Transformers Protection

7.1.1 Introduction

Transformers are static devices, totally enclosed and generally oil immersed. Therefore, chances of faults occurring on them are very rare. However, the consequences of even a rare fault may be very serious unless the transformer is quickly disconnected from the system. This necessitates providing adequate automatic protection for transformers against possible faults. Small distribution transformers are usually connected to the supply system through series fuses instead of circuit breakers. Consequently, no automatic protective relay equipment is required. However, the probability of faults on power transformers is undoubtedly more and hence automatic protection is absolutely necessary.

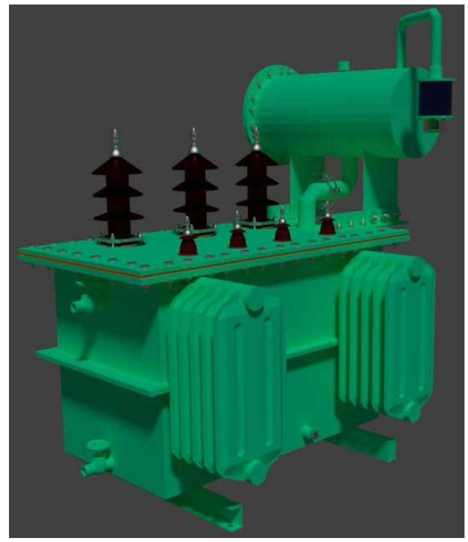

Figure 1: Transformer

Figure 2: Buchholz relay

It is common practice to provide Buchholz relay protection to all 0.5 MVA or above transformers. While for all small size distribution transformers, only high voltage fuses are used as main protective device. For all larger rated and important distribution transformers, over current protection along with restricted earth fault protection is applied. Differential protection should be provided in the transformers rated above 5 MVA. Depending upon the normal service condition, nature of transformer faults, degree of sustained over load, scheme of tap changing, and many other factors, the suitable transformer protection schemes are chosen.

7.1.2 Common transformer faults

As compared with generators, in which many abnormal conditions may arise, power transformers may suffer only from:

a) Open circuits Faults

b) Overheating Faults
c) Winding short-circuits e.g. earth-faults, phase-to-phase faults and inter-turn faults.
d) Through Faults
e) Over fluxing Faults

Open circuits Faults:

An open circuit in one phase of a 3-phase transformer may cause undesirable heating. In practice, relay protection is not provided against open circuits because this condition is relatively harmless. On the occurrence of such a fault, the transformer can be disconnected manually from the system.

Overheating Faults

Overheating of the transformer is usually caused by sustained overloads or short-circuits and very occasionally by the failure of the cooling system. The relay protection is also not provided against this contingency and thermal accessories are generally used to sound an alarm or control the banks of fans.

Winding short-circuits Faults

Winding short-circuits (also called *internal faults*) on the transformer arise from deterioration of winding insulation due to overheating or mechanical injury. When an internal fault occurs, the transformer must be disconnected quickly from the system because a prolonged arc in the transformer may cause oil fire. Therefore, relay protection is absolutely necessary for internal faults.

Through Faults

The fault that is external to the zone/equipment but is fed through it is called through fault. Let's take an example, suppose a fault occurs at a feeder that is fed by a transformer, now because of fault in the feeder, heavy current flows through the transformer although there wasn't any problem in transformer itself. This is what we call through fault.

Over fluxing Faults

As per present day transformer design practice, the peak rated value of the flux density is kept about 1.7 to 1.8 Tesla, while the saturation flux density of CRGD steel sheet of core of transformer is of the order of 1.9 to 2 Tesla which corresponds to about 1.1 times the rated value. If during operation, an electrical power transformer is subjected to carry rather swallow more than above mentioned flux density as per its design limitations, the transformer is said to have faced over fluxing problem and consequent bad effects towards its operation and life. Maximum over fluxing in transformer shall not exceed 110%.

7.1.3 Circulating-Current Scheme for Transformer Protection

Merz-Price circulating-current scheme for the protection of a 3- phase delta/delta power transformer against phase to ground and phase-to-phase faults. Note that *CT*s on the two sides of the transformer are connected in star. This compensates for the phase difference between the power transformer primary and secondary. The *CT*s on the two sides are connected by pilot wires and one relay is used for each pair of *CT*s. During normal operating conditions, the secondaries of *CT*s carry identical currents. Therefore, the currents entering and leaving the pilot wires at both ends are the same and no current flows through the relays.

