M.R.T. & T.R.E. MODULE
INDEX

ELEMENTS OF PROTECTIVE RELAYING

The subject of protective relaying, usually dealt with by MRT divisions in our Electricity Board, is considered as something shrouded with mystery. In every Operation Circle one Assistan[1] Divisional Engineer and One Assistant Engineer are entrusted with the work of protective relaying in all the Sub-stations as against a total of about forty five Assistant Divisional Engineers and over hundred Section Officers performing other duties. Thus the chances of one getting an opportunity to work in MRT and possess first hand practical knowledge are very limited. This is the main reason why majority of the Engineers feel the subject strange.

General :

An electrical power system should be designed and managed to deliver power efficiently and economically to the points of utilisation with minimum interruptions. The reliability of supply and safety of equipment are the main responsibilities of operating Engineers.

The greatest threat to secure system of supply is the short circuit (between phases or phase to ground) : which imposes a sudden and at limes even violent disturbance in the system parameters of voltage, current, frequency etc. An uncontrolled release of energy contains disruptive properties which may cause severe danger to the system. Overloading is common in any system and this leads to excessive-rise in temperatures or load carrying currents ; damage to insulation, and cause faulting to earth or short circuiting of phases.

Rapid fault clearance is essential for protecting the equipment and lines from the damage. It is also essential that only the minimum length of section is isolated so as not to cause inconvenience to others. Fuses are the most simplest and cheapest means employed to protect an electric circuit. The 'selectivity' is obtained by using suitably rated fuses in different circuits. Fuses are employed on L.T and on H.V. side upto 33 KV with horn-gap arrangement. The main draw back in the employment of fuses is that they have to be replace each time they blow out, and check has to be made every time for their rating before replacement, All this consumes time. The period of interruption therefore will be more.

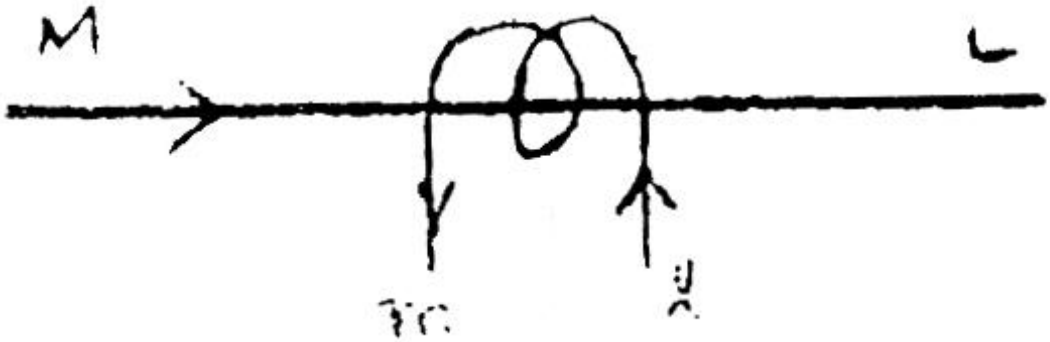
On all H.T. systems switchgear and protective gear are employed for quick, selective and reliable clearance of faults on (i) Transmission lines: (ii) Feeders; (iii) Trans- formers (iv) Generators etc. The switch gear employed in a system must be capable of interrupting normal and fault currents apart from being capable of delivering normal current. Protective gear must be capable of sensing an abnormal condition and cause to operate the circuit breaker to effectively remove the faculty element with minimum disturbance to normal system operation.

The term 'switchgear' generally applied to oil and air circuit breakers and the 'protective' gear to relays employed to perform the function of opening out the circuit breakers for selected conditions.

Current and Voltage Transformers :

A relay works in association with a current transformer or a voltage transformer or both. Current and Voltage transformers (called CTs & PTs) insulate the secondary circuits containing relays, meters etc., from the primary circuit and provide quantities in the secondary which are proportional to these in the primary. The quantities In the secondary should be representative In magnitude and direction of the quantities in the primary. Universal values of voltages and current transformers are 110 V and 1 or 5 Amps. CTs with 5 Amps, secondary rating are generally employed at sub-stations where all controls are situated locally at the switch gear. CTs with 1 Amp. secondary rating are used in substations where controls are located remotely (controlroom). The large drop consequent to the remote location of protective gear is thus avoided. The primary of the current transformer is connected to in series with the load and carries the load current. The secondary winding is connected in a closed circuit with relays, meters etc. The load resistance together with the impedance of the relay constitutes the 'burden' of the CT. The CT is polar in nature and markings of (M) (L) on primary and (m) (1) on the secondary sides indicate the direction of flow of current which is essential in relays and energy meters.

The secondary circuit of a CT should never be broke open when current is flowing since due to sudden increase in the m.m.f. high voltage is developed m secondary winding leading to damage of the CT, relays etc.



Flow of current in primary
And secondary with markings

A voltage transformer is an ordinary transformer with a lesser current capacity. The secondary voltage usually 110 (at full rated primary voltage) is used for metering, directional relays, distance protection etc.

Protective Relays:

Protective relays are the devices which close or open an electrical circuit to control a circuit breaker when the actuating quantity reaches a pre-set value. The actuating quantity can be current, voltage, power etc. According to the kind of the actuating quantity the relays can be classified as over current, user or over voltage relay, over or under frequency relay etc.

Relays are mainly designed to operate on electromagnetic or induction principal.

The relays can further be classified depending on their function as auxiliary, supplementary and signal relays etc. The main relays are the protective elements which respond to any change in the actuating quantity. The auxiliary or supplementary relays are controlled by the main relays to perform some auxiliary functions like introduction of time delay, increasing the making or breaking capacity of contacts, passing command pulses from one relay to another etc. Signal relays functions to register (by flag) the operations of some relay and issue a control warning (visible) and also provide an (audible) alarm.

In general all relays comprise two fundamental elements the discriminating or measuring element and the control element. The measuring element loads to any pre-set change in the actuating quantity and the control element causes to trip the connected circuit breaker or operate another relay, energise a signal relay or do all these. The most essential qualities of a protective relay are :

(i) <u>Reliability</u> :

It is impossible to achieve complete reliability since there is always a risk of failure. Failures can only be reduced by inherent reliable designs backed up by regular and through maintenance. Such checks/maintenance should be carried out without disturbing the wiring and can be achieved by employing test terminal blocks. Failure in control circuits, (trip circuits) can be detected by employing 'on demand' or 'continuous' circuit supervision arrangements (healthy trip circuit indication - discussed later in detail)

(ii) <u>Selectivity</u> :

Selectivity is important in order to minimise and if possible avoid interruptions to other parts which are not covered in the faulty zone. Each relay has a zone for which it is not intended to protect. Selective protection determines that the fault is within its zone and operates to isolate the zone only. Selectivity is achieved by proper application of the relays by the protection engineer and is not be inherent design feature.

(iii) <u>Speed</u> :

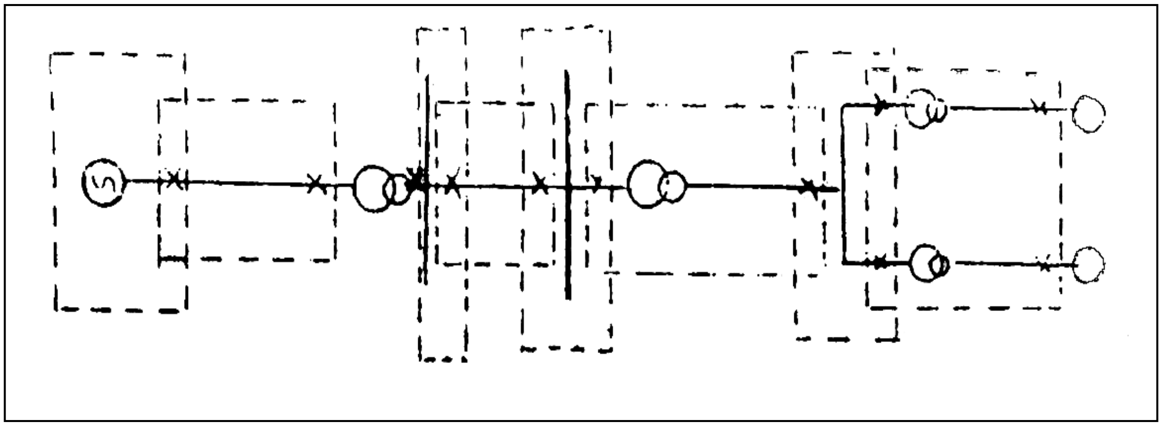
The relays should perform the duty with speed. Speed can be achieved only at the expense of selectivity. It may cause few undesirable tripping which is better compared to 'non-tripping'

(iv)<u>Sensitivity</u> :

Relays should be sufficiently sensitive to operate reliably under minimum fault conditions for a fault within its zone and should remain stable under maximum load or through fault conditions. A low setting does not necessarily imply 'high sensitivity'

(v)<u>Zone of Protection</u> :

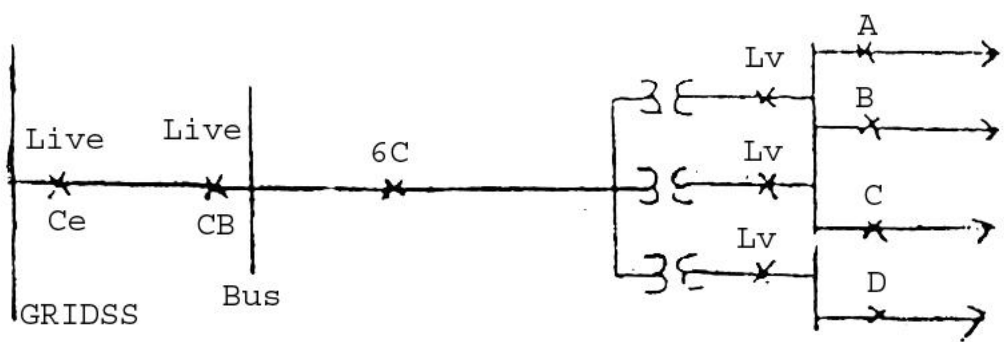
The protected zone is that part of the power system guarded by a certain relay. The zones are arranged to overlap each other so that no part of the system remains unprotected.



Typical arrangement is given above.

Primary and back up protection :

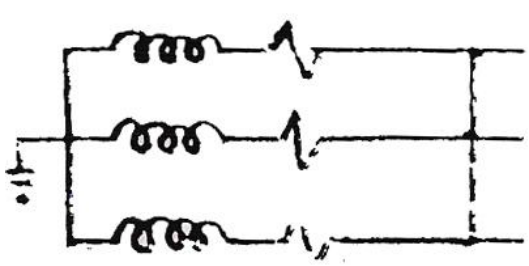
The obvious and essential feature of a protection scheme is reliability. It is evident from the foregoing that many factor may effect the protection scheme leading to its failure. In spite of the protective gear functioning correctly, the circuit breaker itself may fail to trip. It is therefore usual to provide in addition to protection, a back up zone of protection to ensure that in any event the fault is cleared from the system. For example taking a 33 KV line from a grid S.S. to a 33 KV Substation.



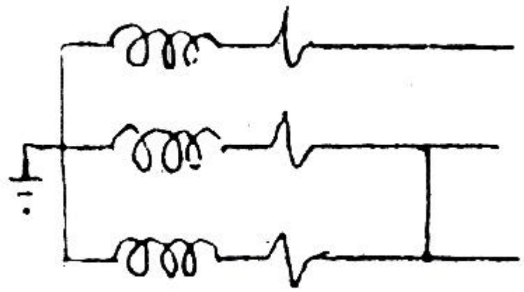
For a fault on feeder (A) the OCB on A should trip on selective operation and if it fails to trip the LV OCBs will trip and so on. The LV OCBs are intended for the protection of Bus system between LV side of the transformers to the feeder OCB and also prevent transformers from overloading. Even then LV protection serves also as back up protection for the feeders in addition to being the primary protection for its own zone.

Kinds of Faults with Relative Probability Index of Occurrence in Overhead Transmission Lines :

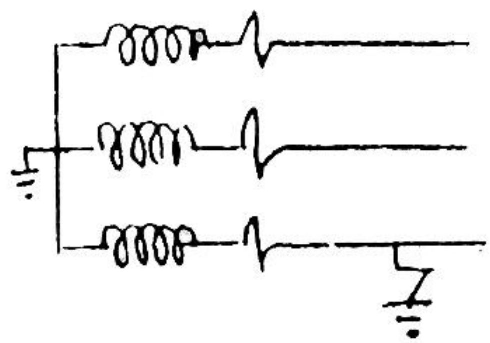
(a) Three Phase 5%



(2) Phase to phase
and
phase to phase to ground
25%

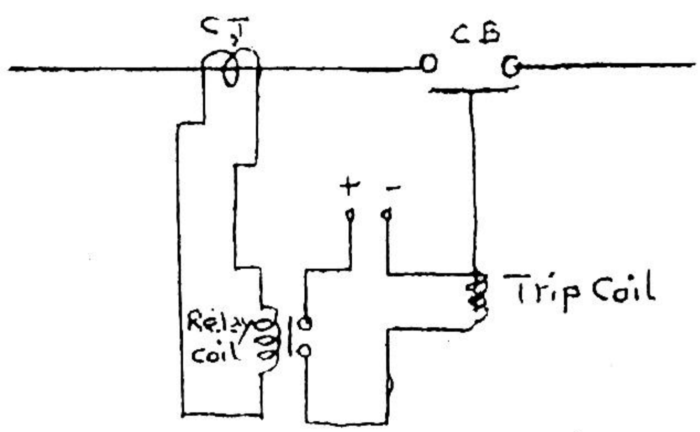


(3) Single Phase
to ground
70%



The universally adopted protection scheme for radial over head transmission lines is the over current protection scheme. In this type of protection the current is the actuating quantity for the relay,

The simplest circuit is given below :



In the circuit shown above, the CT secondary is connected in series with the relay coil and the relay is set to respond or act to a current I_{op}.

When the current exceeds $I_{op,}$ the relay acts and *closes* the two contacts which closes the trip circuit, of OCB and trips the same. The supply to the trip coil is from the battery which is kept on continuous charging. The D.C. supply from the station battery is employed as it is reliable and stable. The D.C. is used f controls, alarms and emergency lighting also. Hence the station battery should good condition. Failure of D.C. supply leads to diestrous consequences.

For small substations where all controls are locally situated station batteries consist of 16 cells totalling an operating voltage of 32 Volts and for bigger substations with more equipment and/or remote controls batteries consist of 11 0 cells totalling 220 Volts operating voltage.

Detailed notes on battery maintenance together with inherent defects and remedies are discussed separately in this note.

(Over Current Relays :)

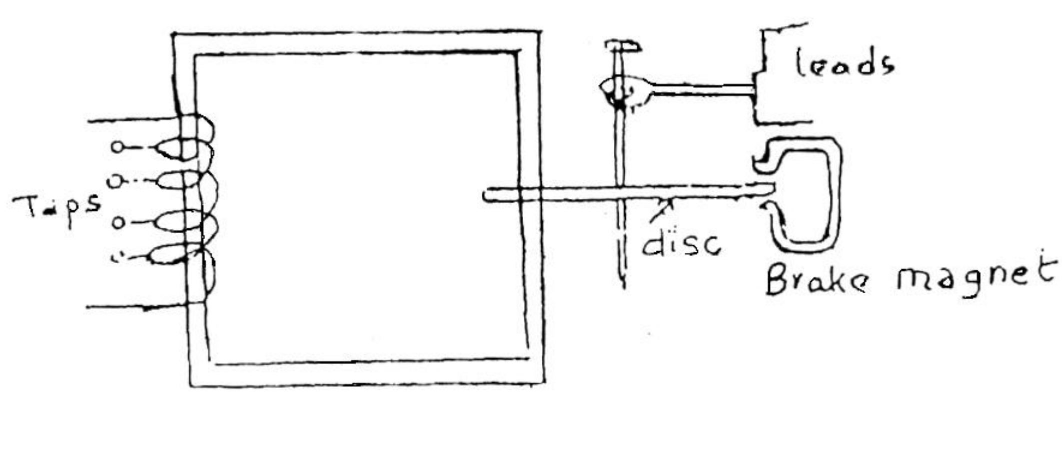
<u>(1) Electromagnetic Relays :</u>

There are two types of electromagnetic relays. They are (i) Solenoid type : (ii) Rotating armature type:

The relay gets actuated for any current over the set value and closes the contacts instantaneously. For the same current for time delay an additional timer has to be incorporated in the circuit for setting intentional and required time delay. These relays are definite time relays which take the same time irrespective of fault current. Hence an additional instantaneous element is incorporate in the relay for tripping the breaker instantaneously in the event of large fault currents. The gradation is obtained by keeping different time settings at different points.

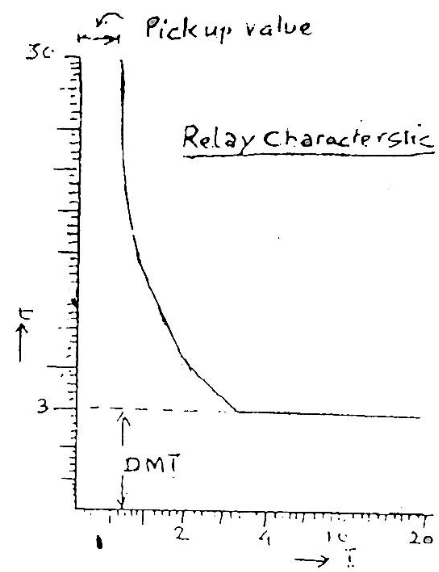
Induction Type Relays :

Relays using induction principle can only operate with alternating current because the induction principle depends on the interaction of alternating magnetic flux and alternating currents. The induction relay is universally used for over current protection in view of its simplicity and reliability. The relay consists of an aluminium dismounted in between the poles of an electromagnet.



Copper rings are proved for shading the poles for splitting the flux into two ϕ1 and ϕ2 separated by angle. The torque produced in the relay is T KI ϕ1 ϕ2 Sin Since both fluxes are proportionately to the current To a i^2 Since K is constant and independent of current.

Thus the speed of the rotation depends on the magnitude of the current and the time of operation also. The distance between the contact bridge and the contacts is constant. The disc is held in position by the restraining spring by the adjustment of which the restraining force is varried. The permanent magnet is provided for the damping of the lotation without which chattering of contacts results in. Since torque is proportional to the square of the current the time of operation is inversely proportional to the square of the current. The time of operation is inversely proportional to the torque and this current characteristic of an induction relay is as given above.

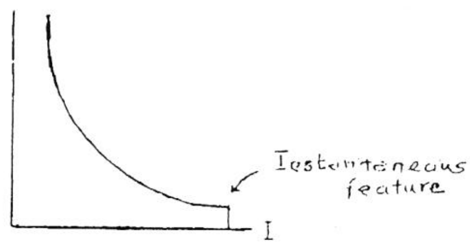


From the above it is evident that the time of operation decreases steeply with the increase of current which is an essential requirement of an over current relay.

The characteristic of an induction current relay possesses and advantage over a definite time relay. The operating current of an induction relay can be set at a dosirod level by having a number of taps on the current coil winding by which the active ampere turns for the same current can be varied. Similarly the time of operation can be varied by rotating the relay disc (i.e.) by varying the distance between contact and contact bridge. Thus any desired characteristic can be obtained. The over current relays are of 1A/5A and in steps of 25%. The over current setting is usually based on the normal load current of the feeder equipment protected.

An Earth fault relay is similar in construction and design to that of an over current relay except that the operating current is usually 20% to 30% of the CT current. The universally adopted current setting for an E/L relay is 20% with lowest time lever setting. The time lever varies from 0-1 and is continuously variable (not in steps). The time lever setting can never be kept at Zero since it shorts the contacts and it is given only for check test/adjustment of relay. The relay characteristic varies from make to make and type to type. The characteristic is given in the form of a graph for guidance in checking and to adopt the settings.

It can be seen from the characteristic that the time of operation falls steeply with the increase in current and attains a constant value at nearly 20 times the operating current (i.e.) the curve runs parallel to current axis. This minimum time of operation is termed as Definite Minimum Time (DMT). The inverse relays are generally termed 'Inverse Definite Minimum Time' relays (IDMT). If desired an additional instantaneous element can be incorporated in the relay for multiples of operating current say *2, 3,* 4, 5 etc. When the operating current reaches the set value of instantaneous element the relay trips the OCB instantaneously and characteristic is as given below :



This addition is advantageous where high time lever setting are adopted to prevent large time for isolating the fault. The gradation can be observed by keeping different time lever settings.

A typical graph showing the current time characteristic of and IDMT relay of English Electric Company type CDG11 given may be studied and the following points studied.

(a) Pick up value (b) Definite minimum time

(c) Time of operation (VS) time lever setting

(d) Overlap of characteristics for different settings of multipliers and time lever setting.

The required curve can be obtained at a particular setting of current and time lever by multiplying the above with the set values. In general, the DMT at 20 times the set value can be justified by the fact that most of the CTs deliver constant secondary current at 20 times the ratio current owing to saturation.

The is also necessary to avoid damage to the secondary wiring and other instruments owing to excessive currents. The operation of relay on a particular phase is indicated by flag operation. Current picks up is usually 1.3 times the set value of current.

P.S.M.	25%	
in	50%	t/1
steps	75%	0 to 1
	100%	continuous
	125%	
	150%	
	175%	
	200%	

Schemes of Protection with DC & CT Connection :

Indicating the three phases as RY and B ; the protection scheme usually employed for a radial feeder is 2 O/L and 1 E/L (i.e.) O/L R ϕ, O/L Bϕ AND E/L. A question may arise why O/L YO is not provided. The reason is based on the types of the faults to be encountered and protection required to ensure cleaning the faults.

1)	Three phases short :	O/L R & B will act.		
2)	Two phases short :	R to Y - R will act		
		Y to B - B will act	|	
		B to R R & B	I	
3)	Phase to Earth	E/L independently	|	to trip
		will act associated	|	the
		with O/L	|	O CB
		of that phase		

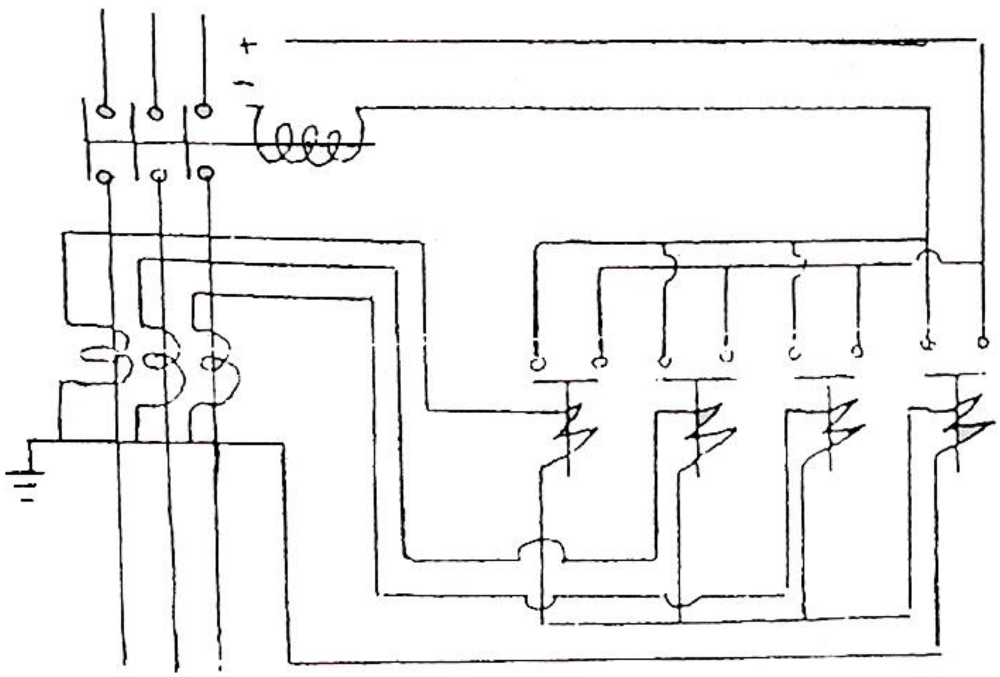
It can be seen that all possible types of faults are covered with 2 O/L, 1 E/L scheme. The O/L Yϕ element is avoided as a point of economy. E/L relay is connected in the star point of a CT circuit and therefore this will act for unbalanced loads also if the unbalance is more than the pick-up value of the E/L relay.

33/11 KV Power transformer's are usually of delta star vector grouping and the neutral of the secondary is earthed. The protection of the L.V. side is O/L and *E/L with a time lever gradation over the feeders. This acts as primary protection for the L.V. side of the transformer (i.e.)

1) Transformer overloaded over its capacity; the O/L setting is limited to the capacity of the transformer always
2) For faults between LV OCB and feeder OCB and
3) Back up protection for feeders.

3 O/L relays are usually provided for the OCB on the H.V. side of the transformer and time gradation is maintained by adopting a higher time lever setting.

Connections of Relays for O/L and E/L Protections :

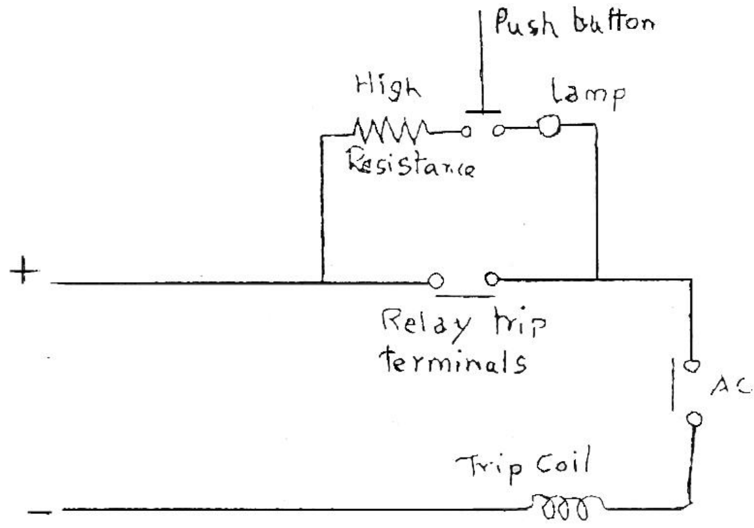


The sketch given is for 3 O/L, 1 E/L relays. In the base of 2 O/L, 1 E/L scheme the O/L, Y phase can be simply noted as shorted.

In the case of the CTs having two or more secondary cores, one winding will be used for protection and the other for metering. In cases of CTs having one core only both metering and protection are combined.

Usually an energy meter is provided to all equipments to record the units sent out. The energy meter is of two element type and is rated for the CT and PT secondary values. The current coils of the Energy meter are connected in series with the current coils of the relays.

Healthy Trip Circuit :



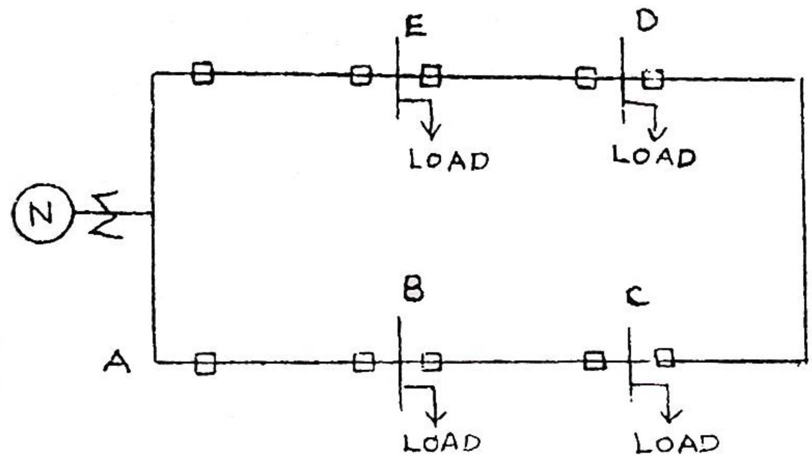
The soundness of the trip circuit is very essential for fault clearance. This therefore needs frequent check. Any failure or open circuiting of the trip circuit leads to disasterous consequences and tripping' of breaker covered as back-up protection.

Healthy trip circuit explained above provides a visual indication in connection with the trip circuit which can be observed on demand by pressing the push button (PB).

The indication provided as a bulb connected in parallel with the relay contacts and in series with a push button and a suitable resistance.

The circuit from - to $^+$of D.C. terminals forms the healthy trip circuit. Normally when the relay operates the two terminals are shorted and trip coil acts. When the circuits breaker are in closed position the A.C. (auxiliary contact) will also be in closed position and the voltage across the relay terminals, when measured with a volt meter it gives the full battery voltage. When a bulb is connected from across the relay trip terminals with a push button in series the bulb glows and the rated current of the bulb flows through the AC and TC indicating its continuity and healthiness. But if the current flowing is greated than the actuating current of the T C. the OCB trips. Hence a resistance of suitable value is connected in series with the bulb to prevent the current flowing in series with the bulb to prevent the current flowing actuating the TC but sufficient enough to glow the bulb. When the relay acts the high resistance and the bulb gets shorted across relay contacts CB operates as usual. The healthy trip circuit explained above is a reliable check. Continuous indication is undesirable as TC is not continuously rated.

After the discussion on simple over current and earth fault relays, next in the list are directional over current and E/L relays. Considering a simple ring feeding various loads at various substations (in the sketch below), the simple non-directional relays will not be suitable and time gradation of the relays is just impossible.



Considering all the Relays are Non-directional :

When a fault occurs in the section A-B the relay at 'B[1] towards A should get earlier than the relays at 'B' towards 'C'. Considering a fault in the section 'B' & 'C the relay at 'B' towards 'C should act earlier than the relay at 'B' towards 'A'. These two are contradictory requirements. This will be the case throughout the ring i.e. at all S.S. at B,C, D and E in sketch above. The requirement can be achieved if all the relays are made directional i.e. relays made to respond for currents to flow out of the bus into the feeder.

The directional relays have additional unit, in the simple O/L relays described above, known as directional unit. This additional unit on operation closes the circuit of the lag coil in the non-directional O/L relay. This means only when the directional units has operated, the O/L or E/L elements operate to trip the faulty circuit.

In the static relays (of directional nature) tripping logic is developed using the directional check indicated above.

Distance Protection :

In modern power systems where huge quantities of power is transmitted on EHT lines and several generating stations are interconnected forming into a grid; over current protection can no longer be employed as large time delays have to be kept on OCBs nearer to generating stations which is undersirable. Transmission lines, therefore require high speed relays with greater selectivity. The type of protection used is the distance protection.

a) Principle of Operation :

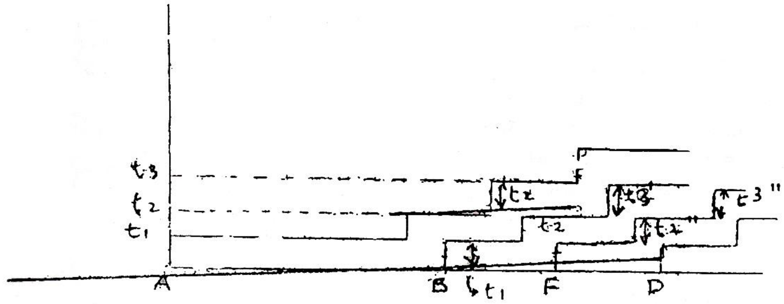
Distance relay compares the currents and the voltages flowing in a feeder at the relay location. It is an Voltage restraint over current relay i.e. the operation of the relay is restrained by the Voltage while actuated by the current. At the time of fault, the restraining force and increase in the operating force of the relay. In its simplest from the equation at the balance point is given as :

$$K_1V^2 = K_2I^2 \text{ or } V / I = \sqrt{k2 / k1} = \text{constant}$$

The relay is on the verge of operation at a constant value of V/I ratio which is expressed as the impudence seen by the relay. Since the impedance seen by the relay is proportional to the length of the line (under fault condition) from the relay location to the fault, the relays are also called “distance relays”.

b) Time distance characterization and R-X diagrams :

i) Operating characterizations with distance or impedance on the X-axis and time of operation of the relay on Y-axis indicate the time – distance characteristics. These are useful in determining the gradation of relays in the various sections both in respect of impedance reaches and time gradation.

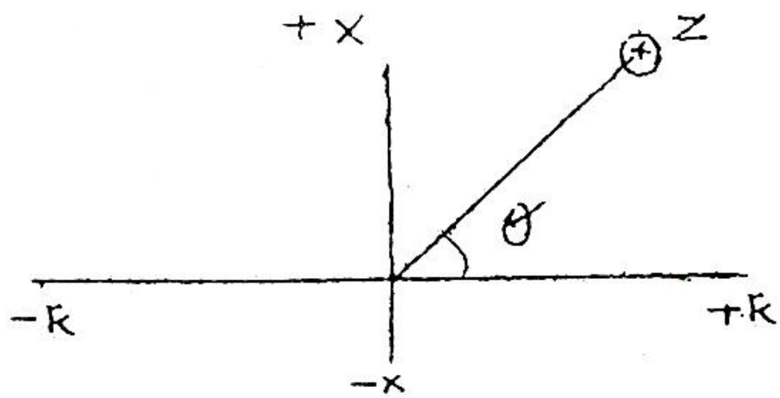


(please note t2 and t3 need not be same for all the relays)

ii) R-X diagram :

For clear understanding of distance relays and insight of R-X diagram is a must. The "R" "X" represent the resistance and reactance on the graphic plane "X" are "Y" axis.

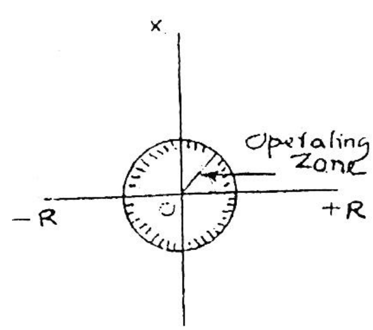
The voltage, current and phase angle between voltage and current at any instant and location can be ploted on R-X diagram with R=V/I Cos O and X=V/1 Sin). A straight line drawn from the origin to a point on R-X plane represents 'Z' measured counter clockwise from +R axis to Z.



c) Characteristics of Various Distance Relays on R-X Diagram

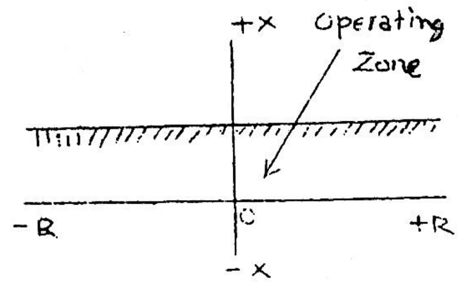
i) Under impedance relays:

The under impedance relay has a circular characteristic on R-X diagram with "origin" as centre. The area of the circle with 'z' as radius its operating zone.

