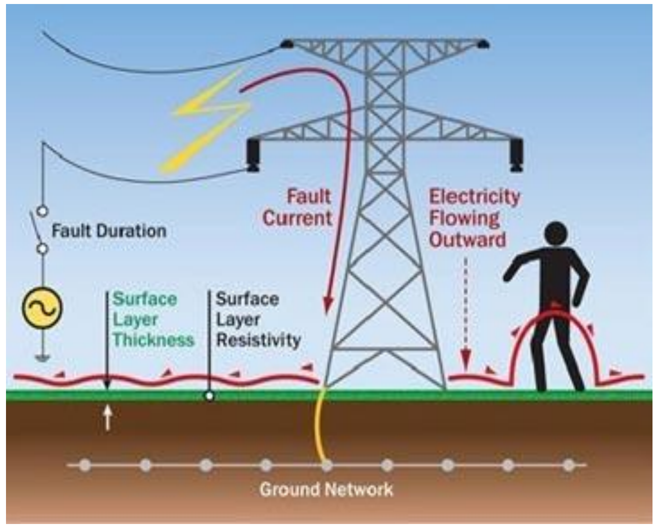
Power System Grounding

7.2.1 Introduction



It means connecting frame of electrical equipment (non-current carrying part) or n power system, ******grounding* or *earthing* 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.

7.2.2 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.** Grounding or earthing may be classified as:

- **(i)** Equipment grounding
- **(ii)** System grounding.

7.2.3 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.

7.2.4 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).

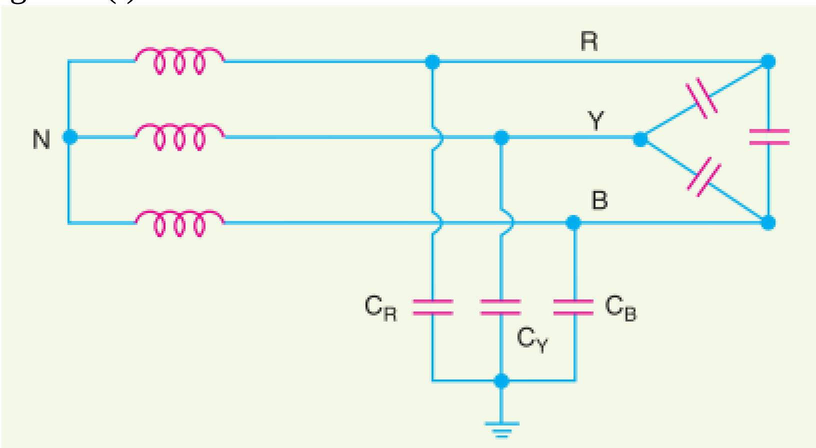


Fig. 26.7

Circuit behaviour under normal conditions. Let us discuss the behavior 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.*

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

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

X_C = Capacitive reactance of the line to ground.

