Lecture 12: Neutral Grounding

12.1 Introduction

In power system, grounding or earthing means connecting frame of electrical equipment(non-current carrying part) or some electrical part of the system (*e.g.* neutral point in a star-connected system, one conductor of the secondary of a transformer etc.) to earth *i.e.* soil. This connection to earth may be through a conductor or some other circuit element (e.g. a resistor, a circuit breaker etc.) depending upon the situation. Regardless of the method of connection to earth, grounding or earthing offers two principal advantages.

- First, it provides protection to the power system. For example, if the neutral point of a star-connected system is grounded through a circuit breaker and phase to earth fault occurs on any one line, a large fault current will flow through the circuit breaker. The circuit breaker will open to isolate the faulty line. This protects the power system from the harmful effects of the fault.
- Secondly, earthing of electrical equipment (*e.g.* domestic appliances, hand-held tools, industrial motors etc.) ensures the safety of the persons handling the equipment. For example, if insulation fails, there will be a direct contact of the live conductor with the metallic part (*i.e.* Frame) of the equipment. Any person in contact with the metallic part of this equipment will be subjected to a dangerous electrical shock which can be fatal.

The process of connecting the metallic frame (i.e. non-current carrying part) of electrical equipment or some electrical part of the system (e.g. neutral point in a star-connected system, one conductor of the secondary of a transformer etc.) to earth (i.e. soil) is called **grounding** *or* **earthing.**

It is strange but true that grounding of electrical systems is less understood aspect of power system. Nevertheless, it is a very important subject. If grounding is done systematically in the line of the power system, we can effectively prevent accidents and damage to the equipment of the power system and at the same time continuity of supply can be maintained. Grounding or earthing may be classified as:

(i) Equipment grounding

(ii) System grounding.

Equipment grounding deals with earthing the non-current-carrying metal parts of the electrical equipment. On the other hand, ***system grounding*** means earthing some part of the electrical system *e.g.* earthing of neutral point of star-connected system in generating stations and sub-stations.

12.2 Equipment Grounding

(i) Ungrounded enclosure.

Fig. 12.1 shows the case of ungrounded metal enclosure. If a person touches the metal enclosure, nothing will happen if the equipment is functioning correctly. But if the winding insulation becomes faulty, the resistance *Re* between the motor and enclosure drops to a low value (a few hundred ohms or less). A person having a body resistance R_b would complete the current path as shown in Figure. 12.1.

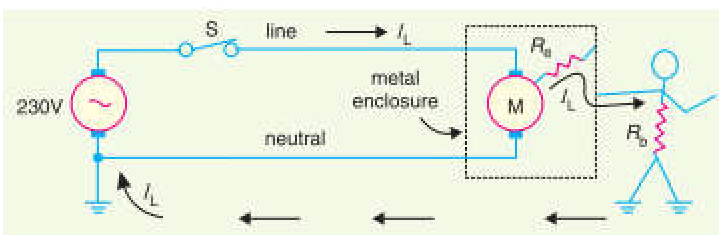

Figure. 12.1

If R_e is small (as is usually the case when insulation failure of winding occurs), the leakage current *IL* through the person's body could be dangerously high. As a result, the person would get severe electric shock which may be fatal. Therefore, this system is unsafe.

(ii) Enclosure connected to neutral wire.

It may appear that the above problem can be solved by connecting the enclosure to the grounded neutral wire as shown in Fig. 12.2. Now the leakage current IL flows from the motor, through the enclosure and straight back to the neutral wire (See Fig.12.2). Therefore, the enclosure remains at earth potential. Consequently, the operator would not experience any electric shock.

