected to rail The U/V relay may still test correctly or erratically if this connection is interrupted (loose, stolen, etc)

2 Should the Under-voltage relay not operate correctly, the resistors on the potential divider, or the relay must be checked, the faulty component must be reported to the electrician and recorded on the test report form.

3 The fuse must be tested before being replaced into the holder

16.11 REFERENCES

1 CEE S.004: "Calculations of under-voltage relay settings for 3kV DC Traction Substations and Tie-Stations"

3 Electrical Safety Instructions (1999).

SECTION 17

BATTERY UNDER VOLTAGE PROTECTION

17.1 THE FUNCTION OF THE DEVICE IN THE ELECTRICAL SYSTEM;

1 The battery under-voltage relay monitors the battery output voltage. The battery is used to as a source of DC power for protection and control equipment in the substation. It is also used for emergency lighting. When the battery supply is faulty or run down it cannot fulfil the function.

17.2 PRINCIPLE OF OPERATION;

1 Control equipment such as relays, spring wind motors; contactors etc. are not designed to operate at voltages lower than approximately 70 % of the design value and will be damaged by overheating at a too low control voltage.

2 The battery undervoltage device is set to a predetermined “Dropout” level. Under-voltage can be caused by charger failure, supply MCB trip or blown fuses. At the “Dropout” value the device initiates the shutdown of the substation by tripping all Primary and Secondary/HSC Breakers. The “Pickup” value is determined to be at a safe operating level for all equipment. In some AC substation designs individual control panels are equipped with separate undervoltage relays

17.3 BASIC PRECAUTIONS

1 Since the battery supply is the power backbone of protection in the substation, the substation must be off load (primary and secondary breakers) before the battery supply is interrupted for tests.

2 ***NEVER ATTEMPT TO CLOSE ANY CIRCUIT BREAKERS UNDER LOW CONTROL VOLTAGE CONDITIONS***

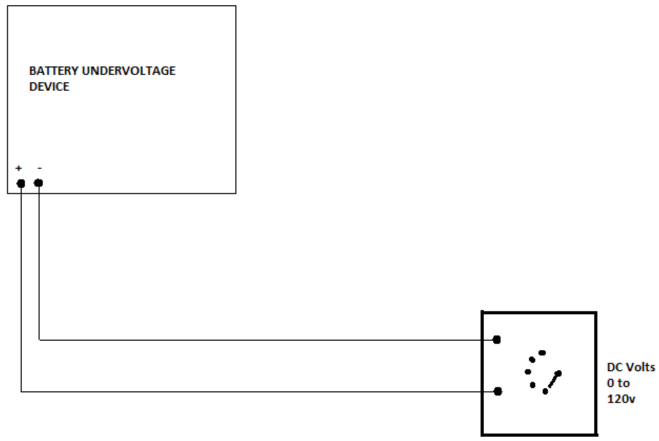
17.4 TYPES OF THE TEST

1 With the DC Supply switched off a variable voltage is applied across positive and negative supply to the control and indication circuit in the control panel.

17.5 TEST EQUIPMENT USED

1 Variable DC voltage test set 0 to 120 volts

17.6 THE TEST CIRCUIT



17.7 THE TEST PROCEDURE

1 The battery supply to the 110V battery undervoltage relay coil must be disconnected to test the battery undervoltage. Connect the output of the 110 Volt DC injection set to the relay and adjust the voltage of the injection set until the pick-up and dropout voltages are reached. The pick-up and dropout voltages should correspond to the values obtained in previous tests.

2 Ensure that when the relay operates on the dropout value, the primary circuit breaker trips, and that the trip & lockout condition is indicated on the A/C control panel.

3 The leakage between the battery positive to earth is to be measured by measuring the DC voltage between the battery positive and the earth terminal in AC subs and D/C earth leakage busbar in DC subs. Similarly the battery negative-to-earth voltage is to be measured between the battery negative and the earth terminal in AC subs and D/C earth leakage busbar in DC subs. These readings should be zero.

17.8 DOCUMENTATION

1 Complete the relevant test sheet.

17.9 THE RANGE OF ACCEPTABLE TEST RESULTS

1 Typical values are in the order of 95 volts for "Pickup" and 85 volts for "Dropout" respectively with an allowable tolerance of 5 %.

17.10 SPECIAL PITFALLS.

1 Confirm proper test connections as high resistance connections will result in erratic operations.

SECTION 18

SECONDARY BREAKERS

3 kV HIGH SPEED CIRCUIT BREAKERS

18.1 THE FUNCTION OF THE DEVICE IN THE ELECTRICAL SYSTEM

1 The HSCB is installed primarily to protect the OHTE against overloads and to isolate the substation from supplies from adjacent substations in case of flashover faults as well as in the case of or 3 kV DC undervoltage operations. Additionally HSCB's are utilised to isolate switching sections during occupations for workpermits on the OHTE.

18.2 PRINCIPLE OF OPERATION

1 Magnetic principles are employed to detect the rate of rise of the load current supplied through the breaker. A moderate rate of rise will permit the passage of large load currents but a rapid rate of rise of fault current will cause the breaker to trip in a time relative to the rate of rise. The arc chute serves to dissipate the energy resulting from the breaker action to trip high fault or load overcurrents.

2 Modern HSCB's are equipped with FPR (Feeder Protection Relays) which prevents the closing on to short circuited locomotives or OHTE. Refer to instruction manuals

18.3 BASIC PRECAUTIONS

1 HSCB must be racked out of the breaker cell for testing purposes.

18.4 TYPES OF THE TEST

1 Insulation tests: In the case of major repairs on a HSCB a High Potential test must be done to prove the insulation.

2 Calibration tests: After major repairs as well as on a routine basis HSCB's must be calibrated to the calculated value of tripping current.

18.5 TEST EQUIPMENT USED

1 High Potential test set rated at 0 to 20 kV AC at 20 milliamps.

2 DC Current injection set rated at 5000 amps.

18.6 THE TEST CIRCUIT

1 Insulation tests

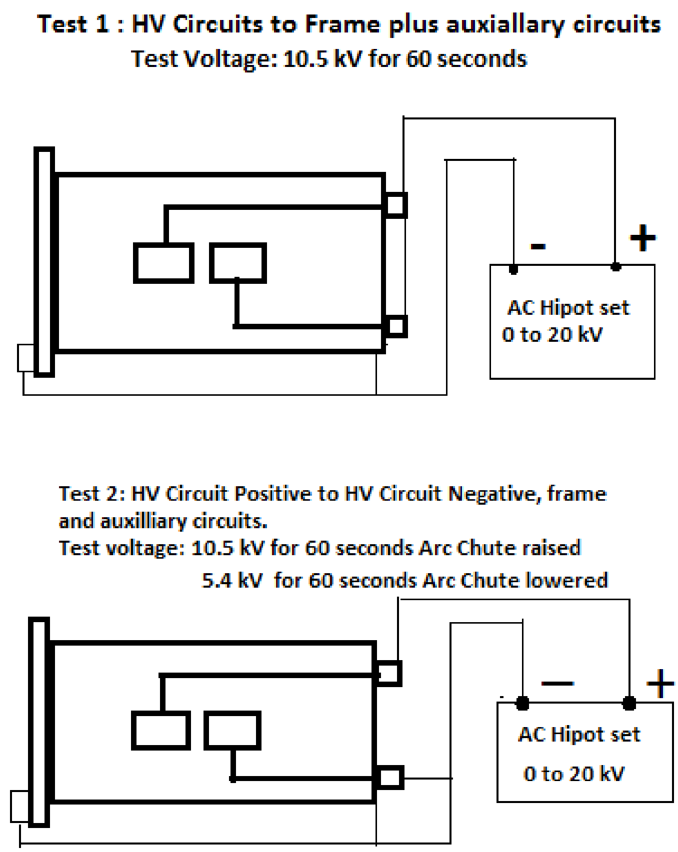


Figure 18.1 Hipot insulation test

2 Calibration Test

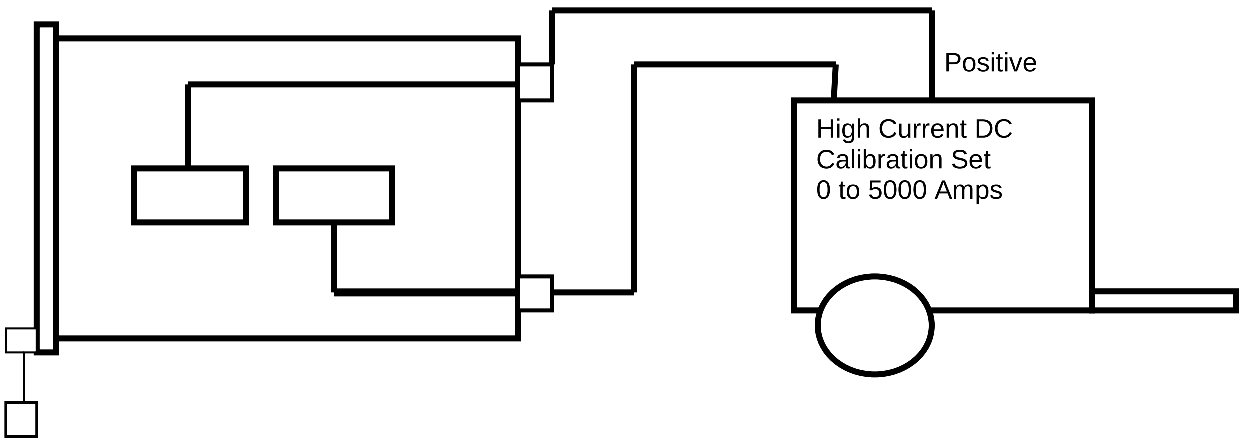


Figure 18.2 Circuit for Calibration of HSCB

18.7 THE TEST PROCEDURE

1 Insulation Test

1 **C**onnect the Hipot test set as shown in figure 18.1 Test 1 for testing the insulation of the power circuits.

2 All auxiliary cellside contacts to be bridged out with binding wire and connected to the frame of the HSCB

3 Switch on the AC supply to the test set and gradually increase the test voltage to the required value.

4 Apply the test voltage for the 60 seconds required.

5 Decrease the test voltage to zero and discharge the parts under test.

6 Connect the Hipot test set as shown in figure 18.1 Test 2 for testing the insulation between the power circuits at the voltages shown with the arc chute raised and lowered for 60 seconds respectively.

7 Decrease the test voltage to zero and discharge the parts under test in each test.

8 Remove all binding wires.

2 Calibration Test

1 Connect the heavy positive and negative cables to the HSCB with the correct polarity. Polarity is not applicable HSCB's fitted with the later Secheron type of breakers.
2 Connect the breaker to the cellside contacts via the test rig and close.
3 Switching on the power, gradually increase the current to the calculated value.
4 Note the tripping value for either over- or under calibration.
5 Do the required adjustments as per HSCB type.
6 Repeat the procedure till correct setting is achieved.

18.8 DOCUMENTATION.

1 Complete the applicable test sheets

18.9 THE RANGE OF ACCEPTABLE TEST RESULTS

1 Insulation test: The HV circuits must withstand the pressure test for the specified time
2 Calibration test: The HSCB must trip within 10 % of the calculated value.

18.10 REFERENCES

1. Substation manual for Electricians.
2. CEE-S_05_ISS_1: Test Voltages for High Speed Circuit Breakers
3. CEE-S_007 Issue 1 of March 2010: Trip value and calibration of 3 kV DC High Speed Circuit Breakers
4. Instruction manuals on HSCB's and the Feeder Protection Relay.

SECTION 19

SECONDARY BREAKERS

25/50 KV AC VACUUM CIRCUIT BREAKERS

19.1 THE FUNCTION OF THE DEVICE IN THE ELECTRICAL SYSTEM

1 Vacuum Circuit Breakers (VCB's) in 25 and 50 kV AC Substations are installed to provide switching and protection functions in AC Electrification systems. VCB's are equipped with instantaneous, thermal and distance protection relays to protect the substation busbars and the OHTE against high load and fault currents. The first generation VCB's was of the indoor type housed in a steel cubicle construction with the new generation VCB's being of the outdoor pedestal type.

19.2 PRINCIPLE OF OPERATION

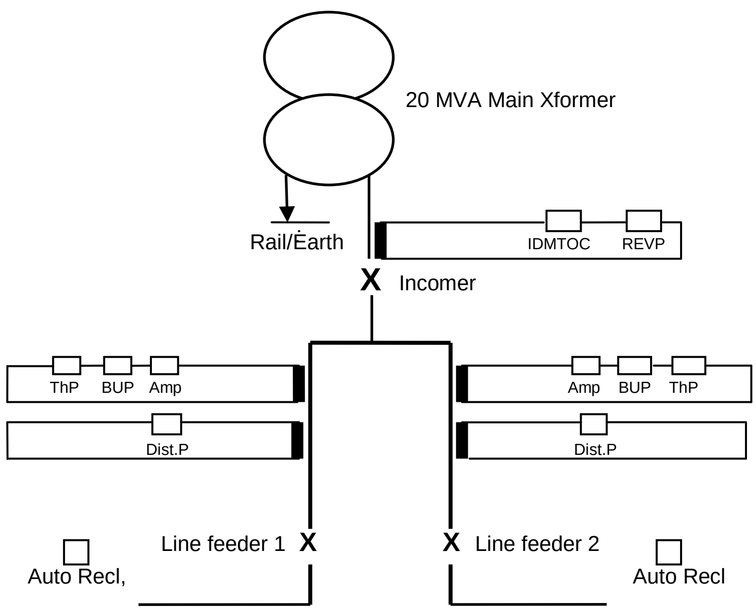


Figure 19.1: Typical layout of secondary breakers (VCB's) in single unit AC Traction substations indicating protection equipment layout..

1 Typical AC traction configuration consists of an incoming VCB supplied from secondary winding of the 20 MVA traction transformer, feeding on to the busbar from which line feeder VCB's supplies the OHTE, the number depending on single or double line sections .

In double unit substations a buscoupler is installed to separate or combine the two busbar sections with instantaneous overload protection in certain designs.

