9·2. Solid Grounding. In solid grounding a direct metallic connection is made as shown in Fig. 9·4 from the system neutral to one or more earth electrodes consisting of plates, rods or pipes buried in or driven into the ground.

Fig. 9·5 shows a three-phase system with its neutral solidly grounded and an earth fault at F in line B.

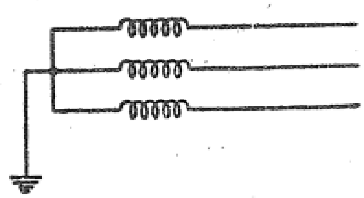

Fig 9·4. Solid Grounding

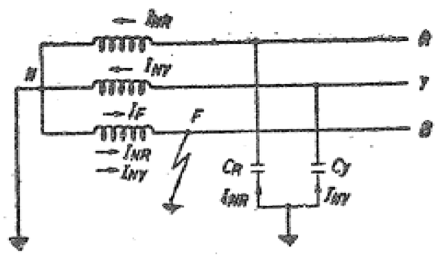

Fig. 9·5

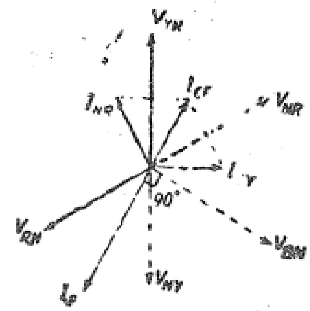

Fig. 9·6

The phasor diagram for this condition is drawn in Fig. 9·6. The current in phase-B has three components :

One, I_{NR}, through phase B, the fault and capacitance C_R to the phase R conductor ; second. I_{NY}, through phase-B, the fault and capacitance C_Y to the phase-Y conductor ; third I_F through phase B, the fault and the ground.

An analysis of the fault by symmetrical components gives

$$I_F=\frac{3V_{ph}}{Z_1+Z_2+Z_0}$$

Since $Z_1+Z_2+Z_0$ is predominantly inductive, I_F lags behind the phase to neutral voltage of the faulted phase by nearly 90°. This is shown in Fig. 9·6.

The voltages driving the currents I_{NR} and I_{NY} are V_{NR} and V_{NY} respectively and since the impedance of the circuits tranversed by these currents is predominantly capacitive, they lead their respective voltages by 90° as shown by phasors I_{NR}, I_{NY}. I_{CF}, the resultant of I_{NR} and I_{NY}, is in phase opposition to I_F.

The following points should be noted

Fig 9·4. Solid Grounding Fig. 9·5 Fig. 9·6

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The following points should be noted

- When a fault to earth occurs on any one phase the system, the voltage to earth of the faulty phase becomes zero, but the healthy phases remain at their normal phase value.
- The flow of heavy fault current If will completely nullify the effect of the capacitive current Icf at the fault and so no arcing ground phenomena or over voltage can occur.
- The flow of heavy current permits the use of discriminative protective gear.

The use of solid grounding is limited only to the systems where the normal circuit impedance is sufficient to prevent very high value of fault current being reached. This is necessary in order to avoid excessive damage at the fault location. Experience shows that combined impedance of the apparatus, circuit and earth return path in the systems operating at voltage s below 2.2kV and those operating at voltage above 33kV is sufficiently high so as to limit the value of the fault current to a safe value.

9.3 Resistance Grounding: when it become necessary to limit the earth fault current, a current limiting device is introduced in the neutral and earth. One method of introducing a current limiting device is resistance grounding. The resistor may be metallic or liquid.

Fig. 9·7 shows an earth fault on phase-B of a resistance grounded neutral system. The phasor diagram is shown in Fig. 9·8. The three currents at F in phase B are I_F, I_{BR}, I_{BY}. Current I_F lags

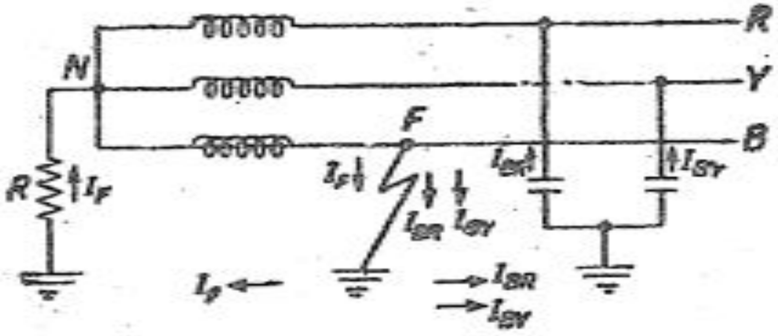

Fig. 9·7.

