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CHAPTER

26

Neutral Grounding

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

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* In electrical and electronic circuits, all the points which are electrically the same (called common points) are connected to the metal chassis. This method of grounding is called *chassis ground* or *circuit ground.* Circuit ground may or may not be connected to earth (*i.e.* soil). For example, in most cars, the negative terminal of the battery and one side of all electrical circuits are connected to the metal chassis.

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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. In this chapter, we shall discuss the importance of grounding or earthing in the line of power system with special emphasis on neutral grounding.

26.1 Grounding or Earthing

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.

26.2 Equipment Grounding

The process of connecting non-current-carrying metal parts (i.e. metallic enclosure) of the electrical equipment to earth (i.e. soil) in such a way that in case of insulation failure, the enclosure effectively remains at earth potential is called **equipment grounding.**

We are frequently in touch with electrical equipment of all kinds, ranging from domestic appliances and hand-held tools to industrial motors. We shall illustrate the need of effective equipment grounding by considering a single-phase circuit composed of a 230 V source connected to a motor M as shown in Fig. 26.1. Note that neutral is solidly grounded at the service entrance. In the interest of easy understanding, we shall divide the discussion into three heads *viz.* **(*i*)** Ungrounded enclosure **(*ii*)** enclosure connected to neutral wire **(*iii*)** ground wire connected to enclosure.

(*i*) Ungrounded enclosure. Fig. 26.1 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 R_e 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 Fig. 26.1.

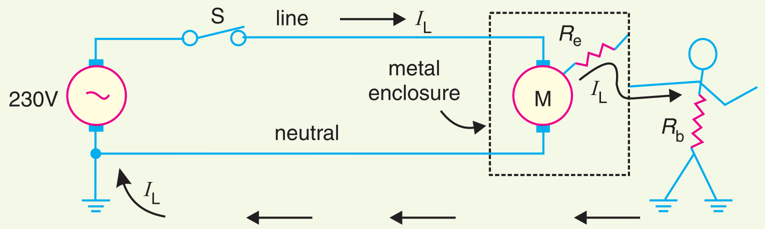

Fig. 26.1

If R_e is small (as is usually the case when insulation failure of winding occurs), the leakage current I_L 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. 26.2. Now the leakage current I_L flows from the motor, through the enclosure and straight back to the neutral wire (See Fig. 26.2). Therefore, the enclosure remains at earth potential. Consequently, the operator would not experience any electric shock.

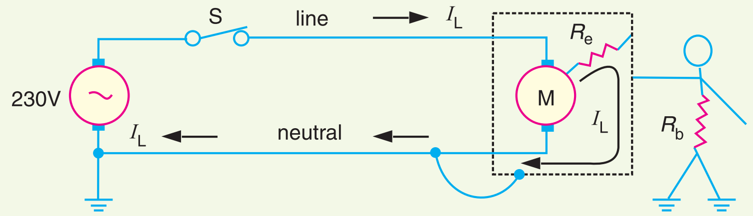

Fig. 26.2

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. 26.3), 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. 26.3). It is because when the motor is off, the potential of the enclosure rises to that of the live conductor.

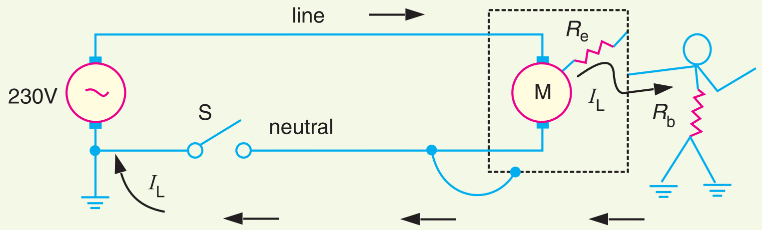

Fig. 26.3

***(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. 26.4. The ground wire may be bare or insulated. If it is insulated, it is coloured green.