2 The incomer VCB is fitted with an IDMT overload relay in the older subs and in later designs programmable hitech relays to detect any busbar flashover faults and serve as backup protection for the Line VCB's

Reverse power protection is fitted in later designs as well to prevent or limit "backfeed" supplies to Eskom through the main transformer.

3 The line feeder VCB's

Older type substations are fitted with the following protection:

Thermal overload relay: The P & B Golds type relay is generally in use to protect the system in terms of overheating of the transformer and OHTE conductors and operates on a thermal element which is heated by the secondary current from the current transformer to operate in specific time at a pre-set setting.

Backup instantaneous protection: This is in the form of an attracted armature type relay (CAG14 relay from GEC being typically installed), to serve as additional protection in the case of severe high currents caused by short circuits or lightning surges.

Distance protection relays: The YTG 14 from GEC.

In AC electrification the OHTE line has resistance and reactance which depends on the length of the line and construction type. Under fault conditions the "distance" relay compares the phase angle (which is relative to the "impedance" between the supply substation and the fault) between the voltage and current to a preset relay value. Under certain conditions, a fault current being of the same magnitude as a load current (with a fault at the end of the section) can exist and a normal over-current relay will not see this fault whereas the distance impedance relay will interpret the fault to be in different Zones by calculating and comparing the phase angle relative to the impedance of the section. This will ensure minimum tripping time not relative to the fault distance. Please refer to annexure 1 for further detail

In later designs the following protection is installed:

Thermal overload relay: The KCCG type relays are used as a wide range of settings is available to protect the system against load currents overheating the transformer or the OHTE.

Backup instantaneous protection: The KCCG type relays allows for an element to be programmed for this function.

Distance protection relays: The Optimho and Protecta relays.

The principle of distance protection as mentioned above is well catered for in these type of programmable type relays with improved characteristics regarding current sensing and reaction(tripping) times. Additionally the system has adequate facilities to download history of tripping values and times when required.

4 Auto Recloser Relays: The VAR 22 from GEC and the MTVR 51 from Alstom
The auto recloser relay is "started" by a trip action caused by an instantaneous or distance protection relay. It allows one reclosing action for the VCB after a preset time in the order of 30 seconds. If the fault or overload still is not cleared the VCB will then trip to Lockout and after inspection of the line or fault repairs will it be able to close the VCB.

19.3 BASIC PRECAUTIONS

1 All testing to be done under cover of a workpermit**.**

2 Ensure that the potential transformer fuses are removed to prevent backfeed

19.4 TYPES OF THE TEST

1 Magnetization curves and ratio (where possible) on current transformers
2. Secondary current injection to test Instantaneous and thermal overload relays.
3 Simulation test by impedance test set applying voltage, current at different phase angle values on distance protection equipment.
4 Auto Reclosing Relay action.

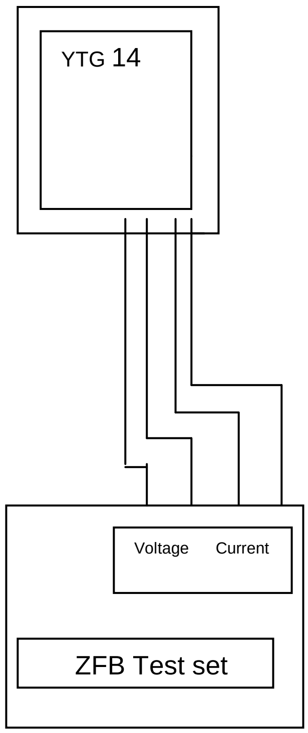
19.5 TEST EQUIPMENT USED

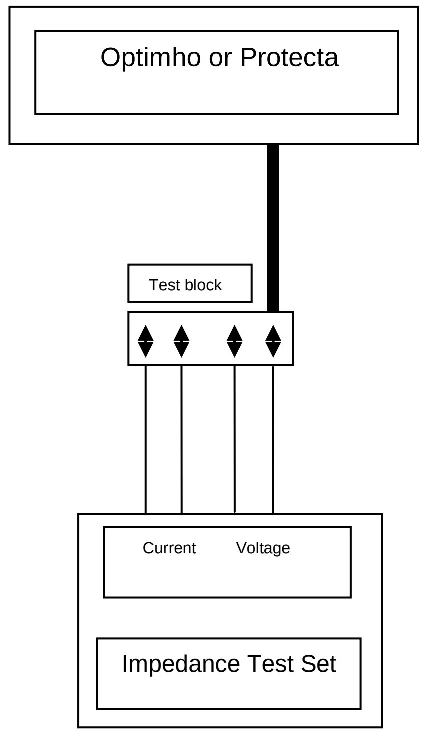
1 Secondary injection test set.
2. Distance Protection YTG 14 relay: ZFB test set
Optimho and Protecta relays: Distance Impedance Test Set.

19.6 THE TEST CIRCUIT

1 For current transformers and overload relays refer to section 08 of this manual.

2 Distance protection relays.





15.7 THE TEST PROCEDURE

1 For Thermal and Instantaneous Overload relay connections, identify the relevant test blocks from the schematic control diagrams referring to section 08 of this manual for secondary injection testing at the prescribed values.
2 For Reverse power relays on the incomer VCB's, apply both voltage (110volt AC) and secondary current at the relay setting to the test block connections, firstly in a forward direction and then in a reverse direction by swapping the polarity of the voltage connection to obtain the tripping value of the current.
3 For Distance Protection on the line feeder VCB's, connect the voltage and current connections to the relevant test terminals and follow the prescribed procedure to confirm the trip values at which the relay is set.
4 Auto Reclosing Relay: After an overload tripping action confirm that the auto recloser recloses the VCB in approximately 25-30 seconds. After initiating a second tripping action immediately after the reclosure the VCB must be tripped to lockout.

15.8 DOCUMENTATION.

1 Complete the relevant test sheets.

15.9 THE RANGE OF ACCEPTABLE TEST RESULTS

1 All values should be within a tolerance of 10 % .

15.10 SPECIAL PITFALLS

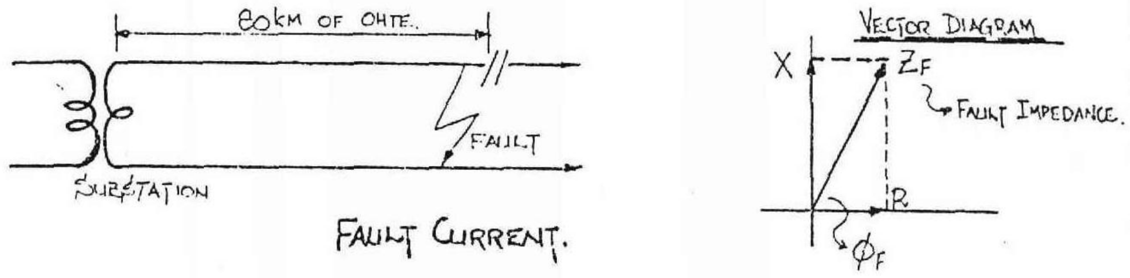
1 Polarities must be correct where voltage is applied in testing reverse power and distance protection relays.

15.11 REFERENCES

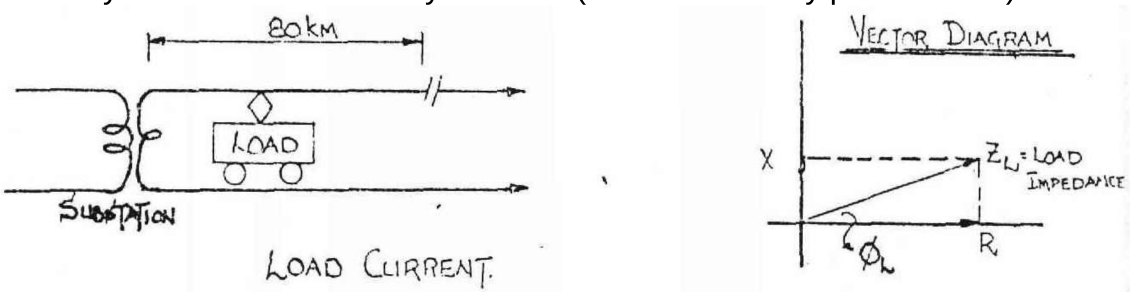
1 PSP Training,: Electrical Power Protection, pp 14.6-14.22
2 Annexure 1 PROTECTION OF OHTE DISTANCE IMPEDANCE PROTECTION (YTG 14 RELAY), Transnet Publication

Annexure 1: PROTECTION OF OHTE DISTANCE IMPEDANCE PROTECTION (YTG 14 RELAY)

An impedance relay is used instead of the normal over-current, as under certain conditions, a load current of the same magnitude as the fault current (with a fault at the end of the section) can be drawn. The distance impedance relay can permit this, by calculating the phase angle and Impedance of the section.

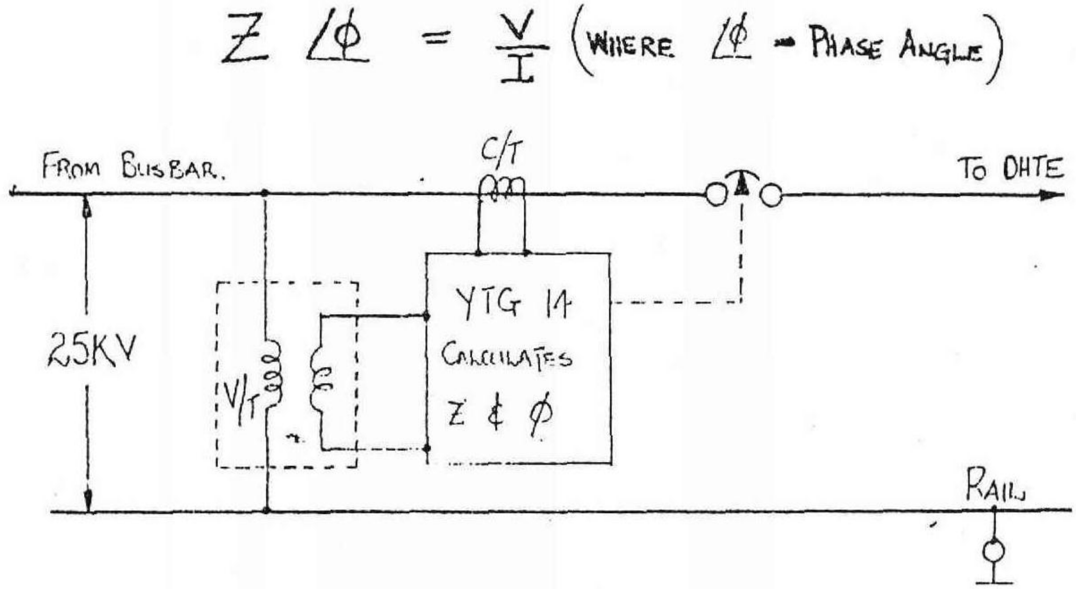


The impedance of the OHTE is highly reactive on a short circuit while the load drawn by a locomotive is mainly resistive (or closer to unity power factor).

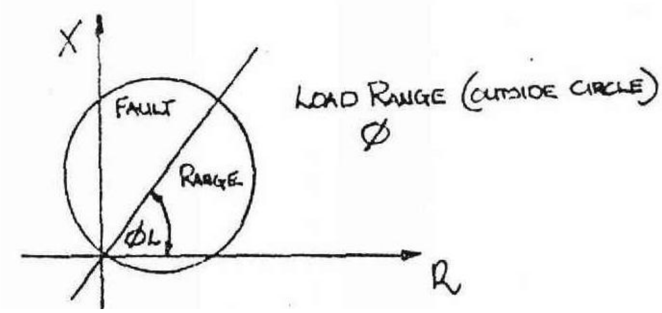


It can be seen that although $Z_L \cong Z_F$, the phase angles Φ_F and Φ_L are not equal: $\Phi_F > \Phi_L$. The YTG relay uses this difference to distinguish whether the current fed into the section is load current or fault current.

The YTG 14 relay calculates the impedance and phase angle from inputs from both the CT and VT

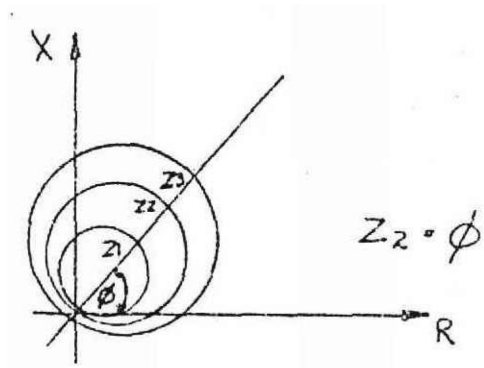


The relay will prevent operation in the whole range of impedances, represented by o circle.

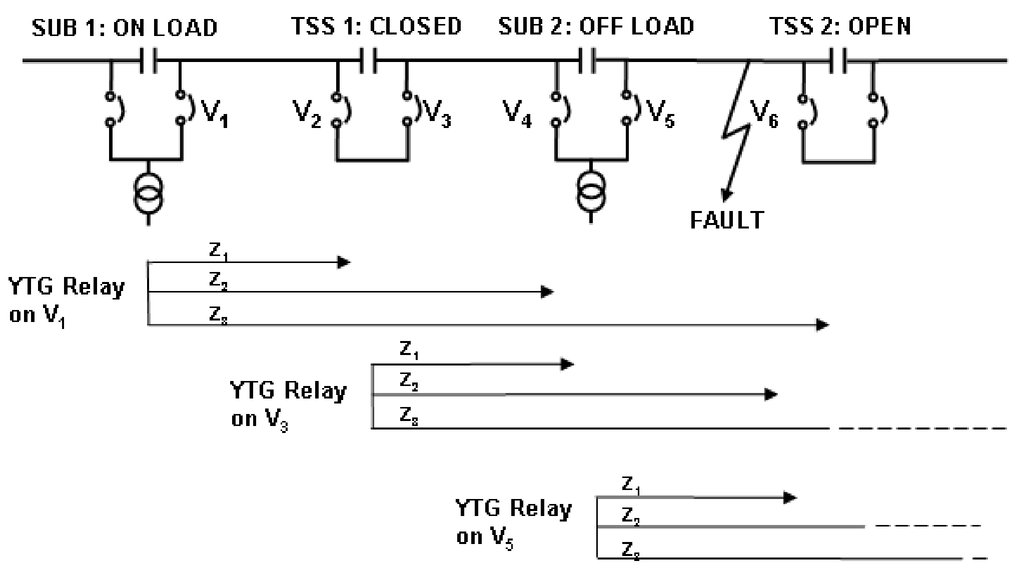


Changing the settings of the relay will change the size of the circle, the position of the mid point of the circle (as determined by the phase angle Φ) and also the time delay before tripping the VCB.

