## TUTORIAL PROBLEMS

1. A 10 MVA, 11 kV, 3-phase star-connected alternator is protected by the Merz-Price balance-current system, which operates when the out-of-balance current exceeds 20% of full-load current. Determine what portion of the alternating winding is unprotected if the star point is earthed through a resistance of 9 Ω. The reactance of the alternator is 2 Ω. **[14·88%]**
2. The neutral point of 25 MVA, 11 kV alternator is grounded through a resistance of 5 Ω, the relay is set to operate when there is an out of balance current of 2A. The CTs used have a ratio of 1000/5. Calculate (neglect reactance of alternator) :
   (*i*) the percentage of stator winding protected against an earth fault
   (*ii*) the minimum value of earthing resistance to protect 95% of the winding **[(*i*) 68·5% (*ii*) 0·8 Ω]**
3. A 3-phase, 20 MVA, 11kV star connected alternator is protected by Merz-Price circulating current system. The star point is earthed through a resistance of 5 ohms. If the CTs have a ratio of 1000/5 and the relay is set to operate when there is an out of balance current of 1·5 A, calculate :
   (*i*) the percentage of each phase of the stator winding which is unprotected
   (*ii*) the minimum value of earthing resistance to protect 90% of the winding **[(*i*) 23·6% (*ii*) 2·12 Ω]**

## 22.6 Protection of Transformers

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 to provide 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.

**Common transformer faults.** As compared with generators, in which many abnormal conditions may arise, power transformers may suffer only from :

(*i*) open circuits
(*ii*) overheating
(*iii*) winding short-circuits *e.g.* earth-faults, phase-to-phase faults and inter-turn 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 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 (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.

## 22.7 Protection Systems for Transformers

For protection of generators, Merz-Price circulating-current system is unquestionably the most satisfactory. Though this is largely true of transformer protection, there are cases where circulating current system offers no particular advantage over other systems or impracticable on account of the troublesome conditions imposed by the wide variety of voltages, currents and earthing conditions invariably associated with power transformers. Under such circumstances, alternative protective systems are used which in many cases are as effective as the circulating-current system. The principal relays and systems used for transformer protection are :

(*i*) *Buchholz devices* providing protection against all kinds of incipient faults *i.e.* slow-developing faults such as insulation failure of windings, core heating, fall of oil level due to leaky joints etc.

(*ii*) *Earth-fault relays* providing protection against earth-faults only.

(*iii*) *Overcurrent relays* providing protection mainly against phase-to-phase faults and overloading.

(*iv*) *Differential system* (or circulating-current system) providing protection against both earth and phase faults.

The complete protection of transformer usually requires the combination of these systems. Choice of a particular combination of systems may depend upon several factors such as **(*a*)** size of the transformer **(*b*)** type of cooling **(*c*)** location of transformer in the network **(*d*)** nature of load supplied and **(*e*)** importance of service for which transformer is required. In the following sections, above systems of protection will be discussed in detail.

## 22.8 Buchholz Relay

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 give 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 as shown in Fig. 22.11. It is a universal practice to use Buchholz relays on all such oil immersed transformers having ratings in *excess of 750 kVA.

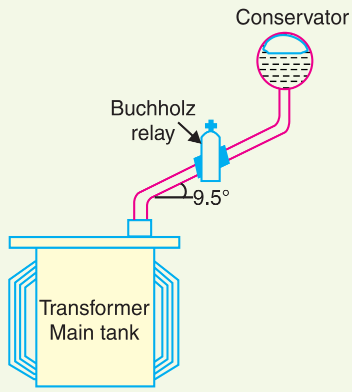

**Fig. 22.11**


Buchholz Relay

**Construction.** Fig. 22.12 shows the constructional details of a Buchholz relay. It takes the form of a domed vessel placed in the connecting pipe between the main tank and the conservator. The device has two elements. The upper element consists of a mercury type switch attached to a float. 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 upper element closes an alarm circuit during incipient faults whereas the lower element is arranged to trip the circuit breaker in case of severe internal faults.

