3. Transformer & Alternator Protection.

Transformer Protection

Ever since the AC supply sys. was developed, the x'mer has been a part of transmission & distribution sys. A well-designed transformer with proper maintenance provides uninterrupted service for many years. The x'mer is static device without any rotating part & is totally enclosed. Hence chances of faults occuring in x'mers are much rare as compared to the faults occuring in generators. Similarly, possibilities of running on abnormal conditions are also less in x'mers. ~~Eve~~ But though, if fault occurs, the x'mer must be quickly disconnected from the sys. The rare faults, if not cleared quickly, may get developed into major/serious problems for the x'mers. Hence the protection must be provided to the x'mers against possible faults.

The various possible x'mer faults are -

1. Overheating
2. Winding faults
3. Open ckts.
4. Through faults
5. Over fluxing

Overheating.

The overheating in x'mer is basically due to overloads & short ckts. Higher loads are permissible for very short duration of time.

If it continues for long time, it is dangerous as it causes overheating. Similarly, failure of cooling system, though it is rare, is another possible cause of overheating.

Generally, ~~the~~ thermal overload relays & temperature relays, sounding the alarm are used to provide protection. Similarly, temp. indicators are provided. The thermocouples or resistance temperature indicators are also provided near the winding. These are connected in a bridge ckt. When the temp. exceeds a safe value, the bridge balance gets disturbed & alarm is sounded. If the corrective action is not taken within certain period, then the CB trips.

<u>Winding faults</u>. —

The winding faults are called as internal fault. These are —

i) Phase to phase fault
ii) Earth fault
iii) Inter-turn fault

The overheating or mechanical shocks cause to damage the winding insulation. If the insulation becomes weak, there is possibility of s/c. betn the phases or betn phase and ground or betn adjacent turns of the same phase winding is also possible.

When such internal faults occurs the X'mer must be quickly disconnected from the sys. If it persists for longer time, it may cause oil fire.

The differential protection is very commonly used to provide protection against such faults. This type of protection is not economical for x'mers below 5 MVA rating. For high capacity x'mers, additional over current protection is also provided.

Open Circuits.—

The open ckt. in one of the three phases is dangerous as it causes the undesirable heating of the x'mer. In case of such faults, the x'mer is manually disconnected from the sys. A separate relay protection is not provided in open ckts. as these are much harmless compared to other faults.

Through faults.—

Through faults are the external faults which occur outside the protected zone. These are not detected by the differential protection. If these persists for long time, the x'mer may get subjected to the thermal & mechanical stresses. The overcurrent relays with undervoltage blocking, zero sequence protection & negative sequence protection are used to give protection against through faults.

Overfluxing —

The flux density in the transformer core is proportional to the ratio of vltg. & freq (V/f). The power x'mers are designed to work with certain value of flux density in the core.

Overfluxing is dangerous situation, in which, the magnetic flux density increases to extremely high levels. The high flux density can induce excessive eddy currents in the windings & in other conductive parts inside the transformers. The heat generated by these eddy currents can damage the wdgs & insulation. The wdg. temperature may also increase due to the heat produced.

Overfluxing is generally experienced in x'mers which are directly connected to the generators. In the generator - x'mer unit, if full excitation is applied before generator reaches its synchronous speed, then due to high V/f ratio, the overfluxing of core may result

The V/f relay called volts/hertz relay is provided to give protection against overfluxing operation. This relay does not allow the exciting current to flow till the generator reaches a synchronous speed.

Apart from these faults, some other faults like tap-changer faults, high vltg. surges due to lightning & switching, incipient faults ie slow developing faults may also occur in x'mers.

Percentage Differential Protection for X'mers.

Percentage differential protection or Merz-Price protection based on circulating current principle can be used for x'mers. The principle is the comparison of the current entering & leaving the ends of a x'mer. The vector difference of currents $(I_1 - I_2)$ passes through the operating coil while average current $\left(\frac{I_1+I_2}{2}\right)$ passes through the restraining coil.
In normal condition, the two currents I_1 & I_2 are equal & balance is maintained. So no current flows through the operating coil & relay is inoperative.

Compared to differential protection used in generators, there are certain points must be considered while using it in transformer ckt. They are:-

1) In power x'mer, the vltg. rating of two wdgs is different, hence there exists difference in currents in pri. & sec. sides. Hence if CTs of same ratio are used on two sides, then relay may operate even if there is no fault.
To compensate this difficulty, the ratios of CTs of both sides are different.

2) In power x'mers, there is an inherent phase difference betn the vltgs induced in h.v wdg & l.v. wdg. Due to this, there exists a phase difference betn the line currents on pri. & sec. sides of the x'mer. Though current ratio of CTs are selected to compensate for turns

ratio of transformer (point 1 above), a differential current may result due to phase difference betn the currents. This may operate the relay through there is no fault.