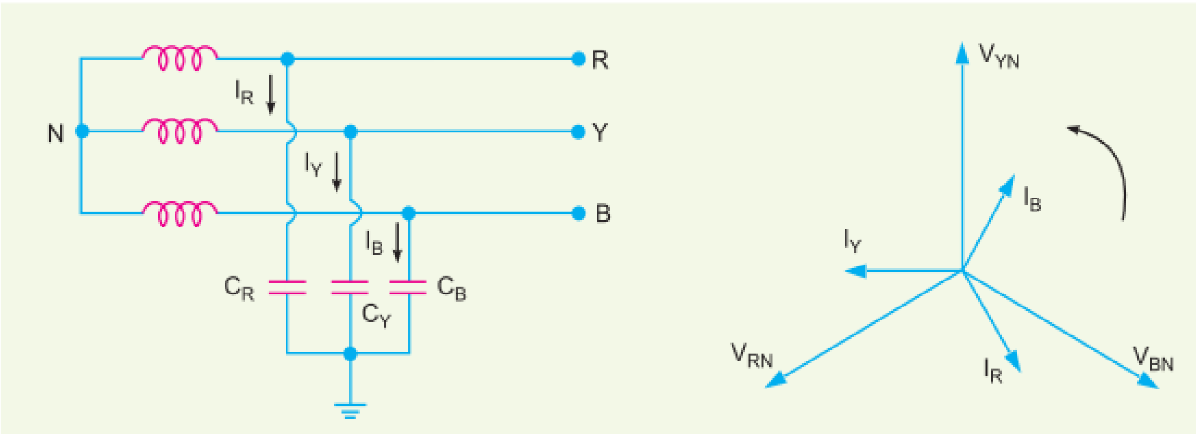


Fig. 26.8

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, $\quad I_C = I_R + I_Y$ .... Phasor sum

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

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

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

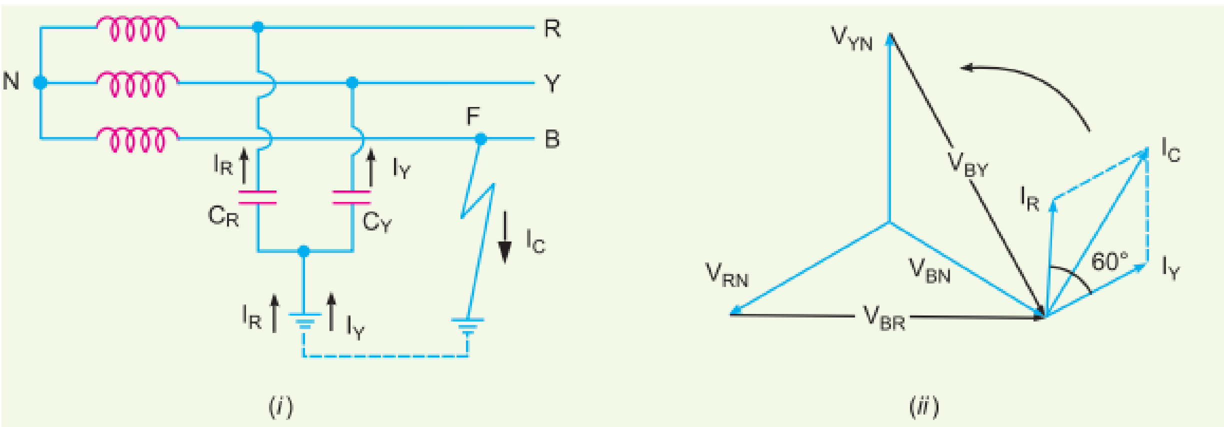


Fig. 26.9

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

Capacitive fault current in line B is

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

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

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

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

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.

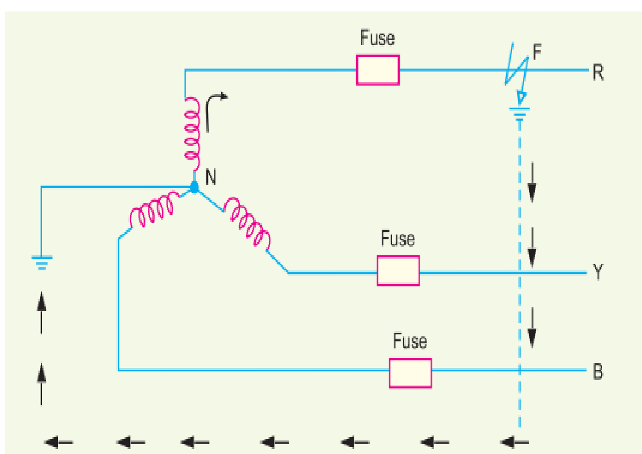
(iii) The capacitive fault current (I_C) becomes 3 times the normal per phase capacitive current.

(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.

7.2.5 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.