**Operation.** The operation of Buchholz relay is as follows :

(*i*) In case of incipient faults within the transformer, the heat due to fault causes the decomposition of some transformer oil in the main tank. The products of decomposition contain more than 70% of hydrogen gas. The hydrogen gas being light tries to go into the conserva-

* Its use for oil immersed transformers of rating less than 750 kVA is generally uneconomical.

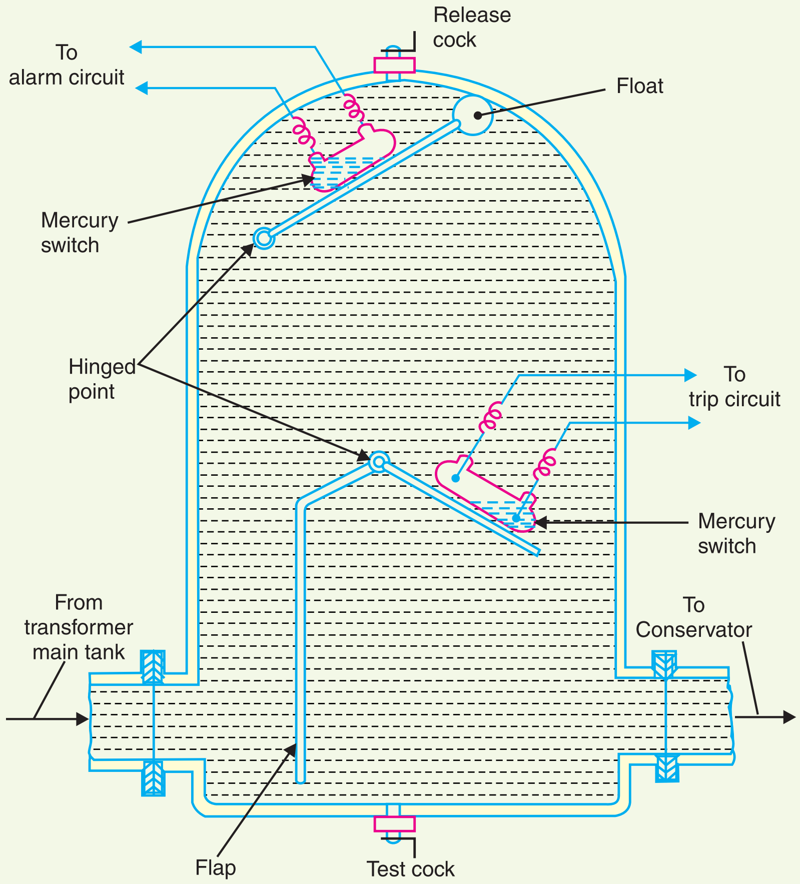


**Fig. 22.12**

tor and in the process gets entrapped in the upper part of relay chamber. When a predetermined amount of gas gets accumulated, it exerts sufficient pressure on the float to cause it to tilt and close the contacts of mercury switch attached to it. This completes the alarm circuit to sound an *alarm.

(*ii*) If a serious fault occurs in the transformer, an enormous amount of gas is generated in the main tank. The oil in the main tank rushes towards the conservator *via* the Buchholz relay and in doing so tilts the flap to close the contacts of mercury switch. This completes the trip circuit to open the circuit breaker controlling the transformer.

***Advantages***

(*i*) It is the simplest form of transformer protection.

(*ii*) It detects the incipient faults at a stage much earlier than is possible with other forms of protection.

***Disadvantages***

(*i*) It can only be used with oil immersed transformers equipped with conservator tanks.

(*ii*) The device can detect only faults below oil level in the transformer. Therefore, separate protection is needed for connecting cables.

---

* The conditions described do not call for the immediate removal of the faulty transformer. It is because sometimes the air bubbles in the oil circulation system of a healthy transformer may operate the float. For this reason, float is arranged to sound an alarm upon which steps can be taken to verify the gas and its composition.

