HANDBOOK
FOR
PROTECTION ENGINEERS

MOHAMMED FASIL T
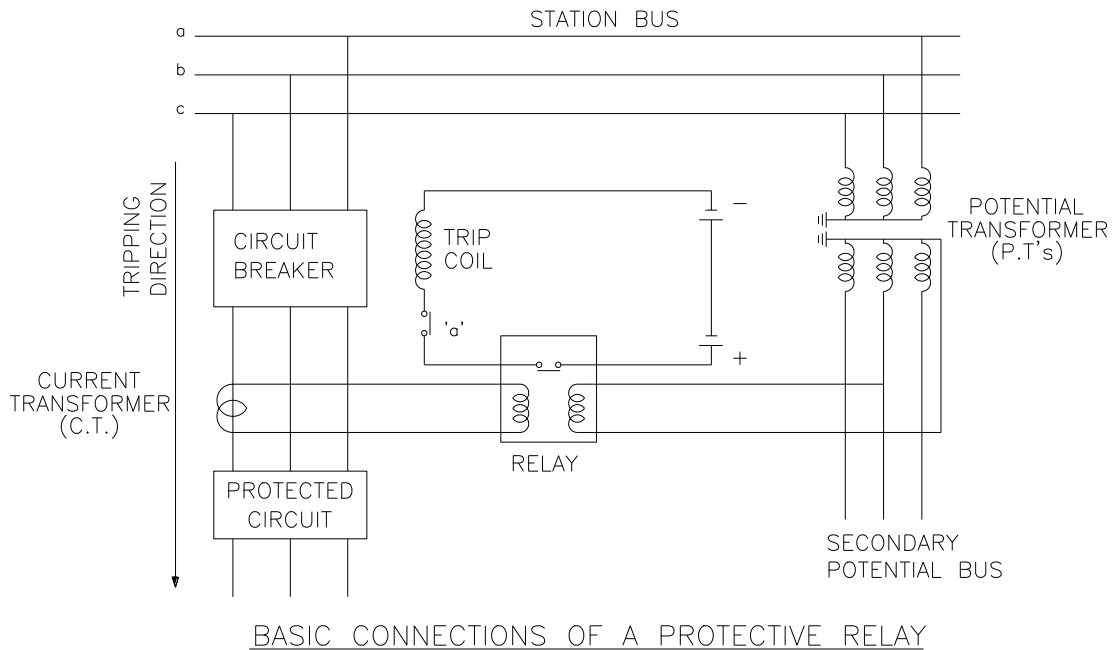**9746988538**
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ACKNOWLEDGEMENTS

The 'Hand Book' covers the Code of Practice in Protection Circuitry including standard lead and device numbers, mode of connections at terminal strips, colour codes in multicore cables, Dos and Donts in execution. Also principles of various protective relays and schemes including special protection schemes like differential, restricted, directional and distance relays are explained with sketches. The norms of protection of generators, transformers, lines & Capacitor Banks are also given.

The procedures of testing switchgear, instrument transformers and relays are explained in detail. The close and trip, indication and alarm circuits for variety of Circuit breakers indicating ferrule numbers are also included. All relevant information and circuit diagrams necessary for trouble shooting are also given.

We have more than 25 years experience, each in protective relaying and included a lot of information by way of original contribution apart from collection of useful information from a large number of reference books, manuals of manufacturers, etc. and it is hoped that this Hand Book will serve as a useful guide for all practicing Engineers.

INDEX

BASIC CONNECTIONS OF A PROTECTIVE RELAY

PROTECTION

OBJECTIVE :   To quickly isolate a faulty section from both ends so that the rest of the
                      System can function satisfactorily.

THE FUNCTIONAL REQUIREMENTS OF THE RELAY:

i)   Reliability   : The most important requisite of protective relay is reliability since
                          they supervise the circuit for a long time before a fault   occurs; if a
                          fault then occurs, the relays must respond instantly and correctly.

ii)   Selectivity   : The relay must be able to discriminate(select) between those
                          conditions for which prompt operation is required and those for which no
                          operation, or time delayed operation is   required.

iii)   Sensitivity   : The relaying equipment must be sufficiently sensitive so that it
                          operates reliably when required under the actual conditions that
                          produces least operating tendency.

iv)   Speed   : The relay must operate at the required speed. It should neither be too
                          slow which may result in damage to the equipment nor should it be   too
                          fast which may result in undesired operation.

HEALTHY TRIP CIRCUT
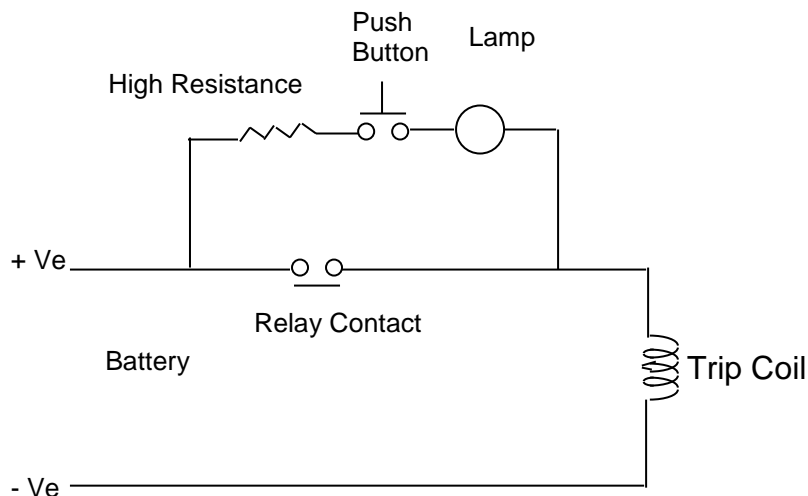

IMPORTANT ELEMENTS :

Switch gear: Circuit breaker Bulk oil, Minimum oil, SF6, Airblast, Vacuum etc. depending on medium used for quenching the arc. Different operating mechanisms such as solenoid, spring, pneumatic, hydraulic etc. are employed.

Protective gear: Relays (current, voltage, impedance, power, frequency, etc. based on operating parameter, definite time, inverse time, stepped etc. as per operating characteristic, logic wise such as differential, over fluxing etc.

Station Battery: A Station battery containing a number of cells accumulate energy during the period of availability of A.C supply and discharge at the time when relays operate so that relevant circuit breaker is tripped.
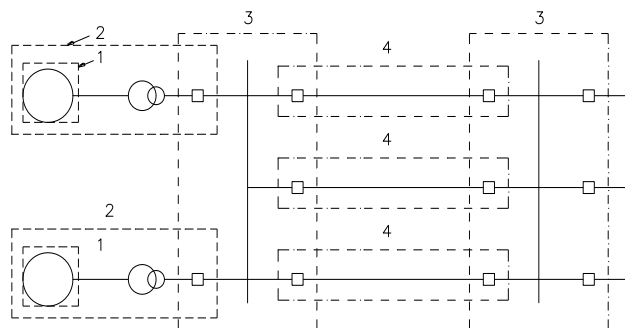
1. GENERATOR PROTECTIVE ZONE
2. GENERATOR TRANSFPRMER UNIT PROTACTIVE ZONE
3. BUSBAR PROTECTIVE ZONE
4. TRANSMISSION LINE PROTECTIVE ZONE

PROTECTIVE ZONES

CODE OF PRACTICE

CODE OF PRACTICE : PROTECTION

1.00   Circuitry

1.01   The entire wiring of circuitry for indications, alarms, metering and protection should be permanent wiring.

1.02   There is no place for temporary wiring or adhocism in Relay circuitry.

1.03   The leads should be identified by ferrules near terminals.

1.04   Every lead should end at a terminal point and no junctions by twisting is allowed. If two wires are to be terminated at same terminal they may be connected at two different terminals and a loop provided.

1.05   The wiring should be by copper leads for C.T secondaries for all cores (i.e.) metering as well as protection.

1.06   The wiring should be by copper leads for PT secondaries also wherever they are intended for protection.

1.07   The copper lead for 1.05 & 1.06 above should be stranded but not single lead type.

1.08   Aluminum leads can be used for indication, alarms and PT secondaries for metering but stranded wires only are to be used. However where PTs are employed for commercial metering, stranded copper wires are to be used.

1.09   The terminations should be lugged by ring shape 'O' lugs. 'U' shape lugs should be avoided.

1.10   For CT Secondary terminations, two nuts with one spring washer and two flat washers to be compulsorily used.

1.11   The terminal strips should be stud type with nuts and not screw-in-type.

1.12   Wherever two batteries are available, the primary protection and back-up protection should be from different batteries.

1.13   Where there is only one battery at a Power Substation, the primary and back-up protections should be given D.C supply through two individual circuits with independent fuses run from D.C bus.

1.13A   When CBs have two trip coils, both main protection and backup protection will energise both the trip coils.

1.14   D.C and A.C supplies should not be taken through different cores of the same cable.

1.15   Independent D.C cables should be run to every equipment in the yard and looping of D.C supply either in the yard or in the control room from one equipment to the other is not permitted.

1.16   The D.C yard lighting for emergency lighting should be through independent cables and not mixed up with protection and other circuitry.

1.17   For indications, alarms, annunciations, controls (closing coil, trip coil, etc. negative (-ve) is always given direct and positive (+ve) is supplied only 'on commands' like close, trip, relay trip, etc.

1.18   Where D.C protection supply is at 24 volts or 32 volts, the battery units should be very near the equipment and not in the control rooms.

1.19   In cases of 1.18 above, each tripping units (24 volts or 32 volts battery with charger) should not be used for more than two circuit breakers or equipment.

1.20   Standard colour codes for leads in control cable of different sizes should be as denoted on the cover page.

1.21   The lead numbers are also standardised as follows so that any MRT Engineer can easily identify the purpose for which the lead is connected by noting the lead number.

J Series	D.C Incoming	J1, J2, etc.
K Series	Control - Closing, Tripping, etc.	K1, K2, K3 etc.
L Series	Alarms, indications and annunciations	L1, L2, L3, etc.
E Series	Potential transformer secondaries	E1, E2, E3, etc.
H Series	LT A.C Supply	H1, H2, H3, etc.
A Series	C.T secondary for special protection	A1, A2, A3, etc.
B Series	Bus bar protection	B1, B2, B3, etc.
C Series	Protection Circuits	C1, C2, C3, etc.
D Series	Metering Circuits	D1, D2, D3, etc.

1.22   CTs with 1 amp secondary rating should be used compulsorily where meters, protective devices etc. are remotely situated with reference to equipment.

1.23   The CT ratios available and adopted with number of cores shall be displayed on each panel as follows: (with underlined position as adopted).
        400 - <u>200</u> - 100 / 1-1-1

1.24   <u>Wherever CT cores are not used "SHORTING LOOPS" should be provided near CT secondary terminals and not in marshaling boxes or at panels.</u>

1.25   The Cable entries near equipment, marshaling boxes and panels should be by use of appropriate size glands.

1.26   The Wiring inside the panels should be clear and neatly fastened avoiding loose wires.

1.27   All wires not in use should not only be disconnected but removed from panels.

1.28   PT secondaries should have group MOCBs with D.C alarm. Fuses at different panels should not be used.

1.29   Few cells from a battery of cells should not be used for separate low voltage D.C circuits. D.C - D.C converters only should be employed utilising full D.C voltage of the entire battery as input.

2.00   **STANDARD LEAD NUMBERS**

Certain lead numbers are standardised as follows and should be compulsorily adopted with ferrules at terminations of leads.
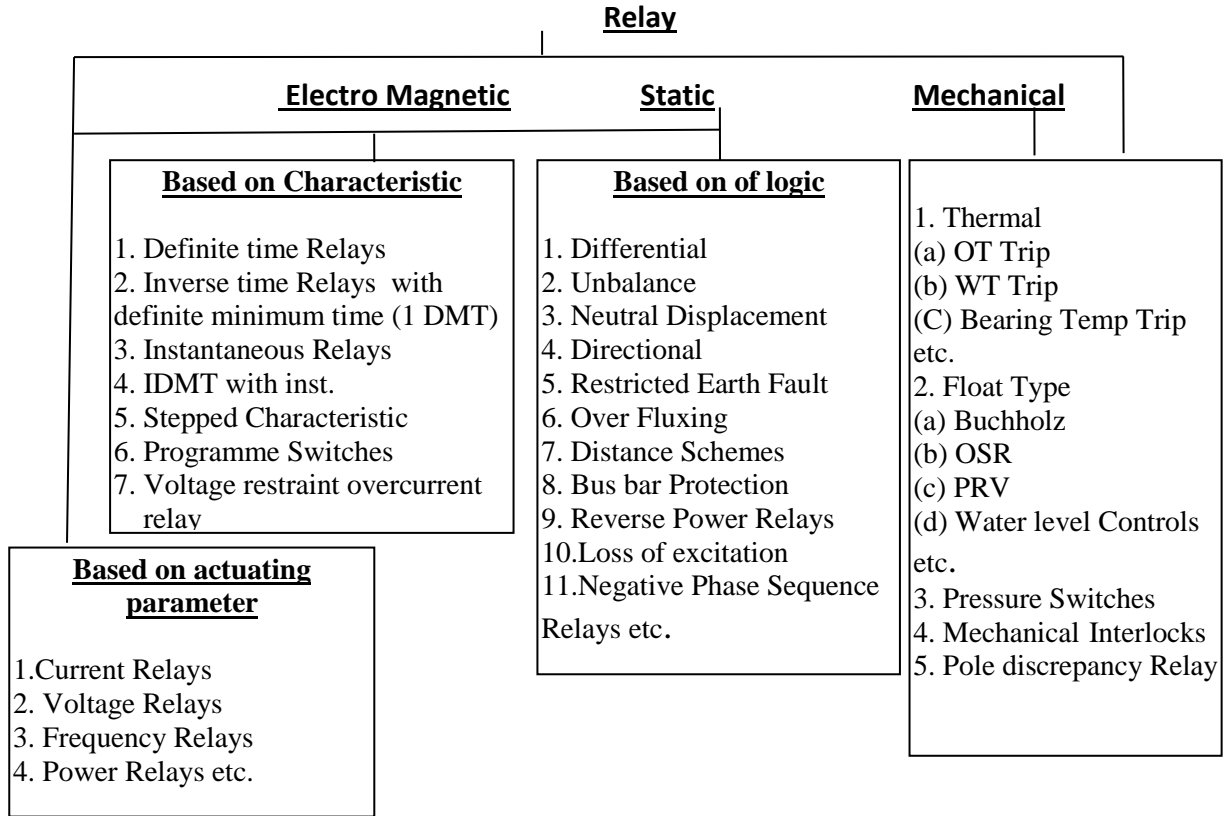
        J1 -   Positive
        J2 -   Negative

Controls & Alarms
Remote Close :   K15R
Remote Trip   :   K5R
Local Close   :   K15L
Local Trip   :   K5L

Relay Family

Relay

Electro Magnetic

Based on Characteristic

1. Definite time Relays
2. Inverse time Relays with definite minimum time (1 DMT)
3. Instantaneous Relays
4. IDMT with inst.
5. Stepped Characteristic
6. Programme Switches
7. Voltage restraint overcurrent relay

Based on actuating parameter

1. Current Relays
2. Voltage Relays
3. Frequency Relays
4. Power Relays etc.

Static

Based on of logic

1. Differential
2. Unbalance
3. Neutral Displacement
4. Directional
5. Restricted Earth Fault
6. Over Fluxing
7. Distance Schemes
8. Bus bar Protection
9. Reverse Power Relays
10. Loss of excitation
11. Negative Phase Sequence Relays etc.

Mechanical

1. Thermal
(a) OT Trip
(b) WT Trip
(C) Bearing Temp Trip etc.
2. Float Type
(a) Buchholz
(b) OSR
(c) PRV
(d) Water level Controls etc.
3. Pressure Switches
4. Mechanical Interlocks
5. Pole discrepancy Relay

Types of Control Panels

1	Control Panels	12	Marshalling Boxes
2	Relay Panels	13	AMG Panels
3	Control & Relay Panels	14	Machine Panels
4	Synchronising Panel or Trolley	15	Duplex(HV,LV) Panels
5	Communication Panels	16	Bus Zone Protection Panels
6	Annunciation Panels	17	RTC Panels (OLTC)
7	D.C. Distribution Board	18	RTI Panels (temp)
8	A.C. Distribution Board	19	Indoor Panels
9	Charger Panels	20	Outdoor Panels
10	Relay Galleries	21	Panels with drawn up mimics & isolator cum breaker status indication (Semaphores) etc.
11	Auxiliary Control Panels		

DEVICE NUMBERS AND THEIR NOMENCLATURE

2	Time delay relay
3	Checking or Interlocking relay
21	Distance relay
25	Check synchronizing relay
27	Undervoltage relay
30	Annunciator relay
32	Directional power (Reverse power) relay
37	Low forward power relay
40	Field failure (loss of excitation) relay
46	Negative phase sequence relay
49	Machine or Transformer Thermal relay
50	Instantaneous Overcurrent relay
51	A.C IDMT Overcurrent relay
52	Circuit breaker
52a	Circuit breaker Auxiliary switch "Normally open" ('a' contact)
52b	Circuit breaker Auxiliary switch "Normally closed" ('b' contact)
55	Power Factor relay
56	Field Application relay
59	Overvoltage relay
60	Voltage or current balance relay
64	Earth fault relay
67	Directional relay
68	Locking relay
74	Alarm relay
76	D.C Overcurrent relay
78	Phase angle measuring or out of step relay
79	AC Auto reclose relay
80	Monitoring loss of DC supply
81	Frequency relay
81U	Under frequency relay
81O	Over frequency relay
83	Automatic selective control or transfer relay
85	Carrier or pilot wire receive relay
86	Tripping Relay
87	Differential relay
87G	Generator differential relay
87GT	Overall differential relay
87U	UAT differential relay
87NT	Restricted earth fault relay
95	Trip circuit supervision relay
99	Overflux relay
186A	Auto reclose lockout relay
186B	Auto reclose lockout relay

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Over Current trip        }
E/f. Trip                } Relay trip : K3 Master trip
Diffl.Trip               }
OSR/OLTC trip :    163T
Bucholz trip       :      63T
O.T trip           :      26T
W.T trip           :      49T
Over fluxing trip  :      99
P.R.V trip         :
Ter.Ala Trip       :      149T
Bucholz Alarm :    63A
W.T Alarm          :      49A
O.T Alarm          :      26A
Ter.Alarm          :      149A
Busbar prot. Trip  :      96
Pole discrepancy trip :   162
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Indication +ve          :      L1
OFF                     :      L3
ON                      :      L5
Semaphore OFF           :      L7
Semaphore ON            :      L9
C.B trip alarm          :      L21
Bus A.B Switch remote OFF :L11
Bus indication ON       :      L13
Line/equipment-OFF      :      L15
           ON           :      L17
           ON           :      L19
           OFF          :      L21
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NORMS OF PROTECTION TO BE FOLLOWED AS PER A.P.E.R.C. ORDERS

For Transmission & Distribution Lines

S.No.	Voltage	Protection Scheme
1.	400 KV Line	Main-I: Non switched or Numerical Distance Scheme Main-II: Non switched or Numerical Distance Scheme
2.	220 KV Line	Main-I : Non switched distance scheme (Fed from Bus PTs) Main-II: Switched distance scheme (Fed from line CVTs) With a changeover facility from bus PT to line CVT and vice-versa.
3.	132 KV lines	Main Protection: Switched distance scheme (fed from bus PT). Backup Protection: 3 Nos. directional IDMT O/L Relays and 1 No. directional IDMT E/L relay.
4.	33 KV lines	Non-directional IDMT 3 O/L and 1 E/L relays.
5.	11 KV lines	Non-directional IDMT 2 O/L and 1 E/L relays.

Notes

i. On some of the old 220KV lines one distance scheme with backup directional IDMT 3 O/L & E/L relays were provided.

ii. On some of the 132KV grid lines, only distance scheme is available

iii. Very few 66KV lines are in service (which are also being phased out)

Busbars: All 220 KV busbars will have busbar protection scheme with main and check Zone.

NORMS OF PROTECTION FOR EHV CLASS POWER TRANSFORMERS

POWER STATIONS

Voltage ratio & capacity	HV Side	LV Side	Common relays
i. 11/132 KV GT	3-Non-dir O/L + 1-Non-dir E/L relay and/or standby E/F + REF	--	Differential or Overall differential, Overflux, Buchholz, OLTC Buchholz, PRV, OT, WT
ii. 13.8/220 KV 15.75/220 KV 18/400 KV 21/400 KV Generator T/Fs	3-Non-dir O/L + 1-Non-dir E/L relay and/or standby E/F + REF	--	Differential or Overall differential , Overflux, Buchholz, OLTC Buchholz, PRV, OT, WT
iii. 220 /6.6KV Station T/Fs	3-Non-dir O/L + 1-Non-dir E/L relay and/or standby E /F + REF	3-Non-dir. O/L relays	Differential, Overflux, Buchholz, OLTC Buchholz, PRV, OT, WT
iv. Gen-volt/6.6KV UAT	3-Non-dir. O/L relays	3-Non-dir. O/L relays	Differential, Overflux, Buchholz, OLTC Buchholz, PRV, OT, WT

SUBSTATIONS			
v. 132/33/11KV upto 8 MVA	3 O/L relays + 1 E/L relay	2 O/L relays + 1 E/L relay	Buchholz, OLTC Buchholz, OT, WT
vi. 132/33/11KV above 8 MVA and below 31.5 MVA	3 O/L relays + 1 dir. E/L relay	3 O/L relays + 1 E/L relay	Differential, Buchholz, OLTC Buchholz, OT, WT
vii. 132/33KV, 31.5 MVA & above	3 O/L relays + 1 dir. E/L relay	3 O/L relays + 1 E/L relay	Differential, Overflux, Buchholz, OLTC PRV, OT, WT
viii. 220/33 KV, 31.5MVA & 50MVA 220/132KV, 100 MVA	3 O/L relays + 1 dir. E/L relay	3 O/L relays + 1 dir. relay	Differential, Overflux, Buchholz, OLTC PRV, OT, WT
ix. 400/220KV 315MVA	3 directional O/L relays (with dir.highset) +1 directional E/L relays. Restricted E/F relay + 3 Directional O/L relays for action	3 directional O/L relays (with dir.highset)+1 directional E/L relays. Restricted E/F relay	Differential, Overflux, Buchholz, OLTC PRV, OT, WT and overload (alarm) relay

<u>Breaker failure protection</u>: The LBB protection scheme will be provided for all 220KV stations (along with busbar protection scheme)

<u>Transformers</u>

i.   No Buchholz relay for transformers below 500 KVA capacity

ii. Transformers upto 1500 KVA shall have only Horn gap protection

iii. Transformers above 1500 KVA and upto 8000 KVA of 33/11KV ratio shall have one group control breaker on HV side and individual LV breakers if there is more than one transformer.

iv. Transformers above 8000 KVA shall have individual HV and LV circuit breakers.

v.   The relays indicate above shall be provided on HV and LV

vi. LAs to be provided on HV & LV for transformers of all capacities and voltage class.

vii. OLTC out of step protection is to be provided where Master follower scheme is in operation

viii. Fans failure and pumps failure alarms to be connected.

ix. Alarms for O.T., W.T., Buchholz (Main tank & OLTC) should be connected.

Points to be checked while drawing CTs

1. Voltage class

2. Indoor /Outdoor

3. Oil filled?Resin cast? Ring type?

4. Short Circuit rating

5. Available ratios

6. Secondary Current values

7. Available cores

8. Burden

9. Class of Accuracy

10. Terminal Connections

11. Over all dimensions etc.

Points to be verified while drawing Circuit Breakers

1. Voltage class

2. Indoor /Outdoor

3. Quencing : Bulk oil or Min. Oil or SF6 or Vacuum or Air blast

4. D.C Control voltage or 24V or 32V or 110V or 220V

5. Rated current (make & break)

6. Rupturing capacity

7. Operating mechanism : Spring? Solenoid? Pneumatic? Hydraulic? Air blast?

8. Terminal connections

9. Overall dimensions

10. Details of CTs if provided with breaker

11. Protective devices along with breaker

12. Details of PT, etc. if provided with breaker etc.

13. Trip/Break time, closing time limit

C.T. RATIOS AND RELAY SETTINGS TO BE ADOPTED

- The C.T ratios and relay settings for all equipment at EHT substation upto L.V breakers of Power transformers shall be approved by SE/Protection.

- The C.T ratios and relay settings for all 33KV, 11KV & 6.6 KV feeder breakers at EHT substations shall be finalised by DE/EM & MRT.

- The relay settings so finalised by SE/Protection or the concerned DE shall not be altered by any other officer.

- The officers above are responsible for relay Co-ordination and gradation.

LIMITS OF ERRORS IN CTs

Class0.1to1.0: The Current Error and phase displacement Error at the rated frequency shall not exceed the values given below when the secondary burden is any value from 25% to 100% to the rated burden.

Limits of % error at % of rated Current					Phase displacement in minutes at % of r.ct			
Class	10	20	100	120	10	20	100	120
0.1	±0.25	±0.20	±0.10	±0.1	±10	±8	±5	±5
0.2	±0.50	±0.35	±0.20	±0.2	±20	±15	±10	±10
0.5	±1.00	±0.75	±0.75	±0.5	±60	±45	±30	±30
1.0	±2.00	±1.50	±1.50	±1.0	±120	±90	±60	±60

Class 3&5	50%	100%
3	±3	±3
5	±5	±5

Application	Standards	
	IS	**BS**
Precession Metering	0.1or 0.2	BL BL
Comml. or Indl.metering	0.5 or 1.0	AM BM CM
Ammeters, power meter	1.0 or 3.0	CD
Relays	$5P_{10}$ or $5P_{20}$	STU
Selective protection	PS	

Composite Error for Protection ISS 2705 Part.III

Accuracy Class	Current error at rated prim. current	Phase displacement at rated prim current +Min.	Composite error at rated prim. current +
5 P	1	60	5
10 P	3	-	10
15 P	5	-	15

LINE CT's SECONDARY CONNECTIONS
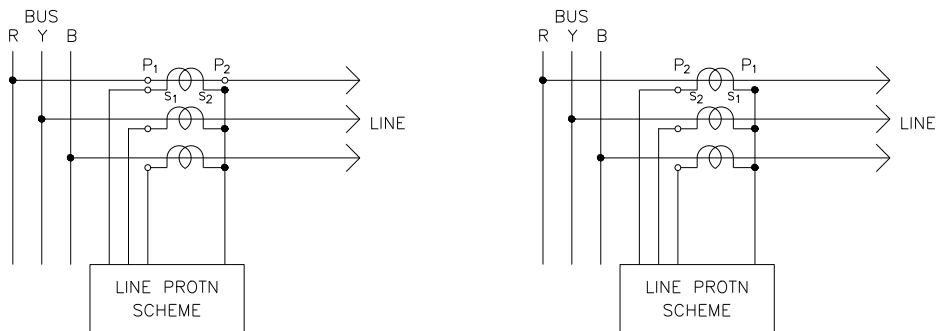
TRANSFORMER CT's SECONDARY CONNECTIONS

16
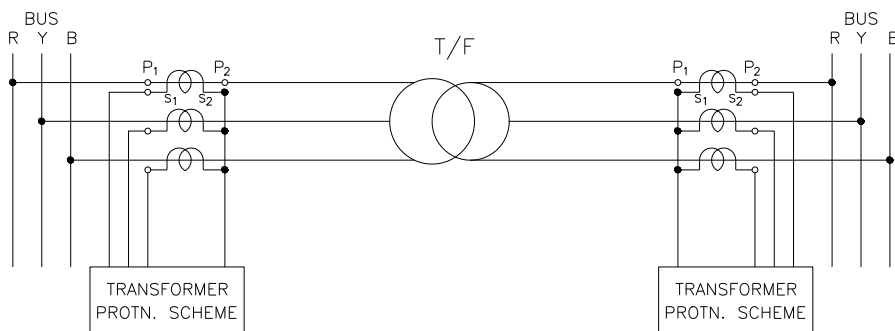
C.T. SECONDARY CONNECTIONS

For protection of various equipment of EHT class, the Star point on secondaries of CT should be made as follows for ensuring correct directional sensitivity of the protection scheme

1. For Transmission Lines   - Line side
2. For Transformers   - Transformer side
3. For Bus bar   - Bus side
4. Generator Protection   - Generator Side

The above method has to be followed irrespective of polarity of CTs on primary side. For example, in line protection, if 'P1' is towards bus then 'S2's are to be shorted and if ' P2' is towards bus then 'S1's are to be shorted.

The C.T secondary connections for Transmission line, Transformer and Busbar are indicated in the figures.

BUSBAR CT's CONNECTIONS
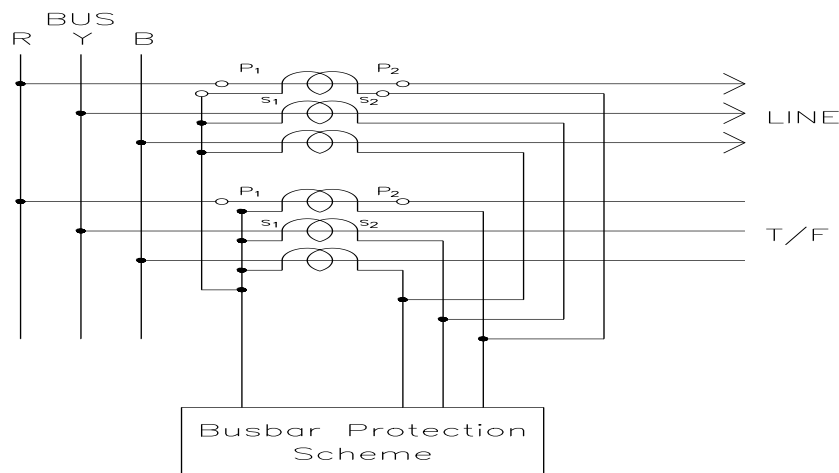
GENERATOR CT's CONNECTIONS
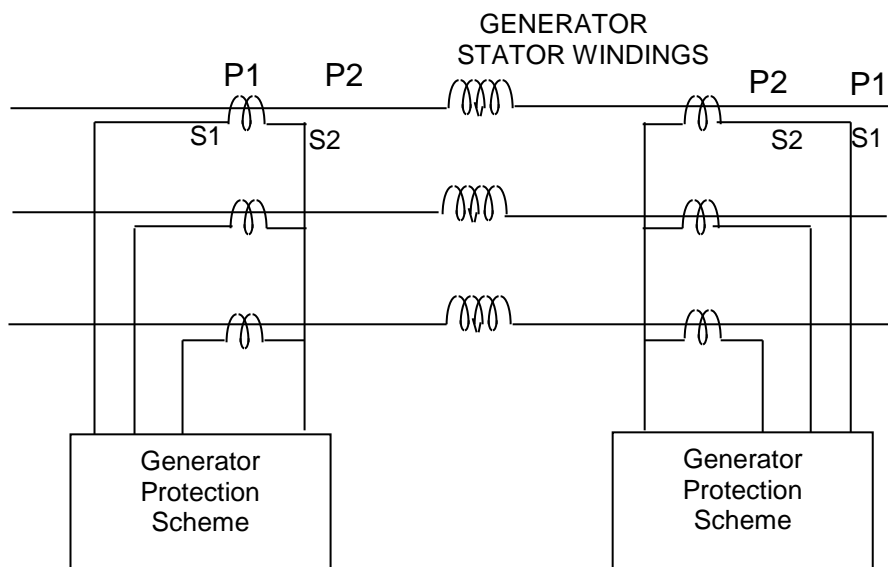
C.T POLARITY TEST

Each current transformer should be individually tested to verify that the polarity markings on the primary and secondary windings are correct. The following figure shows the test unit for this.
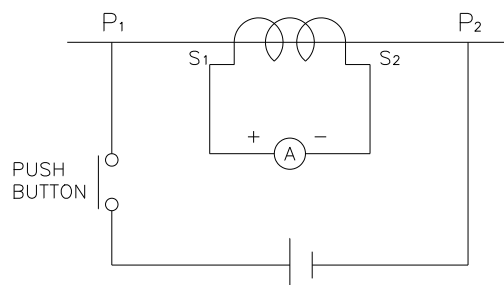
The ammemeter 'A' is a robust, moving coil, permanent magnet centre zero type instrument. A low voltage battery is used to energise the primary windings through a single pole push button. On closing the push-button, with above C.T ammeter markings, the ammeter should give a positive flick, indicating correct polarity of the C.T

PRIMARY INJECTION TEST

This test is carried out to ensure the C.T ratio of current transformers. If this test is carried out after C.T secondary wiring is completed it ensures not only the correct ratio of C.Ts but also the correctness of the entire C.T secondary wiring comprising protection and metering portions. The testing equipment consists of a loading (injection) transformer, controlled by a variable transformer to get the required current on the primary side of the C.T under test.

For carrying out the ratio test on C.Ts, the following circuit is made use of.
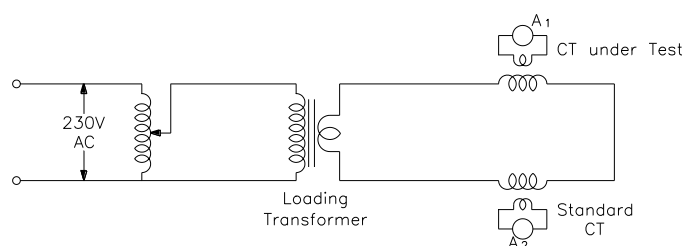
Current is passed through the primary windings of the standard C.T and C.T under test. The ratio of the C.T can be determined by comparing the currents in ammeters A1 and A2.

