Generator Protection

The generators in the P.S. are the alternators, which produce very high AC voltages. The protection of generators is very much complex due to the following reasons.

1) Generators are ~~very~~ very large machines producing very high voltages & are connected to bus bars.

2) Various other equipment are always associated with the generators such as prime movers, excitation systems, voltage regulators, cooling sys. etc.

3) The shutting off of generators result in power shortage.

Generator Faults.

The faults can be classified as,

1. Stator faults
2. Rotor faults.
3. Abnormal running conditions

Stator Faults.

These are the faults associated with the three phase armature wdg of the generator. These are mainly due to insulation failure of the armature wdg. Main stator faults are -

a) Phase to earth fault - These faults mainly occur in the armature slots. These faults are dangerous & can cause severe damage to the expensive machine. If fault currents are high, severe burning of stator core can take place. This may lead to the requirement of replacing the laminations which is very costly & time-consuming. Hence a separate, sensitive earth fault protection is necessary alongwith the earthing resistance.

b) Phase to phase faults - Phase to phase faults means s.c. betn two phase windings. Such faults are uncommon because the insulation used betn the coils of diff. phases in a slot is large. But once phase to earth fault occurs, due to overheating, phase to phase fault may also occur. This fault is likely to occur at the end connections of armature windings. Such fault causes severe arcing with very high temp. This may lead to melting of copper & fire.

c) Stator intern-turn faults - Coils used in the alternators are generally multiturn coils. So short circuit betn the turns of one coil may occur which is called an ~~tern~~ intern-turn fault. This fault occurs due to current surges. If the coils are used are single turn then this fault cannot occur. Hence for large machines of order of 50MVA & more, it is normal practice to use single turn coils.

Rotor Faults.

The rotor of an alternator is generally a field winding as most of the alternators are of rotating field type. The field wdg is made up of number of turns. So the conductor to earth fault & short ckt. betn the turns of the field wdg. are common. These faults are caused due to the severe mechanical & thermal stresses acting on the field wdg. insulation.

The field wdg. is normally not connected to the earth so that a single earth fault doesnot give rise to any fault current. A second earth fault will s.c. part of the wdg. and may thereby produce an unsymmetrical force on the rotor. (The second earth fault means s.c. betn active conductors through the earth). Such force will cause, excess pressure on bearing & shaft distortion

The unbalanced loading on generator gives rise to negative sequence currents which causes negative seq. magnetic field. This negative sequence field rotates in opposite direction of main field which induces emf in rotor wdg & causes heating of rotor wdg.

Rotor earth fault protection & rotor temperature indicators are essential & are provided to large rating generators.

Abnormal running Conditions

In practice, there are number of situations in which generator is subjected to some abnormal running conditions. They are -

a) Overloading - Due to continuous overloading, the overheating of the stator results. This may increase the winding temperature. If it exceeds a certain limit, winding may get damaged. The overcurrent protection is generally set to high value hence continuous overloads of less value than the setting cannot be sensed by overcurrent protection.

b) Overspeeding - In case of hydraulic generators, a sudden loss of load results in overspeeding of generator. This is because the water flow to the turbine cannot be stopped or reduced instantly. Generally a turbogoverner is provided to prevent ~~overp~~ overspeeding. But if there is any fault in the turbine governer, then dangerous overspeeding may take place. Hence supervision is necessary.

c) Unbalanced loading - The unbalanced loading of the generator results in the circulation of negative sequence currents. These currents produce rotating magnetic field which rotates at syn. speed w.r.t. rotor. The direction of rotation of this magnetic field is opposite to that of rotor. Hence effectively the relative ...

the two is double the syn. speed.

Thus the emf gets induced, having double the normal freq in the rotor wdg. The currents produced due to this induced emf are responsible for overheating of rotor wdgs. as well as rotor stampings. Continuous unbalanced load more than 10% of the ~~rot~~ rated load causes tremendous heating.

Negative seq. protection is necessary prevent such a dangerous situation.

d] Overvoltage – The overvoltage is basically due to the overspeeding of generators. Another reason is faulty operation of voltage regulators. Not only internal overvltgs. are dangerous but atmospheric surge voltages can also reach to the generators. Reasons for atmospheric surge vltgs are lightning strokes. To protect the generators from surge voltages, surge arrestors & surge capacitors are often used.

At the time of restriking across the contacts of CBs, the transient overvoltages are generated. Such surges are called switching surges & can be limited by the use of modern CBs.

e] Failure of prime mover – it results in motoring operation of syn. generators. The generator draws active power from the network & continues to run at syn. speed as syn. motor. This may lead to dangerous mechanical conditions. The overheating of turbine ~~se~~ blades may result. To prevent this, the reverse power protection can be achieved by ~~dir~~ using directional power relays.

f] Loss of excitation – The loss of excitation or reduced excitation is possible due to the field failure i.e, opening of field wdg. or due to some other fault in exciter sys.

