1 a) i) Definition of switchgear- Various types of switching equipments are incorporated in power system to make on and off operations on generators. Transformers, busbars, transmission lines etc. either manually or automatically are known as switchgears. — 1 mark

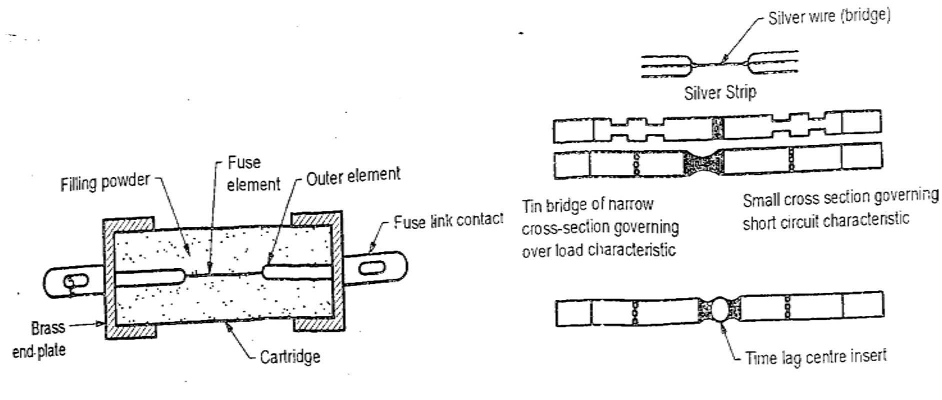
3 Switchgear elements :-

1) Fuses - It is used for overload / short circuit protection in medium voltage (up to 33kv) and low voltage (up to 400 v) installations. — 1 mark

2) Isolator – Theses are used in addition with circuit breakers and are provided on each side of every C.B. to provide isolation and enable maintenance. — 1 mark

3) Circuit Breaker – It performs interruption function. Its function is to make or break the circuit manually or remotely under normal condition and automatically under fault condition. — 1 mark

ii) HRC fuse:



(a) H.R.C. fuse (b) Fuse element

2 marks

HRC fuse mainly consists of heat resisting ceramic body. The current carrying element is compactly surrounded by the filling powder. Filling material acts as an arc quenching and cooling medium when the fuse element blows off due to excessive heat generated under abnormal conditions. Under normal condition, the fuse element is at a temperature below its melting point . Therefore, it carries the normal current without overheating. — 1 mark

When a fault occurs, the current increases and the heat produced is sufficient to melt these elements. Fuse element melt before the fault current reasons its first peak value. Vaporisation of metallic silver element chemically reacts with filling powder and results in the formation of high resistance substance and helps in quenching the arc. — 1 mark

iii) Definitions –

1) Pick up Current - It is the value of operating quantity which is on border above which the relay operates and closes its contacts. — 1 mark

2) Phase Angle Error - It is the phase angle between primary current vector and the reversed secondary current vector. — 1 mark

3) C.T. Burden - The value of load connected across the secondary of C.T. expressed in VA. or ohms at rated secondary current. — 2 marks

iv) Faults on Alternator – (min. 4

Stator faults – Phase to Phase, faults, 1 m each.)
Phase to earth,
Inter turn
1) Under frequency
2) Rotor Earth Fault
3) Over voltages – Arcing ground,
Switching Surges,
Lightening strokes.
4) Thermal overloading.
5) External faults -- Unbalanced loading.
6) Over fluxing.

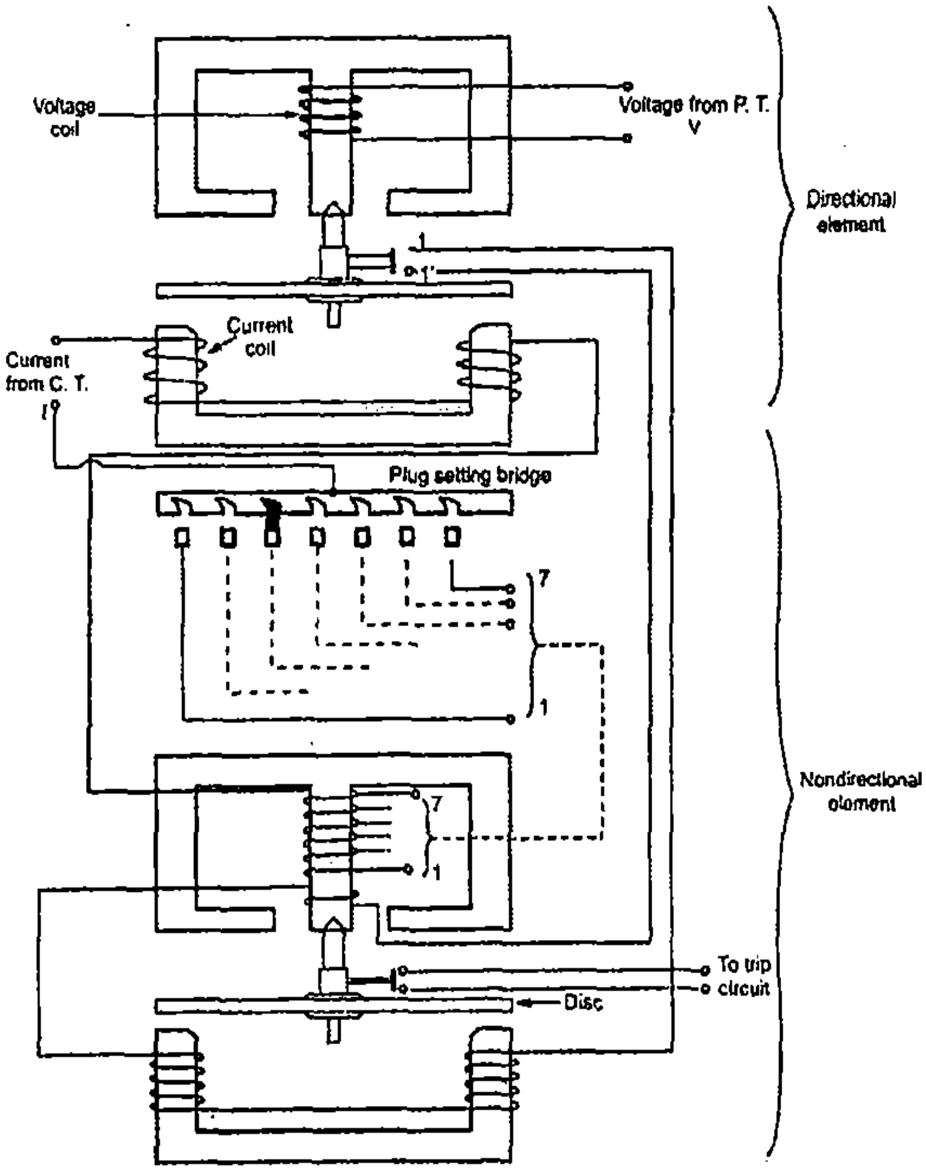
1 b) i) Methods of Arc Extinction –
1) High Resistance Method. 2 mark
2) Low Resistance Method.