VOLTAGE TRANSFORMERS

Class of Accuracy	Application	LIMITS OF ERROR			
		At 90% to 100% of rated burden & 80 to 100% of rated burden UPG		At 90-100% of burden 10 to PF Ph.displace-ment	
		Ratio	Ph.displac e-ment	Ratio	
		0.2			
A	Sub-standard Indication meters	0.5	20	0.5	20
B	1st grade indicating inputs watt meter, Indl & Synchronising	1.0	30	1.0	70
C	1st grade voltmeter	2.0	60	-	-
D	Where ratio is of less importance A, B & C not required	5.0	-	-	-

PERIODICAL TESTINGS

1. The relays should be tested
   a) Annually
   b) Whenever time lever settings are altered.
   c) Whenever mal-operation of relay is suspected
   d) Whenever directed by DE/EM&MRT Concerned
   e) Whenever directed by Chief Engineer/Superintending Engineer/Protection / Vidyut Soudha / Hyderabad.
2. It is the responsibility of Asst.Divisional Engineer (Protection to maintain a Calendar and ensure testing of relays)
3. The Asst.Engineer (Protection) is responsible for the accuracy of test results noted in the Test Record.
4. Breaker opening and closing times should be checked.
   a) at the time of commissioning
   b) annually during service
   c) Whenever trip or closing coils are changed
   d) Whenever major repairs to operating mechanism are done
   e) Whenever breaker contacts are changed.
5. Station earth resistance of earth pits and combined value should be taken
   a) annually
   b) Whenever directed by DE(EM&MRT)
6. The Assistant Divisional Engineer (Maintenance) in charge of the Substation is responsible for measurement and record of Substation earth resistances and carrying out improvements where necessary.
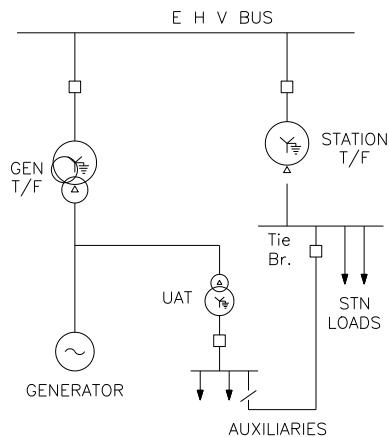
GENERATOR PROTECTION

GENERATOR PROTECTION SCHEME
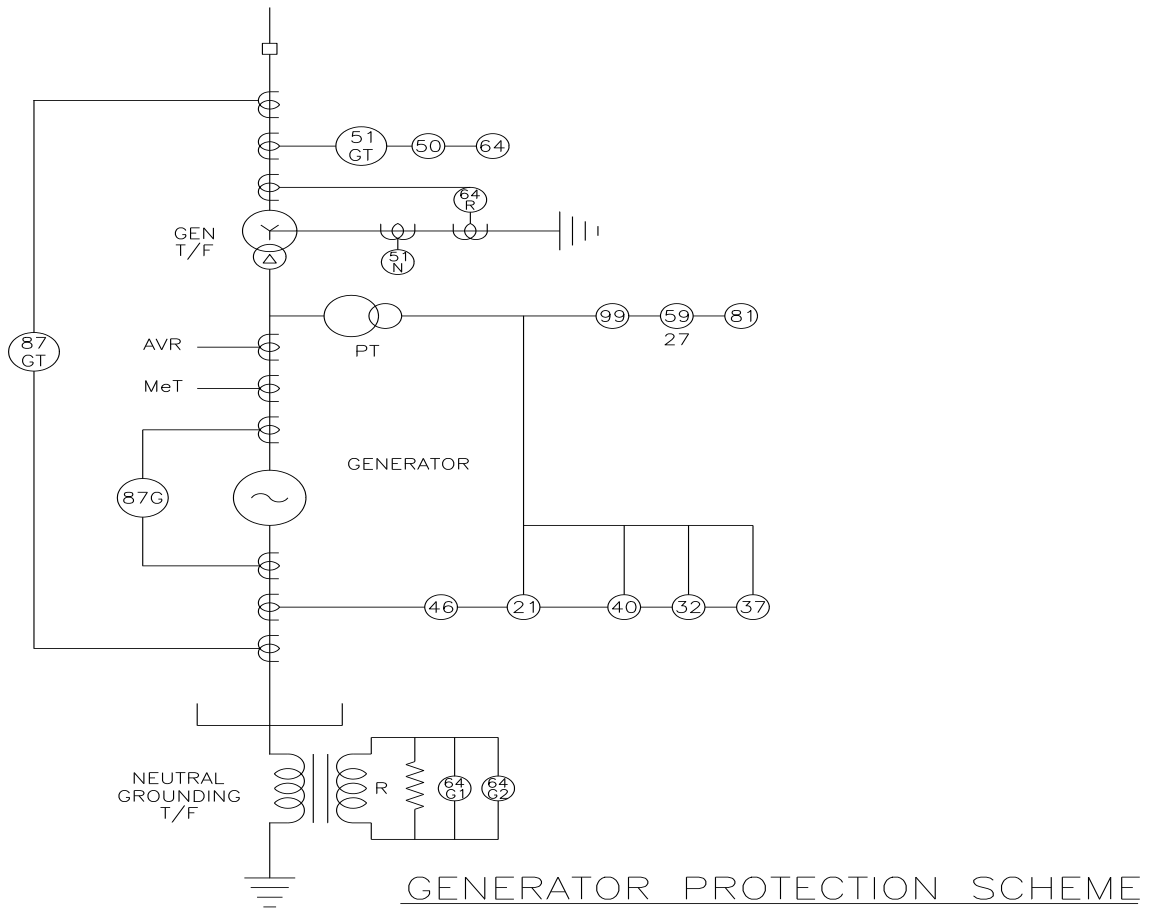
## GENERATOR AND ITS PROTECTION

The core of an electrical power system is the generator. There are power units based on steam, gas, naphtha, water power, diesel engine drive and wind mills. The range of size extends from a few hundred KVA (or even less) for engine-driven and hydro sets up to turbine driven sets exceeding 500MVA in rating.

Small and medium sized sets may be directly connected to the distribution system. A larger unit is usually associated with an individual transformer, transmission system. No switchgear is provided between the generator and transformer may be tapped off the interconnection for the supply of power to auxiliary plant. Provision of a breaker in between Generator and Transformer makes it possible to draw power for the auxiliaries through the UAT from the EHV bus, even when machine is not in service. Typical arrangements are given in figure............

GENERAL LAY-OUT OF GENERATING STATIONS

GENERATOR & GEN. T/F. AS A UNIT
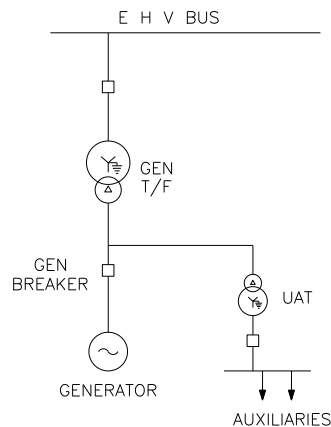
UNIT WITH GENERATOR BREAKER

Protection of 6.6 KV system in generating stations:

Major Thermal Stations auxiliaries are fed from 6.6 KV bus which is connected by a 220/6.6KV Station Transformers and Generation voltage/6.6 KV Unit Auxiliary Transformers.

Station Transformers:

The vector group of these transformers is Star-Delta i.e. the 6.6 KV system is delta connected.

<div align="center">Or</div>

The vector group of these transformers is Star-Star with the 6.6KV side grounded through a high resistance.

Unit Auxilary Transformers :

The vector group of these transformers is Delta – Star (ungrounded Star on 6.6KV System).

Any earth fault on the 6.6 KV system cannot be seen by any E/L relay (since the 6.6 KV system is delta connected or high resistance grounded or ungrounded Star).However 3-O/L relays are provided on the 6.6KV side of the Station Transformers and Unit Auxiliary Transformers . An open-delta voltage of the 6.6 KV bus PT is connected to an over voltage relay with a very low setting. Any earth fault on the 6.6 KV system will cause the presence of open-delta voltage and make the voltage relay operate which is connected to give alarm. The faulty 6.6 KV feeder can be identified by tripping the 6.6 KV outlets one after the other.

Generator Protection – Various Functions

Generating units are the source of the power system and their security against any adverse conditions is most important in the system. The generator protection must ensure a fast and selective detection of any fault in order to minimize their dangerous effects.

Protection of passive elements like transmission lines and transformers is relatively simple which involves isolation of faulty element from the system, whereas protection of generators involves tripping of generator field breaker, generator breaker and turbine.

Generator Protections are broadly classified into three types.

CLASS – A :-   This covers all electrical protections for faults within the generating unit in which generator field breaker, generator breaker and turbine should be tripped.

CLASS – B:-   this covers all mechanical protections of the turbine in which turbine will be tripped first and following this generator will trip on reverse power / low forward power protections.

CLASS – C:-   This covers electrical protection for faults in the system in which generator will be unloaded by tripping of generator breaker only. The unit will come to house load operation and the UAT will be in service. Various protections of this class are:

i)   220 KV (HV side of Generator Transformer) busbar protection.
ii)   Generator Transformer HV side breaker pole discrepancy.
iii)   Generator negative phase sequence protection
iv)   Generator Transformer over current / Earth fault protection
v)   Reverse power protection without turbine trip.

1) **Generator Differential Protection (87 G): -**

It is unit type protection, covering the stator winding for phase to phase faults due to breakdown of insulation between stator phase windings. This relay is not sensitive for single line to earth faults as the earth fault current is limited due to the high neutral earthing resistance.

If CTs of identical ratios are used on neutral and line side of generator, an operating current setting of 20% it can be adopted. It is instantaneous in operation and it trips the generator breaker (Class – A) to eliminate the system in – feed to the fault along with field breaker and turbines.

For all machines of ratings 10 MVA and above, this protection shall be provided.
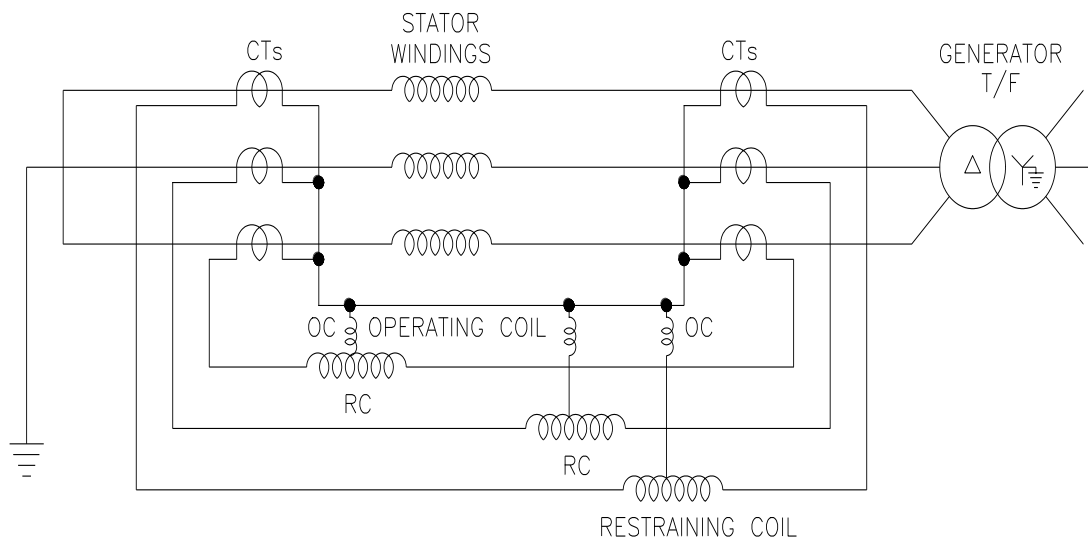
GENERATOR DIFFERENTIAL RELAY

2) **Generator – Transformer Differential Protection (87T):-**

This is similar to Generator Differential Protection, which covers from the generator terminals upto the HV breaker of generator transformer. . Sometimes this relay is not provided where Generator and Generator Transformer Overall Differential relay (87O) is provided.

87G & 87T functions should have the features of through fault restraint, magnetising inrush restraint.

OVERALL DIFFERENTIAL RELAY
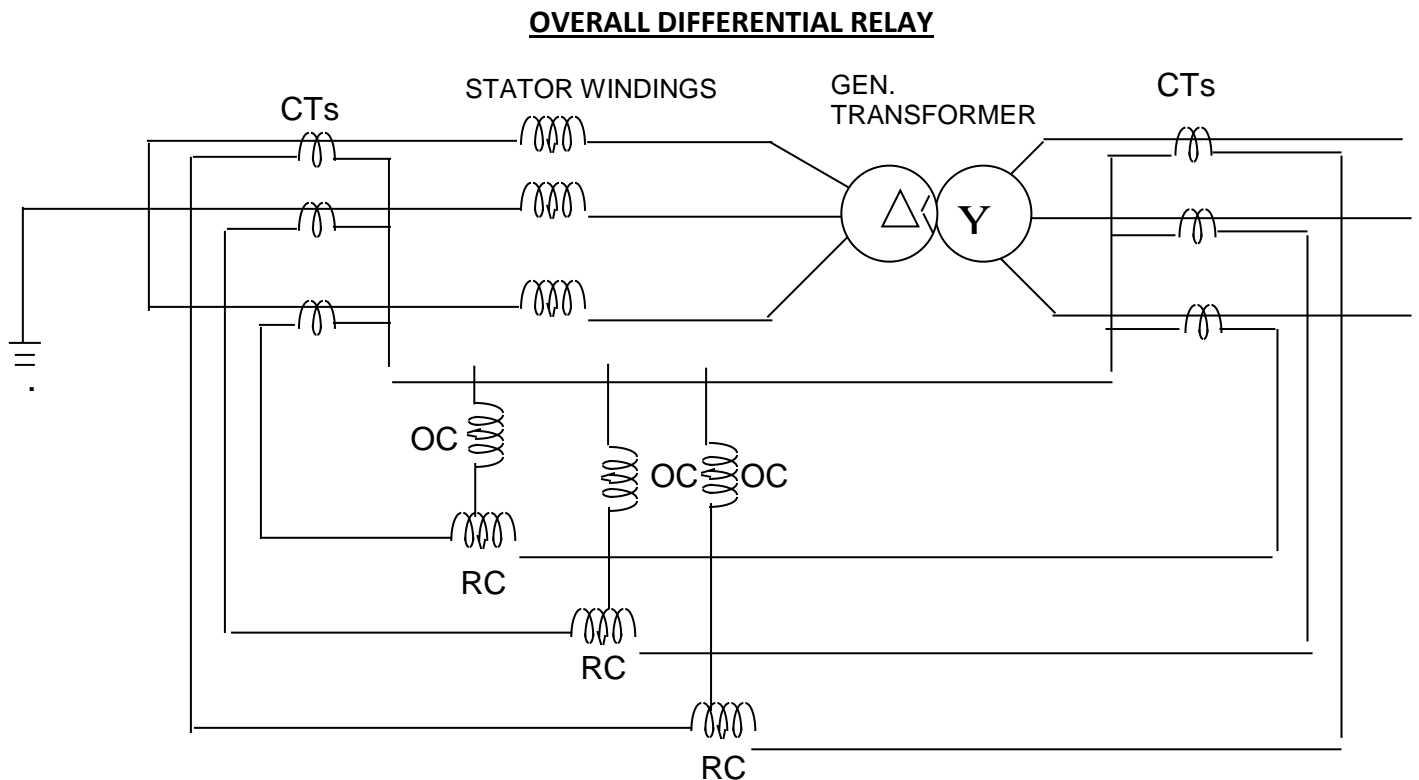
3) **Generator & Generator Transformer Overall Differential Protection (87O):**

Besides generator differential and generator transformer differential, an overall differential relay can be provided between generator neutral side CTs and generator transformer Hv side CTs (and HV side CTs of UAT if provided) covering both generator and generator transformer. The principle of operation of above relay is similar to any differential relay and it is also termed as unit differential relay.

4) **Backup impedance Protection (21G):-**
    This operates for phase faults in the unit, in the HV yard or in the adjacent transmission lines, with a suitable time delay. It operates as a backup when the corresponding main protection fails.

    In A.P. System the reach is set as 120% of generator transformer with a time delay of about 1.0 to 1.5 Sec.
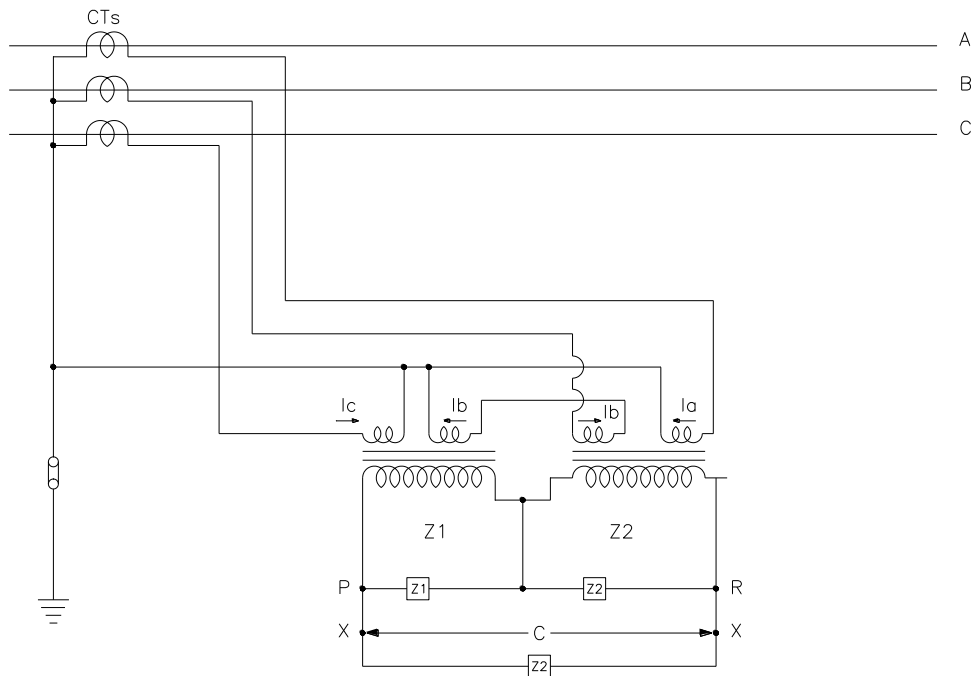
NEGATIVE PHASE SEQUENCE CIRCUIT AGAINST

5) **Voltage restrained overcurrent protection (51 / 27 G):-**

    This will operate when the fault current from the generator terminals becomes low due to excitation system characteristic with under voltage criteria.

    It operates as a backup protection for system faults with suitable time delay.

6) **Negative phase sequence protection (46 G):-**

    It safeguards the generator rotor against over heating caused by the induced double frequency (100 Hz) currents when negative phase sequence currents are present in the stator. The negative phase sequence current(I2) can appear due to unbalanced single phase loads or transmission line unsymmetrical faults.

    It should be set according the Negative Phase Sequence capability of the generator.

    $I2**2$ xt   = 30   for Thermal Units
                = 40   for Hydro Units
    Alarm stage can be set at 50% of continuous withstand capability of the machine with a time delay of 3 to 5 Sec.

7)   **Generator overloads protection (51G);-**

It is used as an additional check of the stator winding temperature high protection. The relay can be connected

   For alarm with a setting of   110% .
       For trip with a setting of   125% with due time delay

8)   **Generator Stator Earth Fault Protection (64G):-**

The high neutral earthing resistance arrangement limits the generator earth fault current, minimising the damage to core laminations. Although a single phase earth fault is not critical, it requires clearance within a short time due to:

i)   It may develop into a phase to phase fault
ii)   If a second earth fault occurs the current is not longer limited by the earthing resistor.
iii)   Fire may result from earth fault arc.
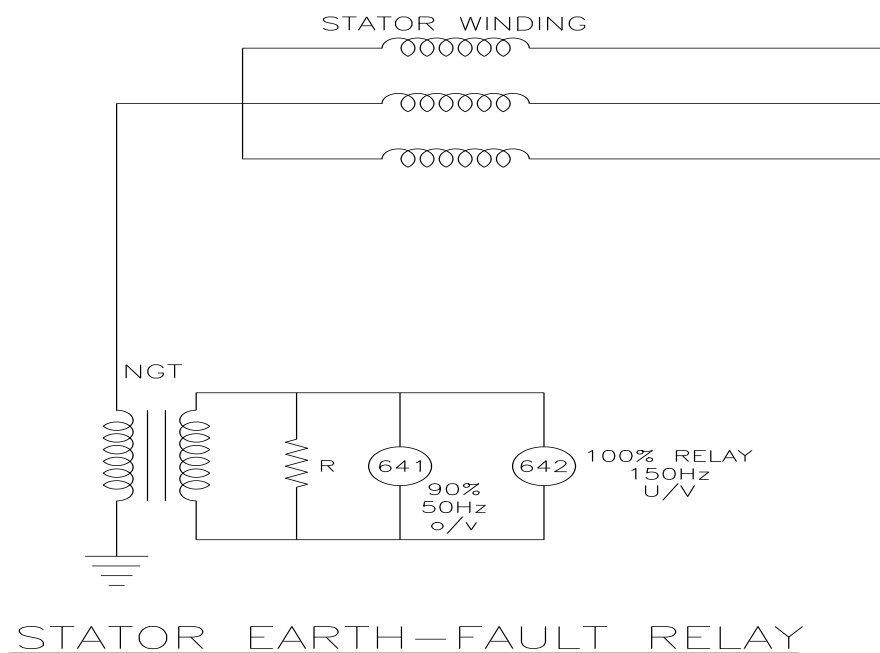
a)   **95% stator earth fault protection (64G1):-**

It is an over voltage relay monitoring the voltage developed across the secondary of the neutral grounding transformer in case of ground faults. It covers generator, LV winding of generator transformer and HV winding of UAT. A pickup voltage setting of 5% is adopted with a time delay setting of about 1.0 Sec. For all machines of ratings 10 MVA and above this shall be provided.

b)   **100% stator earth fault protection (64G2);-**

This is a 3rd harmonic U/V relay. It protects 100% of stator winding.

During the machine running condition there will be certain third harmonic voltage at neutral side of the generator.This 3rd harmonic voltage will come down when a stator earth fault occurs causing this relay to operate. This shall have voltage check or current check unit, to prevent faulty operation of the relay at generator stand still or during the machine running down period.

9)   **Loss of Excitation (40G):-**

In case of loss of excitation, the generator goes out of synchronism and starts running asynchronously at a speed higher than the system, absorbing reactive power from the system. Under these conditions, the stator end regions and part of the rotor get over heated.

This protection shall have:

i)   Mho characteristic lying in 3rd and 4th quadrants of impedance diagram with adjustable reach and offset.

ii)   An under voltage and / or overcurrent relay as additional check.

iii)   A timer with adjustable range of 1-10 Sseconds.

Recommended Settings:-

- Diameter of Mho circle   =Xd
- Off set of Mho circuit from the origin   = xd$^1/_2$
- Time delay   = 1 Sec.
- Under voltage relay   = 110 – 115% of
                                                    generator   rated current

10)   **Low Forward Power Relay (37G):-**

In thermal machines, when the steam flow through turbine is interrupted by closing the ESVs or the governor valves, the remaining steam in the turbine generates (low) power and the machine enters to motoring conditions drawing power from the system. This protection detects low forward power conditions of the generator and trips generator breaker after a time delay, avoiding motoring of generator.

The low forward power relay will be provided with 'turbine trip' interlock in thermal machines. A setting of 0.5% of rated active power of generator with a time delay of 2.0 Sec. shall be adopted.

11)   **Reverse Power relay (32G):-**

Reverse power protection shall be used for all types of generators. When the input to the turbine is interrupted the machine enters into motoring condition

drawing power from the system.   Reverse power relay protects the generators from motoring condition. In thermal machines, reverse power condition appears subsequent to low forward power condition.

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For reverse power relay, a setting of 0.5% of rated active power of generator with 2 stage timer as given below.

i)   **Stage – I: -**   With turbine trip interlock, a time delay of 2 Sec. shall
                                be adopted.

ii)   **Stage – II:-**   Without 'turbine trip' interlock, a time delay of about
                                20 Sec. can be adopted to avoid unnecessary tripping of unit during system disturbance causing sudden rise in frequency or power swing conditions.

12)   **Rotor earth fault protection: -**

This protection shall be provided for machines of all sizes.   This protection shall be connected for alarm and the operator may take the machine at the earliest opportunity after the first earth fault has occurred.

This protection will have a sensitive voltage function operating on bridge measurement basis with auxiliary equipment. It will have two levels, one for alarm and one for trip.   The settings adopted in general are:

i)   For alarm   :   25 KJ Ohm, 1.0 Sec.
ii)   For trip   :   5 K Ohm, 0.5 Sec.
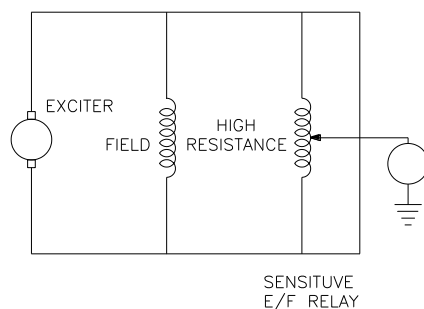
ROTOR EARTH—FAULT RELAY

A modern generating unit is a complex system comprising the generator stator winding and associated transformer and unit transformer, the rotor with its field winding and exciters, and the turbine and its associated condenser and boiler complete with auxiliary fans and pumps. Faults of many kinds can occur within this system for which diverse protection applied will be governed by economic considerations, taking into account the value of the machine and its importance to the power system as a whole

13)   **Pole Slip Relay (98 G):-**

The pole slipping relay is designed to protect synchronous generators against the possibility of the machine running unstable region of the 'power angle curve' which would result in power oscillations and pole slip.   Pole slipping of generators with respect to the system leading to an increase in rotor angular position beyond the generator transient stability limits.   Some of the causes for pole slipping are as follows.

i) Large network disturbance
ii) Faults on the network close to the generator.
iii) Loss of generator field.
iv) Operating the generator in an excessive under excited mode.
v) Loss of evacuation.

Setting recommendations:-

a) If the source of oscillation lies between generator/transformer unit, the machine has to be isolated from the network after the first slip.

   Forward reach of relay characteristics shall cover generator/generator transformer. Tripping in this zone shall be in the first pole slip. The reach of this zone is =0.7x d'

b) If the source of oscillation lies outside the unit in the network, the generator should not be switched off until several pole slips have recurred.

14) Generator Under Frequency Protection (81 G):

   The Under Frequency Protection:

-   Prevents the steam turbine and generator from exceeding the permissible operating time at reduced frequencies.
-   Ensures that the generating unit is separated from the network at a preset value of frequency.
-   Prevent overfluxing (v/f) of the generator (large overfluxing for short times).

   The stator under frequency relay measures the frequency of the stator terminal voltage.

Setting Recommendations:-

For Alarm   : 48.0 Hz, 2.0 Sec. time delay.

For Trip   : 47.5 Hz, 1.0 Sec.   (or)
                 As recommended by Generator Manufacturers.

15)   Generator Over voltage Protection (59 G):

   An over voltage on the terminals of the generator can damage the insulator of the generator, bus ducting, breakers, generator transformer and auxiliary equipment. Hence over voltage protection should be provided for machines of all sizes.

   Settings recommendations:-
   Stage-I   : Over voltage pickup = 1.15 x Un
                        Time delay   = 10 Sec.

   State-II   : Over voltage pickup = 1.3 x Un
                        Time delay   = 0.5 Sec.

16)   Standby Earth Fault Protection (51 NGT):
This relay monitors the current in the generator transformer neutral. It can detect earth faults in the Transformer HV side or in the adjacent network.

Setting recommendations:-

As this relay pickup for faults in the system, it has to be time graded with the transmission lines emanating from that generating station. Normally IDMT relay is provided

Operating Current Setting   = 20% In
Operating Time   = 1.5 to 2.0 Sec.
                                      (or)
                               Greater than (max.) Zone-3 time of adjacent
                               Transmission Lines.

The following hazards require consideration.

a) Stator insulation faults
b) Overload
c) Overvoltage
d) Unbalanced loading
e) Rotor faults
f) Loss of excitation
g) Loss of synchronism
h) Failure of prime mover
i) Low vacuum
j) Lubrication oil failure
k) Loss of boiler firing
l) Overspeeding
m) Rotor distortion
n) Difference in expansion between rotating and stationary parts
o) Excessive vibration

Small capacity induction generators also are in service, mostly mini hydel and windmills of capacity of 200KW to 2000KW, which depend on the system for excitation. Their protection requirements are very simple such as overcurrent relays.

The protective relays generally used for the synchronous generators are listed at in the following page.

Instead of independent relays for each function, microprocessor based numerical relay, which can take care of the entire Generator protections the latest entry.

PROTECTIVE SCHEMES FOR VARIOUS GENERATORS

Functions	Steam	Gas Turbines		Hydro Turbines		
	Small (<10 MVA)	Medium (10-100 MVA)	Large (>100 MVA)	Small (<10 MVA)	Medium (10-100 MVA)	Large (>100 MVA)
Differential	Y	Y	Y	Y	Y	Y
95% Stator E/F	Y	Y	Y	Y	Y	Y
100% Stator E/F	N	Y/N	Y	N	Y/N	Y
Interturn Faults	Y	Y	Y	Y	Y	Y
Backup Impedance	N	Y	Y	N	Y	Y
Voltage controlled O/C	Y	N	N	Y	N	N
Negative Sequence	Y	Y	Y	Y	Y	Y
Field Failure	Y	Y	Y	Y	Y	Y
Reverse Power	Y	Y	Y	Y	Y	Y
Pole Slipping	N	N	Y	N	N	Y
Overload	N	N	N	Y	Y	Y
Over voltage	Y	Y	Y	Y	Y	Y
Under frequency	Y	Y	Y	Y	Y	Y
Dead machine	N	N	Y	N	N	Y
Rotor Earth Fault	Y	Y	Y	Y	Y	Y
Overfluxing	N	Y	Y	N	Y	Y
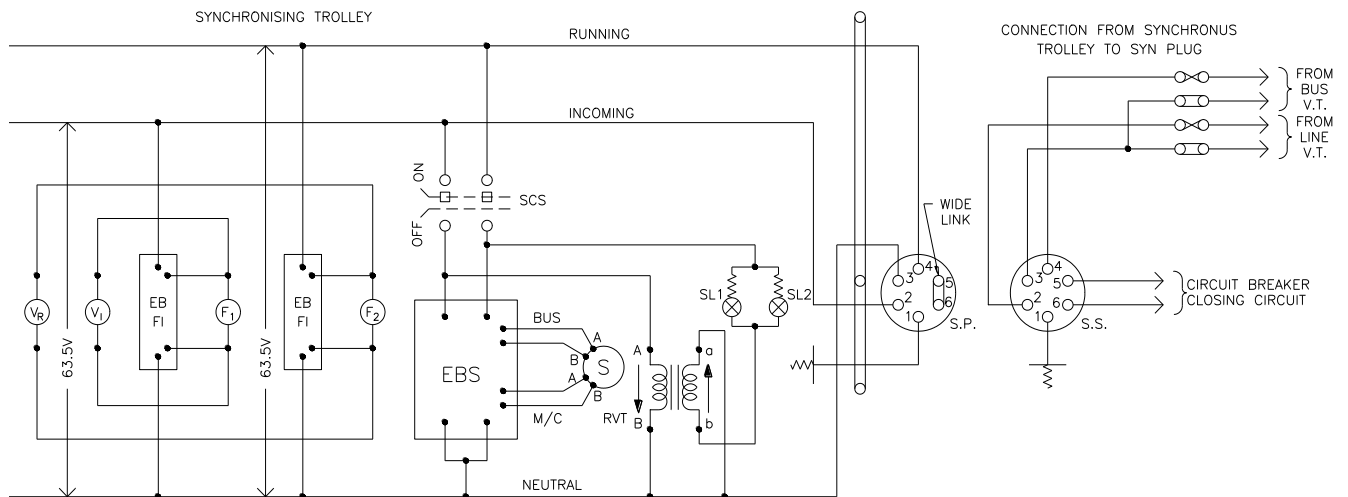
RGF.   DESCRIPTION
VR   VOLT METER (RUNNING)
VI   VOLT METER (INCOMING)
EB FI   EXTERNAL BOX FOR FREQUENCY METER (INCOMING)
EB FR   EXTERNAL BOX FOR FREQUENCY METER (RUNNING)
FI, FR   FREQUENCY METERS (INCOMING; RUNNING)
EBS   EXTERNAL BOX FOR SYNCHROSCOPE
RVT   REVERSING VOLTAGE TRANSFORMER
SL1 & SL2   INDICATING LAMPS (SYNCHRONISING)
S.P.   SYNCHRONISING PLUG
S.S.   SYNCHRONISING SOCKET
SCS   SYNCHROSCOPE CUT-OFF SWITCH

220 KV SYNCHRONISING SCHEME

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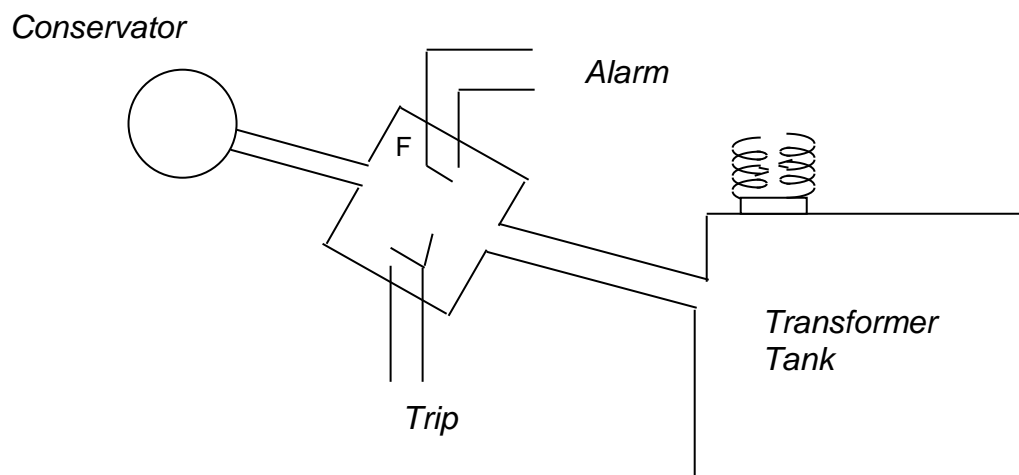# TRANSFORMER PROTECTION

TRANSFORMER PROTECTION

The rating of Power transformers used in A.P System.