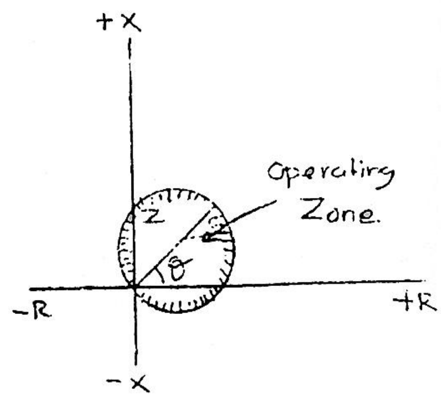


ii) Reactance relays :

The characteristic of the reactance relay on the R-X diagram is a straight line parallel to R-axis, at a distance 'X' set on the relay. The relay operates for the value less than 'X' set on the relay.

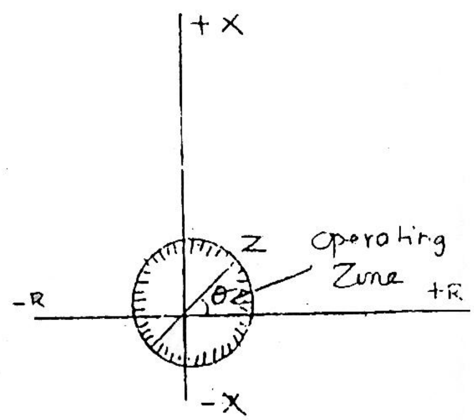


iii) Mho relay :



The operating characteristic of the Mho relay is a circle passing the origin and the diameter of the circle being the impedance 'Z' set on the relay. These relays have maximum reach at a particular angle from R-axixs and this angle is generally termed as M.T.A. (Maximum torque angle) or R.C.A. (Relay characteristic angle). As the operating characteristic being circle and passes through the origin, the Mho relay is inherently directional impendence relay.

iv) Offset Mho relay :



The operating characteristic of offset Mho relay is similar to Mho relay except that it has a small coverage in the third "quadrant" in R-X diagram. The forward reach of the relay is 'Z' at an angle y, set in the forward reach (1st quadrant)

v) Comparison of the characteristic of various relays :

Consider the location of the relay at origin and with the above characteristics in mind, we can say that the under impedance relays and reactance relays are operative for a fault behind the bus while the Mho relays are non-operative.

To make these under impedance and reactance relays directional, we have to use additional directional relays in conjunction with these relays. The offset Mho relay normally used for bus faults with delayed time of operation and for power swing blocking purposes, discussed later.

d) Components of Distance Relay Schemes :

Having studied in brief the characteristics of the various distance relays, let us consider various parts of a complete distance scheme. Essentially the distance schemes consist of the following four elements.

i) Starter relays/Fault detectors
ii) Directional relays
Hi) Measuring relays
iv) Time Delay relays

i) Starter relays :

These are primarily to detect the faults and put the other elements into action. We have in our system various types of starters (fault detectors) for distance relays for example; over current, under impedance and Mho relays. These will supply necessary Voltages and currents to the measuring relays and start the time delay relay.

ii) Directional relays :

If the starters are of non-directional such as over current or under impedence starters in the distance relays they pick up for faults behind the bus if the reach is possible and mal-operate. The directional relays will permit tripping only if the fault is in the required direction even if the starters pick up for faults in the reverse direction.

iii) Measuring relays :

The relays are normally used to complete the trip circuit on operation i.e. ii the fault happens to be within the zone of measuring relay. Normally only one measuring relay will be provided in the scheme. The Voltage and Currents are switched over the measuring relay depending upon the type of fault (R-N, Y-N, B-N, R-Y, Y-B or B-R) on the operation of corresponding fault detector. In certain schemes there will be as many measuring units as many different types of faults and different zones needed. Thus for example a 3 zone relay there will be 1 8 Nos. of measuring units for 6 kinds of faults namely R-N, Y-N, B-N, R-Y, Y-B and B-R. This scheme is known as **"unswitched scheme",** while the former i.e. with only one measuring relay, to be switched over to different types of faults, is known as "Switched Scheme".

iv) <u>Time Delay Relays</u> :

These relays are started by the starter relays or fault detectors to provide time delays for necessary gradation. In case of switched scheme, after the lapse of the time set on the time delay relay, the reach of measuring relay is extended to next reach. In case of unswitched scheme the tripping of the breaker takes place in the corresponding zone after the lapse of the time set.

e) Factors Affecting the Operation of the Distance Relays :

I) <u>Fault resistance</u> :

Fault resistance has tow components, the resistance of the arc and resistance of the ground. The effect of fault resistance on measuring impedance relays is to make them measure higher values. The faults at the end of the first zone are likely to be cleared in the second zone and time and those at the end of second zone in the third zone time.

M) <u>Effect of Infeed</u> :

When a fault occurs on the adjoining section (i.e. beyond the other end bus) and to the other end bus another feeder connected also feeds the faults, the relay measures more impedance than the corresponding to the fault distance. Thus the relays see such faults as if the faults are farther away. This is termed **<u>"Under reach".</u>** Under reach results more time delay.

<u>iii) Effect_of_current branching</u> :

When a fault occurs beyond the other end bus on one of the parallel feeders, the current carried by relay is more than the current fed into the fault due to current flowing in the healthy parallel feeder. This means relay measures less impedance and sees the faults as they are nearer. This is termed as "over reach" and its effects on the distant relay is that it may act quickly and loose selectivity.

iv) <u>Power swings :</u>

Power swings are surges of power such as those appear after removal of a short circuit OR those appear on connecting a generator to its system when the two are out of phase. When the machines are going out of step their internal voltages are out of phase and heavy power will flow among the machines. Approximately at mid impedance part the voltage collapses to very low value while there is heavy current flowing. The distance relays enroute will experience 3 phase fault condition and falsely operate to trip.

To avoid such an operation Power swing blocking relays are used to block the distance protection. In case of a fault the transition from load impedance to fault impedance is sudden while in case of power swing, impedance transition is slow. Most of the power swing blocking relays use this principle for operation and block tripping.

v) P.T. fuse failure :

In a healthy system, if the voltage circuit fuses (P.T. fuses) are accidentally removed *or* P.T. fuses are blown off, the restraining force in the distance relay is -educed/lost and the relay operation to trip as if there is a fault on the feeder. This condition is prevented by the use of P.T. fuse failure relay which monitors the fuses continuously. If fuse blows off the relay operates to open the trip circuit of distance relay and gives out audible alarm indicating P.T. fuse failure.

TRANSFORMER PROTECTION

The transformer is subjected to the following faults :

1) Overloads and External Short Circuits :

All fault conditions produce mechanical and thermal stresses within the transformer windings and the connecting bus bars. Overloads can be sustained for long periods; the limit being the temperature rise in the windings and the cooling medium excessive or continuous overloading result in deterioration of insulation leading of failure. It is usual to provide an alarm for winding and oil temperatures at set values. The normal practice is to cut down the load on the transformer till temperature falls down to a reasonable level.

External short circuit currents are limited by transformer reactance and the duration of transformer sustaining fault current depends on the magnitude of the fault current and the reactance of the transformer.

2) Terminal and Winding Faults :

These are faults within the zone of protection of the transformer and require prompt clearance as the resultant stresses are disruptive and may cause damage due to fire. The majority of the internal faults are the faults occurring within the winding like winding to Earth or outer-turn shorts.

3. **Incepient Faults** :

Incepient faults are internal faults which do not result in any immediate hazard. However if they go undetected, they may develop into a major fault. The major faults are core faults due to failure of insulation between laminations and failure of oil circulation due to loss of oil or blockage. In either case over heating occurs.

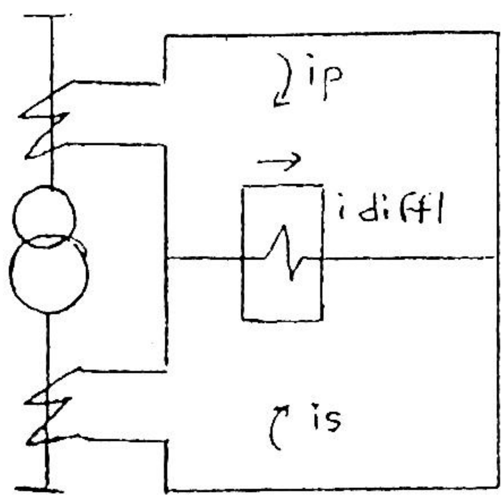
TRANSFORMER PROTECTION SCHEME

1. Plain over current and Earth fault protection utilising IDMT over current relays to protect the transformer against the effects of external short circuits and excess over loads. The current settings must be above the permitted sustained over load and below the minimum short circuit current.

2. Differential Protection :

The differential system covers most of the winding and terminal faults. The principles of operation is as follows :

Assume (for explanation sake) a power transformer with the same vector connections Delta - Delta or Star - Star and a transformation ratio of unity. Then the currents on primary side are indentically equal to the currents on the secondary side though they are not electrically linked. If identical current transformers are used on primary and secondary; the secondary currents are equal at every moment. When connections are given as shown in the figure aside,



the net current flowing through the relay is $I_p - I_s$ and as they both are equal in magnitude and direction the actuating current is zero. The relay, if. set to act for a small actuating current of I_o it will act for a difference in primary and secondary currents which occurs only in the event of an internal fault in the transformer for a through fault the relay is in operatives as $I_p - I_s$ is always zero.

In the case of transformers with transformation ratios more than unity and different vector connections of windings I diff. is obtained by employing CTs with appropriate ratios in primary and secondary and also with, the help of auxiliary matching CTs in order to make the secondary currents equal in magnitude and phase under normal operation.

When a power transformer (without tertiary) is not equipped with tap change equipment and the current transformers on each winding are properly matched both electrically and magnetically, an unbiased relay may be used in the differential scheme. When the mismatch exists between the current transformers due to ratio difference or because of difference or because of difference in their magnetic characteristics or by the operation of the O.L.T.C. (upto variation of 25% of voltage) an unbiased relay must have a setting above the maximum spill currents under maximum thought fault conditions. This setting can be considerably reduced if a relay with bias winding is used. A relay with biasing will be most stable for a through – fault condition and at the same time very sensitive for faults inside the transformer.

The differential relay is set to trip both HV and LV breakers of the power Transformers.

3. Gas operated (Bucholz) relay :

The protective device is used for oil immersed transformers with oil conservators. The operation of the relay is based the principle that oil gets dissociated locally whenever faults leading arcing as high temperatures develop locally. All kinds of faults occurring within the tank will lend to operation of this relay. They may be :

1) Turn to turn short circuit in the windings:
2) Breakdown of insulation of a winding to earth and breakdown of insulation between core lamination etc.

Buchloz relay consists of Two floats one above the other located in casing. Each consists of mercury float which when falls down makes a contact. The relay is fitted by its side flanges in the piping connecting the oil conservator and the transformer tank. Normally the relay remains filled with oil and both the floats are in upward position. The top float when makes the contact gives an alarm and the bottom float trips the HV & LV OCBs of the power transformer when there is a minor fault in the transformer gas collects slowly at the top float displacing the oil and causes the float to sink to make the contact to give alarm. When the fault is server the escape of gas with oil into the conservator will be violent and float also which closes the contact to trip both HV & LV breakers.

The analysis of the gas collected etc., is fully explained in the 'Transformers' booklet.

D.C. SYSTEM

As already mentioned earlier, the D.C. station battery forms the heart of the sub-station. Failure of D.C. supply may lead to unimaginable consequences. Regular maintenance of cells and frequent check of circuits for any leakage is the most important duty of an operating engineer.

Brief description of cells, maintenance needed, common defects with remedies are given below :-

Healthy D.C. supply is part and parcel of a protection scheme.

Batteries :

Batteries used in Sub-stations are secondary batteries also known as accumulators. A secondary battery is an apparatus capable of receiving electrical energy and giving it out again when required. The electrical energy received during charge is transformed into chemical energy and a large portion of the later is recoverable in the form of electrical energy during discharge. There are two types of cells commonly used.

1) Lead Acid type
2) Edision type (Nife)

The later are of old type used alkali as electrolyte and are now almost absolute. Lead Acid cells are used most commonly now in the Board and the same is discussed in this booklet.

The essential parts of an accumulator are the plates (electrodes), the electrolyte and the contained in which they are placed.

Lead plates 1 and 2 serve as electrodes. The positive plates are made of pure lead with a ribbed or corrugated surface. The negative plates are of box. form containing a filling of porous (sponge) active material consisting of lead oxides. In a charged cell the surface of the positive place will consist of lead peroxide (brown in colour while the active material in the negative plate will be in the form of lead (light gray in colour-porous). The container, will be either of glass or moulded plastic, hard rubber etc. The plates are mounted in the containers by shoulders of plates to permit them to be hung from the containers. Short circuits between plates are avoided by providing separators made of ebonite between them.

Generally the number of negative plates exceed by one over the number of positive plates to prevent buckling of the plates because active material works under the same conditions on both side of each plate.

A lead cell after charge is capable of giving out electrical energy by virtue of the chemical reaction between lead (negative plate), sulphuric acid (electrolyte) and lead peroxide (positive plate). During discharge a part of the sulphuric acid in the electrolyte is reduced and lead sulphate is formed on the plates. This causes lowering of cell voltages and Sp. gravity of electrolyte. During charge the reverse process takes place and the active material on the plates is desulphated and the specific gravity and cell voltages are resoted. When the desulphating is complete; further charging produces electrolysis is water in the electrolyte and gas is given off at both the plates. The cell is then fully charged.

The life of a battery is not to be reckoned as a period of time; but as the number of cycles of charges and discharges. A battery maintained on trickle charge and seldom used should last indefinitely.

Electrolyte is prepared from pure sulphuric acid (diluted sulphuric acid). The specific gravity of electrolytic in a fully charged cell should be between 1210 195. The specific gravity falls by 50 pts. when fully discharged.

The terminal voltage of a fully charged cell is of the order of 2.05 V. As a cell becomes discharged the voltage across its terminals gradually dips. Discharge of a battery should not carried on when cell voltage reaches 1.8 V. If continued further its utility deteriorates sharply and suffers complete breakdown.

The efficiency of a battery is the number of ampere hours during discharges expressed as a percentage of the number of ampere hours during charging.

The capacity of a cell is the number of ampere hours it is capable of supplying under certain conditions. For example when a battery is said to have a capacity of 400 Ampere hours; it means that when it is discharged at a certain rate in amperes till such time the terminal voltage of each cell drops to 1.85 V; the product of current in amps and time in hours is 400.

The capacity is generally calculated on 10 hrs. rate (i.e.) in a 400 Ampere hour capacity, the cell voltages drop to 1.85 V. when discharged at 40 Amperes for 10 hrs.

When and cell is gassing most of the energy put in is wasted. The routine procedure for charging are :

1) Trickle Charge ; 2) Boost Charge

1) Trickle Charge:

Batteries should be maintained on a trickle charge for avoiding suphation. It is found possible to maintain the battery in good condition by a steady trickle charge just sufficient to counteract the sulphating action of the electrolytic. The amount of this charge is about 2% of the 10 Hrs., capacity spread over 24 Hrs. (i.e.) for a 600 Amp. battery the rate of trickle charge works out to (2x600) / (100x24) = 0.5 Amps.

To this figures the amperage due to regular duty on the battery is to be added.

2) <u>Boost Charge :</u>

This should be done as and when

i) There is fall in specific gravity.

ii) As per the periodicity specified by the manufacturers. This charging should be done by means of generator set in case of large capacity batteries and a regular charge equipment in case of small batteries.

The charging should be done till

i) All cells are gassing and all plates healthy;

ii) Voltages and specific gravities become constant at their optimum values.

Topping Up :

The electrolyte in the cells should be half an inch above the top edges of the plates and maintained as such by adding distilled water. The water should be forced in at the bottom of the cells by means of syringe so that it mixes thoroughly with the electrolyte. The battery should be inspected thoroughly at lease once in a week. The cells need daily attention.

It is necessary that all cells in a battery contain almost the same specific gravity of electrolyte as they take uniform charge. The difference should not be beyond 20 pts. If particular cells have more specific gravity, electrolyte should be removed (taking car to see that plates are not exposed) by means of a pipette and distilled water added so that all ceils are brought to uniform level in specific gravity and then kept on boost charge if necessary.

Common Mistakes and Consequences :

i) **Too little charging** :

Negative plates coated with deposits, positives appear light in colour, Cells badly sulphated, white sedimentation, low, specific gravity - give boost . charging till gassing. In extreme cases replacement of plates become necessary.

ii) **Too much charging** :

Positives get darkened, accumulation of spongy lead on top edges of negatives - charging rate should be reduced and watched.

iii) **Running battery too low :**

Grids of negative darkened active material expanded and causing bulging positive plates sulphated. Dull grey sediment under negatives.

iv) **Charging at too high a rate :**

Positive plates get buckled, sediments of course positive active material and negative material under respective plates.

STATIC RELAYS IN MODERN POWER SYSTEM PROTECTION

Introduction :

An electrical power system should be designed and managed to deliver efficiently and economically to the points of utilization with maximum reliability and safety of equipment. An uncontrolled release of energy proves disruptive and may cause severe damage to the system. Rapid fault clearance is essential for protecting equipment and lines from severe damages. It is also essential that minimum length of section is isolated so as not to cause inconvenience to others.

Faults in modern power system are liable to be very expensive and protective relaying is employed to locate the fault and open out correct switchgear to isolate the faulty circuit.

Reliability, sensitivity, selectivity and high operating speed and the essential qualities of a protective year. The parameters kept under check are mostly current, voltage, phase angle or direction and frequency, of course, sometimes a combination of some of these.

Advantages of Static Relays :

The need for more sensitive, faster and reliable protection coupled with need for miniaturisisation with rapid growth of power systems both in complexity and fault levels lead to advent of static relays.

The first wholly static relay offered for sale is said to be electronic MHO relay produced in 1948 by the General Electric Company, U.S.A. This did not find enough market as it suffered from proven reliability and lack of confidence in electronic components at that time.

3 phase 3 step distance relay was put into service in 1950 and was reported to be good but this was not put to mass production because of the usage of electronic tubes which were considered unreliable. But carrier equipment using electronic tubes was accepted and widely used for most important lines because carrier relaying was the only practical means by which simultaneous tripping of switchgear at both ends of the long lines could be affected and as there was no alternative except usage of pilot wires which were highly uneconomical above a distance of 1 5 miles.

The first static relay using transistors was an inverse time over current relay in 1959 but the induction relay was not replaced- It was then thought of that the best field of application of semi-conductor relays with their speed, accuracy and sensitivity was differential relay and distance relay. The first commercially produced distance static relay was a transistorised version of the MHO relay. I had a speed of half cycle and this is achieved by employing a Thyristor eliminating the operating time of a tripping relay.

STATIC RELAYS (VS) ELECTROMAGNETIC RELAYS

In electromagnetic relays the measurements are made by means of electromagnets which exert force on an armature carrying contacts. In static relays the measuring element reads and compares the parameter by a stationery network which gives a tripping signal at the 'threashold value' to a tripping device. The measuring element comprises comparators, level detectors, filters and logic circuits. The main advantages are faster operations, low maintenance, low power consumption, wide range of characteristics, compact size, reliability and usage of logic circuits.

ELECTROMAGNETIC (VS) STATIC
(Certain data)

Sl. No.	Funtion	Conventional relay Thyristor	Without Thyristor	Static Relay With Thyristor
1.	Input	1-3 w	10 mw	40 mw
2.	Switching capacity	30 W	10 W	100 W
3.	Power gain	8 – 32	1000	500
4.	Continuous current rating	5 A	1 A	1 A 5 A
5.	Time	10 m sec	20 N. sec	50 N. Sec.
6.	Effect of vibration	Bearing effected	No effect	No effect
7.	Amb. Temp range	-5 to 70 C compensation	Needs compensation	Needs
8.	Effect of pollution	Yes	No	No
9.	Testing	Easy	Difficult	Difficult

Advantages of Static Relays :

1.Speed:

The high speed of operation of semi-conductor devices enable the desired low fault clearing time

2. Long life and high resistance to shock and vibration.

3. High resetting value and absence of overshoot as there is no thermal storage or mechanical inertia.

4. In the absence of contact troubles and bearing frictions truthful characteristics can be achieve.

5. Flexibility of semi-conductor circuitry facilities development of new, versatile and improved characteristics. Ex. In electromagnetic relays the characteristics is a direct function of B.H. curve making it difficult to obtain consistency between individual relays. In static relays the characteristics is based on R.C. circuit which can be precisely controlled.

6. In the case of distance relays with semi-conductor it is possible to obtain impendence characteristics other than the traditional sectors of circle. They are accurate over a wide range of fault currents and line lengths. Operating time is almost constant and less than one cycle with 90% of the ohmic setting for almost all fault conditions.

7. When integrated circuits are used, there will be a massive reduction in size .of complex circuits as components are inter-connected on a printed circuit Board.

8. The case of providing amplification enables greater sensitivity to be .obtained.

9. The increased availability of semi-conductor circuitry in integrated form (ICs) greatly reduces cost, permits greater reliability and also duplication of protection using two dissimilar principles so that possibility of failure of both is remote.

10. The very low burdens permit usage of smaller and some-times simpler equipment for testing. Individual modules can be tested from the points brought out to the front of module or by inserting the module into a connector socket in the test case.

11. Low energy levels permit miniaturisation.

PROBLEMS ENCOUNTERED WITH STATIC RELAYS

1. **Effect of Temperature** : Semi-conductors are considerably affected by change in temperature. All parameters get affected and the most significant problem is the rise in leakage currents caused by increase in temperature.

2. Semi-conducts are also affected by light but this can be completely eliminated by using light proof enclosures.

3. **Vulnerability to voltage spikes** : Voltage spikes are transient over voltages of very short duration (Micro seconds) whose appearances in a transistor relay circuit may cause wrong operation and if is large enough may cause damage to the components especially where ICs are used.

Transient over voltages are caused by sudden switching ON and switching OFF of loads in a nearby circuit. They may appear in case of lightning through capacitive coupling between wires and transformer windings. These may also appear as a burst of high frequency over voltage coming from an arc on the power system to the inter capacitance of voltage instruments transformer windings, or lightenings of instruments due to faults etc. These transisent due to faults etc. These transients cause negligible trouble in electromagnetic relays as (a) their level of insulation is too high for them to be damaged by voltage spikes (b) the inertia of the armature prevents wrong operation due to such a short impulse.

4. **Lack of Technical know-how:** At present, enough expertise is not available and rectification is limited to replacement or parts as a whole. The maintenance personnel are to be trained and Boards fully prepared for adoption
5. Their introduction straight away at existing sub-which lack necessary infrastructure and which are constructed before the introduction of static relays is causing many problems like maloperation, extensive damages to relays etc.
6 The static relays cannot displace certain fields such as multi contact attracted armature relays and inverse time current relays. The electromagnet, to under parts will remain of a very long time indeed because static relays are more complicated and more expensive. A simple attracted armature relay can be

manufactured cheaply and will operate in 10 m seconds and carry sufficient number of contacts to trip two breakers and control two auxiliary circuits.

7. The cost of providing safety towards hazards for static relays against voltage spikes, interferences, noise pollution, temperature (air - conditioning) etc. is also to be kept in view.

8. As these are recent additions they suffer from the lack of 'proven reliability over decades' when compared to electromagnetic relays which are in service for the past 70 years.

RECENT DEVELOPMENTS IN STATIC RELAYS

The largest trends in static relays indicate the following :

a) Miniaturisation :

Due to change over to integrated circuits, the measuring parts have become compact.

b) Increased reliability and reduced price.

c) Use of digital technique is place of analogue techniques.

d) Use of new type of transformers instead of conventional CTs and PTs. Development of opto electric transformers is in progress.

e) Increasing use of digital computers in power system protection. A closer co operation of static relays and digital computers for relay protection.

f) Development of programmed relays instead of fixed wired relays.

SOURCES OF TRANSIENT VOLTAGES AND REMEDIES

I. Direct Effects :

a) Breaking of an inductive circuit.

b) Making of capacitive circuit.

II. Induced Effects :

a) Inductive coupling, wherever wires containing AC or DC input quantities to a static relay (which may be in mA) are in the same cable or in close proximity to wires carrying high currents (tens of Amperes) such as circuit breakers control wires. The sudden starting or stopping of the heavy control circuit ' can induce transient over voltage in the static relay circuit, which can cause wrong operation of the relay and damage the transistors.

b) Capacitive Coupling :

Voltage spikes and high frequency AC in primary circuits can reach the static relay circuit via the capacitance between the two circuits. The most effective path is the inter winding capacitance of instrument transformers and auxiliary transformers. Although such a small capacitance presents a very high impedance to currents of system frequency, it would present a relatively of impedance to h.f. or to a steep wave, spikes generated in the primary circuit by faults or system switching.

c) Effects due to faults in power system :

Where earthling of CTs and PTs is done in the switchyard, circuitry and/or DC supply a static relay are earthed at the relay panel at some distance from the swtichyard, a fault near the station may cause a difference of potential of several KV between the two earth points and this voltage can appear between the AC and DC circuit of the relay.

Another source of voltage transient is the sudden reduction voltage caused by a phase to earth faults. This sudden voltage change represents a very steep voltage surge which can be through the interwinding capacitance of a nearby CT and damage the relays.

d) Effect due to Lightning :

Lightning can also cause very high voltage gradients in the earth and the presence of relay in the residual circuit of the CTs can offer a. very high impendence to the very high frequency lightning current, causing an over voltage to appear between grounding points of the CTs and relay case.

e) Effect of system switching :

When an air break switch is closed, the circuit is made initially by a flash over between contacts at the first voltage peak (i.e.) at the moment when the change on the system capacitance is near its maximum. This initiates damped oscillations at 0.5 to 2 MHZ, some of which are amplified by resonance and supported by subsequent restrikes and the harmonics in the arc current. The worst case, is where a capacitance PT is discharged into other capacitances of an EHT station, such as CTs etc., through a short length of bus bar by the closing of an isolator switch. The closing of a circuit breaker is much less dangerous. The frequency of the oscillation is sufficiently high to pass easily through the inter-winding capacitance of CTs and PTs and can appear as many 'KV' at the terminals of a relay.

Transient over voltages may be reduced to safe values by grounding a the relay and, the shielding of the secondary AC leads to the relay. A further improvement can be provided by an earthed copped foil screen between the windings of the CTs and PTs.

f) Effect of switching inside the relay :

A current or voltage spike has step leading edge which acts like a very high frequency, hence very small inductances, such as wire wound resistors or even the circuit wiring present a very high reactance (both self and mutual) to a current spike. Further more, a very small capacitance such as that between parallel wires small capacitance such as that between parallel wires or between the winding of a transformer and its core, offers a very low impedance to voltage spikes.

A voltage spike however, is dangerous only if it appears in the non-conducting direction of a diode or a transistor. A voltage spike in the DC supply would appear in full across the diode and could break it down. A similar conditions could happen in transistor circuit.

PROTECTION OF STATIC RELAYS AGAINST SPIKES

Interference form voltage or current transients is either electromagnetic or electrostatic. The former can be minimised by arranging the wiring in twisted paths and in some cases, by magnetic screening. The later can be reduced by earthed copper screening. The interference signal that gets through can be suppressed or diverted. Any voltage or current transient can be absorbed by the appropriate connection of surge diverting devices such an non-linear resistors, series inductance, parallel capacitance etc., but proper arrangements of the relay circuit and supply leads can minimise the surge diverting equipment needed.

It is necessary to provide spike divertors which are similar in action to surge divertors in power systems to limit transient over voltage by diverting surge currents. These are to be provided for DC and well as AC circuits such as potential supply to a distance relay. Also suppressors such as RC suppressors across the contacts to prevent electrostatic interference from contact operations and suppress the inductive surge voltage are to be provided.

Conclusions :

1. Although static relays offer many advantages over electromagnetic relays, they can be regarded as a valuable addition to the family of protective relays but not for total replacement of electromagnetic relays at all costs.

2. While going in for EHV lines of 400 KV and above, the cost of manufacture of CTs of conventional type may become prohibitive and linear couplers may become impractical. Research is being conducted into the possibility of transmitting optical accoustic or radio signals to an amplifier at earth potential to avoid problems of insulation. This sensitivity can be achieved by static comparators with amplifying properties.

3. Static relays are bound to make much inroads into the field of protective relaying in modern power systems due to their achievement of miniaturisation and future generating stations, future substations, swtichyards, controlroom etc., are all to be designed for providing the extra infrastructural facilities to accommodate these sensitive and sophisticated devices.

4. Training of personnel in advance to take over maintenance of these devices is essential.

5. It may be necessary to introduce the static relay with a cautioned approach, first using them in series with protective schemes of proven reliability over years, watch their performance carry out the improvement needed and perfecting them in all respects. Independent employment of them should be resorted to only after perfection is achieved both in the devices as well as the installation where they are used.

6. Proper protective measures for static relays are to be incorporated simultaneously.

TRANSFORMERS - CONSTRUCTION - CARE & MAINTENANCE

Introduction :

In the following notes the construction, operation, maintenance and causes of failure of transformers are explained briefly. Specific stress is made on what is likely to happen if a particular item of maintenance is not done in time.

The power generated at various power stations is stepped up and transmitted on extra high tension lines of 132 KV or 220 KV. The voltage is again stepped down 33 KV or 11 KV at various distribution transformers where voltage is stepped down to 440/440 V before supply is made available at consumer's installations. It is roughly estimated that the power generated is transformed 3 or 4 times before it reaches a consumer's installation. Generally the total transformer capacity in a system is 10 to 12 times its generating capacity as standby capacities have to be provided at various stages. In the distribution net work a transformer is the most common of all electrical equipment.

1 THE MAIN FEATURES OF A DISTRIBUTION TRANSFORMER ARE :

1.Magnetic circuits : Comprising limbs, Yokes & clamp structure.

2.Electric circuits : The primary & secondary winding insulation & bracing devices.

3. Terminals : Tappings, tap switch , insulators, i.e. Bushings & leads.
4. Tank, Oil Cooling, devices, Conservator Breather and ancillay apparatus.

CONSTRUCTION FEATURES :

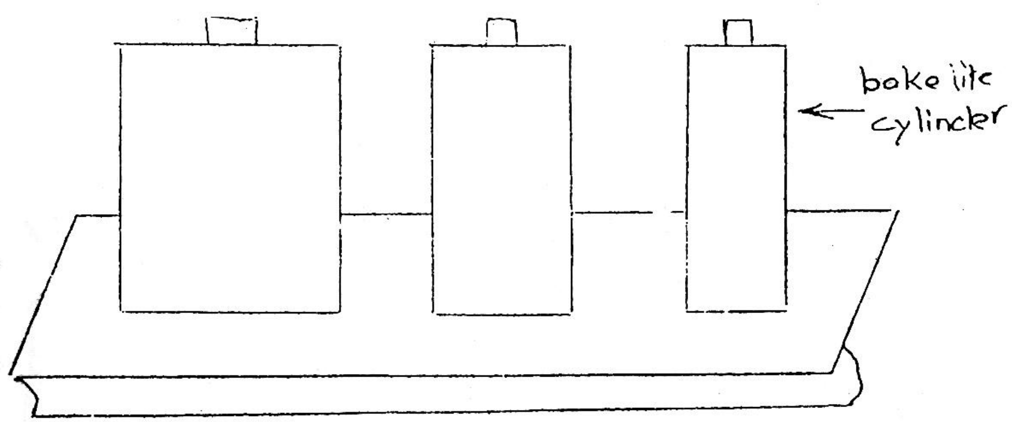
A) CORE :

Special alley steel of high resistance and low hysterisis losses is used in laminated form. The laminations are insulated between one another. The laminations are enamelled or sprayed (after punching) with a mixture of flour chalk and water and then baked. No burns are allowed as they establish contact between adjacent plates. In building the core high pressure is used to minimis air gaps between plates to avoid losses and also to minimise noise during operation.

The core plates are fixed by clamping devices. The core bolts are insulted. The present trend is to utilise CRG steel laminated cores.

B) H.V. & L.V. WINDINGS :

The L V and H.V. windings are generally circular and concentrically arranged. when a transformer is opened the H.V. coils are seen first. When the H.V. coils are lifted the L.V. coils are seen. A typical picture is given below :



The L T coil is normally of copper strip insulated by manila paper. In between the L T coils and H.T coils placed concentrically; separator is used made of leatheried paper on bakelite cylinder. The H.V coils are normally of double paper covered or double cotton covered or enamelled copper wire of suitable guage wound in layers. In between layers presspan paper or manila paper is used for insulation. 2 to 16 Nos. of coils in each H.V. limb are used in which 2 are tapped coils.

Generally the gauges of wire used in H.V. coils are as follows :

1.	250 KVA	14 SWG	Copper
2.	200 KVA	16 SWG	Copper
3.	100 KVA	18 SWG	Copper
4.	75 KVA	19 SWG	Copper
5.	50 KVA	20 SWG	Copper
6.	25 KVA	22 to 24 SWG	Copper

The insulation between HV and LV windings and between L.V. windings and core comprises of bakelite papers, cylinders etc.

The connecting leads between coils and from coils from tapping switch are insulated by sleeves.

C) BUSHINGS :

upto 33 KV voltage ordinary procelain bushings are used. Above this voltage condenser and oil filled terminal bushings *or a* combination of both are employed.

D) COOLING :

The cooling of a transformer is carried out by the following methods.

ON :

Majority of transformers are oil immersed with natural cooling i.e. the hea developed in the cores and coils is passed on to the oil and thence to the tank walls from which it is dissipated. This has an advantage that moisture cannot easily affect insulation.

OB :

In this method the cooling of an ON type transformer is improved by blast over the outside tank.

OFN :

The oil is circulated by pump to natural air coolers.

OFB :

For large transformer artificial cooling may be used. This method comprises a forced circulation of oil to a refrigerator where oil is cooled and again let into the transformer.

OW :

An oil immerser transformer of this type is cooled by the circulation of water in cooling tubes.

E) BUCHOLZ Relay :

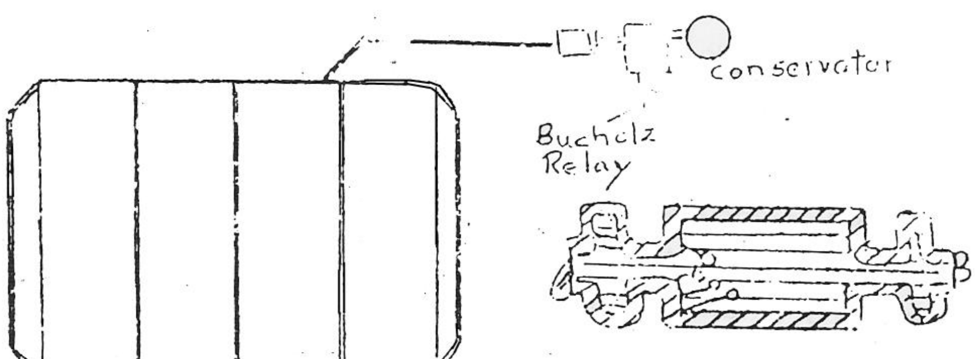
The Bucholz relay is a protective device timately connected with the structure of the transformer and the non-electrical effects of fault conditions. This system is applicable to oil immersed transformers.