7.2.6 Importance of Neutral System

There are many neutral grounding options available for both Low and Medium voltage power systems. The neutral points of transformers, generators and rotating machinery to the earth ground network provides a reference point of zero volts. This protective measure offers many advantages over an ungrounded system, like,

1. Reduced magnitude of transient over voltages
2. Simplified ground fault location
3. Improved system and equipment fault protection
4. Reduced maintenance time and expense
5. Greater safety for personnel
6. Improved lightning protection
7. Reduction in frequency of faults.

7.2.7 Method of Neutral Earthing:

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

1. Solid or effective Earthing
2. Resistance Earthing
3. Reactance Earthing
4. Resonant Earthing System
5. Earthing Transformer Earthing

7.2.8 Solid 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**.

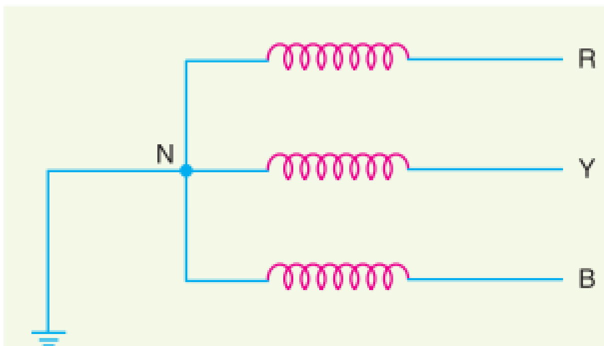


Fig. 26.11

Fig. 26.11 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.

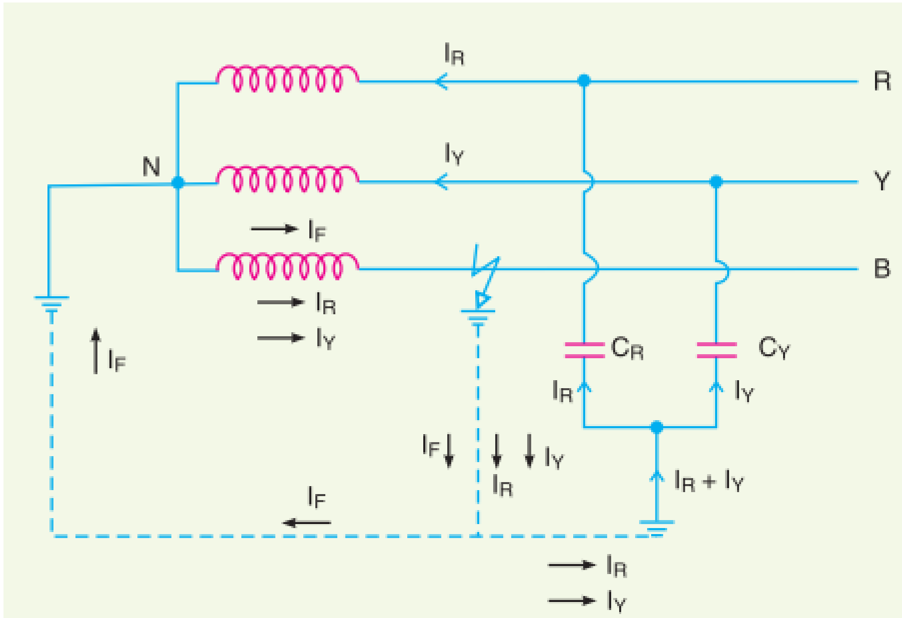


Fig. 26.12

Advantage:

1. The main advantage of solidly earthed systems is low over voltages, which makes the earthing design common at high voltage levels (HV).

Disadvantage:

1. This system involves all the drawbacks and hazards of high earth fault current: maximum damage and disturbances.
2. There is no service continuity on the faulty feeder.
3. The danger for personnel is high during the fault since the touch voltages created are high.

