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USN

Internal Assesment Test - V

Sub: POWER SYSTEM PROTECTION
Code: 17EE72
Date: 07/02/2022
Duration: 90 mins
Max Marks: 50
Sem: 7th(A & B)
Branch: EEE

Answer Any FIVE FULL Questions

		Marks	OBE	
			CO	RBT
1	With a neat circuit diagram explain air break circuit breaker.Write any two applications of it.	[10]	CO5	L1
2	Explain the terms: restriking voltage, recovery voltage and RRRV. Derive expression for restriking voltage and RRRV in terms of system voltage, inductance and capacitance. What measures are taken to reduce it.	[10]	CO5	L1
3	Explain the working of SF6 circuit breaker with neat circuit diagram. Give its four advantages.	[10]	CO5	L2
4	With neat diagram, explain the harmonic restraint relay used to protect against magnetizing inrush current of transformer.	[10]	CO4	L2
5	With a neat circuit diagram, explain rotor earth fault protection of alternator.	[10]	CO4	L2
6	With neat diagram, explain percentage differential protection of star delta connected transformer.	[10]	CO4	L1

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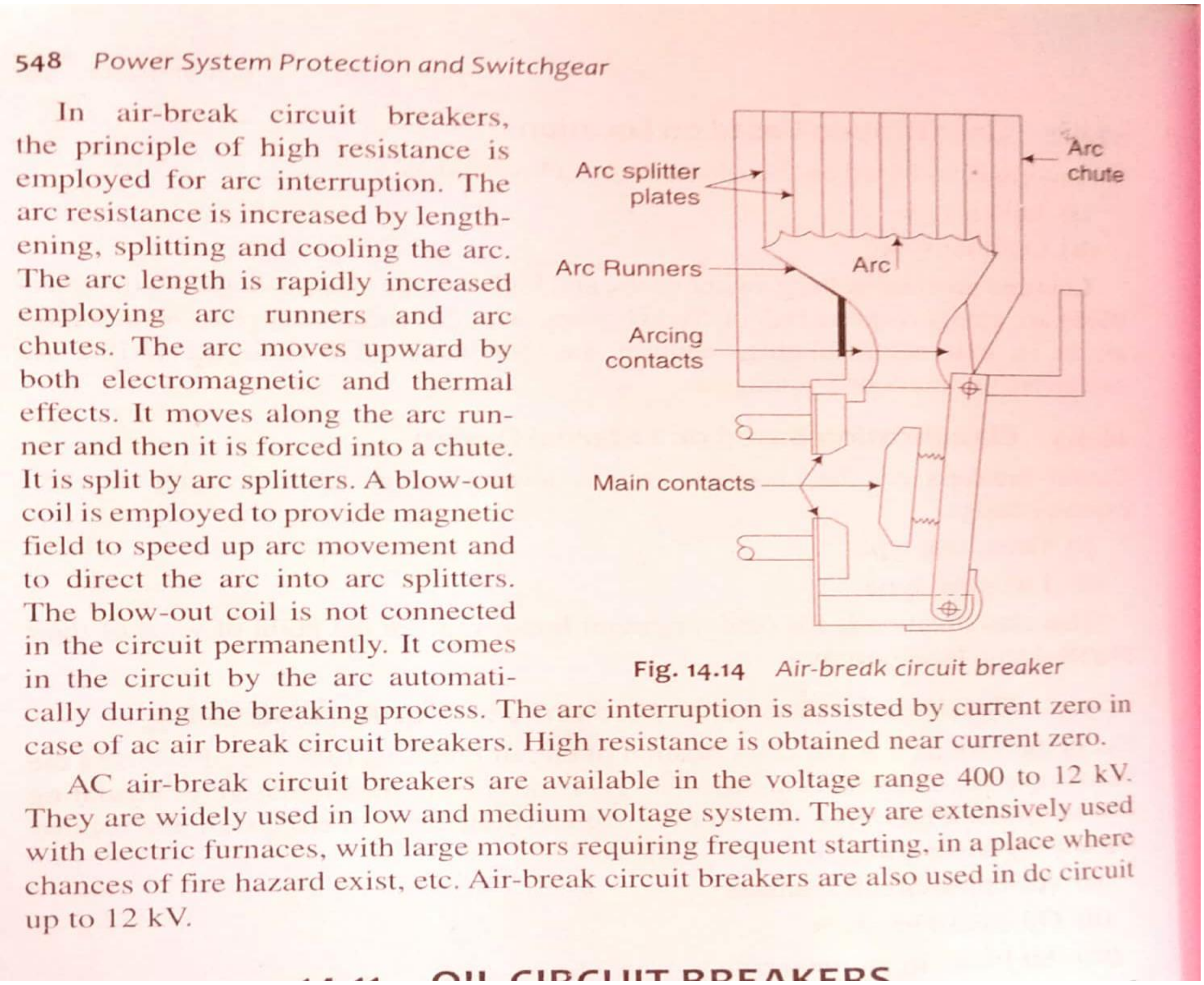
IAT 5