The principal is simple and depends on the fact that transformer breakdowns always preceded by the more or less violent generation of gas. A broken Dint, for example produces a local arc, and vaporizes the oil in the vicinity.

An earth fault has the same result. Sudden short circuits rapidly increase the temperature of the windings, particularly the inner layers, and pocketed oil is there vaporised. Discharges due to insulation weakness (eg.) by deterioration of the oil, will also cause oil dissociation accompanied by the generation of gas. Core faults such as short circuits due to faulty core clamp insulation, produce local heating and generate gas.

This generation of oil vapour or gas is utilised to actuate a relay which in turn signals the fault and cuts the transformer out of circuit wherever breakers are provided.

The relay is an hydraulic device arranged in the pipe line the transformer an the separate oil conservator.



Bucholz Relay

The vessel is normally full of oil. It contains two floats of b1 & b2 which are hinged so as to pressed by their buoyance against two steps. If gas bubbles are generating the transformer due to a fault, they will rise and traverse the piple line towards conservator and are trapped in the upper part of the relay chamber thereby displacing he oil and lowering the flat B1 .This sinks and eventually makes the mercury contact C1 which *closes* an alarm circuit to give Bucholtz alarm.

When the fault is severe enough the lower float B2 gets tipped up to make mercury contact C2 which closes the trip circuits of the IN & OUT breakers of the transformer.

When this alarm operates, the operation staff have to check up whether the alarm is freakish or genuine. It can be examined whether there is gas collection in the Bucholtz relay chamber through the inspection cover. Switch off the Transformer if there is no gas collection and the alarm is freakish and after retifying the circuit the transformer, can be taken into service.

If however there is gas collection the gas can be collected for sampling by opening the upper stop cock into a test tube and if the gas is passed through silver nitrate solution a coloured precipitation is formed and the following table give the probable faults.

Colour	**Cause**
White	Destroyed paper
Yellow	Damaged wood
Black or Grey	Dissociated oil

F) Breather :

The transformer breathes out whenever it is on load or as temperature rise: and it inhales fresh aim from outside through the breather when temperature comes down Just as the nose in a human body contains media to eliminate dust and injurious elements going into the human body the breather contains 'silicagel' to Stop any moisture entering toe Warmer as the presence of any moisture is in jurious to the life of a transformer. The air bubbles through oil and then through a column of Silicgel is 'hygroscopic' i.e. it absorbs moisture readily. The silicagel which is blue in colour turns pink when it absorbs moisture fully.

When the colour turns pink the silicagel has to be reactivated by simple drying up over hot pans. There are other types of silicagel also as non-indicating type, non-reactivating type.

G) Vent Pipe & Diaphram :

The vent piple is an easy passage provided for oil to gush out whenever faults develop in transformer. This is only a safety device to avoid major damage he tank from bursting. The vent pipe is closed at the end by a Diaphram. In fact for some makes of transformers two diaphgrams are provided one at the bottom and the other at the mouth of the vent pipe. The Diaphram gets broken when pressure is developed in the tank and oil gushes out. It is to be ensured that this Diaphram is intact and air-tight as otherwise moisture may enter through this and cause damage to the oil in the transformer.

H) Conservator :

This is reservoir for oil. Whenever oil in the transformer contracts during low temperature the oil is drawn from this and when the temperature is high the oil expands and the excess volume of oil goes into this and is stored.

FUNCTIONS OF A TRANSFORMER :

The transformer is used wherever a step down or step up of voltage is required. The capacity of the transformer is the extent of power in KVA that can be passed through the transformer while it does the voltage transformation at the predetermined ratio.

The number of turns in HV and LV windings decide the voltage ratio.

Supposing the primary winding has NP number of turns and the secondary bindings NS number of turns the primary and secondary voltage VP and Vs area as follows ;

$$VP / VS = NP / NS$$

Therefore the number of turns on HV & LV windings decide the voltage ratio and the size of the winding wire decide the capacity of the transformer.

The tappings for distribution (i.e. for voltage variations to be obtained) are generally in 5 stages of -3, normal, +3, +6, and +9% over the rated voltage on secondary side. This is achieved by adjusting the number of turns in the High Voltage windings. From among the H.V coils certain of them are selected as tapped coils and the coils are tapped at desired turns and taken out. When the tap switch is operated definite number of turns on H.V. side get either included or excluded to give the desired voltage on the secondary side. This is achieved by means of a tap switch.

The tappings abnormally done on high voltage side as for the same power carried the current carried on H.V. side is lower. If Ip and Is are the currents in primary and secondary whose voltage V_p & V_s.

$$V_P I_P = V_s I_s$$

It is noticed that failure of transformers are also occurring due total changing. Some times tap changing switch is not operated fully; or even when is operated in full as can be observed from outside; the tap changing operation is not complete in all 3 phases inside the transformer.

The operation staff may do the following test after each tap change with off load switches : ... .

1. Megger test for continuity on H.T. side between all the phases. Delta primary gives wrong readings and cannot be relied as a confirmatory test.

2. Remove L.T. fuses charge the transformer and ensure equal voltages in all the 3 phases (i.e. between phase & phase & between each phase and neutral) before putting it on load.

Whenever alternate 440 V 3 phase supply is available apply the same to the H.T. bushings and measure the voltages on L.V. side and ensure them to be equal between each two phases and between each phase and neutral.

Incidentally one can know whether the desired step up or step down in voltage is achieved by the tap changing.

II Causes of Failure and Prevention :

From the study of the various causes of failures of a transformer it is easy to know what is to be done to prevent them. The various probable causes of failures and the preventive maintenance necessary are given below :

As explained earlier, the transformer mainly consitsts :

1. Magnetic circuits.
2. Electric circuits.
3. Insulation (Dielectric) terminals
4. Tank, Oil etc.

in any electrical plant, a failure in one part renders the whole equipment unfit for service.

The faults that may lead to a transformer failure can be mainly classified as follows and these often react on one another, It becomes most difficult to identify between the reason and the consequence. Most evidence is lost in the very nature of the failure of the equipment.

1. Failures due to mechanical damages (about 5% failures are on account of these and can be rectivied quickly if spares are available)
2. Failure due to poor di-electric circuit comprising of oil and deterioration of major insulation.
3. Failures due to damages in windings which include, coils, minor insulation, terminal gear (70 to 80% failures are on account of this).
4. Failures due to defective magnetic circuits (Cases are negligible)

All these may occur due to :

a) Defective manufacture (poor design, faulty materials and bad workmanship)
b) Defective or abnormal operation (careless dry out, careless installation, inadequate supervision & maintenance and sustained operating conditions).

<u>Failures due to mechanical damages.:</u>

These are generally (1) Oil leaks (2) flash over of bushings.

1. The welding of the main tank may be defective and also the fittings may be leaky. The causes oil to leak and cause heating of windings and a possible breakdown of equipment. Rough handling during transit may also contribute to

leaks. The gaskets etc., used at each of the flanges, fittings & main cover should be properly placed secure and uniformly tightened.

2. Deposits of coal dust, saline or chemicals on the bushings may cause a flash over. Applying of silicon compound or Metro arc compound as thin layer on the bushings results in increase of creep distance and protect the bushings from flash over due to such deposits. This has been successfully tried at an important SS like Coromandel Fertilizers 132 KV Substation. Where difficulty due to chemicals depositing on the Insulators was being minimized.

3. Wrong paralleling of transformers cause undue overloading of one of them. Transformers to be operated in parallel may preferably contain the same turns ratio of resistance to reactance voltage drops. Otherwise one of them may get unduly overloaded and heated up also resulting in a breakdown. It is important that the difference in impendence percentages of transformer to be paralled does not exceed 8 to 1 0% (maximum).

4. Sufficient place around a transformer to dissipate heat must be provided. It two transformers are kept close the surfaces may get lagged and the oil temperature increases endangering coil insulation.

5. Vapours at the top of an oil cooled transformer may be explosive. Bringing naked lamps at the places may cause damages.

6. In water cooled transformers, the tubes may get clogged and the oil may get heated up. They have to be therefore cleaned periodically.

7. Water may infiltrate into oil through the tubes due to corrosion. It is there better to use copper coils. Also the static pressure of oil must be maintained above that of water by means of pump working against a regulated valve.

Failure in Dielectric circuits:

1. Moisture entering the tank by "breathing action" of the transformer reduces the di-electric strength of the oil. This results in breakdown from coils or terminal lead to tank or core structures. The greatest danger is however the inter turn short in the coils.

2) Deterioation of oil may also occur due to prolonged overloading of the transformer. This action is aggravated by presence of copper and lead. When oil temperature increases, formation of sludge, water and acids is accelerated.

Safe values for oils :

Di-electric strength : 30 Kv for 1 minute (between gap of 4 mm or 0.178".) :

Acidity : Upto 0.7 M grs. /KOH per gram of oil satisfactory.

Above this value : Careful observation on the acidity value is to be made by frequent sampling. When this reaches 1.0; the oil is to be discarded.

3. During service certain amount of oil gets lost due to evaporation and oxidation. Periodical topping up of ail level with fresh tested oil is necessary lest the unit gets overheated.

4. Narrow oil ducts & improper ventilation reduce *the serviceable* life of a transformer. Coil insulation turns brittle and may get punctured on account of this.

5. Sometimes the clearance provided between phases is insufficient. Also insertion of press board barriers may aggravate as they may upset the dielectric stress to throw too much stress across the coil spaces and across the barriers.

6. Wooden ducts provided for taking the terminal leads over them should be properly dried. These may cause short circuit between tapping leads.

7. Suspension of foreign particles reduce the dielectric strength of the insulating oil and may cause a flash over resulting in serious breakdown of the transformer.

8. When the acdity value of the oil increases, it will promote oxidation of the metal parts and results in a breakdown.

Faults in Electric Circuits:

1. When moisture manages to ingress trough the fabric insulation of the coils, circuits between turns occur sooner or later. Impregnation of coils by

applying varnish so that it penetrates deep enough to the inner layers of the coils is to be ensured. Failures from this cause are most common.

2. Presence of sharp edges on the copper conductors may cause, a short circuit between adjacent turns when the transformer vibrates on load or when the windings are subjected to repeated electro magnetic shocks due to short circuit or switching surges as the sharp edges are likely to emerge out through the insulation and cause adjacent turns coming into contact.

3. One or more turns in a coil may get dislodged and a short circuit between them any result; when heavy external short circuit occurs and if the same is not cleared by fuses in time. Breakdown may not immediately occur but when the transformer vibrates on load with the dislodged coils; abrasion of insulation between adjacent dislodged coils may take place causing a break down.

4. Improper drying out and applying full voltage with poor I.R. values will result in failure of insulation between adjacent layers.

The safe I.R. values for a 33/11 KV Power transformers and a 11 KV/440 V Distributed transformer are given below :

The I.R. values in Megaohms are to be taken with a 1000 V Megger.

Temperature	33/11 KV Transformer			11 KV/440 V.Tr		
	HT to E	LT to E	HT to LT	HT/E	LT/E	HT/LET
60°C	65	25	65	50	25	50
50°C	130	50	130	100	50	100
40°C	200	100	260	200	100	200
30°C	above 250	above 200	above 250	above 200	above 100	above 200
	Nearer to infinity as can be read in a megger			Nearer to infinity as can be read in a the megger.		

*Whenever readings are taken at ambient temperature : The temperature also is to be noted and generally in our districts the temperature will be ranging from 30° to 40°c.

5. Sudden changes in load cause sudden expansion and contraction of copper and is likely to damage the insulation fabric.

6. Where individual coils (H.V.) are designed to have too great a radial depth compared to its height, hot sports may develop in the interior of the coils due to inadequate oil passage allowed. The insulation becomes brittle and short circuit between turns may result.

7. Overheat on load occurs at badly soldered joints and oil gets carbonised locally. The heat at the joint will be conducted to a certain length in the copper coil and the insulation may get carbonised to a little extent resulting in a short circuit between turns. The joint itself may give causing an open circuit.

8. When external short circuit occurs; the coils get deplaced violently as a result of the internal imbalance in electro-magnetic conditions.

9. Sustained heavy overloads produce high temperature through out the transformer. The coil insulation becomes brittle and in the course of time flakes off the conductors at places resulting in short circuit between turns. The deposits again cause excessive heating making it a cumulative effect. Transformers with a high ratio of copper losses to iron losses are less able to withstand overload and are therefore more liable to fail on account of sustained overloading.

9. The tap adjusting leads should be carefully handled to ensure that wrong leads are not jointed, otherwise part of windings may get short circuited and heavy currents circulate in the short circuited windings which would produce a fault between turns.

Whenever H.G. fuse on one of the phases blow off and supply continued through the other two phases; and this is injurious to transformer as well as the 3 phase motors of consumers. Immediate cutting off the transformer from service and renewal of the H.G. fuse is necessary.

11. It is to be ensured that bolted joints and all connections are tightly secured and locked last they may become loose in service due to vibrations produced and such joints get heated up rapidly.

12. The transformers for use on large systems are generally provided with adjustable coil clamping device for the purpose of taking up any shrinkage of the insulation which may occur under service. This adjustment is to be made with utmost skill lest undue mechanical pressure may be exerted on the windings and a few conductors may get dislodged resulting in short circuit between them.

13. When a transformer is switched off the magnetising current and thus the magnetic flux tends to collapse instantaneously. Due to various reasons this some times does at much more rapid rate than this corresponding normal cyclic rate of change and as result high voltage rises may occur.

14. Short circuit between turns, breakdown of windings to earth and puncture of insulation may take place due to the following transient phenomena.

(a) Lightening surges reaching the transformer. Usually for the damage in the surge impendence and coils get damaged as they take-the brunt of the shock.

(b) Excessive voltage set up by surges may be accentuated at open tappings, at any point of change of surge impedance like at the termination of conductor reinforcement where employed; spare between series coils, at the neutral or midpoint. Extra insulation is to be provided at these points.

15. In large power systems where many power stations are inter connected; or at places very near to large generating stations the fault levels are usually high and for similar faults the transformers are bound to fail more at these places. Employment of current limiting reactors is to be thought of at these places.

Failures in Magnetic circuits :

1. The laminations are clamped together by inserting bolts through cores and yokes. The bolts are provided with insulations around thorn which may give way. This tantamounts to a short circuit in lamination causing local eddy currents. When this trouble occurs; in the two bolts simultaneously they form a short circuited turn through which magnetic flux passes.

If one of the bolts situated at the ends of the limb fail simultaneously with an adjacent bolt in the yokes; the path between the two bolts is threaded by almost the entirevalue of the magnetic flux when passing from the core to the yoke. The heat generated is so severe to cause a distortion of the whole core also causing charring of the insulation and a resultant short circuit between turns of adjacent windings.

2. Failure may occur of insulation between laminations and insulation between yoke and clamping bolts. The nature of damage is similar to the one explained in the forgoing paragraph. This registers an increases in the iron losses of the transformer.

3. Core clamping bolts should be securely tightened and locked lest vibration will set up causing damage of core insulation and produce failures as explained above.

4. Care should be taken to ensure that the edges of the core and yoke lamination do not develop burrs which produce local short circuit/in the lamination.

5. No metallic fillings should be allowed to be present in between laminations in a finished transformer which cause short circuit.

It can be therefore be seen that :

1. Almost all the parts in a transformer are liable to failure. On opening a failed transformer it is often very difficult to say definitely the reasons for the failure as all evidence is eliminated by the very nature of the breakdown, Consequently the cause of a failure is only a matter *of* guess. At best a close idea of *the real cause* may be obtained by a careful study of the transformer and the operating conditions obtaining at the time of failure *of* transformer and also the weather conditions.

2. Careful design and construction on the part of the manufacturers without subordinating quality to competition in market is necessary. On the part of the purchasers also the economics behind the purchase should not he arrived at by cost alone but by performance guarantees.

3. Timely preventive maintenance is the back bone for safe and efficient operation of any electrical plant. The maintenance schedules as well as the

construction standards drawn up by the APSE Board are exhaustive enough to detect and prevent a possible failure ahead. If these are adhered it may be possible to reduce the failures to a large extent.

4. It is also seen that in several cases the filed officers are misclassifying the transformers. That is several units handed over for periodical overhaul are found sick after receipt in M.R.T. and instances are not remote when good units are handed over as sick.

PRE COMMISSIONING TESTS

The following tests are to be done by the field staff before commissioning a distribution transformer. These are termed pre-comrnissioning tests.

a) Megger Test :

This test is to be done with a 1000 V megger. At normal ambient temperature obtained in our state the I.R. values should not be less than the following :

E.T. to body : 150 Meg Ohm.
L.T. to body : 1 00 Meg. Ohm.
H.T. to L.T. : 150 Meg Ohm.

b) Whenever possible and alternate L.T. supply is available L.T. supply may be given to the H.V. terminals and the voltages on L.V. side measured between phase and phase and phase and natural. This not only confirms the/correctness of tap operation and healtyness of transformer but also gives scope to identify the neutral bushing.

However it can be taken as a thumb rule that "facing the L.T. side of the transformer the extreme right terminal is neutral".

Several cases where a phase, terminal is earthed with mistaken identity for a neutral causing burning of the windings are reported. Hence this caution.

TESTS BEFORE DECLARING THE TRANSFORMER SICK

Instances are not remote when section officers have handed over healthy transformers as sick units. They appear to have been mislead by repeated blowing off the H.G. fuses presumably due to placing lower fuses or due to reasons other than faults in the transformers. Replacing of H.G. fuses is to be properly done. Usage of under size fuses result in frequent blowing off of H.G. fuses and switching surges decrease the useful life of a transformer.

They are advised to do the following test at site if L.T. supply is available or at their section offices before declaring it sick.

(a) Megger test

Megger test H.V. to body and L.V. to body and see if satisfactory I.R. values; are obtained. If not it can be declared sick straight away.

(b) If the I.R. values are O.K. conduct ratio test. If unequal voltages are obtained the transformer is sick. The dimensions of typical H.G. fuse set are given below for the guidance of section officers.

GENERAL INFORMATION :

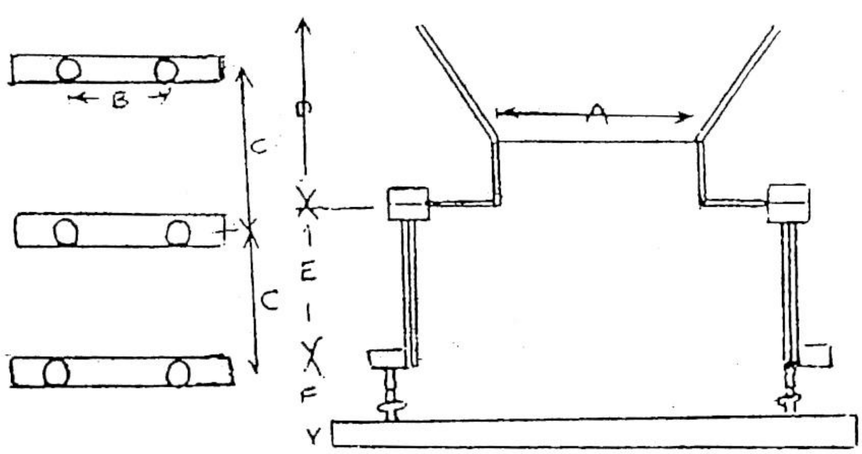
The dimensions of a typical H.G. fuse set are given at the end of the article the guidance of the Section Officers.

GENERAL REMARKS :

No article can be exhaustive on the subject and the points dealt with can probably be only some of the many causes of failure of transformer.

The timely preventive maintenance as approved by Andhra Pradesh State Electricity Board and contained in the technical reference book of Government Electrical Engineers Association of Power and Distribution transformer is pended herewith. The statement also explains in simple form the importance behind each item.

From the foregoing chapters it can be known how the schedules are drawn up covering up the probable reasons for failure of the equipment.



Volts	A	B	C	D	E	F	All dimensions
KV	8	24	30	18	10	10	in inches

POWER TRANSFORMER

Sl. No.	Item	Periodicity	Importance
1.	Checking of oil level in conservator and bushings examination of leaks.	Daily each shift	Low oil level excessive heat and consequential damage of core and windings of bushings.
2.	Checking the colour of silicagel in the breater & replacing or reactivating.	Monthly or earlier if	To ensure that moisture does not enter the transformer and damage insulation
3.	Checking for unusual internal noises	Daily each shift	To detect troubles during early stages and prevent failure. Loose core bolts etc., also can be detected.
4.	Noting loading in Amperes.	-do-	To ensure 3 phase balanced load.
5.	Cleaning of bushings	Weekly or during shutdown.	To clear off extraneous deposits which may cause failure of bushings.
6.	Ensuring that oil comes out when air release valve is opened	Monthly	To ensure that there is no gas formation in Bucholz relay and to ensure that the relay is ready to operation in the event of fault.
7.	Inspection and cleaning of breather	-do-	Same as at 2 above
8.	Checking relief diaphram for cracks	Daily each shift	To prevent moisture entering the transformer.
9.	Measuring I.R. values of windings with 1000 V Megger	Monthly	To ensure healthiness of insulation for H.V. & L.V. windings.
10.	Checking of temperature alarm for correct operation.	-do-	To ensure that they operate in the event of necessity.
11.	Calibration of temperature indicator	Yearly	To ensure that the temperature indicated are accurate.

	Item	Pertiodicity	Importance
12.	Testing of oil from conservator And tank for dielectric strength.		
	a) Upto 1000 KVA (before & after strength to act as	½ yearly oil possess its	To ensure that the wet season)
			dielectric medium
		and that it does	
			not cause corroding
		of metallic parts.	
	b) above 1000 KVA	Quarterly	
13.	Testing of oil from conservator & tank for acidity.	yearly	
14.	Checking up of gap setting of bushing	1/2 yearly	To ensure that in the event of bird faults and lightning the discharge occurs outside the transformer and the main winding are not effected.
15.	Testing of oil for D.E.S from bushings.	Yearly	Same as 12 above
16.	Filtering of transformer oil	Whenever the D.E.S. is Unsatisfactory.	Same as 12 above
17.	Major overhaul of the transformer		
	a) 3000 KVA and below	Once in 7 years	To ensure that all is O.K.
	b) above 3000 KVA	Once in 10 years	
18.	Bucholz relay	Yearly	The importance of Bucholz of relay
	a) Checking operation of Bucholz relay by air injection	yearly	The importance of Bucholz of relay is well explained in
	.		the article and does not need repetition.
	b) Checking Bucholz relay for any gas collection & testing the gas collected.	Quartely	
	c) Nothing the oil level in the inspection glass of Bucholz	Monthly	
19.	Testing of bushings with kipot tester.	Yearly	To ensure that the bushings are capable of withstanding the rated voltages.

	Item	Pertiodicity	Importance
20.	Tap changer		To ensure that the OL TC gear
	a) Overhaul	Yearly	operates trouble free
	b) Checking contracts	Yearly	and that the oil is of
	c) Testing oil for D.E.S.	Quarterly	satisfactory strength
	d) Testing oil for acidity	Yearly	to act as di-electric
	e) Filtering or renewal of oil	Yearly or after 1000 operation or when results or poor.	medium and does not corrode the parts.
21.	Forced cooling system		
	a) Checking fore leakage of water into cooler.	Daily each shift	Water entering into cooler mixes with oil &enter the transformer
	b) Pressure testing oil cooler.	½ Yearly	and damages the core & windings. To ensure
	c) Testing of motors, pumps etc.	½ yearly	the healthiness of
	d) Megger testing of Motors	Quarterly	motors
	e) Checking of transformer ground connections for tightness	-do-	That protective device operate in the event of faults in the motor circuits.
	f) Checking of water jacket	-do-	To ensure free flow of water

DISTRIBUTION TRANSFORMERS

1.	Cleaning transformer tank bushings etc .	Monthly -do-	Extraneous deposits may cause failure of bushings.
2.	Checking oil level in conservator tank	-do-	Low oil increases temperature and core excessive heat.
3.	Checking earth connections	-do-	In the event of faults the are passes to earth through least resistance part.
4.	Checking the colour of silicagel and reactivating where necessary	-do-	To avoid moisture entering the transformer and damaging insulation.

	Item	Pertiodicity	Importance
5.	Checking the diaphragm for cracks	Monthly	To avoid moisture entering the transformer & damaging insulation.
6.	Renewal of H.G. fuses and Section fuses with correct wore.	-do-	This is to avoid failure of fuses due to again and usage of correct fuse wire is to provide adequate protection to transformer.
7.	Measurement of load in amps on the feeder	Quarterly	To ensure 3 phase balanced load on on transformer.
8.	Measurement of voltage at transformer and tail ends	-do-	This is in operation point of view to provide good voltage to consumer. Also faults in transformers can be known in earlier stages if unequal voltage are noticed on no load.
9.	Taking I.R. Values of windings	-do-	To ensure the healthiness of windings
10.	Testing of D.E.S. of oil	Half – yearly	To ensure the suitability of oil provide dielection media
11.	Measurement of each resistance of earth pits	-do-	Same as at 3 above.
12.	Acidity test of oils	Yearly (Now once In 5 years)	If acidity increases it corrodes metallic parts.
13.	Filtering of oil	When the test results are bad	Same as at 10 above
14.	Complete overhaul of transformer	Once in every five years	To ensure that all is O.K. with the transformer.

INSTRUMENT TRANSFORMERS

Instrument Transformers are devices suitable for use with measuring instruments and protective relays, in which the conditions of current, voltage and phase in the primary or high voltage circuit are represented with acceptable accuracy in the secondary or low voltage circuit. These are current and voltage transformers designed to isolate electrically the high voltage primary circuit from the low voltage secondary circuit and thus provide a safe means of supply for indicating instruments, meters and relays.

CURRENT TRANSFORMERS

Current transformers are used in power installations for supplying the current circuits of indicating instruments (Ammeter, Wattmeter, etc.), meter (energy meter etc.,) and protective relays. These transformers are designed to provide a standard secondary current output of 1 or 5 A when the rated current flows through the primary. A fundamental characteristic is its transformation ratio, expressed as the ratio of the rated primary to rated secondary current. Current transformers have two inherent errors; the current ratio and phase errors. These two errors serve as a basis on which current transformers are classified for accuracy. IS : 2705/1 964-68 specified their classes for metering and protective purposes. No current transformer should be left to flow through the secondary winding, there will be no secondary magnetomotive force to act in opposition to the a primary one. As a result, the magnetic flux will suddenly rise to a high value and induce a potential of several thousand volts across the secondary terminals. This will not only endanger the winding insulation, but will also pose a serious hazard for the personnel. According to the design of the primary winding, current transformers can be divided into two main groups. Single turn transformers, suet as rod, bus-bar core balance and busihig type (ring type) and multi-turn transformers such as wound focal. Epoxy cast 33 KV 22 KV, 11 KV and L.T. C are nowadays manufactured in India. The measuring CT is required to perform its function *over* a normal range of load currents. However the protective CT should be able to supply correct values of secondary currents for fault conditions from full load to twenty times the full load. Knee point voltage and saturation factor are important for those CTs for protection. CTs knee point is made purposely low in case of measuring CTs. so that during fault conditions, the C may not produce secondary currents heavy enough to damage the indicating.

Instruments (i.e. is, say, 2.5 - 4.0). The important characteristics of the protection CTs are:

a) Rated VA, class of accuracy
b) Saturation factor or accuracy limit factor
c) Rated short time thermal current
d) Rated primary and secondary currents and their ratio
e) Knee point voltage

Example :

Three 100/5 CTs are used for over current and earth fault as shown in figures.

The magnetizing characteristics are shown in figure. Phase fault relays 50-200% range set at 125%. Earth fault relays range 20-80% set at 40%. Relay burden is 3 *VA for phase relays and* 2.4 *VA for earth* fault and 5 amperes *relay.* Resistance of CT secondary (RCT) is 0.08 ohm. Determine the primary operating current to operate the phase fault and earth fault relays.

Solution: (i) Relay Impedance :

3 VA relay impedance = 3.0 / (6.25) 2= 0.077 ohm at 125% setting 2.4 VA lay impendence = 2.4 / (20)2 = 0.6 ohm at 40% setting (ii) RCT + R relay = 0.08 to 0.77 = 0.157 ohm (iii) Primary current for phase faults.

At the set value of 6.25 A

Volts from Ct = 6.25 x 0.1 57 = 0.98 Volts.

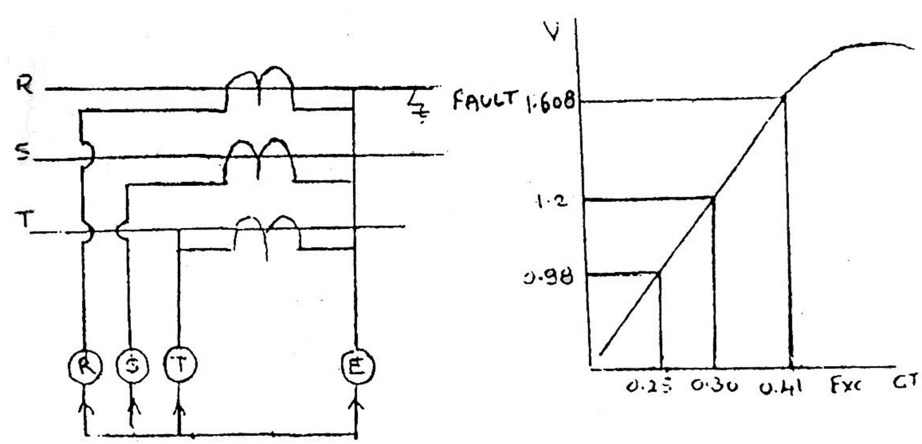


Figure. Current transformer connections.
(a) Connections; (b) Magnetizing curve
From magnetizig curve (refer Fig.) the corresponding magnetizing current

is 0.25 A.

Primary current for phase fault relay operation N(I + Imag) where Image=Magnetizing current of CT

Ia = relay current
N = CT ratio
= 20 (6.25 + 0.25)
= 130 A

iv) For earth fault relays
volts for relay operation = 2 x 0.6 = 1.2 V
From figure, the corresponding magnetizing current is 0.3 amp.
Current through A phase relay = 2.0 + 0.3 + 0.3
=2.6 A
Volts developed by A phase CT = 2.6 (0.077 + 0.08) + 1.2
= 1.608 V
Existing current for 1.608 V = 0.41 A (from figure)
Total Secondary current = 2.6 + 0.41 A = 3.01 A
Primary current "A' phase = 100/5 (3.01)
60.2 A

Through the earth fault relays are set-for operation at 40%, i.e. 40 A of the primary current, they will actually act to operate at 60A due to the effect of shunting of other phases and existing current of CTs.

VOLTAGE TRANSFORMERS

These instrument transformers are used for supplying the voltage circuit of indicating instruments, meters and protective relays. These may be of single phase or three phase design and of the dry or oil filled types. A fundamental rating of the voltage transformer is its transformation ratio and burden, i.e. the total load presented by the instruments connected. All voltage transformers are designed for a standard secondary voltage of 110 or $110/\sqrt{3}^{v}$.

These are divided into classes according to their percentage ratio and phase errors. The errors at which a voltage transformers will operate depend on its burden and the primary voltage.

In practice we must distinguish between three-limb and five-limb three-phase transformers.

The first type has a Y/Y-O connection and an insulated primary neutral. These transformers are only used for measuring/supplying the line voltages to instruments. The second type has a Y-O/Y-O connection. The primary neutral in these transformers is brought out and requires earthing. The five-limb voltage transformers serve for obtaining the line and phase voltages as well as the zero-sequences voltages by means of an auxiliary winding connected as a broken delta. Five-limb VTs are used in capacitor bank protection.

The current transformers may be either of the bushing type or wound type. bushing types are normally accommodated whitin the breaker or the transformer bushings and the wound types are invariably separately mounted. The location of the current transformer with respect to associated circuit-breaker has an important bearing upon the protection scheme. In the case of bulk oil circuit breakers, where the current transformers are accommodated within the bushings, an inherent overlap is provided which ensures clearance of all faults instantaneously. However, this becomes a disadvantage in case the breaker is issued as a sectionalizing breaker in a bus on account of lack of discrimination. Another disadvantage is that in the case of a spare breaker, a separate set of CTs and control and relay panel is required so that protection is available when the main breaker is taken out for maintenance. In the case of air blast and minimum breakers, the current transformers are normally separately mounted and these are located in each circuit position. In this case no overlap is provided and in the event of a fault within the switchgear some sort of intertrip arrangement has to be provided when the circuit breaker is used for bus sectionalizing. The advantage in this case is that a separate set of CTs and control and relay pannel are not required for the spare breaker. The space required in this case is of course more than in the case of bushing type of current transformers.

For ground fault relaying the CTs may be provided either in the bushings of the tertiary winding of the 3 winding transformer or in the transformer neutral or a combination of both depending upon the magnitude of the fault current.

The voltage transformer may be either of the electro magnetic type or the capacitor type. The electromagnetic type VTs are costlier than the capacitor type and are commonly used where higher accuracy is required as in the case of revenue metering. For other applications capacitor type is preferred, particularly at high voltages due to lower cost and it serves the dual purpose of a coupling capacitor for the carrier equipment. For ground fault relaying, an additional core or a winding is required in the VTs which can be connected in open delta. The voltage transformers are connected on the feeder side of the circuit breaker. However, another set of voltage transformers is normally required on the bus-bars for purposes of synchronisation. Sometimes bus. side VTs are preferred from the point of view of satisfactory operation of the relays.

ERECTION AND MAINTENANCE

EHV PTs are normally supplied filled with oil and should not required drying out. Small units of lower voltages may required filling on site and may therefore have absorbed moisture in transit. Where this is suspected, it is advisable to apply heat to the units to bring up the IR value before filling with oil. When dry the IR value of the windings will usually be found to be between 100 and 1000 meg ohsm. When in service the temperature rise is not so high so that the fall in IR value due to this is not of significance.

PT fuses where provided should be examined before commissioning. Some 11 KV PTs are provided with fuses on the HV side to isolate the system in case of a fault in PT. It is not intended to protect the PT. A current limiting resistance is provided in such a case to limit the fault current to a value within the rupturing capacity of the fuse. LV fuses provide protection to transformer against short circuits on the LV side. It is not desirable that either the HV or LV fuses should blow prematurely as that will effect metering and protective relaying and also any control circuits. An important precautions PT circuit is to verify that there are no parallel circuits on the LV side which could energise another PT inadvertently.