1. 400/220 KV 315 MVA Auto Transformers
2. 220/132 KV 100MVA Auto Transformers
3. 220/33 KV 50 & 31.5MVA Transformers
4. 132/66 KV 40 & 27.5MVA Transformers
5. 132/33 KV 50, 31.5, 25, 16, 15 MVA Transformers
6. 132/11 KV 16, 15 & 7.5 MVA Transformers
7. 33/11 KV 8, 5, 3.15 MVA Transformers

Most of the Power transformers of 132/11KV and above are of Star-Star vector grouping with the neutral solidly earthed. There are a few transformers with delta-star (delta on HV side). The 33/11KV and 11KV/415V Transformers are of delta-star (delta on HV side).

The types of faults that the transformers are subjected to are classified as:-

1)   Through Faults:- These are due to overload conditions and external short circuits.

Time graded O/C & E/F relays are employed for external short circuit conditions. Fuses   are provided for Distribution transformers.

2)   Internal Faults:-

a) Electrical Faults: - Faults which cause immediate serious damage such as phase to earth or phase to phase faults, short circuits between turns of HV&LV windings, etc.

b) Incipient Faults: - Which are initially minor faults, causing slowly developing damage. Such as a poor electrical connection of conductors of breakdown of insulation, etc.

The following relays are employed to protect the transformer against internal faults.

  i) Buchholz relays
  ii) Differential relays
  iii) REF relays.
  iv) Overfluxing relays

i) **Buchholz Relays: -**

  Whenever a fault in transformer develops slowly, heat is produced locally, which begins to decompose solid of liquid insulated materials and thus to produce inflammable gas and oil flow. This phenomenon has been used in the gas protection relay or popularly known as Bucholz relay. This relay is applicable only to the so-called conservator type transformer in which the transformer tank is completely filled with oil, and a pipe connects the transformer tank to an auxiliary tank or " Conservator" which acts as an expansion chamber. Figure shown as Bucholz relay connected into the pipe leading to the conservator tank and arrange to detect gas produced in the transformer tank. As the gas accumulates for a minor fault the oil level falls and, with it a float 'F' which operates a mercury switch sounding an alarm. When a more serious fault occurs within the transformer during which intense heating takes place, an intense liberation of gases results. These gases rush towards the conservator and create a rise in pressure in the transformer tank due to which the oil is forced through the connecting pipe to the conservator. The oil flow develops a force on the lower float shown as "V" in the figure and overtrips it causing it contacts to complete the trip circuit of the transformer breaker. Operation of the upper float indicates an incipient fault and that of the lower float a serious fault.
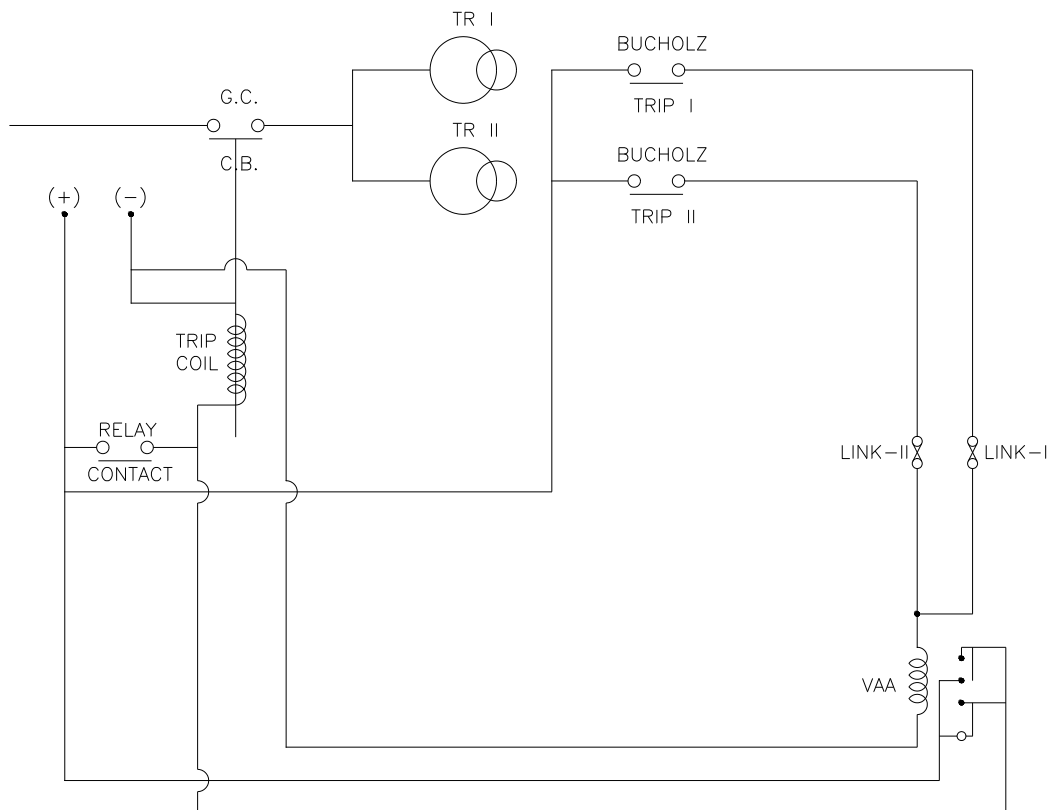
BUCHOLZ TRIP CONNECTIONS FOR POWER TRANSFORMER

Bucholz relay Operation : Certain Precautions:

  The Bucholz relay may become operative not only during faults within the transformer. For instance, when oil is added to a transformer, air may get in together with oil, accumulate under the relay cover and thus cause a false operation of the gas relay. For this reason when the 'Gas' alarm signal is energized the operators must take a sample of the gas from the relay, for which purpose a special clock is provided. Gases due to faults always have colour and an odour and are inflammable.

  The lower float may also falsely operate if the oil velocity in the connection pipe through not due to internal faults, is sufficient to trip over the float. This can occur in the event of an external short circuit when over currents flowing through the windings over-heat the copper and the oil and cause the oil to expand. If mal-operation of Bucholz relay due to overloads or external short circuits is experienced it may be necessary that the lower float is adjusted for operation for still higher velocities.

In installing these relays the following requirements should be fulfilled.

a) The conductor connection the contacts to the terminals on the cover must have paper insulation, as rubber insulation may be damaged by the oil.
b) The floats must be tested for air tightness by for example, submerging them in hot oil to create a surplus pressure in them.
c) The relay cover and the connection pipe should have a slope of 1.5 to 3 percent and not have any protruding surface to ensure unrestricted passage of the gases into the conservator.

ii)   **Differential Relays:**

  A Differential relay compares the currents on both sides of the transformer. As long as there is no fault within the protected equipment (Transformer), the current circulates between the two CTs and no current flows through the differential element. But for internal faults the sum of the CTs secondary currents will flow through the differential relay making it to operate.

**Percentage Differential Relay in a Two Terminal Circuit**
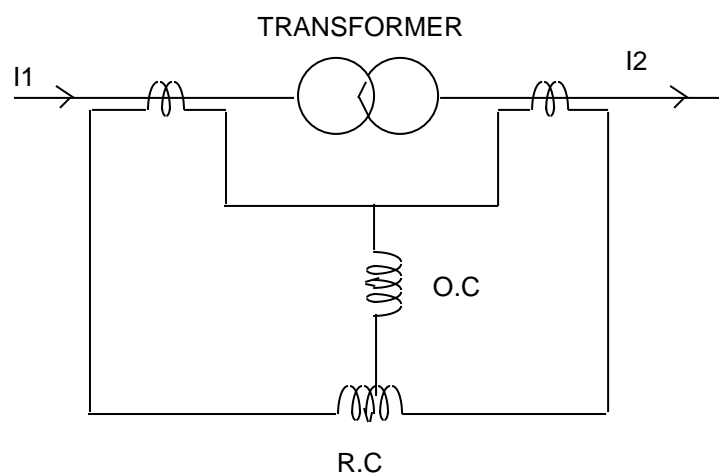
Two basic requirements that the differential relay connections are to be satisfied are:

    a) It must not operate for load or external faults.

    b) It must operate for internal faults.

As on-load tap change facilities are invariably provided in the grid transformers, any departure from the nominal tap position will result in spill currents in the relay circuits. Further, the CTs are often of different types and have dissimilar magnetization characteristics, again resulting in spill current during heavy through fault conditions.

To avoid unwanted relays operation under the above two conditions a "Percentage Bias" differential relays is used.
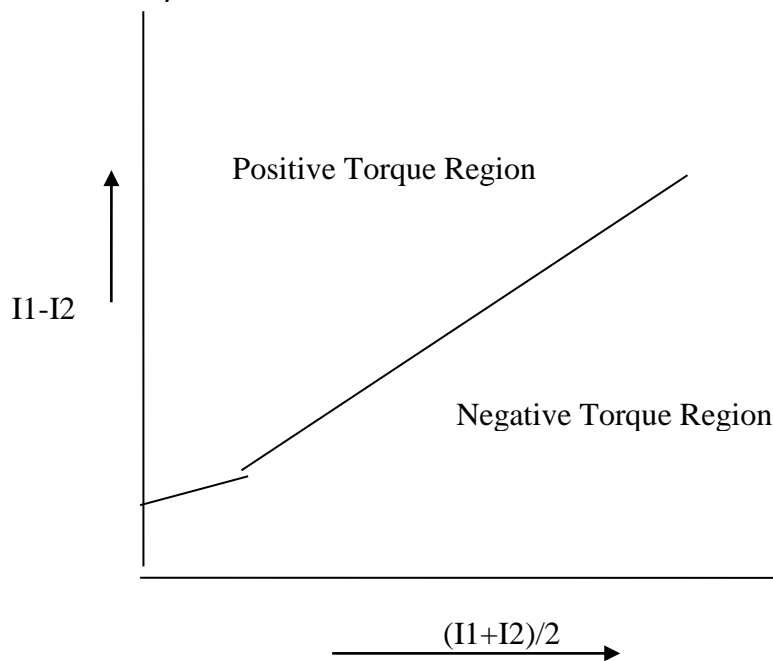
The operating characteristics of percentage bias differential relay is shown in the figure.

The current flowing through the operating coil of the relay should be nearly zero during normal operating conditions and when external short circuit occurs.

While setting the differential relay on a transformer, the (mismatch) current through differential element at normal tap and positive and negative extreme taps are to be computed. Differential element pickup setting and/or bias settings is adopted based on maximum percentage mismatch adding some safety margin.

Differential Current   = $| I1\text{-}I2 |$

Bias Setting   = $\dfrac{|I1\text{-}I2|}{(I1+I2)/2}$

C.T Ratios and connections for differential relay

1. A simple rule of thumb is that the CTs on any Wye (Star) winding of a Power transformer should be connected in delta and the CTs on any delta winding should be connected in Wye (Star).

2. a) If the CTs are to be connected in Star, the C.T Ratio will be In/1A
      Where In is transformer full load current.
   b) If the CTs are to be connected in Delta, the C.T Ratio will be In/0.5775 A.
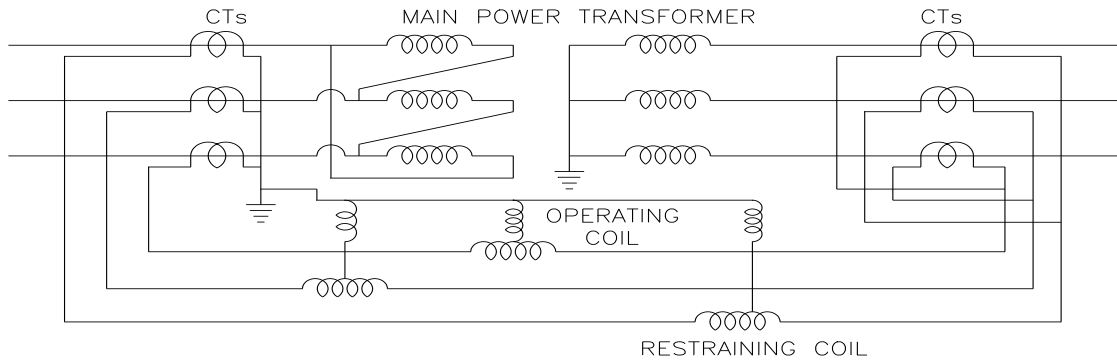
DIFFERENTIAL RELAY CONNECTIONS FOR A DELTA—STAR TRANSFORMER
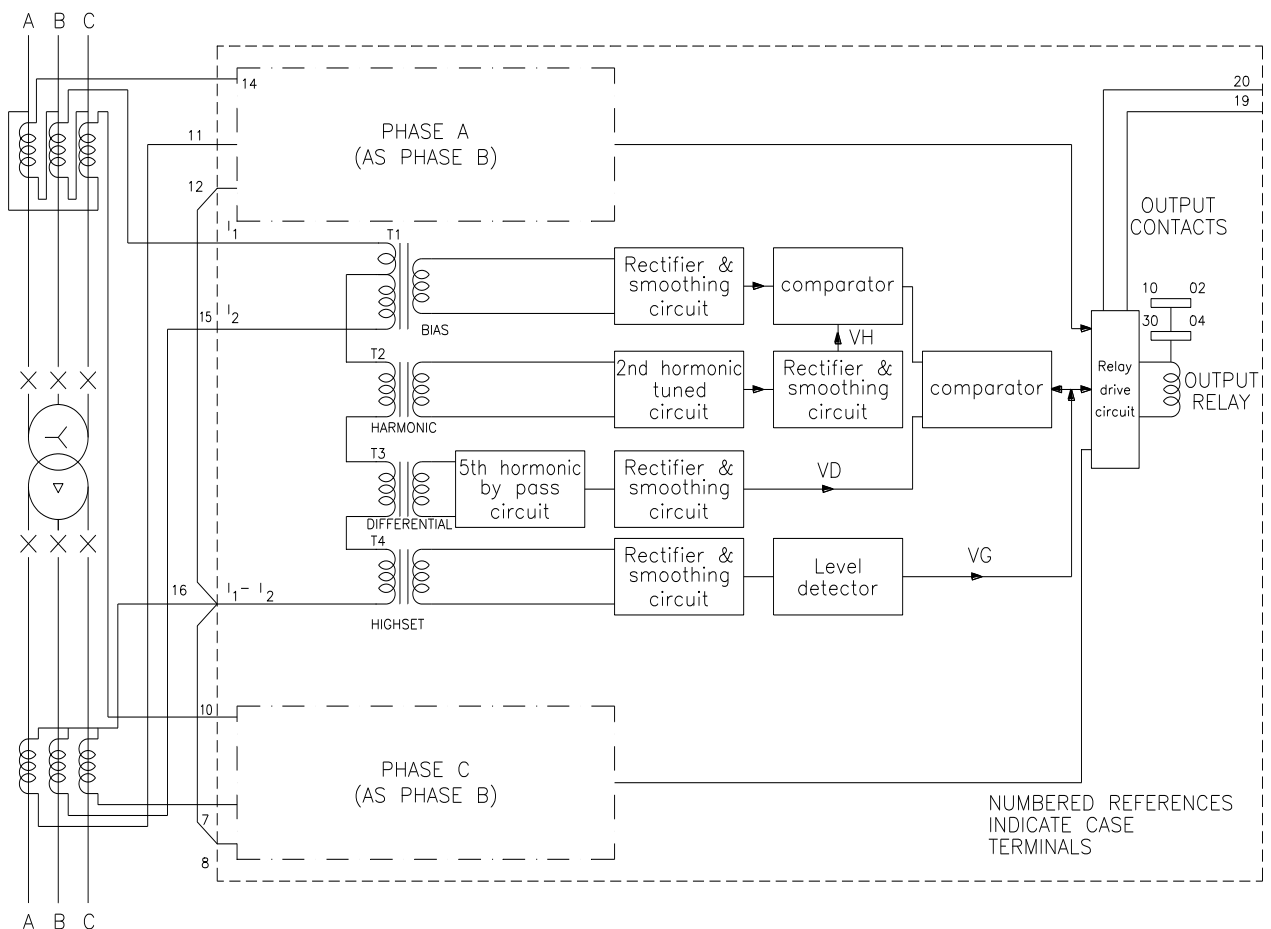
BLOCK SCHEMATIC DIAGRAM OF DTH31 (EE MAKE)

41
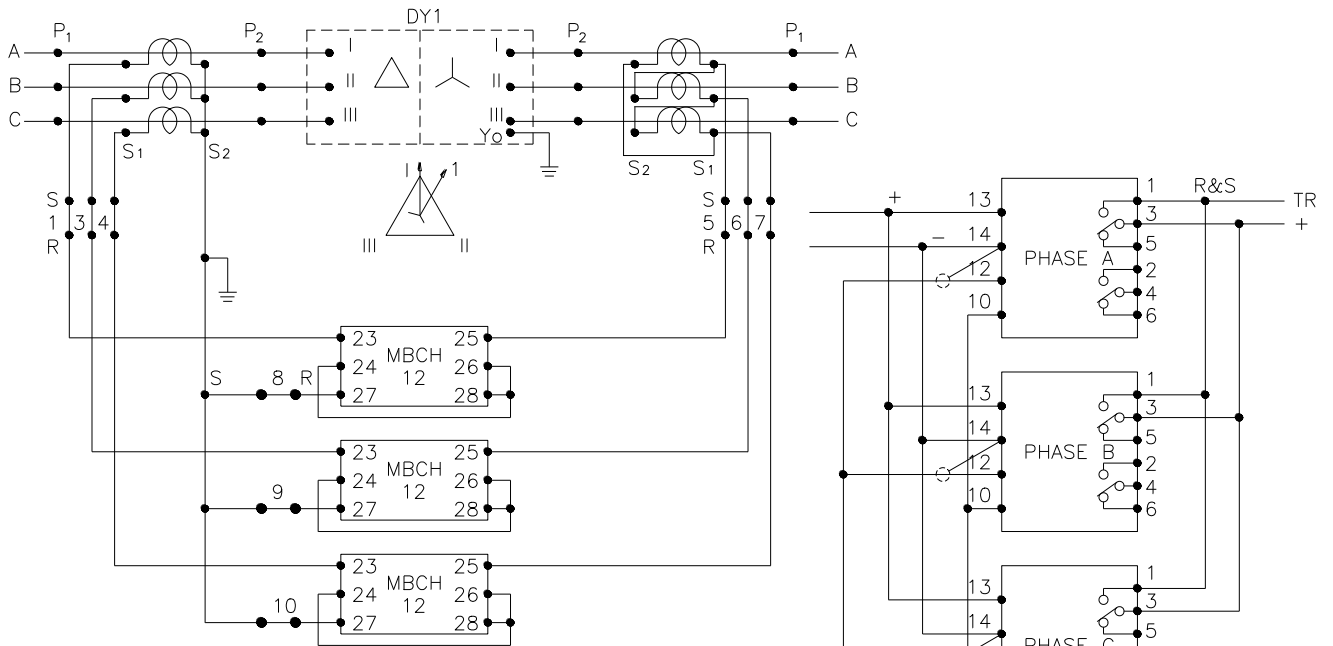
NOTES:—

IT IS ESSENTIAL THAT THE CT CONNECTIONS ARE EARTHED AT ONE POINT ONLY
ALL OUTPUT CONTACTS SHOWN ARE INSTANTANEOUSLY INITIATED FOR ANY
INTERNAL FAULT CONDITION WHEN TERMINALS NO.10 ON EACH PHASE UNIT
ARE CONNECTED TOGETHER AS SHOWN CORRECT PHASE INDICATION IS MAINTAINED.

TERMINAL 12 ON EACH PHASE ASSEMBLY SHOULD BE INTERCONNECTED BY A
SCREENED LEAD RGJ0153 001 WITH THE SCREEN CONNECTED TO TERMINAL 14.

THE RELAY CONNECTIONS ARE TO BE ROUTED THROUGH TEST BLOCK TYPE
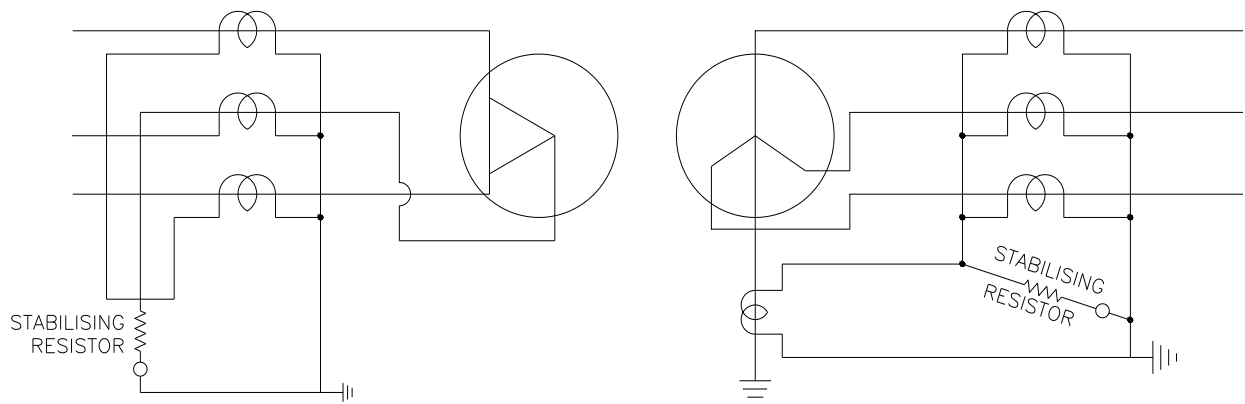MPG FOR TESTING PURPOSES. THE WAYS OF MPG TEST BLOCK ARE SHOWN
BY THE SYMBOL ●—●

TYPICAL APPLICATION DIAGRAM OF MBCH 12
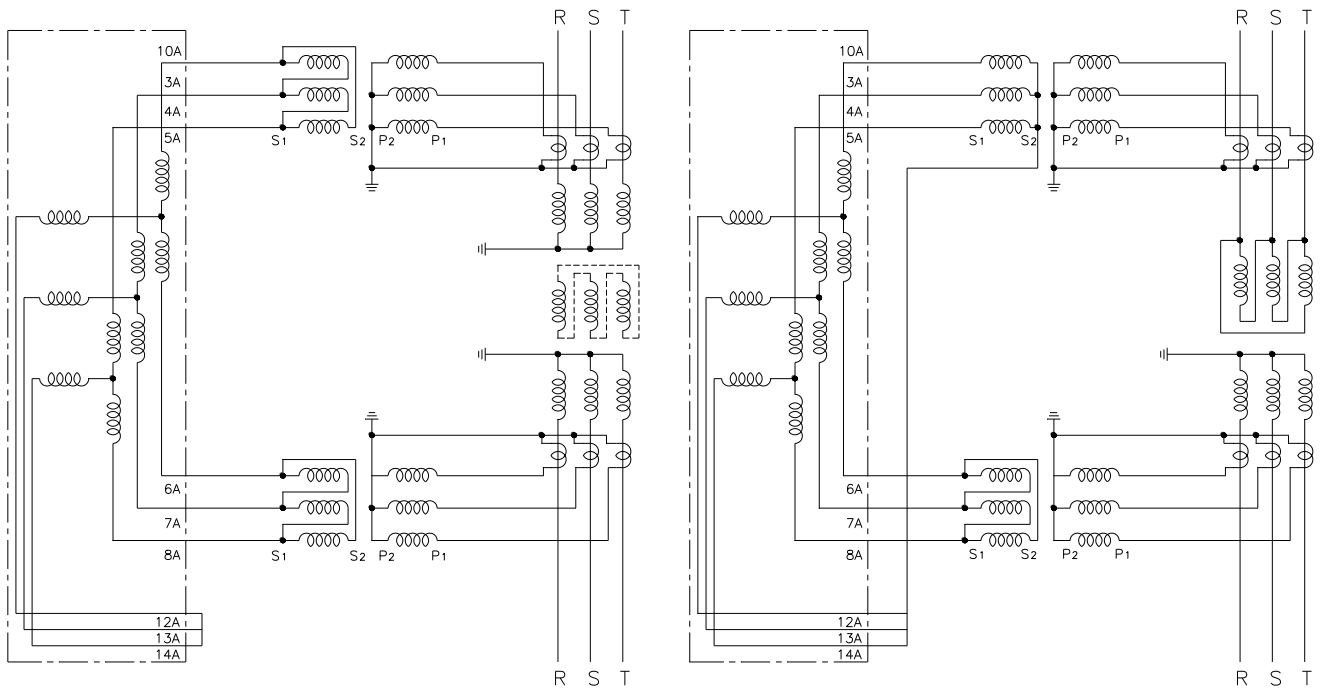
CONNECTION OF
R A D S B

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Restricted Earth Fault Protection (REF): -

This relay is operative only for the internal faults of the transformer and thus fast operating timer can be achieved.

RESTRICTED EARTH FAULT PROTECTION OF TRANSFORMER

1. An external fault on the star side will result in current flowing in the line CT of the affected phase and a balancing current in the neutral CT and current in the relay is zero and hence relay is stable. During an internal fault, the line current on the line CT gets reversed and hence relay operates.

2. The arrangement of residually connected CTs on the delta side of a transformer is only sensitive to earth faults on the delta side because zero sequence currents are blocked by the delta winding.

   For external faults no current flows through REF unless a CT gets saturated. Hence minimum pickup current setting is adopted (10% or 20% In) on REF relay. Based on the through fault current, the stabilising resistor is set such that the relay will not operate for external fault when a CT gets saturated.This relay operates only for internal earth faults,instantaneously.

Fault current for external fault I_f = 2500 A (assume)

C.T.Ratio (line and neutral) = 300/1 A

Secondary fault current $= \dfrac{2500}{300} = 8.33$ A (Sec.)

RCT = C.T.Resistance

TL = Lead Resistance = 7.41 Ohms/Km (2.5 sq mm Cu)

Voltage developed across CT (Saturated)

(V_k) $= I_f (RCT + 2RL)$
     $= 8.33 (5 + 3)$
     $= 66.64$ Volts

Relay burden = 1 VA

Relay Operating
Current = 0.2 A (Set value)

Relay Operating Voltage

$V_R = \dfrac{\text{Relay burden}}{\text{Relay Operating Current}}$

$=$ 1/0.2 = 5 Volts

Stabilising Resistor SR $= \dfrac{V_K - V_R}{ISet}$

$= \dfrac{66.64 - 5.0}{0.2}$

$=$ 308.2 Ohms

Set S_R $=$ 310 Ohms

If the calculated value of S_R exceeds the existing range, the current settings can be raised accordingly and arrived at suitable S_R value.

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Overfluxing Protection

1. Overfluxing condition in a transformer can occur during system over voltage and/or under frequency conditions (V/F).

2. The Overfluxing condition does not call for high speed tripping. The tripping can be delayed depending on the overflux withstand capability of the transformer.

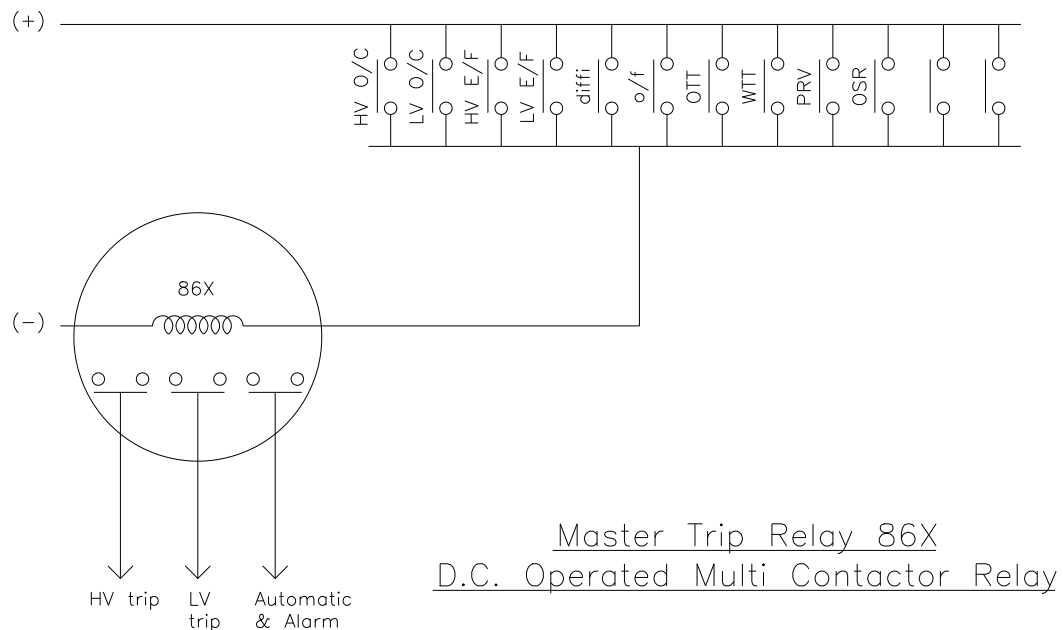3. Relays with definite time delay (nearly 30Sec.) and inverse characteristic are being employed.

Other Protective devices employed

          Pressure Relief Value (PRV)

          Winding Temperature

          Oil Temperature

          OLTC Buchholz

Master Trip Relay 86X
D.C. Operated Multi Contactor Relay

TRANSMISSION LINES PROTECTION

Transmission Line Protection

Distance Relays: -

Introduction:

       The impedance relays also called distance relays are employed to provide protection to transmission lines connected in a network as they are economic and possess several technical advantages. They are comparatively simple to apply, operate with extremely high speed, and both primary and backup protection features are inherent in them. Moreover, they can be easily modified to work as unit schemes by coordinating them with power line carrier facilities and are suitable for high speed reclosing. The impedance relay is made to respond to the impedance between the relay location and the point where fault is incident. The impedance is proportional to the distance to the fault, (hence the name 'distance relay') and is therefore independent of the fault current levels.

Distance Relaying Principle:

       A distance relay compares the currents and voltages at the relaying point with Current providing the operating torque and the voltage provides the restraining torque. In other words an impedance relay is a voltage restrained overcurrent relay.

       The equation at the balance point in a simple impedance relay is $K_1V^2 = K_2I^2$ or $V/I = K_3$ where K_1, K_2 and K_3 are constants. In other words, the relay is on the verge of operation at a constant value of V/I ratio, which may be expressed as an impedance.
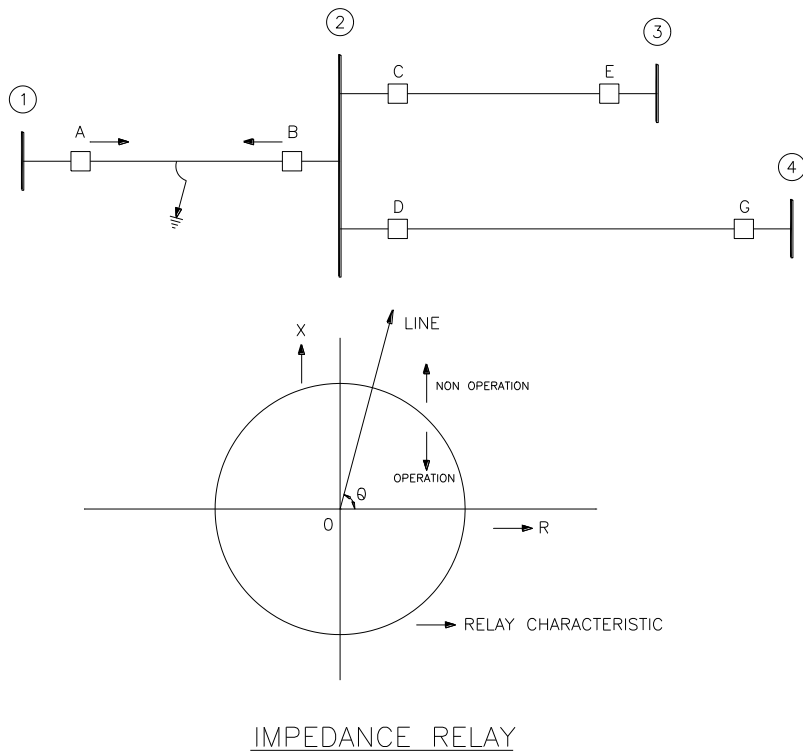
       Since the operating characteristics of the relay depend upon the ratio of voltage and current and the phase angle between them, their characteristics can be best represented on an R-X diagram where both V/I ratio and the phase angle can be plotted in terms of an impedance R+jX. Further, the power system impedance like fault impedance, power swings, loads etc. can also be plotted on the same R-X diagram. Therefore response of a particular relay during power swing, faults and other system disturbances can easily be assessed.

Types of Distance Relays:

(1)   Impedance relay
(2)   Reactance relay
(3)   Mho relay
(4)   Modified impedance relay

(1) **Impedance relay:**

Characteristics of an impedance relay on R-X diagram is shown in fig

IMPEDANCE RELAY

Operation of the impedance relay is independent of the phase angle between V and I. The operating characteristic is a circle with its center at the origin, and hence the relay is non-directional.
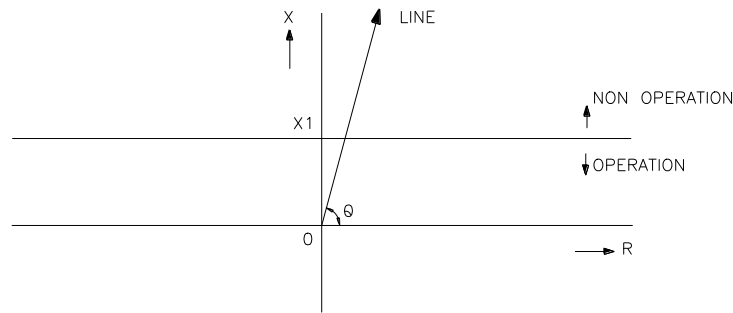
Characteristic of Directional Impedance Relay:

Characteristic of a directional impedance relay in the complex R-X phase is shown in fig.