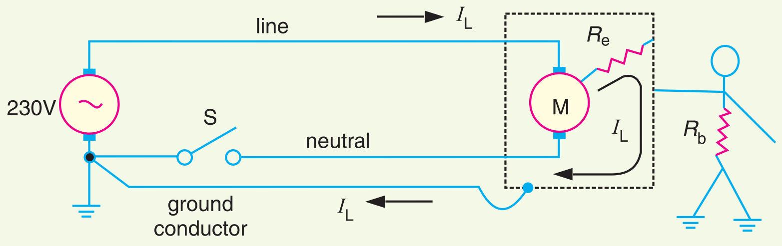

Fig. 26.4

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* **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.

$$I_L = \frac{230\,\text{V}}{20\,\text{k}\Omega} = 11{\cdot}5\ \text{mA}$$

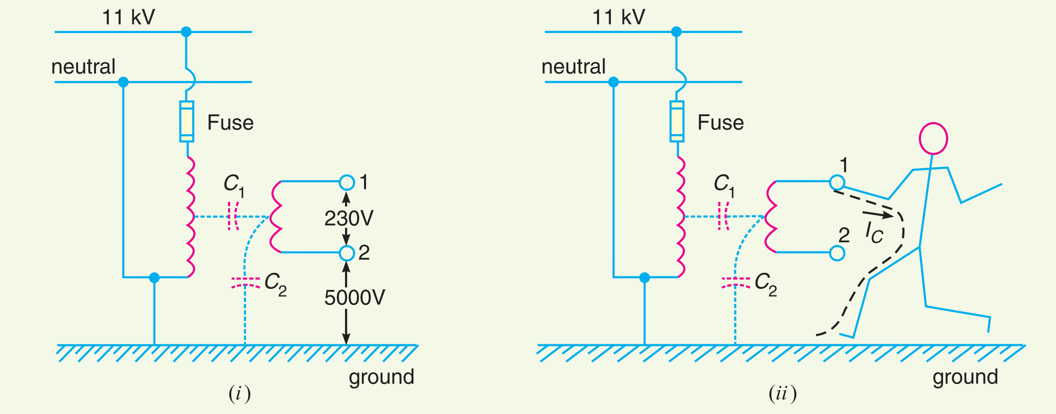
Electrical outlets have three contacts — one for live wire, one for neutral wire and one for ground wire.

26.3 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. But before discussing the various aspects of *neutral grounding*, it is desirable to give two examples to appreciate the need of system grounding.

(*i*) Fig. 26.5 (*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. 26.5, 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 I_C flowing through the body could be dangerous even in case of small transformers [See Fig. 26.5(*ii*)]. For example, if I_C is only 20 mA, the person may get a fatal electric shock.

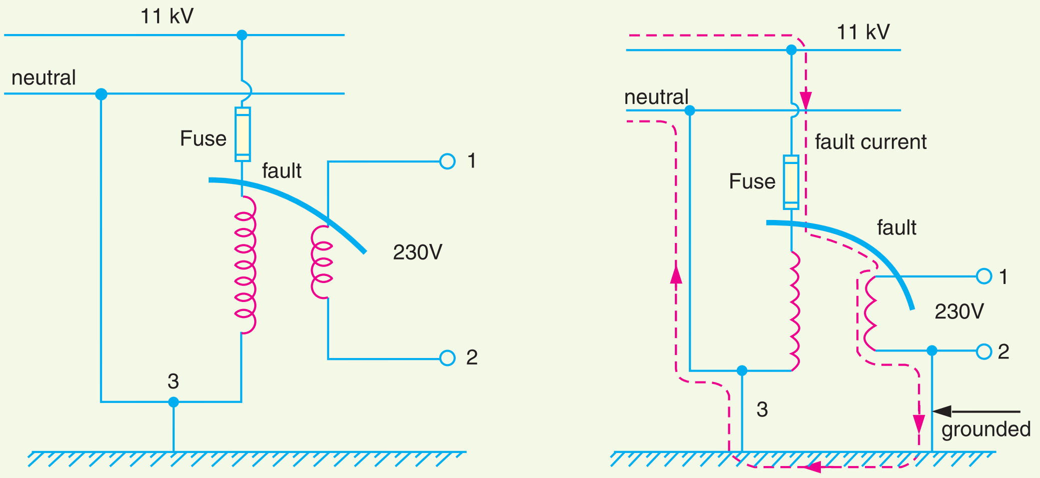


(*i*) (*ii*)

Fig. 26.5

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

(*ii*) Let us now turn to a more serious situation. Fig. 26.6 (*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.



(*i*) (*ii*)

Fig. 26.6

If one of the secondary lines is grounded as shown in Fig. 26.6(*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. 26.6 (*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.

26.4 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. 26.7 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 effect the earth circuit) and, therefore, can be neglected. The circuit then reduces to the one shown in Fig. 26.8(*i*).