CURRENTTRANSFORMERS

Current transformers require little attention except to see that their secondary circuits are completed before the switchgear is commissioned. An open circuit on the secondary side may result in a relatively high voltage due to the whole of the primary ampere-turns. If the primary current is near the rated value, the core will become saturated resulting in a flat topped flux wave. This in turn will produce a high peaked secondary induced voltage wave because of he accelerated rate of flux change. The resulting high voltage may be harmful to equipment and personnel.

The secondary burden of CTs will depend not only on the instrument and relay coils but also on the length and cross-section of the leads between the switchgear and the control panels. Long control cable runs may require more cores of a multi-core CT to be put in parallel or leads of greater cross-section.

H.T. METER ENGINEERING

In any establishment/factory the input and output are measured to establish profit/loss. The measurements are of various types. In electrical field also, number of types of measuring instruments or meters' as they are called are used. Electrical instruments depend for their action on one of the many physical effects of electrical current or potential. Broadly the instruments are grouped as (i) indicating, (ii) Recording and (iii) Integrating.

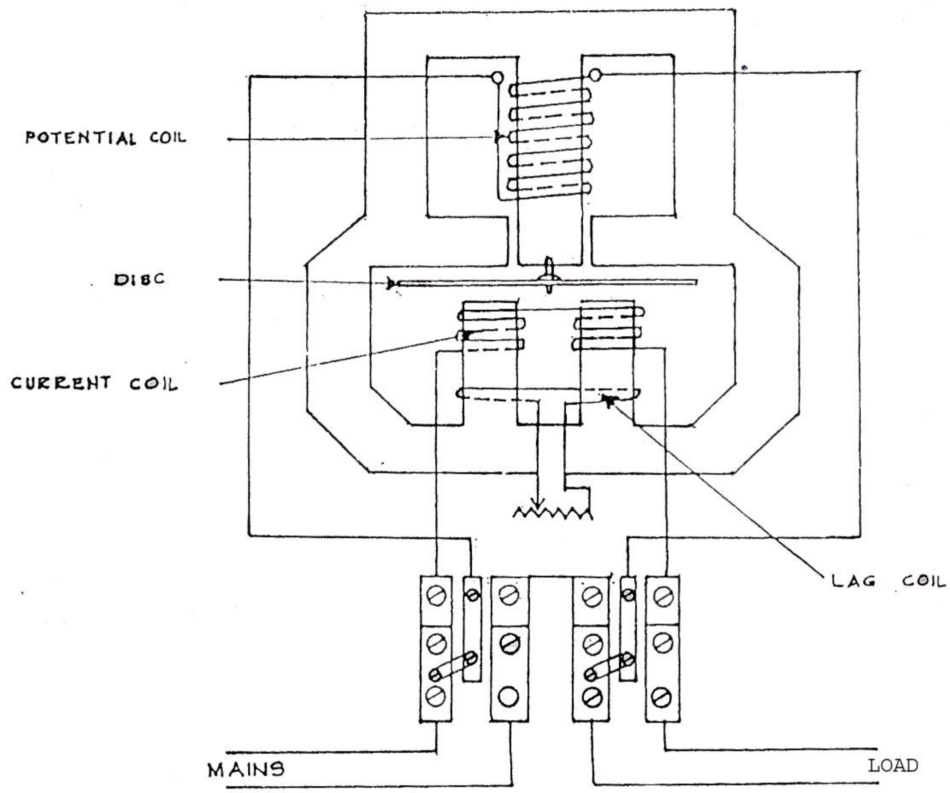
Indicating Instruments are those which indicate the magnitude of a quantity and generally make use of dial and pointer. Ammeters, Voltmeters and Wattmeters are few examples.

Recording instruments give a continuous record of the quantity being measured, as for instance by an ink on paper record or graph, extending over a selected period of time.

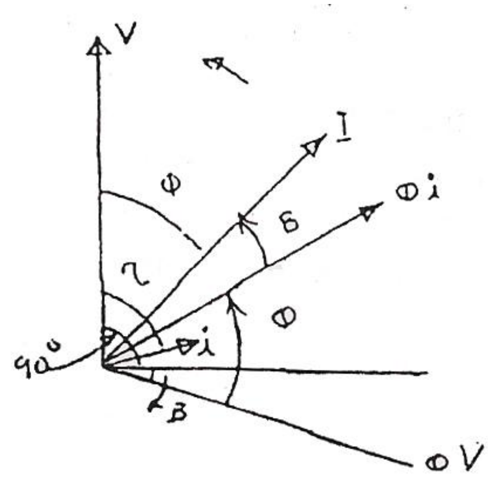
Integrating instruments give the total amount of energy or quantity of electricity over a period of time. The summation which they give is the product of time and an electrical quantity. Ampere hour and watt hour meters are examples. The summated values are generally given by a register consisting of a set of dials and pointers.

In this chapter importance has been given for the integrating energy meter and extended to the Trivector explained in short and the Trainees are recommended to refer standard (books on) electrical books on Measurement anr Instrument Engineering.

Principle of operation of a single phase energy meter .



A general view of the energy meter is indicated in the fig(1). The vector diagram of current and voltages with important fluxes are indicated in fig(2).



The magnetic flux due to voltage coil passes partly through the rotor disc (ϕv)and partly through the side gaps. The winding and the core form a highly inductive circuit, with the magnetic flux ϕV through the rotor disc adjusted to lag a little over 90 behind the voltages supplied to the winding. The current (i) in the voltage winding lags less than 90°. The extra lag between this current and the flux through the rotor is due to magnetic leakage through the side gap.

The current winding is wound equally on the lower or current poles. The magnetic flux from these poles passes directly through the rotor disc and is approximately in phase with the current I through the current winding. The flux may be made to lag slightly behind the current by means of secondary winding on the current poles with an adjustable resistance in series with it. The voltage and magnetic fluxes drive the rotor disc. The driving torque will be proportional to the watts in the circuit to be measured.

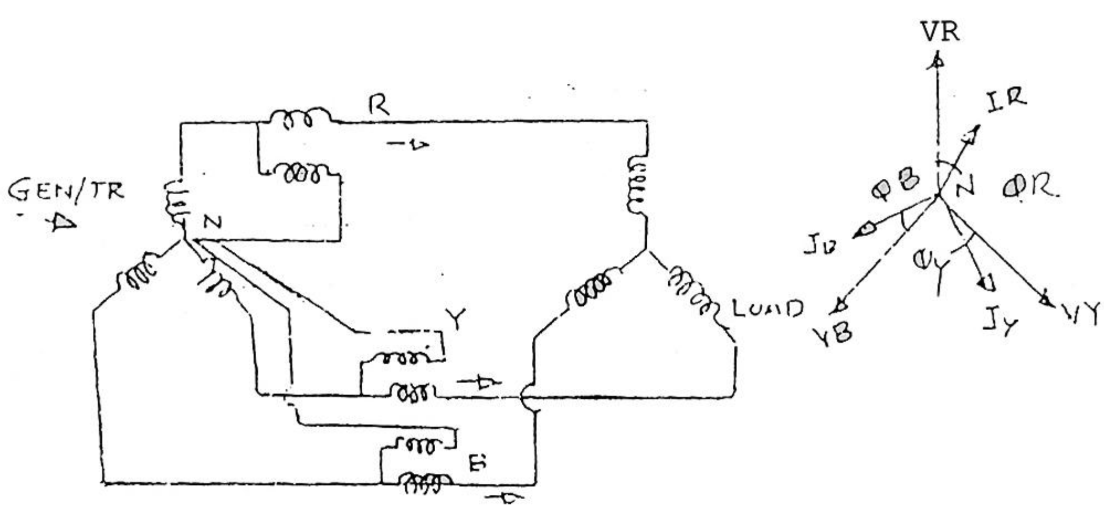
The construction of the coils and laminations are made in such a way that the magnetic circuit has no significant effect on permanent magnet or electromagnets in its vicinity and is itself protected from the magnetic fields. The construction also gives an unvarying gap for the rotor disc and hence a constant driving torque. The breaking system consists of two magnets with their poles brought to close one another. The *breaking effect of such a system on rotor disc* is to make the speed of rotations proportional to the torque applied. This means that the speed of rotation is measure of the load on the meter. A register, train of gear wheels connected to the spindle of the disc, is calibrated to indicate the energy directly.

Meters on Polyphase Circuits :

In case of polyphase circuits the metering needs various considerations - and following few circuits will try to explain some fundamentals in metering of such circuits.

(a) Three phase three wire system :

Consider a generator or transformer supply to be star connected as in the sketch below :

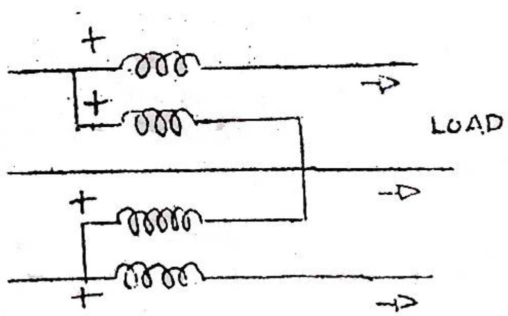


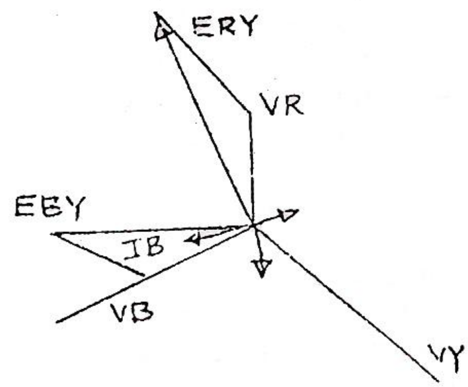
The total power will be sum of
Power generated in each phase.

$$\text{Total power} = V_R\, I_R\,.\,\text{Cos}\,\phi_R + V_y\, I_y\, \text{Cos}\,\phi_y + V_B\, \text{Cos}\,\phi_B$$

Thus with three numbers single phase meters total energy can be measured.

In case of 3-phase, 3-wire system whether balanced or not two element energy meter connected as indicated below will be suffice.



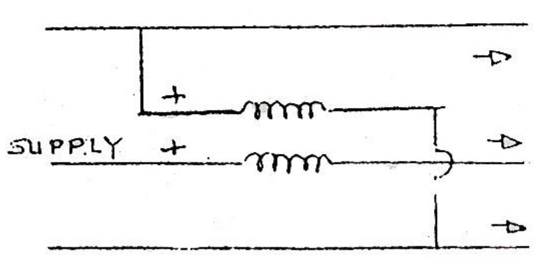


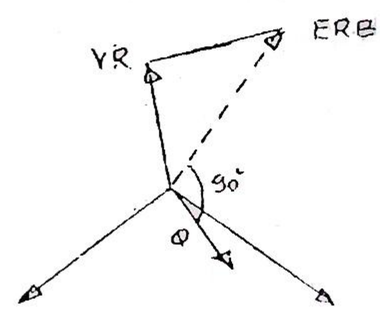
In case of 3 phase 4 wire polyphase system a meter incorporating three no. single phase energy meters as explained earlier is a must for accurate measurement under all conditions of loading.

<u>Measurement of Reactive Power</u> :

Measurement of reactive power (VI Sin ϕ) is not as simple as active power (VI Cos ϕ) for the reason that the accuracy will not be constant over a wide range of variation of power factor.

A simple circuit to measure reactive power/energy is indicated below :





Various methods of giving an active energy meter phase shitted values of current and voltages were tried out for accurate measurement of reactive power/energy of the system. Many of these were not successful of various reasons specially the change of phase sequence after installation of meter and connection, on the incoming feeder after breakdowns.

M/s. Landis & Gyr company have developed a circuitry where the external connections to be made for reactive power / energy meter is similar to the active power/energy meter. Internally a noninductive resistance is shunted to the current coil and a high resistance is connected in series to potential coild resulting in 90° phase shift when compared to the similar active power/energy meter for wide variation in power factors in load. Further this has no effect on the phase sequence of the system even through correct phase sequence is not maintained.

Apparent Power / Energy Meter :

The apparent power or ‘ V A’ is again a very difficult quantity to measure directly by an electrical meter. Most of the measurements are by mechanical coupling of active power/energy meter (rotation of spindle) and reactive power/energy meter through a mesh of gears. Even here M/s. Landys & Gyr have a meter which records KVA virtually accurate over a wide variation of power factor and load itself. Certain companies developed electrical KVAH meter over a limited power factor range but they were not successful.

Maximum Demand Indicators :

A counter driven by he spindle of the energy meter during the certain period of time (say ‘t’ min.) measures the quantity of energy supplied during that item. Now the average power is the ratio of the energy supplied to the period of the time. Therefore the counter can be calibrated in terms of KW if the period of time during which counter is in gear is a constant.

A manual resectable indicator made up of light material is made to move with the counter will indicate the KW during that period, if, in successive periods of intervals, the counter tries to register more reading the indicator is pushed and if the counter does not register more the indicator indicates the maximum average KW drawn during any period of interval.

A Trivector meter on a polyphase system consists of an active energy meter a reactive energy meter and these two are mechanically coupled to register apparent power along with the Maximum demand indicator on KVAH, KWH elements to indicate maximum KVA and KW recorded. The internal connections of L&G make Trivector meter together with external connections to metering CT & PT is indicated in the sketch.

Rotating Substandard Meter:

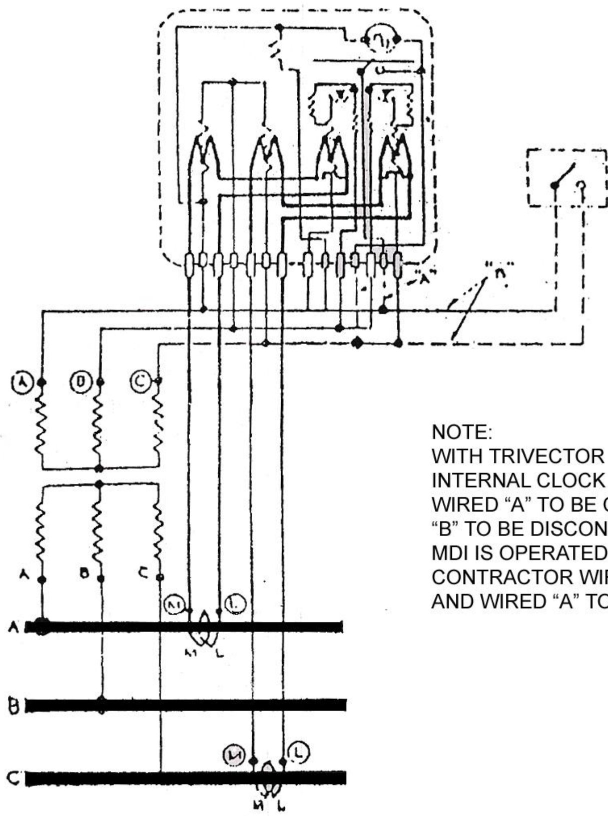
These are very accurate energy meters designed to retain their accuracy over a long period of time and with two additional advantages over the conventional energy meters. They are revolution of these meters can be read upto 1/100 of revolution and meters can be started with a click switch on the meter or by a snap switch in potential circuit controlled by hand. These meters are calibrated against standard meters and are used as standard meters for testing and calibrating the energy meters at various laboratories or at site.

Instrument Transformers :

Instrument transformers are used for safety of the personnel attending the meters used or connected In H.V. systems A detailed discussion on these has already been made while dealing with protection.

Presently A.P.S.E.B. has standardized in procuring meters rated for 2.5, 5, 10 and 20 Amps of use in single phase and three phase meters rated 5 or 10 Amps along with L.T. CTs to suit the capacity of the load. Almost all the meters used on H.V. network is either of 1 Amp rating or 5 Amps using suitable CT.

In case of voltage transformers whatever being the primary voltage the secondary rated voltage is normally 110 V and in very rare cases it is 120 V between phases.



NOTE:
WITH TRIVECTOR MDI IS OPERATED BY INTERNAL CLOCK
WIRED "A" TO BE CONNECTED AND WIRES "B" TO BE DISCONNECTED WHERETRIVECTOR MDI IS OPERATED BY EXTERNAL CONTRACTOR WIRED "B" TO BE CONNECTED AND WIRED "A" TO BE DISCONNECTED.

PHASE SEQUENCE
FRONT VIEW

FIG.4 CONNECTION DIAGRAM OF H.T. TRIVECTOR METER
FF/VA mW mVe SUm /FF1 Ø (TYPE Q) V.T & C.T.

LANDIS & GYR LTD
DRAWING NO. H 107097

DISTRIBUTION TRANSFORMERS

FAILURES & PREVENTION

M. HANUMANTHA RAO
CHIEF ENGINEER

1.0 The high rate of failure of distribution transformers in the filed is causing anxiety and concern to the APTRANSCO. The failure of distribution transformer causes interruption of supply and inconvenience to the consumer and huge expenditure to APTRANSCO for restoration of supply and repair of failed transformers. The average repair cost of a distribution transformer is about Rs. 10000 per unit. The cost of transformer oil is about Rs.22 per litre. From this data it can be seen that the cost of repairing the sick distribution transformers is a great drain on the finacnces of APTRANSCO. Hence any improvement made in the distribution system to bring down the rate of failure of distribution transformers is very welcome and we must strive to the utmost in bringing down the failure rate.

2.0 The power and distribution transformers operate on the some principle of Electro magnetic induction and the construction of these two types of the transformers is similar. It is difficult to define the difference between power and distribution transformers. We can define and identify a distributional transformer from the fact that a distribution transformer once commissioned is never switched off for want of load. It continues to be in service all through the day and all through the year. It is switched off only when some maintenance is required to be done or replaced with a higher capacity transformer for meeting the increased load or disconnected and replaced with another transformer in cases of failure. As long as a transformer is kept under charge the no load losses are always present. It therefore follows that the no load losses of a distribution transformer should be kept at the minimum lever of conservation of electrical energy.

2.1. The distribution transformer has to feed consumers who are some time away at 200 to 250 meters from the transformer location. In such cases there will be considerable voltage drop for he tail end of consumers. The voltage drop should be as small as possible so that the electrical equipment located at tail ends performs better. In other words we need better regulation. Apart from the size of conductor, quantum of line current, distance of the load from the transformers, the percentage impedance of the transformers has an important role to play in the voltage regulation. The lower the percentage of impedance of the transformer the better the regulation and vice-versa. It any therefore be said that the distribution transformer differs from, the power transformer in that the 'no load losses' and the percentage impedance of the distribute transformer are much lower compared to the power transformer.

2.2 While a low percentage impedance of he distribution transformer is desirable from the regulation stand point of view, low percentage of impedance of a transformer means high short circuit currents. It is very simple to arrive at the short circuit current assuming that the short circuit occurs across the L.T. terminals of the transformer. If the full rated L.T. current of a transformer is and if the transformers has a percentage impedance of 'Z' the short circuit current would be (1 x 100/Z). Thus for a distribution transformers having 4% impedance, the short circuit current will be 100/4-25 times the full load current of the transfromer. The distribution transformers must be designed for the large short circuit current withstand capacity as stipulated below :

S.No,	Percentage Impedance	No. of times of full load current	Time in Seconds to withstand without failure
1.	4%	25	2
2	5%	20	3
3	6%	16.6	4
4	6%	-	5 Seconds

2.3 .With the above introduction and background let us examine the reasons for the failure of distribution transformers. We have noticed in 2.2 that the magnitudes of the short circuit currents are very large and that the short circuit withstand times are short. In the event of occurrence of a short circuit on the L.T. terminals of the transformer, the fault must be cleared before withstand time. Otherwise the transformer will fail. In case of power transformer, the relay operation time + circuit breaker operation time should be less than the withstand time. In the case of distribution transformer where fuses are the only protection available, it follows that the fuses must blow off before the withstand time isolating the transformer from the fault. The horn gap fuses on the 11 kV side and the main fuses on the L.T. side of the transformer should be strictly in accordance with the recommended sizes. In actual practice in field, there are no L.T. main fuses at all at many of the transformer structures.. Some times, conductor bits of the over head L.T line are used as L.T. fuses. Similarly the horn gap fuses are also found to be grossly overrated. There is absolutely no realization of the serious consequences arising out of such irresponsible practices. This aspect needs constant checks and supervision by the Section Officers and ADEs. The field staff must be educated regarding the usage of recommended fuse wires. Unless this is done in earnestness there will not be any improvement in the situation. In distribution system like ours where the lines are overhead with negligible underground cables, it is not possible to totally avoid short circuits. However we may reduce the possibility of occurrenence 's of short circuits of LT Lines. The following measures maybe employed to minimize the short circuit.

(a) Avoiding long spans of LT Lines :- Long spans generally result in large sags There is possibility of short circuits if the sag of the conductor is large. Intermediate line support with cross arm and insulators may be employed to remedy the situation.

(b) Avoiding loose spans :- When the span is loose, restringing with proper tension will result in reducing the sag arising out of loose spans.
(c) Provision of a struct instead of stay to the dead-end pole :- If a stay is provided at the dead-end of an 1_T line, it is likely that the stay may be cut in course time resulting in leaning of poles along wit h the dead-end pole. It is always advisable to use a strut pole instead of a stay to dead-end pole to avoid leaning of line supports at a later date.
(d) Maintenance of proper tree clearance ;- It is necessary that the LT lines of the distribution are periodically to ensure that proper tree clearance is maintained. It will be necessary to patrol the lines after a fortnight after good rains because of vigorous tree growth on account of rains. The branches of the trees must be trimmed to have adequate tree clearance.
(e) Usage of mid-span spacers :- Mid-span plastic spacers may be utilised as a first preventive measure to avoid short circuits. The utilisation of spacers effectively prevent short circuits. These spacers are less expensive, effective and easy to install. It is recommended that these spacers may be used generously in the distribution and bring down the failure rate.

2.3.1. The next major cause-for the failure of distribution transformer is the overload. The section officer must have with him e the number and capacities of transformers-in each distribution along with the latest maximum load on them. This is vita! information which the section officer must possess. The section officer must have a list of transformers which are overloaded in this section officer must have a list of transformers which re overloaded in his section and work out the percentage of overload. Continuous overload of the transformer increases the temperature of the transformer oil beyond permissible limits. The increased operating temperature of the transformer makes the paper insulation of the. HV and LV windings brittle and the life expectancy of the transformer is greatly reduced. In addition to the overload if the transformer is subjected to the short circuits the transformer is bound to fail within a very short time. The following remedial measures may be thought of in case of overload.

(a) If the overload is only in one phase and if the other two phases are under loaded balancing of loads may be resorted to.
(b) If the overloaded transformer also feeds the weaker section colony with single phase distribution, it amy be examined if a separate single phase transformer can be erected exclusively for the weaker section colony, thereby relieving the main transformer from overload. If the lines in the weaker section colony are made HVDS and services given with AB Cable, theft of energy may also be simultaneously avoided.
(c) Installation of additional transformer has to be thought of to prevent repeated failure of the existing transformer.
(d) Enhancement of transformer capacity:-The capacity of the existing transformer may be enhanced with a higher capacity transformer so as to feed the incident load without overloading the transformer.

2.4. Deterioration of the Quality of transformer oil :- In distribution transformers of conventional design. (i.e. transformers having conservation, breaher, vent pipe) the transformer oil is in communication with external atmosphere through the breather. In conventional transformer oil. When the ambient temperature is high and when the transformer is fully flooded the transformer becomes hot and the transformer oil expands, resulting in the rise of the transformer oil in the conservator when the level of oil increases the air above. The oil surface in the conservator is pushed out into the atmosphere through the breather. This is called breathing out. When the ambient temperature becomes low along with fall of load on the transformer the temperature of the transformer falls. As a result, the transformer oil contracts thereby causing flow of oil from the conservator in to the transformer tank. The flow of oil from the conservator into the transformer tank, causes partial vacuum to be created on the surface of transformer oil of conservator. Atmospheric air flows into the conservator through the breather and breather pipes. This is called breathing in. The breather contains silica-gel which absorbs moisture from the air which passes through it. The colour of dry silica-gel is dark blue and when the silica-gel absorbs moisture it turns pink. When silica-gel becomes pink it should be reactivated by heating and reused again. If the breather is not maintained properly, moist air will enter the transformer contaminating the oil. This results in low BDV of the oil and fall in IR values of the transformer. The transformer oil has great affinity for oxygen. Even when the breather is maintained properly the dry air which contains oxygen comes into contact with the transformer oil. The transformer oil gets oxidized according to the following relation.

Transformer Oil + Oxygen -: Water + Organic Acids + Sludge.

The oxidation process is however slow. Bright copper surface acts as catalyst for the oxiation process. Due to this reason, it will be ensured that no bright copper surface is allowed inside the transformer. Coating copper parts with tin or covering the copper parts with paper installation are employed to prevent the catalytic action of bright surface. It may be seen that due to oxidation of transformer oil, several disadvantages results, such as fall of BDV of oil, lowering of IR values of the transformer increase in acidity of the oil, Sludge is a brownish semi solid substance which will be adhearing to the windings. The sludge may obstruct the cooling pipes whereby the cooling of the transformer is affected resulting in the rise of operating temperatures. The acidity of transformer oil is expressed in milligrams of potassium hydroxide required to neutralize the acid contained in one gram of oil i.e., mgms of KOH/gm oil. If the acidity value reach 0.8 mgms KOH/gm oil the entire oil has to be replaced with new oil. The degradation of transformer oil on account of oxidation is the reason for prescribing the periodical testing of oil for BDV, acidity value and measurement of IR values of the transformer. Since sealed transformers prevent the access of atmospheric air reaching the transformer it is observed that the characteristics of transformer oil in such transformers do not show any deterioration.

2.5 The leakage of transformer oil from the LT bushings of the transformer is one of the reasons for the failure of transformers. It is observed that due to improper connection of LV connections at the LT bushings, lot of heat is generated due to loose contact and insufficient contact area at the place of connection resulting jn high current density. While some of the heat generated in dissipated into surrounding atmosphere, a portion of the heat goes inside the transformer through the LT busing rods. The heat destroys the rubber oil seals of the bushing rods. This results in the leakage of transformer oil. If the oil leakage is not arrested, all the transformer oil above the LT bushing rods level would leak out. When the transformer is hottest the oil level is maximum. Hence under the above condition of operation of the transformer the quantum of oil leaked out would be maximum. When the ambient temperature falls steeply along with reduction in load, the transformer is subjected to sudden cooling. The cooling of the transformer results in the contraction of oil which is already depleted due to leakage. In such condition the top coils of the transformer may be -deprived of oil and the transformer may fail. In order to prevent the transformer failure due to oil leakage from the bushings, the leakage must be arrested at the earliest opportunity. by availing shutdown on the transformer and replacing the-oil seals and topping up the transformer oil to the required level. Most importantly it must be ensured that the connection at the surface area of the busing rods should be made by using suitable clamps so as to encompass the entire surface area. This would reduce the current density and there by the heat generated. In the latest specification for the distribution transformers, the LT busings are required to be located above the maximum oil level ot the transformer. This means that there can be no leakage of transformer oil at all since the oil level is below the LT bushing rod level. Two part bushing which are leak proof are also recommended to be used in the design of the transformer.

2.6 <u>Failure of transformer due to sudden oil loss due to punctures on</u> the <u>transformer body :</u> There are several instances where the distribution transformers have failed due to leakage of oil through the puncture hole caused by the contact of bare electrical conductor and the transformer tank or radiator assembly. When a transformer is commissioned it must be ensured that the LT cables connected to the transformer and distribution box do not touch the transformer body. The PVC insulation of the LT cables peel off at some places due to overload and high ambient temperature. When the deteriorated LT cables touch the transformer body puncture holes are formed throughout which transformer oil leaks out resulting in the failure of the transformer. It should also be ensured that the neutral connection from the neutral bushing to the earth pit must not touch the transformer body so that neutral current may not damage the transformer. The remedial measure to prevent failure of transformers due to similar faults is to ensure that the LT cable phase connections and neutral connections do not touch the body of the transformer. The insulation condition of the LT cables must be checked during the inspections. Open writing may also be done in rural areas to avid frequent need to renew the deteriorated LV cables.

2.7 Failure of transformers due to high voltage surges:- It has bean our experience to witness simultaneous failure of a group of transformers due to voltage surges caused during thunderstorms. It is a pity that event through lightning arresters are available near the HV bushings of the transformer, they are not connecter to the transformer and properly earthed with the result that the transformer is not protected against high voltage surges even through lightning arresters are procured and available near the HV bushings of the transformers. Prior to the development of the presently used 'shatter proof lighting arresters, the lighting arrester used to be broken into pieces of failure. In order to safeguard the bushings, the lightning arresters were erected at a distance from the bushings. In order to have reliable surge protection, the lightning arrester should be erected as near the transformer as possible. Consequent to the development of the 'shatter proof' lightning arresters, they are erected very near to the equipment which they were supposed to protect. These lightning arresters on failure do not give either visible or audible indication as to the failure. The lightning arrester has to be examined very closely to determine if it failed or not. When a lightning arrester fails, it constitutes a line fault and the feeder is declared as breakdown The line staff have to patrol the feeder, locate and isolate the faulty lightning arrester before the line can be taken into service. This procedure takes considerable time and therefore there are prolonged interruptions to the consumers. In order to obviate then time consuming task, field staff have disconnected the jumper between the bushings and lightning arrester at some places. This practice of disconnection is un-authorised and defeats the very purpose of providing lightening arresters at considerable cost. If proper horn gap fuses are provided for the transformers, the failure of lightning arrester will result in blowing off of the horn gap fuse and the line need not be declarer breakdown since the line stands on the second test charge due to isolation the faulty lightning arrester.

2.8. Wide spread usage of Automatic Staters for agricultural pumpsets is a major cause of failure of Agricultural distribution transformers. Since the present policy is supply of Power for nine hours for agricultural operations and since the timings of availability of supply are inconvenient to the farmers, most of them have installed automatic starters for their Agricultural Pumpsets. As a result, the moment the power is available, all the connected motor pumpsets start simultaneously. Since the starting current of the pumpset is normally twice the rated current of the pump, the distribution transformer feeding these agricultural loads is subjected to serve overload. Even though the starting currents last for fraction of second still the distribution transformer suffers shock. If the connected load is more than the capacity of the transformer, the magnitude of the shock is very severe. As the cut off and restoration of supply takes place at least twice in a day, the transformer suffers corresponding server overload shocks and the transformer may fail prematurely due to thermal shocks and the consequential deterioration of insulation of the transformer. The remedial measure to prevent failures in such cases is to advise the farmers to incorporate time delay in the automatic starters. If such time - delays adopted, incidents of sudden overload can be prevented thereby avoiding transformers failures.

2.9 When control of Agricultural toads is done by single phasing, the farmers in some districts (Mahaboobnagar and Medak) have started using phase advancer's at their pumpsets which enable the farmers to run their three phase motors even in single phasing periods. The Electricity Authorities have prohibited usage of phase advancers. Special inspections have to be made during the period of single phasing to locate and eliminate the phase advancers.

3.0 As on today there are no dedicated Agricultural feeders. The APTRANSCO is advocating usage of single phase motors for pumpsets for reduction of line losses and for maintaining satisfactory voltage levels. Under such condition agricultural load restriction by single phasing cannot be achieved. Similarly switching off the entire feeder for load control causes interruption of the other categories of consumers. Hence dedicated agricultural feeders seem to be the only satisfactory solution for effective control of agricultural load demand.

3.1 The AE and ADE cadres in the distribution have ah importance role in minimising failure rate of the transformers. The ADE must visit the location of failure of the distribution transformer at least on the second failure at the same location and make a thorough investigation as to the cause of a failure. The condition of structure, AB Switch, availability of horn gap fuses, LT fuses (main and section), whether the fuses confirm to the recommendations, earthing of transformer and the neutral, condition of earth pits and other earths of structure, whether LAs connected and whether properly earthed, condition of LV cable, whether LV cable or transformer neutral touching the body of the transformer, whether the LT lines are in proper condition as regards span, sag, up-rightness of line supports and proximity of trees and tree branches, adequate ground clearance and horizontal clearance from buildings and structures. It has to be checked and verified whether the transformer is overloaded, whether un-authorised connections exist on the transformer. The condition of the transformer such as oil level in the transformer, maintenance of breather and silica-gel have to be checked. Finally incase of repeated failures, un-cleared faults of consumers recruitments must be suspected. To detect such faults, aerial fuses for the consumers at least on temporary basis must be provided and the fuse blowing may be watched for the location of the fault. Even through the fault location is time-consuming, it must be done methodically and the fault should be eliminated. The line staff must be trained by the ADE and AEs for this methodical approach for fault elimination. It must be remembered that the duty of AE or ADE does not end by replacing a failed transformer with a healthy transformer. Necessary action must be taken to prevent recurrence. This calls for hardwork and dedication and commitment from the technical cadre, which I am sure are not lacking in you.

TESTING OF ENERGY METER

Testing of meters is carried out under either of the three following conditions.

1) When the meters are received in Departmental stores.
2) At regular intervals of periodicity, and
3) When the consumer challenges the recording of the meter and pays the testing charges.

All the meters are brought to the testing laboratory for testing except the H.T. Trivector meters to be tested for their periodicity under actual loading conditions.

Normally the following tests are carried out in the M.R.T. laboratories.

a) Insulation resistance of the meter.

b) Heat run at full load

c) One set of 'Before adjustment' readings are taken under the following conditions.

i) Full load - Unity power factor

ii) Full load-0.5 P.F. lag

iii) 1/10 full load - Unity Power Factor

In the case of complaint meters, in additions to the above tests a test at 1/2 the full load at Unit Power Factor is done. All these 4 tests are done twice to avoid errors in testing as per the ISS 722 (Part-ll) - 1962 meters with current transformers are permitted to have an error of ±2.5% while those without current transformers to have ± 2%.

d) <u>Minimum Running Currents:</u>

Under Unity Power Factor condition minimum, current required to run a meter (at least three full revolutions) is 0.25% of rated current for meter with dial and pointer type registers and 0.375% of rated current for meters with Cyclometer type registers.

e) <u>Creep Test</u> :

No meter shall run with 110% voltage on the potential coil and no current through the current coil.

f) Dail Test:

This test if carried out to ensure that meshing arrangements of the registers with the spindle is perfect and does not offer any resistance to movement and also the registration is perfect. The error shall not exceed + 1%.

Test Benches :

A simple easy to operate test benches for both single phase and three phase meters are rigged normally in the lab.