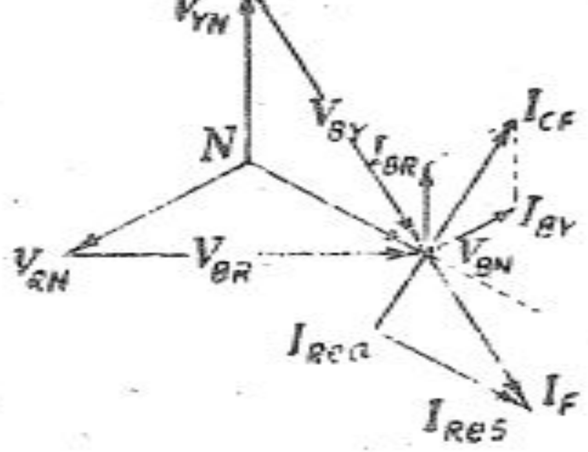

Fig. 9·8.

behind the phase voltage of the faulted phase by a certain angle depending upon the resistance R and the reactance of the system upto the point of fault. I_{BY} and I_{BY} lead V_{BR} and V_{BY} respectively by 90°. I_{CF} is the resultant of I_{BR} and I_{BY} I_F may be resolved into a reactive component and a resistive component. At the point of fault I_{CF} is in phase opposition to I_{RCG}. By adjusting the value of resistance R to a sufficiently low value it is possible to nullify the effect of I_{CF} so that no transient oscillations due to arcing ground may occur. However, if the value of earthing resistance is made sufficiently high so that the reactive current is less than the capacity current I_{CF} then the system conditions approach that of the non-grounded neutral system with the risk of transient over-voltage occurring.

An important consideration in resistance grounded systems is the power loss in the resistor during line to the ground faults. In general, it is common to fix a value which will limit the earth fault current to the full rating of largest generator or transformer. Based on this practice, the value of resistance to be inserted in the neutral connection to earth is

$$R=\frac{V_L}{\sqrt{3}I} \qquad ..(9\cdot3)$$

where R = resistance in ohms

V_L = line voltage in volts

I = full load current of largest machine of transformer in amps.

If at some later stage a still larger machine is added, it may be necessary to reduce the ohmic value of resistance.

Peterson gave the following formula for the most favourable dimensions of the resistance

$$R=(1 \text{ to } 2\cdot5)\frac{1}{(C_R+C_Y+C_B)} \qquad ...(9\cdot4)$$

where C_R, C_Y, C_B are the capacitances of each phase to earth.

Experimental results confirm the accuracy of the above formula.

Resistance grounding is normally employed on systems operating at voltages between 2·2 kV and 33 kV when the total power source capacity exceeds 5,000 kVA as the circuit characteristics of such systems usually give rise to excessive currents under ground fault conditions.

Neutral earthing resistors are normally designed to carry their rated current for a short period, usually 30 seconds.

9.4 Reactance Grounding: Another method of grounding wherein the earth fault current can be limited is reactance grounding. Reactance grounding mean grounding through impedance the principal element reactance.

9·5. Arc-Suppression Coil Grounding. An arc-suppression coil is an iron cored reactor mounte in the neutral earthing circuit and capable of being turned to resonate with the capacitance of th system when one line becomes earthed. The function of the arc suppression coil is to make arcir earth faults self-extinguishing and in the case of sustained faults to reduce the earth current to lo value so that the system can be kept in operation with one line earthed. The arc suppression coil sometimes referred to as a Peterson coil or Ground fault neutralizer while the grounding so achieve is referred to as Resonant grounding.