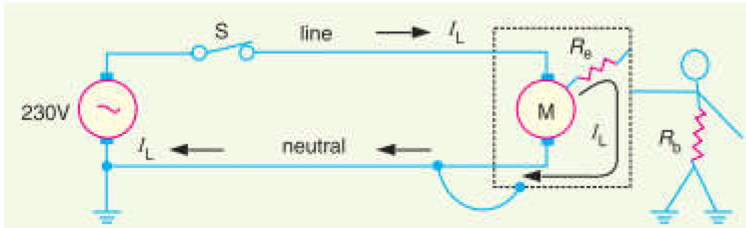

Fig.12.2

The trouble with this method is that the neutral wire may become open either accidentally or due to a faulty installation. For example, if the switch is inadvertently in series with the neutral rather than the live wire (See Fig. 12.3), the motor can still be turned on and off. However, if someone touched the enclosure while the motor is *off,* he would receive a severe electric shock (See Fig. 12.3). It is because when the motor is off, the potential of the enclosure rises to that of the live conductor.

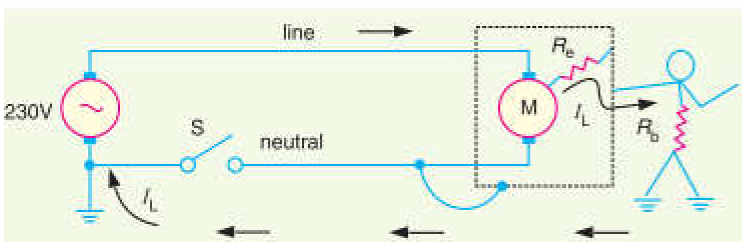

Fig. 12.3

(*iii*) Ground wire connected to enclosure. To get rid of this problem, we install a third wire, called *ground wire,* between the enclosure and the system ground as shown in Fig. 12.4. The ground

wire may be bare or insulated. If it is insulated, it is colored green.

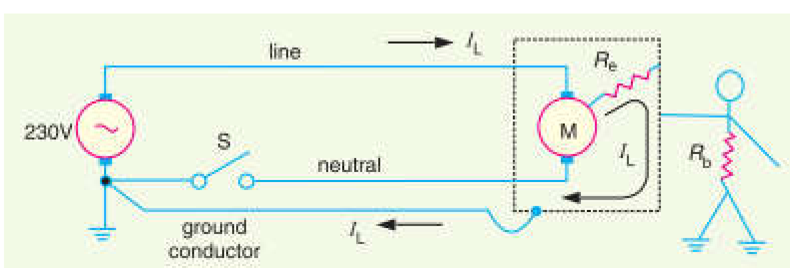

Fig. 12.4

NB. Electric shock. *It is generally believed that currents below 5 mA are not dangerous. Between 10 mA and 20 mA, the current is dangerous because the victim loses muscular control. The resistance of the human body, taken between two hands or between one hand and a leg ranges from 500 Ω to 50 kΩ. If the resistance of human body is assumed to be 20 kΩ, then momentary contact with a 230 V line can be potentially fatal.*

$$I_L = \frac{230V}{20k\Omega} = 11.5mA$$

Electrical outlets have three contacts — one for live wire, one for neutral wire and one for ground wire

12.3 System Grounding

The process of connecting some electrical part of the power system (e.g. neutral point of a star connected system, one conductor of the secondary of a transformer etc.) to earth (i.e. soil) is called ***system grounding.*** The system grounding has assumed considerable importance in the fast expanding power system. By adopting proper schemes of system grounding, we can achieve many advantages including protection, reliability and safety to the power system network.

Examples that illustrate the need of system grounding:

(*i*) Fig. 12.5 (*i*) shows the primary winding of a distribution transformer connected between the line and neutral of a 11 kV line. If the secondary conductors are *ungrounded,* it would appear that a person could touch either secondary conductor without harm because there is no ground return. However, this is not true. Referring to Fig. 12.5, there is capacitance C_1 between primary and secondary and capacitance C_2 between secondary and ground. This capacitance coupling can produce a high voltage between the secondary lines and the ground. Depending upon the relative magnitudes of C_1 and C_2, it may be as high as 20% to 40% of the primary voltage. If a person touches either one of the secondary wires, the resulting
capacitive current *IC* flowing through the body could be dangerous even in case of small transformers [See Fig. 12.5(*ii*)]. For example, if I_C is only 20 mA, the person may get a fatal electric shock.