7.2.9 Resistance Earthing:

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. 26.13 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

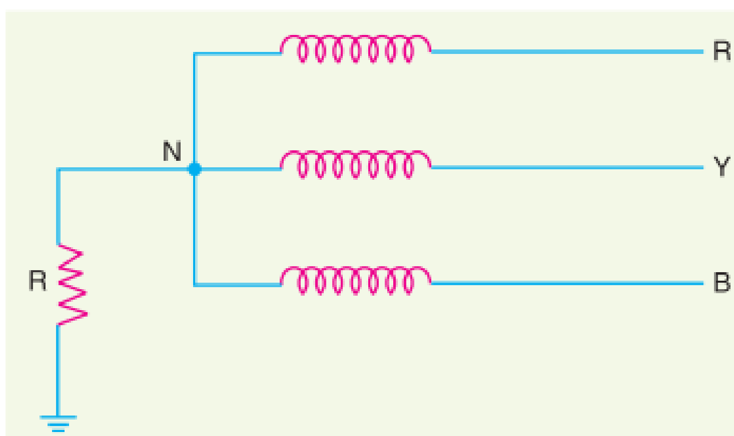


Fig. 26.13

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.

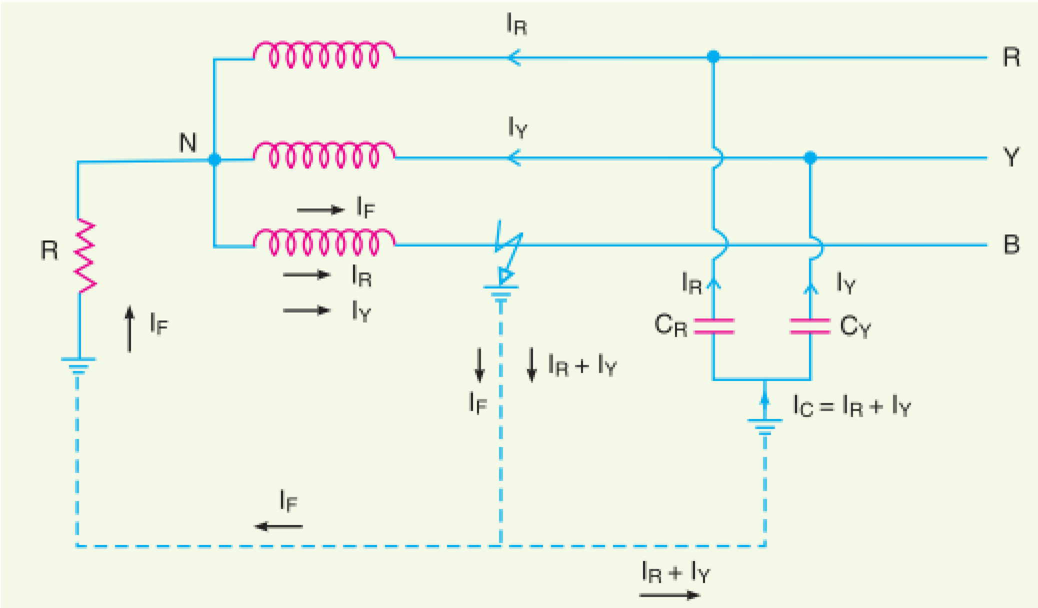


Fig. 26.14

Resistance Grounding Systems limits the phase-to-ground fault currents. Grounding Resistors are generally connected between ground and neutral of transformers, generators and grounding transformers ***to limit maximum fault current as per Ohms Law to a value which will not damage the equipment*** in the power system and allow sufficient flow of fault current to detect and operate Earth protective relays to clear the fault. Although it is possible to limit fault currents with high resistance Neutral grounding Resistors, earth short circuit currents can be extremely reduced. As a result of this fact, protection devices may not sense the fault.

There are two categories of resistance grounding:

1. Low resistance Grounding.
2. High resistance Grounding.

The difference between Low Resistance Grounding and High Resistance Grounding is a matter of perception and, therefore, is not well defined. ***Generally speaking high-resistance grounding refers to a system in which the NGR let-through current is less than 50 to 100 A. Low resistance grounding indicates that NGR current would be above 100 A.***

Low Resistance Grounded:

Advantages:

1. Limits phase-to-ground currents to 200-400A.

2. Reduces arcing current and, to some extent, limits arc-flash hazards associated with phase-to-ground arcing current conditions only.
3. May limit the mechanical damage and thermal damage to shorted transformer and rotating machinery windings.