1) High Resistance Method—
By increasing the resistance of arc path the arc interruption can be obtained.
The resistance of the arc is given by, 2 mark
$\gamma_{arc} = v_{arc} / i_{arc}$
where
i_{arc} = current in arc
v_{arc} = voltage across arc
γ_{arc} = resistance of arc
The equation for arc voltage is given by,
$V_{arc} = (A+Bd+C+Dd)/i_{arc}$,
Where A, B, C, D = constants , and D = length of arc
The arc resistance is increased by following methods
a) Lengthening the arc by arc runners.
b) Splitting the arc by arc splitters
c) Cooling the arc.

2) Low Resistance Method –
This method is employed n a.c. circuit breakers since the alternating current passes through zero 100 times per second in 50 cycle current wave. When current wave passes through every zero the arc vanishes for a brief moment. However, the arc restrikes again with the rising current waves. 2 mark

In this method, at current zero instant, fresh unionized medium (such as oil or fresh air or SF_6 gas) is introduced between the space of contacts. Due to introduction of unionized medium deionization effect takes place. The dielectric strength of the contact space increases to such an extent that the arc does not continue after current zero.

1 b) ii) Diagram: induction type directional over current relay,



Directional overcurrent relay

Labeled 6 marks unlabeled 2 marks, partially labeled 3 marks

2 a) Define –

i) Arc Voltage - It is the voltage that appears across the contacts of C.B. during arcing period. — 1 mark

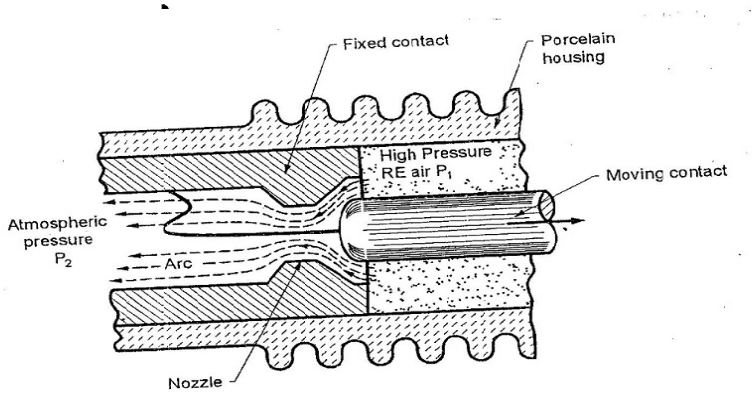
ii) Restriking Voltage - It is the transient voltage that appears across the contacts at or near current zero during arcing period. — 2 mark

iii) Recovery Voltage - It is the normal frequency (50 Hz) r.m.s. voltage that appears across the contacts of C.B. after final arc extinction. — 1 mark

b) Classification – 1 mark

1) Axial blast air circuit breaker
2) Cross blast air circuit breaker

Axial Blast Air C.B. –



2 marks

The fixed and moving contacts are held in closed position by spring pressure under normal condition. When a fault occurs, the tripping impulse causes opening of the air valve, which connects the C.B. reservoir to the arcing chamber pushes away the moving contacts against spring pressure. The moving contact is separated and arc is struck. At the same time, high pressure air blast flows along the arc and arc gets extinguished. 1 mark

c) Advantages of ABCB –

1) High speed of operation
2) Short arcing time.
3) Less weight as compared to O.C.B.
4) No possibility of explosion.

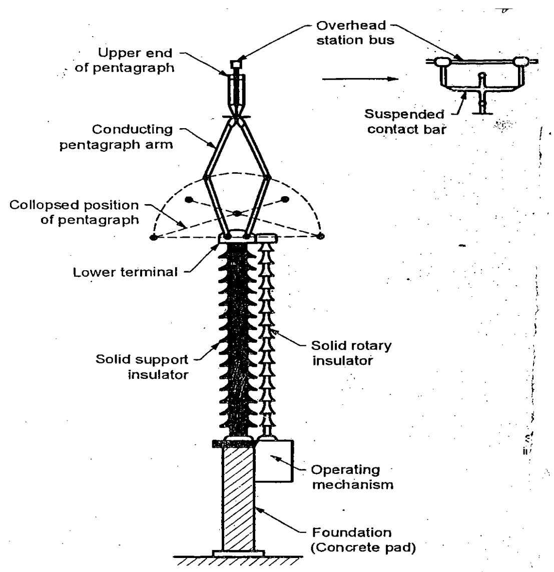
½ each (2 marks)

Disadvantages of ABCB –

1) Cost is more
2) These are more sensitive to RRRV

(1 each) 2 marks

d) Vertical pantograph Type Isolator



2 marks

Isolator operates under no load condition. These are used in addition with circuit breakers and are provided on each side of every C.B. to provide isolation and enable maintenance. Fig. Shows vertical pantograph type isolator. While closing, the linkages of pantograph are brought nearer by rotating the insulator column. In closed position the upper two arms of pantograph close on the overhead strain busbar giving a grip . The current is carried by the upper busbar to the lower bus bar through the conducting arms of the pantograph. While opening, the rotating insulators column is rotated absent its axis. There by the pantograph blades collapse in vertical plane and vertical isolation is obtained between the line terminal and pantograph upper terminal — 2 marks