To compensate this, the CT connections should be such that the resultant currents fed into the pilot wires from either sides are displaced ~~be~~ in phase by an angle equal to the phase shift betn the pri. & sec. currents. To achieve this, the sec. of CTs on star connected sides of power x'mer are connected in delta & vice versa.

3. The neutrals of CT star & power x'mer star are grounded.

4. Many x'mers have tap changing arrangement due to which there is a possibility of flow of differential current. For this, CTs on both sides of power x'mer are provided with tap for their adjustment.

Merz-Price protection for λ-Δ x'mer.

Transformer pri. is star connected while sec. is delta connected. Hence to compensate for phase difference, the CT secondaries on pri. side is connected in delta while the CT secondary on delta side is connected in star. The star points are grounded.

The restraining coils are connected across the CT sec while the operating coils are connected betn the tapping point on the restraining coils & the star point of CT CT secondaries.

With proper selection of turns ratio of CTs, the coils are under balanced condition during normal operating condition. The CT secondaries carry equal currents which are in phase under normal conditions. So no current flows through the relay and the relay is inoperative.

With an internal fault in power x'mer windings, the balance in the CTs get disturbed. The operating coils of relay carry currents proportional to the difference of currents betn the two sides of the power x'mer. This causes the relay operation.

The basic requirements of differential relay are--

i) it must not operate on external faults.
ii) it must operate on severe internal faults.

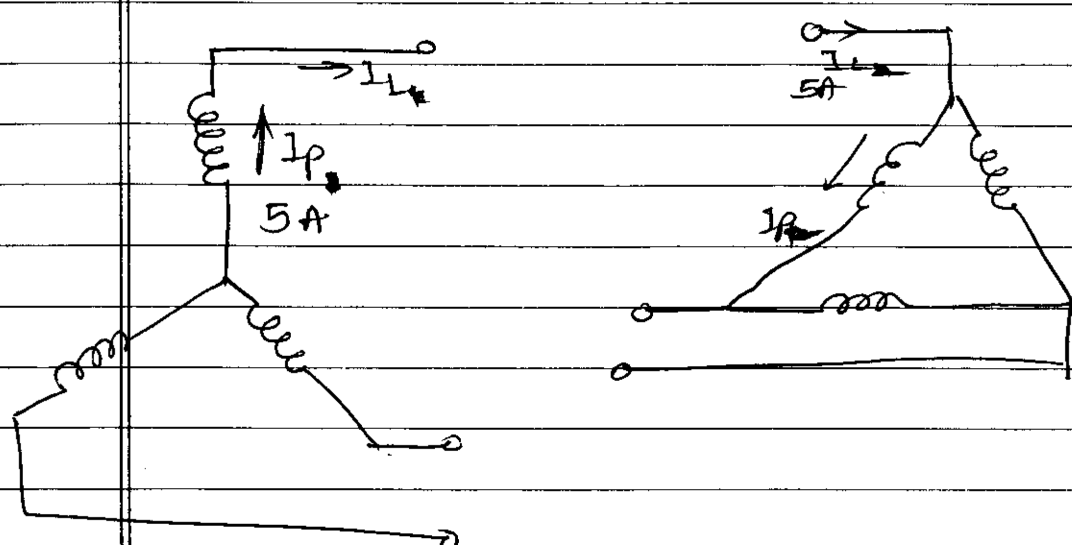
This scheme gives protection ~~ga~~ against s.c. faults betn the turns ie interturn faults also. This is because when there is an interturn fault, the turns ratio of power x'mer gets affected. Due to this, current on both sides of it becomes unbalanced. This causes an enough differential current to flow & the relay operates.

Problems.

1. A 11 kV/132 kV power-transformer is connected in Δ-λ. The CTs on the L.V. side have turns ratio 600/5. Find the suitable turns ratio for CTs on h.v-side.

Soln.

- Let the current on pri. ie l.v. side of x'mer be 600 A.
- This current will flow through each line on pri. side of x'mer.
- Hence current in each sec. of star connected CT on pri. is the phase current I_p



$$\therefore I_p = 600 \times \frac{5}{600} = 5\text{ A}$$

The same is line current I_L which is line current for CTs connected in Δ on sec. side of x'mer.

Hence current in each sec. of CT which is phase current of CT is $1/\sqrt{3}$ times the line value.

$$\therefore I_{p} = \frac{5}{\sqrt{3}} \text{ A. for CT sec. in delta.}$$

Now apparent power on both sides is same.