High Resistance Grounded:

Advantages:

1. Enables high impedance fault detection in systems with weak capacitive connection to earth
2. Some phase-to-earth faults are self-cleared.
3. The neutral point resistance can be chosen to limit the possible over voltage transients to 2.5 times the fundamental frequency maximum voltage.
4. Limits phase-to-ground currents to 5-10A.

7.2.10 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 to changed to obtain the conditions similar to that of solid grounding. This method is not used these days because of the following disadvantages:

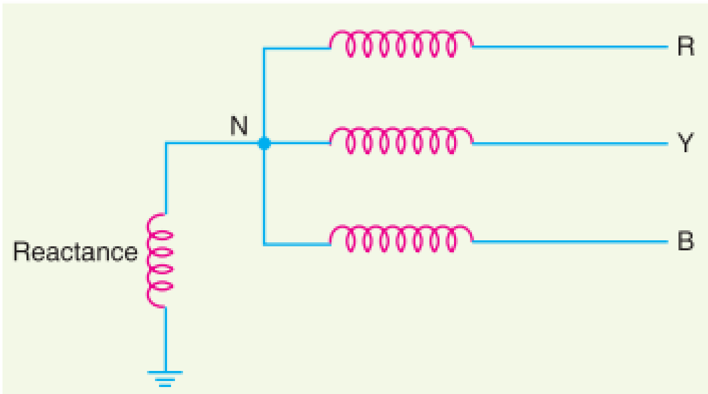


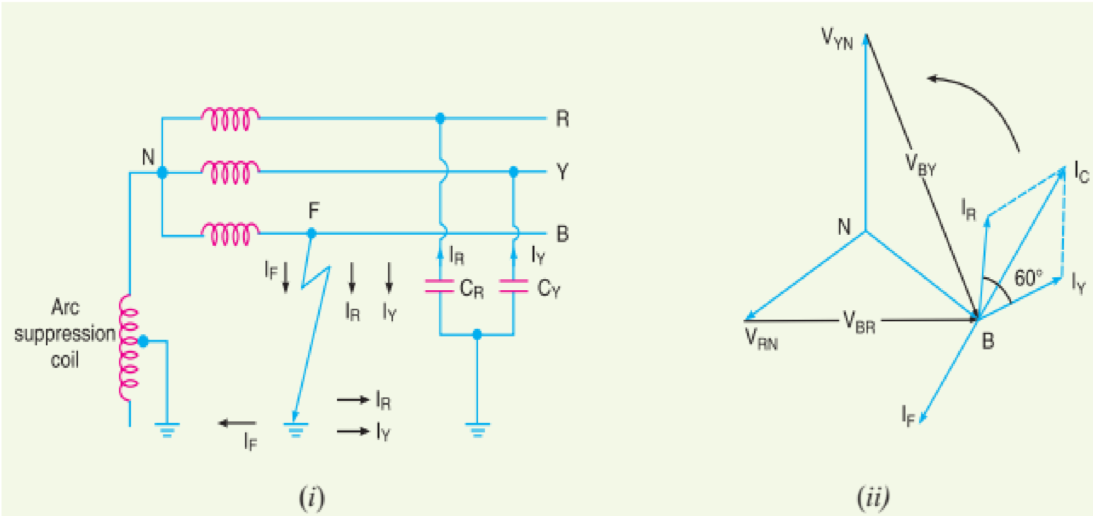
Fig. 26.15

(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.

7.2.11 Resonant earthed system:

Adding inductive reactance from the system neutral point to ground is an easy method of limiting the available ground fault from something near the maximum 3 phase short circuit capacity (thousands of amperes) to a relatively low value (200 to 800 amperes). To limit the reactive part of the earth fault current in a power system a neutral point reactor can be connected between the transformer neutral and the station earthing system.