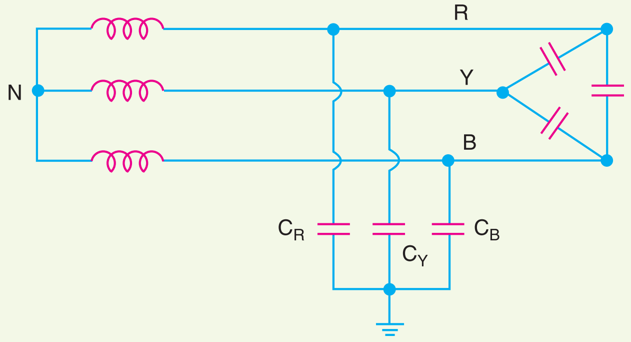


Fig. 26.7

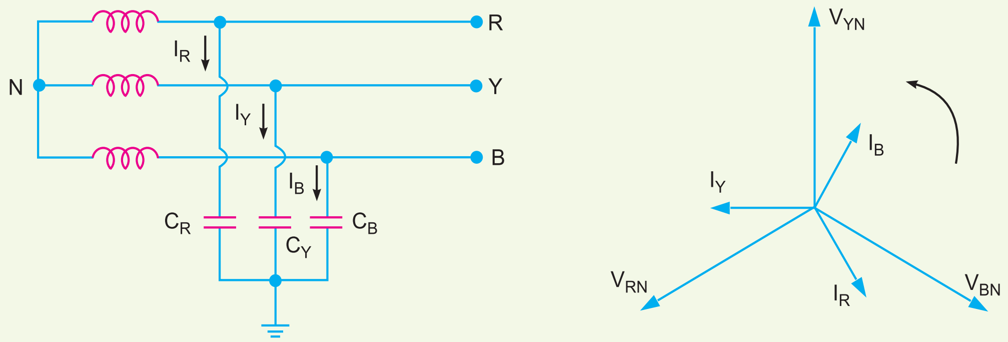
Circuit behaviour under normal conditions. Let us discuss the behaviour of ungrounded neutral system under normal conditions (*i.e.* under steady state and balanced conditions). The line is assumed to be perfectly transposed so that each conductor has the same capacitance to ground.

Therefore, $C_R = C_Y = C_B = C$ (say). Since the phase voltages V_{RN}, V_{YN} and V_{BN} have the same magnitude (of course, displaced 120° from one another), the capacitive currents I_R, I_Y and I_B will have the same value *i.e.*

$$I_R = I_Y = I_B = \frac{V_{ph}}{X_C} \quad \text{.... in magnitude}$$

where V_{ph} = Phase voltage (*i.e.* line-to-neutral voltage)

X_C = Capacitive reactance of the line to ground.



(*i*) **Fig. 26.8** (*ii*)

The capacitive currents I_R, I_Y and I_B lead their respective phase voltages V_{RN}, V_{YN} and V_{BN} by 90° as shown in the phasor diagram in Fig. 26.8(*ii*). The three capacitive currents are equal in magnitude and are displaced 120° from each other. Therefore, their phasor sum is zero. As a result, no current flows to ground and the *potential of neutral is the same as the ground potential.* Therefore, ungrounded neutral system poses no problems under normal conditions. However, as we shall see, currents and voltages are greatly influenced during fault conditions.

Circuit behaviour under single line to ground-fault. Let us discuss the behaviour of ungrounded neutral system when single line to ground fault occurs. Suppose line to ground fault occurs in line *B* at some point *F*. The *circuit then becomes as shown in Fig. 26.9(*i*). The capacitive currents I_R and I_Y flow through the lines *R* and *Y* respectively. The voltages driving I_R and I_Y are V_{BR} and V_{BY} respectively. Note that V_{BR} and V_{BY} are the line voltages [See Fig. 26.9 (*ii*)]. The paths of I_R and I_Y are essentially capacitive. Therefore, I_R leads V_{BR} by 90° and I_Y leads V_{BY} by 90° as shown in Fig. 26.9 (*ii*). The capacitive fault current I_C in line *B* is the phasor sum of I_R and I_Y.