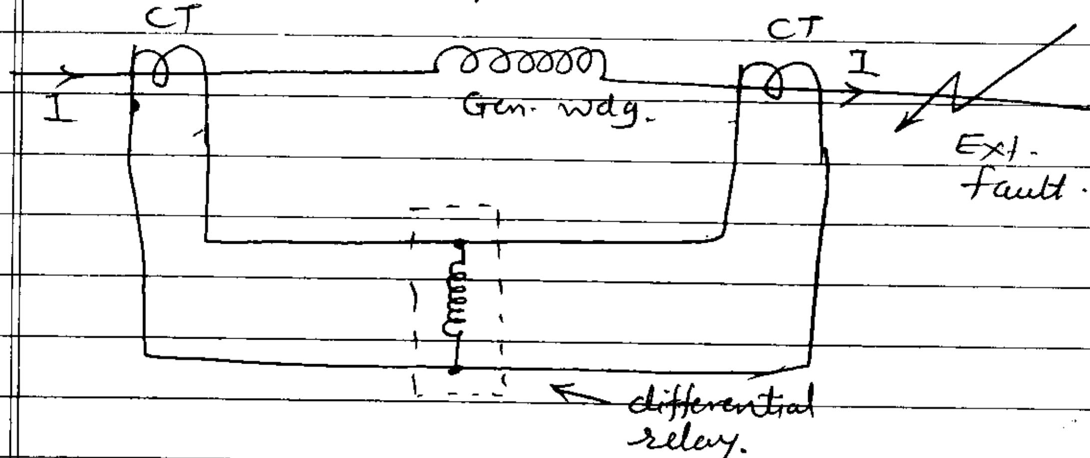
Loss of excitation results in loss of synchronism within a second & causes the the increase in speed of generator. Since power input to the machine remains same, the generator starts working as an induction generator, drawing the reactive power from the bus. The machine starts drawing the exciting current from the sys., which is equal to the full load rated value. This leads to overheating of stator wdg. & rotor body due to induced currents.

g] Cooling sys. failure – causes severe overheating. It can lead to insulation failure.

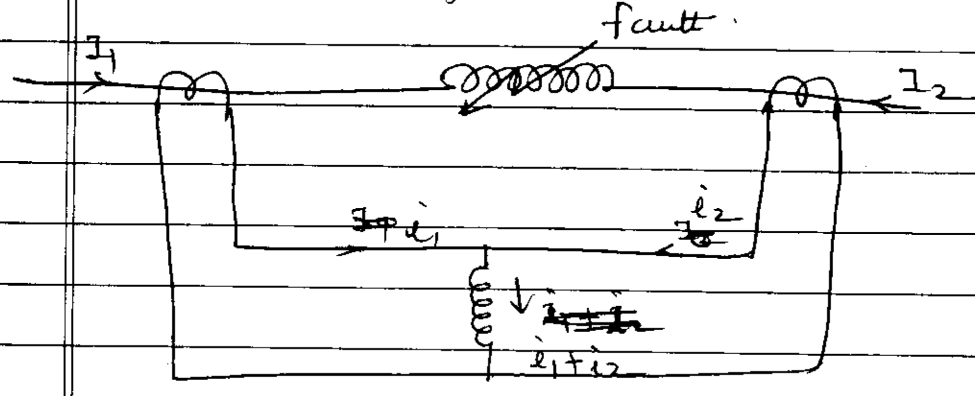
Thermocouples or resis. thermometers are used to sense temp. in large machines.

Basic Differential Protection Scheme for Generators.

Differential relay operates when phasor difference of two or more similar quantities exceeds a predetermined value.



Suppose current I flows through the pri. of CTs & there is an external fault. If the two CTs have same ratio, then no current will flow through relay & it remains inoperative.



If now an internal fault occurs, the current flows through the fault from both sides. Pri. currents are I_1 & I_2 while sec. currents are i_1 & i_2. So the current flowing through the relay will be $i_1 + i_2$. Even some current flowing