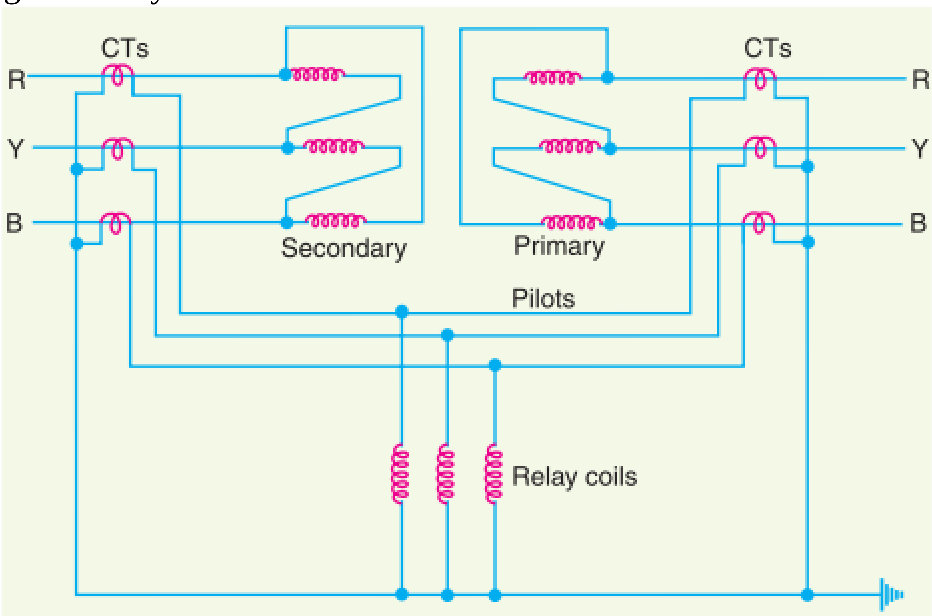

Figure 3: Merz-Price circulating-current scheme

If a ground or phase-to-phase fault occurs, the currents in the secondaries of *CT*s will no longer be the same and the differential current flowing through the relay circuit will clear the breaker on both sides of the transformer. The-protected zone is limited to the region between *CT*s on the high-voltage side and the *CT*s on the low-voltage side of the power transformer. It is worthwhile to note that this scheme also provides protection for short-circuits between turns on the same phase winding. When a short-circuit occurs between the turns, the turn-ratio of the power transformer is altered and causes unbalance between current transformer pairs. If turn-ratio of power transformer is altered sufficiently, enough differential current may flow through the relay to cause its operation. However, such short-circuits are better taken care of by Buchholz relays.

Math Example 7.1.1. *A 3-phase transformer of 220/11,000 line volts is connected in star/delta. The protective transformers on 220 V side have a current ratio of 600/5. What should be the CT ratio on 11,000 V side?*

Solution. For star/delta power transformers, *CT*s will be connected in delta on 220 V side (*i.e.* star side of power transformer) and in star on 11,000 V side (*i.e.* delta side of power transformer) as shown in Fig. 22.16.

Suppose that line current on 220 V side is 600 A.

$\therefore$ Phase current of delta connected *CT*s on 220V side

$$= 5 \text{ A}$$

Line current of delta connected *CT*s on 220 V side

$$= 5 \times \sqrt{3} = 5\sqrt{3} \text{ A}$$

This current (*i.e.* $5\sqrt{3}$) will flow through the pilot wires. Obviously, this will be the current which flows through the secondary of *CT*s on the 11,000 V side.