## 22.9 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. 22.13.

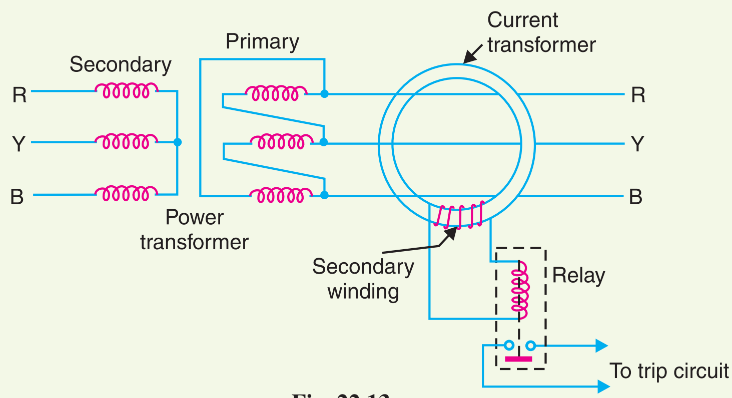


**Fig. 22.13**

The three leads of the primary winding of power transformer are taken through the core of a current transformer which carries a single secondary winding. The operating coil of a relay is connected to this secondary. 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 energises the relay to trip the circuit breaker and disconnect the faulty transformer from the system.

Earth Leakage Relay

## 22.10 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.

* An earth-fault relay is also described as a core-balance relay. Strictly the term 'core-balance' is reserved for the case in which the relay is energised by a 3-phase current transformer and the balance is between the fluxes in the core of the current transformer.

Fig. 22.14 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 energising of either overload relay or earth relay, the circuit breaker will be tripped.

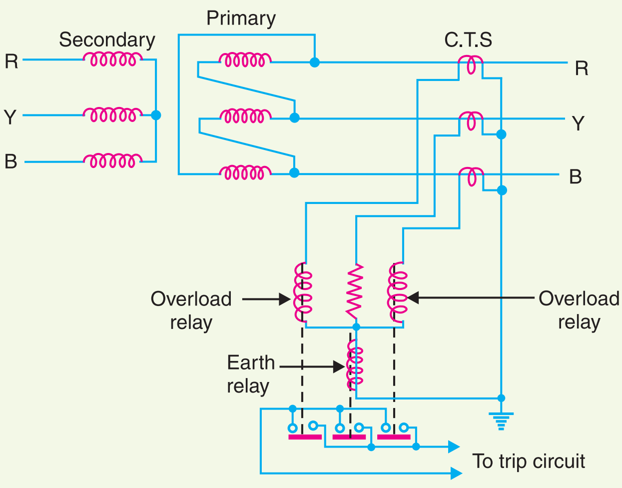


**Fig. 22.14**

## 22.11 Applying Circulating-current System to Transformers

Merz-Price circulating -current principle is commonly used for the protection of power transformers against earth and phase faults. The system as applied to transformers is fundamentally the same as that for generators but with certain complicating features not encountered in the generator application. The complicating features and their remedial measures are briefed below :

(*i*) In a power transformer, currents in the primary and secondary are to be compared. As these two currents are usually different, therefore, the use of identical transformers (of same turn ratio) will give differential current and operate the relay even under no load conditions.

The difference in the magnitude of currents in the primary and secondary of power transformer is compensated by different turn ratios of CTs. If T is the turn-ratio of power transformer, then turn-ratio of CTs on the *l.v.* side is made T times that of the CTs on the *h.v.* side. Fulfilled this condition, the secondaries of the two CTs will carry identical currents under normal load conditions. Consequently, no differential current will flow through the relay and it remains inoperative.

(*ii*) There is usually a phase difference between the primary and secondary currents of a 3-phase power transformer. Even if CTs of the proper turn-ratio are used, a differential current may flow through the relay under normal conditions and cause relay operation.

The correction for phase difference is effected by appropriate connections of CTs. The CTs on one side of the power transformer are connected in such a way that the resultant currents fed into the pilot wires are displaced in phase from the individual phase currents in the same direction as, and by an angle equal to, the phase shift between the power-transformers primary and secondary currents. The table below shows the type of connections to be employed for CTs in order to compensate for the phase difference in the primary and secondary currents of power transformer.

| S. No. | Power transformer connections | | Current transformer connections | |
|---|---|---|---|---|
| | Primary | Secondary | Primary | Secondary |
| 1 | Star with neutral earthed | Delta | Delta | Star |
| 2 | Delta | Delta | Star | Star |
| 3 | Star | Star with neutral earthed | Delta | Delta |
| 4 | Delta | Star with neutral earthed | Star | Delta |

Thus referring to the above table, for a delta/star power transformer, the CTs on the delta side must be connected in star and those on the star side in delta.