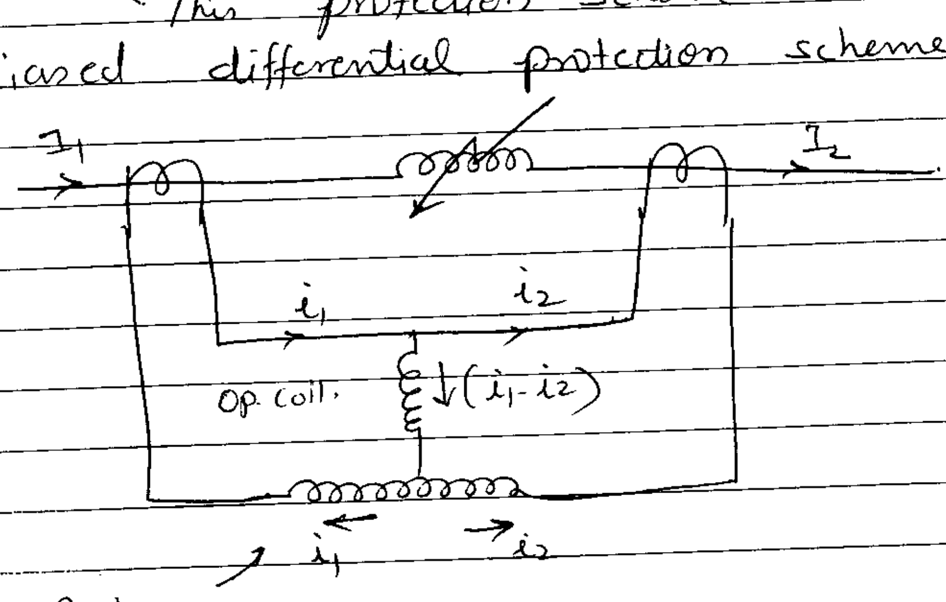
Out of one side while large current entering the other side will cause the differential current. Such current ~~se~~ is responsible to operate the relay.

The basic differential scheme has following disadvantages.

1. This ckt. operates inaccurately with heavy external fault.
2. The CTs may saturate & cause unequal sec. currents & the difference of sec. currents may approach the pick-up value to operate relay unnecessarily.

These disadvantages are overcome in % differential relay.

This protection scheme is also called biased differential protection scheme.



When internal fault occurs, current $i_1 - i_2$ flows through operating coil & current through restraining ~~coi~~ coil is $\frac{i_1+i_2}{2}$

It is called as % differential relay because ratio of differential operating current to average restraining current is fixed percentage.

This basic % differential protection scheme forms the basis of practically very commonly used % differential scheme known as Merz-price protection.

<u>Merz-Price protection of alternator stator windings.</u>

In this method, the currents at two ends of protected section are sensed using CTs. Wires connecting relay coils to the CT secondaries are called pilot wires.

Under normal condition, currents in the pilot wires fed from CT secondaries are equal. The difference current $i_1 - i_2$ through the operating coils of relay is zero. Hence relay is inoperative.

When fault occurs inside the protected section of stator wdgs, the differential current $i_1 - i_2$ flows through the operating coil of the relay. Due to this, the relay operates. This trips the generator CB to isolate the faulty section.

The differential relay provides protection against s.c. fault in the stator wdg.

The CTs are connected in star and are provided on both sides. The restraining coils are energized from the secondary connection of CTs in each phase, through pilot wires.

The operating coils are energized by the tappings from restraining coils & the CT neutral earthing connection.

Similar arrangement is used for the delta connected alternator stator wdg.

The CTs on the delta connected machine winding side are connected in delta while the CTs at outgoing ends are connected in star.

The restraining coils are placed in each phase, energized by the secondary connection of CTs while the operating coils are energized from the restraining coil tappings & the CT neutral earthing.

If there is a fault due to s.c. in the protected zone of the windings, it produces a difference betn the currents in the pri. wdgs of CTs on both sides of the generator wdg of same phase. This results in a difference betn the sec. currents of the two CTs. Thus differential current flows through the operating coils.

When differential relaying is used, CTs at both ends of generator must be of equal ratio & equal accuracy otherwise wrong operation of relay may result.

This scheme provides very fast protection to the stator wdg. against phase to phase fault and phase to ground fault

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Advantages.

1. Very high speed operation with operating time of about 15 ms.
2. Allows low fault current setting thus ensuring max. protection.
3. Ensures complete stability under most severe through & external faults.

Restricted earth fault protection

Merz-Price protection provides the protection against internal earth faults. But for large generators, as these are costly, an additional protection scheme called restricted earth fault protection is ~~also~~ provided.

When the neutral is solidly grounded, then the generator gets completely protected against earth faults. But when neutral is grounded through earth resistance, then the Stator wdgs are partly protected against earth faults. The percentage of wdg. protected depends on the value of earthing resistance & the relay setting.

In this scheme, the value of earth resistance, relay setting, current rating of earth resistance must be carefully selected. The earth faults are rare near the neutral point as the vltg. of neutral point w.r.t. earth is very less. But when the earth fault occurs near the neutral point then the insufficient voltage across the fault drives very low fault current than the pickup current of relay coil. Hence the relay remains inoperative. Hence it is called restricted earth fault protection. It is usual practice to protect 85% of the winding.

Consider that earth fault occurs in phase B due to breakdown of its insulation to earth, as shown in diag. The fault current I_f will flow through the core, frame

frame of machine to earth & complete the path through earthing resistance.