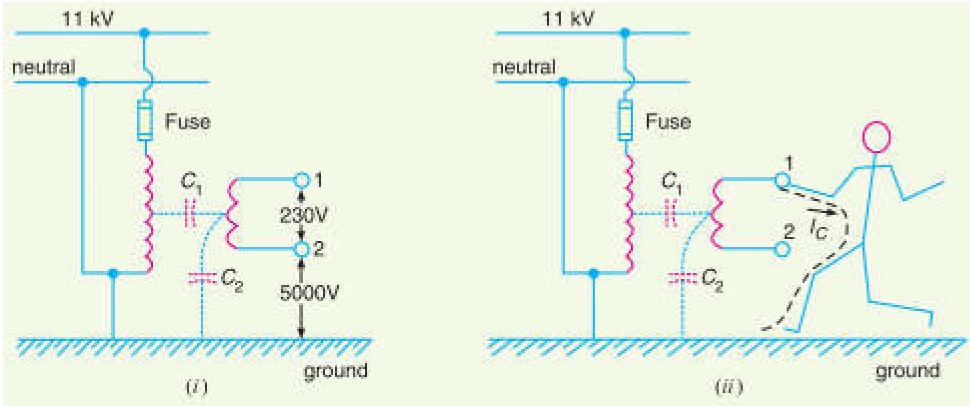

Fig. 12.5

If one of the secondary conductors is grounded, the capacitive coupling almost reduces to zero and so is the capacitive current *IC*. As a result, the person will experience no electric shock. This explains the importance of system grounding.

(ii) Fig. 12.6 (*i*) shows the primary winding of a distribution transformer connected between the line and neutral of a 11 kV line. The secondary conductors are ungrounded. Suppose that the high voltage line (11 kV in this case) touches the 230 V conductor as shown in Fig. 26.6 (*i*). This could be caused by an internal fault in the transformer or by a branch or tree falling across the 11 kV and 230 V lines. Under these circumstances, a very high voltage is imposed between the secondary conductors and ground. This would immediately puncture the 230 V insulation, causing a massive flashover. This flashover could occur anywhere on the secondary network, possibly inside a home or factory. Therefore, ungrounded secondary in this case is a potential fire hazard and may produce grave accidents under abnormal conditions.

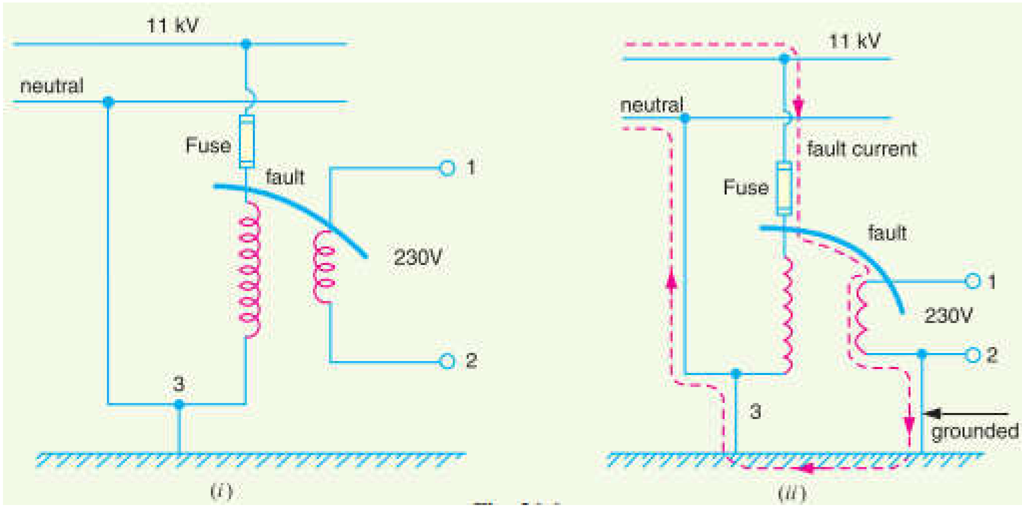

Fig. 12.6

If one of the secondary lines is grounded as shown in Fig. 12.6(*ii*), the accidental contact between a 11 kV conductor and a 230 V conductor produces a dead short. The short-circuit current (*i.e.* fault current) follows the dotted path shown in Fig. 12.6 (*ii*). This large current will blow the fuse on the 11 kV side, thus disconnecting the transformer and secondary distribution system from the 11 kV line. This explains the importance of system grounding in the line of the power system.

