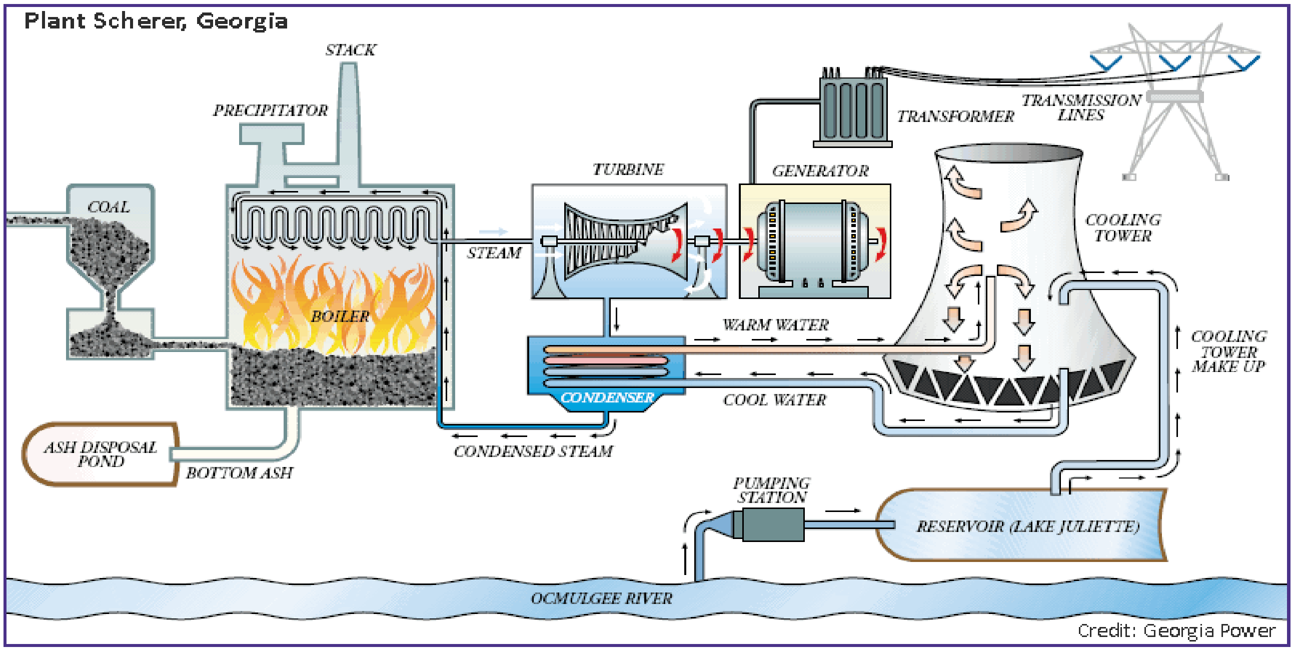
# Generator Protection

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



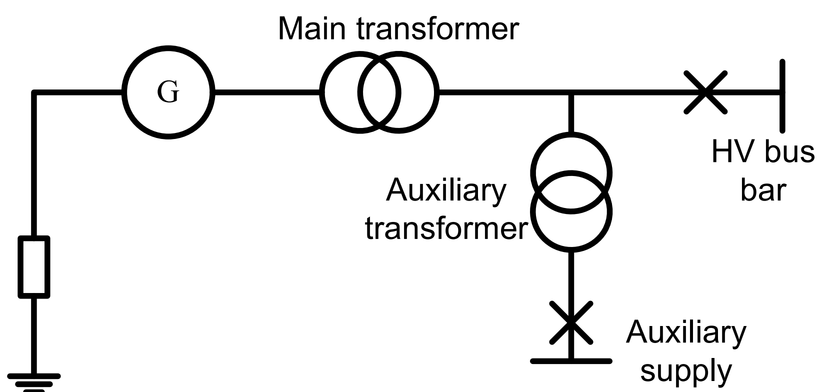

**The following types of faults may occur in generator:**

1. Stator fault-
   a. Phase to ground fault- Very common
   b. Phase to phase fault- Less common, and eventually this fault will involve earth very soon.
   c. Inter turn fault- Uncommon, not covered by conventional protection system. This fault will eventually give rise to earth fault and cleared by E/F protection.
2. Rotor fault
3. Abnormal running condition-
   a. Loss of excitation
   b. Unbalanced loading
   c. Overloading
   d. Failure of prime mover
   e. Over speeding
   f. Over voltage

4. Other problems requiring attention-
    a. Low vacuum
    b. Lubrication oil failure
    c. Excessive vibration
    d. Difference in expansion between rotating and stationary parts.
    e. Bearing temperature
    f. Stator winding temperature
    g. Loss of boiler firing

Some of the above mentioned problems sound an alarm and some cause tripping.