The CT secondary current Is flows through operating coil & the restricted earth fault relay coil of the differential protection.

The setting of restricted earth fault relay & setting of overcurrent relay are independent of each other. Under this secondary current Is, the relay operates to trip the CB.

The voltage V_{bx} is sufficient to drive the enough fault current I_f when the fault point x is away from the neutral point.

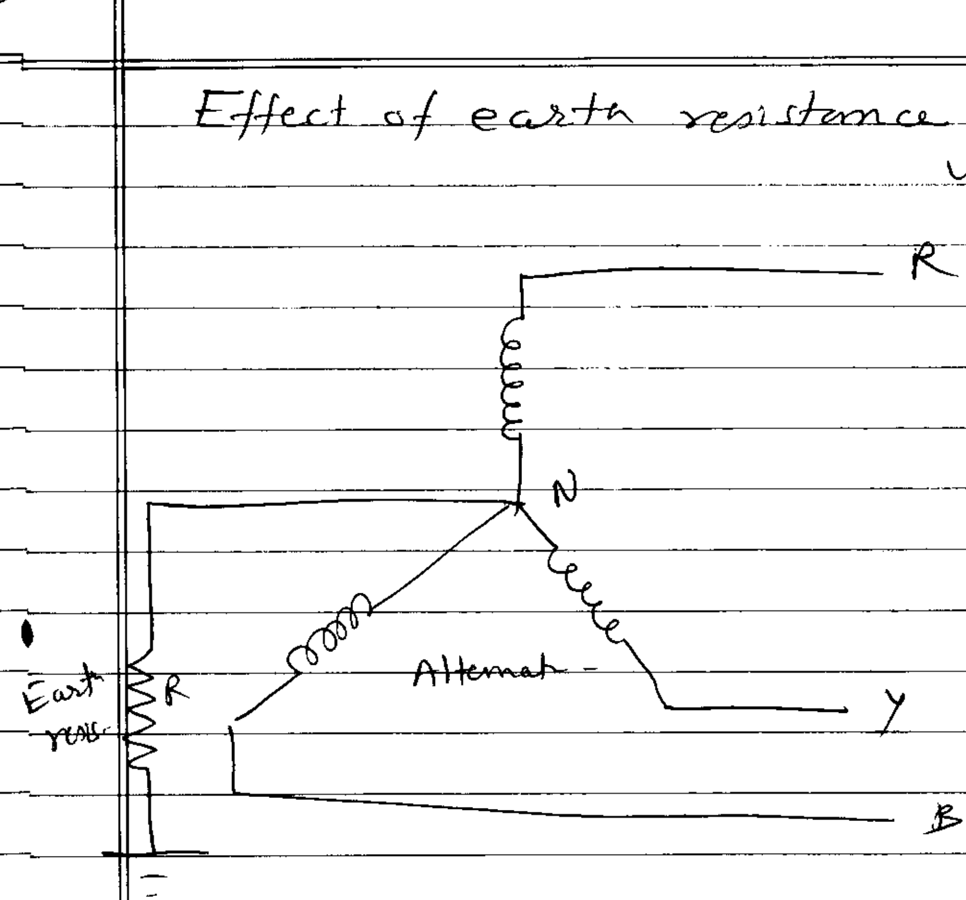
If fault point x is nearer to neutral point, then the vltg. V_{bx} is small and not sufficient to drive enough fault current I_f & hence relay cannot operate.

Thus part of the winding from the neutral point remains unprotected.

To overcome this, if relay setting is chosen very low to make it sensitive to low fault currents, then wrong operation of relay may result. The relay can operate under conditions of heavy through faults, saturation of CTs, etc.

Hence, practically 15% of winding from the neutral point is kept unprotected, protecting the remaining 85% of winding against ph. to earth faults.

Effect of earth resistance on % of winding unprotected.



Consider the earth resistance R used to limit earth fault current.

The value of R limits the earth fault current.

If R is very small, the neutral is almost solidly grounded, then the fault current is very high. But high fault currents are not desirable, hence small R is not preferred for large machines.

For ~~L~~ low resis. R, the value of R is selected such that full load current passes through the neutral, for full line to neutral vltg.

For medium resis. R, earth fault current is limited to about 200 A for full line to neutral voltage, for a 60 MW m/c.

In high resis. R, earth fault current is limited to 10A. This is used for distribution transformer.

Higher the value of earth resis. R, less is the earth fault current & less % of winding get protected. Large % of winding remains unprotected.

V = full line to neutral vltg.

I = full load current of largest capacity gener.

R = earth resis.

$$R = \frac{V}{I}$$

and the % of winding unprotected is,

$$\%\ \text{wdg. unprotected} = \frac{R.I_0}{V} \times 100$$

Where I_0 = min. operating current in CT pri.