12.4 Ungrounded Neutral System

In an ungrounded neutral system, the neutral is not connected to the ground *i.e.* the neutral is isolated from the ground. Therefore, this system is also called *isolated neutral system* or *free neutral system.*

Fig. 12.7 shows ungrounded neutral system. The line conductors have capacitances between one another and to ground. The former are delta-connected while the latter are star-connected. The delta-connected capacitances have little effect on the grounding characteristics of the system (*i.e.* these capacitances do not affect the earth circuit) and, therefore, can be neglected.

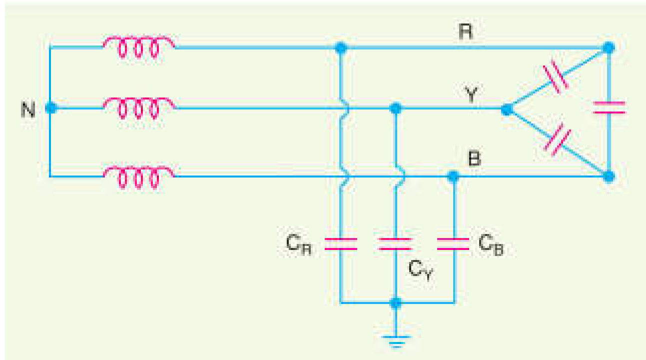

Fig. 12.7

When single line to ground fault occurs on an ungrounded neutral system, the following effects are produced in the system:

(*i*) The potential of the faulty phase becomes equal to ground potential. However, the voltages of the two remaining healthy phases rise from their normal phase voltages to full line value. This may result in insulation breakdown.
(*ii*) The capacitive current in the two healthy phases increase to 3 times the normal value.
(*iii*) The capacitive fault current (I_C) becomes 3 times the normal per phase capacitive current.
(*iv*) This system cannot provide adequate protection against earth faults. It is because the capacitive fault current is small in magnitude and cannot operate protective devices.
(*v*) The capacitive fault current I_C flows into earth. Experience shows that I_C in excess of4A is sufficient to maintain an arc in the ionized path of the fault. If this current is once maintained, it may exist even after the earth fault is cleared. This phenomenon of persistent arc is called *arcing ground*. Due to arcing ground, the system capacity is charged and discharged in a cyclic order. This sets up high-frequency oscillations on the whole system and the phase voltage of healthy conductors may rise to 5 to 6 times its normal value. The over voltages in healthy conductors may damage the insulation in the line.

NB.The the arc is formed, the voltage across it becomes zero and the arc is extinguished. As a result, the potential of the faulty conductor is restored and the formation of second arc takes place. This phenomenon of intermittent arcing is called arcing ground.

Due to above disadvantages, ungrounded neutral system is not used these days. The modern high-voltage 3-phase systems employ grounded neutral owing to a number of advantages.

12.5 Neutral Grounding

The process of connecting neutral point of 3-phase system to earth (i.e. soil) either directly or through some circuit element (e.g. resistance, reactance etc.) is called neutral grounding. Neutral grounding provides protection to personal and equipment. It is because during earth fault, the current path is completed through the earthed neutral and the protective devices (*e.g.* a fuse etc.) operate to isolate the faulty conductor from the rest of the system. This point is illustrated in Fig. 12.8.