I_{L1} is Line current on pri. side of power x'mer

$$\sqrt{3}\, V_{L1} I_{L1} = \sqrt{3}\, V_{L2} I_{L2}$$

$$\sqrt{3} \times 11000 \times 600 = \sqrt{3}\ 132000 \times I_{L2}$$

$$\therefore I_{L2} = 50\text{A} \text{ A.}$$

I_{L2} is Line current on sec. side of power x'mer

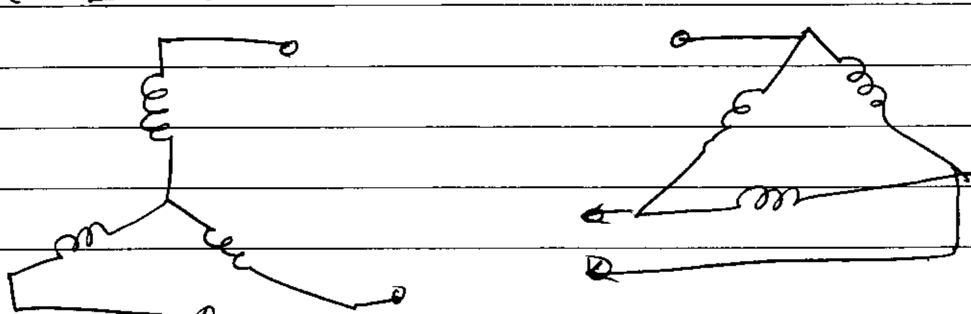
This 50A is current flowing through each pri. of delta connected CT.

$$\therefore \text{CT ratio on h.v. side} = \frac{50}{5/\sqrt{3}}$$

$$= 17.32 : 1$$

2. A 3 ph., 200 KVA, 11kV/400 V x'mer is connected in Δ-λ. The CTs on l.v. side have turns ratio of 500/5. Determine the CT ratio on h.v. side.

X'mer is Δ-λ, hence CTs will be λ-Δ connected.



Let the current on L.V. side is 500A

$\therefore$ Current ~~on~~ through pri. of CT on l.v. side $= I_{L_1} = 500\,A$.

- I_p = current through each sec. of Δ connected CT.

$$= 500 \times \frac{5}{500} = 5\,A.$$

- This 5A ~~is~~ a line ~~current~~ & phase current of star connected power x'mer.
- Same is the pri. current of Δ connected CT on h.v. side.
- $\therefore$ Sec. current of Δ connected CT will be,

$$= \frac{5}{\sqrt{3}}\,A.$$

$\therefore$ Line current through pilot wires is $\sqrt{3}$ times the phase current, ie $5\sqrt{3}\,A$ ($\because$ CT on ~~sec~~ l.v. side are delta connected)

$\therefore$ Same is the current through each sec. of star connected ~~CT~~ CT on h.v. side, ie $5\sqrt{3}\,A$.

Apparant power on both sides of power X'mer is same

$$\sqrt{3}\,V_{L_1} I_{L_1} = \sqrt{3}\,V_{L_2} I_{L_2}$$

$$\sqrt{3}\;11000 \times I_{L_1} = \sqrt{3} \times 400 \times 500.$$

$$\therefore I_{L_1} = 18.18\,A$$

This is current through each pri. of CTs connected in star.

$\therefore$ Current ratio of CTs on h.v. side $= \frac{18.18}{5/\sqrt{3}}$

$= 2.099 : 1$

3. A 3ph., 33/6.6 kV star-delta connected X'mer is protected by differential sys. The CTs on l.v. side have ratio of 300/5. Show that CTs on h.v. side will have ratio $60 : 5/\sqrt{3}$

Let 300 A is flowing in lines on l.v. side

Apparent power on both sides of power X'mer is same.

$\therefore \sqrt{3} \times 33 \times I_{L_1} = \sqrt{3} \times 6.6 \times 300$

$\therefore I_{L_1} = 60\,A$ --- is the pri. current of CT on h.v. side.

- On delta side of power X'mer, the CTs are connected in star. Their sec. current is 5 A ($\because$ current ratio given 300/5) Hence current fed in pilot wires from l.v. side is 5A.

Same current is fed from CT connections on h.v. side which are delta connected. That is the line current (pri.) of CT on h.v. side

$\therefore$ sec. current of CTs on h.v side is $\frac{5}{\sqrt{3}}\,A. = I_{P_1}$

Buchholz Relay

The Buchholz relay is a gas operated relay used for the protection of oil immersed transformers. It is named after its inventor, Buchholz. The slow developing faults called incipient faults in the x'mer tank below oil level operate the Buchholz relay which gives an alarm. If the faults are severe, it disconnects the x'mer from the supply.