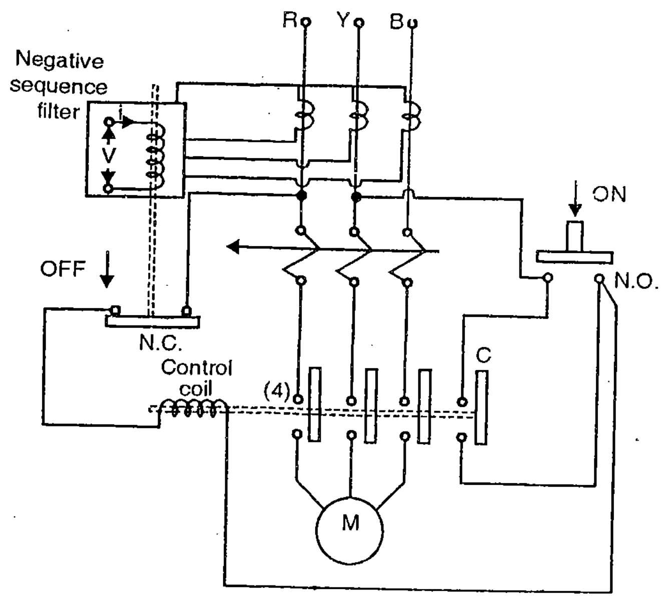
e) Single Phasing –

When one of the supply lines gets disconnected of the three phase supply connection then this situation is known as single phasing. — 1 mark

Effects of Single Phasing on 3 ph Ind. Motor –

Single phasing occurs mainly due to rupturing of a fuse or open circuit in one of the supply lines. Under these conditions, master continues to operate. If the motor is loaded at its full load, it will draw excessive current. Single phasing may cause extreme magnetic unbalance, reduction in torque and overheating due to negative phase sequence currents. This condition may
Cause damage to the motor. — 3 marks

f) Diagram of single phasing preventer:



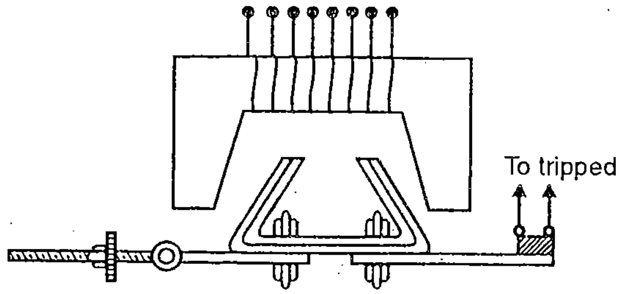
Unlabeled 1 mark

Partially labeled 2 marks

Labeled 4 marks

3 a)

Attracted Armature Relay : -



2 marks

It consist of laminated electromagnet carrying a coil and a pivoted laminated armature. The armature is balanced by a counter weight and carries a pair of spring contact fingers at its free and under normal operating conditions the current through the relay coil is such that counter weight holds the armature in the position shown. When a short circuit occurs, the current through the relay coil increases sufficiently and the relay armature is attracted upwards. This completes the trip circuit which results in the opening of the circuit breaker. 2 marks

b) Fundamental requirements of protective relay:

i) Selectivity : - It is the ability of protective system to select correctly that part of system in trouble and disconnect the faulty part without disturbing the rest of the system.

ii) Speed : The relay system should disconnect the faulty section as fast as possible to prevent the electrical apparatus from damage and for system stability.

iii) Sensitivity : - It is the ability of the relay system to operate with low value of actuating quantity.

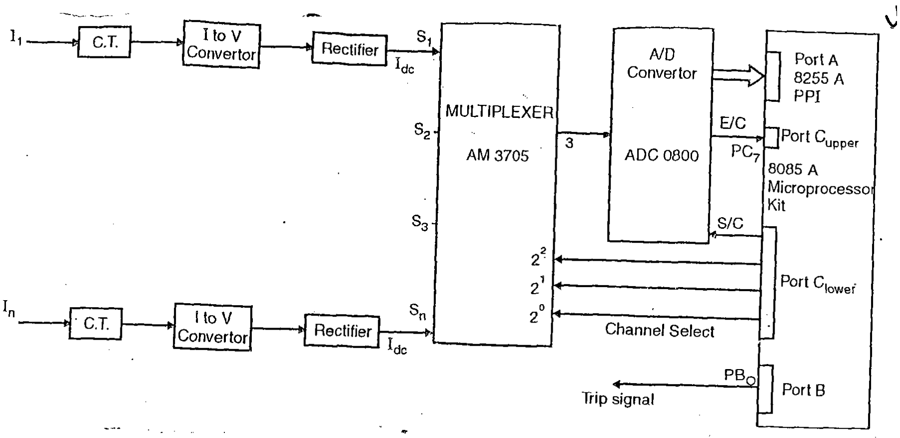
iv) Reliability : - It is the ability of the relay system to operate under predetermined conditions.

v) Simplicity : - The relay system should be simply so that it can be easily maintained.

vi) Economy : - The most important factor in the choice of particular protection scheme is the economic aspect. The protective gear should not cost more than 5% of the total cost of equipment to be protected.

2 pts 1 mark,
3 pts 2 mark,
4 pts, 3 marks,
5 or more pts 4 marks

3 c) Microprocessor based over current relay :



Diag 2 marks

The a.c. voltage proportional to the load current is converted in to d.c. through a precision rectifier. Thus, the microprocessor accepts d.c. voltage proportional to the load current. The schematic diagram is shown above. The out put of rectifier is fed to the multiplexer. The output of multiplexer is fed to the A/D converter to obtain the single in digital form. The A/D conveyor ADC 0800 has been used for this purpose. The microcomputer sends signal to the ADC for stating the conversion. The microcomputer reads the end of conversion signal to examine whether the conversion is over or not. As soon as conversion is over, the micro computer reads the current signal in digital form and then compares it with the pickup values . The microcomputer first determines the magnitude of the fault current and then selects the corresponding time of operation from the look up table. Then it goes in delay subroutine and sends a trip signal to the circuit breaker after the predetermined time delay.