DIRECTIONAL IMPEDANCE RELAY
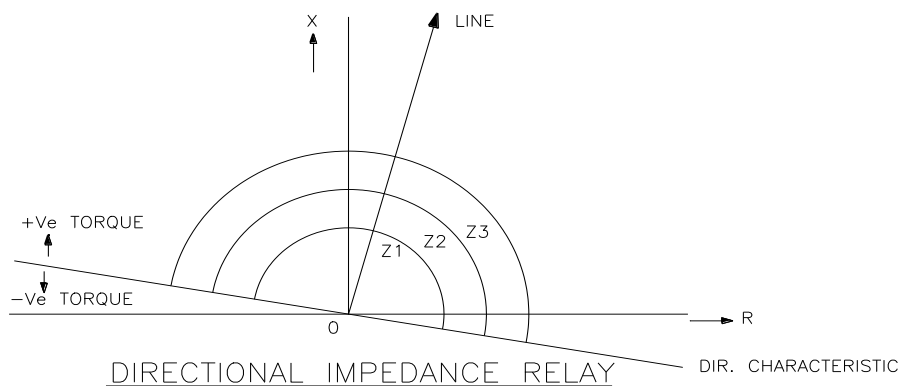
The directional unit of the relay causes separation of the regions of the relay characteristic shown in the figure by a line drawn perpendicular to the line impedance locus. The net result is that tripping will occur only for points that are both within the circles and above the directional unit characteristic.

(2)   The Reactance-type Distance Relay:

Reactance relay measures V/I Sin0 (i.e. Z sin 0 - ⬣). Whenever the reactance measured by the relay is less than the set value, the relay operates. The operating characteristic on R-X diagram is shown in fig
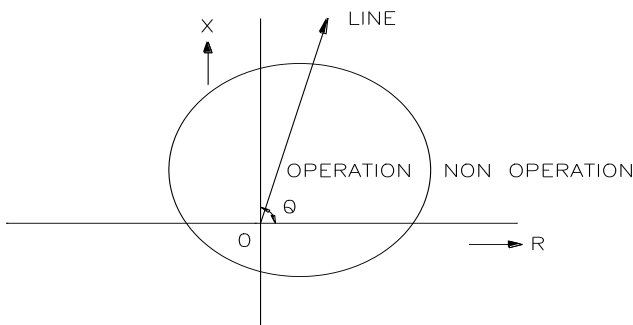

REACTANCE RELAY

The resistance component of impedance has no effect on the operation of reactance relay, the relay responds solely to reactance component of impedance. This relay is inherently non-directional. The relay is most suitable to detect earth faults where the effect of arc resistance is appreciable

(3)   Mho relay:

This is a directional impedance relay, also known as admittance relay. Its characteristic on R-X diagram is a circle whose circumference passes through the origin as illustrated in figure showing that the relay is inherently directional and it only operates for faults in the forward direction.
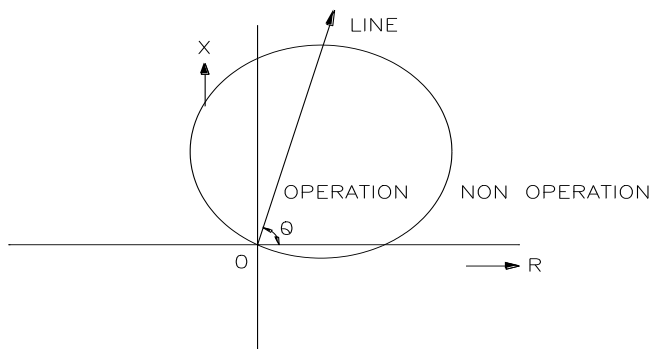
MHO RELAY

OFFSET MHO RELAY

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(4)   Modified impedance relay:

Also known as offset Mho relay whose characteristic encloses the origin on R-X diagram as shown in fig

This offset mho relay has three main applications: -

i)   Busbar zone backup

ii)   Carrier starting unit in distance/carrier blocking schemes.

iii)   Power Swing blocking.

Main Features in Distance Scheme

Distance schemes consist of the following major components:-

i)   Starters.
ii)   Measuring units.
iii)   Timers
iv)   Auxiliary relays

i)   Starters: -
         The starting relay (or starter) initiates the distance scheme in the event of a fault within the required reach (more than zone-3).

         Other functions of the starter are: -
         a)   Starting of timer relays for second and third zones.
         b)   Starting of measuring elements.

         The starters are generally of Mho or impedance type.

         With Mho type starters: -
         Measuring units for phase and earth faults can be either directional or non-directional as Mho starter is inherently directional.

         With impedance type starters: -

         Measuring units have to be directional as impedance starters are non – directional.

         The under impedance relay can be used in conjunction with the directional relay as starter which will then function similar to the Mho starter.

ii)   Measuring units: -

They are generally of a mho or reactance or a combination of mho, reactance and resistance types.

Phase Fault Units:-

These measuring units are fed with line to line voltages (such as Vab, Vbc) and difference between line currents (Ia-Ib).   They measure the positive sequence impedance from the relay location to the fault point.   Three such relays respond correctly to all possible single line to ground faults line to line faults, double line to ground faults and 3-phase faults.   They however do not respond correctly to earth faults.

Earth Fault Units: -

These measuring units utilize line to neutral voltage (Van, Vbn Vcn) and phase currents (Ia, Ib, Ic).   In order to make these units measure the positive sequence impedance correctly, a zero sequence current compensation is to be provided which is obtained by:

$KN = (Z0-Z1)/ 3*Z1$ (where Z1 = positive sequence impedance of line.
                         Z0 = Zero sequence impedance of line)

In the current circuit (1+KN) Ia will be fed for the above   measurement.

iii)   Timers: -
Timer relays when initiated by starters provide the time lag required for zones.   They also will be used for zone extension purpose whenever required.

iv)   Auxiliary relays: -
Distance scheme comprises of several auxiliary relays, which perform functions such as flag indications, trippings, signaling, alarm etc.

Additional Features in distance schemes: -

i)   Power Swing blocking relay
ii)   VT fuse failure relay.
iii)   Switch onto fault relay
iv)   Fault locator
v)   Auto-reclosing scheme.
vi)   Carrier communication scheme.

i)   Power Swing blocking: -

Distance relay which respond to balanced 3-phase changes in the impedance will be affected by power swings. These swings or oscillations occur following a system disturbance such as major load change or a dip in voltage due to delayed fault clearance.

In case of fault, the transition from period of impedance locations (25 to 33% of starter impedance) to fault impedance (starter impedance) is sudden whereas during power swings. The PSB relays use this difference to block the tripping during swings.

ii)   VT fuse failure relay: -

The distance relays being voltage restraint O/C relays, loss of voltage due to main PT fuse failure or inadvertent removal of fuse in one or more phases will cause the relay operation. The fuse failure relay will sense such condition by the presence of residual voltage without residual current and blocks the relay.

iii)   Switch onto fault: -

When the line is switched on to a close by fault (say after line clear with earth switch closed), the voltage at the relaying point will be zero. Faults of this type will normally be cleared by backup zones.

The voltage applied to the relay is low and this condition   occurring simultaneously with the operation of starter will   cause instantaneous trip by SOTF relay. This SOTF feature   will be effective only for about 1-2 seconds after the line is charged. Faults occurring after this time will be measured in the normal way.

iv)   Fault locator: -

It measures the distance between the relay location and fault location in terms of Z in Ohms, or length in KM or percentage of line length.

This relay gets same inputs as the distance relay (connected in series with one of the main relays). The measurement is initiated by trip signal from distance relays.

The fault locator gives the exact location of the fault, thereby reducing the time of restoration.

v)   Auto Reclosing Schemes:-

Types of Faults:-

i) Transient Faults:-

These are cleared by the immediate tripping of circuit breakers and do not recur when the line is re-energised.

ii) Semi-permanent Faults:-

These require a time interval to disappear before a line is charged again.

iii) Permanent Faults:-

These are to be located and repaired before the line is re-energised.

About 80-90% of the faults occurring are transient in nature. Hence the automatic reclosure of breaker (after tripping on fault) will result in the line being successfully re-energised, thereby

    a) Decreasing outage time
    b) Improving reliability
    c) Improving system stability
    d) Reduces fault damage and maintenance time

Dead Time:- The time between the Auto-reclosing scheme being energised and the 1st reclosure of the circuit breaker . This is normally set at 1 Sec.

Reclaim Time:- The time following a successful closing operation measured from the instant the auto-reclosing relay closing contacts making which must elapse before the auto-reclosing relay initiated another reclosing attempt. In other words, it may be said to be the time between 1st and 2nd re-closure.

Types of Auto-reclosing schemes (based on phase):

a) Three phase Auto-reclosing:
This type of auto-reclosing causes an immediate drift apart of the two systems and hence no interchange of synchronizing power can take place during the dead time.

b) Single Phase Auto-reclosing:
In this only the faulty phase (which already has tripped on SLG fault) is reclosed without causing interruption in interchange of synchronising power between two systems through other two healthy phases.

Types of Auto-reclosing schemes (case on attempts of reclosure):

a) Single Shot Auto-reclosing:-

In this scheme, breaker is reclosed only once on a given fault before lockout of circuit breaker occurs. High speed auto-reclosing for EHV system is invariably single shot.

b) Multi-shot Auto-reclosing:-

In this scheme, more than one reclosing attempt is made for a given fault before lockout of the circuit breaker occurs. Repeated closure attempts with high fault level would seriously affect the circuit breaker, equipment and system stability. The factors that must be taken into account:-

    i)   Circuit Breaker Limitations:-
        Ability of circuit breaker to perform several trip close operations in quick succession.

    ii)   System Conditions:-
        In the percentage of the semi-permanent faults (which could be burnt out) is moderate, for example on the lines through the forest, multishot auto-reclosing is followed.

Types of Auto-reclosing (depending on speed):

I)   **High speed Auto-reclosing:**

This aids in fast restoration of supply but should be done by taking into account the following factors:-

    i)   System disturbance time can be tolerated without loss of system stability.

    ii)   Characteristics of protection schemes and circuit breaker.

II.   **Low Speed or Delayed Auto-reclosing:-**

This is suitable for highly interconnected systems where the loss of a single line is unlikely to cause two sections of the system to drift apart and loose synchronism.

For EHV Systems:-

a)   **Choice of Dead Time:-**

Lower limit is decided by deionising time of circuit breaker.

Upper limit is decided by transient stability and synchronism.

Long transmission lines require longer dead time for single phase faults.

The dead time for high speed auto-reclosing scheme with EHV system is 0.3-0.8 Sec.

b)   **Choice for reclaim time:-**

This should not be set to such a low value that the operating cycle of breaker is exceeded when two fault incident occurs close together. The reclaim time will be in the range of 10-30 Sec., depending on the breaker opening and closing mechanisms.

vi)   Carrier Communication Schemes:-

The main disadvantage of conventional time-stepped distance protection is that the instantaneous Zone-1 of the protective scheme at each end of the protected line is set to cover 80% of the line and hence faults in the balance 20% of the line (at each end) are cleared in Zone-2 time, which is undesirable.

The desirable scheme is the one wherein the relays clear the faults on the 100% of the protected line instantaneously and also provide backup for uncleared faults on adjacent lines. This can be achieved by interconnecting the distance relays are each end of the line by a signaling channel (which can be either pilots, a power line carrier communication channel, a radio link or a microwave channel).

The purpose of the signaling channel is to transmit the information about the system conditions at one end of the protected line to the other end and initiate or prevent tripping of the remote circuit breaker. The former arrangement is referred to as a "Transfer trip scheme" while the latter is known as "Blocking scheme"
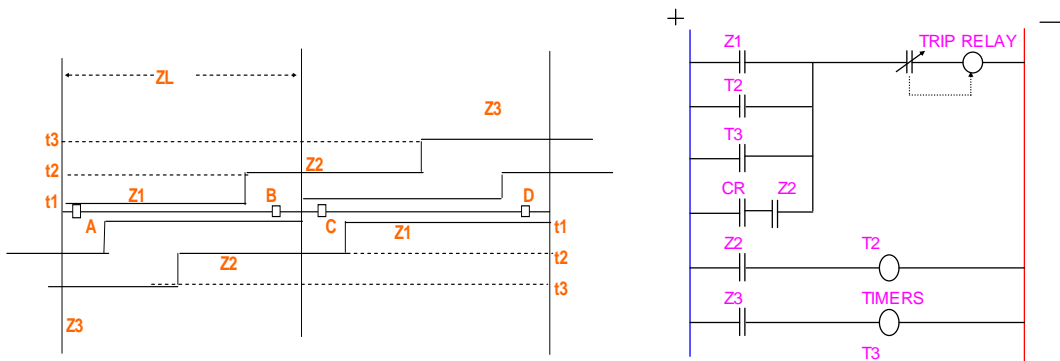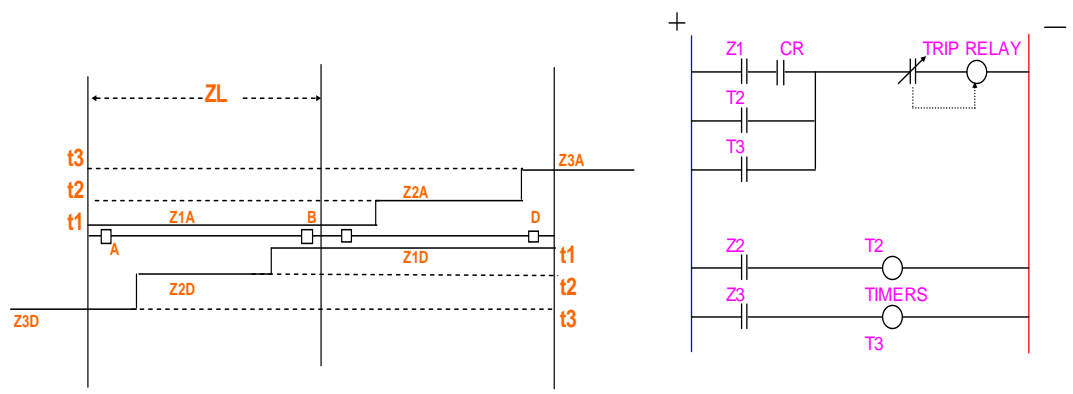

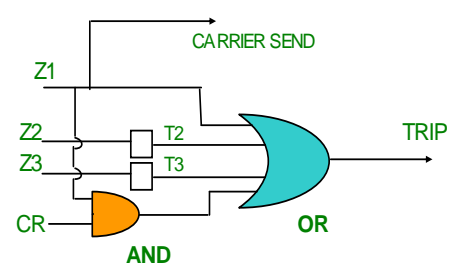|			
CARRIER SEND =Z1			
TRIP =Z1 + Z2*(CR+T2) + Z3*T3			
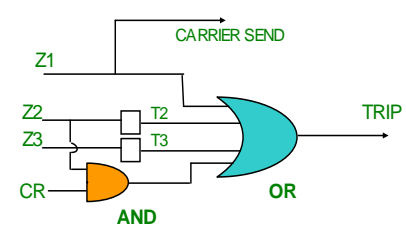
a)   Transfer trip scheme:-

In this scheme, the distance relay at one end of the protected lines sends a carrier signal to the relay at other end of the line for inter-tripping, thereby clearing the faults on entire line instantaneously.

|			
	CARRIER SEND =Z1		
	TRIP =Z1*CR + Z2*T2 + Z3*T3		

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Transfer trip is of two types:-

i)   Under-reaching scheme:-

The scheme in which the Zone-1 relay (set to cover about 80% of ZL) is used to send a signal to the remote end of the feeder for inter-tripping is termed as transfer trip under-reaching scheme. To avoid mal-operation due to receipt of false signal, the receiving end relay operation is inter-locked with its Zone-3/starter operation i.e. the scheme operates either by its own Zone-1 relay operation or by receipt of carried and its Zone-3/starter operation.

ii)   Over-reaching scheme:-

This scheme is suitable for short lines where an underreaching Zone-1 would be too short to be of any practical use. In this scheme the relay set to reach beyond 100% of the line, is used to send an inter-tripping signal to the remote end of the line. It is essential that the receive relay contact be monitored by a directional relay to ensure that tripping does not take place unless the fault is within the protected section. The disadvantage of this scheme is that there is no independent Zone-1 tripping. The fast tripping therefore relies entirely on signaling channel.

The disadvantages of these schemes is that the signal is transmitted over the fault line section. Distortion of the signal may occur due to attenuation introduced into the line by the fault.
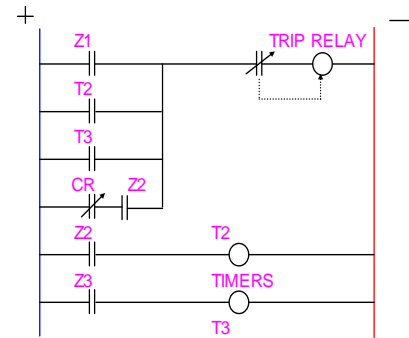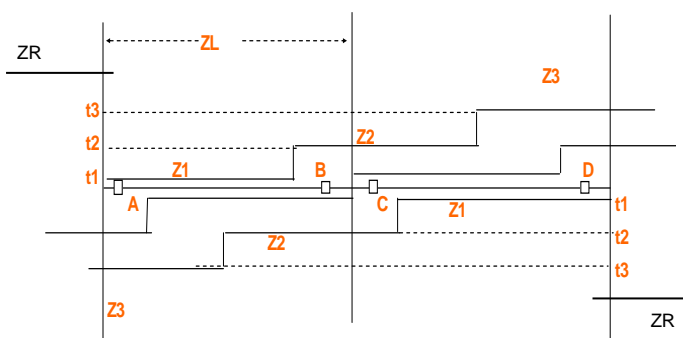
CARRIER SEND   =ZR

TRIP =Z1 + Z2* ($\overline{CR}$ * To+T2) + Z3*T3
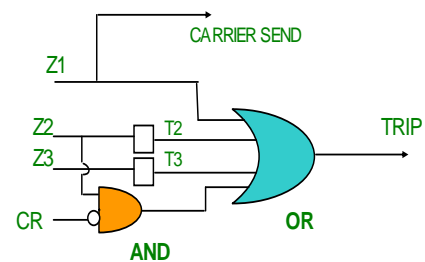
b)   Blocking schemes:-

In this scheme, a blocking signal is sent by the reverse looking directional unit ZR to prevent instantaneous tripping for Zone-2 & Zone-3 faults, external to the protected line. Here ZR must operate faster then forward looking Zone-3 units and the signaling channel must also be extremely fast is operation.

Though all the distance schemes with carrier inter-tripping/carrier blocking facility are procured, the same are yet to be commissioned.
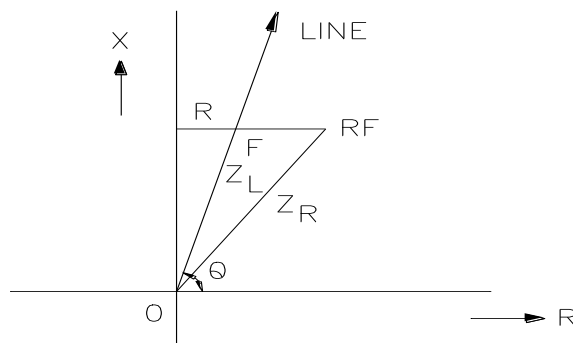
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Factors affecting distance relay operation:-

i)   Fault resistance.
ii)   Infeed effect.
iii)   Branching-off effect.
iv)   Load encroachment.

i)   Fault resistance:-
        Fault resistance has two components:-
        a) Arc resistance.
        b) Ground resistance.

EFFECT OF FAULT RESISTANCE

In a fault between phases, only arc resistance is involved.
For a fault at F, the actual line impedance
= R + JX = ZL

Due to the presence of fault resistance, the impedance measured by the relay
= R + JX + RF = ZR (where ZR > ZL)

Fault arc resistance is given by Warrington's formula:
        $R_{arc} = 8750 \, xl \, / \, I^{1.4}$

where l = length of arc in ft
       I = fault current in Amps

The arc resistance has little effect on accuracy of zone-1 unit as it operates instanteously before the arc can stretch appreciably except in case of short lines. Reactance relays are therefore used for short lines where the fault resistance may be comparable with that of the protected lines and also for ground faults where the ground resistance is high.

The arc resistance will have greater impact on accuracy of backup zones (time delayed) as the arc stretches appreciably.

ii)   Infeed effect:-

The effect of intermediate current source between relay location and fault point is termed as infeed effect. Consider the sketch indicated in fig ---

INFEED EFFECT
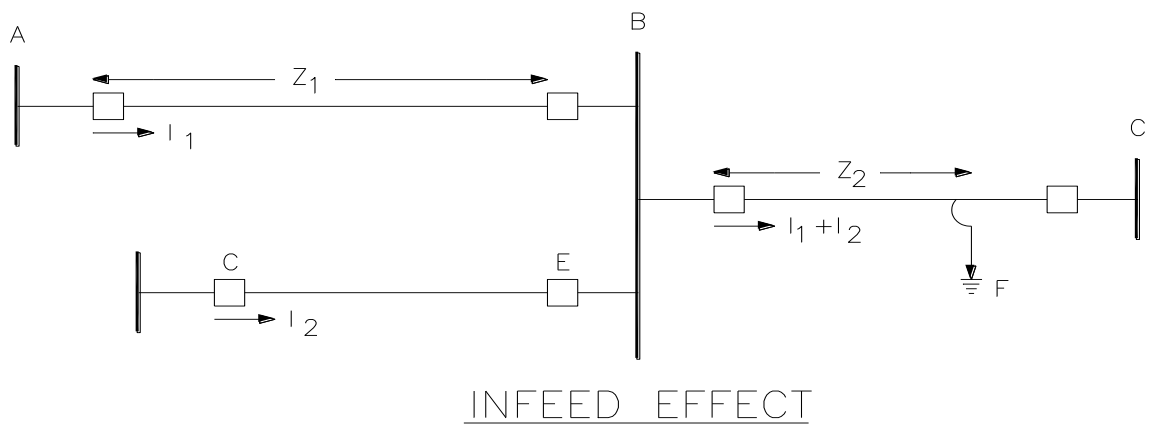
A fault at F on the line BC is at a distance of Z1+Z2 for the relay at station A. But when current I2 flows from bus D, the impedance to the fault as seen by the relay at A is
Z1 + Z2 + Z2 x (I2/I1).

Thus the fault is seen by the relay as farther than what it really is, i.e. distance relay under reaches due to the infeed effect.

The effect of infeed becomes more pronounced with more interconnections at station B.

iii)   Branching-off effect: -

Consider the sketch indicated in fig ---

BRANCHING OFF EFFECT
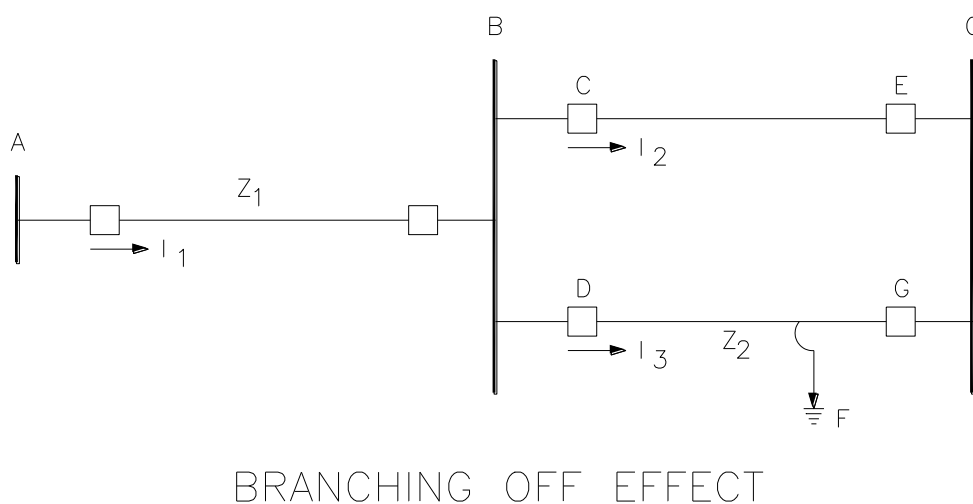
A fault at F is at the distance of Z1+Z2 for the relay at station A. But when current I1 gets distributed as I2 & I3 at station B, the impedance to fault seen by the relay at station   A will be (Z1 + I3/I1 * Z2) which is less than (Z1+Z2).

Then the fault is seen by the relay as nearer than what it really is i.e. distance relay overreaches due to branching-off effect. This overreaching tendency will cause the relay to loose its selectivity.

iv)   Load encroachment: -

While protecting long lines the necessary reach may be so large that the minimum service impedance (or load impedance) falls within the region of the starter. This would result in tripping without there being any fault. The two conditions i.e. operation at heavy load and short circuit differ by virtue of phase angle between voltage and current. For the load impedance, the phase angle will be within +30 to -30 Deg. While during short circuits, the fault impedance has a phase angle of 60 to 80 deg. (i.e. line angle).

Load encroachment problem is more pronounced in case of under impedance starters and gets lessened in case of mho, elliptical, lens etc, type of starters. Relays with suitable characteristic on R-X diagram have to be carefully chosen to protect long and heavily loaded lines, and this becomes easily possible with microprocessor based numerical relays.

Non-switched scheme vs switched scheme: -

In an ideal Non-switched scheme, there will be 6 starters, 3 for phase faults and 3 for ground faults. There will be independent measuring units for both phase faults and earth fault for each phase, for all three zones, totaling to 18 units. This scheme is faster and more accurate but is costly.

In the switched scheme, only one measuring unit will be used for all types of faults. This single measuring unit is switched to the correct fault loop impedance by switching-in the respective voltages and currents by the starter.

The reach of the measuring element gets extended to zone-2 and zone-3 after the elapse of corresponding timings through zone extension process. Switched scheme is relatively slow in operation and has the risk of total scheme failure in the event of failure of the only one measuring unit available.

Zone extension schemes: -

As a via media between non-switched and switched schemes, there are schemes with zone extension facility (such as EE make MM3V & MR3V relays). These schemes consists of 3 measuring units for phase faults and 3 measuring units for earth faults (apart from 3 starters).

The reach of the measuring unit gets extended to zone-2 and zone-3 after elapse of corresponding timings through a zone extension process.

Other Operating Characteristics:

Earlier when electromagnetic relays were in use, the characteristics involving straight lines and /or circles on R-X diagram were only possible. With the advent of static relays, microprocessor based relays and presently of numerical relays, any desired/required-operating characteristic is possible giving wider choice for selection of relays. Infact there are relays, which can be programmed remotely.

Application of distance relays:

Since the distance relays are fed from the secondaries of line CTs and bus PTs/line CVTs, the line parameters are to be converted into secondary values to set the relay as per requirements.

$$Z_{secy} = Z_{pri}/\text{Impedance ratio}$$
(where Impedance ratio = P.T.Ratio/C.T.Ratio)

Hence any changes in C.T .ratio has to be effected along with revision of relay settings only.

For the lines, the impedance in Ohms per KM is approximately as under:

KV	Z1 (= Z2)	Line Angle
132 KV	0.4	60 to 70 Deg.
220 KV	0.4	70 to 80 Deg.
400 KV	0.3	80 to 85 Deg.

The line impedance is to be computed depending on line configuration conductor size and clearness. The values in the table are only representative.

A distance relay is stepped for either 3 zones or 4 zones to provide protection.
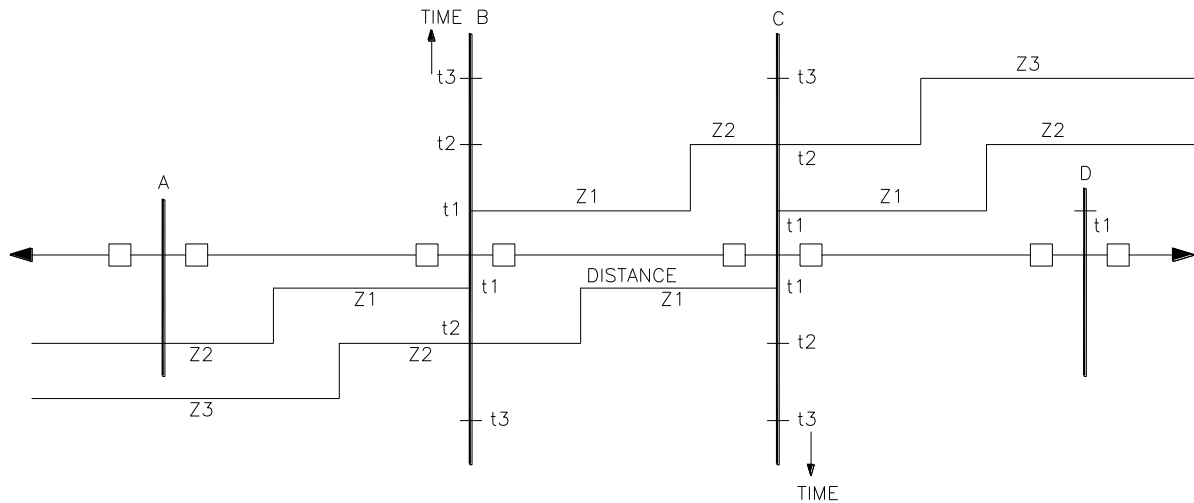
THREE ZONE TIME—DISTANCE CHARACTERISTICS

To ensure proper coordination between distance relays in power system, it is customary to choose relay ohmic setting as follows: -

S.No.	Zones	Reactance	Time
1.	Zone-1	80% of ZL	Instantaneous (no intentional time delay).
2.	Zone-2	100% of ZL + 40-50% of ZSL	0.3 to 0.4 seconds
3.	Zone-3	100% of ZL + 120% of ZSL	0.6 to 0.8 seconds
4.	Zone-4	100% of ZL + 120% of ZLL	0.9 to 1.5 seconds.

where ZL = Positive sequence impedance of line to be protected.
ZSL = Positive sequence impedance of adjacent shortest line.
ZLL = Positive sequence impedance of adjacent longest line.

Note: i)   Where a three zone relay only is available, the zone 3 will be set to cover the adjacent longest line.

jj)   The zonal timings will be carefully selected to properly grade with the relays on all the feeders emanating from the adjacent bus.

<u>Norms of protection adopted for transmission lines in A.P.System:-</u>

i)   <u>132 KV Lines: -</u>

A switched type distance scheme supplemented by three numbers directional O/L relays and 1 No. directional E/L relay.

ii)   <u>220 KV Lines: -</u>

Two Distance Schemes: -

Main-I: -   Non-switched scheme fed from bus PT.

Main-II: -   A switched scheme fed from line CVT.

A provision is generally made for the changeover of voltage supply for the distance schemes from the bus PT to line CVT and vice-versa.

Each distance scheme is fed from independent CT secondary cores.

iii)   <u>400 KV Lines:-</u>

Two Distance Schemes:-

Main-I:-   Non-switched or Numerical distance schemes
Main-II:-   Non-switched or Numerical distance schemes

<u>Details of distance relays:-</u>
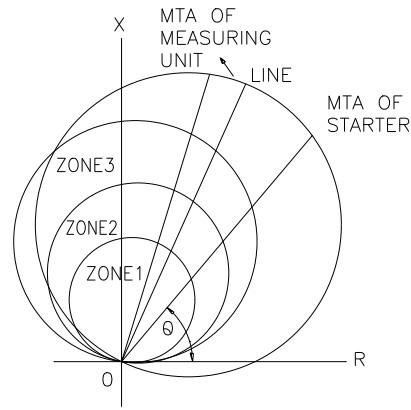
1)   Make: - GEC Alstom Ltd.

i)   MM3V : -   It is an electromagnetic type distance relay with:

3-mho measuring units for phase to phase faults.

3-mho measuring units for phase to earth faults.

3-mho starting units, each starter being associated with one phase and operating for all faults associated with that phase and one offset mho unit for power swing blocking.

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MM3V

R-X diagram is indicated

Setting range in ohms for Zone-1

0.834 to 30
1.335 to 48
1.668 to 60
Z2 = 1 to 3.5 times Z1
Z3 = 1 to 5 times Z1

Some of the schemes are provided with a Zone-4 timer to make the scheme works as a 4 zone relay, the starter itself being the 4th zone.

ii)   MR3V: -

It is an electromagnetic relays with 3 mho units for phase faults, 3 reactance units for earth faults. 3 mho starters, each being associated with one phase for all types of faults and one offset mho unit for power swing blocking.

Setting ranges same as in MM3V.

R-X diagram for phase faults is same as that for MM3V relay and for earth faults it is indicated in figure
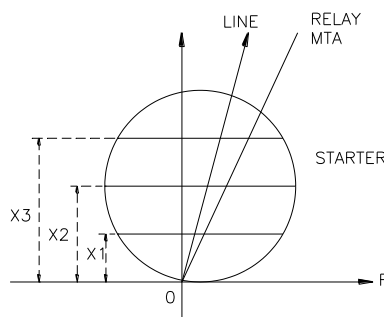
MR3V

iii) RR3V: -

     It is an electromagnetic relay with 3 Nos. reactance units for phase faults, 3 reactance units for earth faults, and 3 mho starters per phase for all types of faults and one offset mho unit for PSB. R-X diagram is indicated in figure
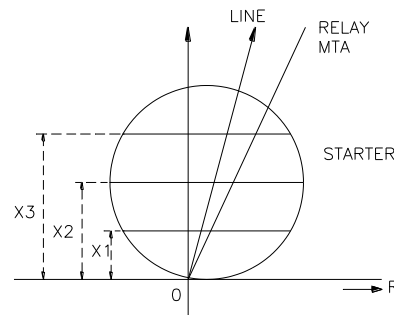
iv) SSRR3V: -

It is an electromagnetic switched scheme with two version i.e. with mho or under impedance starter and available in low and high range.

RR3V & SSRR3V

3 under impedance starters directionalised by mho element or 3 mho element starters and for all types of fault, one reactance-measuring unit for phase and earth faults.

Low range relay:	Z1 = 0.5 to 7.7. Ohms
	(k1 of zone1: 7.7, 3.0, 1.22)
High range relay:	Z1 = 1.3 to 20 Ohms
	(k1 of zone-1: 20, 7.8, 3.16)
	Z2 = (1 to 3.5) times Z1
	Z3 = (1 to 5) times Z1

R-X diagram is same as that for RR3V relay.