It operates on the principle that due to the faults, oil in the tank decomposes, generating the gases. The 70% component of such gases is hydrogen which is light & hence rises upwards ~~to~~ towards the conservator through the pipe. Due to the gas collected in the upper portion of the relay, it operates and gives an alarm.

Continued in the print out.

Advantages -

1. Normally protective relay does not indicate the appearance of fault. It operates when fault occurs. Buchholz relay gives an indication ~~of~~ of the fault at very early stage.
2. It is the simplest protection used for x'mer.

Limitations

1. Can be used only for oil immersed x'mers having conservator tanks.
2. ~~Fast~~ Faults only below oil levels are detected.
3. Setting of mercury switches cannot be kept too sensitive otherwise the relay can operate due to bubbles, vibration, mechanical shocks, etc.
4. The relay is slow ~~to~~ operate having min. operating time of 0.1 sec. & avg time of 0.2 sec.

Buchholz Relay:

Buchholz relay is a safety device which is generally used in large oil immersed transformers (rated more than 500 kVA). It is a type of oil and gas actuated protection relay. It is used for the protection of a transformer from the faults occurring inside the transformer, such as impulse breakdown of the insulating oil, insulation failure of turns etc.

Whenever a fault occurs inside the transformer, such as insulation failure of turns, breakdown of core or excess core heating, the fault is accompanied by production of excess heat. This excess heat decomposes the transformer insulating oil which results in production of gas. The generation of gases depend on intensity the of fault. Gas bubbles tend to flow in upward direction towards conservator and hence they are collected in the buchholz relay which is placed on the pipe connecting the transformer tank and conservator.

Construction:

Buchholz relay consists of an oil filled chamber. There are two hinged floats, one at the top and other at the bottom in the chamber. Each float is accompanied by a mercury switch. The mercury switch on the upper float is connected to an alarm circuit and that on the lower float is connected to an external trip breaker.

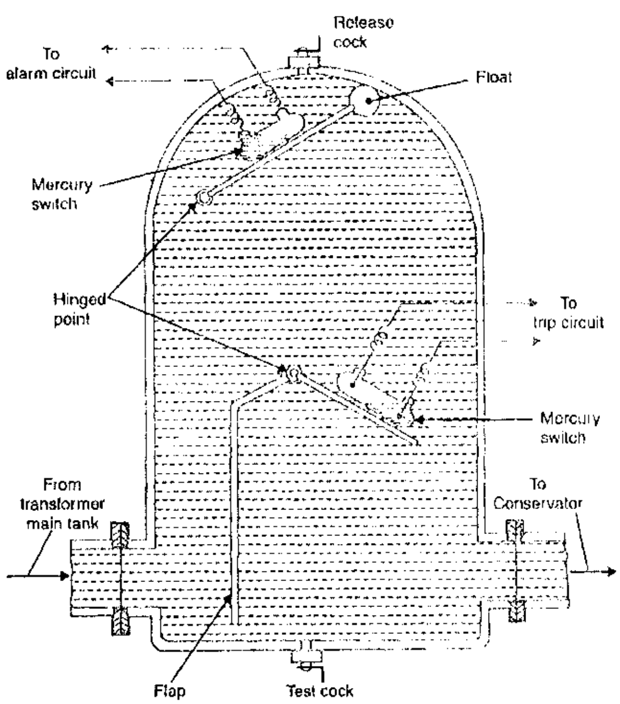
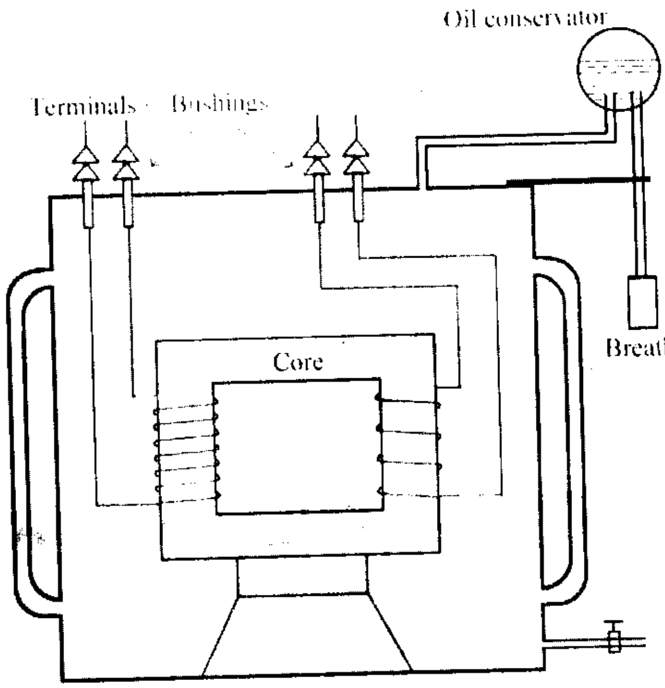


Fig. 22.12

Whenever a minor fault occurs inside the transformer, heat is produced by the fault currents. The produced heat causes decomposition of transformer oil and gas bubbles are produced. These gas bubbles flow in upward direction and get collected in the buchholz relay. The collected gas displaces the oil in buchholz relay and the displacement is equivalent to the volume of gas collected. The displacement of oil causes the upper float to close the upper mercury switch which is connected to an alarm circuit. Hence, when minor fault occurs, the connected alarm gets activated. The collected amount of gas indicates the severity of the fault occurred.