9) Single phase test bench :

Normally the loading transformer which feeds the current elements are connected between R phase and neutral while the potential coils to R phase and neutral. The noninductive resistance are used in the secondary side of the loading transformer. This will be the circuit under unity power factor test both for full load and 1/10 full load. Keeping the potential circuit of energy meters between R Phase and neutral the supply to loading transformer is changed over to neutral and B Phase (note the earlier connection was R Phase and neutral), by the operation of D.P.D.T. changeover switch. Under these conditions the power factor of the load will be 0.5 PF lag as felt by the meters. There will be110% tap for the loading transformer on primary side. By utilising this 10% extra voltage is obtained for testing the meters for creep test. Schematic diagram for the same is Indicate: below ;

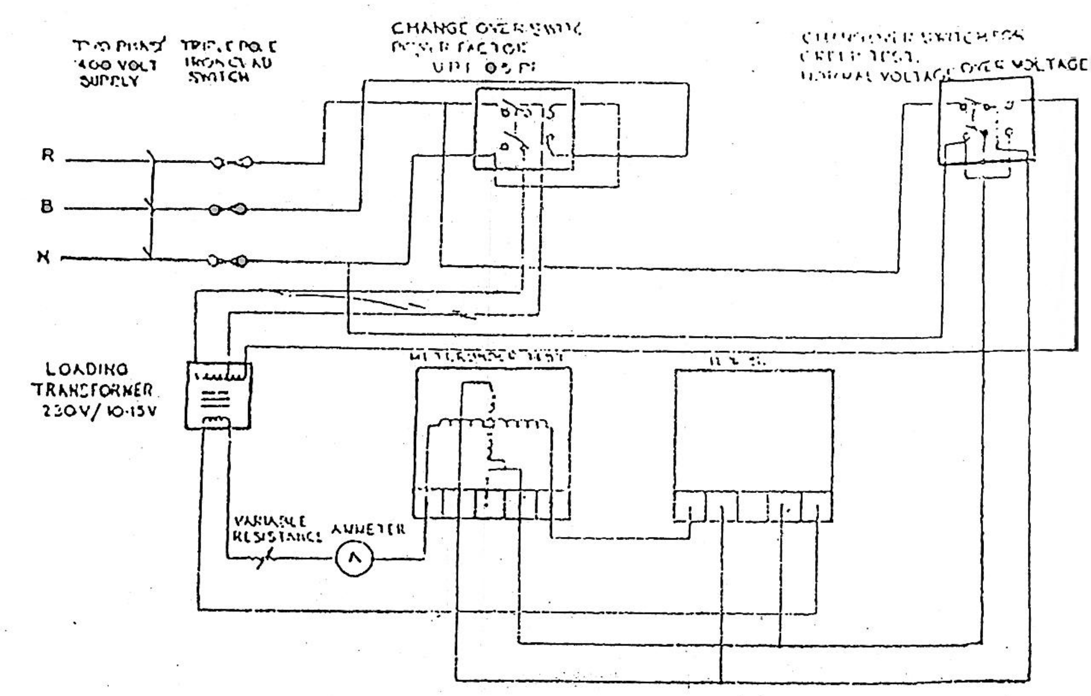
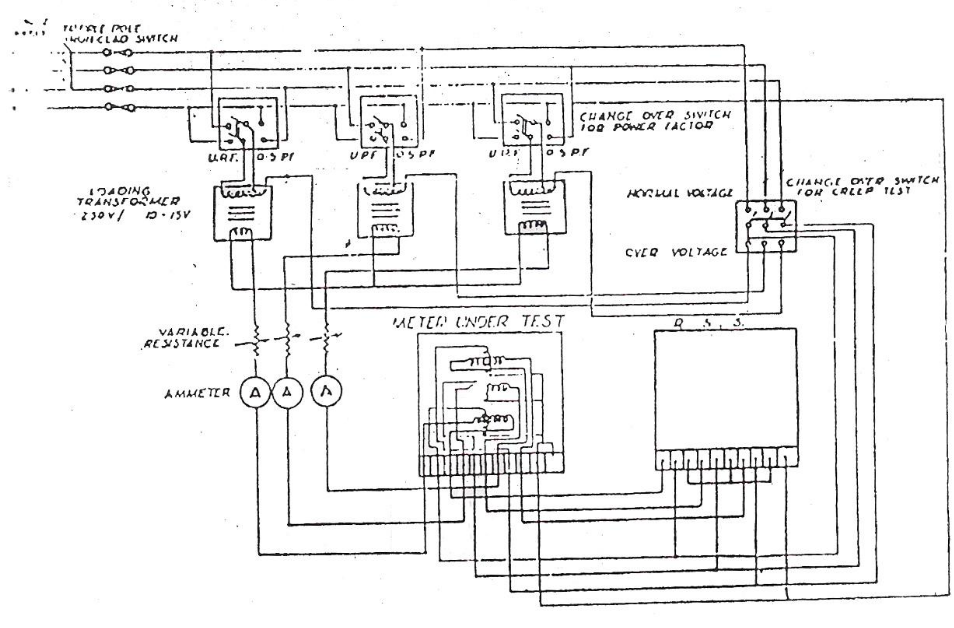


FIG.1 SCHEMATIC DIAGRAM FOR SINGLE PHASE L.T. METER TESTING.

With the help of meter constant i.e. Rev. per KWH, for both the "Meter under test" (MUT) and "Rotating substandard meter" (RSS) a ratio of revolutions of meter under test to RSS is calculated. Number of revolutions on meter are counted and R.S.S. stopped to read equivalent revolutions. As an example let rev. of MUT equal to 10 Rev. of RSS. i.e. if MUT make 9 revolutions, RSS shall make 10 revolutions. If the number of revolutions by RSS is less than 10, the MUT is faster and if it is more the MUT is slow/Accordingly, the adjustments are made. After final adjustments the meter is put for dial test.

b) Three Phase Test Bench :

This will be very much similar to that of single phase except that three loading transformers are provided to feed three elements of the meter and RSS. Schematic diagram is indicated below :



6.2. SCHEMATIC DIAGRAM FOR L.T. POLY PHASE METER TESTING

The procedure is the same as indicate above. A torque balance test is to be carried out in these meters i.e. only two elements are energized at a time in such a way that the potential coils of both elements are parallel and the current through the current coils oppose each other. Under these conditions the disc should not move. After this the dial test on the meter is carried out.

c) L.T./H.T.Three Phase Two Element Meter Testing :

The test bench described under three phase test bench can also be used for this type of meters in the laboratory. Generally two element meters are tested with portable test kits. One of such One is given in the sketch enclosed :

d) Testing of Trivector Meters :

As already described the Trivector meter consists of active power energy meter, reactive power energy meter, and apparent power energy meter with maximum demand indicators on parent power energy meter. For testing of Trivector meter two R.S.S. Meters one for active power energy and the other for reactive power energy measurements are necessary. Testing of energy meter portion win be similar to any of the energy meters described earlier. As regards the testing of reactive power energy meter the testing carried out as under.

a) Full load current of the meter is passed though the current coils at "Zero Power Factor" condition, i.e. $\cos \phi = 0$
b) 1/10 Full load current is passed through the meter at "Zero Power Factor" (Cos =0)
c) Full load current at 0.866 P.F. is passed through the meter (i.e. $\cos \phi = 0.866$)

Except for this the testing is very much similar to that to active power energy meter.

When both active and reactive power energy meters are calibrated dial test for KWH meter, KVAH meter (mechanically summated one), KVRH meter along with the maximum demand indicator is carried out preferably at such a power factor load so that both KWH element and KVARH elements do rotate almost with equal speeds. Total KWH, KVARCH as recorded by RSS meters and Trivector meters shall be compared and they shall be equal with ± 1% error. KVAH is computed with the help of KWH and KVARH of the meter by using the formula

$$KVAH = \sqrt{(KWH)^2 \quad = \quad (KVARH)^2}$$

M.D. indicator reading of .KVA and KW shall be noted and they shall be equal to the ratio of KVAH to the time for the dial test (normally 30 minutes or 15 minute as per the time of M.D. in the meter) and to the ratio of KWH to the time of the dial test.

The .above is in short the testing procedure of Trivector meter

(Precautions to be taken at the time of releasing the supply with Trivector meter :)

1) The metering set i.e., CT and PT or the CT and PT separately shall be sealed by MRT seals after connecting the correct CT ratio.

2) There shall be no fuses in the PT secondary circuit.

3) All the leads from the CT and PT or from the metering set shall not be accessible to the consumer (to meddle with) and will be run in conduits into the metering cubcile.

4) Even in the metering cubcle the leads shall not be accessible.

5) The test terminal block, meter cover and M.D. indicators shall be sealed by M.R.T. staff.

6) At the time of releasing service after all connections are made, the R & B potential links in the test terminal blocks are disconnected, temporary connections are made to inter change the potential supply to the meter. With the above connection the KWH meter shall not rotate under normal load.

7) The phase sequence of PT at the meter terminals shall be R, Y, B.

8) For the safety of the personnel earthing of the meter, metering cubicle metering set shall be ensured.

9) Generally "Y" phase wire of PT secondary in case of three wires or neutral wire in case of 4 wries, is earthed for safety purposes.

10) In case of CT secondary either at metering set or at meter (at only one place) the earthing is done.

The above is some of the points necessary to be, understood in meter testings and candidates are requested to refer the following books for detailed study on the subjects. . ,

1) Electrical measurements and Measuring Instruments
- E.W.Golidng.
2) Meter Engineering - J.L. Funs
3) Electrical Instruments and Measurements
- W. Alaxender
4) Technical Reference Book

- A.P. Government Electrical Engineer's Association

C A P A C I T O R S

Introduction :

The course material explaining broadly the principles of operation, care an: maintenance to be carried out, protective features employed etc, is discussed so that this serves as a handy collection of useful information to the Section Officers incharge of maintenance.

CAPACITORS

Construction :

The essential elements in a capacitor are sheets of Aluminium foil, a special grade capacitor issued paper, and a container for sealing the capacitor units dielectric media such as "ALOCLOR" or Die Phynal Chlorinated Liquid etc. The foil serves as the plates of the Capacitor and the impregnated paper as dielectric Each section of the Capacitor is formed by winding the foil and the paper in coils and flattening them so that two sheets of the foil which serve as the plates lie between several layers of Capacitor tissue paper. Each capacitor unit consists of certain number of sections connected to each other and fitted with a set of leads. The sections are assembled into one unit and are inserted in a sheet metal container and hermetically sealed. The leads are brought out through the sealed porcelain bushings fitted on the cover.

Principles of Operation:

The load fed by an electrical net work contains both active power and reactive Power. Active power is measured in Kilo Watts and the reactive power in Reactive kilo Volt Amperes (R.K.V.A.). For feeding the load (in KW) with more reactive power the current drawn (in Amps.) is higher, if it is possible to reduce the reactive power component in the system the flow of current in the system will be less. This in turn reduces the loses, and improves the power factor. Also as the voltage of as the drop will be les, the voltage level will be letted.

It can be seen that when the K.V.A.R. component is reduced ϕ decreases Cos ϕ tends to Unity and the KVA output tends very nearer to KW output.

When capacitors are connected in the system, they supply the reactive power compensating the lagging reactive power of the load. The capacitors relieve the generators from the supplying of the reactive power equivalent to their capacity and also relieve lines and Transformers of this burden.

Because of the above reason, the location of the capacitors is preferred to be at or near the load centres.

Reactors :

A series reactor is used to limit the in rush currents while charging the capacitors.

Types of connections of the capacitor Banks :

Two types of connection are used for connecting the capacitor banks to the 11 KV bus which are shown in Figs. I & II**.**

Connections as shown in Fig. II are in use at Nuzvid S.S. in operation circle,. Vijayawada.

Protective Features for the equipment :

(A) Individual capacitor fuses :

When a break down occurs internally it causes a total or partial circuit of individual unit. The arc at the fault points causes generation of gas resulting in very high pressure which may cause rupture of the container. Individual fuses are provided for such unit so that the same gets isolated preventing damages likely to be caused to the adjacent units: **<u>The failure of the fuses is an indication of the faulty unit and the same is to be replaced from the system by another healthy unit.</u>**

(B) <u>Over current protection</u> :

To guard against the faults on the capacitor leads and to avoid the overloading of the capacitors, two numbers over current and the number K_L (Inverse definite minimum time).are provided on the Kiosk. The high voltage capacitors are designed to carry 130% of load current as per IS : 2834 of 1964. Hence the over current relays are provided with a setting of 130% of full load current .capacitors.

<u>(C) Unbalance Protections :-</u>

The damage to one or more units of capacitors bank depending upon the extent of over voltages will cause damages to healthy units. To avoid this type of damages two types of protection are employed as shown in Figs. I & II.

A current unbalance relay is connected between the neutrals as shown in Fig. ll or voltage unbalance relays is connected across the broken delta windings of the secondaries of the residual voltage Transformer connected as shown in Fig. I. The above relays provide the protection in the event of unbalance due to damage in one or more units.

For arrangements shown in Fig. II, it is usual to provide a C.T. of ration 10/1 and a current unbalance relay with settings of 10 to 40% with inherent time delay.

For arrangements shown in Fig. I normally a relay with a setting of 5 volts or above is adequate for isolating the bank.

<u>(d) Over CO voltage protection :-</u>

The capacitors are designed to withstand 110% of rated r.m.s. voltage continuously. Therefore the capacitors should not be operated above this voltage level.

To guard against this condition, it is provided with a over voltage relay with a setting of 110% of several rated voltage.

(E) Under voltage Protections :-

This protection is provided to switch off the bank under low voltage : conditions.

Whenever station supply fails at the S.S. having capacitor banks it is necessary the acapaciutos are allowed to discharge completely before they are recharged. An under voltage relay or a No Volt coil will detect the failure of supply and trips the capacitor.

This should not be re-charged till about 5 minutes in Which time the voltage : dies down to approximately 50 Volts or below.

Checks to be conducted Before commissioning a capacitor bank

a.) Capacitor:

1. Check all electrical and mechanical connections are done correctly and tight.
2. Measure the installation resistance by the megger 500V. between banded Terminals and Earth. The value should be > 50 M.

b) Series Reactor.: 1) Check, all electrical connections are done properly.

.2) Measure the break down voltage of Transformer oil. This should be above 30 KV/1 minute.

3) Measure the installation resistance with a 1000 V Megger.

Preventive Maintenance ;

(A) Capacitor :

1. Check the capacitors periodically preferably once in a month after switching off the capacitor and discharging it by discharging rods.
2. Check for each individual units, leakage of oil from the-terminals, welded seam, building and excessive temperature rise.
3. For bus bars check for tight connections and ensure no deformation.

4. Check for cracks and cleanliness of post type insulators.

5. Ensure tight connections and proper clearance for all connecting strips.

6. Check the racks for corrosion and dirt.

(B) Series Reactor :

1. Check the dielectric strength of oil periodically.

2. The usual maintenance done in the case of a Distribution transformer.

Important Instructions to operators on duty for Handling capacitor Banks :

1) Capacitors should not be touched or handled until supply is switched off and the banks are discharged by a suitable discharge rod.

2) The discharging of the capacitor by discharge rods should not be done before 5 minutes after capacitor bank is switched off.

3) Whenever the load on the SS is low (i.e.) less than 25 Amps, the capacitor should be removed from service immediately as this will cause raise in voltage of the system beyond permissible limits.

4) Also whenever the SS voltage is fairly good say 11.6 KV the capacitors can be taken out of service.

5) The capacitor should be switched off whenever the voltage of the system exceeds beyond 10% of normal voltage.

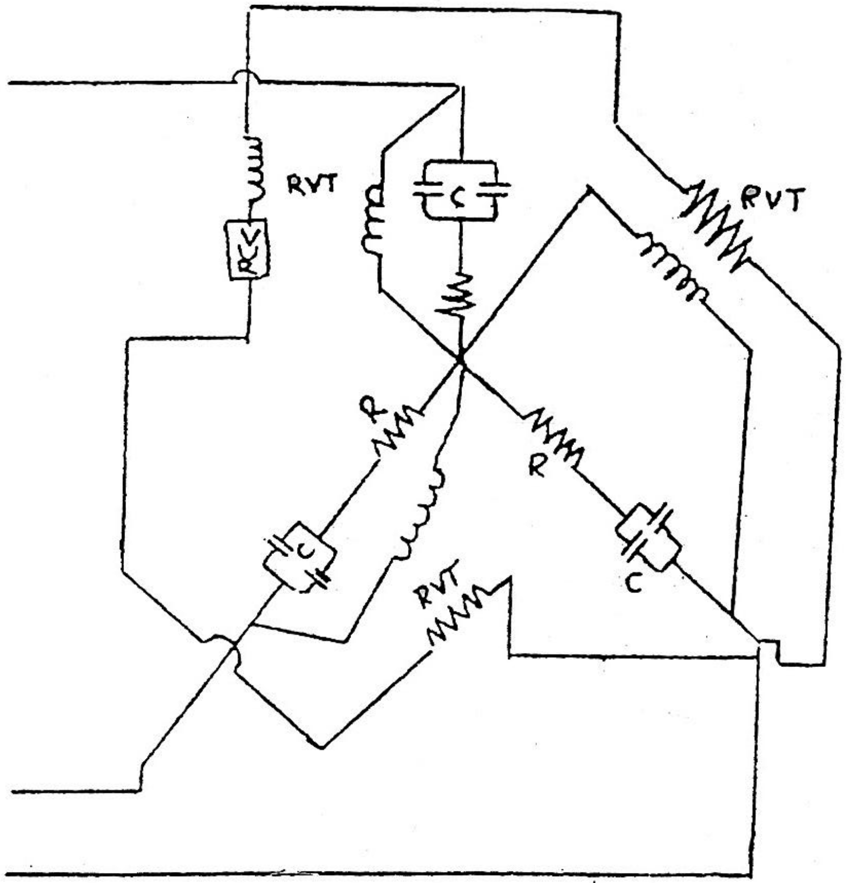
6) The capacitor should be switched off whenever the incoming supply to the capacitor fails. The capacitor should not be charged when they are cut off from the service whenever the OCB trips. A time lag of at least 5 minutes.

7) The temperature rise of capacitor container should not exceed 75^0 C. This should be measured by fixing a thermometer to the wall of the container keeping the thermometer bulb at ¼ of the height of the capacitor box dome from top edge.

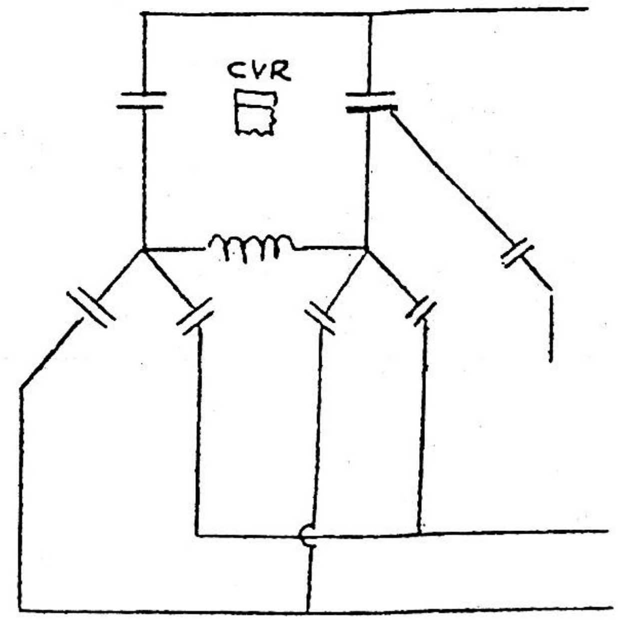
8) Whenever the capacitor expulsion fuses blow off they should be isolated and replaced with a unit of same capacity. If one unit in a bank proves fault one unit each in the inner 2 banks are to be isolated and the capacitors charged with lesser capacity till such time the defective unit is replaced.

9) It is recommend that a shelter is provided for the capacitor bank as it increases the life of the unit.

TYPE I ADOPTED AT R.C.PURAM S.S.



TYPE II ADOPTED AT NUZVID S.S.



SURGE PROTECTION

Mitigation of High-Voltage Surges :

High-voltage surges are mainly due to either a) Lightening discharges, or b) switching. The voltage set-up by lightning discharges are reduced by stringing one or two earth wires above the main conductors. The voltages set-up by switching are reduced by using resistance switching.

The direct lightning stroke to a line causes enormous voltages and there is little possibility of preventing these, it is more common for high-voltage surges to be caused by the charge induced on the conductors of an overhead line when a charged cloud passes over or near to the line. The charge induced on the conductors will have the opposite polarity to that in the cloud. If the cloud passes slowly away, the charges induced on the conductors will gradually flow to earth and no disturbance will be caused. If, however, the cloud is suddenly discharged by a lightning stroke to earth or another cloud, then the induced charge on the line will be suddenly released and a surge voltage will travel along the line in either direction.

The charge induced on an overhead transmission line system by a changed cloud is mainly concentrated in the uppermost conductor since the other conductors are to some extent electrostatically shielded by the uppermost one. If the uppermost conductor is made the earth wire and not one of the system conductors, then the charges induced on the system conductors are considerably reduced. This reduces the surges in the system conductors. It also affords some mitigation of the effects of a direct lighting stroke.

Where an earth wire is present the resistance of the tower footings just be kept low or back flashover from the earth wire may occur. For example, in the extreme case of the resistance to earth of the tower being infinite, any surge voltage wavefront reaching the tower base is doubled and reflected back to the earth wire. Eventual build-up of earth-wire potential to a value well above that of the system conductors may result in a discharge from the earth wire to the system conductors.

Transient currents and voltage naturally occur with most switching operations. Generally switehing-in and disconnecting can be performed without dangerous disturbances arising. The interruption of a high short-circuit current by an efficient circuit-breaker does, however, tend to give high-voltage surges. These can be mitigated by arranging that the circuit breaker will be opened in stags. During the stages one or more resistance sections carry the current which is being interrupted and part, atleast, of the anergy stored in the line inductance is dissipated, in the switch resistance.

Protection of installation :

The insulation which support an overhead line and the installation of cables, switches or transformers will, under some surge conditions, have voltages impressed on them which are greater than the breakdown strength of the insultators or insulation. To prevent the break-down of these costly units and to prevent the interruption of the supply which would result from their break-down. The installation is usually protected by an air-gap so arranged that the surge voltage will, produce break-down, of the air-gap rather than of the insulation. A string of insulators for an overhead line, or the bushing of a transformer, has frequently a rod gap across it Fig.1, so that a spark or an arc ill jump across the rod gap rather than down the insulators or the bushing.

Alternatively a metal ring concentric with the insulator string and about level with the third insulator shed may be used as the lower electrode in place of a' rod electrode.

When setting the rod gap two factors must be taken into account: (a) impulse ratio and (b) time factor.

$$\text{Impulse ratio} = \frac{\text{Breakdown voltage under surge conditions}}{\text{Breakdown voltage under low-frequently conditions}}$$

It is found that the breakdown voltage under surge, i.e. rapidly changing of high-frequency conditions, is often higher than the breakdown voltage under steady or low-frequency conditions. The impulse ratio is a measure of this difference. Supposing the breakdown voltage of a string of insulators is, say, 300 KV at 50Hz and that the string is protected by a rod gap with a breakdown voltage of , say, 200 KV at 50 Hz. If the impulse ratio for the insulators is, say 1.3 : than the surge breakdown voltage for the insulators will be 390 KV, and if the impulse ratio for the rod gap is, say 2.1 then the surge breakdown voltage for the rod gap will bee 420 KV. The rod gap does not then protect the insulators under surge conditions. Either the impulse ratio for the rod gap must be improved or the 50 Hz setting for the rod gap must be reduced. The impulse ratio is found to depend of the geometry of the air gap. A sphere gap, with relatively close spacing, has an impulse ratio of unity - needle gap may have an impulse ratio of between 2 and 3

TIME FACTOR :

The breakdown of insulation or an air-gap does not occure instantaneously on the application of the excess voltage. The time for the complete breakdown to develop depends (i) on the magnitude of the excess voltage (ii) on the material in the breakdown path, and (iii) on the shape and spacing of the electrodes. Naturally the greater the excess voltage the shorter is the time required for breakdown to develop atypical characteristic is shown in Fig.2.

Fig. 3 compares the characteristics of a rod gap and an insulator which are used in conjunction with one another. If the voltage across them were slowly increase the rod gap would correctly breakdown first, i.e. at the lower voltage, if a voltage greater than Vc cwer suddenly applied, the insulator would break down first and thus, under a steep-wave front surge condition, the rod gap does not protractor the insulator for all surge voltages is shown in Fig.4

The time delay is relatively short for sphere gaps and relatively long for needle gaps.

SURGE DIVERTERS :

Rather than permit a surge to impinge on the terminal apparatus it is advantageous to eliminate the surge if possible. The elimination may carried out in two ways, either (a) the surgag may be diverted to earth i.e. short circuited, or (b) the surge energy may be absorbed. The later method is not now used.

Modern surge diverters consist essentially of elements having a none-linear volt/ampere characteristic, and made of a ceramic material consisting of silicon carbide bonded with clay.

To protect plant successfully against high-voltage traveling waves, the surge diverter must operate, as far as possible, simultaneously with the incidence of the surge.

Since the surge is traveling at approximately 3 x 10^8 m/s a short delay will permit the surge to pass the diverter and be transmitted into the plant which the diverter is intended to protect. Moreover, the surge diverter should be placed as closed as possible to the plant to be protected to obviate the risk of a surge being initiated in the line between the horn gap and the plant. The line between the surge diverter and the plant should be protected by an earth wire of wires.

Fig.5 shows approximately a typical characteristic or a Metrosil disc suitable for incorporation in a surge diverter designed to operate on a high-voltage transmission system to protect transformers and other plant from high-voltage surges.

The law connecting the applied voltage and the current is of (he form V = k1B

Where k is the constant depending on the geometrical form and B is a constant depending on the composition and treatment of the substance, ideally B should be zero, so that whatever the value of the surge current the voltage would be constant. In practice values for a B of the order 0.2 are achieved.

The principle of operation is that a stack of Metrosil discs is connected between line and earth close to the transformer (or other plant) to be protected. Becuase of the nature of the volt/ampere characteristic, at normal voltage the diverter passes only a very small current to earth, but when a high over-voltage occurs the resistance of the diverter fails and the diverter passes a high current, diverting the surge energy to earth..

In practice, in a diverter suitable for operation on a 132 KV system, a stack of Metrosil discs 6 in. diameter is assembled in a glazed porcelain housing which is provided on the exterior with rain shade, which may be of a special shape for operation in dirt-laden atmospheres. Spark gaps are incorporated to prevent current flow to earth under normal-voltage conditions. The air in the interior of the porcelain housing consisting the spark-gap assembly is evacuated and then the housing is filled with nitrogen. Fig. 6 shows the details of the arrangement of 33KV Metrocil diverter and spark-gap assembly.

The diverters are mounted vertically, mechanical support being also provided at the top of the assembly for larger ratings. External stress rings are provided for ratings above 110 KV.

The diverters are normally set to operate on twice normal voltage, it being undesirable for them to operate on small over-voltages. Operation is extremely rapid taking less than micro-second. The impulse ratio is practically unit.

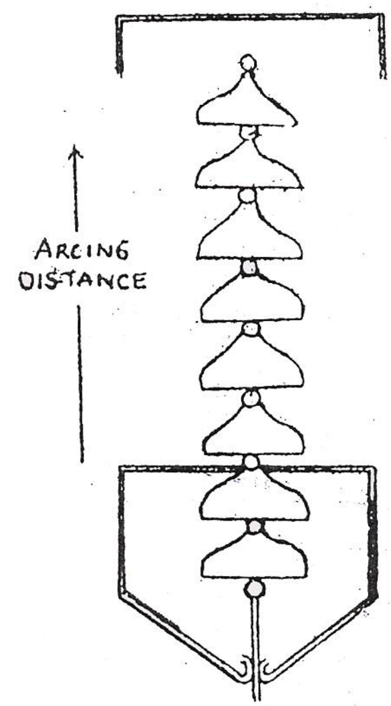


Fig. 1: Rod Gap protecting an Insulator String.

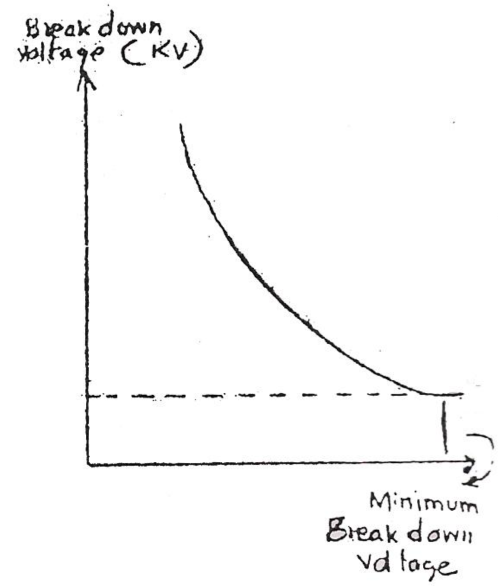


FIG 2. TYPICAL ROD GAP CHARACTERSTICS

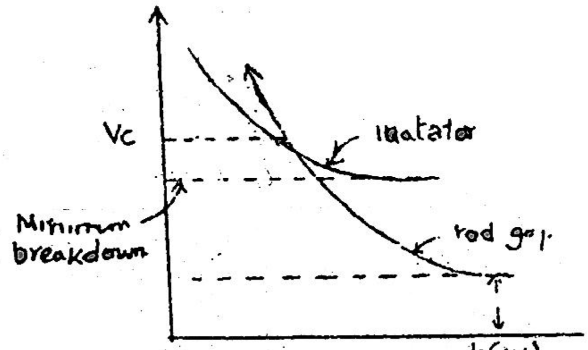


FIG 3 UNSUITABLE COMBINATIONAL INSULATOR AND ROD GAP

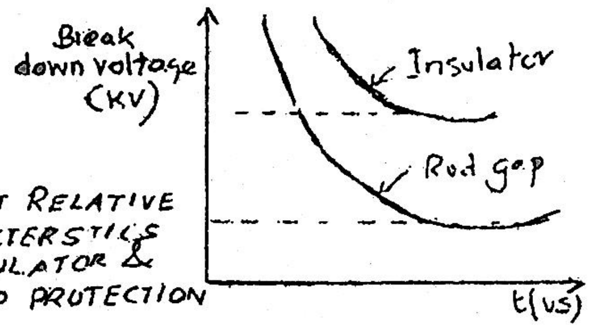


FIG 4. CORRECT RELATIVE CHARACTERSTICS FOR INSULATOR & ROD GAP PROTECTION

BREAKDOWN-VOLTAGE/TIME CHARACTERISTICS

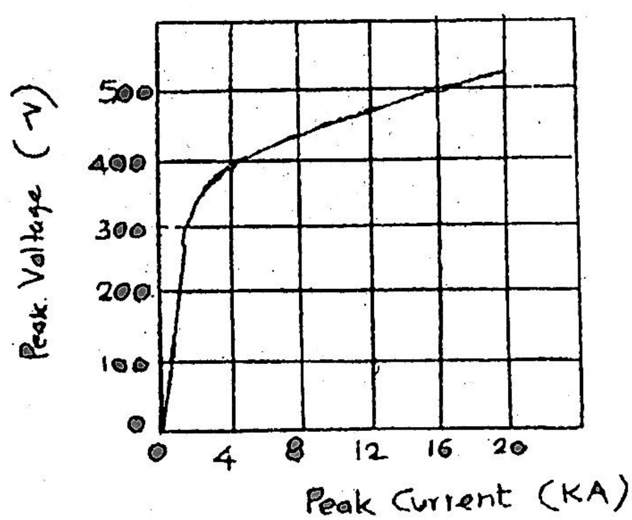


FIG. TYPICAL METROSIL VOLT/AMPRO CHARACTER-STICS

SYMMETRICAL COMPONENTS

Introduction :

The classic paper on the "Method of Symmetrical Coordinates Applied to the Solution of Polyphase Networks" was presented at the 34th Annual Conference of AIEE in Atlantic City on 28th June, 1918 by C.L. Fortesque who introduced the subject thus :

"In the later part of 1913 the writer had occasion to investigate mathematically the operation of induction motors under unbalanced conditions. The work was carried out having particularly in mind the determination of the operating characteristics of phase converters which may be considered as a particular cause of unbalanced motor operation, but scope of the subject broadened out quickly and the writer undertook this paper in the belief that the subject would be interest to many.

The most striking thing about the results obtained was their symmetry : the solution always reduced to the sum of two or more symmetric solutions. The writer was then led to inguire if there were no general principles by which the solution of unbalanced Polyphase systems could be reduced to the solution of two or more balanced cases................"

The main paper is 88 pages is long and the discussions that follow extend 24 pages in which Karaptoff has writely summed up...." Mr. Fortescue deserves the gratitude of the profession for bringing out a new method of numerical computations in unsymmetrical polyphase system..."

Operator 'a' :

Consider the cubic equatio x^3-1 = 0 which is the factored form (x - 1) (X^2+x+1)=0 yields roots of 1, -1/2+J and -1/2-J. Alternatively expressed the roots are 1/0, 1/120. 1/+240 all of magnitude unity and sysmmetrically placed on the Argand diagram at zero, + 120° and +240°. The second and the third roots are indetified as a and a^2, Substituting one of the roots a in the original cubic equation we not $a^3 = 1$.

Likewise from the quadratic factor $(a^2 + a + 1) = 0$ as $(a - 1) = 0$.

Synthesis, of Symmetrical Systems :

By inspection E_a, E_b, E_c, can be written as

$$E_a = (E_a + E_b + E_c) / 3 + (E_a + aE_b = a^{2E}{}_c) / 3 + (E_a + a^{2E}{}_b + a^{4E}{}_c)/3$$

$$E_b = (E_a + E_b + E_c) / 3 + (a^{-1}E_a + aE_b + a^2E_c)/3 + (a^{-2}E_a + a^2E_b + a^4 E_c) /3$$

$$E_c = (E_a + E_b + E_c) / 3 + A^{-1}(E_a + aE_b + a^2E_c)/3 + a^{-4}(E_a + a^2E_b + a^4 E_c) /3$$

Note : $1 + a^{-1} + a^{-2} = 1 + a^3 a^{-1} + a^3 a^{-2} = 1 + a^2 + a = 0$

$$1 + a^{-2} + a^{-4} = a + a^3a^{-2} + a^3a^3a^4 = 1 + a + a^2 = 0$$

This set is true whatever be the nature of Ea, Eb, Ec and therefore it is true of all numbers, real, complex or imaginary, whatever they may represent and therefore similar relations may be obtained for current vectors and impedance operations.

The set of equations can be rewritten as

$$E_a = E_{ac} = E_{a1} + E_{a2}$$

$$E_b = E_{bc} + a^{-1}E_{a1} + a^{-2}E_{a2}$$

$$E_c = E_{cc} + a^{-2}E_{a1} + a^{-4}E_{a2}$$

The first term in each of the equation represents a set of equal vectors 1/3 $(E_a+E_b+E_c)$: : The second term represents a set of vectors $E_{a,}$ $a\text{-}^{1}E_{a1}$, $a^{-2}E_{a1}$, whose sum is zero.