The relay distinguishes between three levels of fault currents (i.e. zones 1, 2 and 3) represented by 3 circles, each with its own time delay (Zone I delay being 0).



Each zone can then be used to protect up to the next VCB (although the relays are not normally set like this).



With a fault as shown, the YTG relay at V_5 will see the fault as a Z_1 fault, and trip immediately. If it fails to trip, the YTG relay at V_3 will see it as a Z_2 fault, and trip V_3 after a time delay. The V_3 relay will therefore act as back up protection for the V_5 relay, the V_1 relay as back up for the V_3 and the V_5 relay, etc.

A special feature of the YTG14 is the “instant trip” facility. This is a circuit arrangement by which the Zone 3 timer is bypassed for a short period after the line becomes ”live” so that immediate tripping takes place if the line is energized on to a zero-voltage fault.

Another feature of the YTG 14 is the memory action which enables the measuring unit to operate for faults which collapse the voltage to zero. This consists of an LC circuit tuned to the system frequency which stores the pre-fault voltage for a short time.

Track Feeder V.C.B.s have one auto reclose operation approximately 5 seconds after a trip. This operates when the Track Feeder is selected to remote control only. On manual selection the autoreclose circuit is bypassed and only one trip will take place, with no autoreclose operation.

PROTECTION OF OHTE OVERLOAD PROTECTION

The YTG relay will not protect the OHTE against sustained overloads.
The OHTE is protected against sustained overloads by a thermal overload relay, which is basically a bi-metal relay fed by a CT. A "P&B Golds" relay is used as this relay's characteristics closely matches the OHTE thermal characteristics.
Operation of this relay will trip the V.C.B.

SECTION 20

SIGNAL SUPPLY & DISTRIBUTION SUBSTATIONS

20.1 THE FUNCTION IN THE ELECTRICAL SYSTEM

1 Signal supply substations are situated along the main line sections to supply power to signal relay room stepdown points by means of three phase transmission lines at either 6.6 or 11 kV. Substation outdoor yard layouts are similar to Traction substations as seen from Figure 20.1 below with the supply authority EHV supply stepped down to the above voltages.

See Figure 20.2 for a typical switching diagram used in a T supply configuration

Distribution substations distributes power supplied by local authorities or Eskom to Transnet stations, yards, workshops and other complexes in towns and cities. Either 6.6 or 11 kV equipment are installed in ringfeed systems with overhead transmission line or underground cable systems. See Figure 20.3 for a diagram of a typical system.

In some installations Signal transmission lines is supplied from Distribution systems depending on the layout..

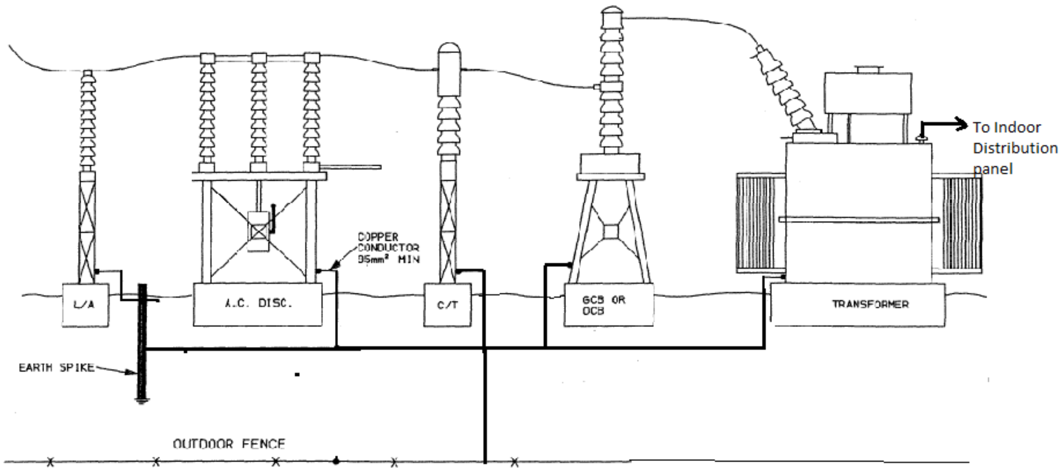


Figure 20.1: Signal Supply Substation outdoor yard layout

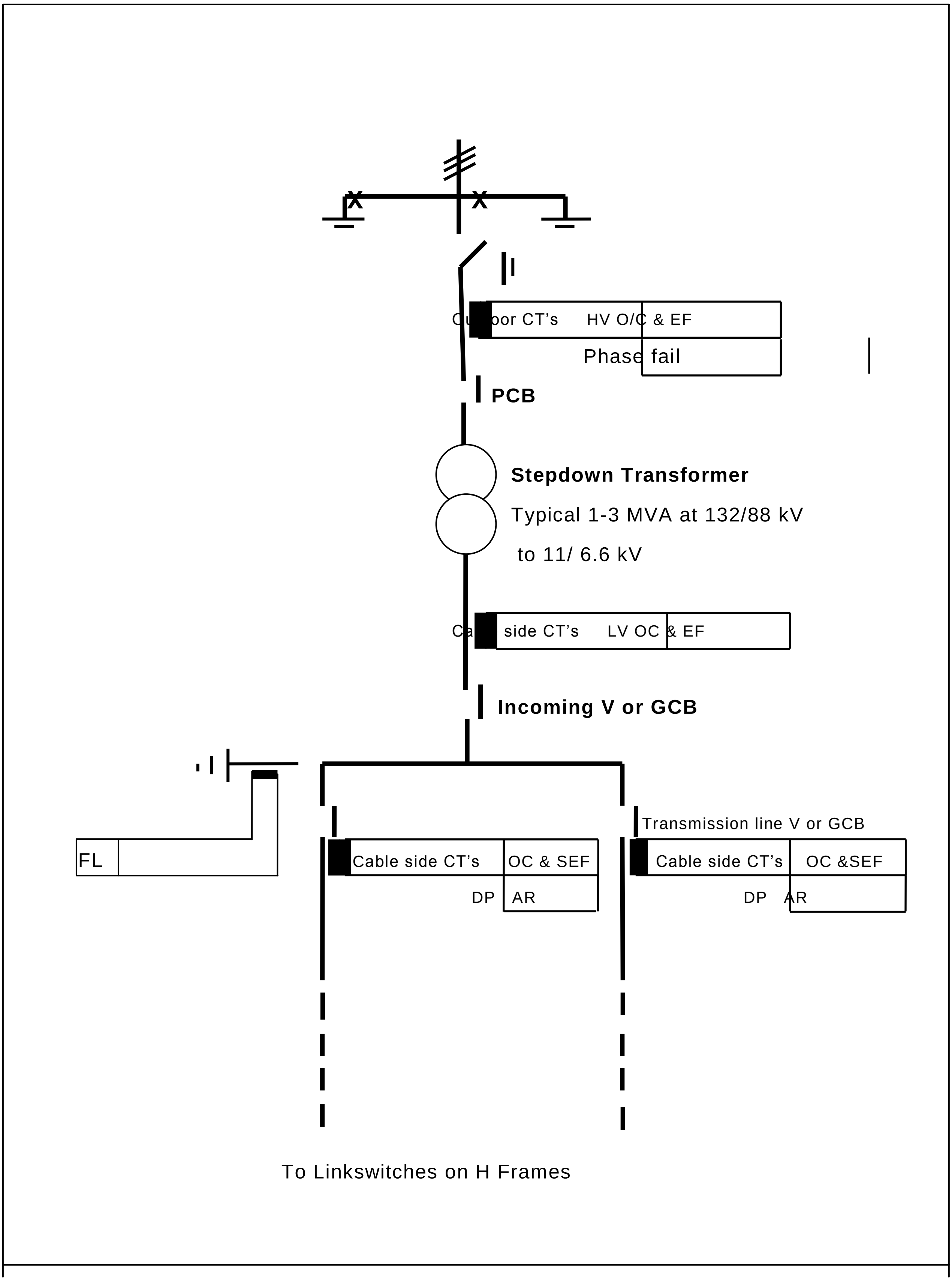


Figure 20.2: Typical Signal Supply Substation Diagram

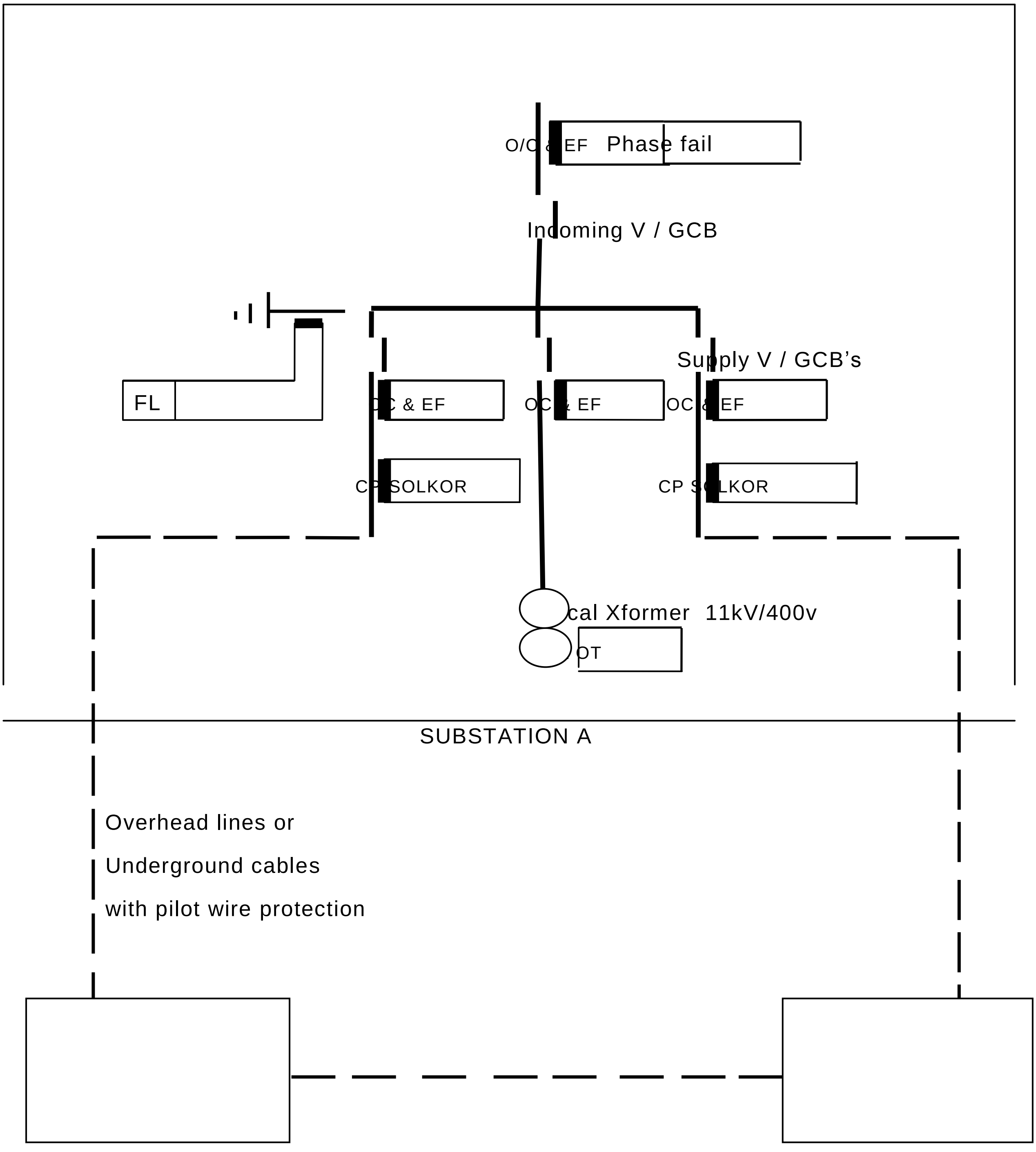


Figure 20.3: Typical Diagram of Distribution Supply Substations in a Ringfeed Configuration.

20.2 PRINCIPLES OF OPERATION

Different elements of protection are applied in Signal and Distribution substations.

1 General overcurrent, earth fault protection are provided by various relay makes and types operating on the magnetic disc for IDMT (Inverse Definite Minimum Time) curves and attracted armature types for instantaneous operation. Most common in the older substations is the GEC CDG type but in upgraded or new installations new generation programmable relays are installed such as the Siemens Argus and Strike Technology FP04 with different elements available for overcurrent and earthfault (normal or sensitive) functions.

The IDMT (Inverse Definite Minimum Time) principle is demonstrated below in an extract from *Electrical Power Protection by Les Hewitson*:

Co-ordination by Time Grading

10.1 Protection Design Parameters on Medium & Low Voltage Networks

Although not appreciated by many engineers, the widespread use of Inverse Definite Minimum Time Overcurrent and Earth Fault (IDMT OCEF) Relays as the virtual sole protection on medium and low voltage networks requires as much detailed study and applications knowledge as does the more sophisticated protection systems used on higher voltage networks.

10.1.1 Introduction

Traditionally, design engineers have regarded medium and low voltage networks to be of lower importance from a protection view, requiring only the so-called simpler type of IDMT Overcurrent and Earth fault relays on every circuit. In many instances, current transformer ratios were chosen mainly on the basis of load requirements, whilst relay settings were invariably left to the commissioning engineer to determine. However, experience has shown that there has been a total lack of appreciation of the fundamentals applicable to these devices as numerous incidents have been reported where breakers have tripped in an uncoordinated manner leading to extensive network disruption or failed to trip causing excessive damage, extended production downtime and in some cases loss of life.