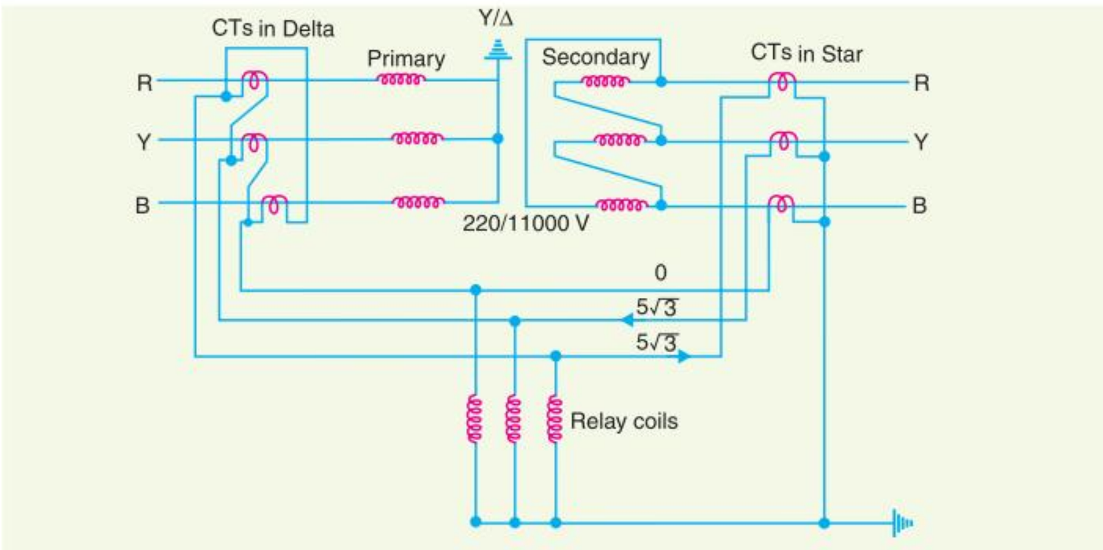

Fig. 22.16

$\therefore$ Phase current of star connected *CT*s on 11,000 V side = $5\sqrt{3}$ A

If I is the line current on 11,000 V side, then,

$$\text{Primary apparent power} = \text{Secondary apparent power}$$

or
$$\sqrt{3} \times 220 \times 600 = \sqrt{3} \times 11{,}000 \times I$$

or
$$I = \frac{\sqrt{3} \times 220 \times 600}{\sqrt{3} \times 11000} = 12 \text{ A}$$

$\therefore$ Turn-ratio of *CT*s on 11000 V side

$$= 12 : 5\sqrt{3} = \mathbf{1{\cdot}385 : 1}$$

Math Example 7.1.2. *A 3-phase transformer having line-voltage ratio of 0·4 kV/11kV is connected in star-delta and protective transformers on the 400 V side have a current ratio of 500/5. What must be the ratio of the protective transformers on the 11 kV side?*

Solution. Fig. 22.17 shows the circuit connections. For star/delta transformers, *CT*s will be connected in delta on 400 V side (*i.e.* star side of power transformer) and in star on 11,000 V side (*i.e.* delta side of power transformer).

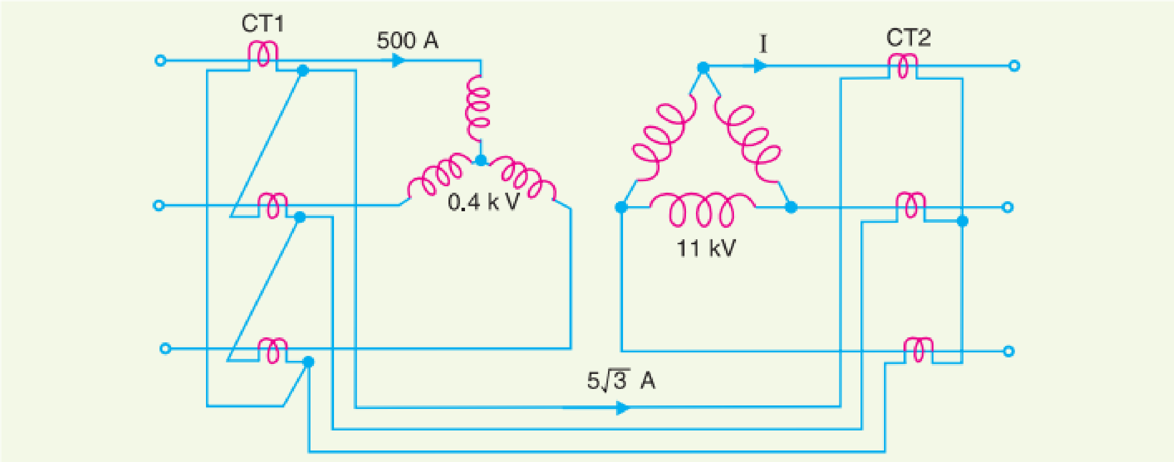

Fig. 22.17

Suppose the line current on 400 V side is 500 A.