Few versions do not have separate zone-4 timer. In such relays, zone-4 time = zone-3 time + 150 msec (fixed built-in delay).

v) SHPM (Quadra mho): -

It is a non-switched static scheme with 18 measuring mho units. The zone-3 measuring elements will act as starters, which have either mho or a lenticular characteristic. The operating characteristic on R-X diagram is indicated in figure

SHPM

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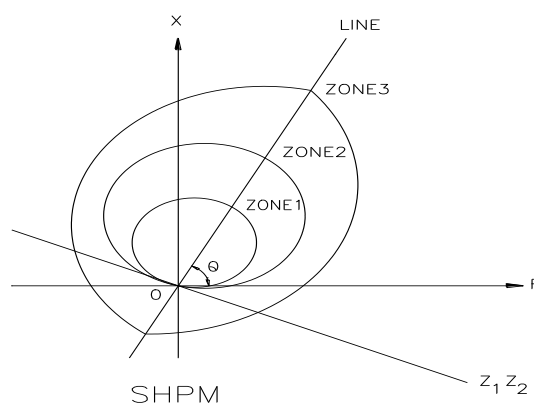
The lenticular characteristics allows healthy overloads and hence prevents tripping on load encroachment.

Setting range: - 0.2 to 240 Ohms.

It has built-in feature of continuous self monitoring (on demand and periodic self testing).

All the additional features provided by relay can be enabled or disabled with the help of switches provided for them.

vi)   PYTS: -

It is a static switched scheme with modular plug-in construction (with built in test points).

It has 3 under impedance starters and a single mho measuring unit. One U/I unit for power swing blocking. R-X diagram is indicated in figure

Setting range: 0.05 to 40 Ohms, with starter having range of 20 to 70 Ohms.

It has an uncompensated U/I starter, which has become a problem due to load encroachment for long lines.

V−I CHR. OF PYTS   PYTS
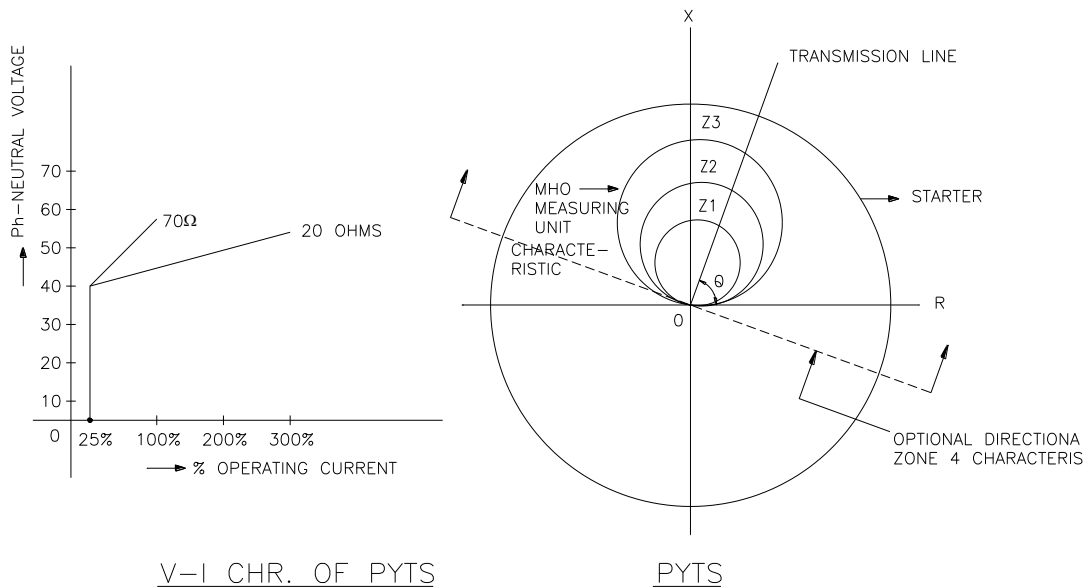
The V-I characteristic of the starter is indicated in above figure.

When the voltage is less than 65% rated, the starter operates at a current greater than 0.25 In. With low voltages at some of the stations, this feature has caused relay to operate unnecessarily.

vii)   OPTIMHO

Optimho distance relay is a non-switched protection scheme having 18 comparators and upto five zones of protection (three basic zones of measurement and two for zone extension schemes)

The relay has partially cross polarised shaped mho characteristics for zone-1 and zone-2 phase units. The zone-3 for phase faults have offset lenticular characteristics which permit the relay to be applied to long heavily loaded transmission lines without encroachment into the load impedance.

For earth faults, zone-1 and zone-2 units have quadrilateral characteristics with independent reaches in resistive and reactive axes. The zone-3 units are offset quadrilateral.

The zone-3 units for phase and earth faults can be chosen for offset or to see in reverse direction. The relay characteristic is indicated in Fig.

PHASE FAULTS   GROUND FAULTS
(a) WITH OFFSET ZONE 3

PHASE FAULTS   GROUND FAULTS
(b) WITH REVERSE ZONE 3
OPTIMHO
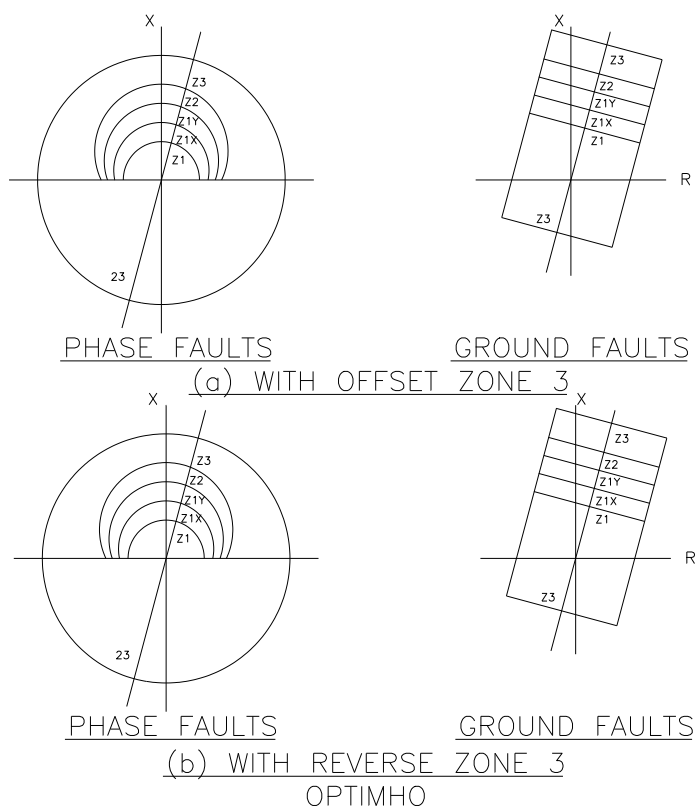
On event of failure of quadrilateral comparators, mho/lenticular comparators are automatically enabled but vice versa is not possible. The relay has self testing facility. It has 8 groups of settings and any one group can be set active.

PD – 521: -

a)   It is a numerical protection relay with polygon characteristics.
b)   It consists of four impedance zones with independent R and X values for each zone
c)   Zone – 4 can be utilized as a special zone for cabie protection.
d)   R – X diagram as indicated in figure.
e)   Through MMI, one can enter and edit the settings (The settings are password protected)

Setting Range   :   0.1 to 2000 Ohms.

Timers   :   0 to 10 Secs.
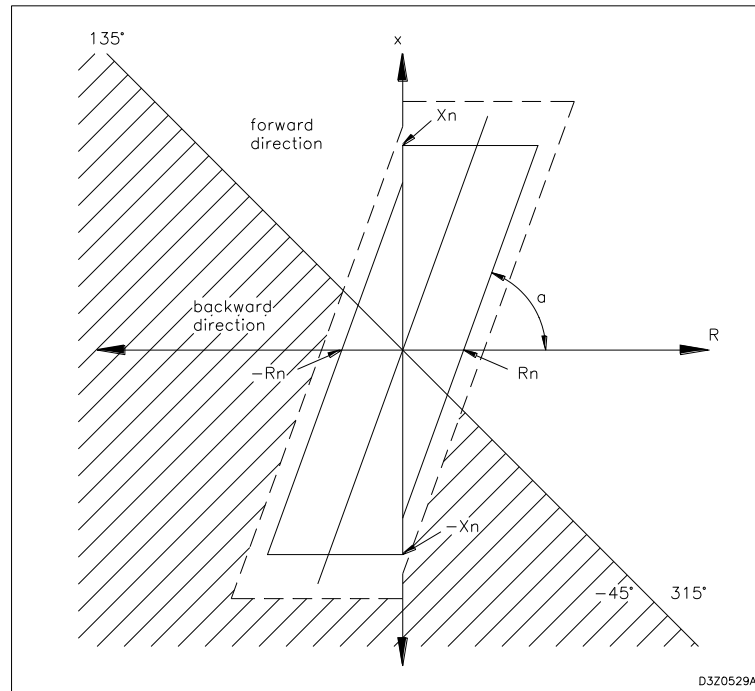
PD. 521

MICOM DISTANCE RELAY (Alstom make):

MICOM P440 series is a distance scheme with advanced numerical technology. MICOM P441 and P442 relays have five zones of phase fault protection and five zones of earth fault protection.

a) **Phase fault protection**

Phase fault quadrilateral characteristics is shown in the figure.
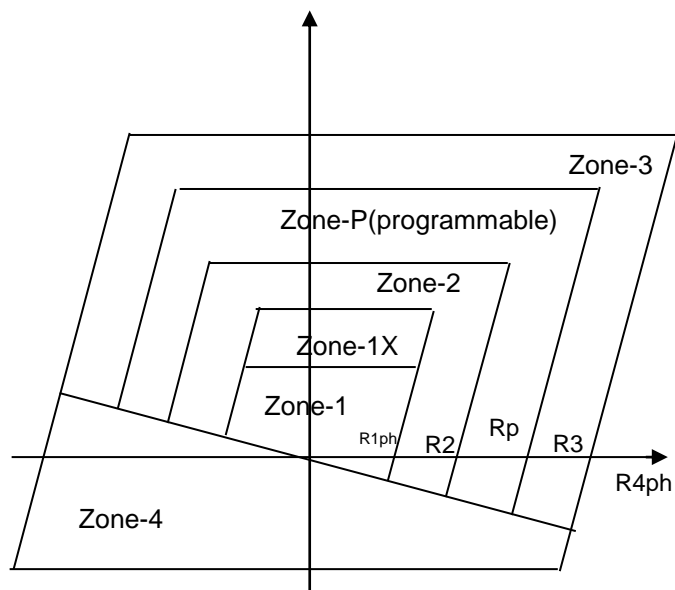
i)   Zones 1,2 & 3 – directional forward zones, as used in conventional three zone distance schemes. Note that Zone-1 can be extended to Zone-1X when required in Zone-1 extension scheme.

ii)   Zone P – Programmable. Selectable as a directional forward or reverse zone.

iii)   Zone-4 – Directional reverse zone. Note that Zone-3 and Zone-4 can be set together to give effectively a forward zone with a reverse offset.

c) **Earth Fault Protection:**

Earth fault quadrilateral characteristics is similar to the phase fault quadrilateral characteristics as shown below. Resistive reaches can be set independently for phase and earth fault protections.
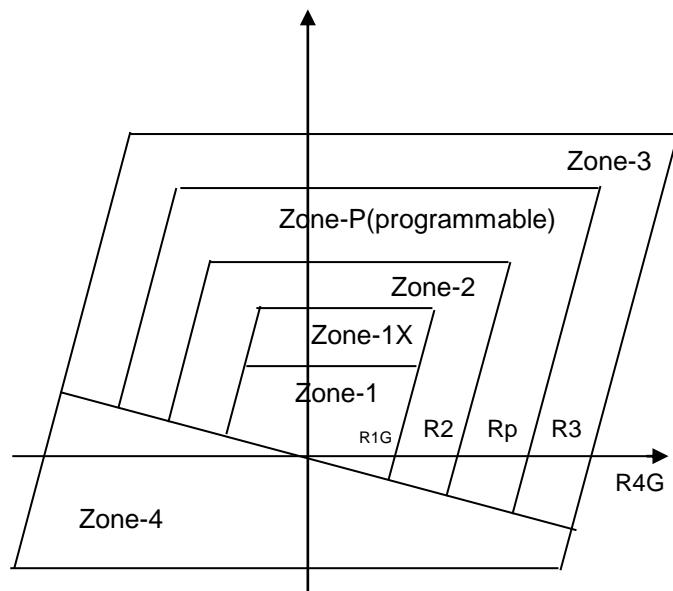
All earth fault elements are quadrilateral shaped, and are directionalised similar to the phase fault elements. The impedance reaches of earth fault elements use residual compensation of the corresponding phase fault reaches.

2) Make: - BBC/HBB

i) **LZ96:**

It is a non-switched scheme with 3 underimpedance measuring units common for ground and 3-phase faults.

3 Nos. under impedance (offset mho) starters, one under-impedance unit for all possible phase to phase faults. R-X diagram is indicated in figure
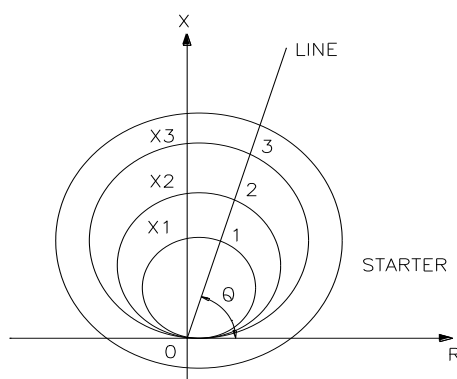
LZ96

Forward and reverse reach can be selected independently in starters (with zone-4 time setting).
Setting range: 0.1 to 100 Ohms.

ii) **LIZ6: -**

It is a switched scheme with 3 under-impedance starters, 3 overcurrent starters and one neutral current starter. It has one reactance measuring unit for all faults. With the provision of angle replica unit the relay has special operating characteristic on R-X diagram indicated in figure, which permits high loading on long lines. This being the initial versions of static relays there have been number of component failure and are being phased out.
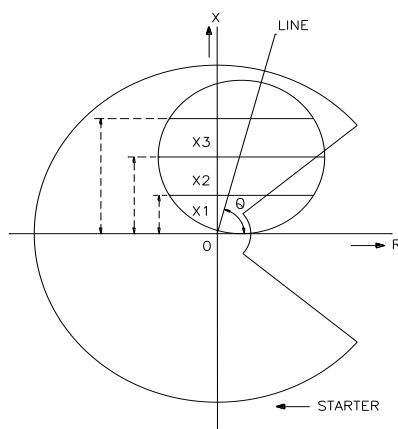
LIZ-6

iii)   L3 relays: -

a) L3WYS:-

This relay consists of 3 under impedance starters and a single directional reactance measuring unit (CM relay).

It is four zone relay, the zone-4, starter step being non-directional. Time settings for all the four zones (including Zone-1) can be varied from 0.1 to 5 seconds. R-X diagram is indicated in figure.
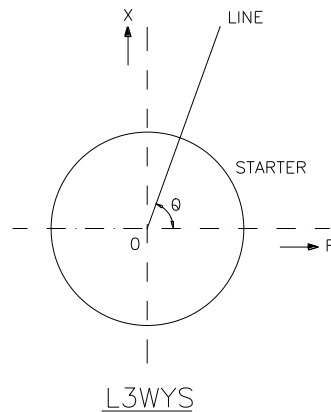
L3WYS

b) L3wyas: -

This is similar to L3WYS relay except that the U/I starters are provided with compounding chokes thereby shifting the circle, making it an offset mho as indicated in figures.

L3WYAS
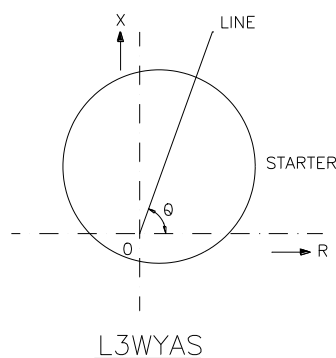
It is also supplemented by Yi/L - power swing blocking unit.

iv)   L6ft: -

It is high speed, single step distance relay usually supplemented to L3wyas or L3wys. It is set to protect 80% of line and without any time delay.

LINE

X

YKe/L

STARTER

θ

0   ► R

L3WYAS + YKe/L
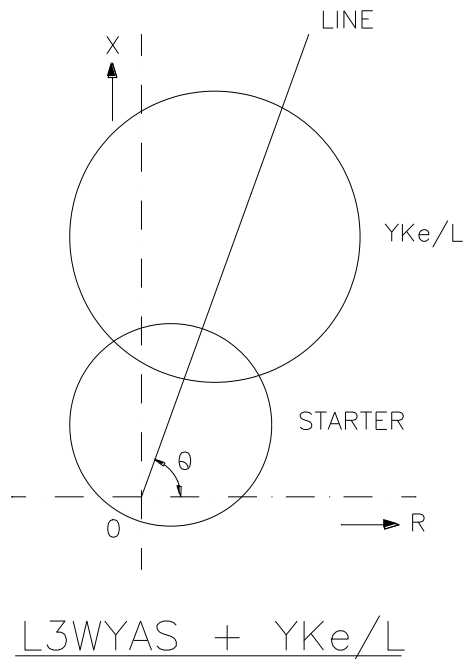
v)   Yke/l relay: -

This consists of three under impedance starters, used in conjunction with L3wyas relays. By provision of compounding chokes, the operating region of the Yke/l relay is shifted much above the origin of the R-X diagram. The operating characteristic of the combination of L3wyas and Yke/l relay is indicated in figure.

It may be seen from the diagram that this combination permits much higher loading and protects longer lines, without any problem of load encroachment.

3) **Make: ABB:** -

i)   <u>RYZFC: -</u>

It has come into service in the initial stage of the advent of static relays, has 3 mho measuring units for earth faults, one mho unit for phase faults and 3 under impedance starters.

In addition, this relay has negative sequence current starter with a fixed setting of 20% of In, which causes the relay to trip in Zone-4. The starter can be made to operate either as a circle or as oval.

R-X diagram is indicated in figure.

RYZFC
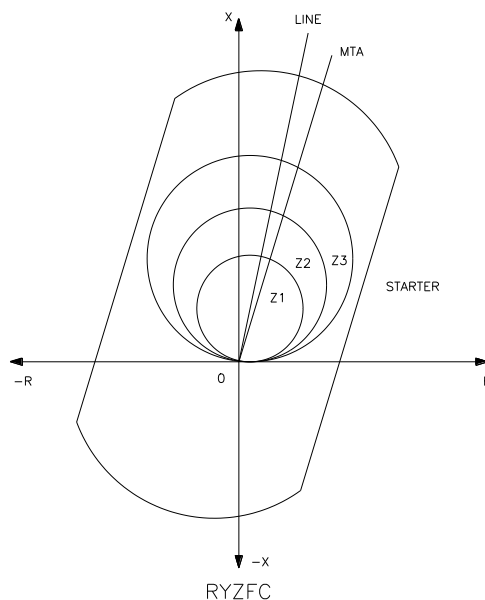
Setting range: - 1.8 to 200 Ohms.

a)   This relay is found to lose its directional sensitivity for closeby reverse faults and hence not recommended for use on feeders emanating from generating stations.

b)   Also the negative phase sequence starter is found to respond to very far end faults.

ii) <u>RAZOG: -</u>

It is a switched scheme with 3 under impedance starters and one reactance measuring unit. It has quadrilateral characteristic.

R-X diagram is indicated in figure.

RAZOG
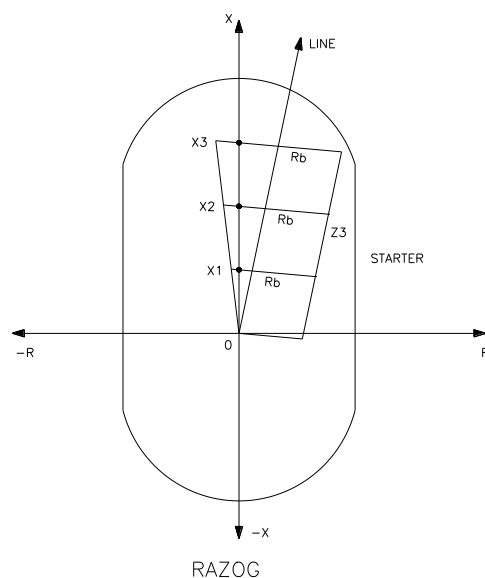
Setting range: 0.25 to 64 Ohms.

The starter can be made to operate either as a circle or oval.

iii)   RAZFE:

It is static three zone non-switched scheme.

For ground and 3-phase faults, the distance relay has a reactance like operating characteristic, the reactance line being inclined by a few degrees towards resistance axis on R-X diagram, which provides excellent margin for high resistance faults and minimises effects of load current and remote ends infeed on distance measurement R-X diagram is indicated below.

PHASE FAULTS

GROUND FAULTS
RAZFE
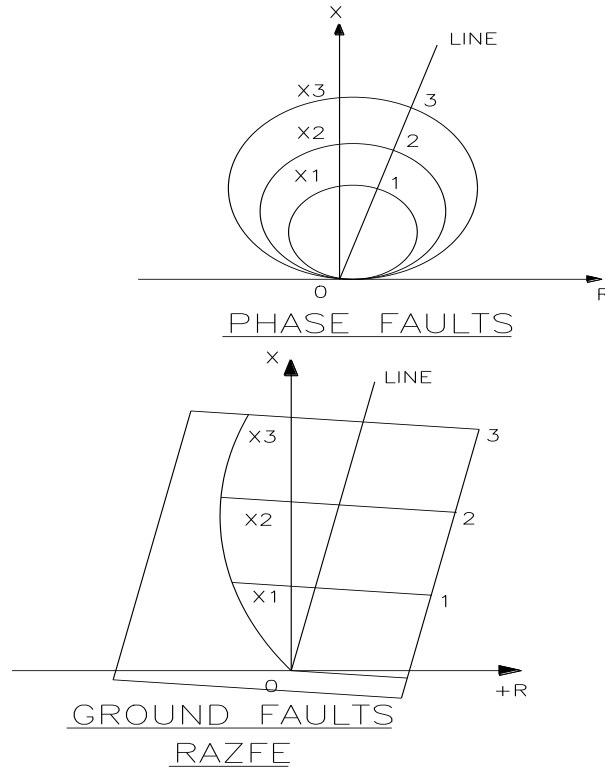
To avoid load encroachment problem, the relay is provided with blinder, which has independent settings in resistive and reactive directions.

For phase to phase faults, mho units are used.

Setting rage: 0.25 to 64 Ohms.

iv)   RAZOA: -

It is a static scheme having 3 under - impedance starters and one measuring unit. The directional measuring unit has got quadrilateral characteristic with independent settings in resistive and reactive directions.   R-X diagram is as indicated.

RAZOA

75
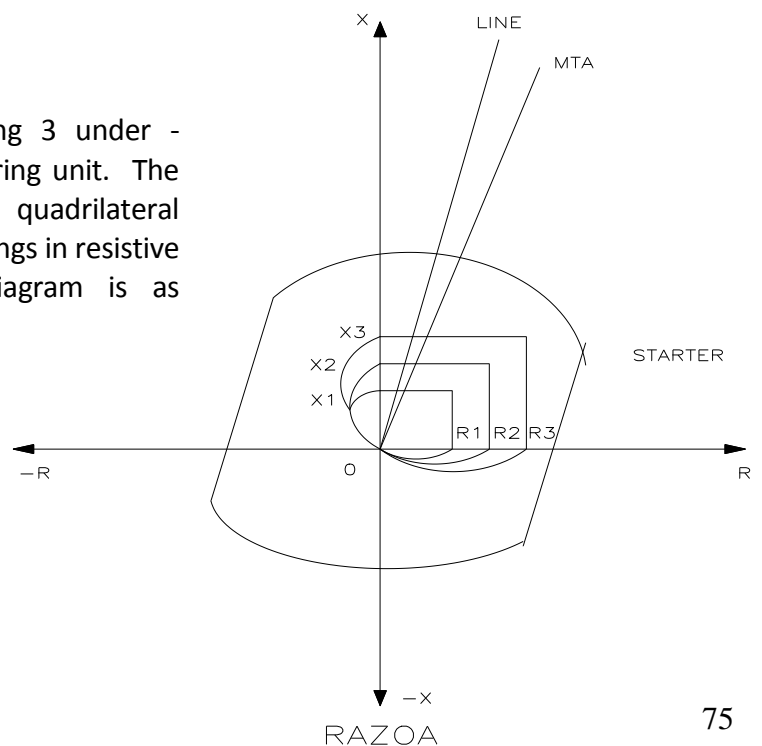
The U/I starter can be made to operate with a circle or oval characteristic with a selectable switch (S3: 1 ON for circle OFF for oval in RGZB module).

RGSB Module:

Directional   : S1: 1 - OFF
Non-directional   : S1: 1 - ON

Setting range   : 0.16 to 64 Ohms.

CHARACTERISTIC OF THE IMPEDANCE MEASURING FUNCTION IN THE LINE PROTECTION TERMINAL REL 100
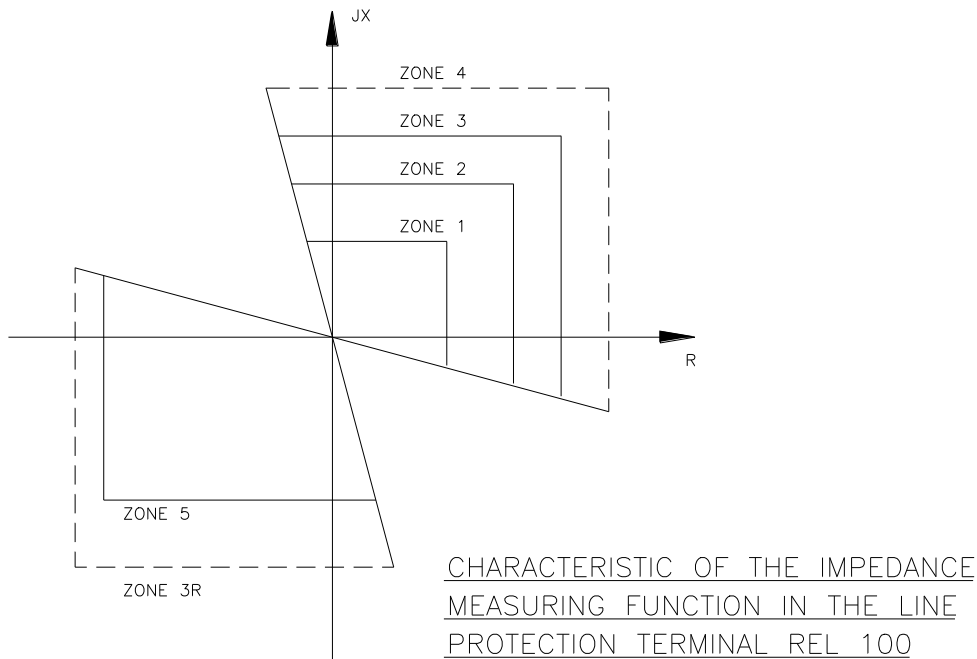
(v)   RELZ-100:
It is a numerical relay with quadrilateral impedance units for phase and earth faults. Each measuring unit has individual and independent setting of the reach in resistive and reactive directions, as well as for the zero sequence compensation factor, KN. Entire Zone-3 reach (in forward direction) is available in reverse direction with a separate timer T3R. R-X diagram is as indicated

Four groups of setting parameters are possible to suit different system conditions. Only one of the groups will be in service by choice. It has continuous self monitoring and self testing feature and indicate the same by extinguishing "Relay Available" LED on the relay. Through MMI, one can enter; edit the settings, read the mean service values of line voltage, current, real, reactive power and frequency. It stores data of latest 3 disturbances occurred. (The settings are not password protected).

Setting rage: 0.1 to 150 Ohms.
Timers: 0 to 10 Secs.

It has a feature which does overload supervision and unsymmetrical load condition, which can be used for alarm or trip.

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vi)   RADSL: -
This pilot wire protection scheme used for protection of short lines. It is very fast operating relay, clearing the faults in 100% of line without any time delay. This is commissioned on 220 KV KTS 'C' Station - KTS V Stage tie lines 1 & 2 at both ends as Main-1 protection scheme (Main-II being RELZ-100 relay).

Likewise GEC make FAC34 pilot wire differential relays are provided on 220 KV NTPC - RAMAGUNDAM tie lines 1 & 2 with backup O/L, E/L relays.

4)   Make: - Universal Electric

i)   MDT45B:
It is a non-switched 3-zone distance scheme with 18 measuring units, 3 Nos. low set starters ZL and 3 Nos. high set starters ZH. It is available in two ranges low and high.

R-X diagram is indicated in figure.

MDT 45B
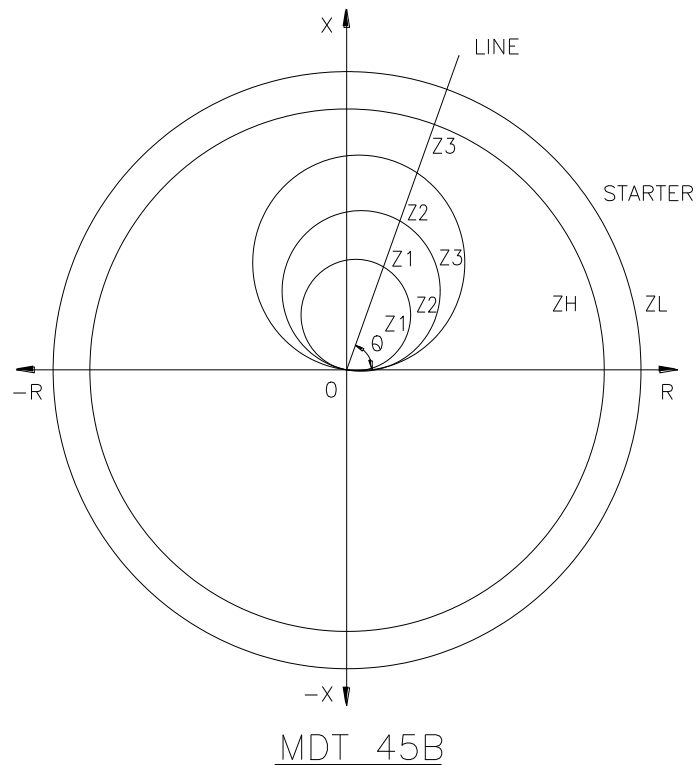
a)   For Low range:
Reactance Measuring units for Zone-1 & Zone-2.
b)   For High range:
Mho measuring units for Zone-1 & Zone-2.

ii)   MDTB101:

It is switched scheme, with 3 impedance starters, one neutral overcurrent starter and one mho measuring unit.

R-X diagram is indicated in figure.

MDTB 101
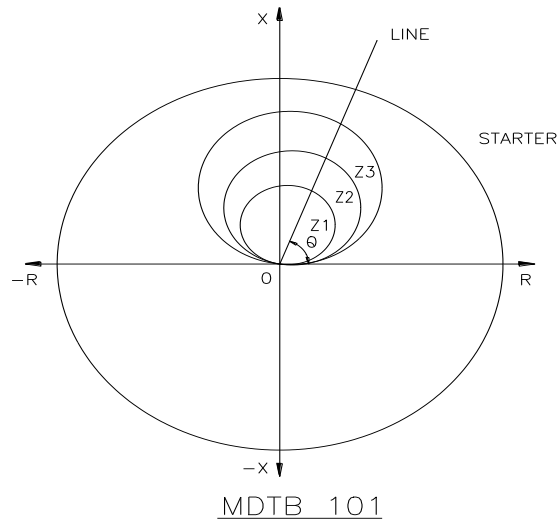
This relay has a V-I characteristic similar to that of PYTS relay. When the voltage is less than 65% rated, the starter operates at a current greater than 0.25 In.

For 220 KV lines, the settings on Main-I distance relay must be on par with that of Main-II relay and vice-versa.

For 132 KV lines, distance relay along with directional O/L, E/L relays are used. The operating time of O/L, E/L relays for adjacent bus faults are set equal to or more than zone-2 time of distance relay.

5)   **Make: - Easun Reyrolle: -**

i)   THR4PE24: -
It is static non-switched scheme with 3 forward zones and 1 reverse zone consists of a total of 24 measuring units. 12 Nos. mho units for zone-1 & zone-2 for phase and earth faults. 6 Nos. offset mho units for zone-3, 6 Nos. Mho units for reverse reach.   R-X diagram is indicated in figure.
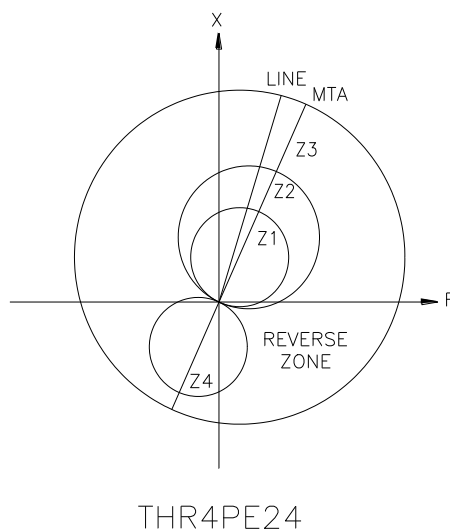
THR4PE24

It has reverse reach set to (c x zone-1) for phase faults and (c x zone-1) (1+KN) for earth faults, KN being compensation factor. Generally c is set equal to '1'.

ii)   THR4PE1: -

It is static switched scheme with 3 offset mho starters and one mho measuring unit. R-X diagram is indicated in the figure.

It is available in low and high ranges: -

THR4PE1
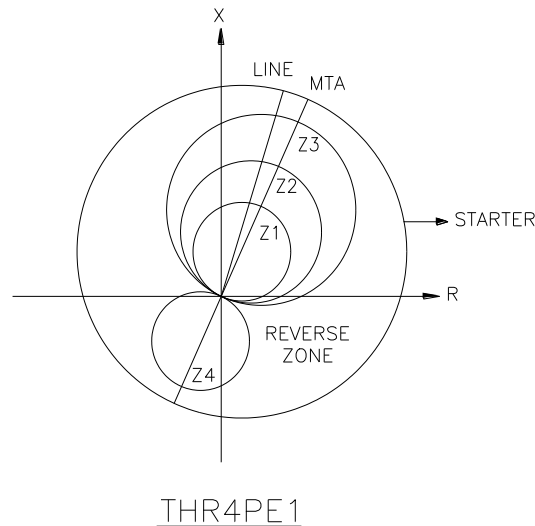
Setting range: -
Low range: -   0.08 to 9.5 Ohms (with A:0.8 to 9.6)

High range: -   0.4 to 47.5 Ohms (with A: 4 to 48)

The starter has a built in reverse reach, equal to 50% of forward reach for phase faults and 50% of forward reach (1+KN) for earth faults, KN being compensation factor.