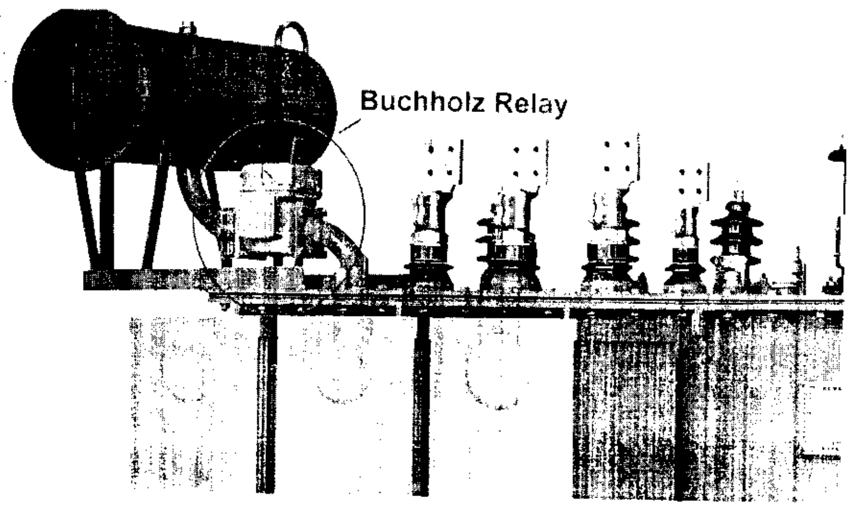
More severe types of faults, such as short circuit between phases or to earth and faults in the tap changing equipment, are accompanied by a surge of oil which strikes the baffle plate and causes the mercury switch of the lower element to close. This switch energize the trip circuit of the circuit breakers associated with the transformer and immediately isolate the faulty transformer from the rest of the electrical power system by inter tripping the circuit breakers associated with both LV and HV sides of the transformer. This is how Buchholz relay functions.

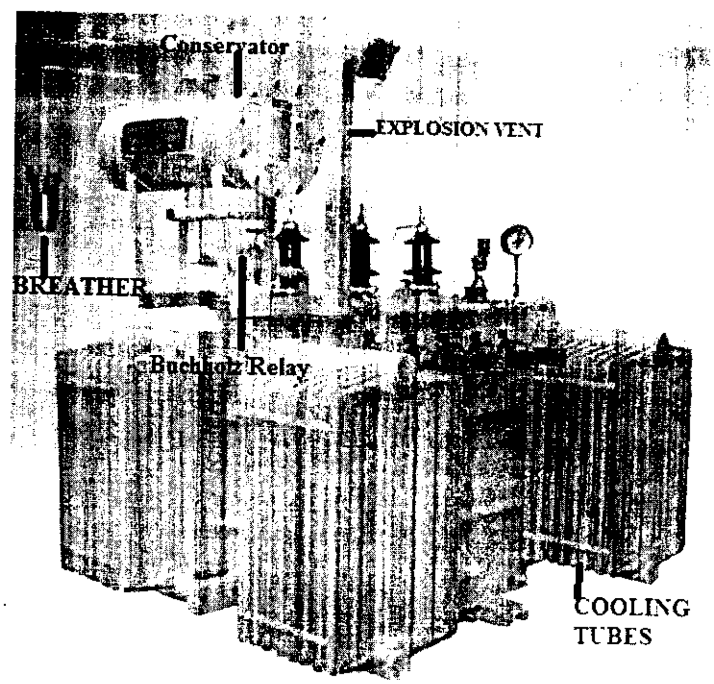


Basically a transformer consists of two inductive windings and a laminated steel core. The coils are insulated from each other as well as from the steel core. A transformer may also consist of a container for winding and core assembly (called as tank), suitable bushings to take out the terminals, oil conservator to provide oil in the transformer tank for cooling purposes etc. **Transformer oil** (also known as insulating oil) is a special type of oil which has excellent electrical insulating properties and is stable at high temperatures. Transformer oil is used in oil-filled electrical power transformers to insulate, stop arcing and corona discharge, and to dissipate the heat of the transformer (i.e. act as a coolant).