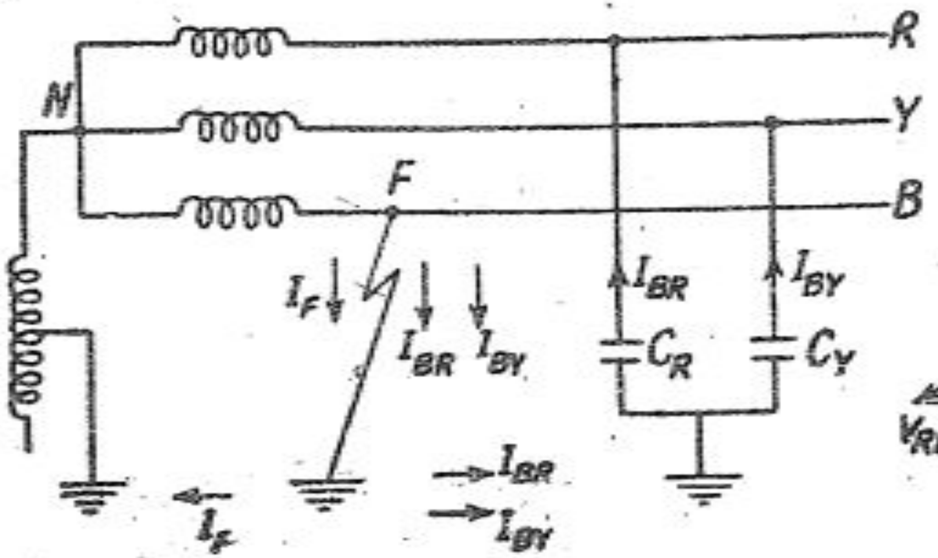

Fig. 9·9.

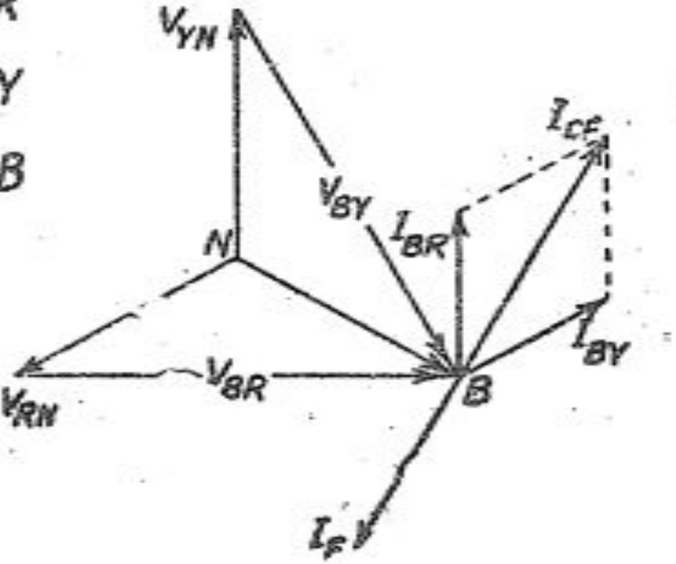

Fig. 9·10.

Under the conditions the voltage of the faulty phase is impressed across the arc suppression coil and a current If lagging by approximately 90 and in phase opposition to Icf, By adjusting the tapping on the coil If can be made to neutralize Icf so that the resultant current in the fault is limited to practically zero.

The inductance of the coil can determined as follows.

$$I_{cf}=3\frac{V_{ph}}{X_C}$$

$$I_f=\frac{V_{ph}}{X_L}$$

Where X_L is the inductance of the coil.

At resonance $I_F=I_{CF}$

i.e $\frac{V_{ph}}{X_L}=\frac{3V_{ph}}{X_c}$

$$X_L=\frac{X_C}{3} \qquad w_L=\frac{1}{3wc}$$

$$L=\frac{1}{3w^2c}$$

Example 9·1. A 132 kV, 3-phase, 50 cycles, overhead line, 50 km long has a capacitance to earth for each line of 0·0157 μF per km. Determine the inductance and kVA rating of the arc suppression coil suitable for this system.

Solution. $$L=\frac{1}{3\omega^2 C}=\frac{10^6}{3\times 314^2\times 50\times 0{\cdot}0157}=4{\cdot}3 \text{ henrys}$$

$$I_F=\frac{132/\sqrt{3}}{X_L}\times 1{,}000 \text{ amps}$$

$$=\frac{132}{\sqrt{3}}\times\frac{1{,}000}{2\pi(50)(4{\cdot}3)}=56{\cdot}4 \text{ amps}$$

Rating $=56{\cdot}4\times 132/\sqrt{3}=4{,}300$ kVA

Voltage Transformer Earthing:

A system having it is neutral point earthed through a single phase voltage transformer operates virtually as an insulated neutral system.

The voltage transformer acts as a very high reactance earthing device and does not assist in mitigating the over voltage condition which are associated with insulated neutral systems. It is only as a voltage measuring device to indicate a fault to earth on the system. The application of the voltage transformer in the neutral earthing circuit is normally confined to generator which is directly connected to step up transformer. The inter connecting cables between the generator and transformer is very short the capacitance of the circuit will be negligible there will be no risk of over voltage due to arcing ground.