Make: - Seimens Ltd.

7SA511 relay:
It is a numerical protection scheme with 16 bit microprocessor. With three version of detectors.
i)   Phase selective overcurrent fault detector.
ii)   Voltage controlled (under-impedance) fault detector (with independent R & X reaches) and
iii)   Polygonally shaped angle-dependent impedance fault detector.

It has five zones (two of which can be used for communication schemes).
R-X diagram is indicated below.

X LINE

X3

X2

X1

0   R1 R1E R2 R2E R3 R3E → R
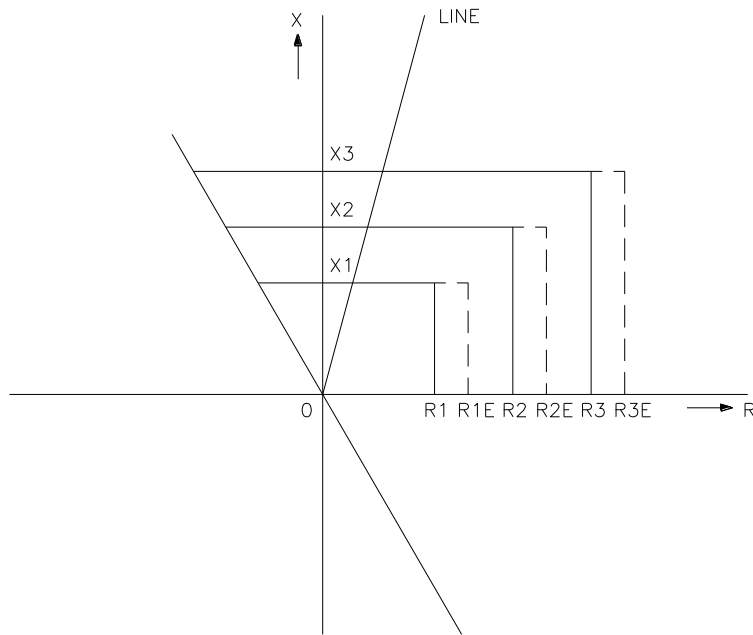
_7SA511_

Apart from common features, it provides Emergency overcurrent function, which comes into picture when main distance scheme is blocked due to VT fuse failure conditions.

It provides two user defined logic functions. It has continuous self monitoring and self testing feature. It stores data of latest three faults and measures values of load current, operating voltage, power and frequency continuously.

Setting range: 0.1 to 200 Ohms with 0.0 to 32 sec (in step of 0.01 sec) timers.

Four groups of settings are possible to suit different system conditions. Only one of the groups will be in service by choice.

SEL – 321: -   It is numerical relay with

a) Four Mho zones for phase faults with independent phase to phase overcurrent supervision.
b) Four ground faults for Mho and Quadrilateral zones with independent phase and residual overcurrent supervision and zero sequence compensation.
c) Two Quadrilateral zones for power swing blocking.
d) Load-encroachment characteristics.
e) Instantaneous, Definite time and IDMT overcurrent characteristics.
f) Six (6) setting groups are available in the scheme.
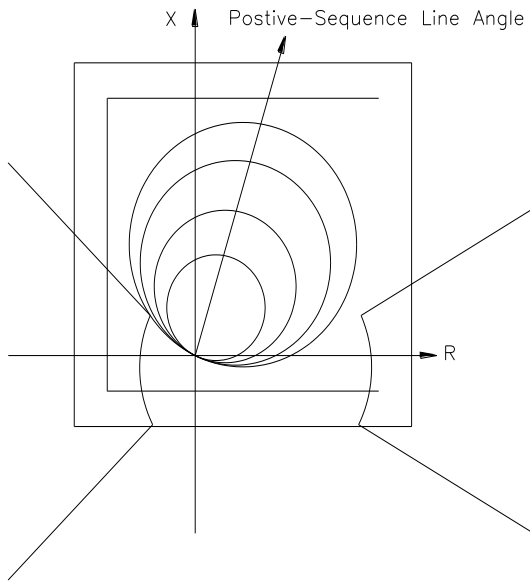
Three—Phase and Phase—Phase Distance Characteristics

DVG 1015—196
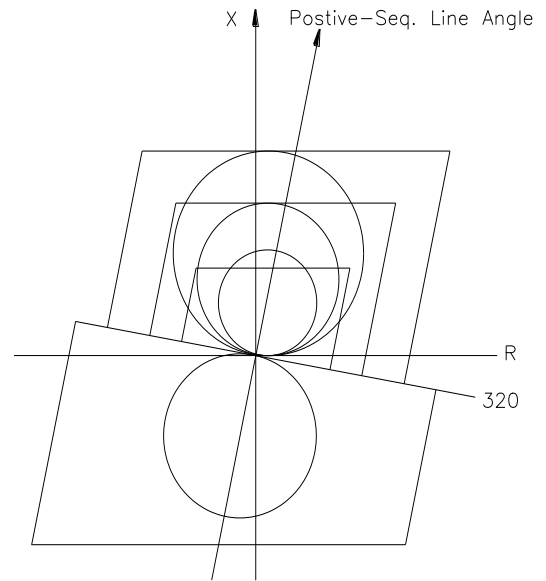
Ground Distance Characteristics

DVG 1015—194

SEL321

Setting ranges:-

For Mho zones	:	0.25 to 320 Ohms (Secondary)
For Quadrilateral Zones	:	
Reactance	:	0.25 to 320 Ohms (Secondary)
Resistance	:	0.25 to 250 Ohms (Secondary)
Timers	:	0-2000 Cycles

Relay indications: purpose and meaning: -

The relay indications are a guide to identify the type and broad location of fault. They are the means to assess the relay performance by tallying with the actual faults occurred. They help in review and analysis of the trippings occurred. Different manufacturers used different symbols/flags of signaling different types of faults.

Whenever the relays operate, their indications should be noted before they are reset

Relay indications with their meanings on various types and makes of relays are indicated in the following tables.

CHART SHOWING RELAY INDICATIONS FOR VARIOUS RELAYS

S.No	Make & Type of Relay	Distance protection operated Trip.	Type Phase to phase	Indica-tions	Type Phase to Earth	Indica-tions	Z1	Z2	Z3	Z4	Switch On-to Fault Trip	Power Swing Blocking	Carrier Relay Operated	V.T Fuse Failure
1.	EE/GEC MM3V		R-Y	30(A-B)	R-E	30A		30G	30G	2/21			85X	Tripping Blocked
			Y-B	30(B-C)	Y-E	30B	30G	30H	30H					
			B-R	30(C-A)	B-E	30C			30J					
2.	MM3T		R-Y	AB	R-E	AN	Z1	Z2	Z3					Tripping Blocked
			Y-B	BC	Y-E	BN								
			B-R	CA	B-E	CN								
			R-Y-B	AB,BC,CA										
3.	RR3V		R-Y	30(A-B)	R-E	30A	30G	30G	30G					Tripping Blocked
			Y-B	30(B-C)	Y-E	30B		30H	30H	2/21				
			B-R	30(C-A)	B-E	30C			30J					
4.	MR3V		R-Y	30(A-B)	R-E	30A	30G	30G	30G					
			Y-B	30(B-C)	Y-E	30B		30H	30H	2/21				
			B-R	30(C-A)	B-E	30C			30J					
5.	MR3V		R-Y	30A	R-E	30D	30G	30G	30G					Tripping Blocked
			Y-B	30B	Y-E	30E		30H	30H					
			B-R	30C	B-E	30F			30J					
6.	SSRR3V		R-Y	A,B	R-E	A	Z1	Z1,Z2	Z1,Z3					
			Y-B	B,C	Y-E	B				2/21				
			B-R	C,A	B-E	C								
			R-Y-B	A,B,C										

CHART SHOWING RELAY INDICATIONS FOR VARIOUS RELAYS

S.No	Make & Type of Relay	Distance protection operated Trip.	Type Ph to ph	Indica-tions	Type Ph to E	Indica-tions	Z1	Z2	Z3	Z4	Switch On-to Fault Trip	Power Swing Blocking	Carrier Relay Operated	V.T Fuse Failure
7.	EE/GEC PYTS		R-Y	A,B	R-E	A		Z2	Z3	Z4	SOTF	PSB		
			Y-B	B,C	Y-E	B								
			B-R	C,A	B-E	C								
			R-Y-B	A,B,C										
8.	SHPM "QUADRO MHO"		R-Y	A,B	R-E	A		Z2	Z3		SOTF		AIDED TRIP	V-FAIL
			Y-B	B,C	Y-E	B								
			B-R	C,A	B-E	C								
			R-Y-B	A,B,C										
9.	LZ-96	D	R-Y	R,S	R-E	R								
			Y-B	S,T	Y-E	S								
			B-R	T,R	B-E	T		2	3	4			HF (Yellow)	
			R-Y-B	R,S,T										
10.	LIZ-6		R-Y	R,S	R-E	R,E		T2	T2, T3	T2,T3T4				
			Y-B	S,T	Y-E	S,E								
			B-R	T,R	B-E	T,E								
			R-Y-B	R,S,T										

CHART SHOWING RELAY INDICATIONS FOR VARIOUS RELAYS

S.No	Make & Type of Relay	Distance protection operated Trip.	Type Ph to Ph	Indica-tions	Type Ph to E	Indica-tions	Z1	Z2	Z3	Z4	Switch On-to Fault Trip	Power Swing Blocking	Carrier Relay Operated	V.T Fuse Failure
			Type Ph to Ph	**Indica-tions**	**Type Ph to E**	**Indica-tions**	**Z1**	**Z2**	**Z3**	**Z4**				
11.	L3wyas/ L3wys/ Lz3	PD (D)	R-Y	PAR(R), PAS(S)	R-E	PAR(R)PE(E)		PSII (2)	PSII PS-III (2) (3)	PSII PS-III (2) (3)	PTa		PtrH	
			Y-B	PAS(S) PAT(T)	Y-E	PAS(S) PE(E)								
			B-R	PAT(T) PAR(R)	B-E	PAT(T) PE(E)								
12.	L6FT	PD3											PTa5	
13.	ASEA / ABB :- RYZFC	UD	R-Y	R,S	R-E	R		2	2,3	2,3,4		P	CS/CR	
			Y-B	S,T	Y-E	S								
			B-R	T,R	B-E	T								
			R-Y-B	R,S,T										
14.	RAZOG	UD	R-Y	R,S	R-E	R		2	2,3	-		P		
			Y-B	S,T	Y-E	S								
			B-R	T,R	B-E	T								
			R-Y-B	R,S,T										
15.	RAZFE	U	R-Y }		R-E	RN	Z1	Z2,	TK2,			P		
			Y-B }	2-phase	Y-E	SN	Z2	TK2	TK3					
			B-R }		B-E	TN								
			R-Y-B	3-Phase										

CHART SHOWING RELAY INDICATIONS FOR VARIOUS RELAYS

S.No	Make & Type of Relay	Distance protection operated Trip.	Type Ph to ph	Indica-tions	Type Ph to E	Indica-tions	Z1	Z2	Z3	Z4	Switch On-to Fault Trip	Power Swing Blocking	Carrier Relay Operated	V.T Fuse Failure
			Type Ph to ph	**Indica-tions**	**Type Ph to E**	**Indica-tions**	**Z1**	**Z2**	**Z3**	**Z4**				
16.	ASEA/ ABB RAZOA	Trip	R-Y	R,S	R-E	R,N		2	2,3	2,3,4		P		
			Y-B	S,T	Y-E	S,N								
			B-R	T,R	B-E	T,N								
			R-Y-B	R,S,T										
17.	REL-100	Trip Z	R-Y	PSR,PSS	R-E	PSR,PSN (Trip-R)	TRZ1 Zm1, Zm2, Zm3	TRZ2 Zm2, Zm3	TRZ3 Zm3	TRZ3R Zm3R (Reverse)	TREF SOTF	PSB	CRZ/CBZ	VTF / VTS
			Y-B	PSS,PST	Y-E	PSS,PSN (Trip-S)								
			B-R	PST,PSR	B-E	PST,PSN (Trip-T)								
			R-Y-B	PSR,PSSPST										
18.	UE MDT-45B		R-Y	AB,ZIS	R-E	A	Z1	Z2	Z3	Z4	SOFT	PSB	RR/CS	SV
			Y-B	BC,ZIS	Y-E	B								
			B-R	CA,ZIS	B-E	C								
			R-Y-B	ABC,ZIS										
19	UE MDTB-101		R-Y	AB	R-E	A		Z2	Z3	Z4	SOFT		CAT	VTF
			Y-B	BC	Y-E	B								
			B-R	CA	B-E	C								
			R-Y-B	ABC										
20.	ER THR4PE24	PO	R-Y	r, y	R-E	r							Pt	
			Y-B	y, b	Y-E	y		1	2	3				
			B-R	b, r	B-E	b								
			R-Y-B	r, y, b										

CHART SHOWING RELAY INDICATIONS FOR VARIOUS RELAYS

S. No	Make & Type of Relay	Distance protn. operated Trip.	Type of Fault with Indications				Zone Indication				Switch On-to Fault Trip	Power Swing Blocking	Carrier Relay Optd	V.T Fuse Failure
			Type Ph to ph	Indica-tions	Type Ph to E	Indica-tions	Z1	Z2	Z3	Z4				
21.	THR4PE1	PO	R-Y	r, y	R-E	r, Earth		2	3	2&3				
			Y-B	y, b	Y-E	y, Earth								
			B-R	b, r	B-E	b, Earth								
			R-Y-B	r, y, b										
22.	SIEMENS RIZ-24a		R-Y	JR,JS,R,S	R-E	JR,TM, R,M		T2	T3	T4		P		
			Y-B	JS,JT,S,T	Y-E	JS,JM,S,M								
			B-R	JT,JR,T,R	B-E	JT,JM,T,M								
			R-Y-B	JR,JS,JT,R ,S,T										
23.	75A511		R-Y	LED 2,3, 12,13	R-E	LED 2,5,12	LED 7	LED 8	LED 9	LED 10			AR	
			Y-B	LED 3,4, 13,14	Y-E	LED 3,5,13								
			B-R	LED 4,2, 14,12	B-E	LED 4,5,14								
			R-Y-B	LED 2,3, 4,12,13, 14										
24	IGE:- a) GCY-51A													
			R-Y	R,Y										
			Y-B	Y,B			I	II	III					
			B-R	B,R										
	b) GCX-51A				R-E	R								
					Y-E	Y								
					B-E	B								

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Distance relays in service in A.P.System:

S.No.	Make	Main-I distance relay	Main-II relay
1.	GEC Alstom/ EE	MM3V	MR3V
		-	SSRR3V (MHO/UI starter)
		-	RR3V
		SHPM OPTIMHO	PYTS
		EPAC	PD521
		MICOM	MICOM
2.	ABB/ASEA	RYZFC RAZFE |	RAZOG
		RELZ-100 |	RAZOA
		REL511	
		REL521	
		REL316	
		RADSL	
3.	BBC/HBB	LZ96	LIZ6
		L3wyas+L6ft	
		L3wys+L6ft	
4.	SEIMENS	7SA511	7SA511
		-	RIZ24a
5.	ER	THR4PE24	THR4PE1
		SEL-321	
6.	UE	MDT45B	MDTB101
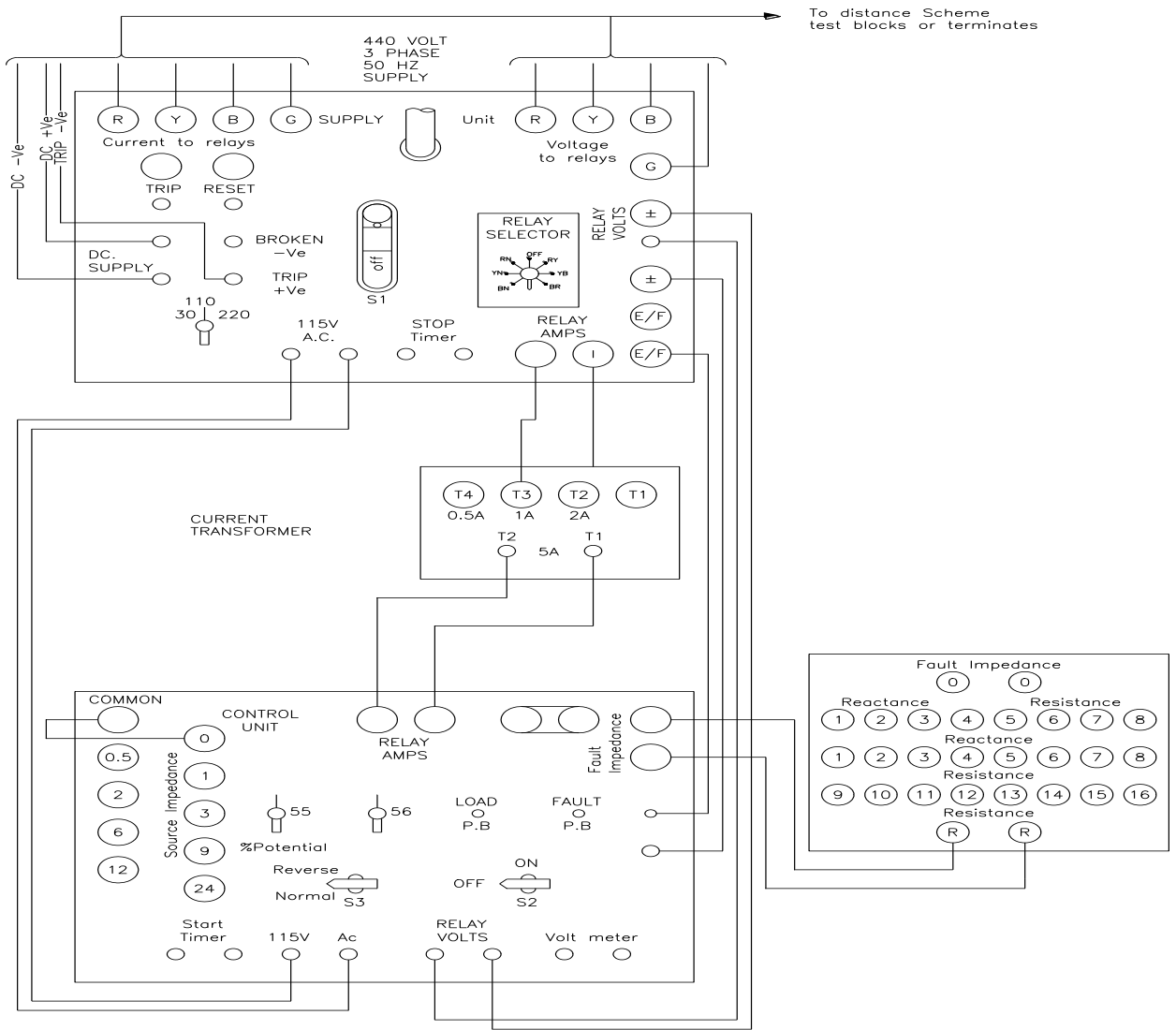
FIGURE 3
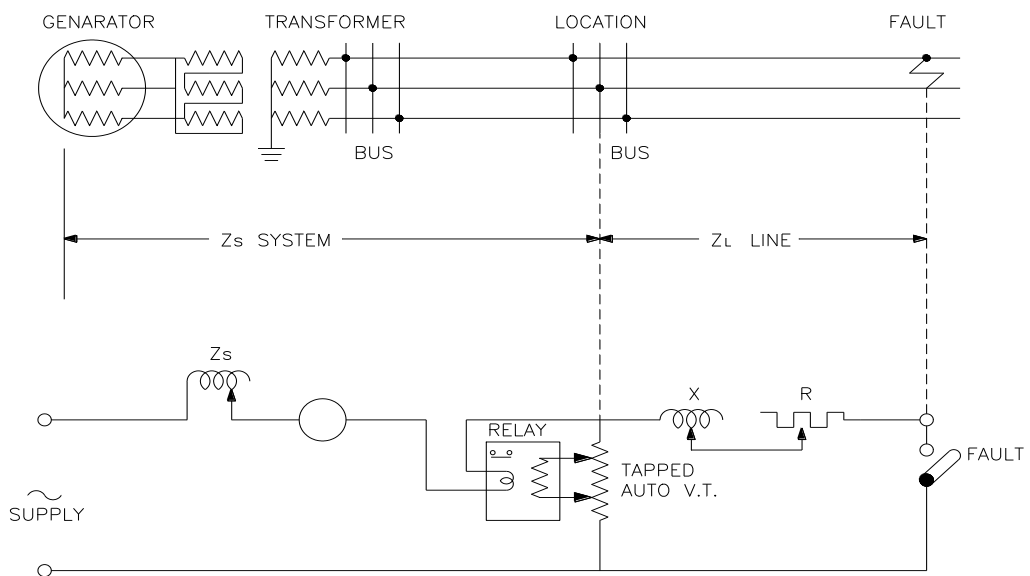
TEST CIRCUIT EQUIVALENT OF POWER SYSTEM

CURRENT TO RELAYS VOLTAGE TO RELAYS

R Y B N   R Y B N

OFF
BN   RY
YN   YB
RN   BR
OFF

RELAY SELECTOR SWITCH TYPE
ODH 8 POSITION 20 WAY

1(0)   1(±)

E(0)   E(±) E$_p$(0) E$_p$(±)

RELAY
AMPS

±

CURRENT TRANSFORMER
(IF REQUIRED)

COM T1
2A T2
1A T3
0.5A T4

T1
T2

5A

3 SINGLE PHASE TRANSFORMERS
420/400, 380/110, 63.5
VOLTS Δ/λ CONNECTED

RELAY
VOLTS

SOURCE 'Z'

RELAY
VOLTS

±   ± RELAY
AMPS

S3
REVERSE

NORMAL

R
Y
B

T3
T1
T2

20A
2A

2A

E/F
110V

63.5v

90A

Ammeter

10%
110V T4
V.T.1%

S3
S1

LOAD
RES

PB

L1

R1

FAULT IX

FAULT R

Fault impedance Unit

86-3   Red
86-4   Green

115V
AC

2A   PB

110V rectifier
300M/AMPS

GJSM
14W
1300Ω

100 uf
350V

FAULT
CONTACTOR

Trip PB   86-1
330Ω
150Ω
130Ω
120Ω   S4
62Ω
250Ω
86   25W 25W
R
Reset RB

86-5

Stop
timer

86-2

DC±Ve   +Ve   DC-Ve

Broken -Ve

SUPPLY UNIT

CONTROL UNIT

Start
timer

S1 MAIN SUPPLY SWITCH
S2 CONTROL UNIT SUPPLY SWITCH
S3 CURRENT REVERSING SWITCH
S4 VOLTAGE SELECTOR SWITCH (TRIP RELAY)
    220V/110V/30V D.C
86 TRIPPING RELAY TYPE VA DET3
86R TRIPPING RELAY RESET COIL
PB PUSH BUTTON
Ⓧ INDICATING LAMP

SCHEMATIC DIAGRAM 3 PHASE PROTABLE DISTANCE TEST SET MK11 (EE ZFB)

BUSBAR PROTECTION

Busbar Arrangements & Protection

In order to maintain system stability and minimise fault damage due to high fault levels, instantaneous tripping for busbar faults is necessary.

Busbar protection scheme should be:
a) Completely reliable
b) Absolutely stable for heavy through faults
c) Selective
d) Accurate and fast operating

**General Busbar Arrangements**

a) Single Busbar Arrangement

This has only single busbar to which all lines/Transformers/Generators, etc. are connected. In the event of the fault on the bus entire bus has to be deenergised and a major outage occurs.

b) Single Sectionalised Busbar Scheme

In this, main bus is divided into two sections with a circuit breaker. One complete section can be taken out for maintenance or for breakdown works without distribution continuity of other section.
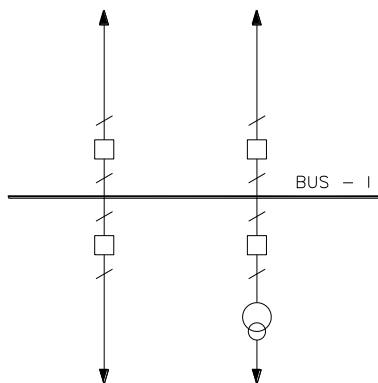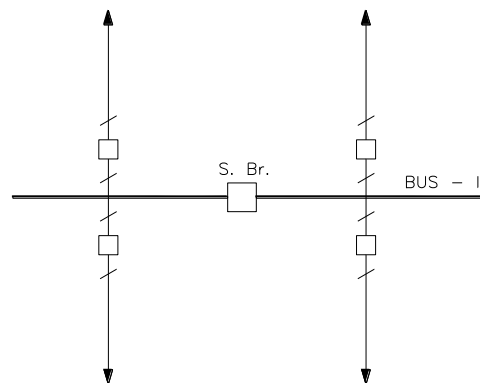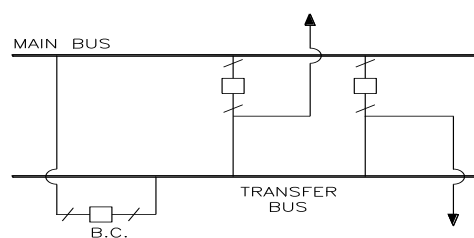

SINGLE BUSBAR   SINGLE SECTIONALIZED BUSBAR

c) Main & transfer busbar scheme: -
    With this arrangement, any line breaker (one at a time) requiring maintenance can be transferred to transfer bus. The feeder protection thus gets transferred to trip bus couple breaker. On fault occurrence or maintenance, entire bus becomes de-energised.

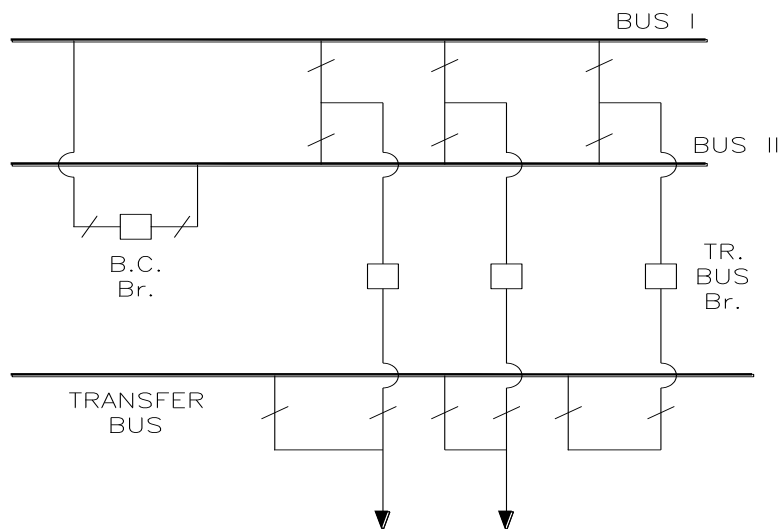MAIN AND TRANSFER BUSBAR

d) Double Bus arrangement: -

Flexibility of transferring any line to any of the buses. On fault occurrence or maintenance only one bus becomes dead, while other bus remains in service.

BUS─I

BUS─II

B.C.
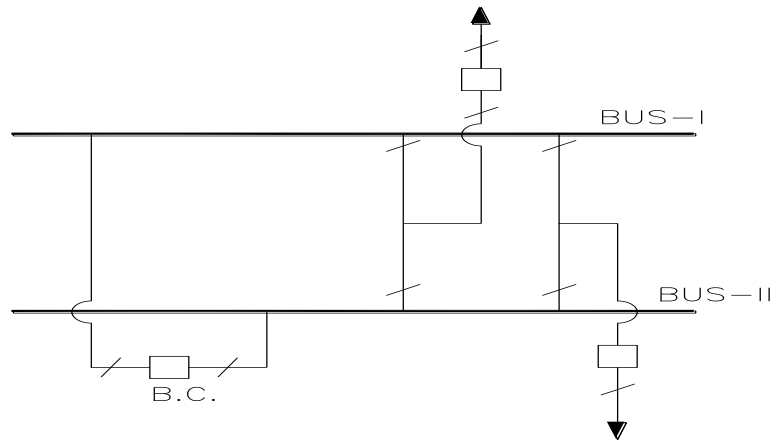
DOUBLE   BUSBAR

e) Double bus and transfer bus arrangement:-

Combination of main and transfer bus and double bus arrangement.
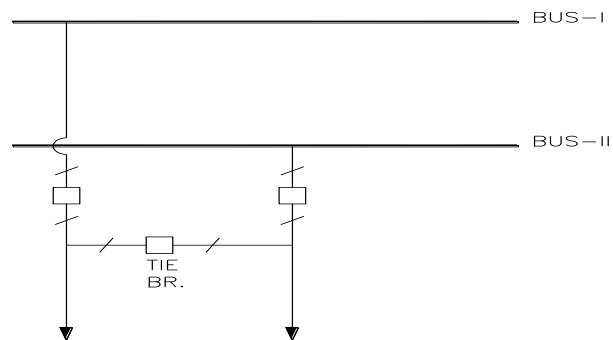
BUS I

BUS II

B.C.
Br.

TR.
BUS
Br.

TRANSFER
BUS

DOUBLE AND TRANSFER BUSBAR

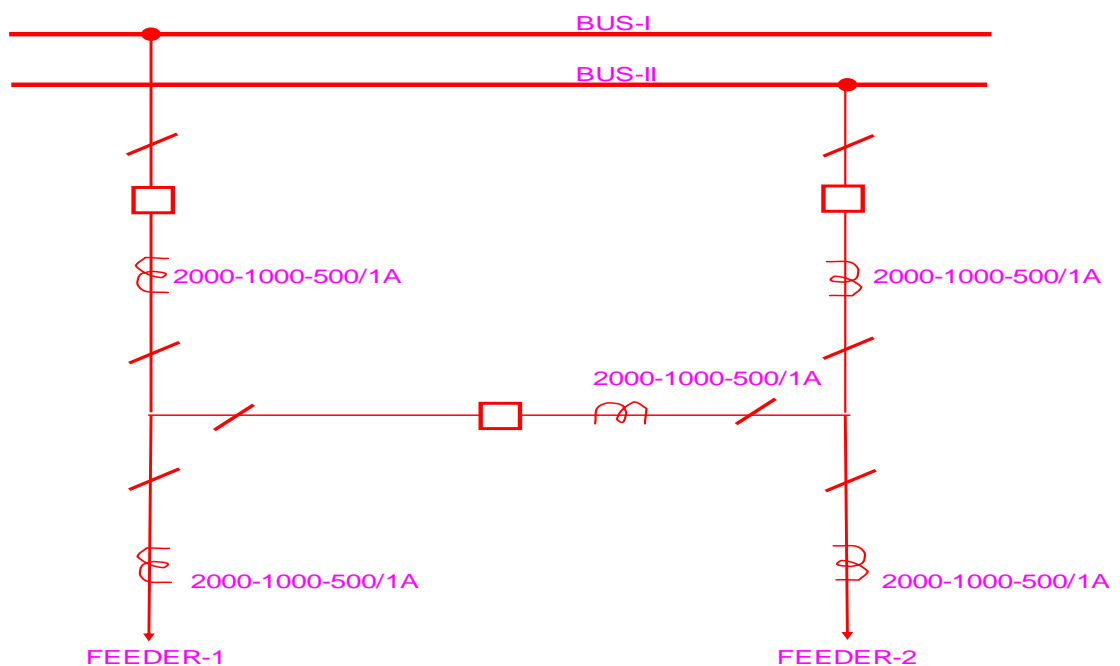f) Breaker and half arrangement: - (One and half Breaker arrangement)

Advantages:-

1) It has 3 breakers for two connections.Each circuit is connected to a particular bus.

2) No changeover of line from one bus to the other is required.

3) This pairing is done such that one is a source and the other a load.

4) For breaker maintenance of any line, the load gets transferred to the other bus.

5) On occurrence of a bus fault or for maintenance all the interconnections will be on healthy bus.

6) Even if both buses become dead, lines can still be in service through the tiebreakers.

BREAKER AND HALF SCHEME

ONE AND HALF BREAKER SCHEME WITH 5 CT METHOD

BUS-I

BUS-II

2000-1000-500/1A

2000-1000-500/1A

2000-1000-500/1A

2000-1000-500/1A

2000-1000-500/1A

FEEDER-1

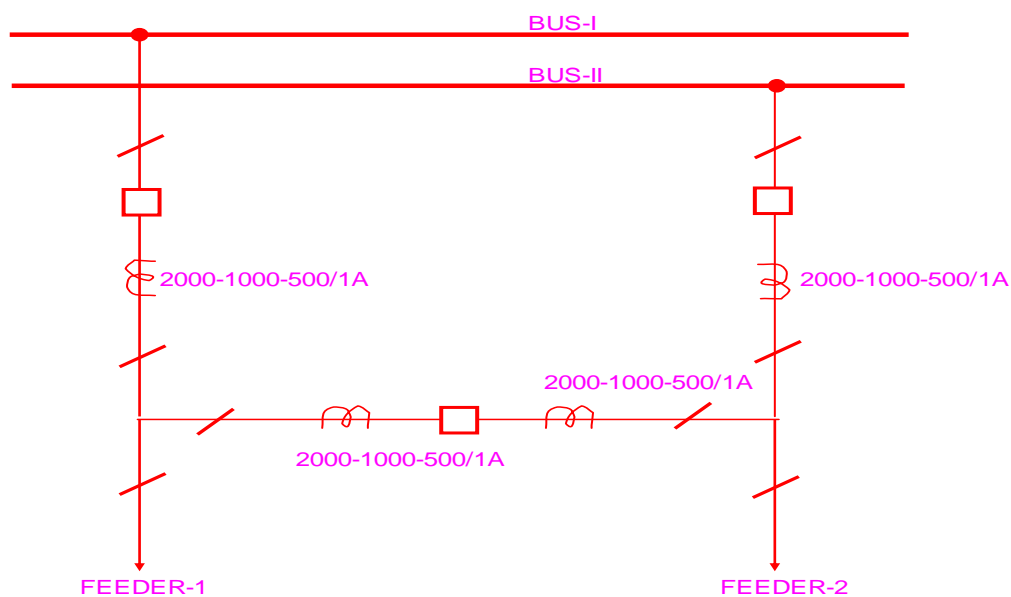FEEDER-2

<u>400 KV System Protection:</u>

Generally the 400 KV Substations are provided with breaker and half arrangement. In breaker and half scheme five CTs method or four CTs method will be adopted for protection.