Fault current in line *B*, $I_C = I_R + I_Y$ .... Phasor sum

Now, $$I_R = \frac{V_{BR}}{X_C} = \frac{\sqrt{3}\,V_{ph}}{X_C}$$

and $$I_Y = \frac{V_{BY}}{X_C} = \frac{\sqrt{3}\,V_{ph}}{X_C}$$

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

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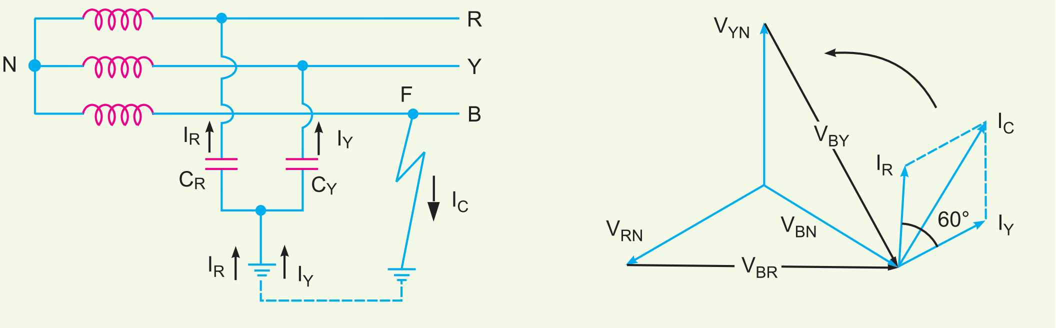
* Due to line-to-ground fault in line *B*, the potential of phase *B* becomes equal to the ground potential. This short circuits the capacitance of this line (*i.e.* capacitance C_B). Hence no capacitive current flows through C_B.



(*i*) (*ii*)

Fig. 26.9

$$= \sqrt{3} \times \text{Per phase capacitive current under normal conditions}$$

Capacitive fault current in line B is

$$I_C = \text{Phasor sum of } I_R \text{ and } I_Y$$

$$= {}^{\dagger}\sqrt{3}\, I_R = \sqrt{3} \times \frac{\sqrt{3}\, V_{ph}}{X_C} = \frac{3V_{ph}}{X_C}$$

$$\therefore \quad I_C = \frac{3V_{ph}}{X_C} = 3 \times \frac{V_{ph}}{X_C}$$

$$= 3 \times \text{Per phase capacitive current under normal conditions}$$

Therefore, 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 $\sqrt{3}$ 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 of 4A 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 overvoltages in healthy conductors may damage the insulation in the line.

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† Referring to Fig. 26.9(*ii*), the magnitudes of I_R and I_Y are equal and the angle between them is 60°. Therefore, the resultant capacitive fault current I_C is given by:

$$I_C = 2I_R \cos 60°/2 = 2I_R \cos 30° = 2\, I_R \times \sqrt{3}/2 = \sqrt{3}\, I_R\,.$$

* When 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.

26.5 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. 26.10.

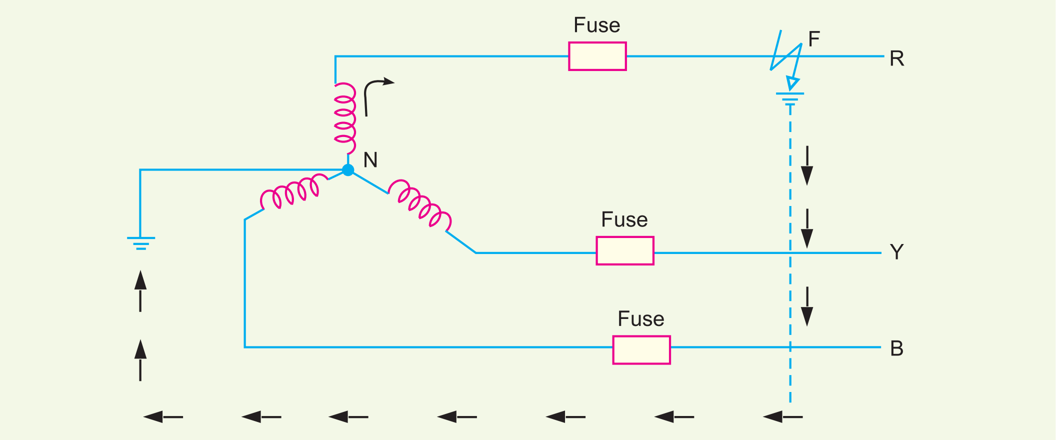

Fig. 26.10

Fig. 26.10 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.

26.6 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 overvoltages 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.