Conservator is a cylindrical tank mounted on supporting structure on the roof the transformer main tank. The main function of ***conservator tank of transformer*** is to provide adequate space for expansion of oil inside the transformer.

Whenever electrical power transformer is loaded, the temperature of the transformer insulating oil increases, consequently the volume of the oil is increased. As the volume of the oil is increased, the air above the oil level in conservator will come out. Again at low oil temperature; the volume of the oil is decreased, which causes the volume of the oil to be decreased which again causes air to enter into conservator tank. The natural air always consists of more or less moisture in it and this moisture can be mixed up with oil if it is allowed to enter into the transformer. The air moisture should be resisted during entering of the air into the transformer, because moisture is very harmful for transformer insulation. A silica gel breather is the most commonly used way of filtering air from moisture. **Silica gel breather for transformer** is connected with conservator tank by means of breathing pipe.





Negative sequence Relay

The negative sequence relays are also called as phase unbalance relays because these relays provide protection against negative sequence component of unbalanced currents existing due to unbalanced loads or phase-phase faults. The unbalanced currents can cause overheating.

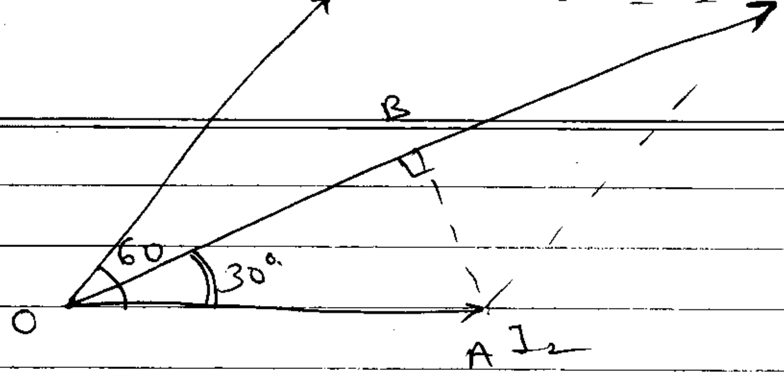
A negative sequence relay has a filter ckt. which is operative only for -ve seq. components. Low order of overcurrent can also cause dangerous situations, hence a -ve seq. relay has low current settings.

Basically it consists of a resistance bridge network. The magnitudes of impedances of all the branches of the network are equal. The Z_1 & Z_3 are purely resistive while Z_2 & Z_4 are combinations of resistance & reactance. The current in the branches Z_2 & Z_4 lag by 60° from the currents in the branches Z_1 & Z_3. Vertical branch BD consists of inverse time charatteristics relay. The relay has negligible impedance.

Current I_R gets divided into two equal parts I_1 & I_2 and I_2 lags I_1 by 60°

$$\bar{I}_1 + \bar{I}_2 = I_R$$

Let $I_1 = I_2 = I$



Drop a perpendicular from A on the diagonal at point B. ∴ B bisects the diagonal

$$\therefore OB = \frac{I_R}{2}$$

in $\triangle OAB$, $\cos 30 = \frac{OB}{OA}$

$$\therefore \frac{\sqrt{3}}{2} = \frac{(I_R/2)}{I}$$

$$\therefore I = \frac{I_R}{\sqrt{3}} = I_1 = I_2.$$

Now I_1 leads I_R by 30°, while I_2 lags I_R by 30°.

Similarly I_B is divided into two equal parts I_3 & I_4 and we can write as,

$$\frac{I_B}{\sqrt{3}} = I_3 = I_4$$

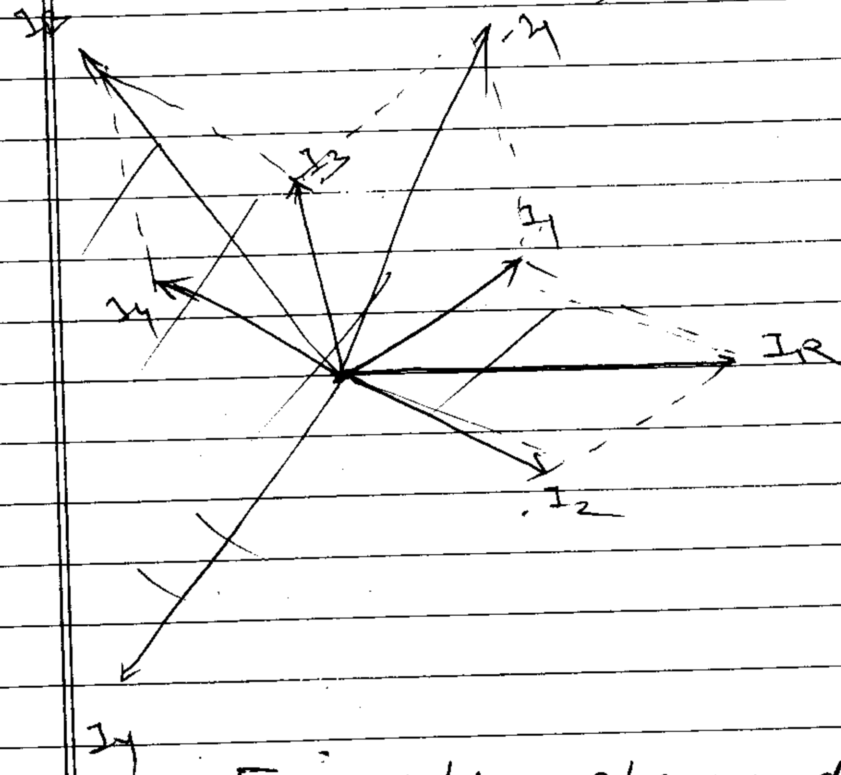
Current I_4 leads I_B by 30° while I_3 lags I_B by 30°