If relay setting used is 15%, then I_0 is 15% of full load current of the largest m/c & so on.

Prob.

1\. A generator is protected by restricted earth fault protection. The generator ratings are 13.2 kV, 10 MVA. The % of wdg. protected against ph. to gnd fault is 85%. The relay setting is such that it trips for 20% out of balance. Calculate the resistance to be added in the neutral to gnd connection.

Given, $V_L = 13.2\ kV$, Rating = 10 MVA

$\therefore$ Full load current, $I = \dfrac{\text{rating in VA}}{\sqrt{3} \cdot V_L}$

$$= \frac{10 \times 10^6}{\sqrt{3} \times 13.2 \times 10^3} = 437.386\ A$$

$\because$ Relay setting is 20% out of balance, ie for 20% of the rated current, the relay activates.

$\therefore I_0 = 20\%$ of 437.386

$= 87.47\ A$

= Min. operating current.

V = Line to neutral (phase) vltg

$= V_L/\sqrt{3} = 7621.02\ V$

% of winding protected = 15%

$$\therefore 15 = \frac{R \cdot I_0}{V} \times 100$$

$$\therefore 15 = \frac{R \times 87.47}{7621.02} \times 100$$

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2. The neutral point of a 11 kV alternator is earthed through a resis. of 12 Ω. The relay is set to operate when there is out of balance current of 0.8 A. The CT have a ratio of 2000/5. What % of wdg. is protected against earth fault. What must be the min. value of earthing resis. required to give 90% of protection to each phase?

$V_L = 11\ kV$, $R = 12\ \Omega$ CT ratio = 2000 : 5

i_0 = relay current = 0.8 A → current on CT sec.

∴ I_0, ~~current~~ min. operating current on CT pri.,

$$I_0 = i_0 \times \frac{2000}{5}$$

$$= 320\ A$$

V = line to neutral vltg = $\frac{V_L}{\sqrt{3}}$

$$= \frac{11 \times 10^3}{\sqrt{3}} = 6350.8529\ V$$

∴ % wdg. unprotected = $\frac{R \cdot I_0}{V}$

$$= \frac{12 \times 320}{6350.8529}$$

$$= 60.46\%$$

∴ % wdg. protected = 100 − 60.46

= 39.54 %

B ~~Eo~~ To provide 90% protection, i.e 10% will be unprotected.

$$\therefore 10 = \frac{R \times I_0}{V} \times 100$$

$$= \frac{R \times 320}{6350.46} \times 100$$

$$\therefore \boxed{R = 1.984\ \Omega.}$$

3. A 50 MVA, 3ph., 33kV syn. generator is protected by merz-price protection using 1000/5 ratio CTs. It is provided with restricted earth fault protection with earthing resistance of 7.5 Ω. Calculate the % of winding unprotected in each phase against earth faults if the min. operating current of the relay is 0.5 A.

$V_L = 33\,kV.$

CT : 1000 : 5

$i_0 = 0.5\ A$ = relay current

$\therefore I_0$ = min. operating current in CT pri.

$$= i_0 \times \frac{1000}{5}$$

$$= 100\ A$$

$$V = \frac{V_L}{\sqrt{3}} = \frac{33 \times 10^3}{\sqrt{3}} = 19052.55\ V.$$

$$\therefore \%\ \text{wdg. unprotected} = \frac{R I_0}{V}$$

$$= 7.5 \times 100 \quad 3.936\%$$

Overcurrent & Earth-fault protection for generator back-up.

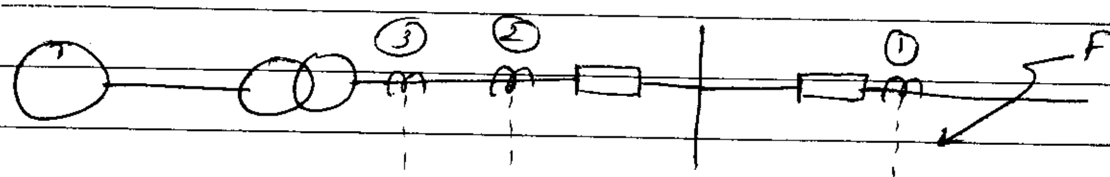
For generators above 1MW, where primary protection to stator wdg is provided by differential protection, the overcurrent & earth fault protection gives back-up protection for external phase to phase faults & earth faults.

Induction type, inverse definite minimum time (IDMT) relays may be used for generator back-up protection for external faults.

Since faults in stator wdg are fed by stator winding itself, their Influence on current in the outgoing terminals of generator depends upon fault level of the main bus.

Hence, overcurrent & earth fault relays do not provide satisfactory protection against internal fault. However, these relays provide back-up protection to generators against external faults.

The setting selected is such that the overcurrent & earth-fault protection doesnot normally operate for external faults such as F.