Small and medium sized sets may be directly connected to the distribution system. A large unit is usually associated with an individual transformer, through which the set is coupled to the EHV primary transmission system. No switchgear is provided between the generator and the transformer, which are treated as a unit; a unit transformer may be tapped off from the interconnection for the supply of power to auxiliary plant.



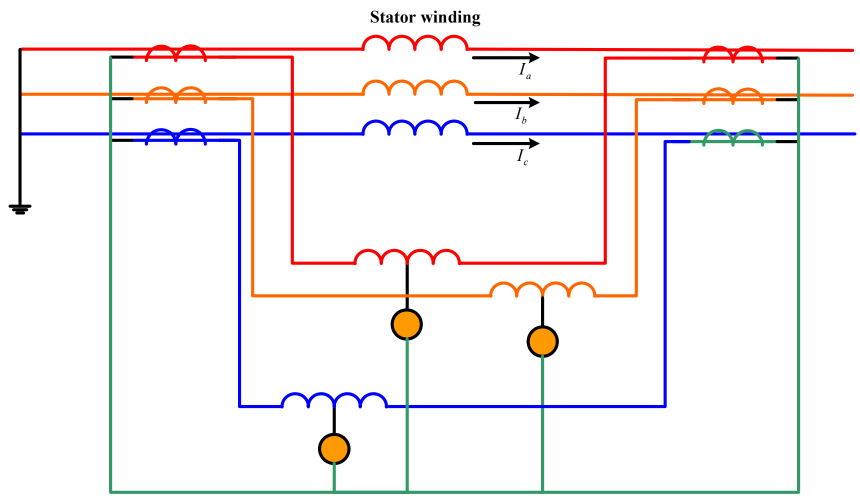

**Generator transformer unit**

## Earthing of a generator

The neutral point of a generator is usually earthed so as to facilitate protection of the stator winding and associated system. Impedance is inserted in the earthing lead to limit the magnitude of earth fault current. Severe arcing to the machine core burns the iron at the point of fault and welds lamination together. Replacement of a faulty conductor may not be serious matter but damage to the core cannot be ignored. Degree of fault current limitation varies from approximately rated current on one and to comparatively low value on the other. Some manufacturers have found that if the earth fault current does not exceed 5A, burning of core will not readily occur.

## Stator Protection

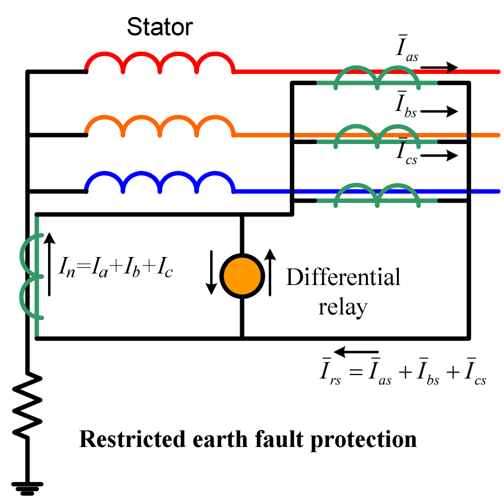
The most satisfactory method of protecting an alternator stator against phase faults and earth faults is the differential protection (Merz-Price circulating current technique). The protection scheme is shown in Figure.




## Restricted earth fault protection by differential system

If the neutral of the generator is solidly grounded, it is possible to protect complete stator winding against phase to ground fault by using he scheme shown in above figure.