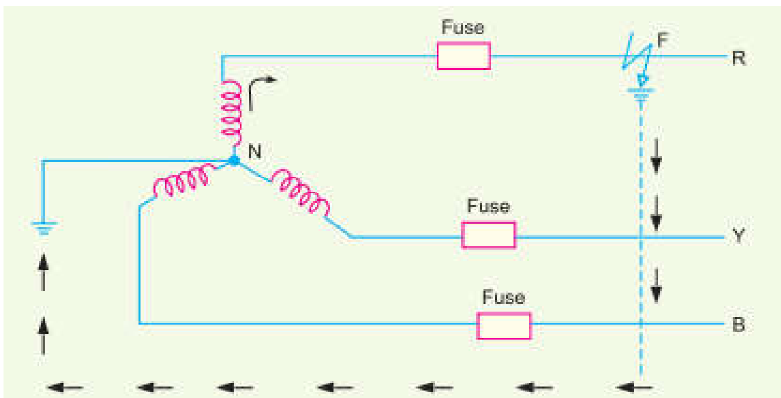

Fig. 12.8

Fig. 12.8 shows a 3-phase, star-connected system with neutral earthed (*i.e.* neutral point is connected to soil). Suppose a single line to ground fault occurs in line *R* at point *F.* This will cause the current to flow through ground path as shown in Fig. 26.10. Note that current flows from *R*-phase to earth, then to neutral point *N* and back to *R*-phase. Since the impedance of the current path is low, a large current flows through this path. This large current will blow the fuse in *R*-phase and isolate the faulty line *R*. This will protect the system from the harmful effects (*e.g.* damage to equipment, electric shock to personnel etc.) of the fault. One important feature of grounded neutral is that the potential difference between the live conductor and ground will not exceed the phase voltage of the system *i.e.* it will remain nearly constant.

12.6 Advantages of Neutral Grounding

The following are the advantages of neutral grounding :

(*i*) Voltages of the healthy phases do not exceed line to ground voltages *i.e.* they remain nearly constant.

(*ii*) The high voltages due to arcing grounds are eliminated.

(*iii*) The protective relays can be used to provide protection against earth faults. In case earth fault occurs on any line, the protective relay will operate to isolate the faulty line.

(*iv*) The over voltages due to lightning are discharged to earth.

(*v*) It provides greater safety to personnel and equipment.

(*vi*) It provides improved service reliability.

(*vii*) Operating and maintenance expenditures are reduced.

12.7 Methods of Neutral Grounding

The methods commonly used for grounding the neutral point of a 3-phase system are:

(i) Solid or effective grounding.
(ii) Resistance grounding.
(iii) Reactance grounding.
(iv) Peterson-coil grounding.

The choice of the method of grounding depends upon many factors including the size of the system, system voltage and the scheme of protection to be used.

12.7.1 Solid or effective grounding

*When the neutral point of a 3-phase system (e.g. 3-phase generator, 3-phase transformer etc.) is directly*connected to earth (i.e. soil) through a wire of negligible resistance and reactance, it is called* **solid grounding** *or* **effective grounding**. Fig. 12.9 shows the solid grounding of the neutral point. Since the neutral point is directly connected to earth through a wire, the neutral point is held at earth potential under all conditions. Therefore, under fault conditions, the voltage of any conductor to earth will not exceed the normal phase voltage of the system.

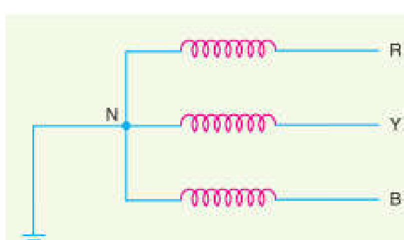

Fig. 12.9

12.7.2 Resistance Grounding

In order to limit the magnitude of earth fault current, it is a common practice to connect the neutral point of a 3-phase system to earth through a resistor. This is called resistance grounding. When the neutral point of a 3-phase system (e.g. 3-phase generator, 3-phase transformer etc.) is connected to earth (i.e. soil) through a resistor, it is called resistance grounding.

Fig. 12.10 shows the grounding of neutral point through a **resistor R. The value of R should neither be very low nor very high. If the value of earthing resistance R is very low, the earth fault current will be large and the system becomes similar to the solid grounding system. On the other hand, if the earthing resistance R is very high, the system conditions become similar to ungrounded neutral system. The value of R is so chosen such that the earth fault current is limited to safe value but still sufficient to permit the operation of earth fault protection system. In practice, that value of R is selected that limits the earth fault current to 2 times the normal full load current of the earthed generator or transformer.