This chapter reviews some of the fundamental points for the design engineer to watch for in planning the application of IDMTL OCEF protection to Medium Voltage switchboards and networks.

10.1.2 Why IDMT?

To achieve selectivity and co-ordination by time grading two philosophies are available, namely:

- Definite Time Lag (DTL), or
- Inverse Definite Minimum Time (IDMT)

For the first option, the relays are graded using a definite time interval of approximately 0.5 seconds. The relay A at the extremity of the network is set to operate in the fastest possible time, whilst its upstream relay B is set 0.5 seconds higher. Relay operating times increase sequentially at 0.5 second intervals on each section moving back towards the source as shown in Figure 10.1.

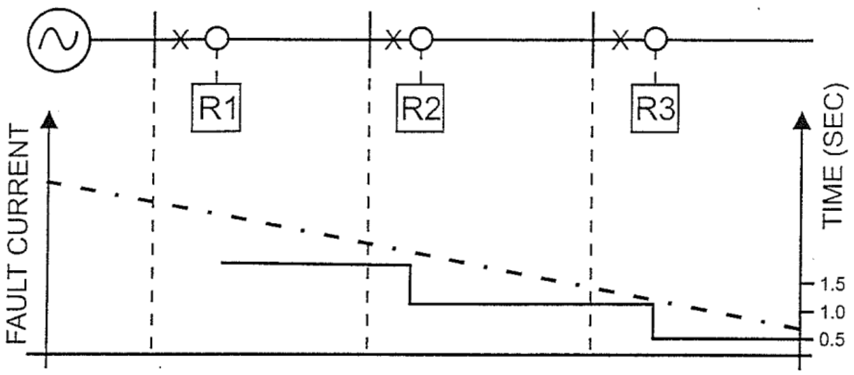


Figure 10.1
Definite Time Philosophy.

The problem with this philosophy is the closer the fault to the source, the higher the fault current, the slower the clearing time – exactly the opposite to what we should be trying to achieve!

On the other hand, inverse curves as shown in Figure 10.2 operate faster at higher fault currents and slower at the lower fault currents, thereby offering us the features that we desire.

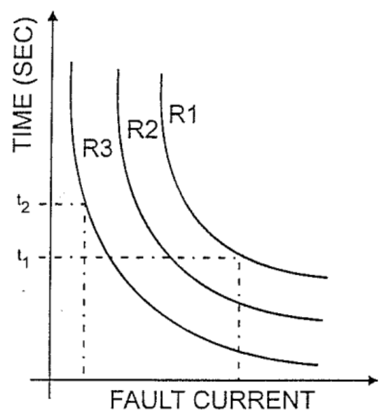


Figure 10.2
Inverse Definite Minimum Time.

With modern programmable relays IDMT Curves applicable to electromechanical relays can easily be obtained from the wide range of curves available.

Typical connections for overcurrent and earth fault protection is shown below in figure 20.4.

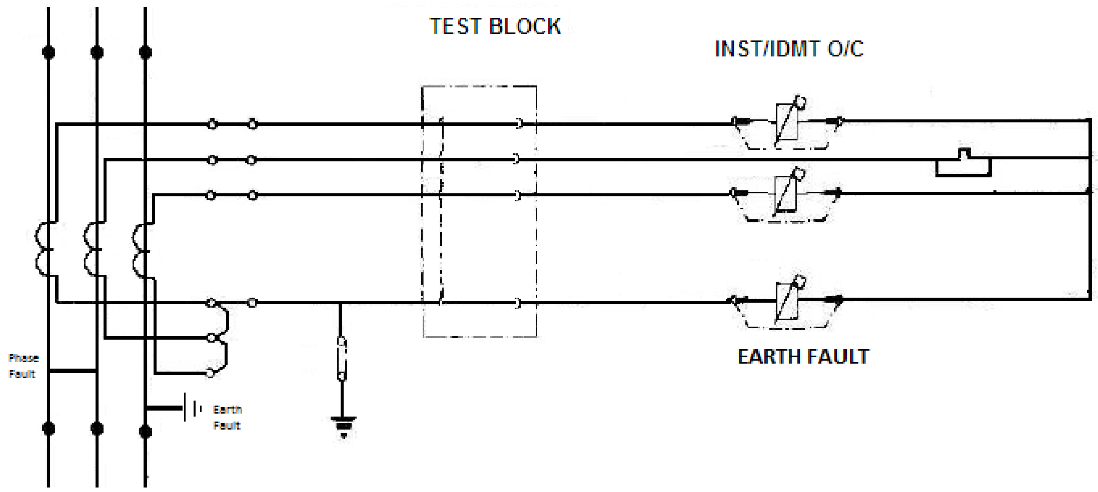


Fig 20.4 Typical connections for general O/C and E/F protection

A phase to phase fault will circulate current through the high set overcurrent elements and trip on instantaneous and with a large overcurrent the IDMT element will trip after a preset time .Overcurrent settings ranges from 50 to 200% with timing elements from 0.05 to 1 second.

A phase to earth fault will circulate current from the CT through the high set element which will not react at low current values, and to earth through the low set element tripping the earth fault element. Earth fault settings ranges from 10 to 40% with timing elements from 0.05 to 1 second.

2 Sensitive Earth Fault is installed on circuit breakers supplying Transmission lines to ensure protection in case of short circuit faults at long distances from the supply point. Due to the available lowest setting of 10% on the normal earth fault element and relatively high load current transformer ratio's a distant fault will not trip the relay due to the impedance limiting the fault current. The Sensitive Earth Fault relay facilitates current settings from 0.4 to 40% and time settings from 0.1 to 99 seconds. A typical setting is at 2% for current at a time of 10 seconds.

3 Cable protection is mostly provided by SOLKOR relay systems which belongs to the circulating current class of differential protections which can be recognised by two main features. Firstly, the current-transformer secondaries are arranged to produce a current circulating around the pilot loop under external fault conditions balanced wire principles. Secondly, the protective relay operating coils are connected in shunt with the pilots across points which have the same potential when the current circulates around the pilot loop.

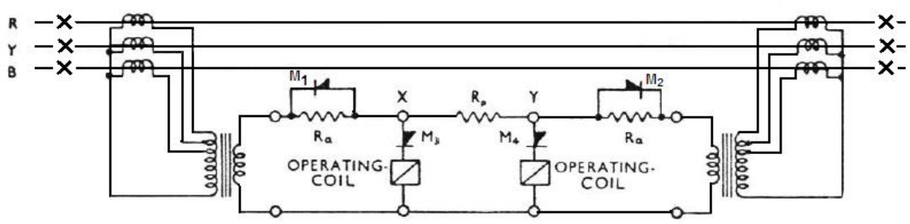


Fig 20.4 Connection of SOLKOR cable protection equipment.

Normal 3 phase load currents flows through the cable from point A to B. The resulting secondary currents flowing in the summation transformers in a balanced system. In the case of a phase or earth fault the currents at point A and B will not be equal causing the summation winding of the faulty phase to be out of balance allowing current to flow from the secondary winding of the summation transformer to the operating coil tripping the relay. Padding resistors are installed to compensate for differences in pilot wire resistance which should be in the order of 1000 ohms. Refer to Solkor annexure for further study.

4 Transformer protection: Signal supply and Distribution transformers may have Buchholtz relays, and Oil and/or Winding temperature protection depending on the rated KVA.

5 Phase fail protection This provides a trip facility to the HV incoming breaker in case of failure of the Supply Authority supply. The "AC Fail/Available" indication to Electrical Control" is obtained from this relay as well. Modern relays provides for phase rotation checks as well.

20.3 BASIC PRECAUTIONS

1 All testing to be done under the cover of a work or test permit.

2 Safety measures to be in place during primary current injection tests on Solkor equipment as high voltages may be generated on the pilot cable connections.

20.4 TYPES OF THE TEST

1 Overcurrent and earth fault protection (Normal and Sensitive)

Current transformers: Ratio and Magnetization curves. (Refer to Section 4)

Relays: Primary or Secondary Current injection and timing tests.

2 Sensitive Earth fault:

Current transformers: Ratio and Magnetization curves. (Refer to Section 4)

Relays: Primary or Secondary Current injection and timing tests.

3 SOLKOR Cable Protection

Current transformers: Ratio and Magnetization curves. (Refer to Section 4)

Relays: Current injection and stability tests.

4 Transformers

Buchholtz Relay: Air injection (Refer to Section 6)

Oil or Winding Overtemperature: Simulation tests (Refer to Section 7)

5 Phase fail Protection.

20.5 TEST EQUIPMENT REQUIRED

1 Primary/Secondary Injection Test Set

2 Multimeters

3 Set of Light and Heavy test leads.

4 Megger 500v (for SOLKOR pilots cables)

20.6 THE TEST CIRCUITS

1 & 2 Overcurrent and Earth Fault (incl. Sensitive Earth Fault) protection

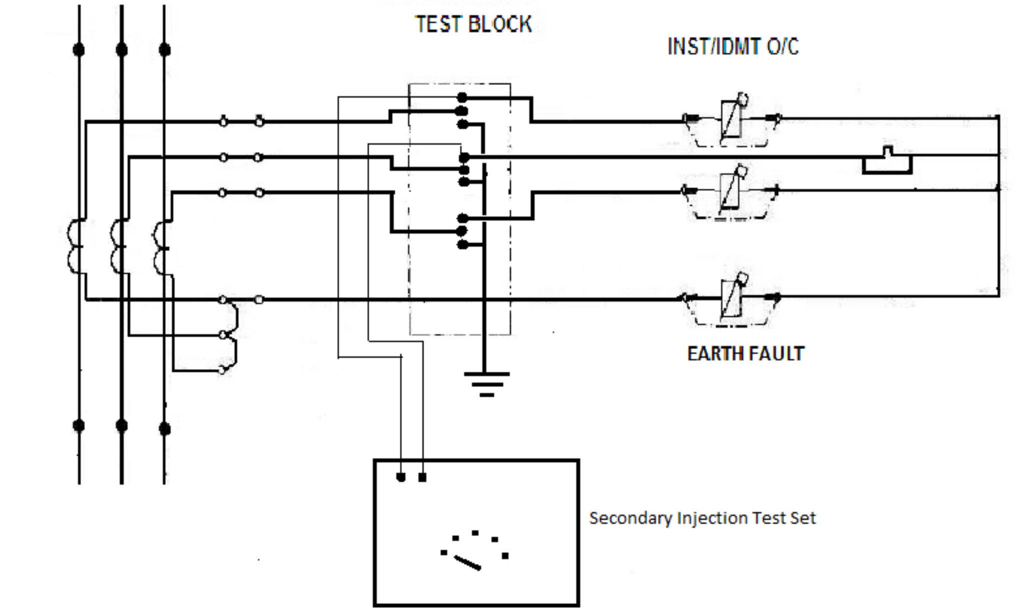


Figure 20.5: Testing O/C Red to Yellow phase by secondary injection

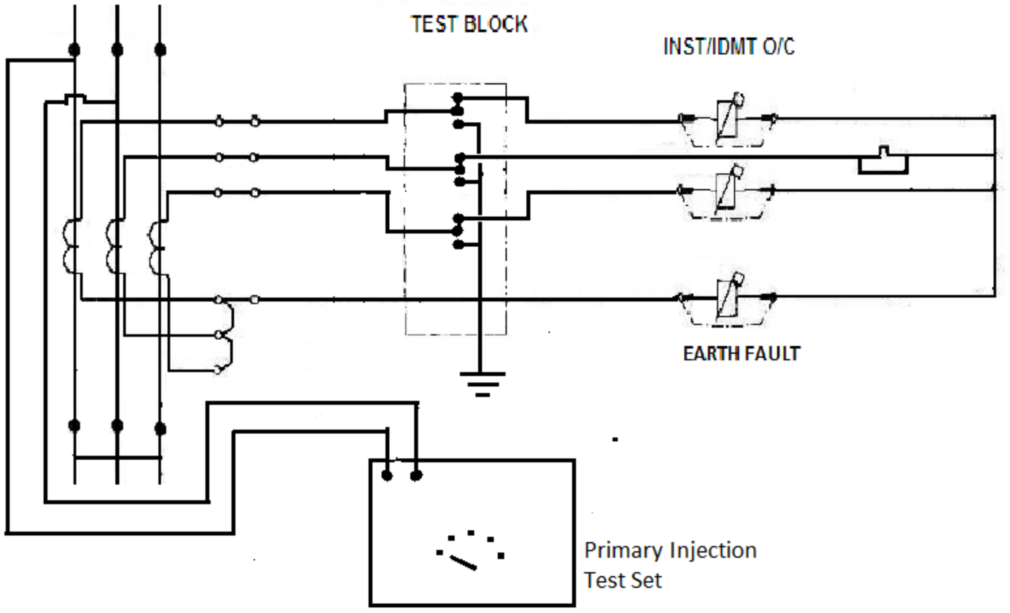


Figure 20.6: Testing O/C Red to Yellow by Primary Injection.