Likewise, the third term represents yet another set E_{a2}, $a^{-2}E_{a2,}$ $a^{-4}E_{a2}$, whose sum is also zero. We indetify sets of equal vectors whose sum is zero as symmetrical sets. The set E_{a2}, $a^{-1}E_{a2,}$ $a^{-2}E_{a2,}$ can be rewritten as E_{a1}, $a^{2}E_{a1,} = E_{c2}$, and represented graphically as shown is Fig. 1 (a) Likewise the set E_{a2}, $a^{-2}E_{a2,}$ $a^{-4}E_{a2}$ can be rewritten as E_{a2}, $aE_{a2,}$ $a^{2}E_{a2}$ and represented as at Fig. 1 (b).

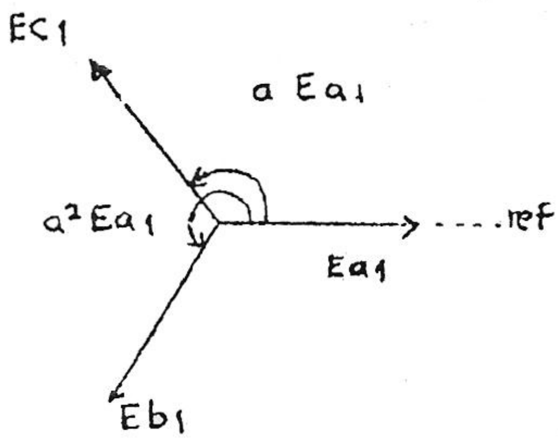


Figure - 1 (a)

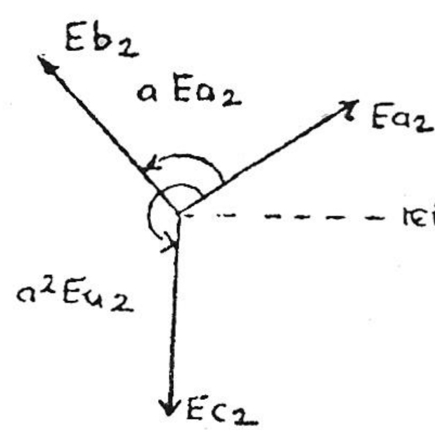


Figure - 1 (b)

Phase sequence should not be confused with the rotation of vectors. Both positive and negative sequence vectors could be rotated in the same direction but the sequence in which they reach their maxima - minima are different.

In view of the symmetry the choice of one vector from each set is adequate to determine the remaining members of the sets. Choosing E_{a0}, E_{a1} E_{a2} we have

$$E_a = E_{ao} + E_{a1} + E_{a2}$$

$$E_b = E_{ao} + a^2E_{a1} + aE_{a2} \qquad \text{........ (3)}$$

$$E_c = E_{ac} + aE_{a1} + a^2E_{a2}$$

In matrix notation

$$\begin{bmatrix} E_a \\ E_b \\ E_c \end{bmatrix} \begin{matrix} \\ = \\ = \end{matrix} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} E_{a0} \\ E_{a1} \\ E_{a2} \end{bmatrix} \qquad \text{........ (4)}$$

From (1) and (2) the inverse relations of (5) can be written down

$$E_{ao} = (E_a + Be + E_c) / 3$$

$$E_{a1} = (E_a + aE_b + a^2E_c) / 3 \qquad \text{........ (5)}$$

$$E_{a2} = (EE_a + a^2E_b + aE_c) / 3$$

In matrix function

$$\begin{bmatrix} E_{a0} \\ E_{a1} \\ E_{a2} \end{bmatrix} \begin{matrix} = \\ = \\ = \end{matrix} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} E_a \\ B_e \\ E_c \end{bmatrix} \qquad \text{........ (6)}$$

Substituting (6) in (4) establishes h^{-1} the identity.

(A) $(A)^{-1} = 1$

$$\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a \\ 1 & a^2 & a \end{bmatrix} \textbf{X1/3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Operators J and a:

Operator j causes rotation through $+90^0$ such that two successive operations of yields a rotation through 180^0
i.e., (j) (j) = -1. By definition a = 1 1/$\underline{120^0}$

…a^2 = a. a = 1/$\underline{240^0}$
and a^3 = a.a a = /$\underline{360^0}$ yielding the original vector. An important difference must be noted between the use of operator j and a. The operator j is unit magnitude at $+90^0$ and –J means that the complex number j is changed by an angle of 180^0 to give unit magnitude at 270^0 Thus j=1/$\underline{90^0}$ and –j=1/$\underline{270^0}$h = 1/$\underline{-90^0}$

Hence it is sometimes said that +j indicates rotation through $+90^0$ while –j indicates rotation through -90^0. Similar statement with regard to operator a is not correct. Since = 1/$\underline{120,}$ -a = 1/$\underline{180}$

1/$\underline{120}$ = 1/$\underline{300}$ = 1/$\underline{-60}$ = 1/$\underline{-120}$. See Fig.2

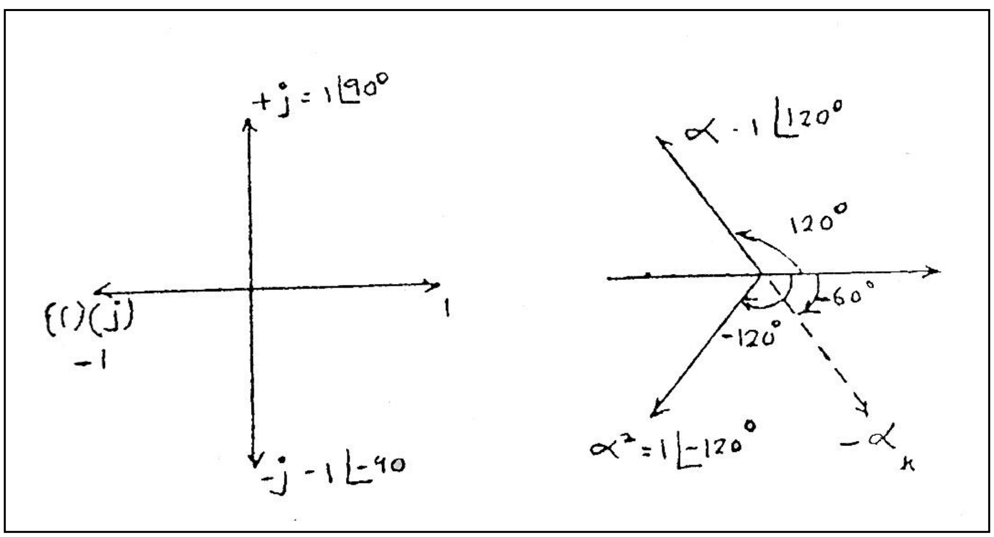


Table 1: Properties of the Vector Operation "a"

$1=1 + j\ o = \varepsilon j^{0}$

$a= -1/2 + j\ \sqrt{3}/2 = \varepsilon j^{0}$

$a^{2} = -1/2 - j\ \sqrt{3}/2 = \varepsilon j^{240}$

$a^{3} = 1 + j^{0} = \varepsilon j^{0}$

$a^{4} = a = -1/2 + j\ \sqrt{3}/2 = \varepsilon j^{120}$

$a^{5} = a^{2} = -1/2\ j\ \sqrt{3}/2 = \varepsilon j^{240}$

$a + a^{2} + 1 = 0$

$a + a^{2} = -1 = 0$

$a + a^{2} = -1 + \sqrt{}\ j^{0} = \sqrt{3}\ \varepsilon j^{180}$

$a - a^{2} = 0 + \sqrt{}\ j^{3} = \sqrt{3}\ \varepsilon j^{90}$

$a^{2-a} = 0 - j\ \sqrt{3} = \sqrt{3} = \varepsilon j^{270}$

$1-a = 3/2 - j\ \sqrt{3}/2 = j\ a^{2}\ \sqrt{3} = \sqrt{3}\ \varepsilon\ j^{330}$

$1- a^{2} = 3/2 + j\ \sqrt{3}/2 = -ja\ \sqrt{3} = \sqrt{3}\ \varepsilon\ j^{30}$

$a-1 = -3/2 + j\ \sqrt{3}/2 = -j\ a^{2}\ \sqrt{3} = \sqrt{3}\ \varepsilon\ j^{150}$

$a^{2}-1 = -3/2 + j\ \sqrt{3}/2 = -j\ a\ \sqrt{3} = \sqrt{3}\ \varepsilon\ j^{210}$

$1 = a = -a^{2} = ½ -j\ \sqrt{3}/2 = \varepsilon\ j^{300}$

$(1 + a)\ (1 + a^{2}) = 1 + jo = \varepsilon\ j^{0}$

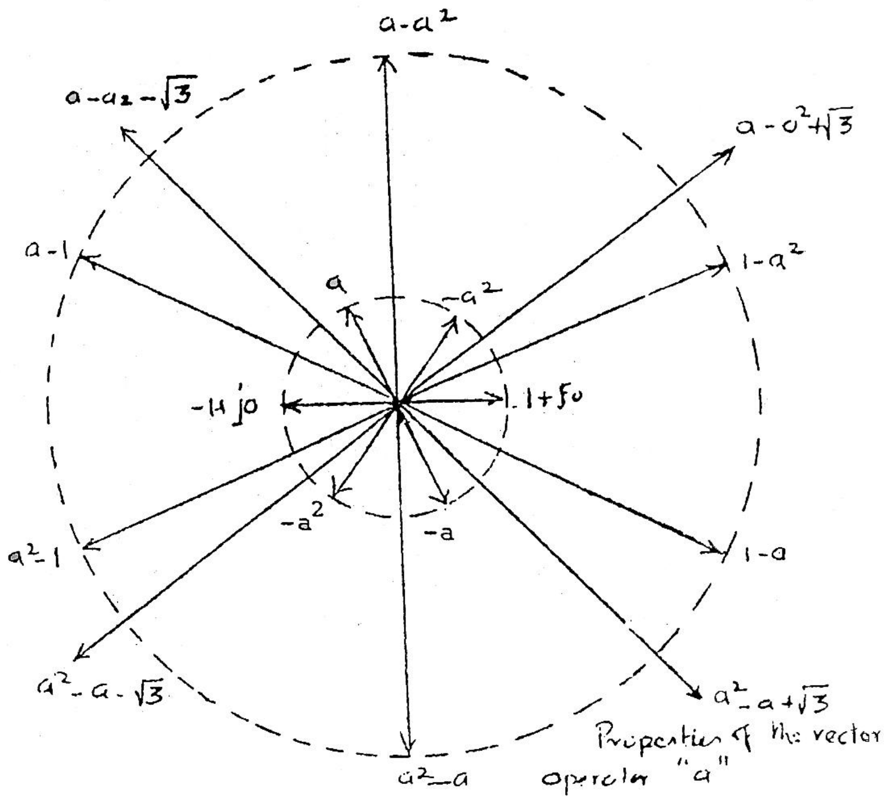
$(1 - a)\ (1 - a^{2}) = 3 + jo = \varepsilon\ j^{30}$

$1 + a/1 + a^{2} = a = -1/2 + j\ \sqrt{}\ 3/2 = \varepsilon\ j^{120}$

$1 – a/1 - a^2 = -a = ½ -j \sqrt{3}/2 = \varepsilon\, j^{300}$

$(1 + a)^2 = a = -1/2 + j \sqrt{3}/2 = \varepsilon\, j^{120}$

$(1 + a) / (1 + a^2) = a^2 = -1/2 + j \sqrt{3}/2 = \varepsilon\, j^{240}$



Numerical Illustrations

i. given $V_a = 10/\underline{30^0-}$, $V_b = 30/\underline{-60}$, $V_c = 15/\underline{145^0}$,

determine the symmetrical components in terms of phase a.

$V_{a1} = 1/3\ (10/\underline{30} + a\ 30\ /\underline{-60} + a^2 15/\underline{145.})$

$= 1/3\ (10/\underline{30} + a\ 30\ /\underline{-60} + a^2 15/25) = 12.42 + j12.45 = 17.6 / 45^{02})$

$V_{a2} = 1/3\ (10\underline{30} + a2\ 30\ /\underline{-60} + a\ 15/\underline{145.})$

1/3 (10/30 + 30/180 + 15/265) = -7.55 –j3.32

= 8.25 / -156.2

V_{ao} = 1/3 (10/$\underline{30}$ + 30/-60 + 15/145) = 3.79 –j 4.13

= 5.60 - /47.4

One conductor of a 3-phase line is open,. The current flowing to the delta connected load through line a 10A. with the current in line a as reference and assuming that line c is open. Find the symmetrical components of the currents.

I_{ao} = 1/3 (10/$\underline{0}$ + 10 /180 + 0) = zero

I_{a1} = 1/3 (10/$\underline{0}$ + 10 /300 + 0)

= 5 – j 2.89 = 5.78 /+30

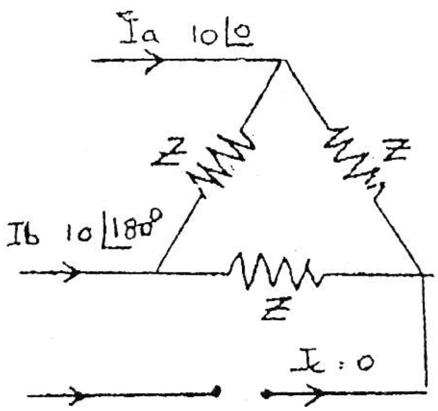
I_{a2} = 1/3 (10/$\underline{0}$ + 10 /60 + 0)

= 5 + j 2.89 = 5.78 /+30

I_{b1} = a2I $_{a1}$= 5.78/-$\underline{150^0}$

I_{b2} = a2I $_{a2}$= 5.78/+$\underline{150^0}$

I_{b0} = I $_{ao}$= 0



Note that even through I_c = 0 components I_{c1} and I_{c2} exists.

Tutorial problems:

V_a =150/$\underline{0}$, V_b =86.6/$\underline{-90^0}$ V_c = 86.6 /$\underline{90^0}$

Ans: V_{a1} = 100/$\underline{0}$, V_{a2} =0, V_{ao} -50/$\underline{0}$

I_{a1} = 91/30, I_{a2} = 24.4 /-30 I_{ao} = 33.3/-90

Ans: I_a =100 I_b =100/$\underline{-90^0}$ I_c = -100

In may be seen that simultaneous presence of three sets of balanced voltages (currents) results in a set of unbalanced voltages. At first glance it would appear that three unbalanced voltages have been resolved into nine component voltages complicating the problem. However, it is observed that the inherent symmetry permits the use of only their balanced components voltages which can be trated on per phase basis. In symmetrical circuits, currents and voltages of different sequence do not react upon each other; currents of positive – sequences, similarly currents of negative. Sequence and zero-sequence produce respectively voltage drops of negative and zero-sequence. Fudamental relations have been developed to deal with unsymmetrical circuits which cause interaction of sequence quatities.

The symmetrical components provide discriminating control parameters in dealing with problems of stability, damper winding torque, ground faults etc.

Three – phase Line – to Line Voltages :

The line-to-line voltages of either star or delta in terms of line-to-line neutral voltages are:

$$V_{ab} = V_{an} - V_{bn}$$

$$V_{bc} = V_{bn} - V_{cn}$$

$$V_{ca} = V_{cn} - V_{an}$$

Regardless of the unbalance in Line-to-Line voltages their sum is zero. Thus the zero sequence component of the Line-to-Line voltages :

$$V_{abc} = V_{bco} = V_{cao} = 1/3\,(V_{ab} - V_{bc} - V_{ca}) = 0$$

Therefore three – phase line-to-line voltages can be represented by positive and negative sequence system of voltages only. This fact is used extensively in rotating machine analysis.

The positive – sequence component of the Line-to-line voltages :

$$V_{ab1} = 1/3\ (V_{ab} + a\,V_{bc} + a^2 V_{ca})$$

Replace V_{ca} by – $(V_{ab} + V_{bc})$

$$V_{ab1} = 1/3\,(V_{ab}\,(1-a^2) + V_{bc}\ (a- a^2)$$

$$=1/3\,[\sqrt{3}\,V_{ab}\ /\underline{30} + \sqrt{3}\ V_{bc}/90]$$

$$= /30\ /\ \sqrt{3}\ [\ V_{ab} + V_{bc}/60\ ]$$

In terms of positive sequence components of L-N voltages

$$V_{ab1} + V_{a1} - V_{b1} = V_{a1}(1 - a^2) = \sqrt{3}\, val\, /\underline{30} \quad \ldots\ldots \quad (8)$$

If follows that

$$V_{a1} = 1/3\ [\ V_{ab} + V_{bc}\ /\underline{60}) \quad \ldots\ldots \quad (9)$$

The negative – sequence component of Line-to-line voltages

$$V_{ab2} = 1/3\ (\ V_{ab} + a^2 V_{bc} + a\, V_{ca})$$

$$= 1/3\ (\ V_{ab}(1\text{-}a)\ +\ V_{bc}\ (a2\text{-}a)$$

$$= 1/3\ \sqrt{3} V_{ab} - 30 + V_{bc}\ /\text{-}\underline{60})$$

$$= /\text{-}30\ /\ \sqrt{3}(V_{ab}\ +\ V_{bc}\ /\underline{\text{-}60}) \quad \ldots\ldots \quad (10)$$

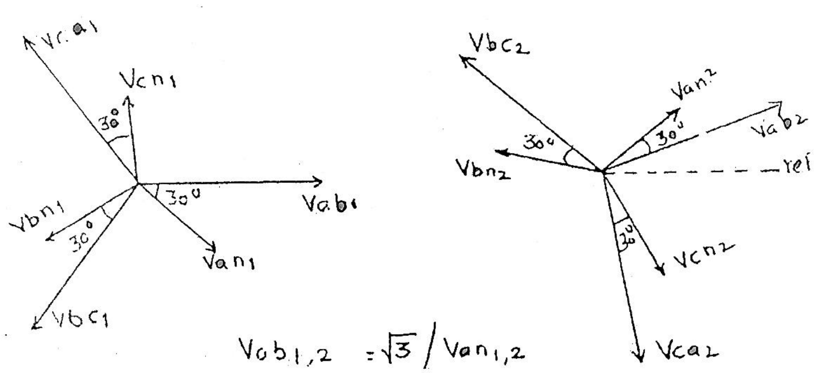
In terms of the negative – sequences component of line-to-neutral voltages

$$V_{ab2} = V_{a2} - V_{b2} = V_{a2}\ (1\text{-}a) = \sqrt{1/3} V_{a2} /\underline{30} \quad \ldots\ldots \quad (11)$$

It follows that

$$V_{a2} = 1/3\ (\ V_{ab} + V_{bc}\ /\text{-}\underline{60}) \quad \ldots\ldots \quad (12)$$

Graphic representation of eqn. (8) and (11) is given in Fig. 3 with Vab1 reference
:



It is instructive to note that while there is no zero-sequence component of line-to-line voltages there could exist zero-sequence component of line-to-neutral voltage as illustrated in the following example:

V_{an} = 10/0 ; V_{bn} = 20/-90 ; V_{cn} = 10/135

= 10 + Jo = -j20 = -7.07 + j 7.07

The line –to-line voltages are

$V_{ab} = V_{an} - V_{bn}$ = 10 + j 20

$V_{bc} = V_{bn} – V_{cn}$ = 7.07 – j 27.07

$V_{ca} = V_{cn} - V_{an}$ = 17.07 + j 7.07

V_{abo} = 1/3 ($V_{ab} + V_{bn} + V_{ca}$) = 0

V_{ano} = 1/3 (V_{an} = $V_{bn} + V_{cn}$) = 0.98 – j 4.31

If zero-sequence components of both line-to-line voltages and line-to-neutral voltages are zero the system is balanced.

Theorem:

The centroid of the triangle of line-to-line voltages locates the netutral in the absence of zero-sequence line-to-neutral voltage.

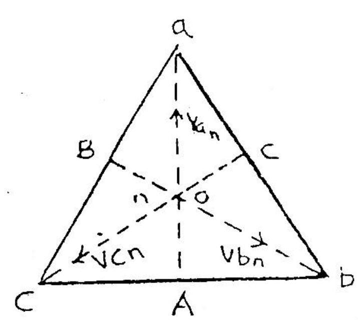
The validity of this can be established by showing that the vector sum of na, nb, nc vanishes in the construction shown in fig. A, B, C are mid point of the sides opposite a, b, c. The medians a A, bB, cC, intersect at the centroid n. The medians are divided in the ratio 2:1 by n. Therefore.

V_{an} = an = 2/3 (Ab + ba)
= 2/3 (1/2 V_{bc} + V_{ab})
= 1/3 (V_{ba}) + 2/3 (V_{ab})

Similarly,

V_{bn} = nb = 2/3 (Bc + cb) = 1/3 V_{ca} + 2/3 V_{bc}

V_{cn} = nc = 2/3 (C_a+ac) = 1/3 V_{ab} + 2/3 V_{ca}



Adding the three results

$$V_{an} = V_{bn} + V_{cn} = V_{ab} + V_{bc} + V_{ca} = 0$$

This shows that the ser of star voltages V_{an} , $V_{bn,}$ V_{cn} is the quinlent set a delta voltage V_{ab}, $V_{bc,}$ V_{ca} such that there are no sequence voltages.

<u>Graphical constructions for zero sequence voltage :</u>

Based on its definition the zero-sequence component can be determined by taking one third the vector sum of the three phase voltages. The method is simple and direct.

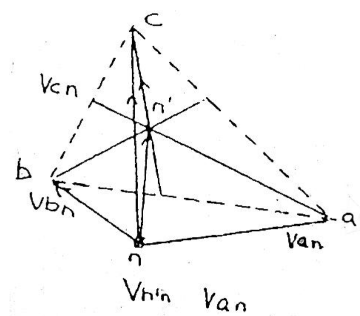
Another method involves completing the triangle of L-L voltages joining the extremeties of the phase voltage vectors, determining the certroid of this triangle. The vector from the system neutral to the centroid then gives the zero sequence voltage in proper phase and magnitude with respect to the L-N voltages, see Fig.

Tutorial :

Given $V_a = 1000 / \underline{35^0}$
$V_b = 3000 / \underline{100^0}$
$V_c = 2000 / \underline{270^0}$

Obtain sequence components graphically.

Ans : $V_{a1} = 1077/\underline{186^0}$, $V_{a2} = 1800 / \underline{6^0}$
$V_{ao} = 516 / \underline{79^0}$

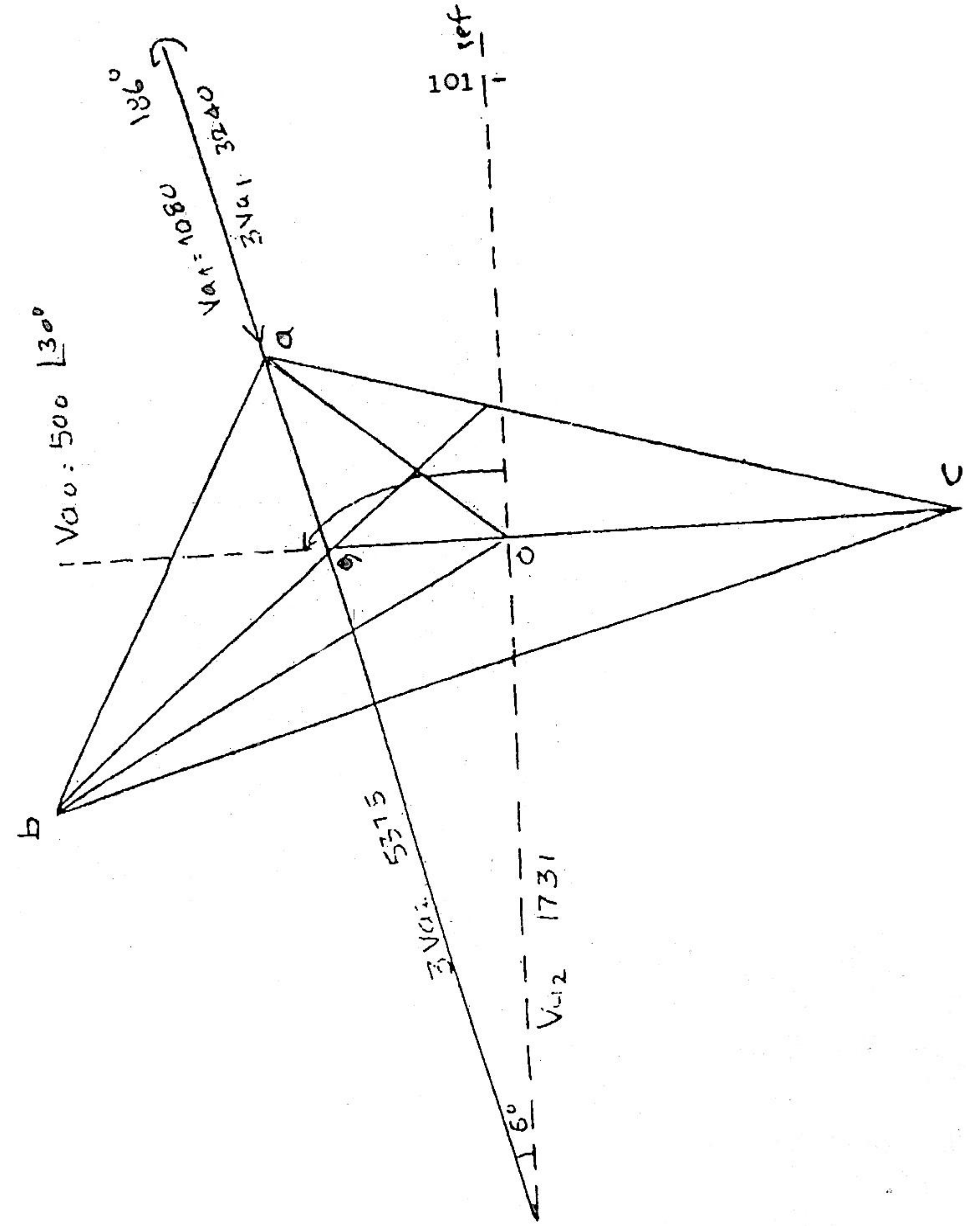


<u>Graphical Construction :</u>

In terms of L-L voltages which constitute a closed triangle we have sent that

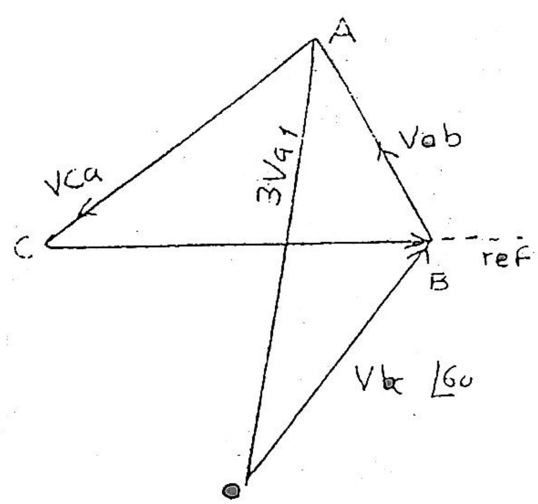
$$V_{a1} = 1/3\ [\ V_{ab} + V_{bc}\ /60]\ \text{and}\ V_{a2} = 1/3\ [V_{ab} + V_{bc}\ /\text{-}60\ ]$$

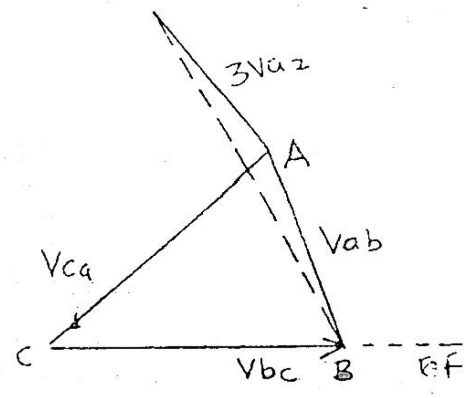
These equations suggest simple geometric construction for evaluating the sequence of L-N voltages.



Positive sequence Va 1 :

Construct the triangle ABC with BC as reference. D is the vertex of the equilateral triangle BCD. The vector DA then represents 3 V_{a1} in magnitude and phase. See Fig.





Proof : CB = V_{abc} **BD = BC /** $\underline{60^0}$

i.e., BD = - BD = CB / $\underline{60^0}$ = Vbc / $\underline{60^0}$

DA + DB = BA

Vbc / 60 + V_{ab} = 3 V_{a1}

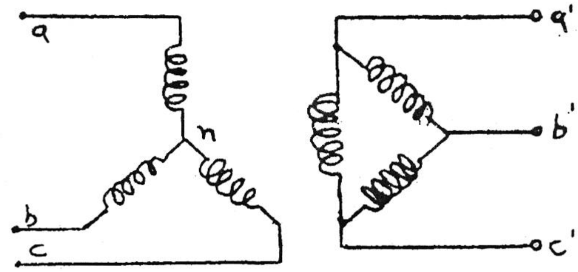
ii. Negative Sequence Va2 :

Construct the equivaloral triangle CBE (on the other side of D. EA represents 3 Va2 to scale both in magnitude and phase.

Delta - star Transformer Banks :

Example : In a delta - star bank the operation of the three transformers and their polarities of windings are such that (see Fig.)

X A : $V_{a,b,} = n V_a$
X B : $V_{b,c,} = nV$
X C : V,.. = n V



When n is the voltage transformation ratio. The primary line-line voltage are unbalanced such that V_{ab1} = 4000 /-<u>60⁰</u> V_{ab2} = 1000 /-<u>90⁰</u> Determine $V_{ab,}$ $V_{bc,}$ and V_{bc}

Solution :

V_{an1} = (Vab1) / -3 /<u>-30</u> = (4000) √3 /<u>-90</u>

V_{an2} = (V_{ab2}) √ 3 /30 = (1000) √3/<u>-60</u>

V_{an} = V_{an1} + V_{an2} = √3 (4000 / <u>-90</u> + 1000/<u>-60</u> = (1000) √3/<u>-60</u>

= 1 √3(500 – j 4866)

= 2820/84.1

V_{ab} = 10 x 2820 / -84.1 = 28,200 /-84.1

V_{bn} = a^2V_{an1} + aV_{an2} = 1 √3 (4000 / 150 + 1000/60)

= 1/√3 (-2000/ √3 + j 2000 + 500 + j 500 / √3)

= 1/√3 (-2964 + j 2866) = 2380 / 136^0

V_{bc} = 10 x 2820 / <u>136</u> = 23600 / 136

V_{cn} $= a^2V_{an1} + a^2V_{an2} = 1 / \sqrt{3}$ (4000 / $\underline{30}$ + 1000/$\underline{180}$)

$= 1 / \sqrt{3}$ (2000 / $\sqrt{3}$ + j 2000 – 1000)

$= 1 / \sqrt{3}$ (2464 / j 2000) = 1830/39.20

V_{ab} $= V_{an} - V_{bn} = 1/ \sqrt{3}$ (500 – j 4866 + 2964 – j 2866)

$= 1 / \sqrt{3}$ 3464 –j 7732) = 4870 / -66^0

V_{bc} $= V_{bc} - V_{an} = 1/ \sqrt{3}$ (-2964 + j 2866) - 2464 – j 2000)

$= 1 / \sqrt{3}$ (-5428 + j 866) = 3175 / 171^0

Impedance to positive – negative- , and zero-sequence currents :

These are defined as flows :

Impedance to positive – sequence $Z_{a1} = V_{a1} / I_{a1}$

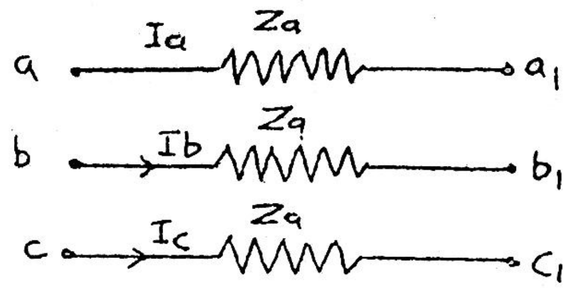
Impedance to negative – sequence $Z_{a2} = V_{a2} / I_{a2}$

Impedance to zero – sequence $Z_{a0} = V_{a0} / I_{a0}$

Impedance to zero – sequence Zao = vao/Iao_{a1}

When a balanced voltage of a given sequence is applied to a symmetric device a definite current of the same sequence flows, the ratio of voltage to current defines the impedance to that sequence. The impedance of symmetrical static networks are the same for the positive and negative sequence impedances are different.

$V_{aa} = I_a z_a$
$V_{bb} = I_b z_a$
$V_{cc} = I_c z_a$



Resolve the voltage and currents into their symmetrical components.

$$V_{aa1} + V_{aa2} + V_{aa0} = (I_a + I_{a2} + I_{a0})\, z_a$$

$$a^2V_{aa1} + aV_{aa2} + V_{aa0} = (a^2I_{a1} + aI_{a2} + I_{a0})\, z_a$$

$$aV_{aa1} + a_2V_{aa2} + V_{aa0} = (aI_{a1} + a^2I_{a2} + I_{a0})\, z_a$$

Multiply the second line by a and third by a2 and add

$$3V_{aa1} = 3\, I_{a1}z_a$$

Multiply the second line by a2 and third by a and add

$$3V_{aa2} = 3\, I_{a2}z_a$$

Add the three equations

$$3V_{aa0} = 3\, I_{a0}z_a$$

It is seen that each sequence of current produces voltage drop only of that sequence. There is thus no mutual coupling between sequence networks in symmetrical cases.

Sequence Components of Three Unequal self-impedences :

$$Z_{aa1} = 1/3\, (Z_{aa} + az_{bb} + a2z_{cc})$$

$$Z_{aa2} = 1/3\, (Z_{aa} + az_{bb} + a2z_{cc})$$

$Z_{aa0} = 1/3\ (Z_{aa} + z_{bb} + z_{cc})$

Z_{aa1}, z_{aa2}, z_{aa0} are called positive called positive - sequence, negative - sequence and zero-sequence impendence respectively. These have no physical signifince but are useful in analysis.

Sequence rule as applied to Component Voltages :

If the voltages drop across one phase is written in terms of the symmeotrical components of both current and impudence, nine component voltages appear.

$$V_a = I_a Z_a$$

$$= (I_{a1} + I_{a2} + I_{ac})(Z_{aa1} + Z_{aa2} + Z_{aa0})$$

$$+\ I_{a1} + Z_{aa1} + I_{a1} Z_{aa2} + I_a\ Z_{aa0}$$

$$+\ I_{a0} + Z_{aa1} + I_{a0} Z_{aa2} + I_{a0}\ Z_{aa0}$$

These nine components can be grouped in such a manner as to form the positive -, negative -, and zero - sequence components of Va. This grouping may be made in accordance with an easily remembered rule :

Sequence Rule :

The order of voltage system to which an IZ drop belongs is equal to the sum of the order of the systems to which I and Z belong individually.