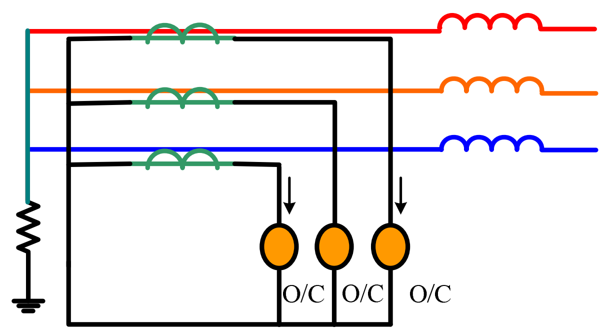
If, however, the neutral is grounded through resistance, as is usually the case, to limit the ground fault current, about 80-85% of the stator winding can be protected by the scheme of fig .2. Remaining 15-20% winding from the neutral remains unprotected, though possibility of earth fault in this region is low. In order to provide complete winding protection, a separate earth fault protection, called restricted earth fault protection, is required in addition to the scheme shown in Fig.2. The scheme is shown in Fig.3.




**Restricted earth fault protection**

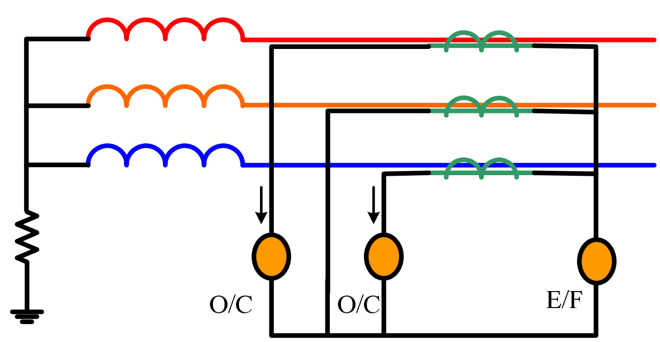
## Over current and earth fault protection

It is usual to apply over current relays of IDMT pattern to generators as a generator back up feature. If a single generator feeds an isolated system, over current protection scheme for winding fault will be used as shown in figure:




O/C Protection Scheme

If a generator operates in parallel with others and forms a part of an extensive interconnected system, then over current and earth fault relays at the line end of the machine, as shown in following figure, will provide the backup protection of any fault on the stator winding of the machine under consideration. In this case the operation of the backup scheme for stator winding fault is due to current fed back from the system.




**O/C and E/F protection as backup scheme**

## Stator earth protection

Stator winding protection can usefully be supplemented by an earth fault system in addition to the over current relay. An earth fault relay is energized by a CT in the neutral circuit. For a machine directly connected to a bus bar, this earth fault relay must be graded with feeder protection. For a generator transformer unit, the stator winding and the primary winding of the transformer form an isolated system which cannot interchange the zero sequence current with the transmission system; for this reason no grading problem exists.Two alternative methods are employed for the above mentioned earth fault protection shown in Fig .6(a) and 6(b).

## First method

For the large generator if the neutral is earthed through high resistance, then the scheme shown in Fig. 6(a) is employed. Here EF1 is an instantaneous O/C relay with a setting of 10% (earth fault current is 10% of the full load current). EF2 is a time delayed IDMT O/C relay with a setting of as low as 5%. The EF1 can protect about 90% of the stator winding. EF2 can protect about 95%.

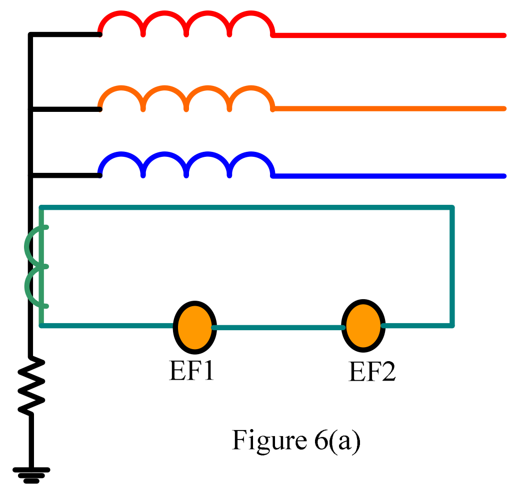



Figure 6(a)

## Second method

In this case the neutral of the generator is connected through a VT, as shown Fig. 6(b). The rates primary voltage of the VT is generally equal to phase to neutral voltage of the generator. The over voltage (E/F) relay is connected to the secondary of the VT with a setting of 10% of the rated voltage of the VT.