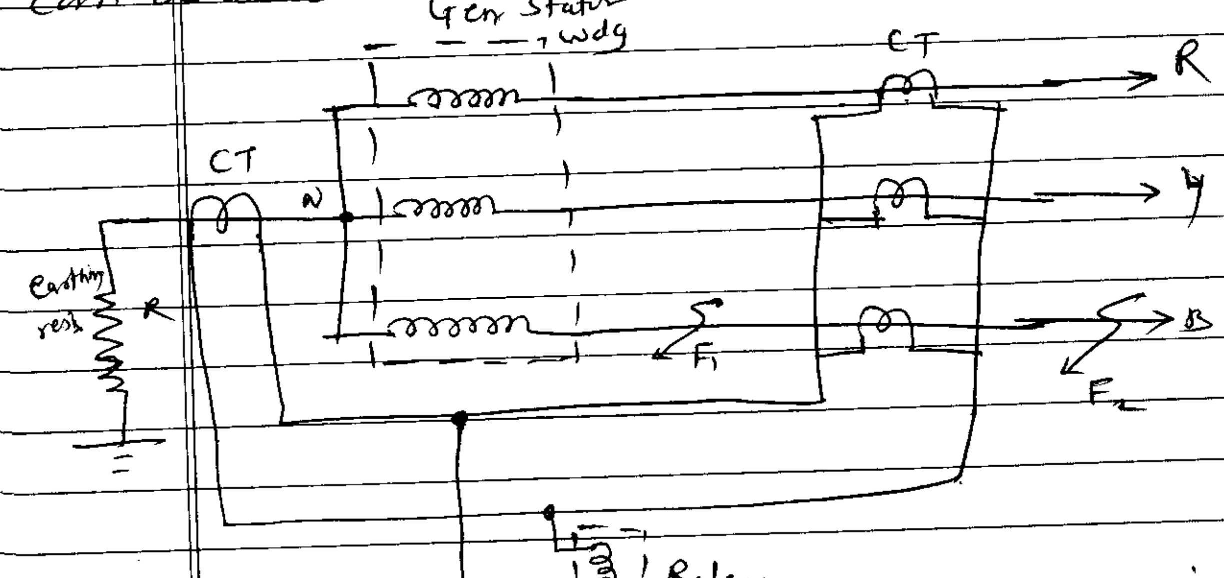
However, if fault F continues for a long time due to failure of line protection, the fault will be fed by the generator. Hence the overcurrent & earth fault protection of genr

③. may be set to operate with due time lag for higher values of external fault currents.

Hence high set definite minimum time, induction type, inverse over current, earth fault relays are recommended for generator back up.

Balanced earth fault protection

In practice, for small rating generators, the neutral ends of the three phases are connected to a single point. Hence, it is not possible to introduce CT in each phase on neutral side as required in Merz-Price protection. In such cases balanced earth fault protn can be used.



At the outgoing side, the three CTs are connected in parallel. A single CT is connected on the neutral side in the pilot wire connecting neutral of alternator to earth. A relay is connected across CT secondaries.

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Under normal conditions, the alternator line currents add to zero. Hence the vector sum of the currents through the CT secondaries is also zero. Hence no current through relay & relay is inoperative.

If the fault occurs at F_2, ie at a position outside protected zone, then the sum of the alternator line currents is exactly equal to the current in neutral. Thus zero current flows through the relay keeping it inoperative.

But if fault occurs at F_1, then vector sum of alternator line currents is different than the current through the neutral side current x'mer. Hence a residual current flows through the relay. If it is greater than the pick-up value of the relay, the relay operates.

Stator protection against inter-turn faults.

The Merz-price protection sys. gives protection against phase to phase faults & earth faults. It doesnot give protection against interturn faults. The interturn fault is a s.c. betn the turns of the same phase wdg. Thus the current produced due to such fault is a local circuit current & it does not affect the currents entering & leaving at the two ends of wdg where CTs are located. Hence Merz-price protection cannot give protection here.

In single turn generator, there is no question of interturn fault. Interturn protection is provided for multiturn generators such as hydroelectric generators. These gen. have double wdg. generators, ie, each phase wdg is divided into two halves, due to very heavy currents which they have to carry

The scheme is shown in the diag. The scheme uses cross differential principle. Each phase of gen. is doubly wound & split into two parts S_1 & S_2. The CTs are connected in the two parallel paths of each ph. wdg. The secondaries of the CTs are cross connected. The CTs work on circulating current principle. The relay is connected across the cross connected secondaries of CTs.

Under normal conditions when two paths are sound, then the currents in the two parallel paths S_1 & S_2 are equal. Hence currents in CT sec. are also equal. The secondary current flows round the loop & is same at all points. Hence no current through relay & it is inoperative.