∴ Phase current of delta connected *CT*s on 400 V side

$$= 5 \text{ A}$$

Line current of delta connected *CT*s on 400 V side

$$= 5 \times \sqrt{3} = 5\sqrt{3} \text{ A}$$

This current (*i.e.* $5\sqrt{3}$ A) will flow through the pilot wires. Obviously, this will be the current which flows through the secondary of the *CT*s on 11000 V side.

∴ Phase current of star-connected *CT*s on 11000 V side

$$= 5\sqrt{3} \text{ A}$$

If I is the line current on 11000 V side, then,

$$\text{Primary apparent power} = \text{Secondary apparent power}$$

or $$\sqrt{3} \times 400 \times 500 = \sqrt{3} \times 11000 \times I$$

or $$I = \frac{\sqrt{3} \times 400 \times 500}{\sqrt{3} \times 11000} = \frac{200}{11} \text{ A}$$

∴ C.T. ratio of *CT*s on 11000 V side

$$= \frac{200}{11} : 5\sqrt{3} = \frac{200}{11 \times 5\sqrt{3}} = \frac{10 \cdot 5}{5} = \mathbf{10{\cdot}5 : 5}$$

TUTORIAL PROBLEMS

1. *A 3-phase, 33/6·6 kV, star/delta connected transformer is protected by Merz-Price circulating current system. If the CTs on the low-voltage side have a ratio of 300/5, determine the ratio of CTs on the high voltage side.* **[60 : 5 3]**
2. *A 3-phase, 200 kVA, 11/0·4 kV transformer is connected as delta/star. The protective transformers on the 0·4 kV side have turn ratio of 500/5. What will be the C.T. ratios on the high voltage side?* **[18·18 : 8·66]**

7.1.4 Buchholz relay

Buchholz relays have been applied to large power transformers at least since the 1940s. The relay was first developed by Max Buchholz (1875–1956) in 1921.

Buchholz relay is a gas-actuated relay installed in oil immersed transformers for protection against all kinds of faults. Named after its inventor, Buchholz, it is used to produce an alarm in case of incipient (i.e. slow-developing) faults in the transformer and to disconnect the transformer from the supply in the event of severe internal faults. It is usually installed in the pipe connecting the conservator to the main tank. It is a universal practice to use Buchholz relays on all such oil immersed transformers having ratings in excess of 750 kVA.

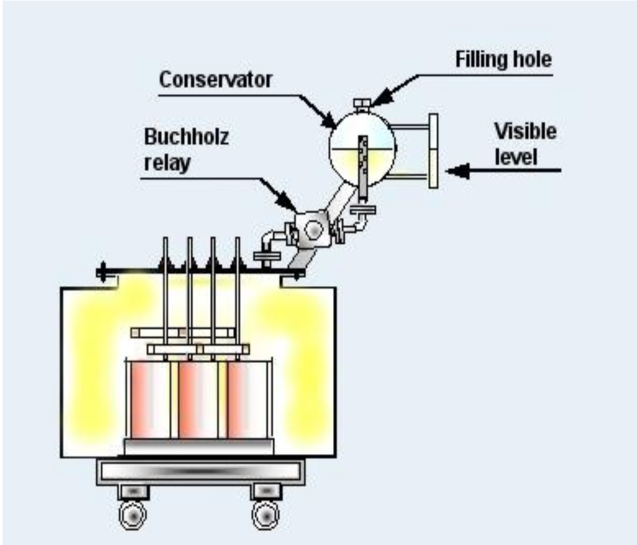

Figure 4: Different Parts of Transformer

The Buchholz relay is a protective relay for equipment immersed in oil for insulating and cooling purpose. It is intended mainly for transformers or choke coils having a conservator vessel.

In the field of electric power distribution and transmission, a **Buchholz relay** is a safety device mounted on some oil-filled power transformers and reactors, equipped with an external overhead oil reservoir called a *conservator*. The Buchholz Relay is used as a protective device sensitive to the effects of dielectric failure inside the equipment.