Positive sequence terms are of first order
Negative sequence terms are of second order
Zero sequence terms are of zero order

Using the sequence rule the nine components can be grouped as

$$\begin{matrix} (I_{a1}\ Z_{aa0} + I_{a2} Z_{aa2} + I_{ac}\ Z_{aa1}) \\ +\ (I_{a1}\ Z_{aa1} + I_{a2} Z_{aa0} + I_{ac}\ Z_{aa2}) \\ +\ (I_{a1} Z_{aa2} + I_{a2} Z_{aa1} + I_{a0}\ Z_{aa0}) \end{matrix} = \begin{bmatrix} V_{a1} \\ +V_{a2} \\ +\ V_{a0} \end{bmatrix}$$

Application of Sequence rule to Unbalanced 3-Wire Loads :

In a three wire unbalanced load the absence of neutral implies absence of the zero sequence current lao.

This results in only two equations.

$$V_{a1} = I_{a1} Z_{aa0} + I_{a2} Z_{aa2}$$

$$V_{a2} = I_{a1} Z_{aa0} + I_{a2} Z_{aa0}$$

Examble :

An unbalanced 3-wire star-connected load is supplied from an unbalanced system of voltages as shown :

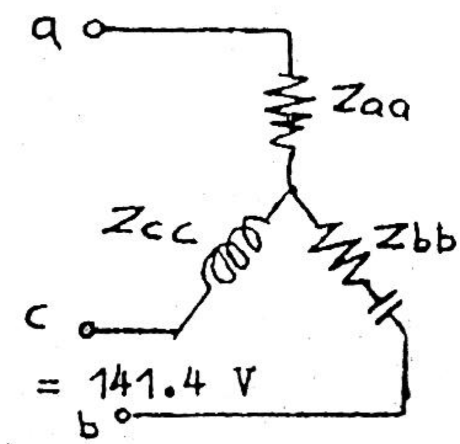
$Z_{aa} = 6 + jo$ ohms

$Z_{bb} = 5.2 – j\ 3$ ohms

$Z_{cc} = 0 + j\ 12$ ohms

$V_{ab} = 200\ V_1$ $V_{bc} = 141.4\ V_1$ $V_{ca} = 141.4$ V

$V_{ca} = 141.4$ V



Determine the line current la, Ib, Ic using symmetrical components (ii) verity the result by conventional circuit analysis.

Solution :

with Vab as reference and the sequence ab-bc-ca.

$V_{ab} = 200\angle 0$; $V_{bc} = 141.4\angle -135°$; $V_{ca} = 141.4\angle +135°$

Resolving the voltages into their symmetrical components

$V_{ab1} = 1/3\ (200\angle 0 + 141.4\angle -135°; + 120° + 141.4\angle 135-120)$

$= 157.8\angle 0$

$V_{ab2} = 1/3\ (200\angle 0 + 141.4\angle -135°; - 120° + 141.4\angle 135-120)$

$= 42.3\angle 0$

V_{abc}= Zero

$V_{an1} = V_{ab}/\sqrt{3}$ /-$\underline{30}$ = 91 / $\underline{-30}$ = 78.85 – j 45.5

$V_{an2} = V_{ab2}/\sqrt{3}$ /$\underline{30}$ = 24.4 / $\underline{30}$ = 21.15 + j 12.2

The symmetrical component of impedances are :

Z_{aa1} = 1/3 [(6+j0) + (5.2-j3) (-0.5+j0.866)+(0+j12) x (-0.5 –j 0.866)]

= 1/3 [(6+j0) + (0+j6)+(10.4 – j6)]

= 1/3 (16.4 + j0) = 5.47 + j0 = 5.47/0

Z_{aa2}= 1/3 [(6+j0) + (5.2-j3) (-0.5+j0.866)+(0+j12) (-0.5 –j 0.866)]

= 1/3 [(6+j0) + (-5.2-j3)+(-10.4 – j6)]

= 1/3 (-9.6 – j9) = (-3.2 – j3) = 4.38/-136.8

Z_{aa0}= 1/3 [(6+j0) + (5.2-j3) = (0+j12)]

= 1/3 [(11.2+j9) = 3.73 + j3 = 4.78/$\underline{38.8°}$

V_{a1} = 1a1zaa0 + la2zaa2

91/-$\underline{30}$ = la14.78 / $\underline{38.8}$ + la24.38 / $\underline{-136.8}$

$V_{a2} = I_{a1} Z_{aa1} + I_{a2} Z_{aa0}$

24.4/$\underline{30}$ = I_{a1} 5.47 / $\underline{0}$ + I_{a2} 4.78 / $\underline{38.8}$

Solving simultaneous equations for la1 and la2

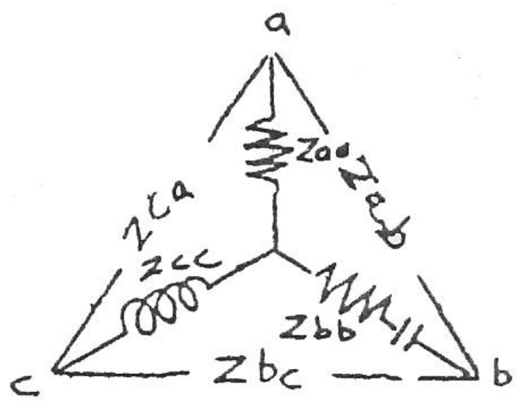
I_{a1} = 10.95 /39.8 = 8.42 – j7.02

I_{a2} = 11.8 /77.4 = 2.56 + j11.5

$I_a = I_{a1} + I_{a2} = 10.98 + j4.48 = 11.8/\underline{22.8}$

$V_{an0} = I_{a1} Z_{aa2} + I_{a2} Z_{aa1} = -34 + 60.2$

The voltage-to-Neutral



$V_{an} = V_{an1} + V_{an2} + V_{an0}$

$= 78.85 - j\,45.5$

$21.15 + j\,12.3$

$-34.0 + j\,60.2$

$= 66. + j26.9$ V

ii.Conventional circuit analysis :

Replace the star load impedance by their equivalent delta.

$Z \;\; = (Z_{aa}\; Z_{bb} + Z_{bb}\; Z_{cc} + Z_{cc}\; Z_{aa}) / Z_{cc}$

$= 9.7 - j5.7 = 11.2\,/\underline{-30} \quad Z_{aa}\; Z_{bb} = 31.2 - j18$

$Z_{bc} = \varepsilon/Zaa = 11.2 + j\,19.4 = 22.5 / 60\; Z_{bb}\; Z_{cc} = 36 + j\,62.4$

$Z_{ca} = \varepsilon / Z_{bb}\; 23.1/90 \qquad Z_{cc}\; Z_{aa} = +j\,72/\varepsilon = 67.2 + j\,116.4$

$I_{ab} = V_{ab} / Z_{ab} = 200/\underline{0/1}1.2/\underline{-30} = 17.85/30 = 15.4 + j8.92$

$= \underline{134.5/60}$

$I_{ca} = V_{ca} / Z_{ca} = 141.\underline{4/13.}5/23, /\underline{90} = 6.15/\underline{45} = 4.35 + j\,4.35$

$I_a = I_{ab} - I_{ca} = 11 + j\,4.57$ (checks)

$V_{an} = I_a\ Z_{aa} = (11 + j\,4.57)(6+j0)$

$= 66 + j\,27.42$ (checks)

Power from Symmetrical Components :

For any unbalanced 3 - phase system the total power consumed is the sum of powers absorbed in each phase.

Thus $P = P_a + P_b + P_c$

$= V_a\, I_a \,Cos\, \phi_a + V_b\, I_b\, Cos\, \phi + Vclc\, Cos\, \phi c$

Where is the angle between V, Ia, etc. Each of the phase components can be resolved into symmetrical components of voltage and current yielding nine component terms.

$Pa = V_{a1}\, I_{a1}\, Cos\, \phi_a 1 + V_{a1}\, I_{a2}\, Cos\, \phi 2 + V_{a1}\, I_{a0}\, Cos\, \phi 3$

$+ V_{a2}\, I_{a1}\, Cos\, \phi_a 4 + V_{a2}\, I_{a2}\, Cos\, \phi 5 + V_{a2}\, I_{a0}\, Cos\, \phi 6$

$+ V_{a0}\, I_{a1}\, Cos\, \phi_a 7 + V_{a0}\, I_{a2}\, Cos\, \phi 8 + V_{a0}\, I_{a0}\, Cos\, \phi 9$

Where 0 is the angle between the voltage and current of that term. Similar expressions can be written for Pb and Pc. Noting the symmetry on simplification, we find tha

$P=P_a\, P_b\, P_c$

$= 3\, V_{a1}\, Cos\, \phi 1a / Val + 3V_{a2} Cos\, \phi 1_{a2} / V_{a2}$

$+ 3\, V_{a0}\, I_{a0} Cos\, \phi 1_{a2} / V_{a2}$

In a similar manner the copper loss for any unbalanced three phase system can be evaluated

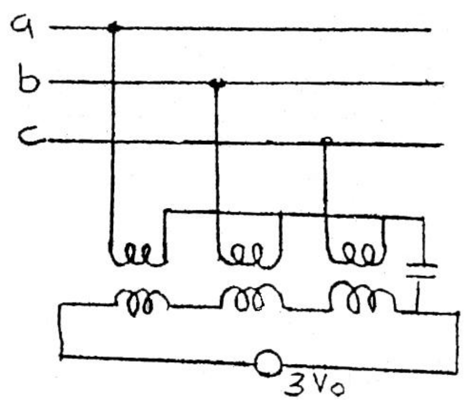
$P = I^2\, R_a + I^2_b\, R_b + I^2 R_c$

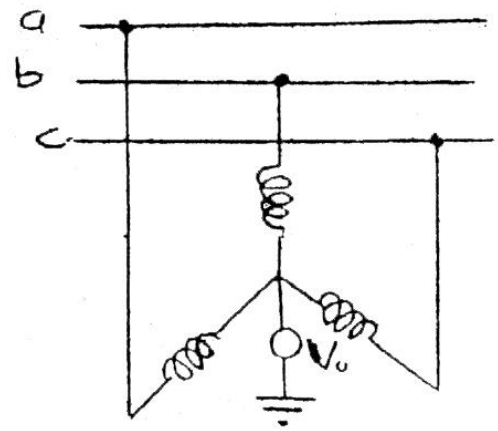
$= 3\, I^2_1\, R_1 + 3\, 1^2_2\, R_2 + 3\, I^2 R_0$

Where R_{1t} R_2, R_o are sequence components of impedance" as defined earlier.

Measurement of Sequence 16 Stages :

Zero - sequence voltage may be measured by means of a voltmeter reading one third of the sum of the three line-neutral voltages as depicted in the circuit using three potential transformers.





There accurately balanced impedences with the voltmeter connected between starpoint and ground/neutral can also be used to measure zero-sequence voltage.

Special positive-and negative-sequence voltmeters can be built based on the defining equations:

$$V_{a1} = 1/3\,(V_a + aV_b + a^2V_c)$$

$$V_{a2} = 1/3\,(V_a + a^2V_b + aV_c)$$

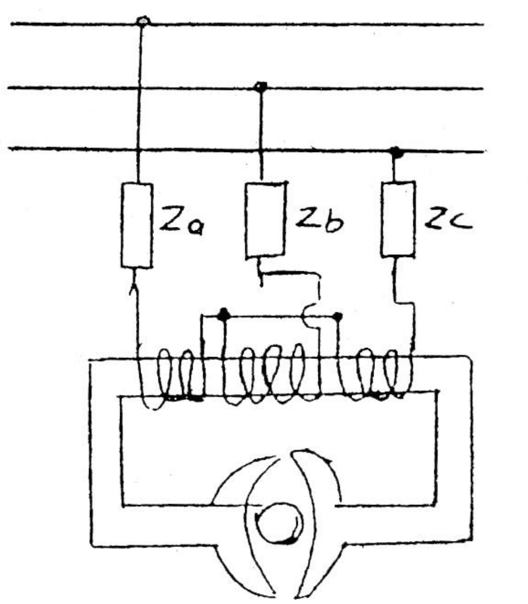
Note reversal of phase b and c voltage

$$Z_b = Z_c\, l/\underline{60}$$

$$Z_c = Z_b\, l/\underline{-60}$$

The driving torgue is

Proportional to the current



Positive Sequence Voltmeter

$$I = V_a / Z_a - \left[\frac{V_b}{Zb} + \frac{V_c}{Z_c} \right]$$

$= V_a / Z_a$ [1- / -60 - / + 60]

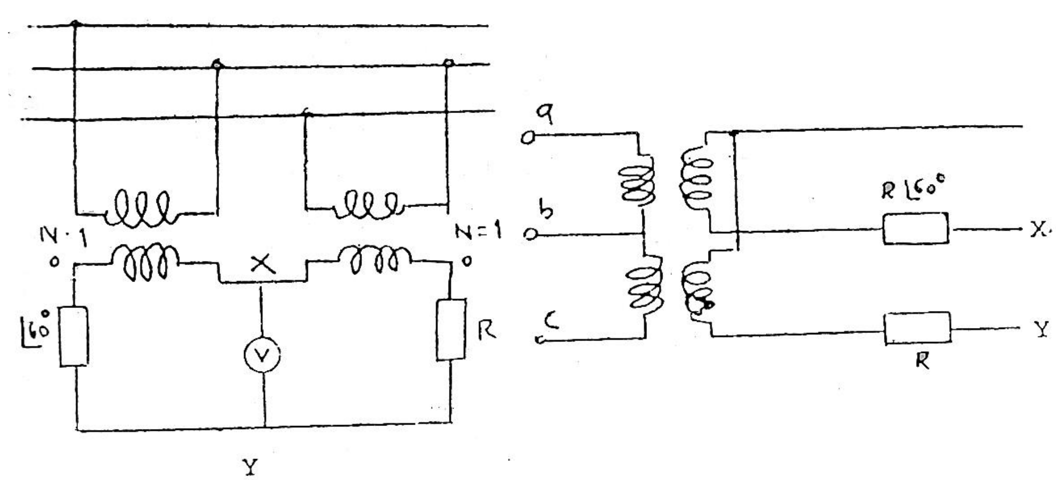
$= V_a / Z_a$ [1 + /120 + /240] αV_{al}

by interchaging the impedences in phrases b and c the driving torque is proportionate Va2.

Instead of a special purpose voltmeter as described above a static circuit using ordinary voltmeter is indicated below :

Positive Sequence Voltage Filters :

The circuit at the left has been redrawn for analyzing the positive sequence filter.



Apply superposition theorom :

V_{bc} = 0 V ab/N

V_{ab} = 0 V bc/N

Combining the two

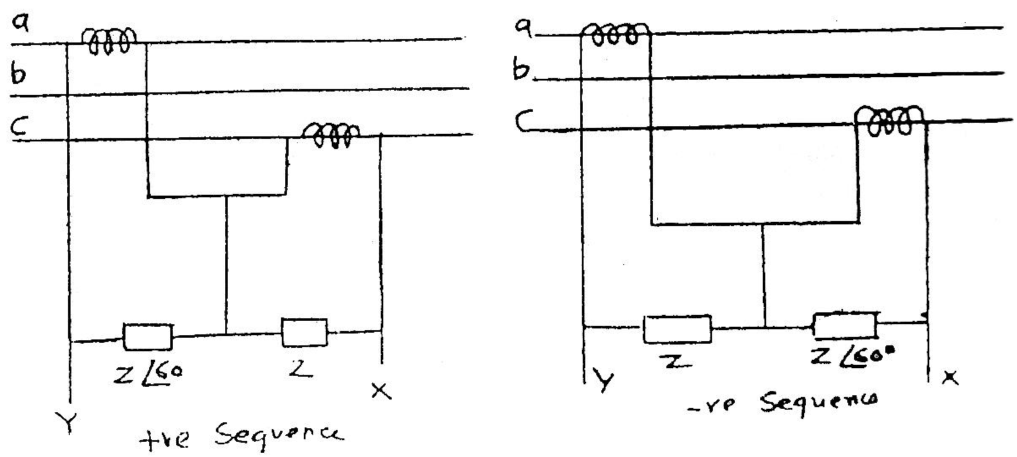
V^{xy}= /-30 / √3N (Vab + Vb0/60) = √3N Va1 √-30

Note that only one inductive impedance is required and a conventional voltmeter be used to measure Vxy.

<u>Negative</u> - <u>Sequence voltage Filter</u> :

Interchanging the impedences results in the voltmeter reading proportional negative-sequence voltage.

Sequence Current Filters : (When zero sequence current is absent)



H.T. SERVICES, METERING, COMMISSIONING -TESTING

The terms and conditions of supply of A.P.S.E. Board stipulate that where the contracted demand is 50 K.V.A. (70 K.V.A) and above, the consumer shoulc avail the supply at H.T. i.e. at 11000 Volts and above. It also stipulates that supply voltage is to be availed as below :

(a)	For contracted demand upto and including 1500 K.V.A.	11,000 Volts
(b)	For contracted demand from 1501 K.V.A. and upto and including 5000 K.V.A.	33,000 Volts
(c)	For contracted demand from 5001 K.V.A. and above	At 132 K.V. or at 220 K.V.

The H.T. Tariffs stipulated a two part tariff i.e. a rate for Maximum demand and a rate for the units consumed. A maximum demand upto 4000 K.V.A. contracted demand is computed as the average K.V.A. Demand for 30 minutes and for contracted Demands of 4000 K.V.A. and above it should be the average for 15 minutes. In addition to this the tariffs also stipulate that-the consumer should maintain a average power factor of 0.85 per month and power factor if it falls below this limit the consumer has to pay surcharge for the low P.F.

Consumers requiring power under H.T. Tariffs have to submit the particulars in the "C" form and obtain the feasibility certificate from the concerned authority, the feasibility issued is generally valid for 6 months upto 5 M.V.A. contracted load and for 12 months for contracted loads above 5 M.V.A. The authorities competent to issue the feasibility certificate are as follows :

1.	More than 1000 K.V.A. Demand	Board
2.	For demands from 299 K.V.A. upto 1000 K.V.A.	Chief Engineer, Zone.
3.	For demands less than 299 K.V.A.	Superintending Eng. Operation.

After the feasibility is issued, the application of the consumer should be processed. The application should accompany :

1. Sale Deed of the site.
2. Registration of SSI/Medium/Heavy Industry.
3. Site layout indicating the supply point.
4. A.D.D. for Rs. 25/- drawn in favour of the Senior Accounts Officer of the Circle towards Registration of Application.
5. Panchayat or Municipal permission.
6. Other statutory approvals such as from Pollution Board etc.

After due processing of the application, necessary detailed estimates are to be got sanctioned. The consumer on intimation has to pay the required service line charges, service connection charges and security deposits. After payment the consumer has also to execute an agreement with the Divisional Engineer / Operation. After completion of all works, the approval of the Electrical Inspector has to be obtained before final release of supply. The H.T. consumers have also to segregate their lighting loads and colony loads and separate meters are to be provided for this purpose in their L.T. layouts.

As present H.T. Services at 11 K.V. are released through 11 K.V. cable type metering set only. The layout of such 11 K.V. service is as per enclosed sketch. It is to be noted that two structures are required (1) to be provided outside the consumer premises with the incoming A.B. Switch and H.G. fuses set, (2) to be provided inside the consumer's premises with the C.T. and P.T. set, meter box and out going HG. Fuse set.

The following points are to be noted in deciding the service point.

The structure should be as near to the entrance as possible and easily accessible for inspection. The location of the structure is to be decided by the Assistant Divisional Engineer/Operation and Divisional Engineer/Operation. If necessary they may consult the Divisional Engineer / M.R.T.

The metering set i.e. C.T. and P.T. set and the meter after drawal from stores should be got tested and sealed in the M.R.T. Laboratories before being erected. The M.R.T. should also be intimated the contracted demand and other details to enable them to adopt the correct C.T. ratio required.

The metering set essentially consists of 2 Nos. C.Ts. and one star sta-Potential Transformer. The current Transformers are located in the outer phases i.e. in "R" and "B" phases. Generally C.Ts. are rated as follows :

(a) 20/10/5A

(b) 30/15/5A

(c) 60/40/20/5A

The changing of the C.T. ratio is to be done by internal links mounted or insulation boards inside the tank. The ratio changing is generally done on the secondary side of the current transformer i.e. on 5 Amps side. The C.Ts. are of metering accuracy class with a burden of generally 15 V.A.

The Star Star P.T. is generally of metering accuracy class with a burden of about 100 V.A. The primary neutral of this P.T. should be kept floating only and should not be earthed. On the Secondary side sometimes the neutral is earthed and in some cases the "Y" potential is earthed. Whetever it is, only one terminal i.e. either the neutral "Y" phase should be earthed for the purpose of protection. Similarly the 'L' of the C.Ts. are also earthed on secondary side.

The meteting sets are generally with side entry cable boxes for the 11 K.V. system and a secondary box on one end for taking out the secondary wiring. The incoming and out-going 11 K.V. terminals are marked inside the cable boxes. The Secondary terminals are generally marked as follows :

R	Y	B	N	for the P.T.
RM	RL	Bm	Bl	for the C.T.

The following tests are done at the M.R.T. Laboratory before issuing the metering set for erection at field.

1) Verification of the markings of terminals on H.T. side and L.T. side.

2) Polarity test on C.Ts. and P.Ts.

3) Test to determine associating of voltages and current.

4) Ratio tests on C.Ts. and P.Ts.

5) Meggering of the set.

(Testing the oil for its dielectric and acidity values)

After satisfactory tests, the set is to be sealed at the following points in the laboratory before being issued to field officers for erection

1) Top cover (four corner bolts)

2) Inspection cover. (Two cover bolts)

3) Secondary terminal box.

The cable entry boxes at either end are to be sealed by the Asst. Divil. Engineer/Operation.

The secondary wiring from the metering set to the meter box should be run through G.I. pipe and pipe at both ends should be fixed with check nuts respectively to the secondary terminal box and meter box.

The metering sets require the following maintenance.

1) Oil samples to be got tested for dielectric strength and acidity once every year.

2) Meggering once in a year.

3) Complete overhaul once in a 5 years.

Test Block :

These Secondary wiring is terminated inside metering box on what is known as a test block. The purpose of the test block is to facilitate of the meter while the 11 K.v. service is live by opening out the P.T. Circuit and shorting the secondaries of the C.T. It consists of links in the potential circuit which on opening the screws drop down thus isolating the meter circuit from the P.T. The Current terminals are 3 Nos. per each phase respectively M, A and L. The 'M' and 'L' are given to the meter. The C.T. 'M' is given to 'M' while the 'L' of the C.T. is given to 'A'. There are Shorting links or screws to show M&A or A and L. While the meter is in service the shorting links or screws to show M & A is kept open while keeping the link between L and A closed. If suppose the current is to be monitored, then connect the ammeter between A and L and open out the shunting link between them. Thus the Ammeter comes is service with the meter and will be rending the load current at that time.

For the purpose of testing, the shorting link between M and A are closed This shorts the G.T. secondary. The testing kit current leads are then connected between M and L The shorting between L and A should then be opened now the testing kit current flows into the meter.

T.V.R. Meters :

. The name "Trivector Meter" is the trade name of M/s. Land is & Gayer Limited London. The indigenous meters of Electro Magnetic type are based essentially on the same principle as in the L & G. The L & G. have designed a KWh element is a 3 phase 3 wire meter i.e. two watt meter method The R Current is associate with RY voltage and thus records 3 E.I. Cos (30 + ϕ) .T. The B Current associated with By voltage and thus records v3 E.I. Cos (30 - ϕ) .T. It can be seen that when P.F. is unity and thus ϕ = 0, both elements will be recording rndentically 50% of the total. In fact this can be used and the P.F. of the service can be computed by noting the time taken for equal number of dise revolutions. When one element is only made to work. The ratio of the times taken by the ‘B’ element and 'R' element will give the approximate P.F. as per the table given below :

Time	Ratio	P.F.
	1.0	1.0
	0.8	0.98
	0.65	0.94
	0.5	0.87
	0.4	0.8
	0.27	0.71
	0.18	0.64
	0.10	0.58

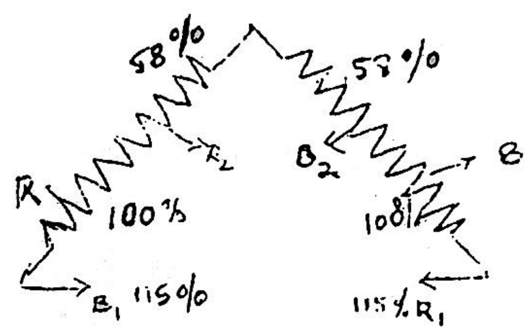
M.D. Mechanism :

The K.A.H. Drive obtained as above is engaged to the M.D. indicator needle by the use of a solenoid connected through a set of timer contacts to the supply. The timer is set to open out the supply to the solenoid after expiry of 15 minutes or 30 minutes as the case may be. The solenoid is kept open for a period called detentate time which should not exceed 1% of the total integrating period i.e. 9 seconds or 18 seconds respectively. After the expiry of the detentate time the solenoind once again is energized and the M.D. mechanism gear wheel gets engaged. This engagement results in the movement of the driving needle along with K.V.A.H. register against some spring tension (The spring tension is generally very low and does not effect the performance of the meter). The driving needle presses against the needle vane and thus both the driving needles will be moving. when the solenoid supply is interrupted the driving needle because of the spring tension comes back to zero position. The detentate time is for the purpose of this type of resetting of the needle. However, the indicating needle is retained at the place as it is generally held by friction at that position and will be indicating the maximum demand.

RKVAH element :

The RKVAH element is exactly similar to KWh element. Only the currents and voltages are so arranged to obtain $\sqrt{3}$ E.I. Sin (30 + ϕ) T and $\sqrt{3}$ E.I. Sin (30-ϕ) T. The L &G. have used non inductive resistance shunt for the current coil and high resistance in series with the voltage coil. Thus they achieved a shift of 90° between the two vectors.

Another method is to use phase shifting transformers which are as illustrated below:



This essentially consists of 2 Nos. transformers with.58%, 100% and 115% tappings. The transformers are connected in open delta formation. Between R1 and R2 and B1 and B2 110 Volts which are exactly shifted by 90° to the RY Voltage and BY voltage respectively are obtained.

Tests :

The I.S.S. 722/1972 deals with meters of all varieties. The I.S.S. specifies type tests and routines tests. Type, tests are tests carried out at National Laboratory on one or two pieces and arranged by the manufacturers.

Routine tests are test conducted on the meters and include the following mainly,

1. Insulation resistance.
2. Creep Test.
3. Staring current test.
4. Error limits, Generally errors should not be more than 2.5%.
5. Energy register test or dial test.

The I.S.S. Specified certain standards for the meters as follows :

1. The errors in the meters should not change with a 10% variation of voltage.
2. The errors in the meters should not change with a 5% variation in frequency.
3. Even when the meter is fixed 50 to the vertical, the errors in the meter should not change.

For further details the latest version of the I.S.S. is to be referred.

Meters:

The induction disc type meters are already familiar to the audience. The meter terminals and its wiring is generally indicated by a circuit diagram phased in side the shape of W with the ends facing on to the centre limb. The centre limb produces the required magnetic filed. The series or current magnet is in the shape of "IT. A system of break magnets is arranged with permanent magnets to create necessary working torque. These are so located as not to cause interference with the other main magnets. The distance of this brake magnet on the radius of the disc can be altered and it can be locked in that position. This magnet is to be adjusted for obtaining the errors at full load. U.P.F. to be within limits.

Inductive Load Adjustment :

The KWh element is to be tested at Full Load 0.5 P.F. and RKVAh element at full load 0.8 P.F. for their performance under varying P.Fs. The adjustment is done by varying the position of the shorting screw, on the adjustable coil. This is coil of few turns wound on the centre limb of the voltage coil or current coil and the circuit is closed through a 'U' shaped low resistance wire. The 'U' shaped wire is provided with a shorting screw and nut. By moving this screw up or down the Inductive Load error can be varied However, in the L. & G, type meter this adjustment is done by a shading band on the centre limb of voltage coil and adjustment is obtained by moving it up or down on the limb.

Low Load Adjustment :

Inspite of the best effects by using jewel bearings etc. the friction load plays a vital role when the meter is operating on light loads. Hence the meter is tested for its accuracy at 10% of F.L. and U.P.F. The meter is provided with a shading vane between centre pole of the voltage magnet and the disc to one side of the centre line of the pole. The action of the voltage flux on the disc is slightly shifted and in fact a differential flux is caused resulting in a forward torque *on* the disc which is approximately equal to the friction torque. The movement of this vane caused change of this torque and thus provide an adjustment.

Creep :

Creeping of meter is generally tested by applying 10% over voltage to the meter. The meter should not creep. However, meters may be found creeping during services. The A.P.E.D. manual specifies that creep is to be measured by noting the time for one disc revolution. If the time taken for one disc revolution is 5 minutes or more, the creep is said to be in limits. However, if the time taken is less than 5 minutes, then the bills of the consumer have to be adjusted for the creeping.

The creep is arrested by providing two diametrically opposite holes on the disc when the hole comes under the voltage magnet pole the rotation is stopped.

In other design two small iron pieces are provided one on the spindle of the disc and the other on the voltage coil core. When the piece on the spindle approaches the one on the voltage core an attractive force is developed and meter rotation stops.

All H.T. T.V.R. meters should be tested once every year. In case of services of 5 M.V.A. and above and where the consumer is a private party the meter should be tested twice in a year.

Testing Kit :

For the testing of the meters a phantom load testing kit is used. The kit operates at 3ϕ 440 Volts or *3*ϕ 11 0 Volts. An internal P.T. develops the required out put voltage. A selector switch with the available to generate + 10% Voltage for the purpose of the creep test. The voltage selector switch gives the required output voltage.

The kit consists of loading transformers i.e. transformers whose secondary is a low voltage of the order of 6 of 10 volts. The primaries of these transformers are fed through varies so that the secondary voltages is varied. The Secondary from this transformer is fed to a phase shifter The phase shifter is essentially a transformer on the principle of stalled rotor of an induction motor. By varying the position of the rotor reference to the stator the phase angle is varied. The out put of this phase shifter is brought out to current terminals on the kit. The kit also consists of ammeters in series to indicate the current. Also a selector switch is provided to select 1 A. or 5 A. current and this switch also is wired so that it drives 1 % of rated current in one of its positions. This current also should be at U.P.F. irrespective of the shifter position for testing the starting current of the meter. The kit also is provided with phase sequence indicator as some meters do not work accurately in the reverse sequence. The meter disc rotation is compared with rotating sub-standard meters. The R.S.S. Meters are calibrated at standard Laboratory at Madras atleast once an year and its errors at various points are to be obtained. The R.S.S. Meters will have electrically operated click switches or mechanically operated on off switches to start them and stop them.

Procedure of Testing:

Connect the meter under test along with the R.S.S. meters one for KWh and the other RKVAh to the phartom load test kit. Select the required current range and voltage range on the R.S.S. and as well on the kit. Suppose the meter rated as follows :

C.T. Ratio	:	10/5 A.
P.T. Ratio	:	1000/110 V.
Constant	:	12 REv. / Unit.

Select the R.S.S. current also as 5 amps. At this current let the constant of the R.S.S. be 1 800 Rev./Unit. Hence the ratio of meter Rev. and R.S.S. revolutions are as follows :-

12 x 10/5 x 11000/110	=	1800
i.e. 2400	=	1800
or 12	=	9

Thus for every 12 revolutions of the disc on the meter the R.S.S. should record 9. If the R.S.S. records more than the meter is having negative error and if it records less than the error is +ve.

Suppose the R.S.S. records n1 revolutions instead of n revolutions, then the error is

$E_1 = (n - n_1)/ n_1 \%$

This error is not the true error since the R.S.S. is having an error E2 given by the standard laboratory.

Thus, the error E = E1 + E2

The errors are adjusted as already discussed to be within the limits.

After adjusting the various errors, the meter is run at about 40% to 60% of rated current and at 0.866 P.F. for the period of the maximum demand along with the R.S.S. Meters. For this purpose it may be necessary to wait until the timer is operated. This is called a dial test and the recording of the meter dials are compared with those of the R.S.S. and the errors should be within the limits.

Installing the Meter :

The meter is installed in the consumer premises and in a meter box. The meter box preferably should have a glass on the front side so that the meter can be seen even when the box is sealed. The meter is to be fixed on an insulating.

Board such as wood or other material. The test block also is to be installed on this Board. The wiring from the metering set the test block and from the test block to the meter terminal should be run behind the meter Board so that these are not accessible out side. The following points should be sealed by M.R.T.

1. Meter cover.
2. Meter terminal cover.
3. Test Block.
4. Meter Board fixing screws.
5. Meter fixing screws.

The following points are to be sealed by the meter reader.

1. Meter M.D. Indicator resetting device.
2. Meter Box.
3. A.B. Switch handle.
4. Metering set cable boxes.

The M.R.T. should note the date of testing on the meter and also the M.F. to be adopted for recording the meter. Suppose the meter is rated as below :-

C.T.R. = 10/5 A. :P.T.R. = 11000/110 V.

Suppose it is served by a C.T. of ratio 60/5A and P.T. of 33000/110 A. Then the M.F. to be adopted is

$$M.F. = \frac{60/5 \times 33000/110}{10/5 \times 11000/110}$$

$$= 60/10 \times 33000/11000$$

$$= 6 \times 3 = 18.$$

Suppose the last digit on the meter is indicating 100 Units. Then the total M.F.= 18 X 100 = 1800.

General :

1. The H.T. Service of 100 K.V.A. contract M.D. and above are to be read monthly by the Divisional Engineer/ Operation and for all other H.T.

Services the meter readings are to taken by the Asst. Divil. Engineer Operation, However the Asst. Engineer / Distn. concerned is primarily responsible for the up keep and maintenance of the H.T. Services.

2. As per the approved schedule of maintenance the following is to be done.

a)	Topping up of oil	Monthly.
b)	Meggering of the set	Quarterly.
c)	Checking earth resistance	Quarterly.
d)	Testing of oil for D.E. strength	Half yearly.
e)	Tightening of all connections	Half Yearly.
f)	Testing of Oil for Acidity	Yearly.

3. Where metering kiosks are provided they should be maintained as in the case of regular kiosks. They should be kept seated after the maintenance work.