<u>Five CTs Method:</u>

The CTs arrangement is shown in the figure for 5 CTs method in breaker and half scheme.

    a)   Line side CTs will be utilised for Line Protection

    b)   Bus side CTs will be utilised for bus protection.

    c)   Teed Protection will be used to cover blind area between bus CTs, Line CTs and Tie Breaker CT.

    d)   Two differential relays are provided for each T-Section by summating the three concerned CTs i.e. CT1, CT2 & CT5 for T-Section of feeder-1 and CT3, CT4 and CT5 for T-Section of feeder-2.

### ONE AND HALF BREAKER SCHEME WITH 4 CT METHOD

Four CTs method:

The CTs arrangement is shown in the figure for 4 CTs method in breaker and half scheme.

a)   For feeder protection both bus CT and opposite tie breaker CT will be summated and connected to the relay (CT1 & CT4 for feeder-1, CT2 & CT3 for feeder-2).

b)   Bus side CTs will be utilised for busbar protection.

c)   There is no uncovered zone in 4 CTs method.

Busbar Protection Scheme

1)   High impedance circulating current scheme

2)   Biased differential or low impedance circulating scheme.

S.No.	Details	High impedance circulating current relay	Low impedance biased differential relay
1.	Principle	The currents entering and leaving the busbar are compared continuously. It involves choosing of impedance high enough to stabilise the relay for heavy external faults.	It has differential and bias setting. The resultant bias is proportional to arithmetic sum of all currents, whereas the operating current is vector sum of all circuit currents.
2.	CTs	It requires all identical CT ratios	It can work with CTs of unequal ratios also.
3.	Burden	Imposes comparatively high burden on CTs. Auxiliary CTs reduce the performance of scheme	Imposes less burden on CTs. Auxiliary CTs have no effect on performance of scheme
4.	CT Saturation	Operation of scheme even when CTs get saturated during internal faults	Operation of scheme even when CTs get saturated during internal faults.
5.	Performance	Highly sensitive for internal faults and completely stable for external faults	Highly sensitive for internal faults and completely for external faults
6.	Relays in A.P System	GEC make CAG34, PBDCB	GEC make MBCZ ABB make RADSS

BUSBAR PROTECTION SCHEME
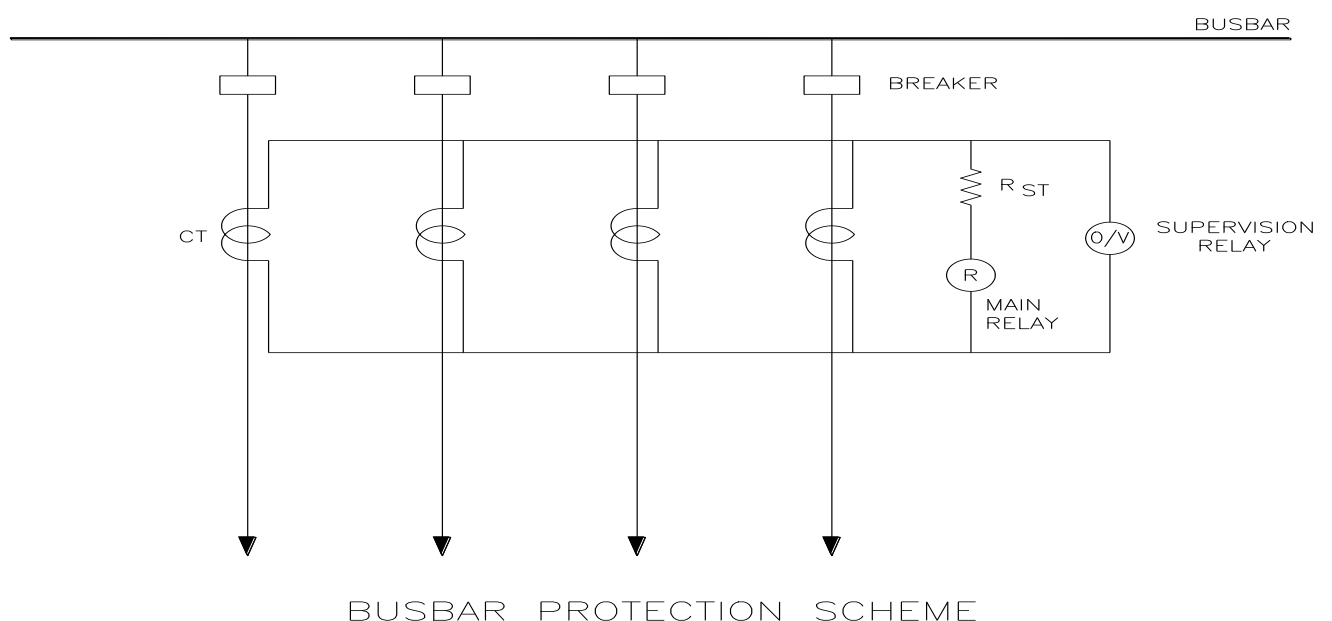
RELAY SETTING CALCULATION PRINCIPLES

High Impedance Busbar Protection:-

Relay Operating Current and Stabilising Resistor are to be set in high impedance scheme. An Operating Current (I_{op}) of 10% or 20% of I_n can be set.

During through fault, the voltage developed across the relay is

$$V = I_f (R_{CT} + 2 R_L)$$
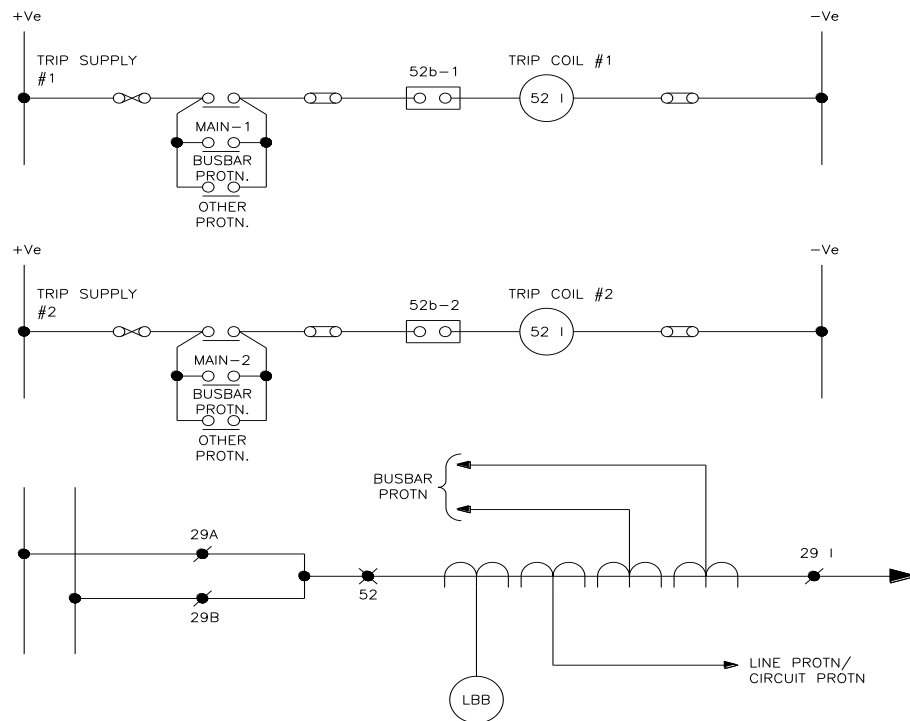
Where I_f = Fault current

   R_{CT} = Internal resistance of CT

   R_L = Cable resistance

Stabilising Resistor R_{st} can be computed as follows.

$$R_{st} = \frac{V}{I_{op}} \quad (-) \quad \frac{\text{VA burden of relay}}{I_{op}{}^{**2}}$$

C.B. TRIPPING

PRIMARY CIRCUITS

For some high impedance schemes, only Voltage Setting 'V' will be set.(The calculations are similar to that of Restricted Earth Fault relay setting for the Transformer protection).

Low Impedance Busbar Scheme:-

This relay operates on circulating current principle and differential current setting (20% In) is adopted on the relay. The bias setting is generally set by the relay manufacturer based on bus fault levels.

Busbar Protection

a) Check Feature: -

      To prevent incorrect tripping due to damage to wiring and equipment from extraneous sources, check relay is provided. This check relay is provided by duplication of primary protection using a second set of current transformers cores on all circuits other than bus section and bus couple units. The check system is arranged in a similar manner of the primary protection, but forms one zone only covering the whole of the busbars (in case of single sectionalized busbar or both the buses (in case of double busbar arrangement).
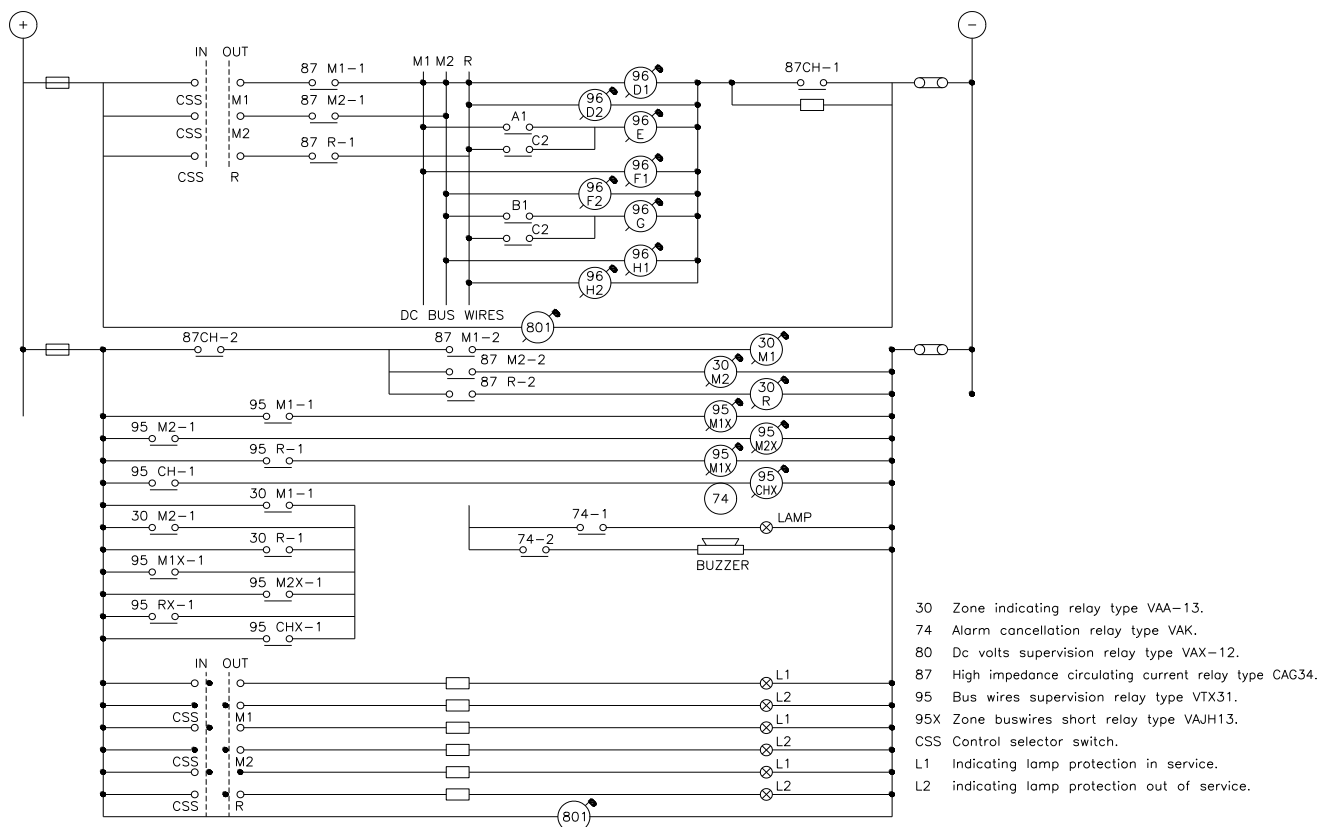
D.C. CIRCUITS FOR HIGH IMPEDANCE CIRCULATING CURRENT SCHEME

b) Supervision

      When a CT secondary winding or connections between CT and the relay circuit become open circuited, the relay may mal operate for load or through faults depending on the effective primary setting. This condition of an open circuit can be detected by using supervision (over voltage) relay, which is arranged to give alarm.

The supervision must be time delayed to avoid a false alarm during genuine fault conditions, typically three seconds is adopted.

BACK TRIPPING LBB THROUGH BUSBAR PROTN, CKTS.
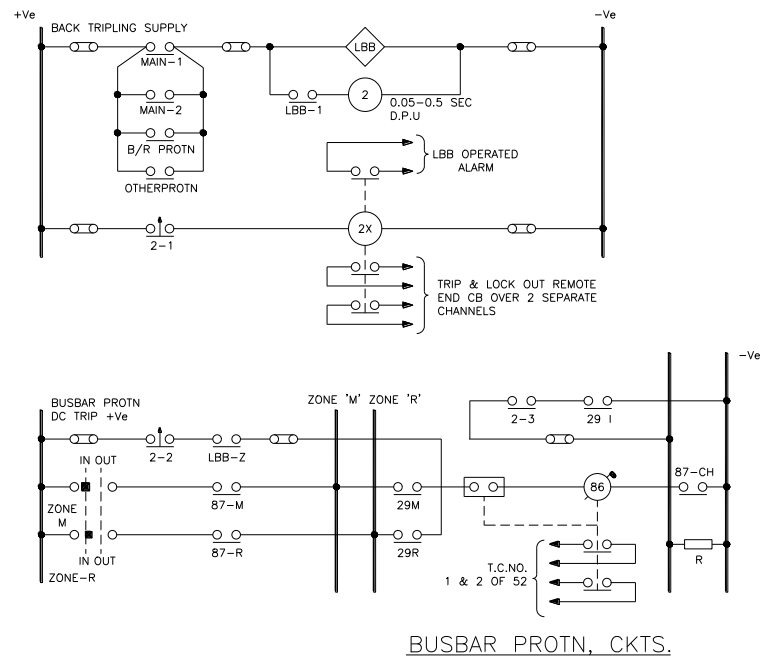
BUSBAR PROTN, CKTS.

BREAKER FAILURE RELAY (LBB PROTECTION)

Main protective schemes provided for line /transformer/generator are required to operate and clear the fault immediately, isolating the faulty section of the system. It is then important that the circuit breaker operates correctly, clearing the fault quickly by tripping. However there is a risk that breaker may not trip (either due to mechanical sluggishness or due to inability to interrupt heavy fault current). Then the fault gets cleared by backup relays at remote stations.

Increasing power system complexity demands shorter fault clearing times. It is therefore necessary to provide breaker failure relay (also called "Local breaker backup relay" or "Stuck breaker protection"). This scheme will isolate the bus to which the stuck breaker is connected, faster. It comprises of O/L & E/L relays with a timer. The LBB relay is energised by trip command of main protection schemes and thus initiate master trip relay of the busbar protection scheme after elapsing of defined time. Then the entire breaker connected to the bus get tripped, thus isolating faulty element.

In A.P System, ABB make RAICA, GEC make CTIG39 type breaker failure relays are commonly used. The general practice is to set the current setting = 20% of In and Time setting = 200 m .Sec. The schematic diagrams for the application of the LBB relay (type CTIG) are indicated in the figure.

Even if the bus bar protection scheme is not available, the LBB scheme can be made use of by providing special trip circuits and trip relays similar to that of bus protection trip circuits for each line. A schematic for such application is indicated in figure.

O/L & E/L RELAYS

Types of O/L Relays:-

1)   Inverse definite minimum type relays (IDMT):-

        a) Normal Inverse

        i) 3.0 sec relays - i.e. 3.0 sec. at ten times pickup with T.L of 1.0

        ii) 1.3 sec relays - i.e. 1.3 sec. at 10 times pickup

        b) Very Inverse relays

        c) Extremely Inverse relays

2)   Definite Time Relays

        Instantaneous highest O/L relay supplementing the above O/C relays. By providing a timer, the required time delay can be obtained.
        The O/L, E/L relays are used for line protection (for 11KV to 132KV) and for Transformer Protection.

O/C relaying is very well suited to distribution system protection for the following reasons:-

1. It is basically simple and inexpensive
2. Very often the relays do not need to be directional and hence no PT supply is required.
3. It is possible to use a set of two O/C relays for protection against inter-phase faults and a separate O/C relay for ground faults.

Pick-up Setting
For coordination of the inverse time O/C relays, the pickup current and time dial setting are to be choosen. The pickup of the relays must be choosen such that it will operate for all short circuits in its own line and provide backup for adjoining lines, keeping in view of maximum full load current.

O/C relay
Pickup setting = I max.load

E/F Relay
Pickup setting = 20% of rated current.

For the E/F relay, the load current is not a factor in the selection of pickup settings and is normally set at 20% of rated current.

Time Settings
        The actual operating time of the O/C & E/F relays can be varied by proper selection of the 'Time Dial Setting' which is selectable from 0.1 to 1.0.

        Time dial settings are to be chosen by having proper coordination and gradation in the system. Gradations between successive relays are obtained by 'Selective time interval' which is usually set between 0.3 to 0.4 Sec.

The operating time of various types of IDMT relays are in the sketches. Also can be obtained by the formulae: -

Normal inverse : $t = \dfrac{0.14 \times TL}{(PSM)^{0.02} - 1}$

Very inverse : $t = \dfrac{13.5 \times TL}{PSM - 1}$

Extremely inverse : $t = \dfrac{80 \times TL}{(PSM)^2 - 1}$

where PSM = Fault Current/(C.T.Ratio x Plug Setting)

Calculation example for O/L & E/L relay on line/Transformer:

For remote bus fault, fault current through the protected element

= 3-Phase : 3000 A (Assume)
  SLG : 2500 A (Assume)

O/L relay:

Adopted C.T.Ratio on protection line = 600/1 A (Assume)
Pickup Setting for O/L relay = 1 A (Plug Setting)

PSM for O/L relay $= \dfrac{3000}{(600/1 \times 1)} = 5$

Actual time of operation for O/L & E/L relays is generally set to grade with the down side system.

Assume time setting required   = 0.4 Sec.

Actual Time of Operation (ATO) : 0.4 $= \dfrac{0.14}{(5)^{0.02}-1} \times TL$ (For Normal Inverse)

       T.L $= \dfrac{0.4 \times 0.0327}{0.14} = 0.093$

Set Time Dial (TL) for O/L relay   = 0.1

Actual Time of Operation (ATO) for O/L relay
(With T.L:0.1) $T = \dfrac{0.14}{(5)^{0.02}-1} \times 0.1 = 0.42$ Sec.

E/L relay:-
Pickup setting for E/L relay = 0.2 A

PSM for E/L relay $= \dfrac{2500}{600/1 \times 0.2} = 20.8$

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If PSM exceed 20, set PSM = 20

Actual Time of Operation (ATO)

for E/L relay $\qquad = 0.4 = \dfrac{0.14}{(20)^{0.02}-1} \times T.L$

$$T.L = \dfrac{0.4 \times 0.0617}{0.14} = 0.176$$

Set T.L = 0.2

Actual Time of Operation for E/L relay with T.L = 0.2

$$T = \dfrac{0.14}{(20)^{0.02}-1} \times 0.2 = 0.45 \text{ Sec.}$$

Selective time interval:

The time interval between two successive breakers to provide the required selectivity is termed as selective time interval.

Consider the following:-
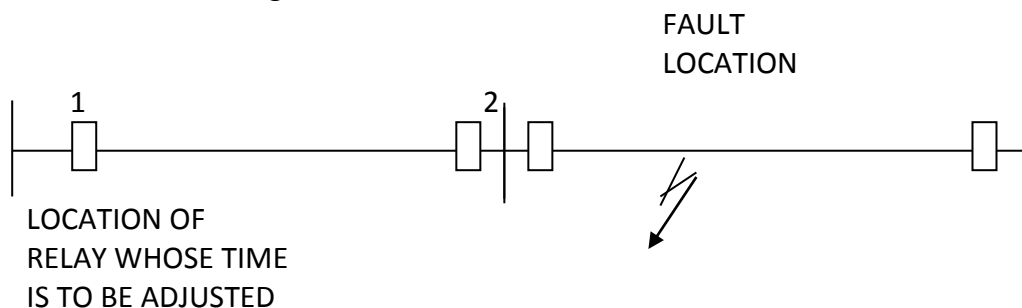
The operating time of the relay at 1
i.e., $t_1 = t_2 + b_2 + 0_1 + f$

where t_2 = operating time of relay at 2
$\quad b_2$ = breaker operating time at 2
$\quad f$ = factor of safety time
$\quad 0_1$ = overtravel time of relay at 1

The selective time interval $\quad S = b_2 + 0_1 + f = 0.3 \text{ to } 0.4 \text{ Sec.}$

A

B

C

ALARM   TRIP   T1   T2

T1   T2

T1   T2

C.T. SHORTING
CONTACTS

1   2   3   4   5   6   7   8   9   10   12

ISOL
SW

NOTE:
ONE OVERCURRENT ELEMENT IS
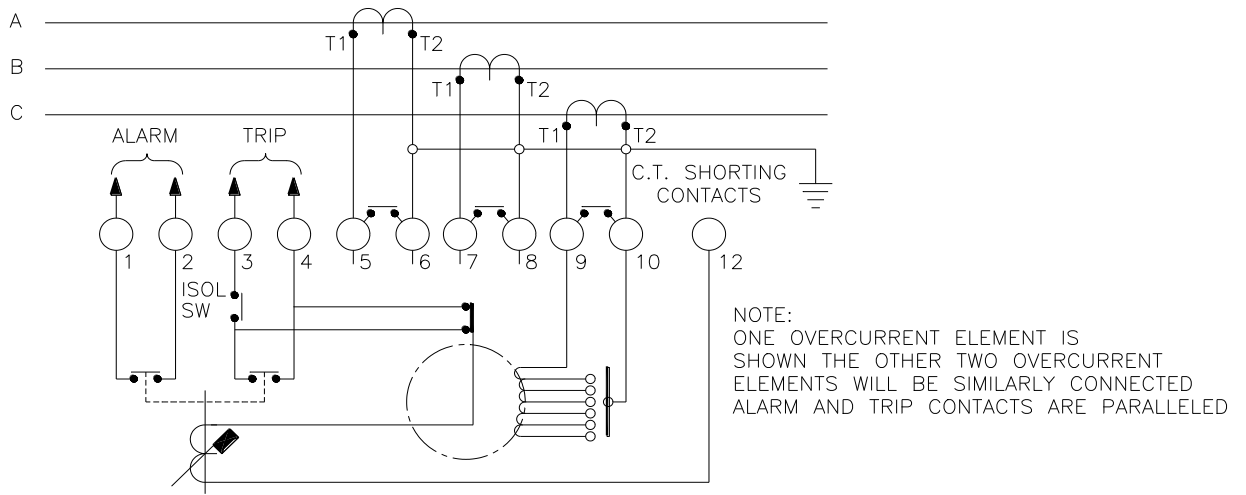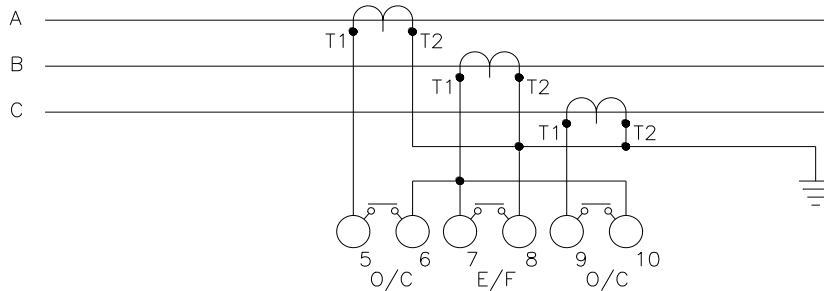SHOWN THE OTHER TWO OVERCURRENT
ELEMENTS WILL BE SIMILARLY CONNECTED
ALARM AND TRIP CONTACTS ARE PARALLELED

THREE PHASE OVERCURRENT PROTECTION WITH SHUNT REINFORCING
UNIT IN SIZE 3D DOUBLE ENDED VERTICAL CASE

A

B

C

T1   T2

T1   T2

T1   T2

5   6   7   8   9   10

O/C   E/F   O/C

C.T. CONNECTIONS FOR THREE-PHASE OVERCURRENT AND
EARTH FAULT PROTECTION. EE MAKE, CDG TYPE

P1   P2

S1   S2

Relay operater when current
flows in this direction

V1

V2

current
coil

9   7
8

voltage
coil

10A

V2

V1

9   7
8

10B

9   7
8

10C
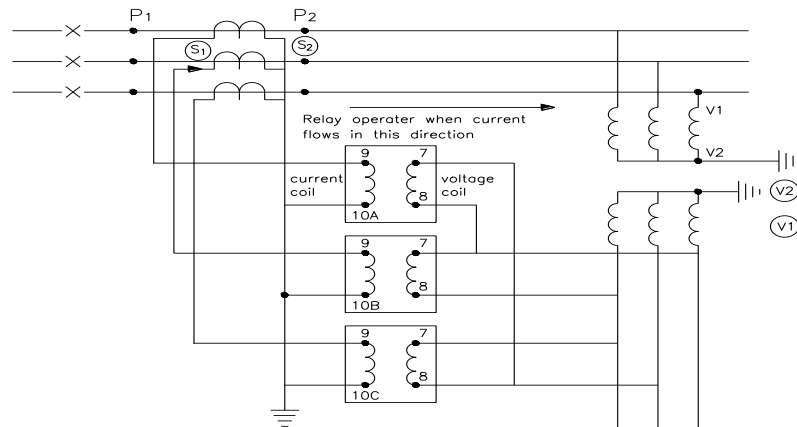
DIRECTIONAL OVER
CURRENT RELAYS
EE, CDD TYPE

A

B

C

P1   P2

S1   S2

Relay operater when current
flows in this direction

V1

V2

V2

V1

current
coil

9   8
10   7

voltage
coil
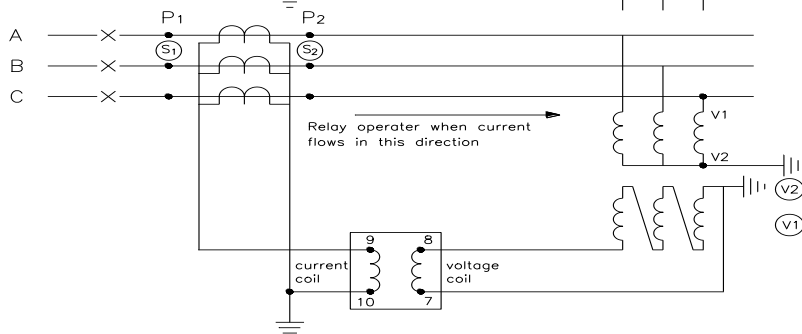
DIRECTIONAL EF RELAY. EE, CDD TYPE
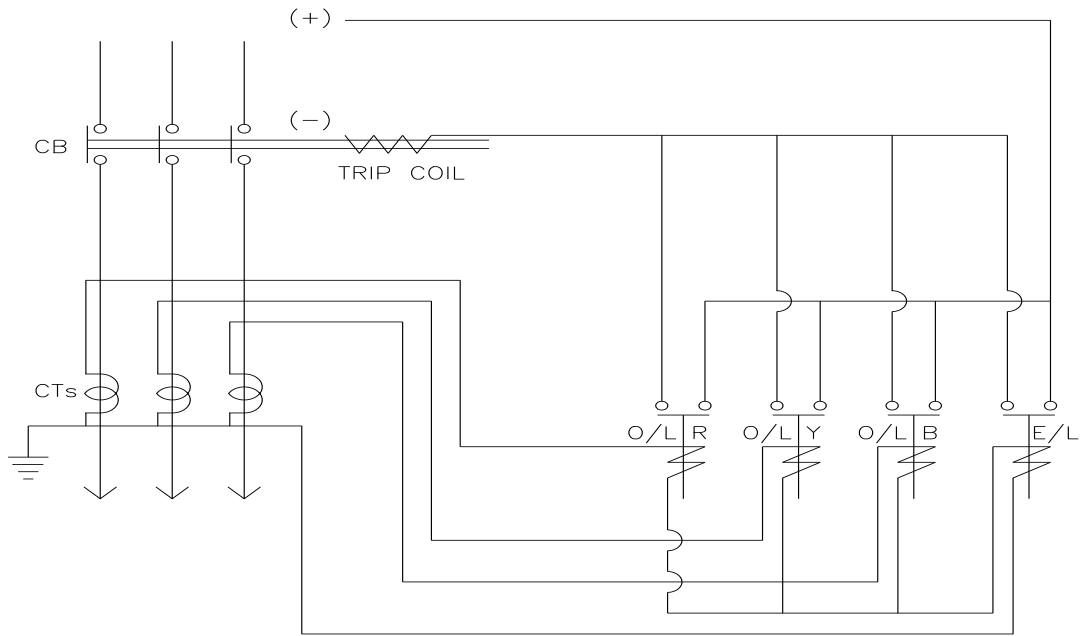
3 OVER CURRENT AND 1 EARTH FAULT SCHEME

DIRECTION OF
CURRENT FOR
OPERATION OF RELAYS

NOTE: FOR NON DIRECTIONAL RELAY
THE VOLTAGE CKTS MUST BE
IGNORED
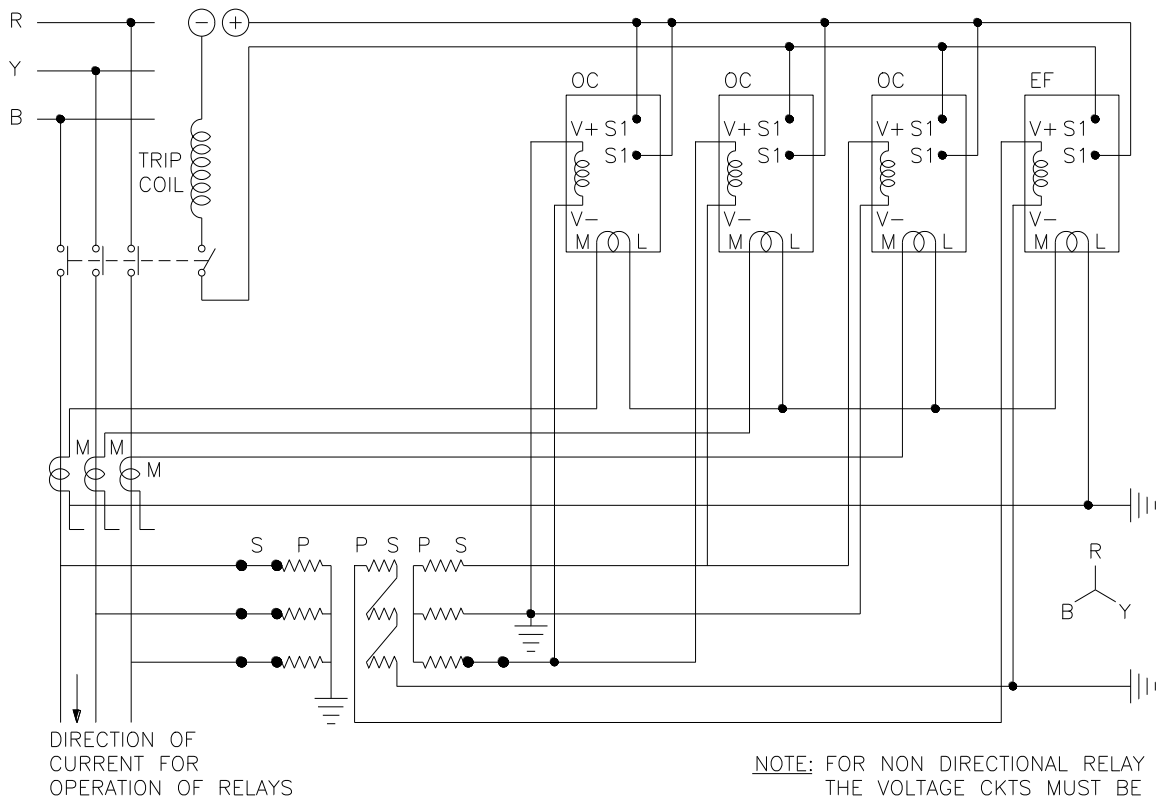
ER MAKE, TJM-12
CONNECTIONS FOR DIRECTIONAL OVER CURRENT AND
EARTH FAULT RELAYS (90° CONNECTED)