1 mark

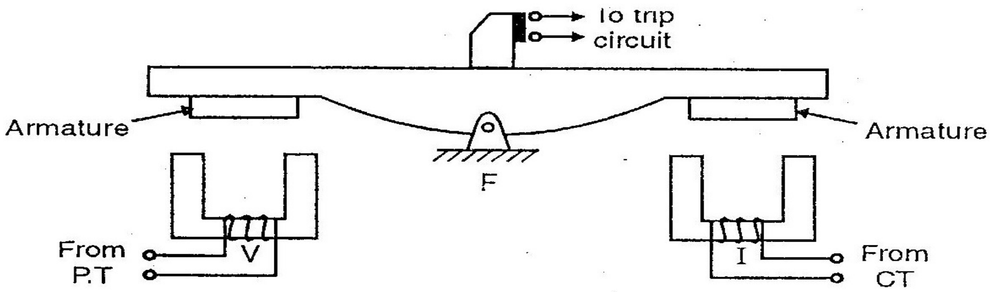
1 mark

d) Distance Relay - The action of relay depends upon the distance (or impedance) between the point where the relay is installed and the point of fault. 1 mark

Types --

1) Impedance relay
2) Mho relay
3) Reactance relay

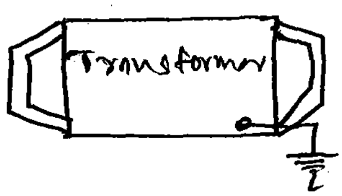
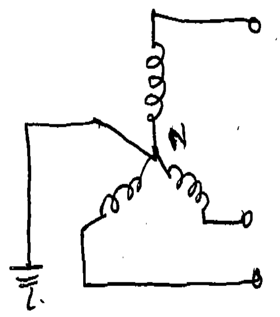
1 mark



2 mark

Definite – distance type impedance relay

3 e)

Equipment earthing:	Neutral earthing:	
1) 	1) 	Any 4 points out of 6 1 marks each = 4 marks
2) When the non current carrying metallic part of the electrical equipment are connected to earth it is called as equipment earthing.	2) When neutral of transformer, generators, motors is connected to earth is called as neutral earthing.	
3) It is provided for protection of human being from electric shocks	3) It is provided for eliminating arching ground and over voltage surge	
4)It is nothing to do with stability.	4) Stability of the system increases	
5)Equipment earthing is provided through pipe earthing and Plate earthing	5) Neutral earthing is provided through solid earthing, Resistance earthing and reactance earthing	
6)It does not provide any means for protection system against earth fault	6) It provides suitbale means for earth fault protecting system	

f) Definition -

Neutral Earthing –

When neutral of transformer, generators, motors is connected to earth is called as neutral earthing. — 1 marks

Importance of Neutral Earthing –

1) The main advantage of neutral earthing is that arcing grounds are eliminated. Neutral of the system is connected through an adjustable reactance.
2) No increase in voltage of healthy phases.
3) As arcing ground eliminated life of insulation increases.
4) Stable neutral point maintained.
5) Over voltages due to lightening are discharged to earth.
6) Heavy earth fault current can be controlled by employing resistance or reactance in earth connection.

Any three pts. 1 each = 3 marks

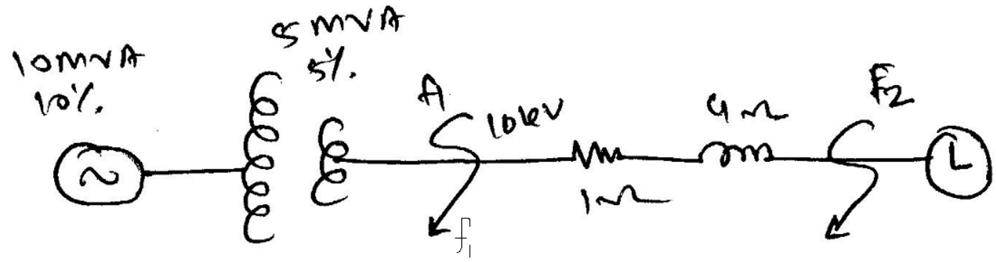
4 a) i) 1) Symmetrical faults: Faults giving rise to equal currents in lines displaced by equal phase angles i.e 120^o in three phase systems. — 1 mark

Example: short circuit of all three phase conductors of a cable at a single location. — 1 mark

2) Un-symmetrical faults: Faults in which not all the line currents are equal and not all have the same phase w. r. t the respect the corresponding three phase voltages. — 1 mark

Example (any one): single phase line to ground fault (L-G), two phase to ground (L-L-G) fault and phase to phase (L-L) fault. 1 mark

4 a) ii)

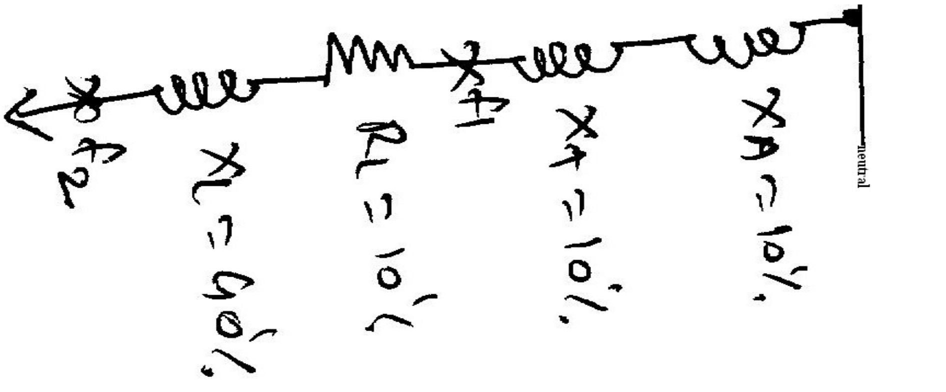


Let 10000 kVA be the base kVA,
% reactance of alternator at base kVA is
% X_A = (base kVA/rated kVA) x % reactance at rated kVA.
= $[(10000/(10\text{x}10^3)]$ x 10 = 10%.