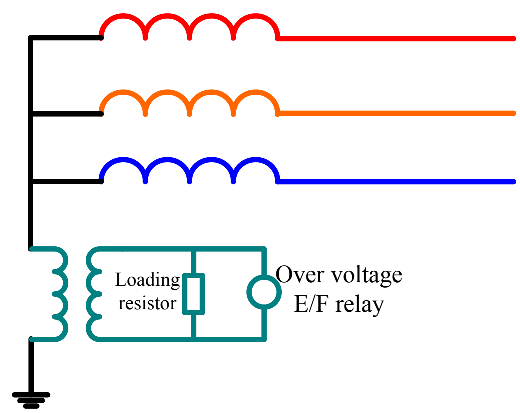



Figure 6(b)

## Unbalance loading protection

When a three phase rotating electric machine, including an alternator, is connected to perfectly balance three phase power system, no negative sequence current is developed in its rotor winding. If, however the power system is unbalanced as usually is the case, a negative sequence current of double the system frequency is induced in the rotor winding. This neutrally causes more rotors over heating than that in the absence of this current. Flow of large amount of negative sequence current in the rotor winding for long period can cause damage to the rotor winding. Under this situation a necessary measure must be taken to save the machine. So, the negative phase sequence current can be used as a parameter in the design of negative sequence protection scheme of large and expensive rotating electric machines including generators.

## Negative Phase Sequence scheme

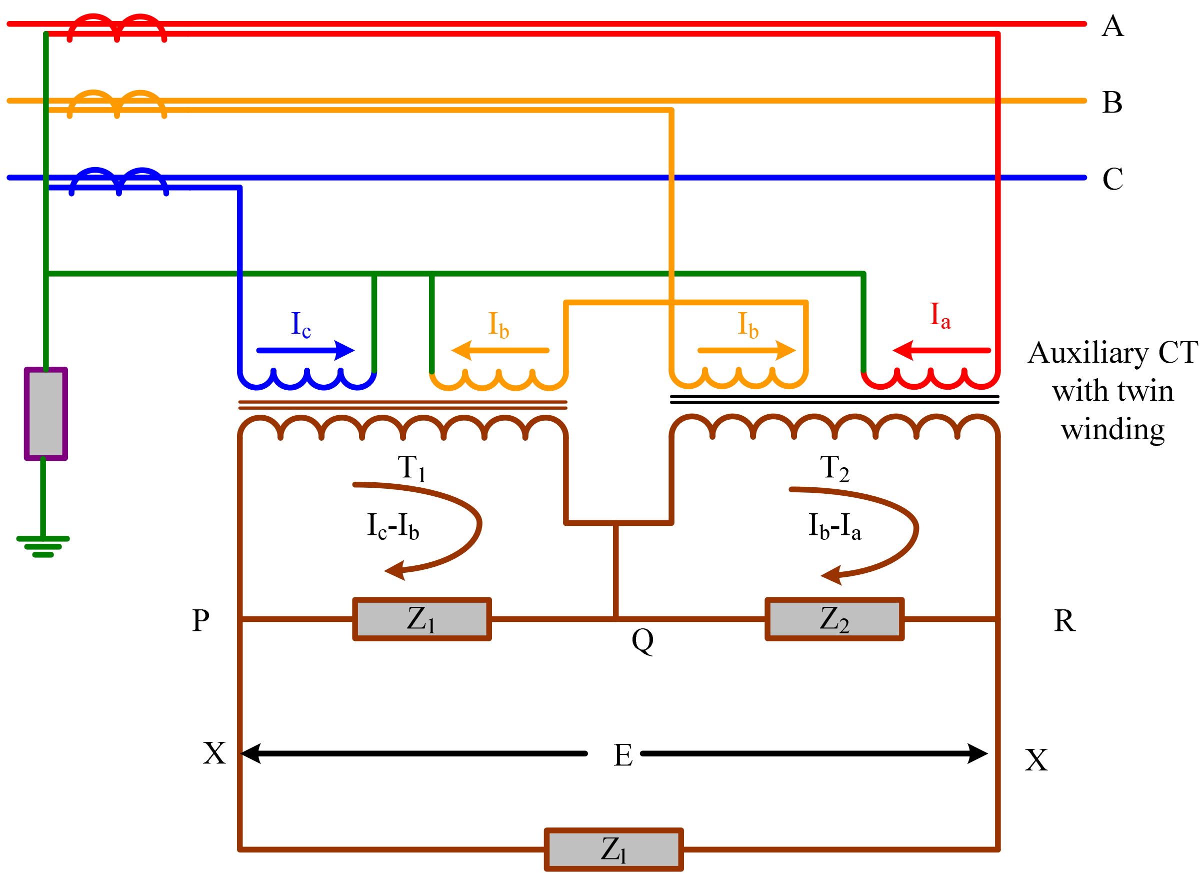
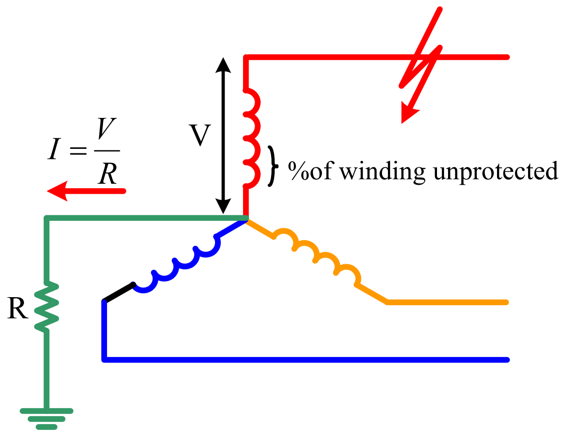