(*iii*) Most transformers have means for tap changing which makes this problem even more difficult. Tap changing will cause differential current to flow through the relay even under normal operating conditions.

The above difficulty is overcome by adjusting the turn-ratio of CTs on the side of the power transformer provided with taps.

(*iv*) Another complicating factor in transformer protection is the magnetising in-rush current. Under normal load conditions, the magnetising current is very small. However, when a transformer is energised after it has been taken out of service, the magnetising or in-rush current can be extremely high for a short period. Since magnetising current represents a current going into the transformer without a corresponding current leaving, it appears as a fault current to differential relay and may cause relay operation.

In order to overcome above difficulty, differential relays are set to operate at a relatively high degree of unbalance. This method decreases the sensitivity of the relays. In practice, advantage is taken of the fact that the initial in-rush currents contain prominent second-harmonic component. Hence, it is possible to design a scheme employing second-harmonic bias features, which, being tuned to second-harmonic frequency only, exercise restrain during energising to prevent maloperation.

While applying circulating current principle for protection of transformers, above precautions are necessary in order to avoid inadvertent relay operation.

## 22.12 Circulating-Current Scheme for Transformer Protection

Fig. 22.15 shows 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.

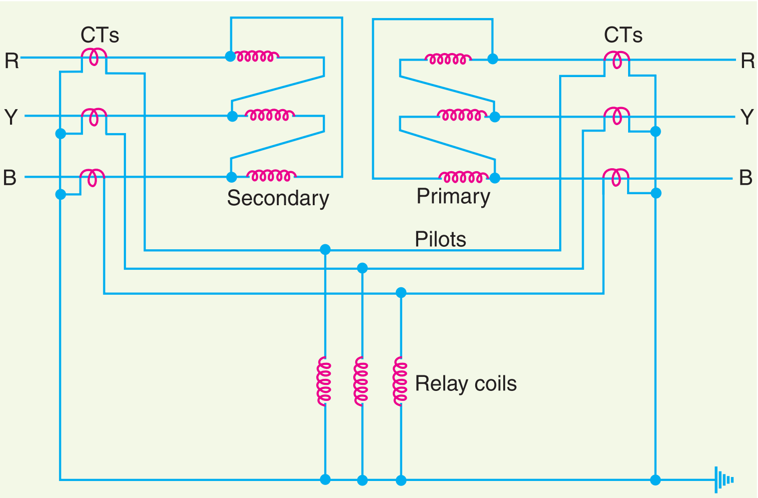


**Fig. 22.15**

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. 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.

**Example 22.5.** *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.

∴ 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.