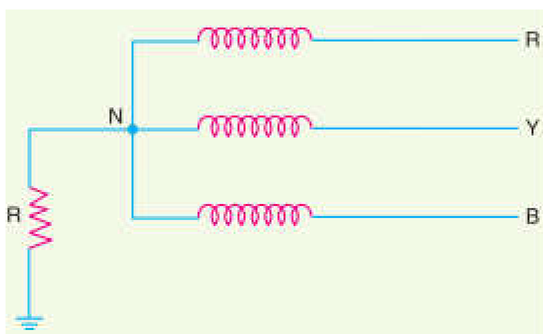

Fig. 12.10

12.7.3 Reactance Grounding

In this system, a reactance is inserted between the neutral and ground as shown in Fig. 26.15. The purpose of reactance is to limit the earth fault current. By changing the earthing reactance, the earth fault current can be changed to obtain the conditions similar to that of solid grounding. This method is not used these days because of the following disadvantages :

(*i*) In this system, the fault current required to operate the protective device is higher than that of resistance grounding for the same fault conditions.

(*ii*) High transient voltages appear under fault conditions.

12.7.3 Arc Suppression Coil Grounding (or Resonant Grounding)

We have seen that capacitive currents are responsible for producing arcing grounds. These capacitive currents flow because capacitance exists between each line and earth. If inductance L of appropriate value is connected in parallel with the capacitance of the system, the fault current IF flowing through L will be in phase opposition to the capacitive current I_C of the system. If L is so adjusted that $I_L = I_C$, then resultant current in the fault will be zero. This condition is known as *resonant grounding.*

When the value of L of arc suppression coil is such that the fault current I_F *exactly balances the capacitive current* I_C*, it is called* **resonant grounding**.

An arc suppression coil (also called Peterson coil) is an iron-cored coil connected between the neutral and earth as shown in Fig. 12.11.The reactor is provided with tapings to change the inductance of the coil. By adjusting the tapings on the coil, the coil can be tuned with the capacitance of the system i.e. resonant grounding can be achieved.

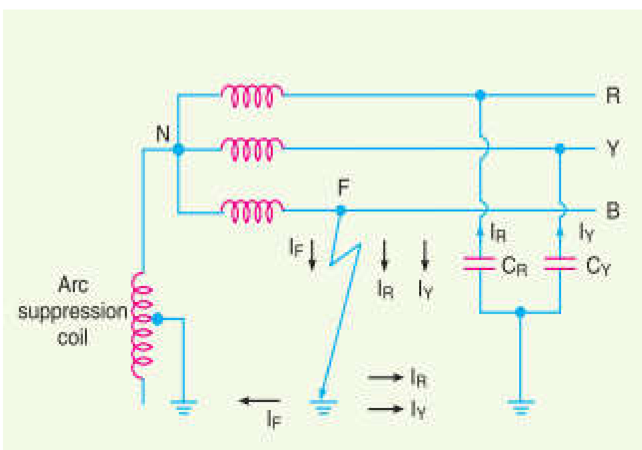

Fig. 12.11

Advantages. The Peterson coil grounding has the following advantages:

(*i*) The Peterson coil is completely effective in preventing any damage by an arcing ground.

(*ii*) The Peterson coil has the advantages of ungrounded neutral system.

Disadvantages. The Peterson coil grounding has the following disadvantages :

(*i*) Due to varying operational conditions, the capacitance of the network changes from time to time. Therefore, inductance *L* of Peterson coil requires readjustment.
(*ii*) The lines should be transposed.

For resonant grounding, the system behaves as an ungrounded neutral system. Therefore, full line voltage appears across capacitors C_R and C_Y.

$$I_R = I_Y = \frac{\sqrt{3}V_{ph}}{X_C}$$

$$I_C = \sqrt{3}I_R = \sqrt{3} \times \frac{\sqrt{3}V_{ph}}{X_C} = \frac{3V_{ph}}{X_C}$$

Here, X_C is the line to ground capacitive reactance.

$$Fault\ Current, I_F = \frac{V_{ph}}{X_L}$$

Here, X_L is the inductive reactance of the arc suppression coil.