Figure:7

The twin windings of the two auxiliary CTs ($T_1$and$T_2$) are so connected to the line CTs that under normal balanced load condition, $I_{a,}I_b, I_c$ flow in the direction shown. Impedance $Z_1$ and $Z_1$ are connected across the $T_1$ and $T_2$. Load impedance $Z_l$ is connected across the terminal XX.

When primary load current flows, the current through $T_1$will be $(I_c - I_b)$ and that through $T_2$ will be $(I_b - I_a)$. For a given value of load impedance $Z_1$ and $Z_2$ are chosen such that points P and R remain at the same potential i.e. Voltages across QR and QP are equal and opposite. Under unbalance conditions, these voltage differ and an output voltage, proportional to the negative phase sequence, is produced across XX (voltage E) so as to operate the relay. The protection remains stable on symmetrical overloads up to about three times the full load current.

### Effect of neutral grounding resistance on the detection of earth fault on stator winding of a generator:




Assume R is the resistance in neutral connection to the earth and the fault current for line to ground fault is equal to full load current of the generator or transformer; the value of impedance to be inserted in neutral to earth connection is given by: R=$\frac{V}{I}$,

Where, R= impedance in ohms between neutral and ground

V= line to neutral voltage

I= full load current of the largest machine

Percentage of winding unprotected = $\frac{R.I_0.100}{V}$ *where*

R= Ohomic value of impedance

$I_0$= minimum operating current in CT primary

V= line to neutral voltage

**Example-1:**

**A** generator is provided with restricted earth fault protection. The ratings of the generator are 11KV, 5000 KVA. The percentage of winding protected against line to ground fault is 80%. The relay setting is such that it trips for 25% out of balance. Calculate the resistance to be added in neutral to ground connection.

**Solution:**

V=11000/$\sqrt{3}$=6340V

I=5000/ ($\sqrt{3}x11$)=262A

So $I_o = 262 \times \frac{25}{100} = 65.5\ A$

The percentage of winding unprotected = $\frac{R \times I_0 \times 100}{V}$

20 =$\frac{R \times 65.5 \times 100}{6340}$, or R=1.94 ohms

**Example-2**

The neutral point of a 10kV alternator is earthed through a resistance of 10 ohms; the relay is set to operate when there is an out of balance current of 1A. The CTs have a ratio of 1000/5. What percentage of the winding is protected against fault to earth and what must be the minimum value of earthing resistance to give 90% protection to each phase winding.

**Solution:**

1st part:

Out of balance current in pilot wire is 1A.

Corresponding current in CT primary=1x1000/5=200A.

Hence, current $I_0$ for which the relay operates is 200A.