A system in which at least one of the neutrals is connected to earth through an

1. Inductive reactance.
2. Petersen coil / Arc Suppression Coil / Earth Fault Neutralizer.

To control the transient over voltages, the design must permit at least 60% of the 3 phase short circuit current to flow underground fault conditions.

Advantages:

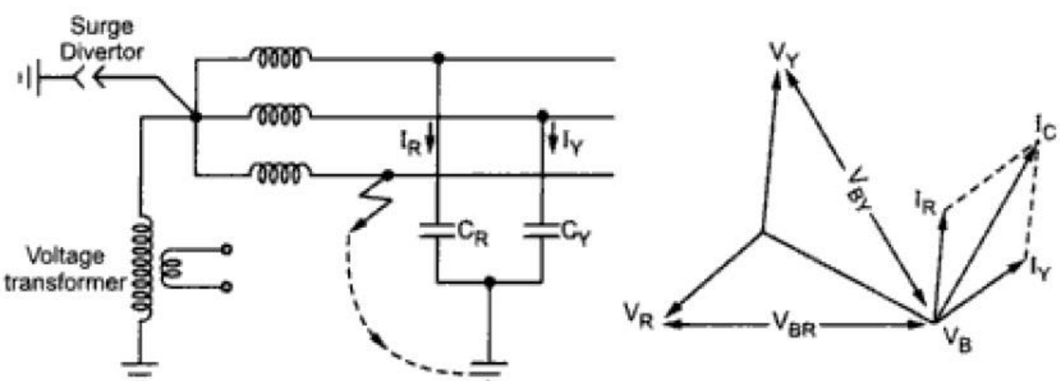
1. Small reactive earth fault current independent of the phase to earth capacitance of the system.
2. Enables high impedance fault detection.

Disadvantages:

1. Risk of extensive active earth fault losses.
2. High costs associated.

7.2.12 Earthing Transformers:

For cases where there is no neutral point available for Neutral Earthing (e.g. for a delta winding), an earthing transformer may be used to provide a return path for single phase fault currents.



In such cases the impedance of the earthing transformer may be sufficient to act as effective earthing impedance. Additional impedance can be added in series if required. A special 'zig-zag' transformer is sometimes used for earthing delta windings to provide a low zero-sequence impedance and high positive and negative sequence impedance to fault currents.

7.2.15 Comparison of Neutral Earthing System:

Condition	Ungrounded	Solid Grounded	Low Resistance Grounded	High Resistance Grounded	Reactance Grounding
Immunity to Transient Over voltages	Worse	Good	Good	Best	Best
73% Increase in Voltage Stress Under Line-to-Ground Fault Condition	Poor	Best	Good	Poor	
Equipment Protected	Worse	Poor	Better	Best	Best
Safety to Personnel	Worse	Better	Good	Best	Best
Service Reliability	Worse	Good	Better	Best	Best
Maintenance Cost	Worse	Good	Better	Best	Best
Ease of Locating First Ground Fault	Worse	Good	Better	Best	Best
Permits Designer to Coordinate Protective Devices	Not Possible	Good	Better	Best	Best
Reduction in Frequency of Faults	Worse	Better	Good	Best	Best
Lighting Arrestor	Ungrounded neutral type	Grounded-neutral type	Ungrounded neutral type	Ungrounded neutral type	Ungrounded neutral type
Current for phase-to ground fault in percent of three-phase fault current	Less than 1%	Varies, may be 100% or greater	5 to 20%	Less than 1%	5 to 25%

7.2.14 Conclusion:

Resistance Grounding Systems have many advantages over solidly grounded systems including arc-flash hazard reduction, limiting mechanical and thermal damage associated with faults, and controlling transient over voltages. High resistance grounding systems may also be employed to maintain service continuity and assist with locating the source of a fault. When designing a system with resistors, the design/consulting engineer must consider the specific requirements for conductor insulation ratings, surge arrestor ratings, breaker single-pole duty ratings, and method of serving phase-to-neutral loads.