% reactance of transformer at base kVA is
% X_T = (base kVA/rated kVA) x % reactance at rated kVA.
= $[(10000)/(5\text{x}10^3)]$ x 5 = 10%.

Line impedance is given as (1 + j4) ohms.
% impedance of line at base kVA is
% $Z_L = [(\text{kVA}/((10)(\text{ kV})^2)]$ x impedance
= $[(10000/((10)(10)^2)]$x (1 + j4) = (10 + j40)%. 2 mark

Neutral



I) Case I: fault at load end of line; (at point f_2)
Total impedance from generator to fault point f_2 is,
% Z_{f2} = %X_A + %X_T + %Z_L = j10 + j10 + (10 + j 40),
= (10 + j60) %. = $\sqrt{(10^2 + 60^2)}$ % = 60.83 %

Hence short circuit kVA = base kVA x (100/ % Z_{f2})
= 10000 x (100/60.83) = 16439 kVA. 1 mark

II) Case II: fault at HV terminals of transformer (at point f_1)
Total fault path impedance from generator neutral to fault point f_1 is
% Z_{f1} = %X_A + %X_T = 10 +10

= 20 %.
Short circuit kVA = 10000 x (100/20)
=50000 kVA. 1 mark

4 a) iii) Current limiting reactors- In order to limit the short circuit currents to a value which the circuit breakers can handle, additional reactances known as reactors are connected in series with the system at suitable points are called as current limiting reactors. 1 mark

Two advantages-
1) By introducing reactors, the magnitude of short circuit current gets controlled and hence suitable small capacity C.Bs can work safely. 2 marks
2) Introduction of reactors in the system ensures continuity if supply.

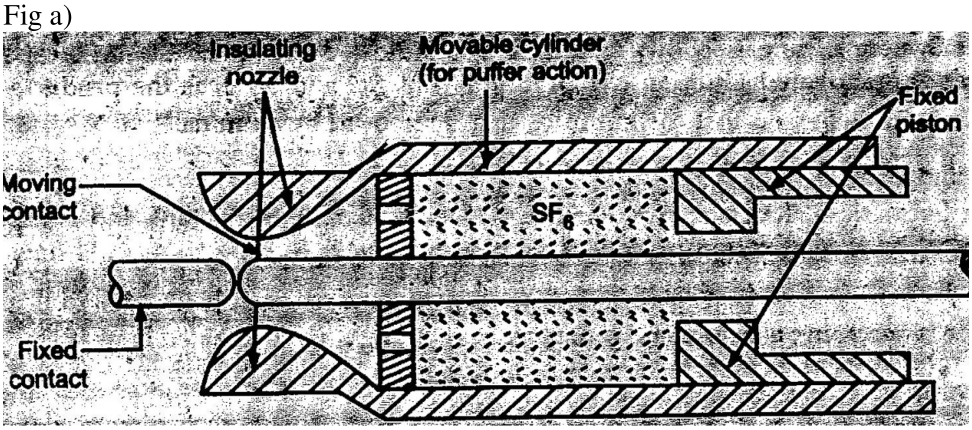
Methods of connecting reactors-
1) In series with the generator
2) In series with each feeder 1 mark
3) In busbar

4 a) iv) Common transformer faults-

Faults:	Protection needed	
1)earth fault	Earth fault relay	
	Differential protection	1 mark each
2)Through fault	HRC fuses	= 4 marks
	Graded time lag d.c. relay	
3)Over loads	Temperature relay sound alarm	
	Thermal O.L. relay	
4)Incipient fault	Buchholz's relay	

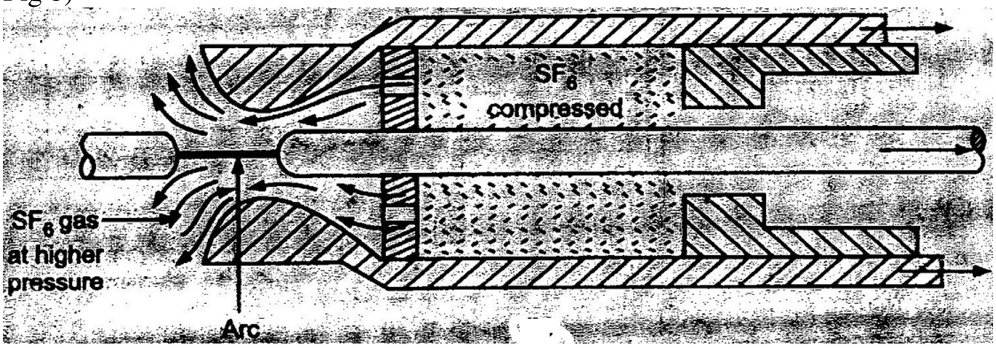
4 b) i) SF_6 C.B.-
Diagram-

Fig a)



Unlabeled 1 mark, partially labeled 2 marks, Labeled 3 marks

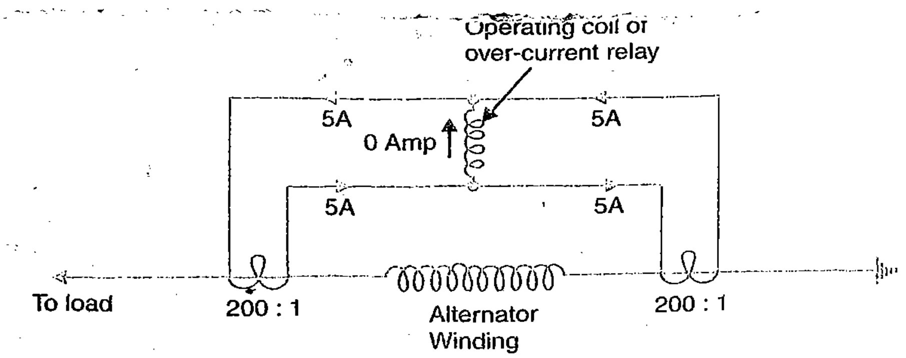
Fig b)