Construction:

The Buchholz relay takes the form of a domed vessel placed in the connecting pipe between the main tank and the conservator. The device has two elements.

1. The upper element

The upper element consists of a mercury type switch attached to a float. The upper element of the relay closes the alarm circuit during incipient faults.

2. The lower element

The lower element contains a mercury switch mounted on a hinged type flap located in the direct path of the flow of oil from the transformer to the conservator. The lower element is arranged to trip the circuit breaker in case of severe internal faults.

Figure 5: Internal Construction

Mode of Operation:

There are many types of internal faults such as insulation fault, core heating, bad switch contacts, faulty joints etc. which can occur. When the fault occurs the decomposition of oil in the main tank starts due to which the gases are generated. As mentioned earlier, major component of such gases is hydrogen. The hydrogen tries to rise up towards conservator but in its path it gets accumulated in the upper part of the Buchholz relay. Through passage of the gas is prevented by the flap valve.

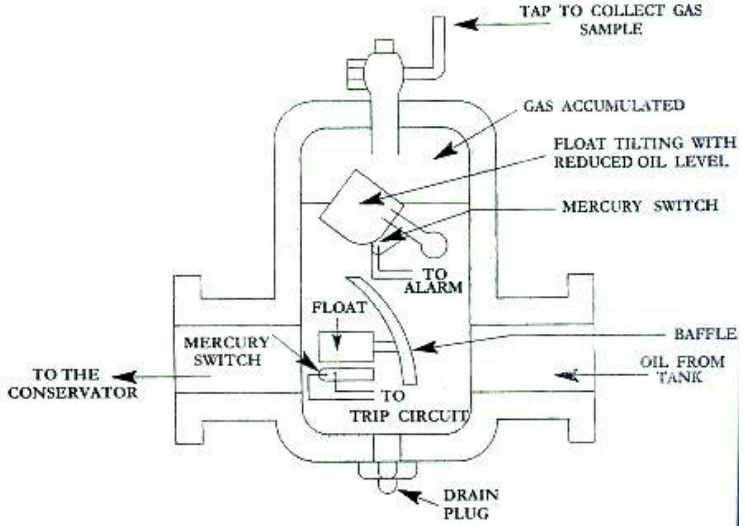

Figure 6: Buchholz relay

When gas gets accumulated in the upper part of housing, the oil level inside the housing falls. Due to which the hollow float tills and close the contacts of the mercury switch attached to it. This completes the alarm circuit to sound an alarm. Due to this operator knows that there is some incipient fault in the transformer. The transformer is disconnected and the gas sample is tested. The testing results give the indication, what type of fault is started developing in the transformer. Hence transformer can be disconnected before grows into a serious one. The alarm circuit does not immediately disconnect the transformer but gives only indication to the operator. This is because sometimes bubbles in the oil circulating system may operate the alarm circuit through actually there is no fault.