The current entering the relay at junction B is the vector sum by I_1, I_3 and I_4

$$\therefore I_{Relay} = \bar{I}_1 + \bar{I}_3 + I_4$$

$$I_{relay} = I_y + \frac{I_R}{\sqrt{3}} + \frac{I_B}{\sqrt{3}}$$

(leads I_R by 30°) (Lags I_B by 30°)



From the phasor diag,

the vector sum is zero,

ie $I_{relay} = 0$

ie no negative seq. current exist.

It can be seen from phasor,

$$I_1 + I_3 = -I_y$$

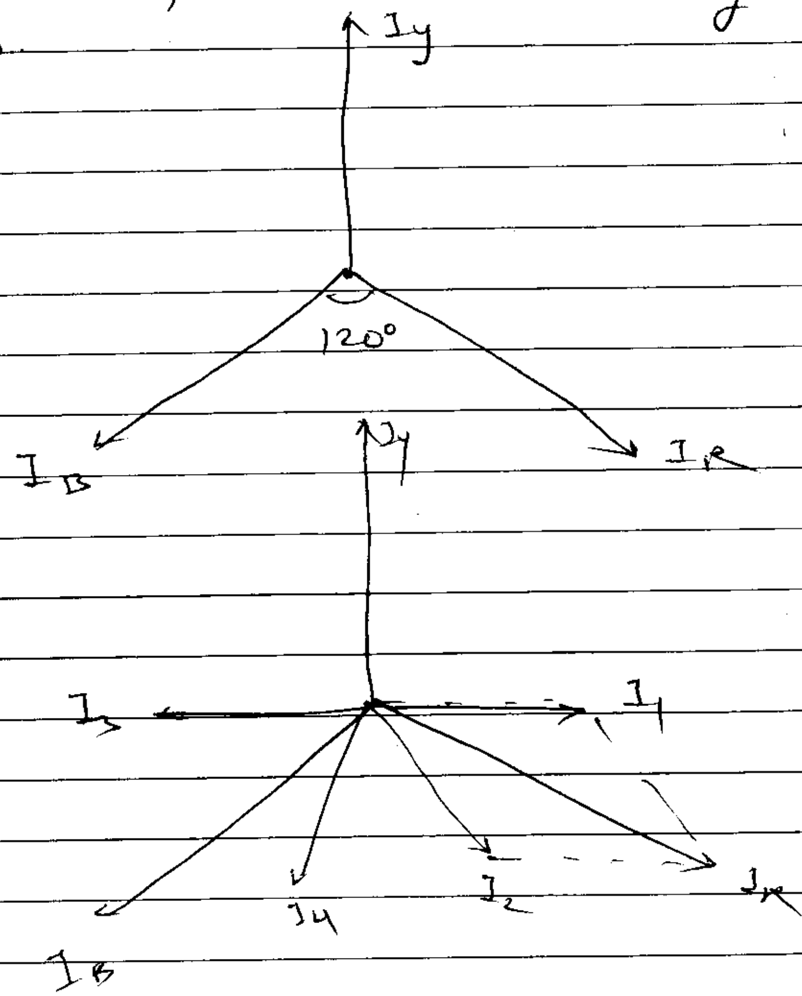
$$I_1 + I_3 + I_y = 0.$$

Thus the current entering the relay at point B is zero

Similarly, the resultant current at junction D is also zero

Thus relay is inoperative at balance condition

Now consider, there is unbalanced load on generator or motor, due to which -ve sequence currents exists. The phase sequence of ~~sec~~ C.T. secondary current changes.