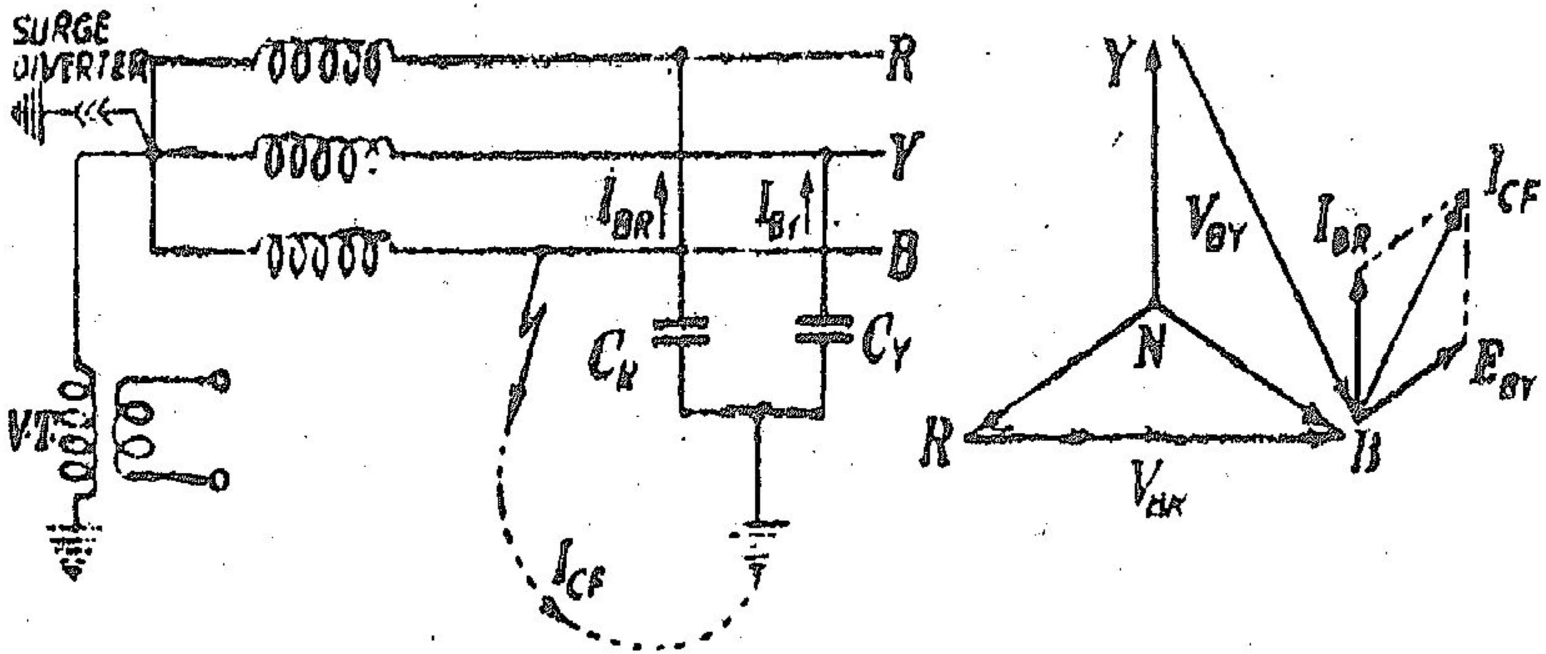
SURGE
DIVERTER
R
Y
B
VT
I_{BR}
I_{BY}
C_R
C_Y
I_{CF}
Y
V_{BY}
I_{BR}
I_{CF}
N
E_{BY}
R
B
V_{BR}

Fig. 9·12.

9·7. Earthing Transformer. In cases where the neutral points of a three-phase system are not accessible or where the transformers or generators are delta connected, an artificial neutral earthing point may be created with the help of an interconnected star earthing transformer, generally called neutral earthing compensator, as shown in Fig. 9·13 (*a*). Earthing transformer is three-limbed type transformer having two equally proportioned windings on each limb. One set of windings is connected in star to provide the neutral point. The other ends of this set of windings are connected to the second set of windings as shown so that the directions of the currents in the two windings on each limb are opposite to each other. With this arrangement of windings the transformer offers a low impedance path to the flow of zero phase sequence currents under system fault conditions since the only magnetic flux which results from the zero sequence currents is the leakage flux about each winding section. Under normal operation only small exciting current circulates in the windings of the earthing transformer.