If s.c. is developed betn the adjacent turns of the part S_1 of wdg, then currents through S_1 & S_2 are no longer same. Thus unequal currents will be induced in the CT secondaries. The difference of these currents flows through the relay R & relay operates.

Such protection sys. is extremely sensitive.

Negative Sequence Protection

When load on the generator becomes unbalanced, -ve ph. sequence currents flow. The -ve seq. compo produce a rotating magnetic field which rotate at syn. speed in a direction opposite to direction of rotor field. Hence effective speed betn the two is double the syn. speed. It induces double freq. currents in the rotor which causes severe heating of the rotor & can damage it. The unbalance stator currents can also cause severe vibrations & heating of stator. Hence it is necessary to provide the -ve seq. protection.

The -ve ~~seq.~~ ph. seq. filter alongwith the overcurrent relay provides the necessary protection against the unbalanced loads.

The relative ~~asym~~ asymmetry of a three ph. generator is given by the ratio of -ve seq. current to the rated current. It can be expressed as,

$$\% S = \frac{I_n}{I} \times 100$$

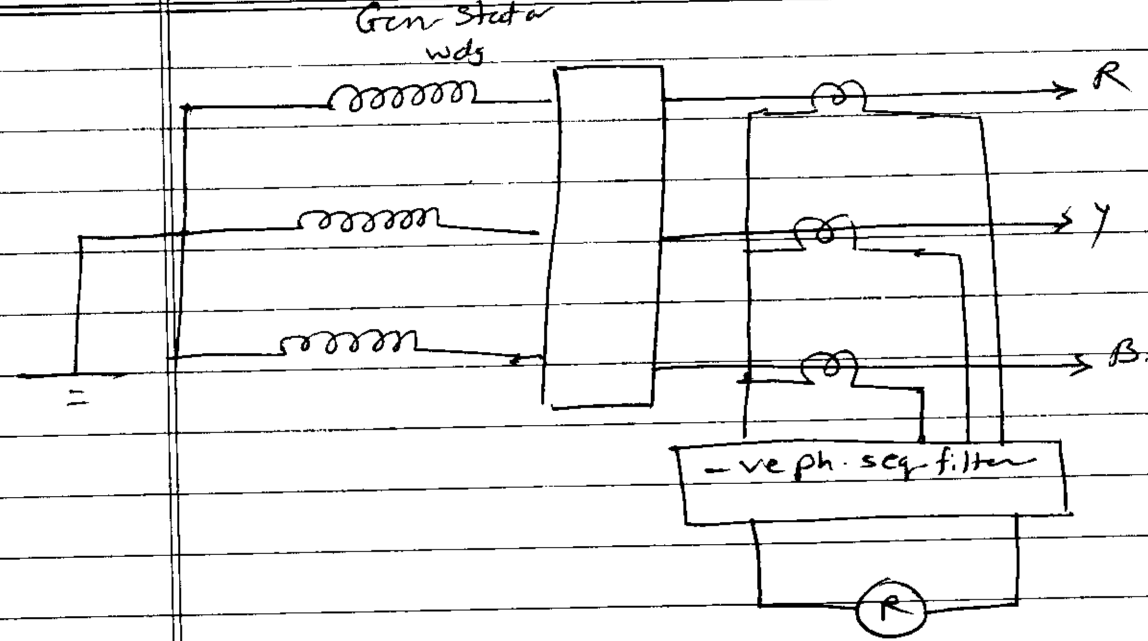
% S - percent asymmetry

I_n - -ve seq. current

I - rated current.

The protection scheme is shown below.

A -ve ph. sequence ~~is~~ filter is connected to the secondaries of CTs. A -ve ph. seq. filter consists of resistors & inductors. These are so arranged that under normal operating conditions, the relay is inoperative



The filter ckt is stable for symmetrical overloads upto about three times the rated full load.