Construction-
The fixed and moving contacts are kept in insulating nozzle section as shown in figure. The whole assembly i.e. insulating nozzle, puffer action cylinder moves with the moving contact. A fixed piston is provided at the other end of moving contact. The chamber is filled up with SF_6 gas. 1 mark

Working-
Under normal operating conditions the contacts are closed (fig a). on the occurrence of fault the contacts are opened, movable contact moves towards right, the movable cylinder, insulating nozzle moves simultaneously (fig b).
An arc is struck between fixed contact and moving contact. The travel of movable cylinder causes increase in pressure of SF_6 gas, the SF_6 gas is now compressed i.e. it is under high pressure. The SF_6 travels to left towards the arc i.e.it puffs over arc. This results in extinction of arc. 2 marks.

4 b) ii) Differential relay: operates when the vector difference of two or more similar electrical quantities exceeds a predetermined value. 1 mark

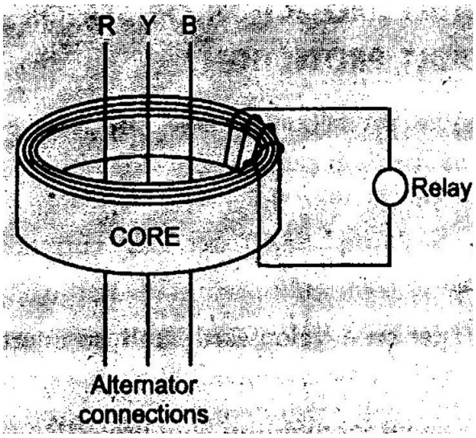


Diag. 3 marks

A current differential relay is one that compares the current entering a section of the system with the current leaving the section. Under normal operating conditions, the two currents are equal but as soon as fault accurs, this condition no longer applies. The difference between the incoming and outgoing currents is arranged to flow through the operating coil of the relay. If this differential current is equal to or greater than the pickup value, the relay will operate and open the circuit breaker to isolate the faulty section 1 mark

Fig. Shows an arrangement of an overcurrent relay connectied to opeate as a differential relay A pair of identical C.T's are fitted on either end of the section to be protected (Alternator winding in this case). The secondaries of CT's are connected in serie in such a way that they carry the induced currents in the same direction. The operating coil of the over current relay is connected across the CT secondary circuit. This differential relay compares the current at the two ends of the alternator windings. 1 mark

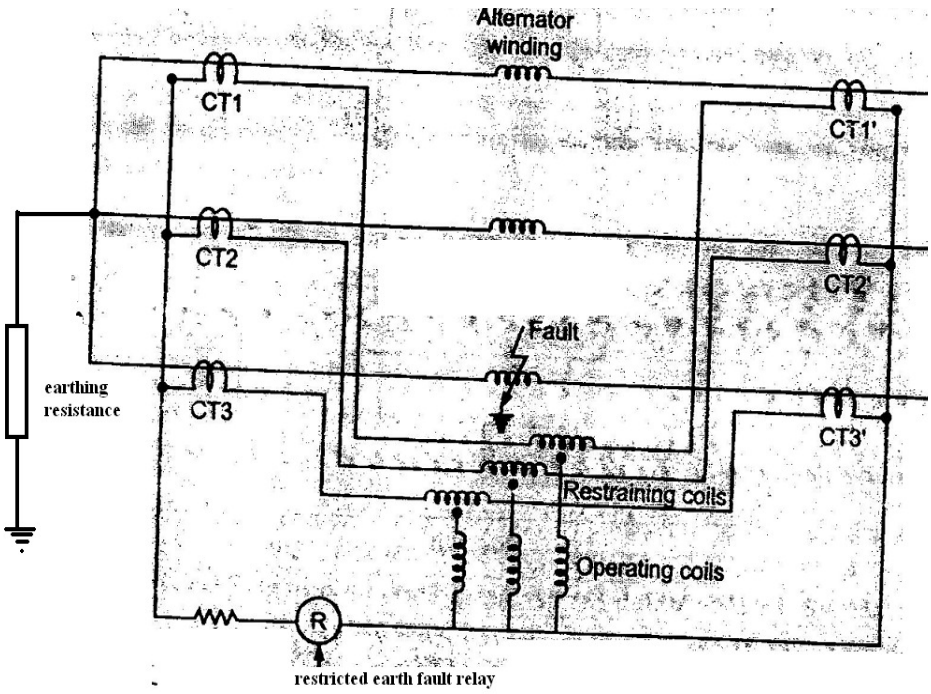
5 a) Balanced earth fault protection:



Diag. 2 mark

Core balance CT used whose core does not saturate due to high currents (fault currents) producing high flux densities. As seen in the figure the fluxes under normal conditions are balanced and their vector sum is zero. Hence the CT secondary current is negligible and relay does not operate. When earth fault occurs, the balance is disturbed and sufficient current is induced in the secondary to operate the relay. 2 marks

5 b) Schematic arrangement of differential protection of alternators:

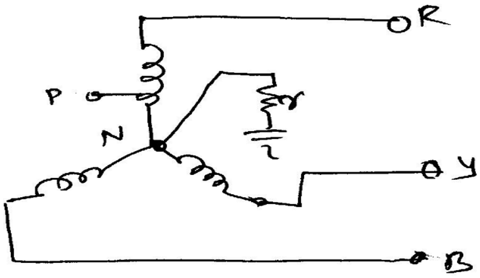


Labeled diagram 4 marks

Partially labeled 2 marks

Unlabeled 1 mark

5 c) MVA =10, V_L = 6.6 kV, % X = 10, I_P = 175 A.
Earthing resistance 'r' = ?