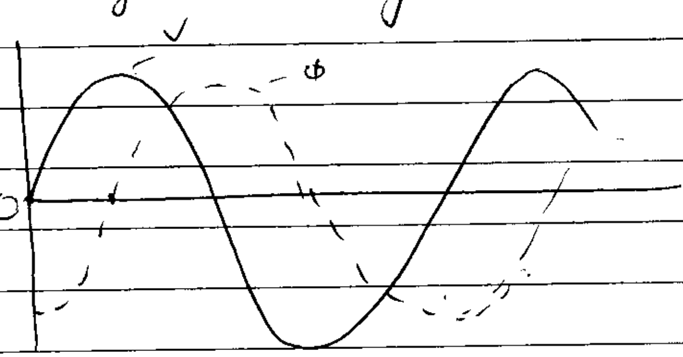
$\therefore$ Phasor diag of I_1, I_3 & I_y is shown above, under unbalance cond^n.

Compo. I_1 & I_3 are equal & opposite to each other & hence cancel each other.

$\therefore$ relay coil carries current I_y, and when this current is more than predetermined value, the relay operates.

Transformer Inrush Current
(Magnetizing inrush current)

When a transformer is switched on while keeping sec. side open, it acts as a simple Inductance. In the transformer the flux produced in the core is in quadrature with applied voltage. The flux will reach its maximum value 1/4 cycle later than the voltage reaching its max.



At the instant O, when the voltage is zero, the corresponding steady state value of flux should be the negative max. But it is not practically possible to have flux the instant at which we switch on the supply. This is because there is no flux linked to the core prior to switching on the supply. The steady state value of flux will not be reached instantly. So the flux in the core will also start from its zero value at the time of switching on the transformer.

Date ______
Page ______

According to Faraday's law, the induced vltg. is, $e = \frac{d\phi}{dt}$ where ϕ is the flux in the core. ∴ Flux will be calculated as integration of vltg. wave as,

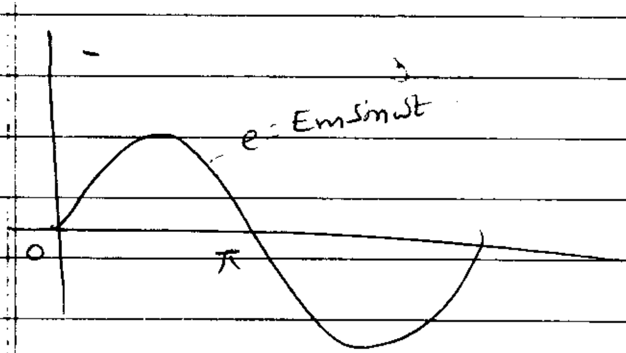
$$e = E_m \sin\omega t$$
$$= \frac{d\phi}{dt}$$
$$\therefore \phi = \int e\,dt$$
$$= E_m \int \sin\omega t\,dt.$$

$$\therefore \phi = \frac{E_m}{\omega}.$$

If transformer is switched on at the instant of voltage zero, the flux wave is initiated from same origin as voltage waveform. The value of flux at the end of first half cycle of the vltg. waveform can be calculated as,

$$\phi_m = E_m \int_0^{\pi} \sin\omega t\,dt$$

} To obtain max peak of flux, integrate the area under the induced emf waveform's first half cycle



$$\boxed{\phi_m = \frac{2E_m}{\omega}}$$

Thus in a transformer, that is suddenly started, the flux reaches approximately twice its normal peak magnitude

1.
2.
3.

If the pri. wdg of the X'mer is suddenly connected to the AC voltage supply at the exact moment when the instantaneous voltage is at its +ve peak, then vltg. eqn can be written as,

$$V = V_m \sin(\omega t + 90^\circ)$$
$$= V_m \cos \omega t$$

Hence, the induced emf eqn will be,

$$e = E_m \cos \omega t = \frac{d\phi}{dt}$$

If the initial flux in the core is assumed to be zero, then max. flux at steady state will be,

$$\boxed{\phi_m = \frac{E_m}{\omega}}$$

Hence, if x'mer is switched on when vltg. is at its zero, the flux developed is twice than the flux at the instant of switching at +ve peak of vltg.

This is the mechanism of causing the inrush current in x'mer primary. The magnitude of ~~in~~ inrush current strongly depends on the switching instant. If there is some residual magnetism in the x'mer core at the time of switching on, the inrush is ~~so~~ even more severe.

This current decays rapidly for first few cycles & then decays slowly.

There are no. of ways ensuring immunity from the operation of relay due to magnetizing ~~inrush~~ inrush current.

- The relay setting may be kept little higher than max. inrush current.
- The time setting may be kept high enough for the inrush current to fall to a value below the operating current before the relay operates.