Owing to the very low impedance of the earthing transformer windings under fault conditions, it is necessary sometimes to limit the value of the fault current by the addition of a resistor in series with the neutral earthing connection as shown in Fig. 9·13 (*b*). This is necesrary in systems operating at voltage between 2·2 kV and 3·3 kV where the total power source capacity exceeds 5,000 kVA.

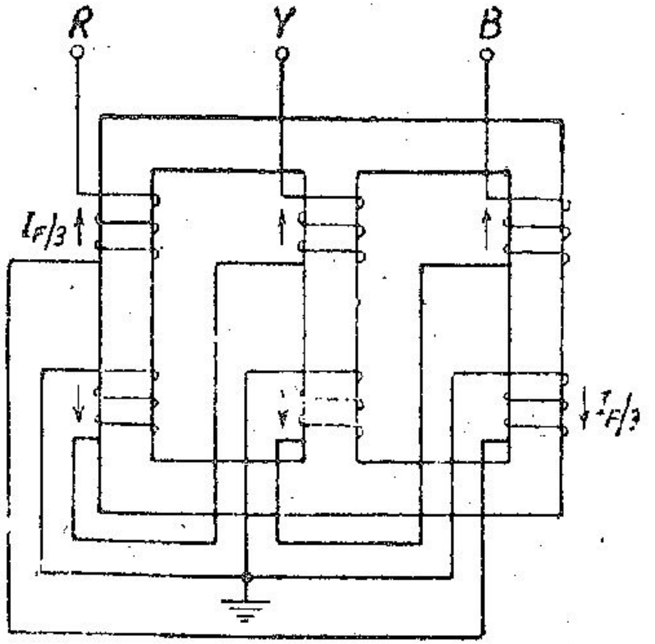

Fig. 9·13 (a) Schematic winding arrangement of an Inter-connected star Earthing Transformer.

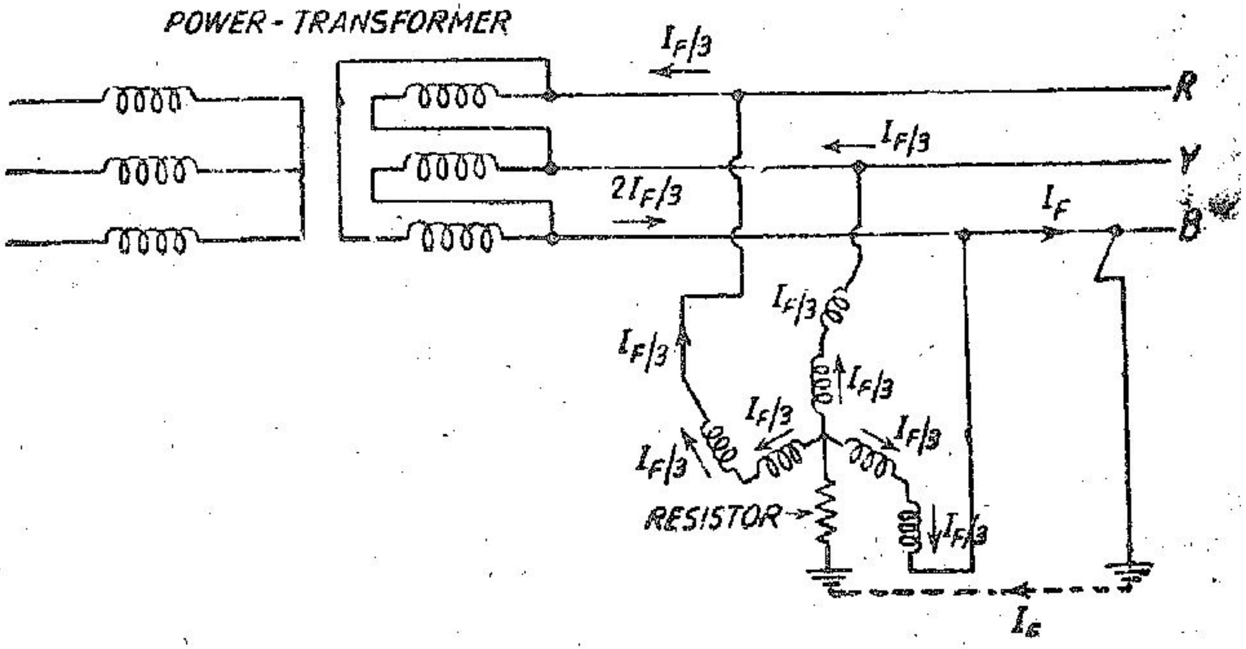

Fig. 9·13 (b)