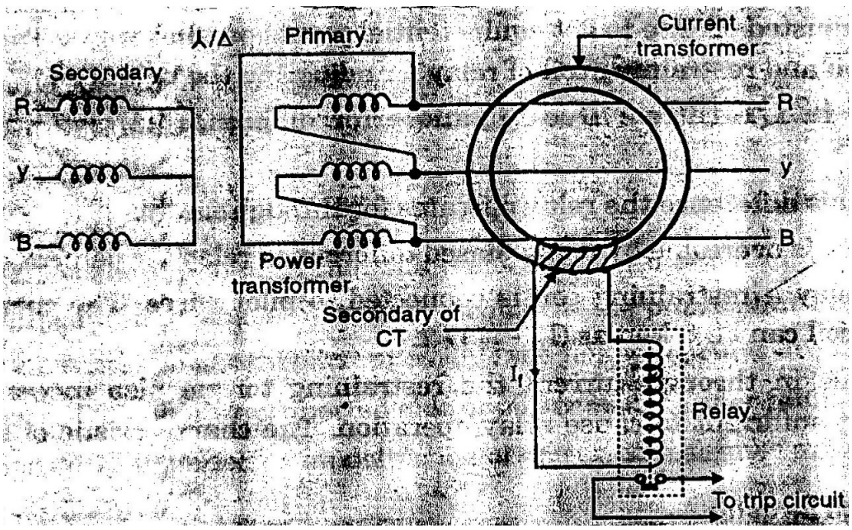


NP is the 10 % section of winding remaining unprotected by 'r'.
$V_{PH} = V_L/\sqrt{3} = (6.6 \times 10^3/\sqrt{3}) = 3810.5$ V.
Full load current $I = (MVA \times 10^6)/(\sqrt{3}V_L \times 10^3)$
$= (10 \times 10^6)/(\sqrt{3} \times 6.6 \times 10^3) = 874.77$ A. 1 mark

If generator winding reactance per phase is 'x' (ohms), then
$\% X = [(Ix)/(V_{PH})] \times 100$,
$10 = [(874.77x)/3810.5] \times 100$, from which
x = 0.4356 ohms. And
Reactance of 10% winding is $X_{PN} = x/10$
= 0.4356/10 = 0.04356 ohms. 1 mark

Emf in 10% of winding is $V_{PN} = V_{PH} \times 0.1$
= 3810.5 x 0.1 = 381 V.
Fault path impedance through 10 % winding is,
$Z_F = \sqrt{(r^2 + (X_{PN})^2)} = \sqrt{(r^2 + 0.04356^2)}$' 1 mark
Earth fault current due to 10% winding is
$I_F = V_{PN} / Z_F = 381/\sqrt{(r^2 + 0.04356^2)}$,
But given I_F is 175 A. hence
$175 = 381/\sqrt{(r^2 + 0.04356^2)}$ from which,
r = 2.176 ohms. 1 mark

5 d) Core balance protection of transformer:



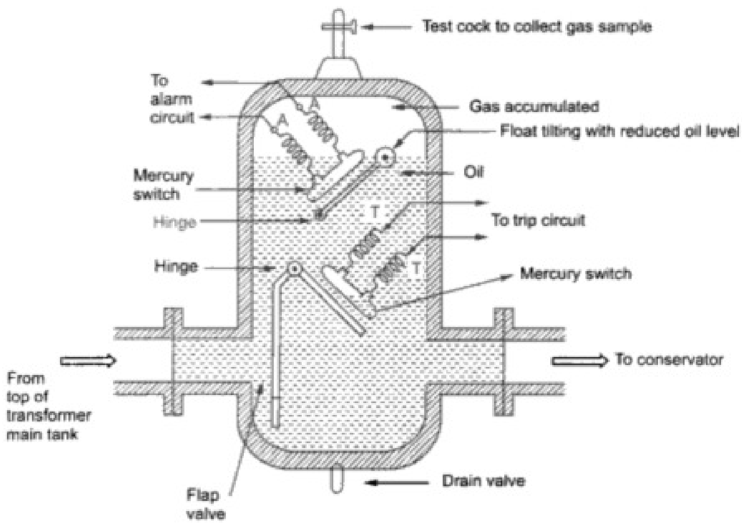
labeled 2 marks
Unlabeled 1 mark

Under balance condition i.e normal condition the phasor sum of the three line lead currents through the core of the CT is zero ($I_R + I_Y + I_B = 0$) due to which there is no resultant flux to induce emf in secondary. 1 mark

When earth fault occurs $I_R + I_Y + I_B \neq 0$, and resultant flux is present and induces emf in the secondary winding which feeds the relay coil to operate and trip the related circuit breaker and isolates the faulty transformer.

1 mark

5 e) Buchholz's relay:



Labeled 4 marks, unlabeled 2 marks.

5 f) Transformer 3 phase – Star – Delta, 220 V/ 11000 V, current ratio on 220 V side is 600/5.

Secondary current of star connected CTs is $5\sqrt{3}$ A. 1 mark

Also primary apparent power = secondary apparent power,

$\sqrt{3}V_1I_1 = \sqrt{3}V_2I_2$

$\sqrt{3} \times 220 \times 600 = \sqrt{3} \times 11000 \times I_2$,

$I_2 = 12$ A, which is the line current of secondary of main transformer which is the primary current for star connected CTs. 1 mark

CT ratio = primary current : secondary current

$= 12 : 5\sqrt{3}$ 2 marks

6 a) Voltage surge (or transient voltage): defined as sudden rise in voltage for short duration on power system. 1 mark