20.6 THE TEST CIRCUITS (ctnd)

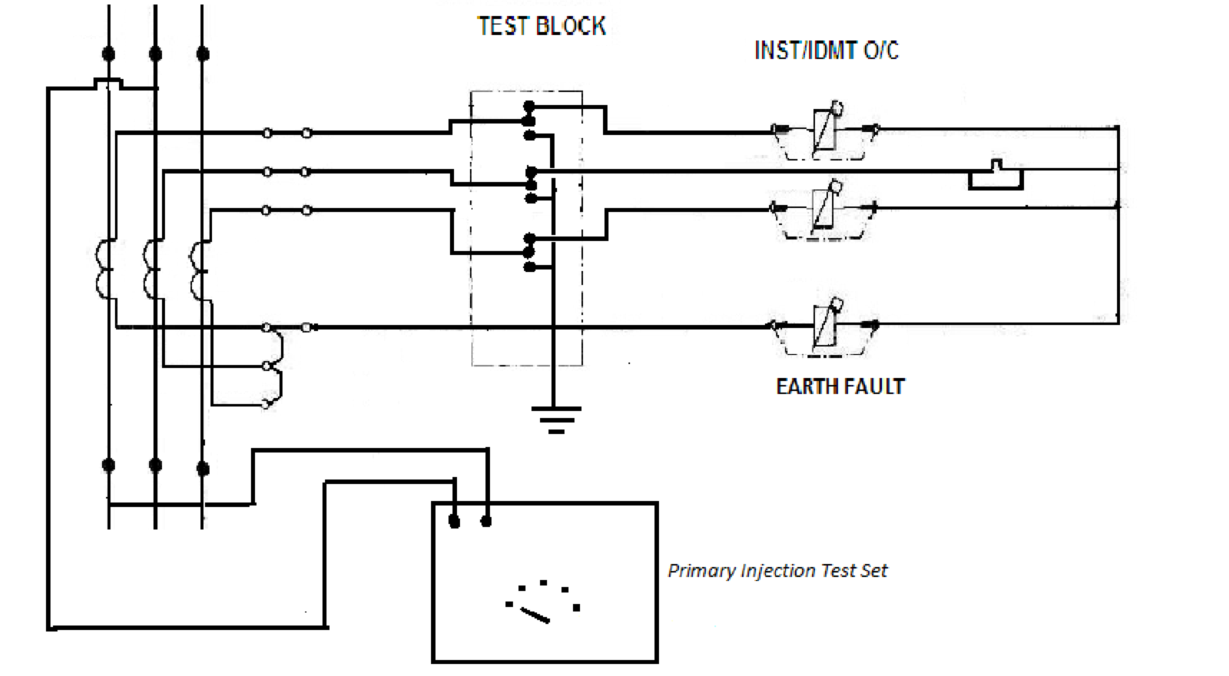


Figure 20.8: Testing E/F Yellow phase by primary Injection.

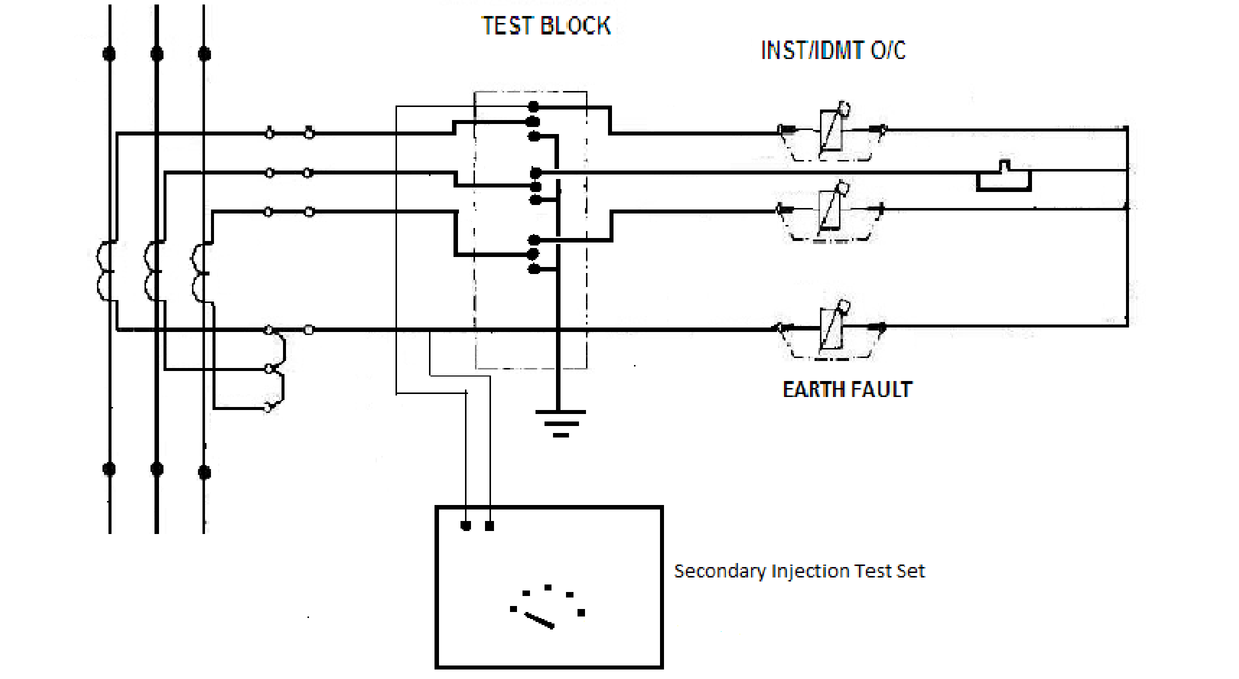


Figure 20.6: Testing E/F from Redto Earth by Secondary Injection

20.7 THE TEST PROCEDURE

Overcurrent protection

IDMT (Instantaneous) Overcurrent elements are tested by injection of either primary, secondary or test winding current at multiples of the relay setting. Refer to *Figure 20.5 and 6* for connections for secondary and primary injection respectively. Relay trip times are recorded at 2, 4 and 6 times the full load current by setting the current at the required value and switching on the test set controls for current and timing circuits. For primary and secondary injection test leads are connected across a pair of phases in turn, i.e. Red to Yellow, Red to Blue and Yellow to Blue.

Earth fault and sensitive earth fault protection

Earth fault elements are tested by similar injection with leads connected from Red, Yellow and Blue phase individually to Earth at similar Time Multiplier Settings recording the trip times as above. Refer to *Figure 20.7 and 8* for connections for secondary and primary injection respectively.

During factory tests the relay is tested at a number of plug and time multiplier settings. With field commissioning and routine tests it is only tested at the prescribed settings as calculated according to the conditions of application.

Current and Time Multiplier Settings

Older type relays eg CDG: IDMT setting for current is selected on the plug setting faceboard with the time selected by adjusting the magnetic disc travel on the time setting disc. High speed elements are adjusted by spring tension mechanisms.

On modern programmable relays different elements are selected for time delayed and instantaneous protection with a wide range of tripping curves available. A range of output relays are available for tripping, lockout and alarm functions. The history of fault tripping is obtainable as well as continuous load current displays.

Typical makes installed in new and refurbished substations are:
MiCom from Alstom, Argus from Siemens Reyrolle and FP1000 or FP04 from Strike Technologies.

20.6 THE TEST CIRCUITS (ctnd)

3 SOLKOR Cable protection

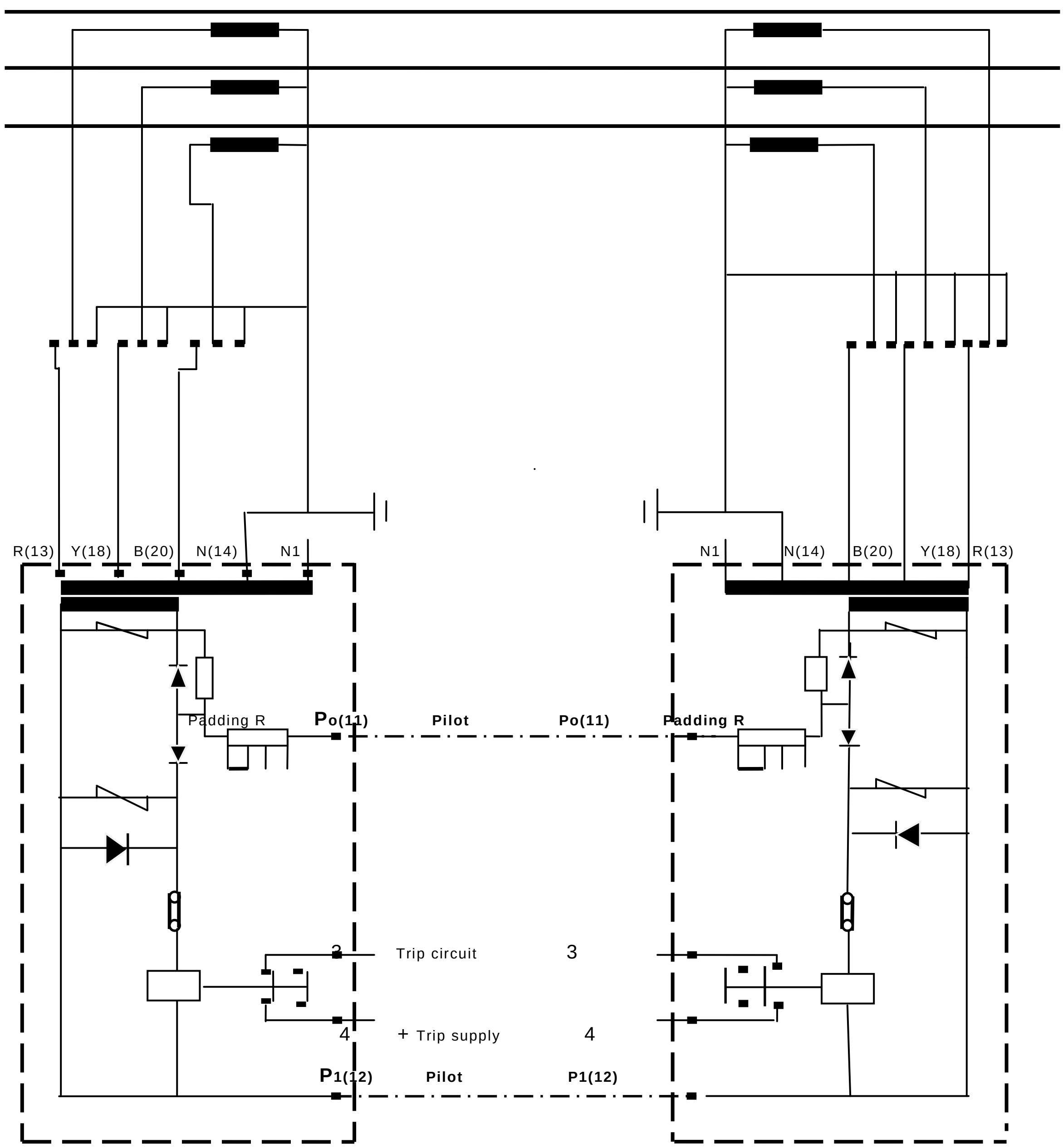


Figure 20:9:Typical schematic diagram for a SOLKOR feeder protection system.

20.7 THE TEST PROCEDURE

General Connection check.

Visually inspect and confirm relay and connections to be as shown in *Figure 20:9*. Confirm starpoint of current transformers to be on cable side at both ends of cable. The N(14) tap terminal is normally connected to earth with the N1 used where extreme low settings are required.

Insulation of secondary wiring

With all fuses, earthing connections and -links removed test the insulation of the secondary wiring to earth by applying the 500v megger to be 5 Mohms minimum.

Pilot wire tests

Insulation tests: With the pilot wires disconnected at both ends, test the insulation by applying the 500 volt megger to the individual cores to earth to be minimum at 5 Mohm during commissioning and 1 Mohm with routine tests.

Loop resistance test: With the pilot cores shorted at one end measure the loop resistance to be more than 1000 ohms. Add padding resistors with the same value at both ends determining the value by applying the calculation standard of 0.5(1000-Rp) where Rp is the total loop resistance of the pilot cores.

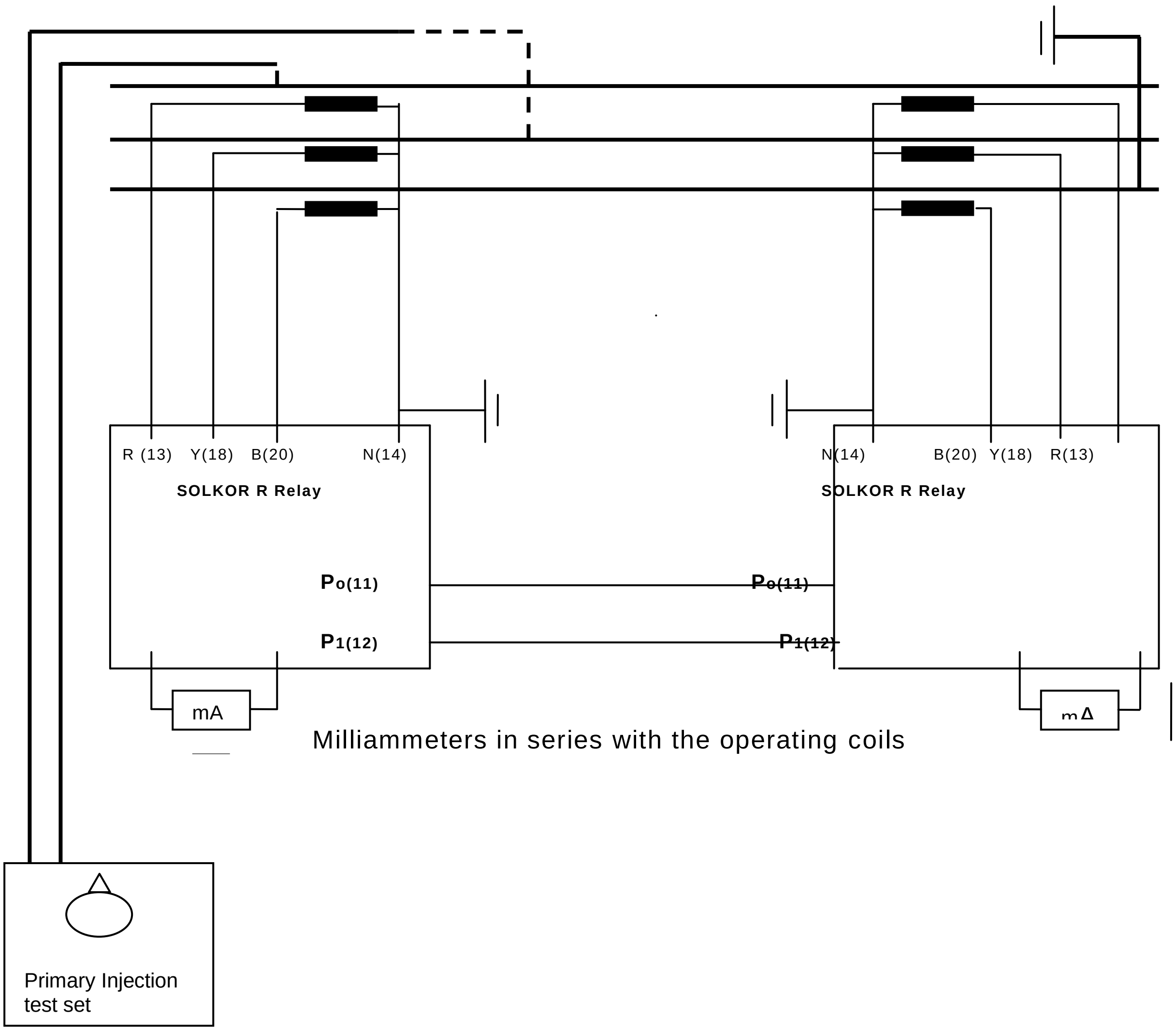


Figure 20:10: Typical test connections for primary injection for an earth fault and phase fault (in dotted lines) setting tests.