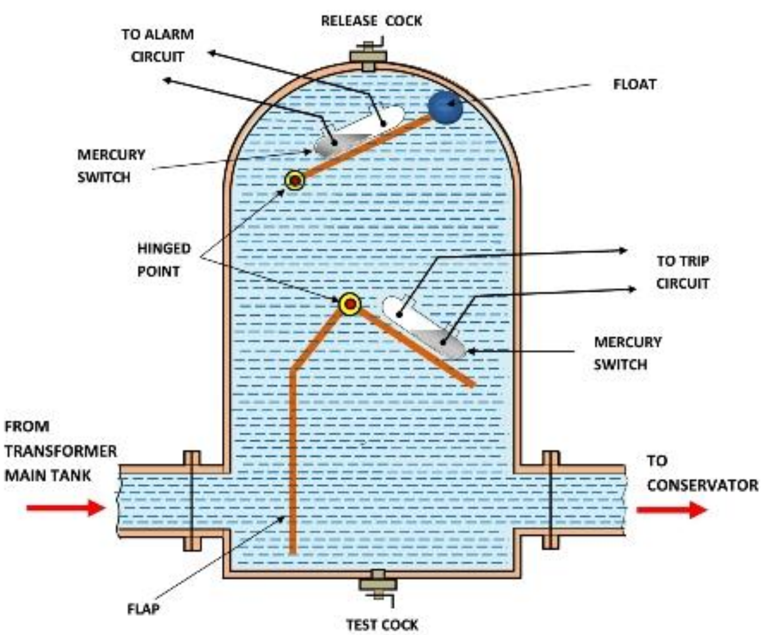

Figure 7: Buchholz relay

However if a serious fault such as internal short circuit between phases, earth fault inside the tank etc. occurs then the considerable amount of gas gets generated. Thus due to fast reduce level of oil, the pressure in the tank increases. Due to this the oil rushes towards the conservator. While doing so it passes through the relay where flap valve is present. The flap valve gets deflected due to the rushing oil. Due to this the mercury switch contacts get closed. This energizes the trip circuit which opens the circuit breaker. Thus transformer is totally disconnected from the supply.

The connecting pipe between the tank and the conservator should be as straight as possible and should slope upwards conservator at a small angle from the horizontal. This angle should be between 10 to 30.

For the economic considerations, Buchholz relays are not provided for the transformer having rating below 500 KVA.

Figure 8: Buchholz relay

Advantages:

1. It is the simplest form of transformer protection.
2. It detects the incipient faults at a stage much earlier than is possible with other forms of protection.
3. Low cost.

Disadvantages:

1. It can only be used with oil immersed transformers equipped with conservator tanks.
2. The device can detect only faults below oil level in the transformer. Therefore, separate protection is needed for connecting cables.
3. Setting of the mercury switches cannot be kept too sensitive otherwise the relay can operate due to bubbles, vibration, earthquakes mechanical shocks etc.
4. The relay is slow to operate having minimum operating time of 0.1 seconds and average time of 0.2 second.

7.1.5 Harmonic Restraints and Harmonic Blocking:

Magnetizing inrush current in transformer is the current which is drown by a transformer at the time of energizing the transformer. This current is transient in nature and exists for few milliseconds. The inrush current may be up to 10 times higher than normal rated current of transformer. Although the magnitude of inrush current is so high but it generally does not create any permanent fault in transformer as it exists for very small time. But still inrush current in power transformer is a problem, because it interferes with the operation of circuits as they have been designed to function. Some effects of high inrush include nuisance fuse or breaker interruptions, as well as arcing and failure of primary circuit components, such as switches. High magnetizing inrush current in transformer also necessitate over-sizing of fuses or breakers. Another side effect of high inrush is the injection of noise and distortion back into the mains.

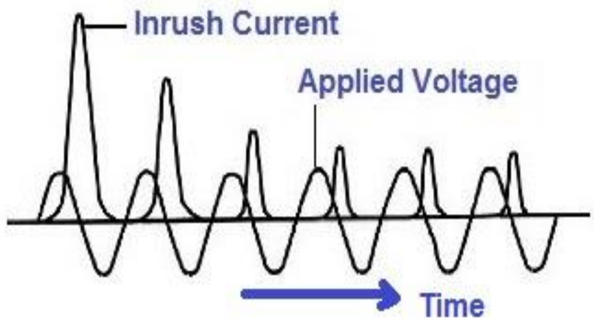

Figure 9: Inrush Currnt

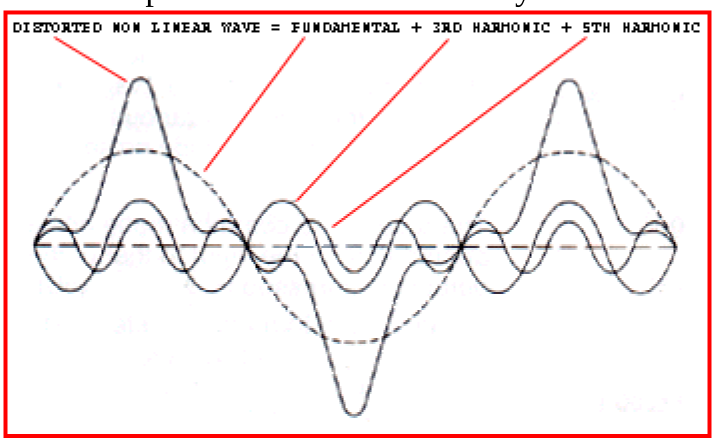

Figure 10: Harmonic Components

The inrush current has some characteristic properties. Its magnitude may be as high as sixteen times the full load current. It decays very slowly - from around ten cycles for small units to 1 minute for large units. The harmonic ******* of the inrush current is different from normal load current and from fault currents. A typical waveform of inrush current has a large fundamental frequency component, a significant D.C component, and 2nd and 3rd harmonic components. The 2nd harmonic component does not appear in the transformers under any other conditions except during energization. Desensitizing of the differential relay to the inrush current involves the use of the second harmonic component to restrain the relay from operating.