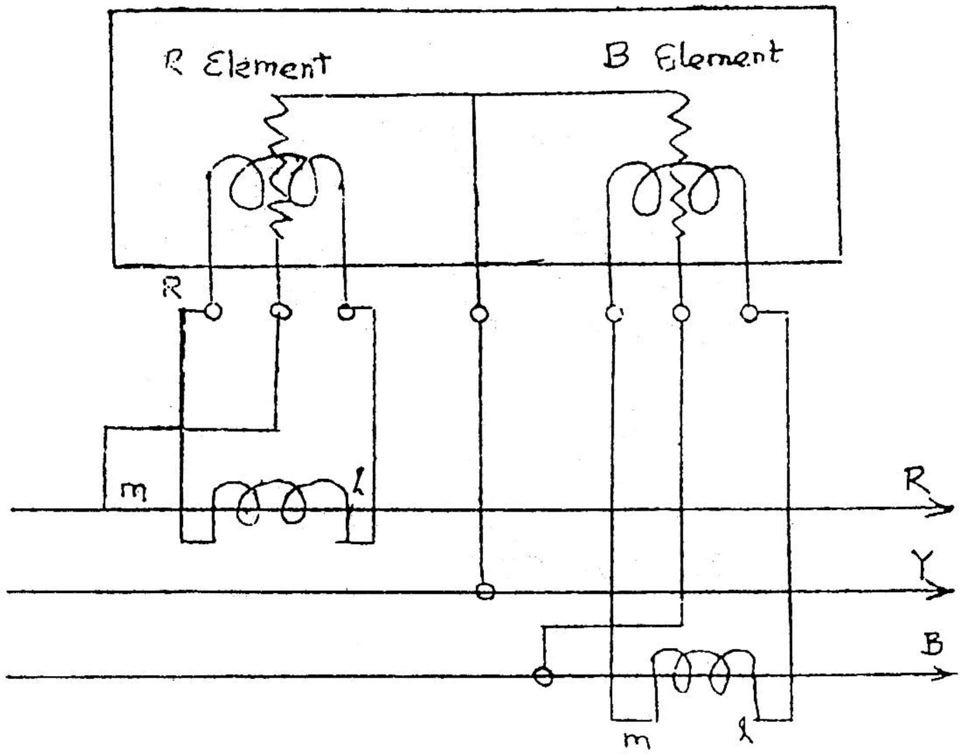
4. The monthly meter readings should be comparatively studied and reasons if any for less consumption should be ascertained. It is preferable that the monthly production figures are collected so as to judge the accuracy of the readings taken.

5. After release of a new H.T. Service, the Asst. Divil. Engineer/ Operation should inspect the service, say in 15 days, before the monthly readings are due and see that the meter is working satisfactorily.

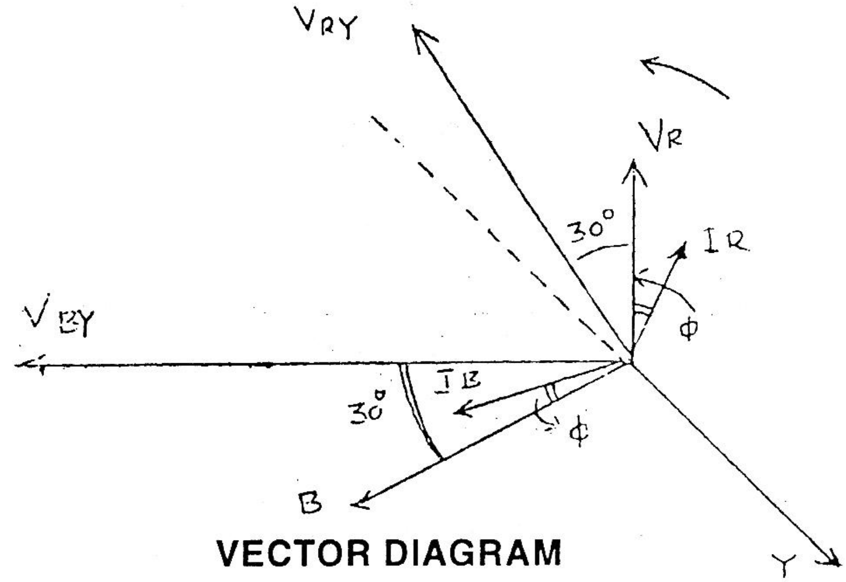
6. For all H.T. Services released, the Asst. Divil. Engineer/ Operation and Asst. Divil. Engineer / M.R.T. should be present at the time of release of supply and see that all pre-cautions are taken in metering and on its accuracy.

7. All complaints of H.T. Meters be made to Divisional Engineer / M.R.T. and Asst. Divil. Engineer / M.R.T. within 2 days of their observation and the M.R.T. should rectify the defect promptly. At no case a defective meter should be allowed for more than 7 days.

8. Depending on the nature of complaint, if necessary, the D.P.E. Organisation may be called for, for detailed investigation.

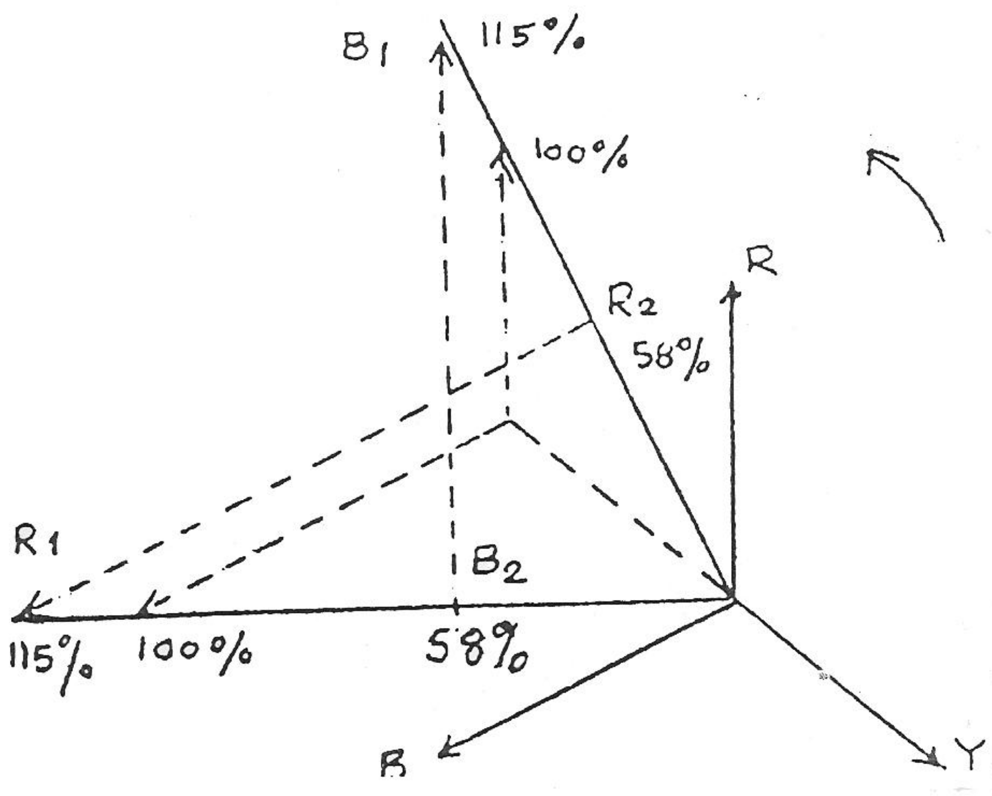


3 Φ 3 WIRE METER CONNECTIONS

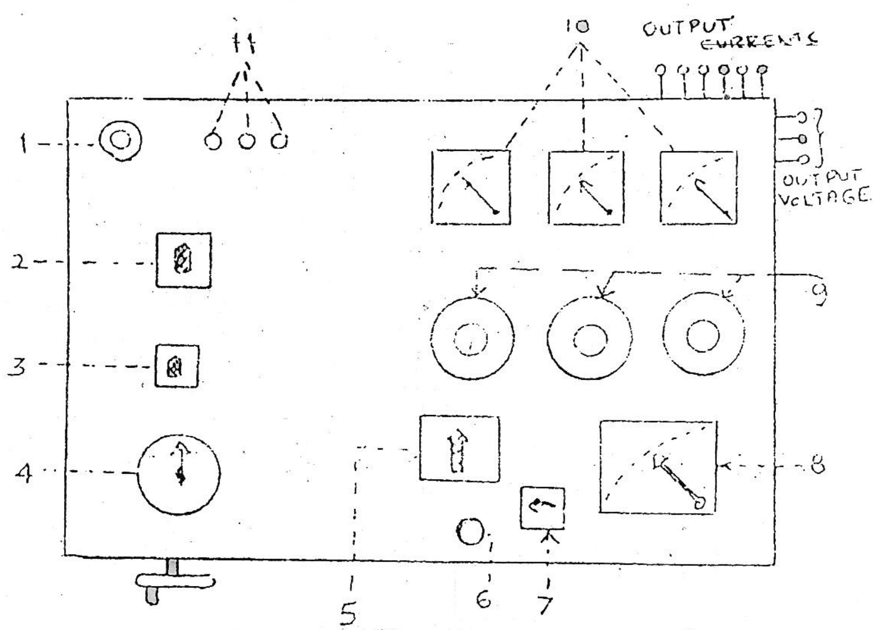


VECTOR DIAGRAM

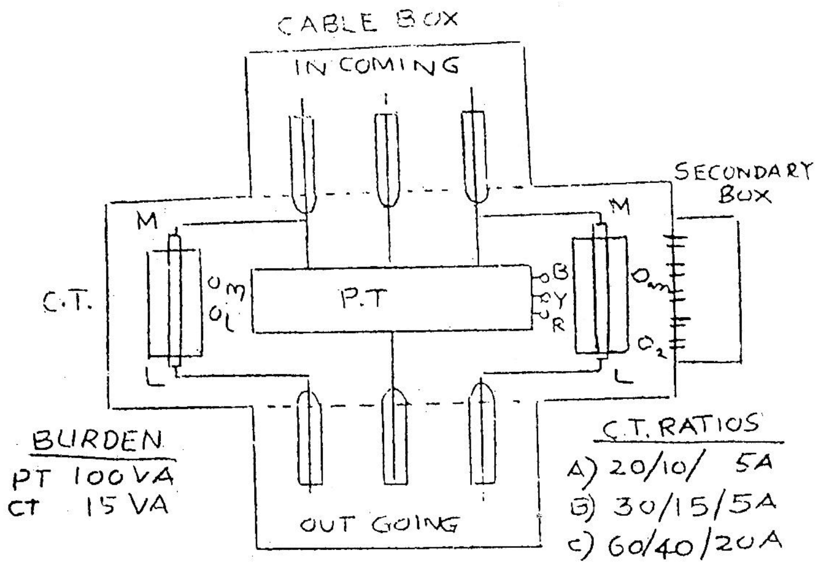
PHASE SHIFT TRANSFORMERS



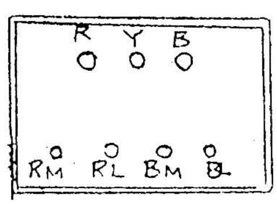
VECTOR DIAGRAM



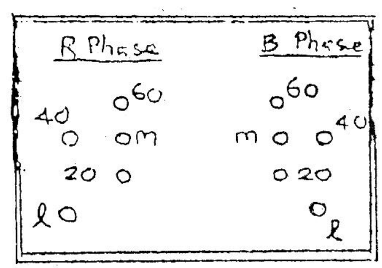
1. Input supply plug
2. Input voltage selector
3. Output voltage selector
4. Phase Shifting Transe
5. Current Selector
6. Push Button for Sequence Indication
7. Phase sequence Indicator
8. Out Put oH Meter
9. Current Variacs
10. Ammeters.
11. Incoming Supply Fuses.



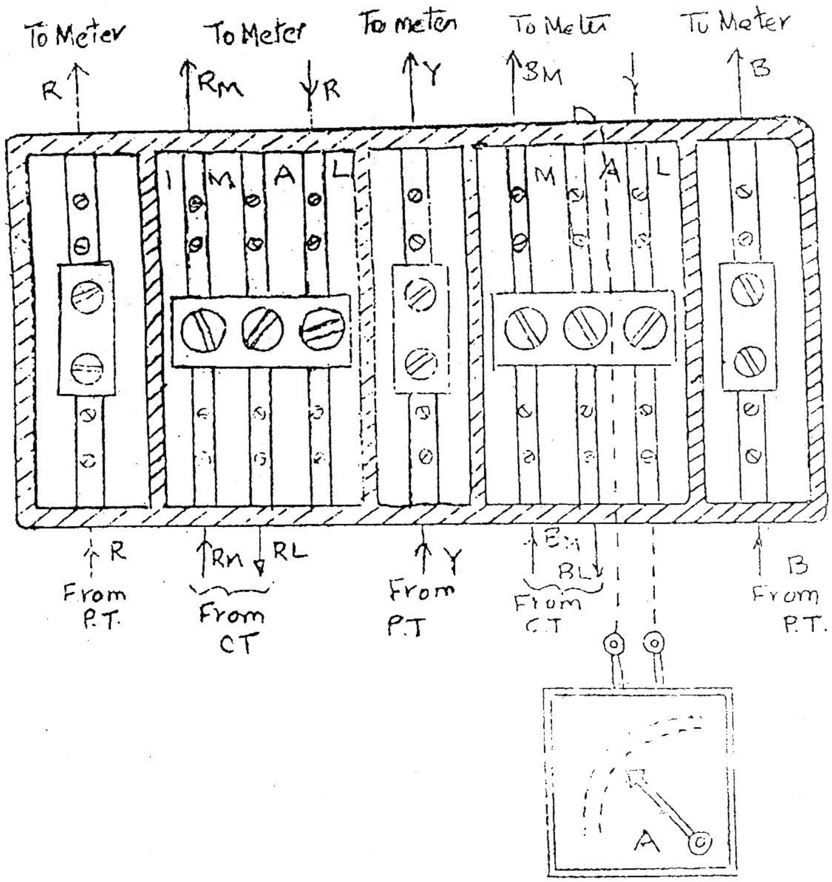
METERING SET



SECONDARY BOX



RATIO CHANGING BOARD



AM METER

METER TEST BLOCK

COMMUNICATION AND SUPERVISORY CONTROL AND DATA ACQUISITION (SCADA) SYSTEM INTHE POWER SYSTEM

Electrical Energy is one of the most vital areas in our country's development plans. The prime responsibility of any Power System organisation is to generate enough power and distribute the same throughout the State Grid to National Grid most economically, efficiently and reliably. Uninterrupted power supply to any consumer or industry is a must. In order to maintain continuity of supply in a power system it must be ensured that a sound, most reliable and efficient communication exists in the State Grid or National Grid. Communication is always the back bone for any efficient power grid system.

The various type of communications could be effectively in a power system are listed below :

1) Satellite communication system
2) Micro. wave/U.H.F. communication
3) V.H.F. Communication
4) Optical Fibre system
5) H.F. Communication system
6) P.L.C.C.

A judicious combination of the above communication systems to suit the particular areas of operation will be most desirable. The area where communication is required in Power system are broadly divided into the following categories.

1) Project Management during construction.
2) Operation of generating units in Power Stations.
3) Load despatch operations
4) Data acquisition and control functions
5) Protection of Transmission lines and equipments.
6) Communication for breakdown operation of Power lines, EHT lines as well as L.T. lines.
7) Communication for urban distribution system
8) Communication for Administrative requirements.

The type of communication most effective and economical for efficient execution of the task assignment must be judicially adopted.

Some salient points for selection of type of communication for the various requirements are discussed below :

1) Project Management- Communication requirement :

It is important to- note that a new project site, without any previous communication infrastructure, it should be made possible, to establish necessary communication facilities in a short time to make the system really useful. For this purpose V.H.F. communication will be best suited at site for use by the site Engineers at the work spot to the officers or executive within the project campus. An intercom system or PAX is also required for the various site offices at the campus. H.F. communication system or Satellite link will be most ideal for communications with Headquarters office from the project site. This is a vital requirement for expeditious execution of project.

2) Operation & Monitoring of generating units of Power Stations and Control of Generation by the Load Despatch Stations :

It is desirable to have three types of communications for the operation and monitoring of generating units at Generating Stations.

a) Satellite communication system from all generating stations to the Main Load despatch Centres.

b) H.F. Communications as back up above for transmissions of messages etc.

3} PLCC Express Communication for Load Frequency Control System.

Generation control is essential for efficient Power Grid maintenance. such communication to generating stations is very vital and has to be 100% available and efficient.

4) Load despatch Operation :

There is phenomenal growth of grid which is continuously expanding and operation of a Power Grid with all complexity requires a sound communication system which is most reliable and with cent percent availability of channels to communicate directly to any part of gird. The present day trend is to have a computerised load despatch centre with graphic display VDUS. The load despatch will be able to carry out economic load despatch, Load Frequency control, State Estimation, contingency analysis and Security functions with the help of the computer. The computer is expected to be fed with real time data from all generating and important E.H.T. Sub-stations which again require a sound communication system for data transmission.

5) SCADA System :

It is necessary for the load despatcher to have all the data of the grid system upto date and monitor the system for reliable operation. For this purpose the data from the various generating stations and sub-stations are to be acquired, transmitted to the control centre. The control centre in turn will process the data acquired from time to time and generate control commands to be transmitted to various stations for executions and reports back compliance. The SCADA (Supervisory Control and Data Acquisition) system has to rely on a sound communication system.

The Main Function of SCADA are

1) Provides the control center with updated information or the operating conditions of the Sub-Stations.

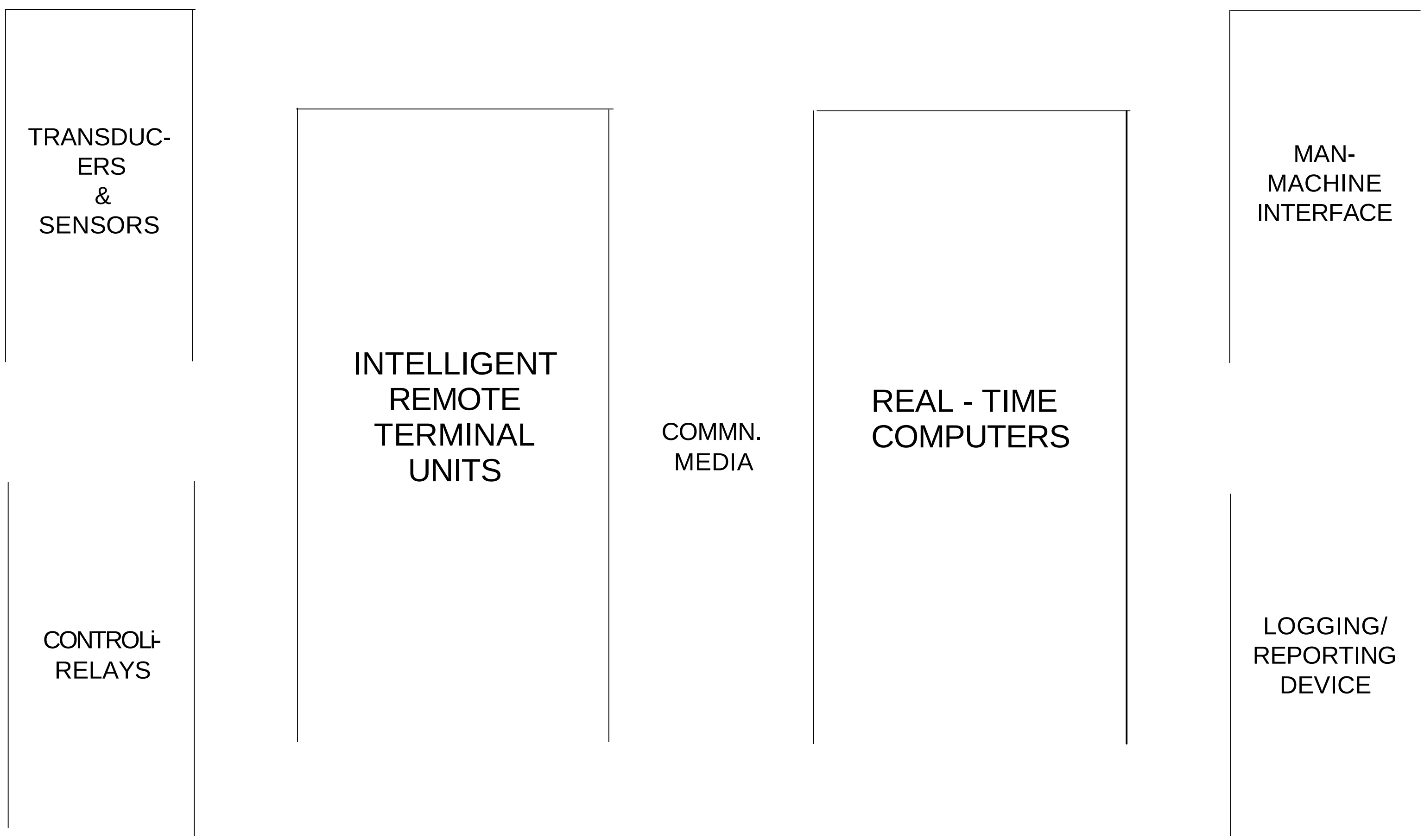
2) Efficient Supervisory Control of all the equipment of the Sub-Stations.

3) Providing information of any changes in the status of Sub-Station equipment, Abnormal conditions of equipment.

THE SCADA NETWORK CONSISTS THE FOLLOWING THREE SUB SYSTEMS

1. Instrumentation Sub System
2. Telemetry/Computer Sub System
3. Communication Sub System

COMPONENTS OF SCADA SYSTEM



OPERATIONAL PROBLEMS & POTENTIAL APPLICATIONS OF DAS

- Fault location, isolation and service restoration
- Maintaining good voltage profile
- Load balancing
- Load control
- Metering

APPLICATION FUNCTION -1 FEEDER DEPLOYMENT & SECTIONALISING

- Determines the feeder section which has experienced a persistent or a transient fault
- Feeder fault detector is employed
- Logic to isolate the fault
- Restores service to unfaulted feeder sections by reconfiguration

APPLICATION FUNCTION - II
INTEGRATED VOLT-VAR CONTROL

- Responsible for maintaining feeder voltages within prescribed limits

- Controls a combination of Load Tap Changer's, Voltage regulators and Switched capacitors

- Also controls feeder reactive power flow

APPLICATION FUNCTION - III
LOAD BALANCING

- Function intended to minimize feeder overloads through better load division among feeders

- Reconfiguration is done to balance the loads

BENEFITS OF SCADA

1) The System data is at fingertips.

2) The Status of system components are continuously monitored at a Central Station.

3) The System can be run in the most effective way to maximize the use of existing assets to defer the costs of reinforcement.

4) During outages of certain parts of the system, the SCADA system helps in restoring the supply by transferring loads between Primary Substations.

5) Helps in reducing system losses by transferring loads between Primary substations at times of low loads.

6) It enables to calculate fault levels at various points of system under different running conditions.

7) Energy audit of Primary Points of the system can be carried out.

8) Over loading of Systems components can be avoided.

9) Good communication with substations, consumer service centers by central control station helps in

    a) Reducing duration of out ages of equipment.

    b) Quick restoration of supply.

    c) Promptness in attending consumer complaints.

THE VARIOUS PROBLEMS COMMONLY COME ACROSS SUCH ERECTION OF AUTOMATION SYSTEM IN AN EXISTING SUBSTATION ARE AS FOLLOWS

1) Running of the cables in between the existing equipment and interphasing panels and also between interphasing panels and RTUs.

2) Erection of RTU Panels interphasing panels batteries and charges in the existing Control Rooms.

3) Erection of Communication Towers.

4) Providing of components such as Change-over switches, contactors interposing relays in the existing control panels and equipment.

5) The existing earthing system in the substations and improving the same.

6) The Inter connection of the equipment in the control panels to the interphasing panel and testing the system in the substation as a whole.

SCADA IS USED FOR

- Supervisory Control of the system
- DATA Acquisition System
- Distribution Management System
- Historical Accounting and Reporting (HAR)

GENERAL FUNCTIONS

- Calculation of hourly active and reactive power values
- Event lists generation
- Alarm list generation
- Report Generation
- Display of Status indications
- Curve Menu
- Minute/15Mts/30Mts/hourly load values

SUB-SYSTEM OF SCADA SYSTEM

- Control centre equipment
- SCADA software
- Distribution Automation System Application function
- Communication System
- Field Data Acquisition Devices (RTU)
- Pole Top Data Acquisition Units
- Power Supplies
- Services.

MODULES OF THE SCADA SOFTWARE

- Integrated Data Engineering Software Module (IDES)
- Data Handling
- SCADA Calculations
- Operator Functions
- Control Functions
- Control System Operation
- Control System Maintenance

MODULES OF THE SCADA SOFTWARE

- Dynamic Network Colouring (Charges)
- Event Processing
- Historical Data Processing - Time Tagged Database (TTD)
- RTU Communication Software
- Tele-control Protocol : 1EC 870-1-101

COMMUNICATION SYSTEM

- Basic Communication microwave communication
- Primary Backbone Communication
- TDMA operating on to 2-3 GHz band connects central station to all the nodal station in 220/132KV Sub-Station
- Secondary Backbone Communication
- MAR interlinks all 33/11KV Sub-Station uses pairs of frequencies in the band 849-935 MHz

DISTRIBUTION MANAGEMENT SYSTEM

- . Trouble Call Management
- Emergency Load Shedding
- Fault Localisation
- Supply Restoration
- Automated Meter Reading
- Integrated Volt-Var Control
- Load Control
- Load Balancing
- Automated Mapping & Facilities Management

LOAD BALANCING

- The aim is for minimum network loss configuration
- To balance the loads on the Sub-Station and feeders such that none of them are overloaded beyond their capacity.
- In respect of Sub-Station continuous rating of power transformers is considered as Sub-station capacity.
- In respect of feeders the thermal loading limits of the conductor at 60°C is taken as capacity of the feeder
- The network control function helps in better utilization of distribution facilities (Transformer and feeder capacities)

LOAD BALANCING

- This increases life expectancy of the equipment
- The network configuration is maintained by closing &opening switches.
- Pole top RTU's are used at the network switches
- Network Analysis can be done by displaying the loads & losses
- Transformer loading & feeder loading before & after load balancing can be reported.

AUTOMATED MAPPING & FACILITIES MANAGEMENT

- Viewing Raster Image of the Network
- Viewing Vector Map of the Network
- Viewing Vector Map with raster image as the background image
- Digitize Electrical Network
- Single line diagram of all feeders in the network are displayed
- Zoom into double the original size
- Zoom out to half of the original size
- Area Zoom
- Cluttering & Decluttering

INTEGRATED VOLT-VAR CONTROL

- Shunt Capacitors & Voltage regulators are to be used.
- Network Analysis
- Simulation - Case Studies
- To provide good voltage profile & to maintain voltage with in permissible limits
- To minimize distribution losses
- Can be achieved by supplying required reactive power at the specified locations by installing switched shunt capacitor banks & voltage regulators on the feeders, which can be controlled remotely.
- ON/OFF of shunt capacitors
- Raise/Lower taps of voltage regulators
- Pole top RTU's for Capacitors & Regulators

LOAD CONTROL

- Aims at controlling load such that the system load curve matches with system optimal capability to minimize over all cost.
- LC necessiated as Electricity demand & supply very widely in a day arc over a year.
- The pattern of consumption varies in the course of the day reflecting patter- of human activity and also during the year due to seasonal variations.
- System capability varies depending upon the mix of the generating facilities namely base load intermediate load and peak load plants
- The module contemplates direct control of bulk loads of 11 KV & above
- To match load curve with generation capability curve whenever shortages are predicted.

LOAD CONTROL

- Can regulate demand of bulk consumers in planned manner.
- This is different from Emergency load shedding.
- LC function will come into operation when the mismatch between availability & demand is predicted in advance and utility decides to avail relief from HT customers.
- Load relief can be long term or short term.
- Emergency load shedding when there is a sudden outage. In this case load reliefs are availed on feeder basis not an individual HT customer.
- Customer priorities can be maintained.

TROUBLE CALL MANAGEMENT

- To analyse the reasons for outage reported by the customers and take remedical action to restore supply speality
- The application analyses the calls recorded and identiies the possible faulty device.
- Keeps the track of crew available and directs the crews to the location for quick rectification of faults.
- Provices timely information to the customers on the status of rectification.
- Reduces losses due to long interruptions.
- Improves customer relation.
- Generates daily & historic reports.
- Employee attendance on call for 24 hrs.
- Planned maintenance
- Line clear

EMERGENCY LOAD SHEDDING

- To balance Generation & Load demand under normal and emergency conditions.
- Cascade tripping can be prevented by planned automatic load shedding program.
- Prevents network coliapse.
- Increases Network Stability & Power Quality.
- Identifies the sheddable feeders in a Systematic and Scientific manner.
- Cyclic Load shedding.
- Group Load shedding.
- Group cum cyclic load shedding
- Groups Formation

FAULT LOCALISATION

- If a fault occurs on a radial distribution feeder the faulty section will be identified.
- Opening of switches at both ends, Isolates the faulty section.
- On fault in the feeder, Circuit beaker trip.
- Test charge two to three times & declare faulty.
- Isloate outgoing AB switch at Sub-station & Close breaker to ensure breaker is OK.

SUPPLY RESTORATION

- To restore supply by Isolating faulty section.
- To restore supply in case of over loading.
- To restore supply in case of equipment taken for maintenance.
- To restore supply in case of feeder taken for maintenance.
- Dispatcher to examine the Network, Identify the switches to be opened & restore supply. This may not be best solution.
- Necessary to provide computer aided decision support to the dispatcher to restore supply quickly to maximum possible area.

SUPPLY RESTORATION

- This decision support system provides optimal switching schedule.
- Minimizes losses, Minimizes switching operations avoids overloading of Sub-station feeder.
- It gives faulty feeder details.
- To find alternate sources.
- To find alternate transformer.

AUTOMATED METER READING

- Remotely collecting data for billing, maximum demand monitoring & load survey.
- For a specified customer or all customers.
- Readings-Real time data, Daily, Monthly & Yearly Data-All customer/ SP-Customer.
- Theft of Energy Detection-Using "PROSIM" simulate a tampering situation for a customer.
- Load curves-Daily, Monthly & Annual:
- Monitors quality of Electricity provided.
- Monitors status of metering equipment.
- AMR customers will be provided by TVM with RS-232 Port.
- TVM & Sub-station RTU will have same protocol.
- Remotely Disconnect/Reconnect supply by providing load switches at customer premises.
- Customer bills & other reports can be generated at control centre.
  1. Customer - All / Specified Customers
  2. Meters - Customer - AII/SP Customer
  3. Metering System - Circuit Breaks - All/Sp. Customers/Customer

Cus. ID - Meter Type CT, Battery / P.T. Battery
CMD, CB Connected
SI.No. Date of Installation

FACILITIES MANAGEMENT

- Existing details for the facility.
- Maintenance Details - Periodicity.
- Outages - Damages, Causes, Types, Reports Tripping Events, Inspections, Service Status.
- Company Details Company wise details of materials available in various Sub-station & Availability of spares in various stores details of Telephone Numbers, Contact Person Name & Details
- Reports.

FACILITIES MANAGEMENT

- Personnel Details - Line clear mode, Crew type designation Specialization, Crew Office, Employee.
- Organization setup - Office Type Record, Administrative Type, Network Unit Type, Facilities hierarchy.
- Formats - Inspection Report, Maintaining Report.
- Outages - Inspection Report, Damages Present, Repairs, Repairs Facility, Transport Facility.

6) Another important function for grid system is safety of the equipment and protection of the transmission lines. It will be seen that the stability of the grid has to be maintained whenever a power line trips on fault. System protection is ensured by relay protection or carrier protection or carrier inter trip and auto reclose. For this purpose power line carrier communication is essentially required.

7) Breakdown Operation of Power Lines :

It is necessary that power lines breakdowns are attended promptly and normalcy restored in the shortest possible time. Generally breakdown spot is remote and inaccessible by any sort of conventional communication i.e. P&T.

For contacting nearest sub-station breakdown gang have to move out to nearest town or village where P&T communication is available and communicate for taking line clears or returning line clears. If only communications is made available at the breakdown spot, lot of time can be saved for attending to the breakdown and restoring the power line for normal operation. VHF or HF communication is most suitable. PLCC communication can be availed by hooking up the power line with mobile carrier sets.

8) Communication for Urban Distribution System :

The complexity of monitoring un-interrupted supply in main cities increased multifold and problems are many. Interruptions to power supply should be minimised and preventive maintenance is a must and constant vigilance should be kept on the distribution system. The latest procedures in tackling and handling distribution system from substations is to have a centralised control centre and have mobile squads to move about to attend to emergencies. Communication from control centre to the mobile squads is essential and should be reliable. VHF systems offer a viable solution for this purpose. A sound communication network between the Central control station and the maintenance gang, the break-down of un-interrrupted power supply in a major distribution system. It is also essential that the central control station should have a SCADA system for obtaining data from the various sub-stations feeding the distribution system. The Central control station should also have direct communication link by PLCC or Satellite to the sub-load despatch centre or Main load despatch centre. A combination of PLCC with VHF link will be best suited for an urban distribution system.

9) Last but not least important area for use of communication is for administrative requirement. The State Head-quarters office should be able to contact the various district offices of the Grid system. The zonal and Circle offices of the Electricity supply system have expanded considerably and it is essential to have communication with their offices for administrative purposes. P&T direct lines hired form P&T Department will be of use of a H.F. communication system for transmission of administrative messages will best suit for the purpose The above points discussed mainly indicate the importance of communication requirements for a power system and the important role *of* communication in a power system. Next let us consider the different types of communication available

for utilisation of power system. The main option for going in for a particular type of communication system depends on the specific requirement of that particular station or the purpose for which communication is required. The satellite communication system is one of the latest and most reliable communication system available which can be exploited for use in a modern load despatch center. It is possible to have both data and speech transmission from main load despatch to the sub-load despatch centre or all important generating stations and EHT substations. It can also be deployed for communication and data transmission from State Load despatched to Regional Load Despatch centres and to contact National Load centre. In future a national grid centre is likely to be evolved to coordinate the regional Electricity centrist for which the satellite communication, or microwave communication can be conveniently used. Use of Microwave or U.H.F. -can be successfully resorted to, for a nation wide power communication system interlinking all regions and State Electricity Boards or Electricity undertakings.

10) The optical fibre system which is the latest communication system can also be thought of for data transmission and speech between stations which are not far off. Fibre optical system may be cost effective to Microwave or UHF systems. Fibre optical system has definitely more advantage over other systems with regard to noise interference, signal fading, frequency interference etc. VHF communication can be best utilised for Urban distribution system and for breakdown operation of Power lines. PLCC remains the basic system and can be relied upon for point to point communication between sub-stations and for protection systems in power grid. PLCC can be used as a back up communication system for other mode of communication systems for data transmission and speech. The PLCC system will remain a mainstay for operation of Power Systems for a decade or more. With proper frequency planning PLCC can play a vital role in maintaining power system stable and reliability.