For resonant grounding, $I_L = I_C$.

$$\frac{V_{ph}}{X_L} = \frac{3V_{ph}}{X_C}$$

$$X_L = \frac{X_C}{3}$$

$$\omega L = \frac{1}{3\omega C}$$

$$L = \frac{1}{3\omega^2 C}$$

L is the value of inductance of the arc suppression coil for resonant grounding

12.8 Voltage Transformer Earthing

In this method of neutral earthing, the primary of a single-phase voltage transformer is connected between the neutral and the earth as shown in Fig. 12.12. A low resistor in series with a relay is connected across the secondary of the voltage transformer. The voltage transformer provides a high reactance in the neutral earthing circuit and operates virtually as an ungrounded neutral system. An earth fault on any phase produces a voltage across the relay. This causes the operation of the protective device.

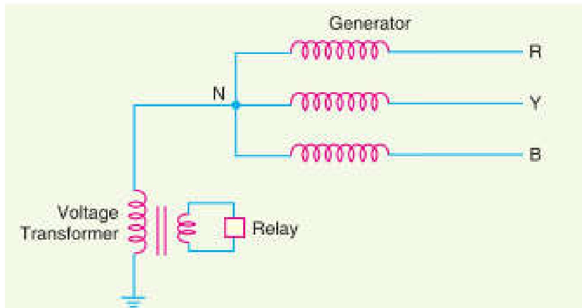

Fig. 12.12

Advantages. The following are the advantages of voltage transformer earthing :

(*i*) The transient over voltages on the system due to switching and arcing grounds are reduced. It is because voltage transformer provides high reactance to the earth path.

(*ii*) This type of earthing has all the advantages of ungrounded neutral system.

(*iii*) Arcing grounds are eliminated.

Disadvantages. The following are the disadvantages of voltage transformer earthing :

(*i*) When earth fault occurs on any phase, the line voltage appears across line to earth capacitances. The system insulation will be overstressed.

(*ii*) The earthed neutral acts as a reflection point for the travelling waves through the machine winding. This may result in high voltage build up.

Applications. The use of this system of neutral earthing is normally confined to generator equipment which are directly connected to step-up power transformers.

Example 12.1

Calculate the reactance of Peterson coil suitable for a 33 kV, 3-phase transmission line having a capacitance to earth of each conductor as 4.5 μF. Assume supply frequency to be 50 Hz.

Solution. Supply frequency, $f = 50$ Hz

Line to earth capacitance, $C = 4.5\mu F = 4.5 \times 10^{-6} F$

For Peterson coil grounding, reactance X_L of the Peterson coil should be equal to $X_C/3$ where X_C is line to earth capacitive reactance.

$$Reactance\ of\ Peterson\ coil, X_L = \frac{X_C}{3\omega C} = \frac{1}{3 \times 2\pi \times 50 \times 4.5 \times 10^{-6}} = 235.8\Omega$$

Example 12.2.

A 50 Hz overhead line has line to earth capacitance of 1.2 μ*F. It is desired to use earth fault neutralizer (Peterson coil). Determine the reactance to neutralize the capacitance of (i) 100% of the length of the line (ii) 90% of the length of the line and (iii) 80% of the length of the line.*

Solution

(i) *Inductive reactance of the coil to neutralize capacitance of 100% of the length of the line is*

$$X_L = \frac{X_C}{3\omega C} = \frac{1}{3 \times 2\pi \times 50 \times 1.2 \times 10^{-6}} = 884.19\Omega$$

(*ii*) Inductive reactance of the coil to neutralize capacitance of 90% of the length of the line is

$$X_L = \frac{X_C}{3\omega \times 0.9C} = \frac{1}{3 \times 2\pi \times 50 \times 0.9 \times 1.2 \times 10^{-6}} = 982.43\Omega$$

(iii) *Inductive reactance of the coil to neutralize capacitance of 80% of the length of the line is*

$$X_L = \frac{X_C}{3\omega \times 0.8C} = \frac{1}{3 \times 2\pi \times 50 \times 0.8 \times 1.2 \times 10^{-6}} = 1105.24\Omega$$