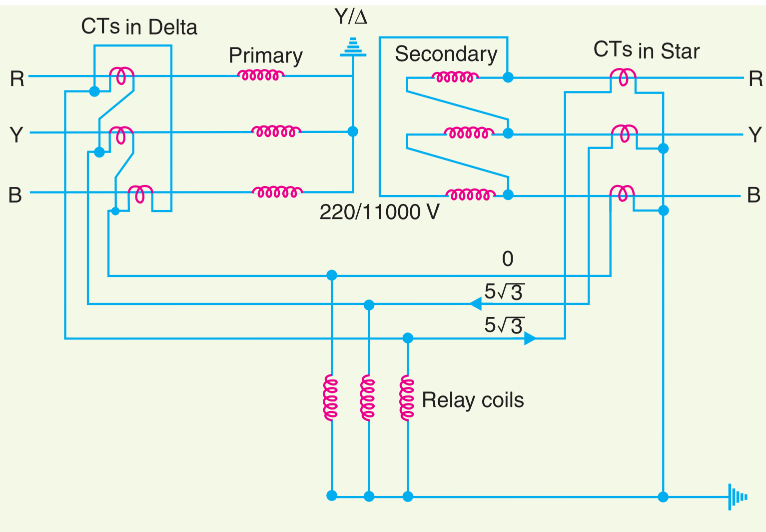


**Fig. 22.16**

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

∴ Turn-ratio of *CT*s on 11000 V side

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

**Example 22.6.** *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).

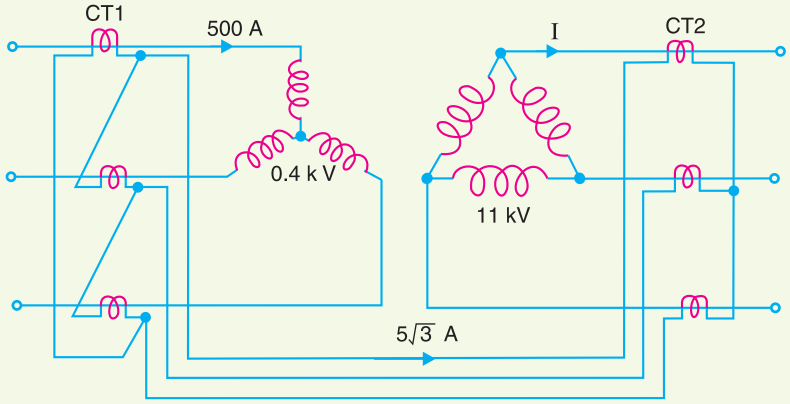


**Fig. 22.17**

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,

Primary apparent power = 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 : $5\sqrt{3}$ ]**
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]**

## SELF - TEST

**1. Fill in the blanks by inserting appropriate words/figures.**

(*i*) The most commonly used system for the protection of generator is ............

(*ii*) Automatic protection is generally ............ provided for field failure of an alternator.

(*iii*) The chief cause of overspeed in an alternator is the ............

(*iv*) Earth relays have ............ current settings.

(*v*) Buchholz relay is installed between ............ and conservator.

(*vi*) Buchholz relays can only be used with oil immersed transformers equipped with ............

(*vii*) For the protection of a delta/star power transformers, the CTs on delta side must be connected in ............ and those on the star side in ............

(*viii*) Overload protection is generally not provided for ............

(*ix*) Buchholz relay is a ............ relay.

(*x*) Automatic protection is generally not provided for ............ transformer.

**2. Pick up the correct words/figures from the bracket and fill in the blanks.**

(*i*) Buchholz relay can detect faults ............ oil level in the transformer. (*below, above*)

(*ii*) The most important stator winding fault of an alternator is ............ fault. (*earth, phase-to-phase, inter-turn*)

(*iii*) Balanced earth-fault protection is generally provided for ............generators. (*small-size, large-size*)

(*iv*) An earth-fault current is generally ............ than short-circuit current. (*less, greater*)

(*v*) Merz-Price circulating current principle is more suitable for ............ than ............ (*generators, transformers*)

## ANSWERS TO SELF-TEST

**1.** (*i*) circulating-current system (*ii*) not (*iii*) sudden loss of load (*iv*) lower (*v*) main tank (*vi*) conservator (*vii*) star, delta (*viii*) alternators (*ix*) gas actuated (*x*) small distribution

**2.** (*i*) below (*ii*) earth (*iii*) small-size (*iv*) less (*v*) generators, transformers

## CHAPTER REVIEW TOPICS

1. Discuss the important faults on an alternator.
2. Explain with a neat diagram the application of Merz-Price circulating current principle for the protection of alternator.
3. Describe with a neat diagram the balanced earth protection for small-size generators.
4. How will you protect an alternator from turn-to-turn fault on the same phase winding ?
5. What factors cause difficulty in applying circulating current principle to a power transformer ?
6. Describe the construction and working of a Buchholz relay.
7. Describe the Merz-Price circulating current system for the protection of transformers.
8. Write short notes on the following :
   (*i*) Earth-fault protection for alternator
   (*ii*) Combined leakage and overload protection for transformers
   (*iii*) Earth-fault protection for transformers

## DISCUSSION QUESTIONS

1. What is the difference between an earth relay and overcurrent relay ?
2. How does grounding affect relay application ?
3. Why is overload protection not necessary for alternators ?
4. Can relays be used to protect an alternator against (*i*) one-phase open circuits (*ii*) unbalanced loading (*iii*) motoring (*iv*) loss of synchronism ?
5. How many faults develop in a power transformer ?

GO To FIRST