Fault setting test

The primary injection test with connections as shown in *Figure 20.10* is done to confirm that the overall fault settings are in order with the pilot cores correctly connected. This will prove that the secondary wiring from the current transformers to the summation transformers are connected as required at each end as well.

Gradually increase the primary current until the local relay operates recording the current value in table 1 confirming it to be as shown in column 3. If the system is operating correctly the current in the operating coil of the remote relay should be half of the current in the operating coil of the local relay. With an open circuit in the pilot cores the local relay will operate at approximately half of the percentage listed in column 3 of Table 1. Repeat the test for the yellow and red phase to earth, confirming the required percentages.

Similarly the test is done for phase to phase fault with connections as per dotted lines for red to yellow phase in above test connection diagram.

Repeat the primary injection test from the remote substation and confirm that the most sensitive earth fault setting at both ends refer to the same phase.

5 Phase fail Protection

Tested by disconnecting connections or removing fuses depending on wiring and Vt supply arrangements. Phase rotation is tested by changing two phase connections at the bottom end of fuses or MCB,s

20.8 DOCUMENTATION

1 Complete the relevant test sheet BBB0346 Version 2 for qvercurrent and earthfault.

Complete the relevant test sheet XXX000for SOLKOR cable protection.

20.9 THE RANGE OF ACCEPTABLE TEST RESULTS

1 In general a tolerance of 10% for current values and 5% for Minimum time values are applicable .

20.10 SPECIAL PITFALLS.

1 Confirm proper test connections at all times as high resistance connections can lead to difficulties in reaching required current values.

THEORY AND PRACTICE OF PILOT WIRE PROTECTION

Principle of a Solkor feeder protection relay [1]

Solkor R belongs to the circulating current class of differential protections which can be recognised by two main features. Firstly, the current-transformer secondaries are arranged to produce a current circulating around the pilot loop under external fault conditions. Secondly, the protective relay operating coils are connected in shunt with the pilots across points which have the same potential when the current circulates around the pilot loop. In this particular scheme equipotential relaying points during external fault conditions exist at one end during one half cycle of fault current, and at the other end during the next half cycle. During half cycles when the relay at either end is not at the electrical midpoint of the pilot system the voltage appearing across the relay is in the reverse direction to that required for operation.

At each end of the feeder the secondaries of the current transformers are connected to the primary of the **summation transformer**. For various types of current distribution in the three current transformers, a single phase quantity appears in the summation transformer secondary winding and is applied to the pilot circuit. By this means a comparison between the currents at each end of a three phase line is effected over a single pair of pilot wires on an equivalent single phase basis. The tappings on the summation transformer primary have been selected to give an optimum balance between the demands of fault setting and stability.

Principle of a summation transformer [2]

The main purpose of the summation transformer is to enable either balanced or unbalanced three phase currents to be re-produced as a single phase quantity. This makes it possible in a feeder protection to compare the various fault currents on a single phase basis over only two pilot cores. As this device is essentially a transformer it can also be used to reduce the burden imposed by the pilot circuit on the current transformers by changing the impedance levels. In addition, it provides isolation between the current transformers and the pilot circuit and makes it possible to have the current transformers earthed and the pilots unearthed.

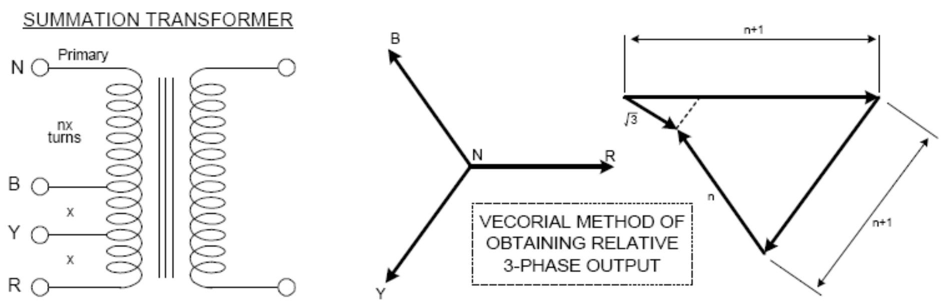


Fig X.1

Fault Type	Effective Primary Ampere-turns	Relative Output
R-E	I(nx + x + x) = Ix. (n+2)	n+2
Y-E	I(nx + x) = Ix. (n+1)	n+1
B-E	I(nx) = Ix. (n)	n
R-Y	I(x) = Ix. (1)	1
Y-B	I(x) = Ix. (1)	1
B-R	I(2x) = Ix. (2)	2
3P	I(√3x) = Ix. (√3)	√3

Table X.1

Circuitry

The basic Solkor-R protective circuit is that shown in Fig. X2. The protective relay operating coils are connected in shunt with the pilots, across points which have the same potential when current circulates round the loop. In this scheme, equipotential relaying points during external faults exist at one end during one half-cycle of fault current and at the other end during the next half-cycle. During the half-cycles when the relay at either end is not at the electrical mid-point of the pilot system, the voltage appearing across the relay is in the reverse direction to that required for operation.

At each feeder end, the secondaries of the line current transformers are connected to the primary of a summation transformer. For various types of current distribution in the three current transformers, a single phase quantity appears in the summation transformer secondary and is applied to the pilot circuit. Thus the comparison of currents entering and leaving the feeder is on a single phase basis. In the basic diagram the resistance of the pilot cable is represented by R_p, the rest of the loop comprising the. resistors R_a and the rectifiers M_1 and M_2. The operating elements which are made unidirectional by rectifiers M_3 and M_4, are connected in shunt with the pilots at points X and Y.

When a fault occurs external to the protected zone, an alternating current circulates around the pilot loop. On alternate half-cycles one or other of the resistors R_a at the two ends of the pilot is short-circuited by its associated rectifier M_1 or M_2, and the total resistance in the pilot loop at any instant is therefore substantially constant and equal to R_a+R_p. The effective position of R_a however, alternates between the two ends being dependent on the direction of current. This change in position of R_a makes the voltage distribution between the pilot cores different for successive half-cycles of the pilot current, the effective circuits on successive half-cycles being shown in Fig. X.2 at (a) and (b).

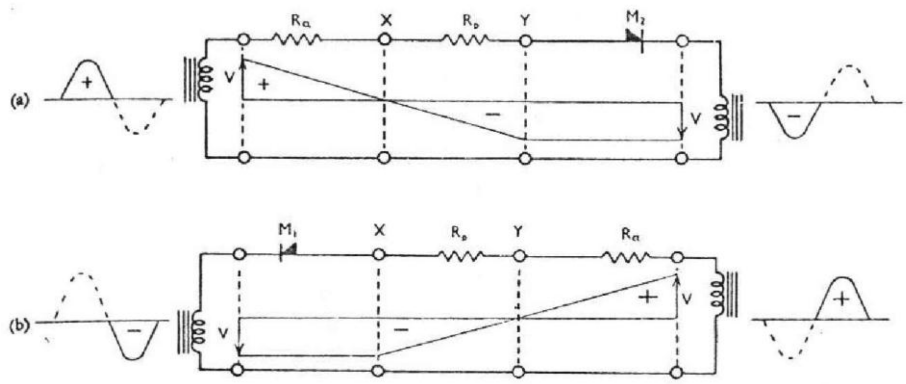


Fig.X.2.-Behaviour of basic circuit under external fault conditions.(a) and (b) show effective circuits during alternate half-cycle.

These diagrams indicate also the resulting potential-gradient between pilot cores when R_a is equal to R_p and it will be seen that the voltage across the relays at points X and Y is either zero (because the relay is at an electrical mid-point) or in the reverse direction for conduction of current through rectifier M_3. Therefore, when R_a=R_p, a reverse voltage appears across the relay circuit during one half-cycle and zero voltage during the next. The voltage across each relaying point X and Y during a complete cycle is shown in Fig. X.3 at (a).

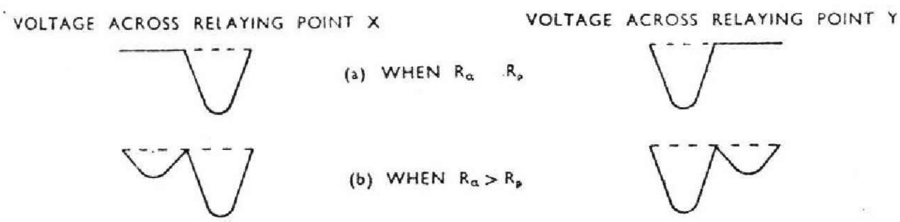


FIG X.3.-Voltage across relaying points X and Y during one cycle of external fault current

In practice, resistors R_a are made greater than the pilot loop resistance R_p and this causes the point of zero potential to occur within resistors R_a as shown in Fig. X.4 and the voltage across X and Y throughout a complete cycle is now that shown at (b) in Fig. X.3.

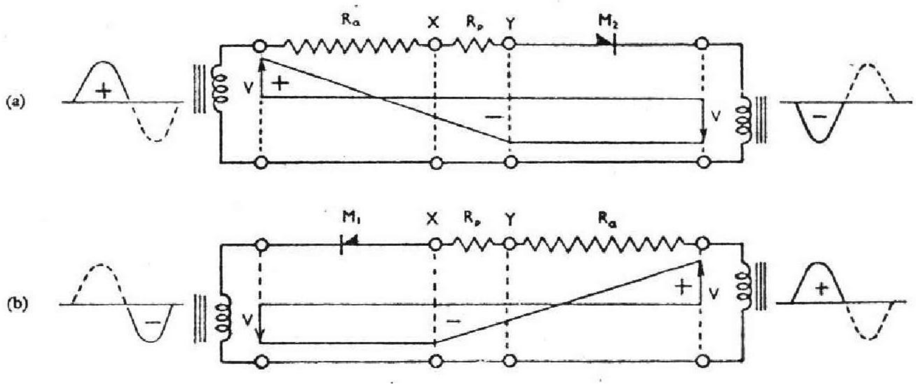


Fig.X.4.-Behaviour of basic circuit under external fault conditions when R_a is greater than R_p. (a) and (b) show effective circuits during alternate half-cycles

Thus, instead of having zero voltage across each relay on alternate half-cycles, there is on both half-cycles a voltage in the reverse direction to that required for operation and as this voltage must be overcome before operation can take place the effect is to enhance the stability on through faults.

When a fault occurs within the protected zone and with current fed equally from both ends, the effective circuits during successive half-cycles are those shown at (a) and (b) in Fig. X.5. From this it is seen that

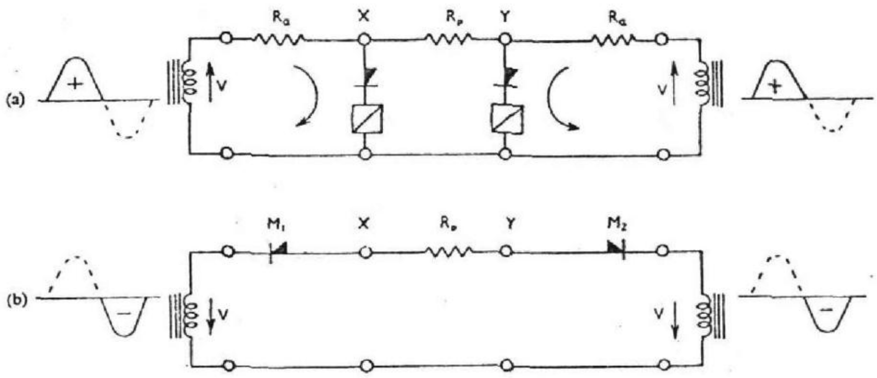


Fig. X.5.-Behaviour of basic circuit under internal fault conditions fed from both ends. (a) and (b) show the effective circuits during alternate half- cycles.

pulses of current pass through each relay on alternate half-cycles and the relays at both ends will operate. If the current is fed from one end only, the relay at the remote end (in series with the pilot loop resistance R_p) is energised in shunt with the relay at the feeding end. The relay at the feeding end operates at the setting current and the relay at the remote end at approximately 23 times the setting current. Providing therefore, that the fault current is not less than 23 times the fault setting, the relays at both ends operate to completely isolate the circuit.

Fig. X.6 is a schematic diagram of the complete protective system. All schemes of differential protection for feeders so far described have required the use of pilot cables. When a feeder is of any length this can be costly and is rarely economical when the line is greater than 15 to 20 miles in length.

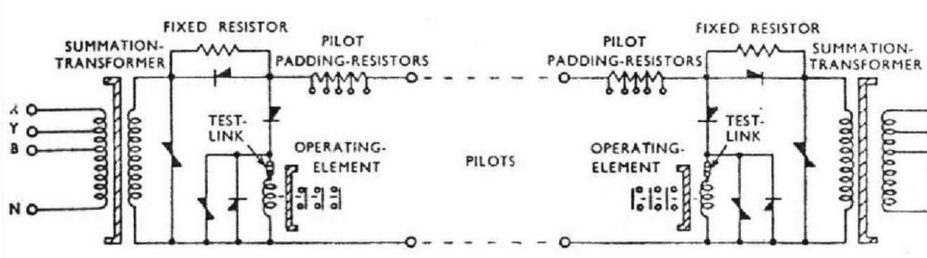


Fig.X.6.-Schematic diagram of complete "Solkor-R" protective system

It is natural, therefore, that a scheme or schemes should be sought in which discriminating protection is obtained without the use of pilot cables and two such schemes which have been available for a number of years are those known as "Distance" (or "Impedance") and "Carrier Current". The complexity of the modern versions of both are such as to make it impossible to give other than a brief indication of the basic principles.