A   B   C   P1   P2

LOAD CURRENT

S1   S2

V1

VN

Vn

Vr

9   8

TEMPORARY
LOOP

10   7

DIRECTIONAL E/F RELAY
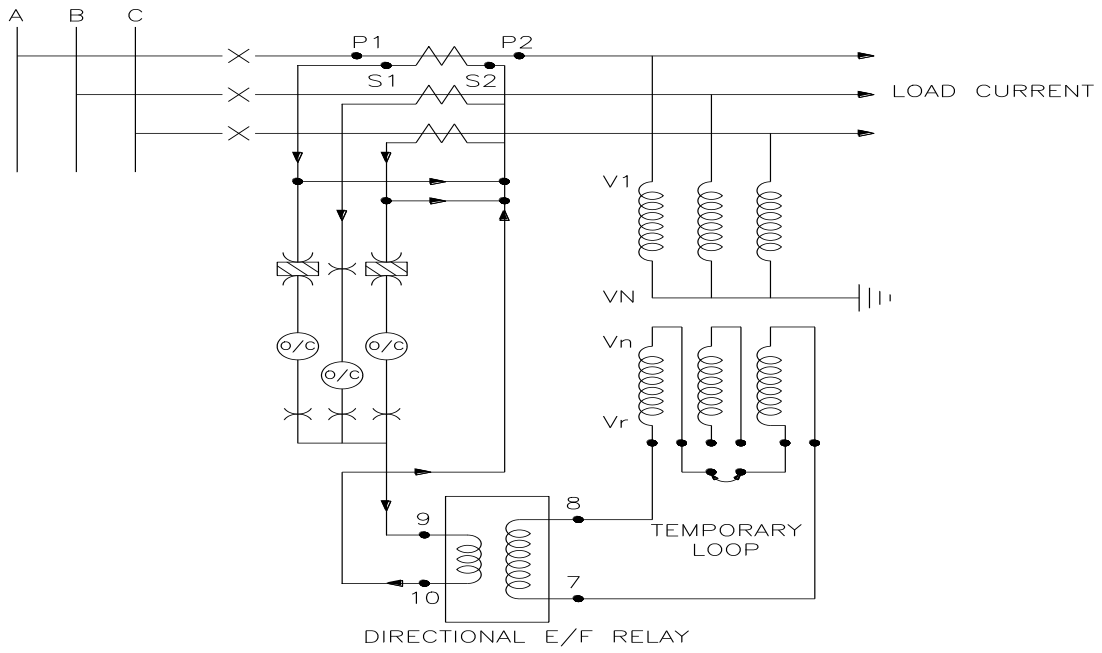
LOAD TEST ON DIRECTIONAL EARTH FAULT RELAY

ALARM   TRIP   OPERATING
CONTACTS   CONTACTS   COIL

1   2   3   4   5   6   7   8   9   10

RELAY CRADLE DRAW OUT CONTACT
FINGERS

TEST PLUG

C.T.SHORTING LINK

RELAY CASE DRAW OUT
CONTACT FINGERS

ALARM   TRIP   CURRENT
CIRCUIT   CIRCUIT   CIRCUIT

A.C MAINS

TO INJ. TRANS.   TO C-CONTROL   RELAY CURRENT

TIMER   TIMER   RELAY CONTACTS

ON   OFF
SUPPLY   A   T

Coarse Medium Fine

EARTH   EARTH   RELAY SETTINGS
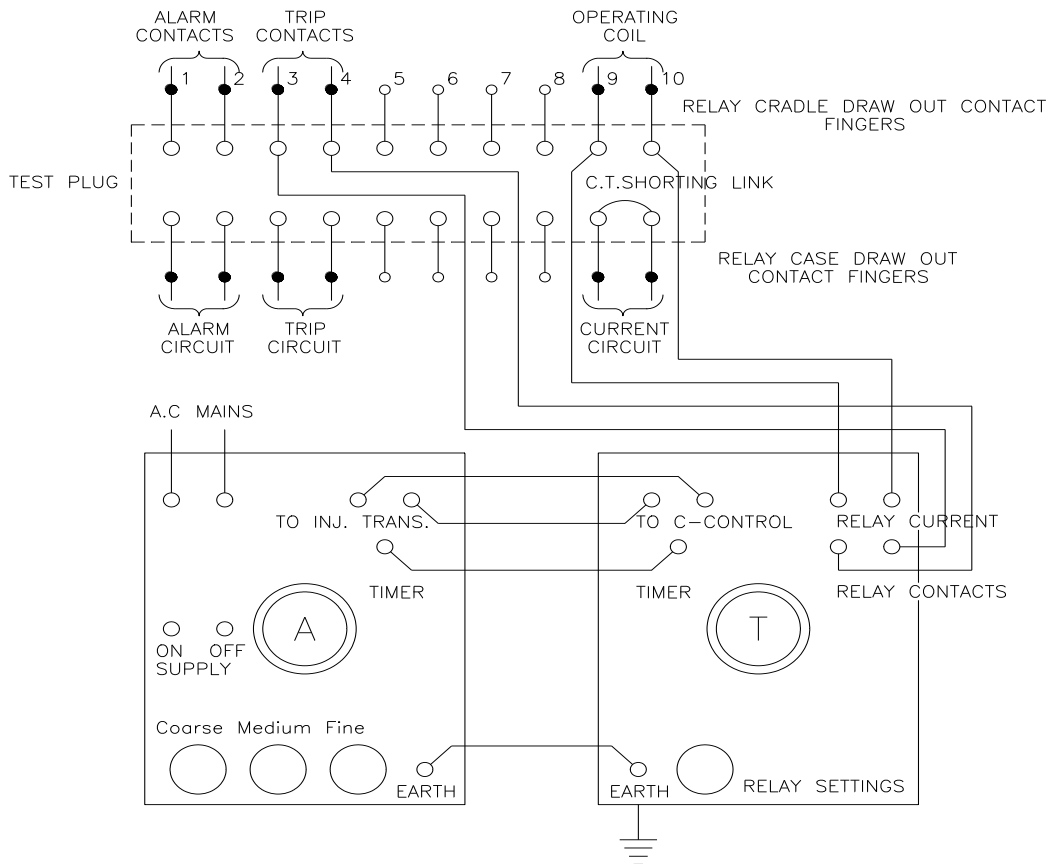
CONNECTION FOR TESTING SINGLE POLE CDG RELAYS IN DRAW OUT CASES
USING ENGLISH ELETRIC OVER CURRENT TEST EQUIPMENT TYPE CFB.

CIRCUIT BREAKERS

CIRCUIT BREAKERS

The function of a Circuit breaker is to isolate the faulty part of the power system in case of abnormal conditions.

A Circuit breaker has two contacts - a fixed contact and a moving contact. Under normal conditions these two contacts remain in closed position. When the circuit breaker is required to isolate the faulty part, the moving contact moves to interrupt the circuit. On the separation of the contacts, the flow of current is interrupted, resulting in the formation of arc between the contacts. The contacts are placed in a closed chamber containing some insulating medium (liquid or gas) which extinguishes the arc.

Arc Interruptions

There are two methods of arc interruption
   i.   High Resistance Interruption
   ii. Current Zero Interruption

(i)   High Resistance Interruption
        In this method of arc interruption, its resistance is increased so as to reduce the current to a value insufficient to maintain the arc. The arc resistance can be increased by cooling, lengthening, constraining and splitting the arc. This method is not suitable for a large current interruption.

(ii)   Current Zero Interruption
        In case of a.c supply, the current wave passes through a zero point, 100 times per second at the supply frequency of 50 Hz. This feature of arc is utilised for arc interruption. The current is not interrupted at any point other than the zero current instant, otherwise a high transient voltage will occur across the contact gap.

Restriking voltage and Recovery Voltage
After the arc has been extinguished, the voltage across the breaker terminals does not normalise instantaneously but it oscillates and there is a transient condition. The transient voltage which appears across the breaker contacts at the instant of arc being extinguished is known as restriking voltage. The power frequency rms voltage, which appears across the breaker contacts after the arc is finally extinguished and transient oscillations die out, is called recovery voltage.

Classification of Circuit Breakers

Depending on the arc quenching medium employed, the following are important types of circuit breakers.

   i.   Oil Circuit Breakers
   ii. Air Blast Circuit Breakers
   iii. Sulphur Hexafluoride (SF6) Circuit Breakers
   iv. Vacuum Circuit Breakers

Comparison of SF6, CB & ABCB for Number of Interrupters per Pole:

Rated Voltage KV	145 KV	245 KV	420 KV	765 KV
SF6 CB	1	1 or 2	2 or 4	4
ABCB	4	4 or 6	8 or 10	10 or 12

The piston is pushed down by high pressure oil on top area of the piston

During closing stroke high pressure oil is admitted from the bottom of piston. Piston bottom area being larger than that on the top the differential pressure acts and the piston is pushed upwards for closing stroke.

Rating of Circuit Breakers

Circuit breakers have the following important ratings

  i. Breaking Capacity

  ii. Making Capacity

  iii. Short-time Capacity

Breaking Capacity

The breaking capacity of a circuit breaker is of two types.
  (i) Symmetrical breaking capacity
  (ii) Asymmetrical breaking capacity

(i) Symmetrical breaking capacity

It is the rms. Value of the ac component of the fault current that the circuit breaker is capable of breaking under specified conditions of recovery voltage.

(ii) Asymmetrical breaking capacity

It is the rms value of the total current comprising of both ac and dc components of the fault current that the circuit breaker can break under specified conditions of recovery voltage.

Making Capacity

The rated making current is defined as the peak value of the current (including the dc component) in the first cycle at which a circuit breaker can be closed onto a short circuit. Ip in Figure. is the making current.

<u>Short-time Current Rating</u>

The circuit breaker must be capable of carrying short-circuit current for a short period while another circuit breaker (in series) is clearing the fault. The rated short-time current is the rms value (total current, both a.c. and d.c. components) of the current that the circuit breaker can carry safely for a specified short period.

<u>Rated Voltage, Current and Frequency</u>

The rated current is the rms value of the current that a circuit breaker can carry continuously without any temperature rise in excess of its specified limit.

The rated frequency is also mentioned by the manufacturer. It is the frequency at which the Circuit breaker has been designed to operate. The standard frequency is 50 Hz. If a circuit breaker is to be used at a frequency other than its rated frequency, its effects should be taken into consideration.

<u>Operating Mechanism</u>

Different manufacturers adopt one of the following:
1. Pneumatic
2. Hydraulic
3. Spring

1.   <u>Compressed air system for pneumatic mechanism:</u> -
The pressure of the operating air produced by the self-enclosed motor compressor unit is supervised by a pressure gauge and controlled by a pressure switch (located in the breaker control cabinet). The pressure switch has four sets of contacts each of which operates at a different pressure level for the following functions: Start/stop, low pressure indication, reclosure interlock, closing and opening interlock.

This type of system is provided for each pole of 420 KV and 765 KV CB.

2.   <u>Hydraulic Mechanism</u>: -

The hydraulic cylinder is mounted at the base of interrupter unit and the hydraulic rod is pushed-up during closing stroke and pushed down during opening stroke. Moving contact and puffer cylinder are linked with the hydraulic rod.

The hydraulic oil at atmospheric pressure from the low pressure tank is pumped into accumulators at high pressure (310 kg/cm^2). High pressure oil is used for opening and closing operations.

During opening operation high pressure oil from lower area of hydraulic piston is discharged into low pressure tank by opening appropriate hydraulic valve.

3. <u>Spring Mechanism: -</u>

For CB upto 245 KV, spring operating mechanism is used. The closing spring gets charged by geared motor. During closing stroke the closing spring is discharged. It closes the breaker and also charges the opening springs.

The Circuit breaker mechanism is basically very simple since it comprises a motor-reducer and two springs (one for closing and one for opening), plus their solenoid operated latching devices.

The closing spring after having been charged by the motor-reducer is kept ready for closing by its latching device.

As soon as energised, the closing control coil friggers the closing latch thereby causing the closing spring to operate the breaker to the closed position and simultaneously charge the opening spring.

From now on, trip latch keeps the breaker in the closed position and the opening springs ready for opening.

The compact design of the mechanism avoids the need for the opening springs to be located close to each pole and permits the opening operation to be performed by only one spring accommodated in the control cabinet.

<u>Reasons for preference of SF6 Breakers</u>

⟹ Less number of interrupters per pole, hence cheaper.

⟹ Maintenance free. Very long contact life.

⟹ Reliable

⟹ Non-explosive

⟹ Does not require compressed air system

⟹ Silent operation

⟹ **Technically superior**

Performs all the required duties including line switching, transformer switching, reactor switching, etc.

without excessive over voltages.

Easy to install, operate & maintain.

OPENING & CLOSING TIMES

a) Closing Time Measurement of Circuit Breaker using Digital Time Internal Meter

To measure the closing time of circuit breaker (i.e. the time elapsed from the movement of the extending control supply to the Closing coil to the movement of actual closing of the circuit breaker), the following circuit is made use of.
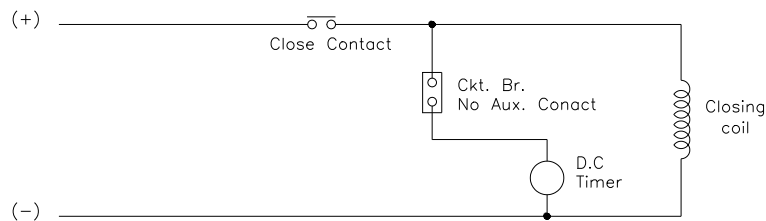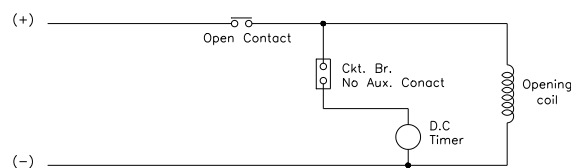

In this mode, NC/NO "start" and NC/NO "stop" switches should be in 'No' position.

The counter starts when the two terminals of "START" switch are shorted by closing the D.P.D.T switch. Simultaneously the D.C supply is extended to the closing coil of the breaker. The counter stops counting when the two terminals of 'STOP' switch are shorted through the 'main contact' of circuit breaker, as soon as it closes and the timer displays the time interval, which is the closing time of circuit breaker.

Hence the principle is that the energisation of the closing coil of the circuit breaker and starting of the counter should be simultaneous.

b) Measurement of Circuit Breaker Opening time

To measure the opening time of circuit breaker, (i.e., the time elapsed from the movement of extending control supply to the trip coil of the circuit breaker to the movement of actual tripping of circuit breaker), the following circuit is made use of.

In this mode, NC/NO "START" switch should be in "NO" position and NC/NO "STOP" switch should be in 'NC' position.

The counter starts when the two terminals of "START" switch are shorted by closing the D.P.D.T switch. Simultaneously the D.C supply is extended to the trip coil of the breaker.

The counter stops counting when the two terminals of "STOP" switch are opened with the opening of the circuit breaker "MAIN CONTACTS". The time internal displays the time internal, which is the "Opening time" of circuit breaker.

Pole Discrepancy Relay:

Two cases are to be studied:

1) Three Phase Tripping.

     All the thee poles should simultaneously trip or close. While tripping,if any one or more of the poles do not open simultaneous with the other, after a set time (of 0.1 Sec.), the pole discrebancy relay will give a trip command again to trip the same. Similarly while closing the breaker, if any of the three poles do not close simultaneous with the other, the pole discrebancy relay, after a preset time (of 0.1 Sec.) will give a trip command to trip the closed pole(s).

2) Single phase tripping and Auto Reclosure:

     While the application principle is same as with the three phase tripping, the time setting of the pole discrebancy relay shall be more than the dead time (of 1 Sec.) of the auto reclosure relay.
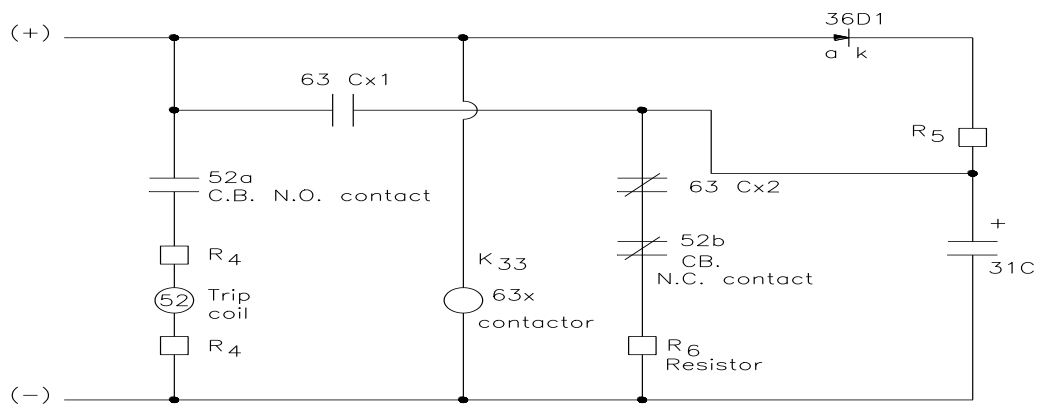
Circuit breaker operation Analyzer: -

     This instrument helps in measurement of contact make and break times, contact travel speeds.

CIRCUIT BRAKER
INDICATION CIRCUITS
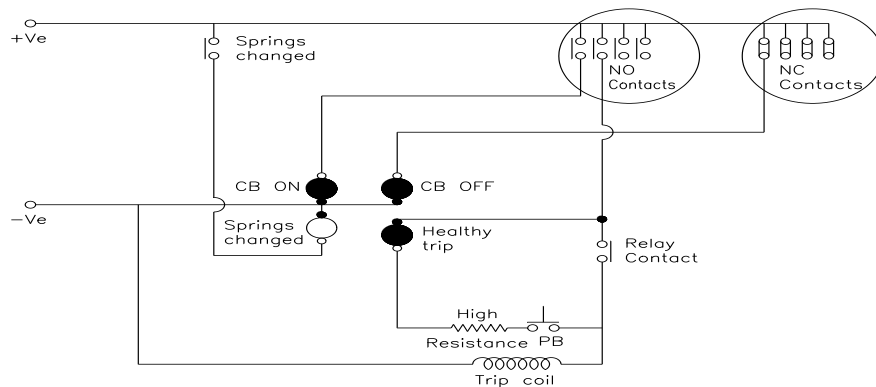
(Close, Trip, Healthy Trip & Spring Charge Indications)

Capacitor Tripping Device for Circuit Breakers

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STATION BATTERY

BATTERY OPERATION AND MAINTENANCE

I) 1. (a) The Ampere hour capacity of 220V batteries at smaller Sub-stations shall be 80.

(b) The same at EHT Sub-stations shall be 200

(c) Batteries with 300Amps hour capacity shall be used only at Power houses or Sub-stations where solenoid closing of circuit breakers is in use.

2. The trickle charging rate shall be

"Amp hour capacity x 2/24x100 plus regular discharge in amps".

3. The boost charge rate shall not exceed " Amp.hour capacity divided by ten".

4. The individual cell voltage shall not go down below 2.1 volt.

5. The specific gravity should not differ by more than 30 points between cells in the same battery maximum and minimum. Where the difference is more; electrolyte should be diluted by adding distilled water in cells with higher specific gravity thus narrowing down the difference and all cells in the battery given a boost charge.

Under no circumstances electrolyte or concentrated acid should be added to cells with low specific gravity.

6. Usage of alkali cells and acid cells in the same substation should be avoided to avert inadvertent mix up of electrolyte or usage of accessories of one with the other.

7. Leakage indication lamps should be compulsorily connected on the charges panel for continuous indication of healthiness.

8. Every D.C. Circuit takes off should be through protective fuses (H.R.C) or m.c.bs.

9. (i) Once in a day A.C. supply to charges should be switched off and D.C. voltage measured and noted.

(ii) In that condition with no A.C. supply to charger, the duty performance of the battery by closing or tripping of a relatively un-important breaker is to be ensured. Mere availability of D.C voltage is no index of healthiness of battery.

(iii) A.C supply to charger is to be restored immediately after this test.

10. Certain charger panels have "Switch Off" arrangement whenever A.C supply fails. There should be switched on after each restoration of supply.

11. Leakages in D.C circuitry should be attended on top priority first by sectionalisation, then by isolation and finally be rectification.

Lead Acid Batteries (Common)

1. Check up the Electricity to level in the cell of all the cells in morning shift every day. If the electrolyte is low, top up the cell with distilled water.

2. Check up the voltage and specific gravity of six cells in each shift and record as per cell numbers given (PILOT CELLS)

3. Check up the D.C voltage of the combined cells (battery) after switching off the battery charger every day in the morning shift. Record the battery voltage and current with the charger off.

4. Ensure that the battery is in floating condition normally by adjusting the rheostat of the charger.

5. Never charge a battery at a voltage higher than 2.4 V per cell i.e., it works out to 264 V for 220 V Battery and limit the charger ampere capacity also.

6. If any of the cells is found to be having low voltage and specific gravity, by pass the cell. The removed cell should be charged separately and replaced after the voltage and specific gravity attains normal value. Improvement should not be attempted by adding acid to electrolyte.

7. Check the condition of all the cells every month for voltage and specific gravity. Charge the battery if required. The voltage and specific gravity readings shall be taken before and after charging. The charging rate shall be limited to 10 hours rating to avoid excessive gassing and evaporation of Electrolyte.

8. All the cells shall be physically checked for fracture and buckling of the container and excessive rise. Check battery terminals for tightness. Apply Vaseline (petroleum jelly) whenever necessary. This check should be attempted after the battery is brought to full charge.

9. Keep the charger off, observe the voltage with D.C lighting 'on' continuously for two hours. Observe the voltage and current. The voltage should not fall by 10% when the discharge on the battery is at 10Hrs i.e., 25Amps for 250Hrs. battery 30Amps for 300Hrs. battery etc. Every discharge shall be compensated by charging. As the ampere hour efficiency is always less than unity, the charging ampere hours shall be more than discharge ampere hours.

The battery charger panels, in some cases have a no volt trips. Whenever A/C supply fails, the charger should be switched on after restoration of AC supply.

EARTHING PRACTICES

EARTHING PRACTICES AT SUBSTATIONS

Introduction

Earthing practices adopted at Generating Stations, Substations, Distribution structures and lines are of great importance. It is however observed that this item is most often neglected. The codes of practice, Technical Reference books, Handbooks contain a chapter on this subject but they are often skipped considering them as too elementary or even as unimportant. Many reference books on this subject are referred to and such of those points which are most important are compiled in the following paragraphs. These are of importance of every practicing Engineer in charge of Substations.

Importance of Earthing & Practices

- The earthing is provided for
  a) Safety of Personnel
  b) Prevent or atleast minimise damage to equipment as a result of flow of heavy fault currents.
  c) Improve reliability of Power supply

- The earthing is broadly divided as
  a) System earthing (Connection between part of plant in an operating system like LV neutral of a Power Transformer winding and earth).
  b) Equipment earthing (Safety grouding)

     Connecting frames of equipment (like motor body, Transformer tank, Switch gear box, Operating rods of Air break switches, etc) to earth.

- The system earthing and safety earthing are interconnected and therefore fault current flowing through system ground raises the potential of the safety ground and also causes steep potential gradient in and around the Substation. But separating the two earthing systems have disadvantages like higher short circuit current, low current flows through relays and long distance to be covered to separate the two earths. After weighing the merits and demerits in each case, the common practice of common and solid (direct) grounding system designed for effective earthing and safe potential gradients is being adopted.
- The earth resistance shall be as low as possible and shall not exceed the following limits:

Power Stations	-	0.5 Ohms
EHT Substations	-	1.0 Ohms
33KV Stations	-	2.0 Ohms
D/t Structures	-	5.0 Ohms
Tower foot resistance	-	10.0 Ohms

Step Potential

Step Potential is the difference in the voltage between two points which are one metre apart along the earth when ground currents flowing.

Touch Potential

Touch Potential is the difference in voltage between the object touched and the ground point just below the person touching the object when ground currents are flowing.

Specification of Earthing

Depending on soil resistivity, the earth conductor (flats) shall be buried at the following depths.

	Soil Resistivity in ohms/metre	Economical depth of Burial in metres
1)	50 – 100	0.5
2)	100 – 400	1.0
3)	400 – 1000	1.5

To keep the earth resistance as low as possible in order to achieve safe step and touch voltages, an earth mat shall be buried at the above depths below ground and the mat shall be provided with grounding rods at suitable points. All non-current carrying parts at the Substation shall be connected to this grid so as to ensure that under fault conditions, none of these part are at a higher potential than the grounding grid.

Plate Earths

- Taking all parameters into consideration, the size of plate earths are decided as

  Power Stations & EHT Station-   Main -   100 x 16mm
                                          Auxiliary -   50 x 8mm
  Small Stations   -   75 x 8mm

- The complete specifications for providing earth mats at EHT & 33KV Substations, Distribution transformers & Consumers premises are reproduced below.

Specification for Earthing System

I) EHT Substation

1. The earth mat shall be as per the approved layout. The earth mat shall be formed with the steel flats buried in the ground at a depth of 750mm on edge.

2. The earth mat shall extend over the entire switchyard as per the layout.

3. All the junctions of the steel flats while forming the earth mat and taking risers from the earth mat for giving earth connections to equipment, steel structures, conduits cable sheaths shall be properly welded. All joints shall be provided with suitable angle pieces for proper contact between flats.

4. Provisions shall be made for thermal expansion of the steel flats by giving smooth circular bends. Bending shall not cause any fatigue in the material at bends.

5. The earth mat shall be formed by welding 50x8 mm steel flat to the 100 x 16mm peripheral earth conductor. The grounding grid shall be spaced about 5 meters i.e in longitude and about 5 meters in the transverse directions. After the completion of earth mat, the earth resistance shall be measured. In case the earth resistance is more than one ohm the earth mat shall be extended by installing extra electrodes, so that the earth resistance is less than one ohm.

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6. All fence corner posts and gate posts shall be connected to the ground by providing 32mm dia M.S rods of 3 metre length near the posts and connected to the main grounding mat.

7. All paint enamel and scale shall be removed from surface of contact on metal surface before making ground connection.

8. The risers taken along the main switchyard structures and equipment structures (upto their top) shall be clamped to the structures at an interval of not more than one metre.

9. 50 x 8mm ground conductor shall be run in cable routes and shall be connected to the ground mat at an interval of 10 metres.

10. Grounding electrodes of 32mm dia 3mtr. long MS rods shall be provided at the peripheral corners of the earth mat. The grounding rods shall be driven into the ground and their tops shall be welded to clamp and the clamp together with the grounding rods shall be welded to the ground mat.

11. Lightening arrestors shall be provided with earth pits near them for earthing.

12. Cast iron pipes 125mm dia and 2.75 metres long and 9.5mm thick shall be buried vertically in the pits and a mixture of Bentonite compound with Black cotton soil a ratio of 1:6 is to be filled 300 mm dia and the pipe for the entire depth. Where it is not possible to go to a depth of 2.75 metres, 1.3 x 1.3 MMS plates, 25mm thick shall be buried vertically in pits of 2 metres depth and surrounded by Bentonite mixture atleast 2 metre away from any building or structure foundation. The plates shall be atleast 15 metres apart. These earth pits in turn shall be connected to the earth mat.

II) **Earthing at 33KV Substations**

1. Providing of earth pit and earth matting include the following connected works:

a) Excavation of earth pits of size 21/2ft x 21/2ft x 9ft in all type of soils.
b) Providing of CI pipe of 3 inch diameter 9ft length with flange. All connections to CI pipe shall be with GI bolts and nuts.
c) Filling of earth pit excavated with Bentonite with Black cotton soil (1:6) in alternate layers.
d) Providing of cement collar of size 2ft diameter 2ft height 1 inch below the ground level.
e) The top of the CI earth pipe should be at the surface level of the ground.

2. Providing of earth matting with MS flat 75 x 8mm including the following connected works:
a) Excavation of trench in all types of soils of size 2½ ft depth and 1 ft. width.
b) Laying of M.S flat 75 x 8mm in the excavated trench.
c) Inter connecting all earth pits and welding properly at jointing location and junctions.
d) Back filling of earth completely.

III) Earthing at Consumer's premises

The earthing at Consumer's premises shall be as per sketch below using a 6mm thick plate
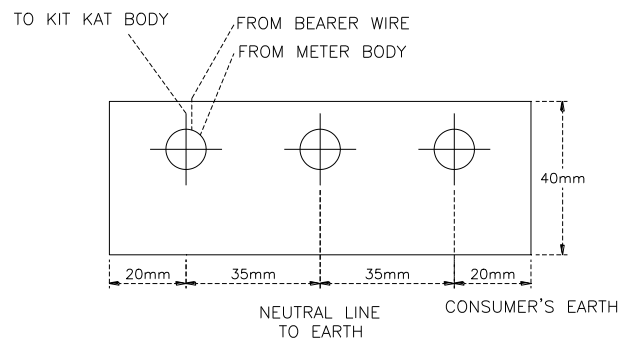
IV) Earthing at D/P Structure

Three electrodes forming an equilateral triangle with minimum distance of 6500 mm, so that adequate earth buffer is available. Each Electrode shall be 'A' grade GI pipe of 2 inch thick and 8ft long and buried vertically so as to leave about 4 inch pipe length above ground level to fix a 'U' shaped clamp.
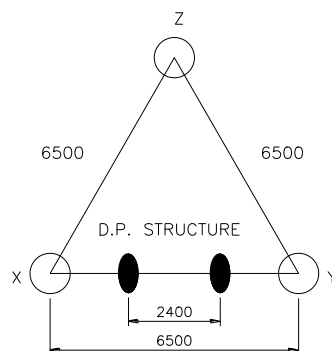
Note:

1. The connections to the three earth conn.Electrodes should be as follows.

(A) To one of the earth electrodes on either side of double pole structure (X or Y)

   i.   One direct connection from three 11KV Lightening Arrestors.
  ii.   Another direct connection from the LT lightening Arrestors if provided.

(B)   To each of the remaining two earth electrodes.

   i.   One separate connection from neutral (on the medium voltage side) of the Transformer (Two wires)
  ii.   One separate connection from the Transformer body and the handle of the 11KV A.B switch (Two separate body earths to tank)
  iii.   One separate connection from the Earthing Terminal of poles.

(C)   4mm G.I wire should be used for earth leads.

JOINTS
- There shall be minimum joints preferably no joints enroute to earth electrodes
- Where Joints are unavoidable, they shall be brazed, rivetted or welded (and painted with red lead and alluminium paints one after the other and finely coated with bitumen)

TOWER LINE GROUNDING
1) Ground rods are driven at the base of the tower. Where it is not feasible, an electrode is located within a distance of 200 ft. of the tower and grounding rods are provided at that point and tied to the tower base by a single buried wire.
2) If low resistance is not obtained with 200ft, crowfoot counterpoise with 4 wires is installed. The counterpoise conductors shall be 6 SWG galvanised steel wires taken away from the tower at mutually right angles and kept atleast 50ft apart. Each of these wires is terminated at a rod at the nearest point where low resistance is obtained. If counterpoise wires cannot be terminated within half span from the tower the wire is carried through a continuous counterpoise to the next tower, where the procedure is repeated.

Measurement of Earth Resistance
The measurement of earth resistance is done using three terminal earth meggars or four terminal earth meggars.

Three Terminal: Two temporary electrodes or spikes are driven one for current and the other voltage at a distance of 150 feet and 75 feet from the earth electrode under test and ohmic values of earth electrode is read in the meggar.

Four Terminal: Four spikes are driven into the ground at equal intervals. The two outer spikes are connected to current terminals of earth meggar and the two inner spikes to potential terminals of the meggar till a steady value is obtained.

Maintenance of Earthing System
The following Maintenance schedule in mandatory at each of the Substations

Sl.No	Item	Periodicity
1.	Watering of Earth Pits	Daily
2.	Measurement of earth resistance of individual earth pits	Half yearly @
3.	Measurement of combined earth resistance at all the pits	Half yearly...
4.	Checking of inter connections between earth pits and tightness of bolts and nuts	Quarterly

@ Earth resistance of individual earth pits can be measured by disconnecting the earth connections to the electrode. This is possible if the connections are made to a common clamp which is in turn is fixed round the pipe.

... Combined earth resistance shall be the same at every earth pit unless it gets disconnected from the earth mat

Definitions of General Earthing Terms

Soil Resistivity: This is the resistivity of a typical sample of soil

Earth Surface Voltage: The voltage between a specified point on the ground around the rod and reference earth.

Earth Electrode

      These are conductors, which are in direct contact with the soil and provide the conductive part in electrical contact with earth. They can include rods, tape, steel reinforcing bars.

Definitions of Terms associated with Power Systems

Neutral Point

      The common point of a star connected poly phase system or the earthed mid-point of a single phase system.

Independent Earth Electrode

      An earth electrode located at such a distance from other electrodes that its electrical potential is not significantly affected by electric currents between Earth and other electrodes.

Exposed Conductive Part

      Conductive part of equipment and which is not normally live, but which can become live when basic insulation fails.

Points of Earthing

1. Earth mat of 75 x 8 MS flat should be laid as outer of the switchyard compulsorily and see that the pole structures are enclosed in the outer mat.
2. Make vertical and horizontal sections for the outer mat as shown in the fig. The internal vertical and horizontal sections may be 75 x 8 or 50 x 6 MS flat.
3. The Earth mat should be laid minimum 600MM, below the ground level under the Earth mat and Bentonite powder is to be laid upto 25mm and over the earth mat. The same Bentonite compound with Black cotton soil a mixture of 1:6 ratio is to be placed upto 100 mm and the remaining earth trench is to be back filled with the soil.
4. See that each and every pole structure is earthed with 50 x 6 MS flat to the Earth Mat.
5. For every breaker there will be fine earth connections to the earth mat with 50 x 6 MS flat (a) Breaker body (b) Relay Panel (c) CT's of the Breaker (d) and two sides of the breaker structure.
6. Lightening arrestor is to be connected one end directly to the earth mat and the other end is to the nearer earth pit or to the earth mat.

7. Line Isolators are to be connected directly to the earth mat.
8. The Power transformer body is to be connected two sides to the earth mat.
9. Twin neutral earthing should be done to Power Transformer as shown in the fig. one Earth flat of size 75 x 8mm M.S flat is directly connected to the earth pit and the earth pit is again connected to the Earth mat. The second neutral is directly connected to the earth mat,
10. Provide flexible jumpers thoroughly brazed as shown in figure
11. All AB switches operating rods are to be provided with coil earths and the AB switch support is to be earthed to the earth mat.

12. All the exposed earth flat which is dropping down from the breakers, CT's structures should be applied with bituminous paint.

13. 75 x 8 MS flat is to be laid around the control room from main earth and the panels of the breakers, midpoint of the Battery and Battery stand structures are to be earthed to the earth flat and make a section in front of the control room.

14. The distance between any two earth electrodes should be twice the length of the Electrode.

15. The cable (11 x 33KV) sheaths are to be earthed with 25 x 3 GI strip to the Earth mat.

16. The neutral of the station transformer is to be connected to the Earth mat directly with   25 x 3 GI strip. The body of the Station transformer two sides to be connected to the earth mat with 25 x 3 GI strip.

17. All the welding joints should be painted with bituminous paint.