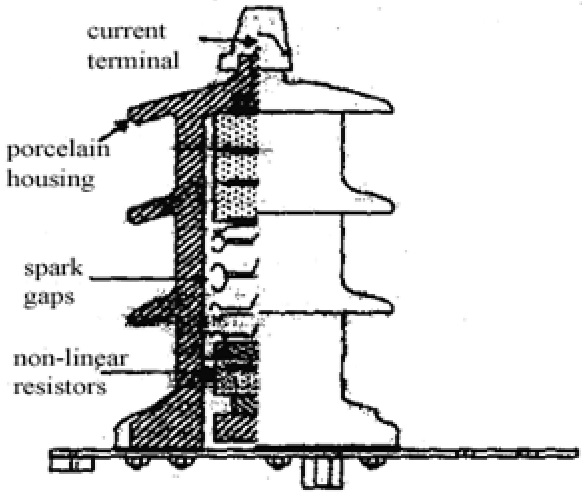
Causes:

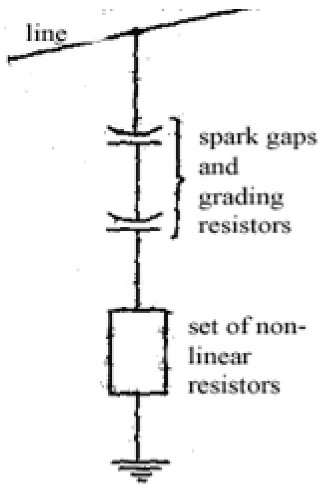
Internal to power system	External to power system	
1) Switching surges,	1) Lightening strokes.	2 marks internal causes and 1 mark External
2) Arcing grounds,		
3) Insulation failures,		
4) Resonance.		

6 b) Thyrite type lightning arrestor : -

Working :-

- When the line voltage is normal the air gap assembly does not break down. 1
- When a lighting stroke occurs the series spark gap breaks down providing the earth path for the surge current through the non linear resistors, which offer a low resistance to surge current and again regain back high value after the surge gets conducted to earth. 1

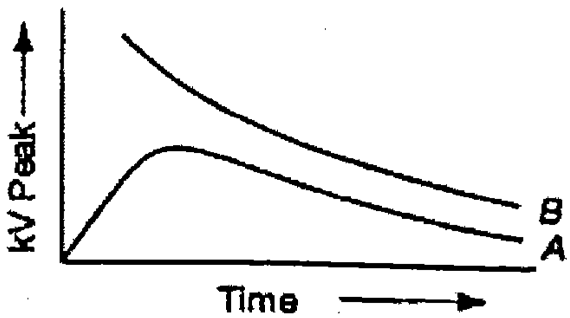




2

6 c) Insulation co-ordination :

Insulation coordination is the co-relation of the insulation of electric equipment and lines with the characteristics of protective devices such that the insulation of the whole power system is protected from excessive over voltages. 1

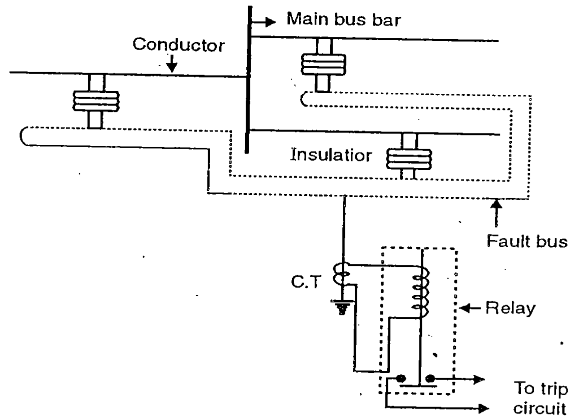


1

Curve A is volt time curve of protective device and curve B is that of equipment protected 1

Insulation coordination is needed to protect the equipment in the power systems. Especially the costly transformers, generators etc from the harmful over voltage that occur in the system. The Basic Impulse (Insulation) levels of the various devices and equipment are graded selectively to provides protection to the costly equipment 1

6 d) Fault bus protection:



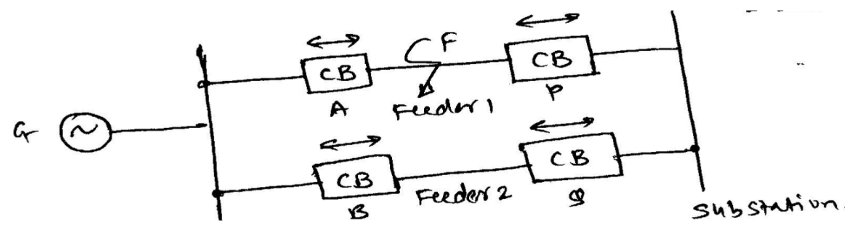
2 marks

Each phase bus is surrounded by an earthed metal mesh or structure – (called as fault bus) 1

Hence the busbar fault will never be an interphase one

The earth path current is sensed by the CT and if it is above the relay setting value the relay trips the concerned circuit breaker indicating bus bar fault. 1

6 e) Time graded over current protection for parallel feeder:

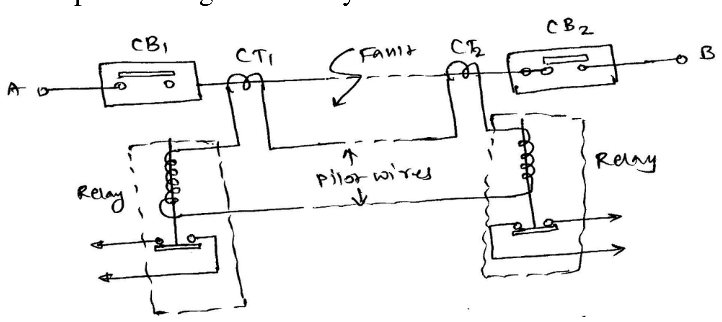


2 marks

To overcome the disadvantage of loss of supply due fault in radial feeders parallel feeders are installed between supply end (generator) and substation end. When fault occurs on any one feeder supply is maintained through the other. 1 mark

Each feeder is provided with non-directional over current relay with inverse time characteristics at the supply end and an reverse power or directional relay at the substation end. 1 mark

6 f) Merz price voltage balance system:



3 marks for labeled diagram, unlabeled /incomplete diag. 1 mark

Advantages:

1) Can be used for ring system and parallel feeders.
2) Provides instantaneous protection for ground faults.

1 advantage only 1 mark