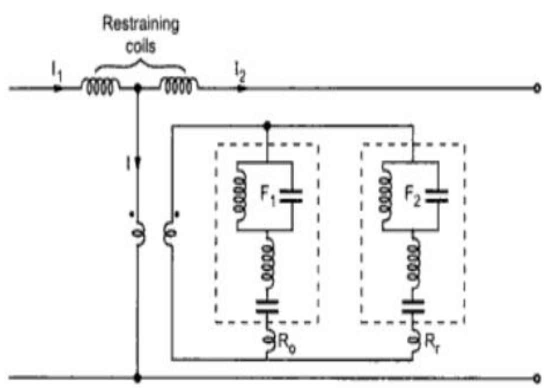

Figure 11: Harmonic Blocking Relay

7.1.6 Frame Leakage Protection:

This protection is nothing but the method of providing earth fault protection to the transformer. This protection can be provided to the metal clad switchgear.

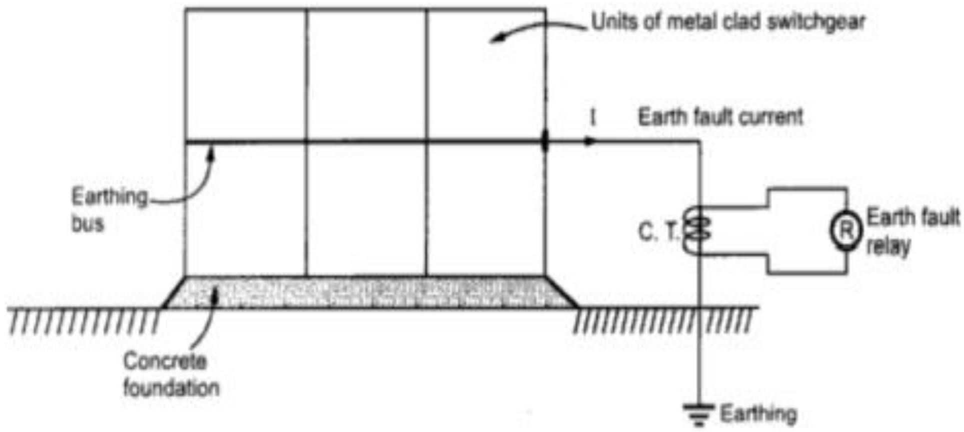

Figure 12: Frame Leakage Protection

The metal clad switchgear is lightly insulated from the earth. The frame of the switch i.e. enclosure is grounded. This is done through a primary of current transformer in between. The concrete foundation of switchgear and the other equipment are lightly insulated from the ground. The resistance of this equipment with earth is about 12 ohms. When there is an earth fault, then fault current leaks from the frame and passes through the earth connection provided. Thus the primary of C.T. senses the current due to which current passes through the sensitive earth fault relay. Such a protection is provided only for small transformers. For the large transformers, the differential protection is enough to sense and operate for the earth fault.

7.1.7 Earth-Fault or Leakage Protection:

An earth-fault usually involves a partial breakdown of winding insulation to earth. The resulting leakage current is considerably less than the short-circuit current. The earth-fault may continue for a long time and cause considerable damage before it ultimately develops into a short-circuit and removed from the system. Under these circumstances, it is profitable to employ earth-fault relays in order to ensure the disconnection of earth-fault or leak in the early stage. An earth-fault relay is essentially an overcurrent relay of low setting and operates as soon as an earth-fault or leak develops. One method of protection against earth-faults in a transformer is the **core-balance leakage protection** shown in Fig.