Current Transformer Requirements

The main requisite is that the saturation voltage of the current transformers should not be less than that given by the formula:

$$V_k = \frac{50}{I_n} + \frac{I_F}{N}\left(R_{CT} + 2R_L\right)$$

Where I_n = Rated current of Solkor Rf relay.

I_F = Primary current under maximum steady state THROUGH FAULT conditions.

N = Current Transformer ratio.

R_{CT} = Secondary resistance of the current transformer

R_L = Lead resistance between the current transformers and the Solkor R/Rf, per phase.

For the above purpose the saturation voltage i.e. the knee point of the magnetising curve, may be taken as that point on the curve at which a 10% increase in output voltage requires 50% increase in magnetising current.

To ensure good balance of the protection the current transformers at the two ends should have identical turns ratios. Close balance of the ratio is provided by current transformers to IEC60044: pt1, class px, whose ratio error is limited to ±0.25% and these CTs are recommended to meet the above requirements.

It is recommended that no other burdens should be included in the current transformer circuit, but where this cannot be avoided the additional burden should be added to those listed when determining the current transformer output voltage required.

In addition to the above, the secondary magnetising currents of the current transformers at different ends of the feeder should normally not differ by more than $I_N/20$ amperes for output voltages up to 50/I Volt where I = rated current of Solkor Rf relay. This criteria is applied to quantify matching of the transient response of the two CTs so that relay operations do not occur due to differing responses of the CTs to normal load switching or the incidence and clearance of out of zone faults. This condition is usually easily satisfied by modern CTs of similar size since the magnetising current is usually a lower value. Care should be taken when applying a new CT to be paired with existing CT and also when interposing CTs are required to match CT ratios.

The fault current used for the above calculation should be the THROUGH FAULT level. This condition must be considered to ensure that the relay will not be caused to operate for through faults due to secondary differential current being created by the failure of the CT to measure correctly due to core saturation. During a high level internal fault the relay will operate before the saturation effect becomes significant. The THROUGH fault level is often not readily available and may be significantly different to the source Busbar fault level which is commonly quoted incorrectly based on switchgear rating rather than on the actual current level which is limited by system impedances. The remote end fault level will be distorted by any parallel infeed or backfeed and is only equivalent to the through fault level for truly radial systems.

REFERENCES

1. Siemens 7PG21 Solkor Rf product technical manual.

2. J&P Switchgear book. R.T. Lythall. Newes-Butterworths.

SECTION 21

VOLTAGE TRANSFORMERS

21.1 THE FUNCTION OF THE DEVICE IN THE ELECTRICAL SYSTEM

1 Voltage transformers are used in the electrification systems as follows:

DC substations: Loose standing Voltage transformers is normally installed in the Eskom Yard to provide a supply is received from Eskom for metering as well as ”AC Fail/Available” indication to “Control”.

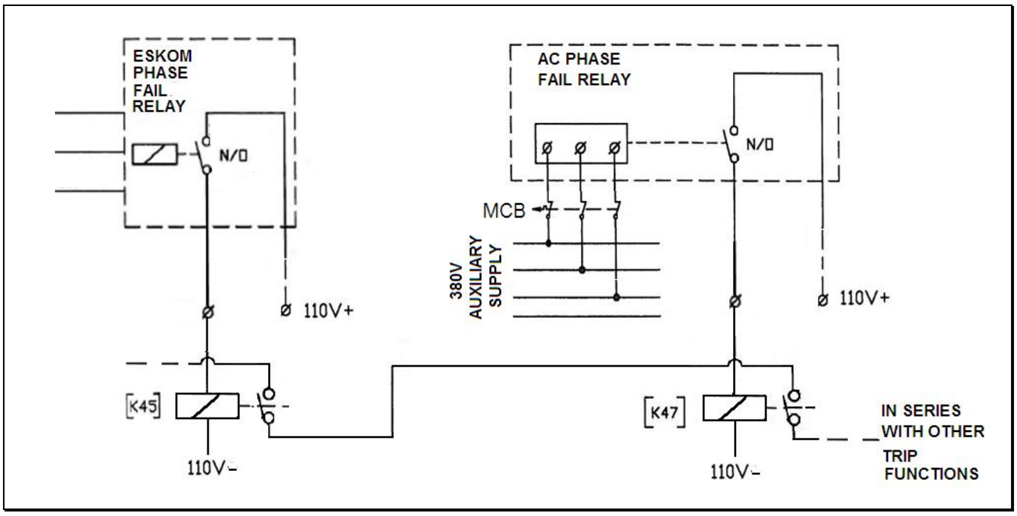


Figure 21.1: VT supply from Eskom VT utilised for “AC Fail/Available” with alternative from auxiliary supply.

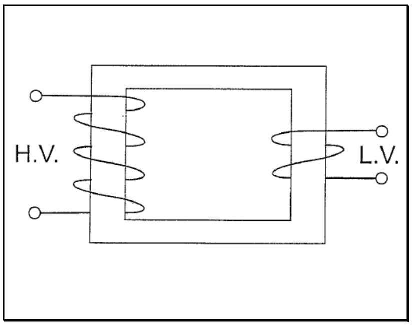
AC Traction Substations: : Loose standing Voltage transformers is normally installed in the Eskom Yard to provide a supply is received from Eskom for metering

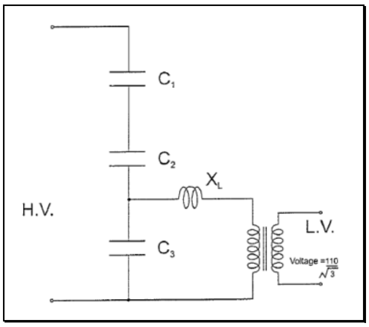
A VT supply from the secondary LV busbar is used to provide the reference voltage for distance protection as well as ”AC Fail/Available” indication to “Control”.

Signal and Distribution Supply Substations: VT’s are used for indicating instruments and phase fail/rotation protection as well as ”AC Fail/Available” indication to “Control”.

21.2 PRINCIPLE OF OPERATION

1 Voltage transformers are either of the transformer type or the capacitive type (CVT):





Primary voltages can range from 132, 88, 66, 33, 22, 11 and 6.6 kV with secondary normally at 110v. Protection of VT's is normally HV and LV fuses.

In distribution substations VT's are normally of the retractable type with the HV fuses located in the HV bushings. Refer to annexure for further study.

21.3 BASIC PRECAUTIONS

1 The Eskom VT supply is likely to be earthed, hence this must be considered if this VT supply is used in equipment which is installed in the substation's earthing scheme. An isolation transformer would be required if the earth needs to be connected to an earth leakage circuit in any way.

2 All testing to be done under cover of a workpermit.

21.4 TYPES OF THE TEST

1 Insulation test.

2 Ratio Test .

The above tests are normally done at commissioning and after repairs. During routine tests only operational checks and meter calibrations are required

21.5 TEST EQUIPMENT USED

1 Megger 2.5 kV.

2 Three or single phase Supply set

3 AC Voltage injection set 0 -150 volts.

3 Multimeters

4 Set of light leads

21.6 THE TEST CIRCUIT

1 Insulation test.

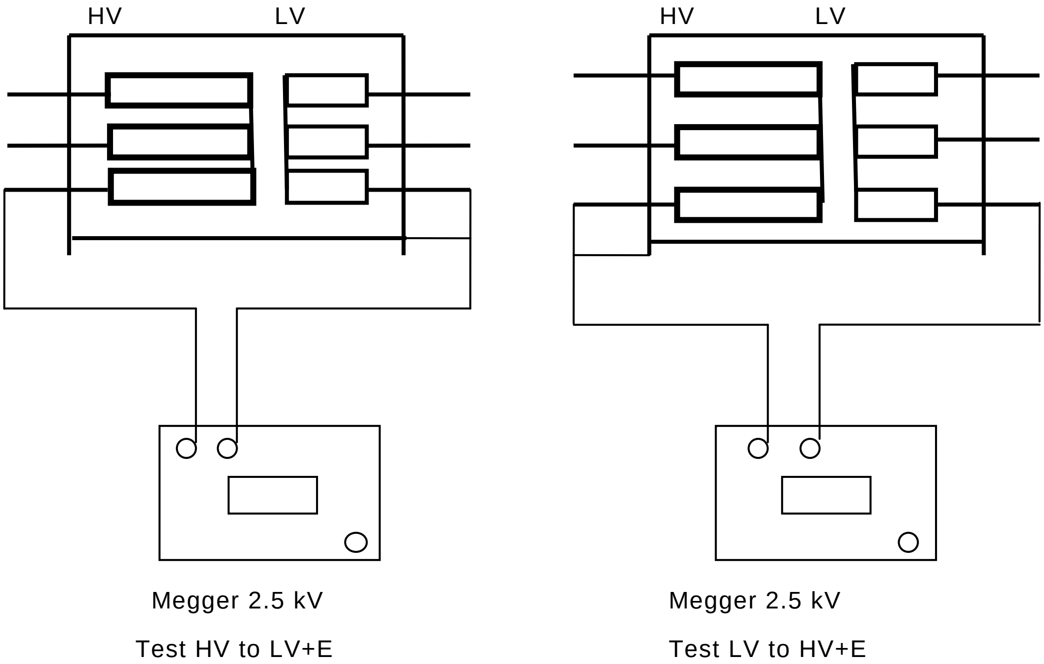


Figure 21.3: Connections for Insulation test on a 3 phase VT typical in distribution substations

2 Ratio test

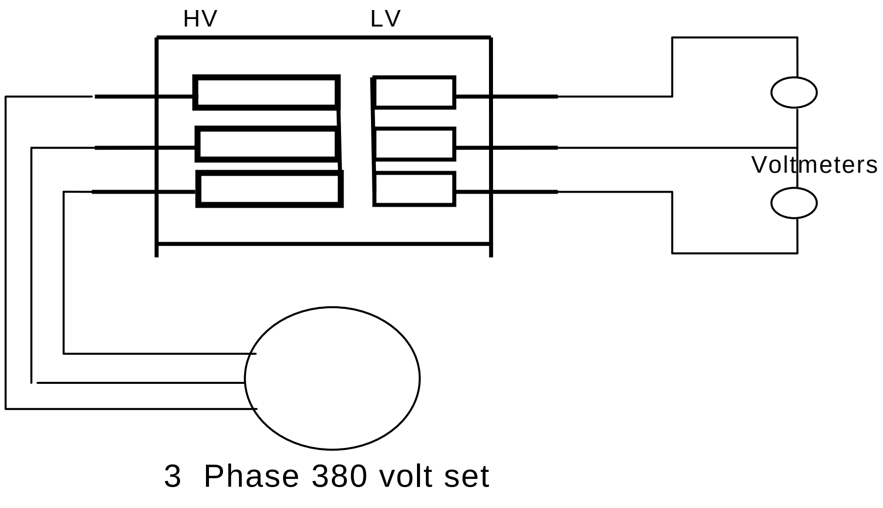


Figure 21.4: Connections for Ratio test on a 3 phase VT typical in distribution substations

21.7 THE TEST PROCEDURE

1 Insulation Test

Connect megger as shown in Figure 21.3

2 Ratio Test

Connect 3 phase supply to HV winding with fuses removed as shown in Figure 21.4 and measure the voltage on the LV between phases and compare with calculated values.

21.8 DOCUMENTATION.

1 Complete the relevant test sheet

21.9 ACCEPTABLE TEST RESULTS

1 Insulation values must conform to 2Mohm per KV standard.

2 Ratio: Measured voltages must be within 5 % of calculated values.

21.10 SPECIAL PITFALLS.

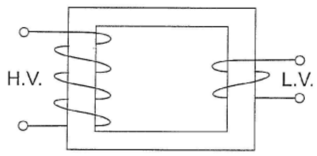
1 Short circuits in the LV winding will not rupture the HV fuses in some instance. This will cause low or no readings between phases when operating the selector switch. A ratio test must then be done.

21.11 REFERENCES.

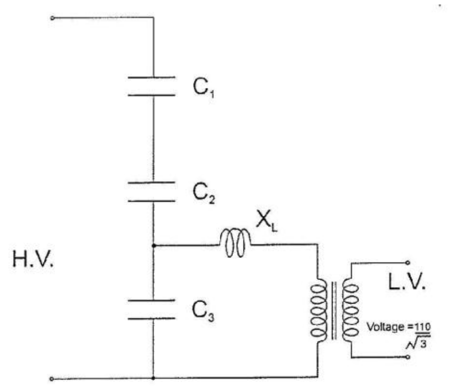
1 IEC 60186 voltage transformers

ANNEXURE ON VOLTAGE TRANSFORMERS

There are two types of voltage transformer used for protection equipment, the purely electro-magnetic type (commonly referred to as a VT) and the Capacitor type (referred to as a CVT). These two types are illustrated schematically as follows:



Electro-Magnetic Type



Capacitor Type VT

The magnetic voltage transformer is similar to a power transformer and differs only in so far as a different emphasis is placed on cooling, insulating and mechanical aspects.

The primary winding has a large number of turns and is connected across the line voltage either phase-to-phase or phase-to-neutral.

The secondary has less turns, consequently as the volts per turn remains constant, then less voltage and higher currents are obtained.

Output burdens of 500 VA per phase are common.

The capacitor V.T. is more commonly used on high voltage networks. The capacitor allows the injection of a high frequency signal onto the power line conductors to provide end-to-end communications between substations for distance relays, telemetry/supervisory and voice communications.