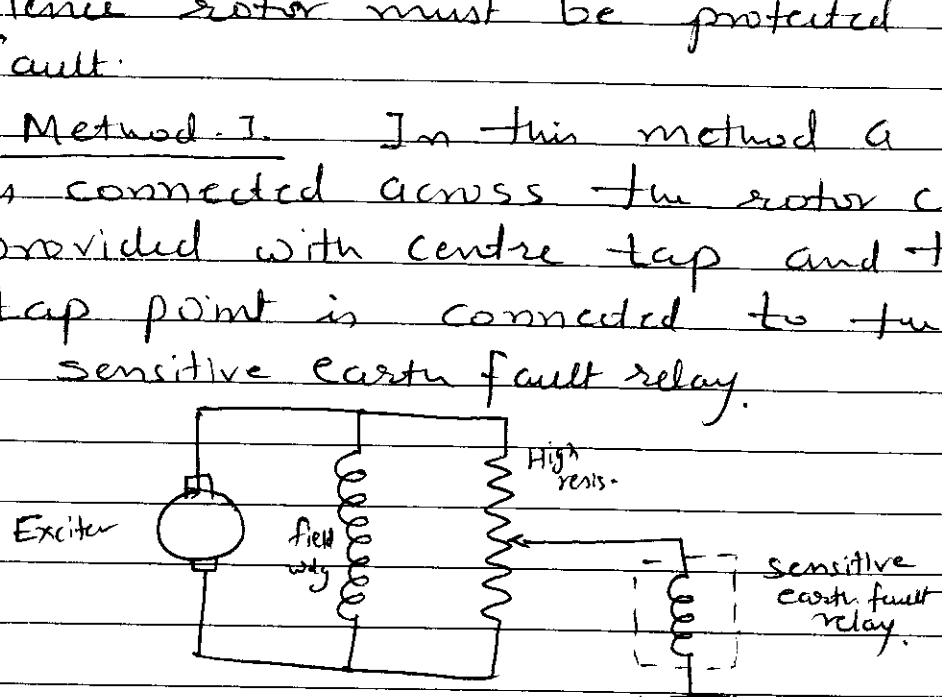
When unbalanced load occurs, the -ve ph. seq. filter ckt produces an output proportional to the -ve ph. seq. compo. This is directed through the relay coil. Hence relay operates.

Rotor Earth Fault protection

The rotor ckt. of the alternator is not earthed & dc voltage is ~~in~~ given to it. Hence single ground fault in rotor doesnot cause circulating current to flow through the rotor ckt. Hence single ground fault in rotor doesnot cause any damage to it. But it causes an increase in the stress to ground at other points in the field wdg when voltages are induced in the rotor due to transients. Thus the probability of second ground fault increases.

If the second ground fault occurs, then part of the rotor wdg. is bypassed and the currents in the remaining portion increase rapidly. This causes unbalance of rotor ckt & hence mechanical & thermal stresses in it. Due to this the rotor may get damaged. Also damage of bearings & bending of rotor shaft takes place due to vibrations. Hence rotor must be protected against earth fault.

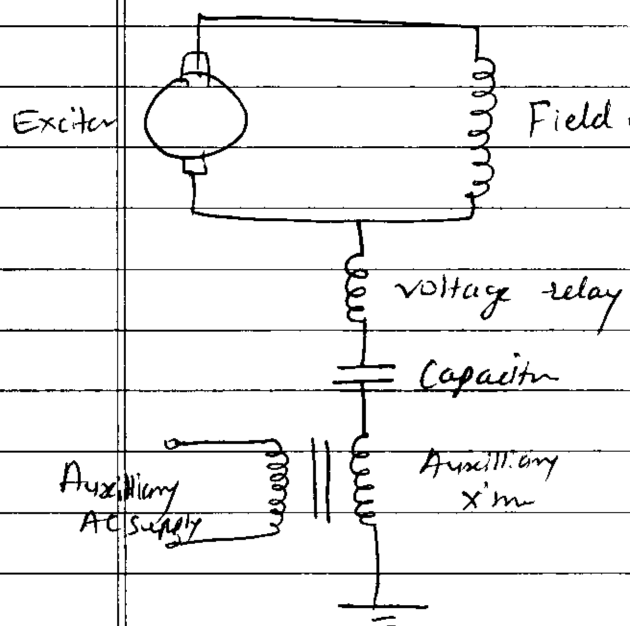
Method-I. In this method a high resistance is connected across the rotor ckt. It is provided with centre tap and the centre tap point is connected to the ground through a sensitive earth fault relay.



The relay detects the earth fault for most of the rotor ckt. except the centre point of rotor. Thus most of rotor wdg. is protected against earth fault.

Method II –

AC / DC injection method



Here, one vltg. sensitive relay is connected at any point of field & exciter ckt. Other terminal of vltg. sensitive relay is connected to the gnd ~~by a~~ through a capacitor & secondary wdg. of auxiliary X'mer as shown above.

If any earth fault occurs in the field wdg or in the exciter ckt, the relay ckt. gets closed through earthed path & hence secondary vltg. of the auxiliary X'mer will appear across the vltg. sensitive relay & the relay will operate.

Main disadvantage of this system is

There would be always a chance of leakage current through the capacitor to the field & exciter ckt. This may cause unbalance in magnetic field & hence mechanical stresses in the m/c. Also, as there is separate source of vltg for operation of relay, the protection of relay is inactive when there is a failure of supply in the AC ckt of the scheme.

The drawback of leakage current of AC injection method can be eliminated in DC injection method. Here, ~~the~~ capacitance is replaced by a high resistance.

The earth fault relays are instantaneous in operation and are connected to an alarm ckt. for indication. This is because, a single ground fault doesnot require an immediate action of isolating the generator.