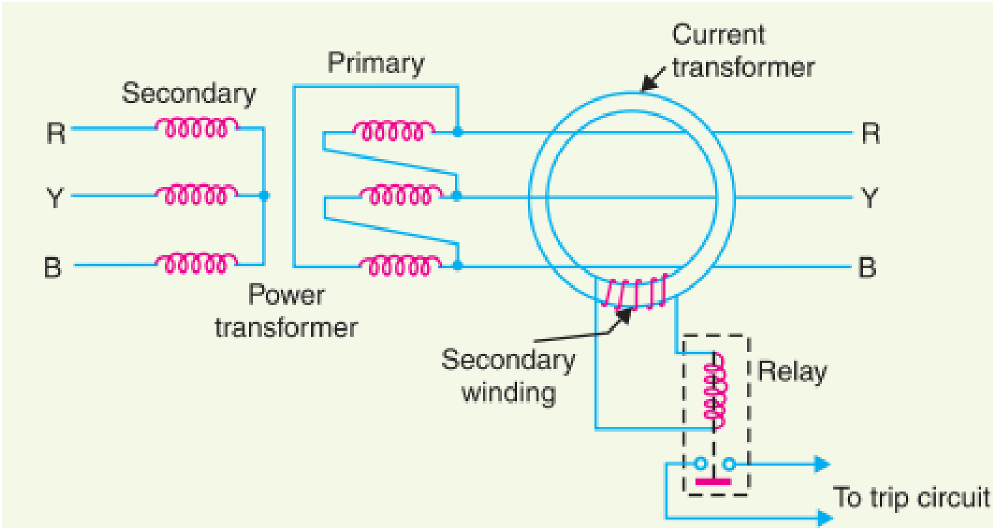

Figure 13: Transformer Earth Fault Protection Relay

Under normal conditions (i.e. no fault to earth), the vector sum of the three phase currents is zero and there is no resultant flux in the core of current transformer no matter how much the load is out of balance. Consequently, no current flows through the relay and it remains inoperative. However, on the occurrence of an earth-fault, the vector sum of three phase currents is no longer zero. The resultant current sets up flux in the core of the C.T. which induces e.m.f. in the secondary winding. This energizes the relay to trip the circuit breaker and disconnect the faulty transformer from the system.

7.1.8 Combined Leakage and Overload Protection:

The core-balance protection described above suffers from the drawback that it cannot provide protection against overloads. If a fault or leakage occurs between phases, the core-balance relay will not operate. It is a usual practice to provide combined leakage and overload protection for transformers. The earth relay has low current setting and operates under earth or leakage faults only. The overload relays have high current setting and are arranged to operate against faults between the phases.

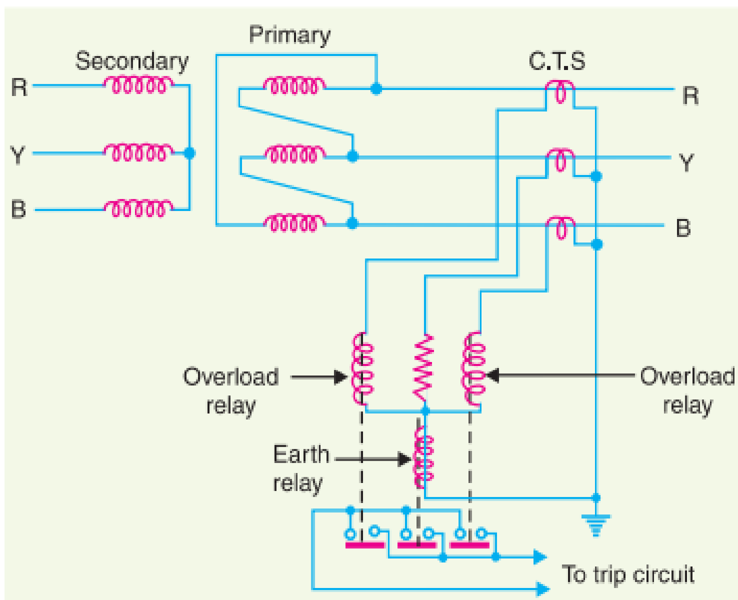

Figure 14: Combined Leakage and Overload Protection Relay

Fig.14. shows the schematic arrangement of combined leakage and overload protection. In this system of protection, two overload relays and one leakage or earth relay are connected as shown. The two overload relays are sufficient to protect against phase-to-phase faults. The trip contacts of overload relays and earth fault relay are connected in parallel. Therefore, with the energizing of either overload relay or earth relay, the circuit breaker will be tripped.