Accuracy of Voltage Transformers

Voltage transformers for protection are required to maintain reasonably accuracy over a large range of voltage from 0 - 173% of nominal. Extreme accuracy, such as would be required for metering, is not necessary for protection. Typical permissible errors as laid down by the IEC 186 are as follows:

Accuracy class, voltage transformers						
		Range		Limits of errors		
		Burden	Voltage	Ratio	Phase displacement	
Standard	Class	%	%	%	min	Application
IEC 186	0.1	25-100	80-120	0.1	5	Laboratory
	0.2	25-100	80-120	0.2	10	Precision metering, Revenue metering
	0.5	25-100	80-120	0.5	20	Standard revenue metering
	1.0	25-100	80-120	1.0	40	Industrial grade meters
	3.0	25-100 .	80-120	3.0	-	Instruments
	3P	25-100	5- V_f*)	3.0	120	Protection
	6P	25-100	5- V_f*)	6.0	240	Protection
*) V_f= Voltage factor						

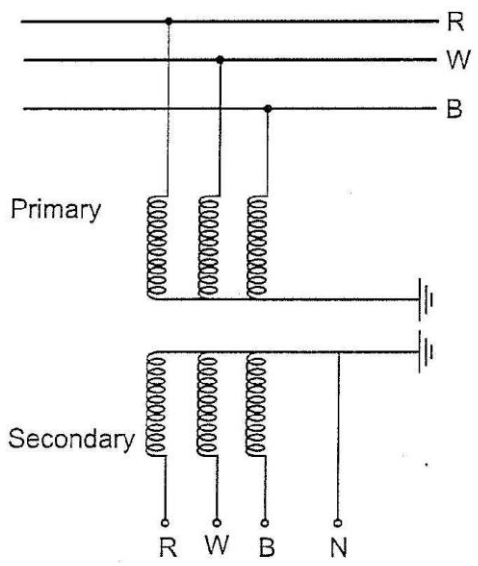
These accuracies are adequate and easily obtainable.

Thus apart from ensuring that voltage transformers are not overloaded and that there is not an excessive volt drop in the secondary leads, the question of accuracy of VT's can be ignored and is generally neglected in practice.

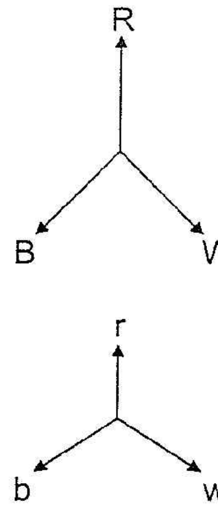
Connection of Voltage Transformers

Electro-magnetic voltage transformers may be connected inter-phase or between phase and earth. Capacitor voltage transformers can only be connected phase-to- earth.

Voltage transformers are commonly used in 3-phase groups, generally in star-star configuration:



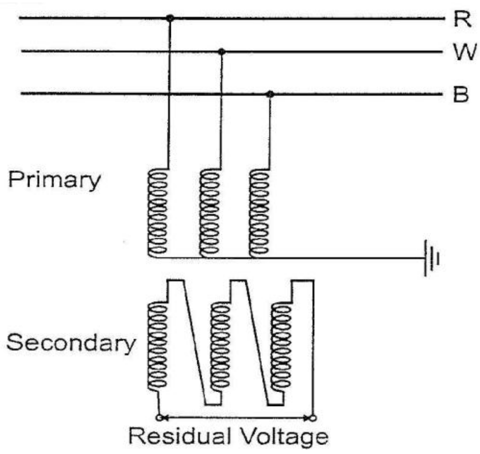
Voltage Transformers connected in star-star configuration.



Vector Diagram for VT'S in star-star configuration

With this arrangement the secondary voltages provide a complete replica of the primary voltages and any voltage (phase-to-phase or phase-to-earth) may be selected.

A particular quantity, frequently used in protection is The "residual voltage" which is the vector sum of the three phase voltages. The normal way of obtaining this voltage is as follows:



Connection to source Residual Voltage.

The residual voltage (neutral displacement voltage, polarising voltage) for earth-fault relays can be obtained from a VT between neutral and earth, for instance at a power transformer neutral. It can also be obtained from a three-phase set of VTs, which have their primary winding connected phase to earth and one of the secondary windings connected in a broken delta. The Figure below illustrates the measuring principle for the broken delta connecting during an earth-fault in a high-impedance earthed (or unearthed) and an effectively earthed power system respectively.

From the figure below it can be seen that a solid close-up earth-fault produces an output voltage of $U_{rsd} = U_{5n}$ in a high impedance earthed system, and $U_{rsd} = U_{2n}$ in an effectively earthed system. Therefore a VT secondary normal voltage of:

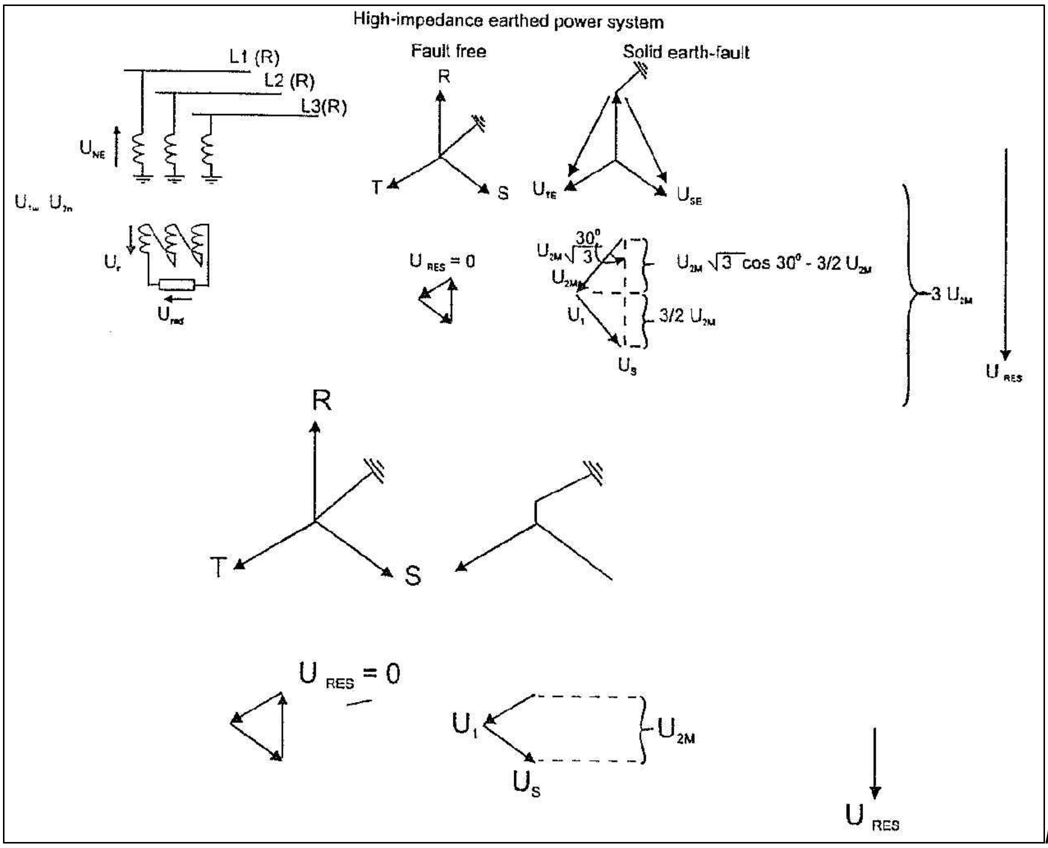
$$U_{2n} = \frac{110}{3} V$$

is often used in high-impedance earthed systems and U_{2n} = 110V in effectively earthed systems. A residual voltage of 110V is the obtained in both cases. VTs with two secondary windings, one for connection in Y and the other in broken delta can then have the ratio.

$$\frac{U_n}{V3} / \frac{110}{V3} V / \frac{110}{3} V$$ and

$$\frac{U_n}{V3} / \frac{110}{V3} V / 110V$$

for high impedance and effective earthed systems respectively. Other nominal voltages than 110V e.g. 100V or 115V are also used depending on national standards and practice.



Residual Voltage (neutral displacement voltage) from an open Delta Circuit

Ferro-resonance in magnetic voltage transformer

When the ferro-resonance in a CVT is an internal oscillation between the capacitor and the magnetic IVT, the ferro-resonance in a magnetic voltage transformer is an oscillation between the magnetic voltage transformer and the network. The oscillation can only occur in a network having an insulated neutral. An oscillation can occur between the network's capacitance to ground and the non-linear inductance in the magnetic voltage transformer, The oscillation can be triggered by a sudden change in the network voltage.

It is difficult to give a general figure of a possible risk of ferro-resonance. It depends on the design of the transformer. We can roughly calculate that there will be a risk of resonance when the zero-sequence capacitance expressed in S km transmission line is

$$S < \frac{42000}{U_n^{\ 2}} km$$

It is possible to protect a voltage transformer from secondary short-circuit by incorporating fuses in the secondary circuits. High voltage fuses on the primary side will not protect the transformers, they protect only the network. Short-circuit on the secondary windings gives only a few amperes in the primary winding and is not sufficient to rupture a high voltage fuse.

The voltage drop in the secondary circuit is of importance. The voltage drop in the fuses and long connection wires can change the accuracy of the measurement. It is especially important for revenue metering windings of high accuracy (Class 0.2, 0.3).

The total voltage drops in this circuit must not be more than 0.1 percent.

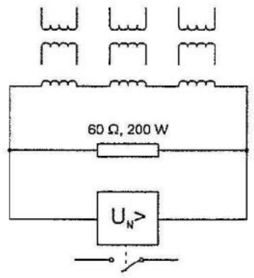
U_n - System voltage in kV.

The corresponding value for cable is:

$$S < \frac{1400}{U_n^{\ 2}} km$$

Damping of ferro-resonance

The magnetic voltage transformer will be protected from fero-resonance oscillation by connecting a resistor across the open delta point in the 3-phase secondary winding! A typical value is 50-60 ohm, 200W.



Damping of Ferro-resonance

Resistance in fuses

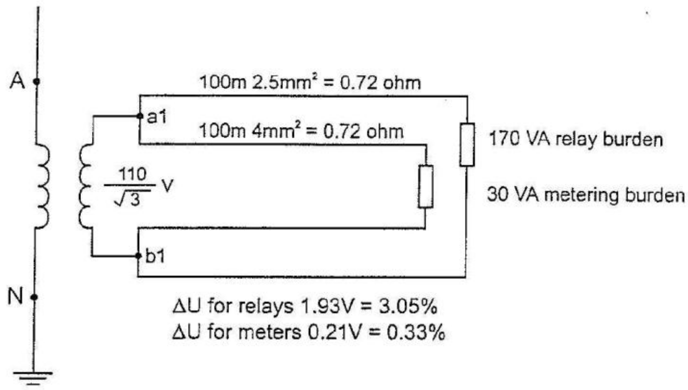
Typical values:

6A	0.048
10A	0.024
16A	0.0076
25A	0.0042

6-10 A is a typical value for safe rupture of the fuses.

The voltage drop in the leads from the V.T. to the associated equipment must be considered as this, in practice, can be far from negligible.

This is where the separation of the metering circuits (with low burden) from protective circuits (with higher burdens) is actual.



The accuracy of a Voltage Transformer is guaranteed at the Secondary Terminals.

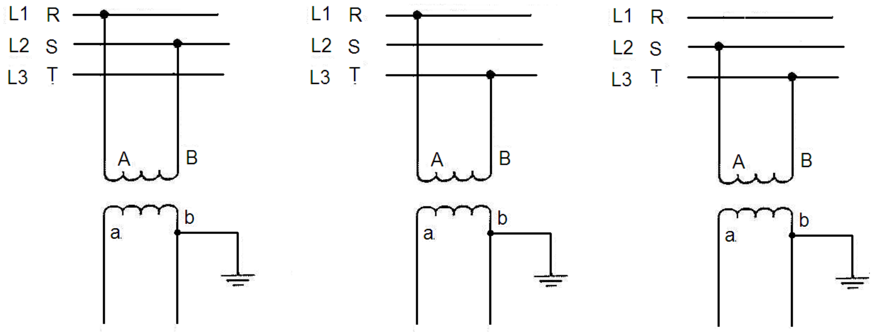
Secondary Earthing of Voltage Transformers

To prevent secondary circuits from reaching dangerous potential, the circuits shall be earthed. Earthing shall be made at only one point of a V.T. secondary circuit or galvanically interconnected circuits.

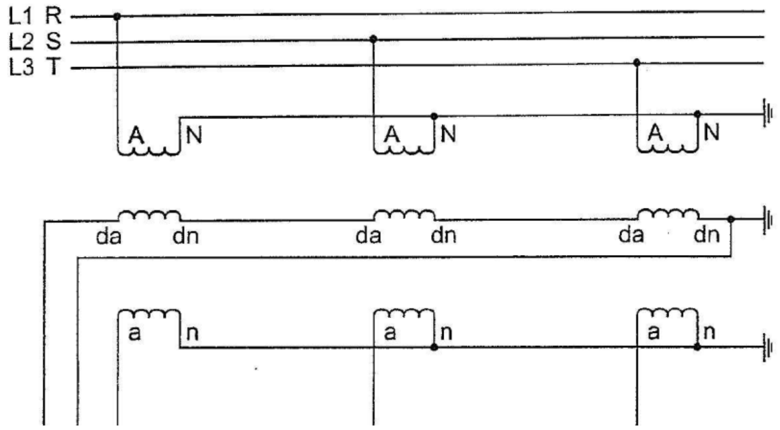
A V.T. which on the primary is connected phase-to-earth, shall have the secondary earthing at terminal n.

A V.T. with the primary winding connected between two phases, shall have that secondary terminal earthed which has a voltage lagging the other terminal by 120 degrees.

Windings not used shall be earthed.

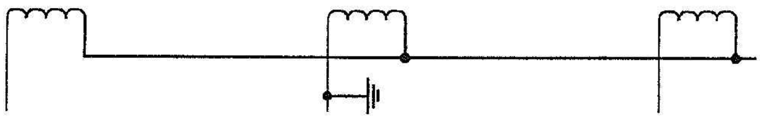


VT'S connected between phases.



A set of VT's with one Y-connected and one broken delta secondary circuit.

Alternatively, it is often common practice to earth the white phase as shown below. This practice stems from Metering where the 2 watt meter method requires 2 CT's and 2 line voltages. With this arrangement the red and blue phases now at line potential to the white and it saves the expense and bother of running a neutral conductor throughout the panels.



VT secondary earthed on white phase

REFERENCE

Les Hewitson Pr. Eng. PSP Training. “Power Protection course Version 3.01 May 1998, Commonwealth English Edition.