Therefore, % of winding unprotected = $\frac{R \times I_0 \times 100}{V} = \frac{10 \times 200 \times 100}{\frac{10}{\sqrt{3}} \times 10^3}$=34.64%

So percentage of winding protected = (100-34.64)% = 65.36%

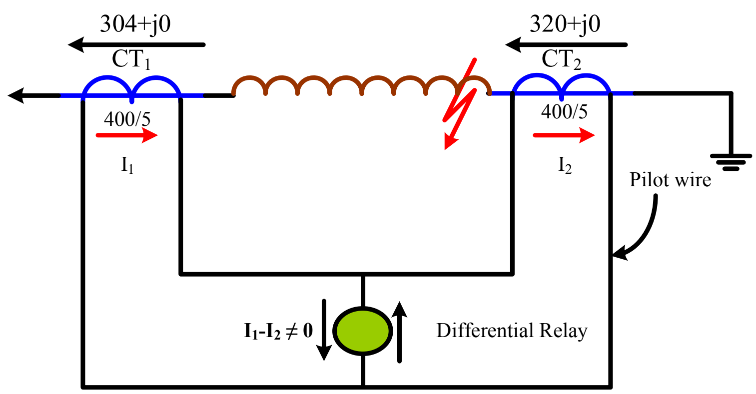
2nd part:

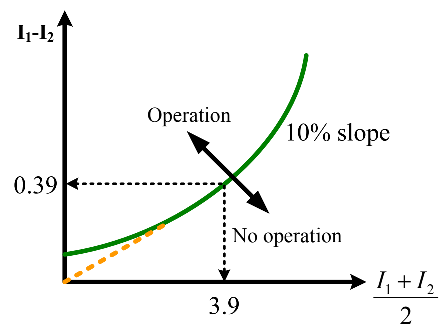
90% of the winding is protected i.e. 10% remains unprotected; R=?

$$10 = \frac{R\times200\times100}{\frac{10}{\sqrt{3}}\times10^3} = \frac{R\times200\times100\times\sqrt{3}}{10^4} or,\ R = \frac{10\times10^4}{200\times100\times\sqrt{3}} = 2.89 ohms$$

**Example-3:**

The figure shows a percentage differential relay applied to the protection of an alternator winding. The relay has a 10% slope of characteristic $I_1 - I_2$ Vs $(I_1+I_2)/2$. A high resistance ground fault occurred near the grounded neutral end of the generator winding while generator is carrying load. As a consequence, the currents in ampere flowing at each of the winding are shown in the figure. Will the relay operate to trip the breaker? Assume CT ratio of 400/5.




**Solution:**

Secondary current of $CT_1$, $I_1$=304×5/400=3.8A

Secondary current of $CT_2$, $I_2$=320×5/400=4.0A

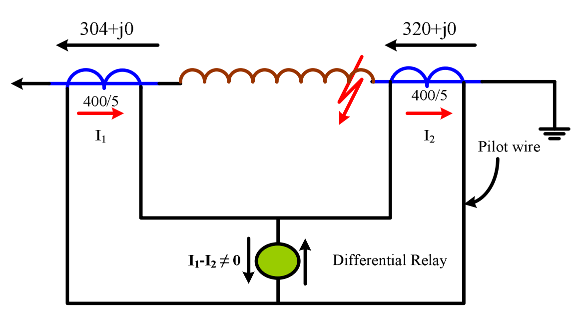
The differential current flowing through the relay coil |ΔI|= 3.8-4.0=0.2A

Current in the biasing coil $(I_1+I_2)/2|$= (3.8+4.0)/2=3.9A

From the characteristic curve, it is seen that in order to operate the relay, $|I_1 - I_2|$ is 0.2A. Hence the relay will not operate.

**Example-4**

The figure shows a differential protection scheme. The fault current for an earth fault on the winding are indicated. The CT ratio is 400/5. The relay is set operate for current of 0.1A in its coil. Under the indicated conditions, will the relay operate? The relay is without bias.



**Q-1. What happens when the field of a fully loaded generator is suddenly opened? What is the remedy?**

Ans: The generator will fall out of step within 1 sec and will continue to run as an induction generator taking reactive power from the system. To avoid this tripping scheme is so arranged that the opening of the field CB causes the tripping of the generator unit CB.

**Q-2. If the prime mover of a generator fails, what happens with the generator interconnected with a power system?**

Ans: The generator will continue to work as synchronous motor taking active power from the power system. The machine rotates as synchronous motor and the turbine acts as a load.

Motoring protection is mainly for the benefit of the prime mover. Under this condition, normally 2-10% of the rated power is taken from the system.

Reverse power protection (by directional power relay) with a certain time lag is used in order to avoid the motoring. A definite time lag is used in order to avoid tripping the machine during normal power swing.