Question paper Solution

Q.1



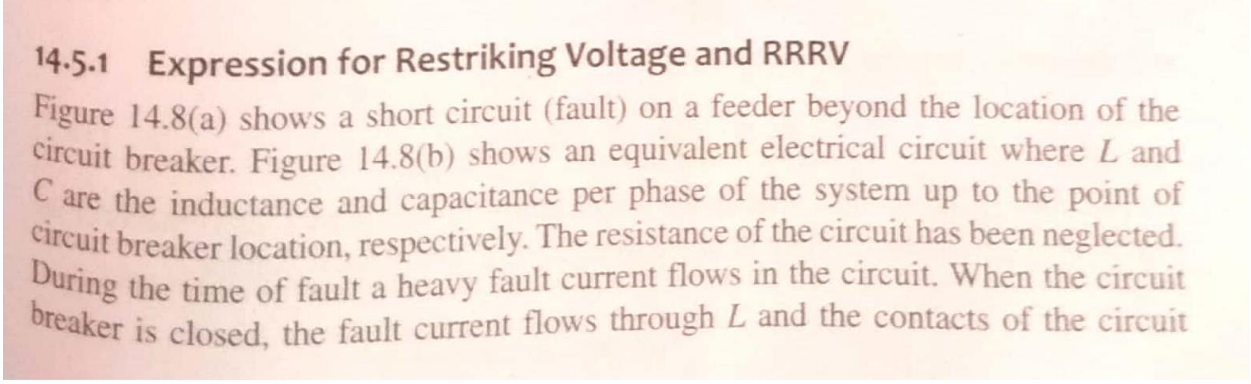
In air-break circuit breakers, the principle of high resistance is employed for arc interruption. The arc resistance is increased by lengthening, splitting and cooling the arc. The arc length is rapidly increased employing arc runners and arc chutes. The arc moves upward by both electromagnetic and thermal effects. It moves along the arc runner and then it is forced into a chute. It is split by arc splitters. A blow-out coil is employed to provide magnetic field to speed up arc movement and to direct the arc into arc splitters. The blow-out coil is not connected in the circuit permanently. It comes in the circuit by the arc automatically during the breaking process. The arc interruption is assisted by current zero in case of ac air break circuit breakers. High resistance is obtained near current zero.

Fig. 14.14 *Air-break circuit breaker*

AC air-break circuit breakers are available in the voltage range 400 to 12 kV. They are widely used in low and medium voltage system. They are extensively used with electric furnaces, with large motors requiring frequent starting, in a place where chances of fire hazard exist, etc. Air-break circuit breakers are also used in dc circuit up to 12 kV.

OIL CIRCUIT BREAKERS

Q. 2



14.5.1 Expression for Restriking Voltage and RRRV

Figure 14.8(a) shows a short circuit (fault) on a feeder beyond the location of the circuit breaker. Figure 14.8(b) shows an equivalent electrical circuit where L and C are the inductance and capacitance per phase of the system up to the point of circuit breaker location, respectively. The resistance of the circuit has been neglected. During the time of fault a heavy fault current flows in the circuit. When the circuit breaker is closed, the fault current flows through L and the contacts of the circuit

14.5 RESTRIKING VOLTAGE AND RECOVERY VOLTAGE

The voltage across the contacts of the circuit breaker is arc voltage when the arc persists. This voltage becomes the system voltage when the arc is extinguished. The arc is extinguished at the instant of current zero. After the arc has been extinguished, the voltage across the breaker terminals does not normalise instantaneously but it oscillates and there is a transient condition. The transient voltage which appears across the breaker contacts at the instant of arc being extinguished is known as *restriking voltage*. The power frequency rms voltage, which appears across the breaker contacts after the arc is finally extinguished and transient oscillations die out is called *recovery voltage*. Figure 14.7 shows the restriking and recovery voltage.

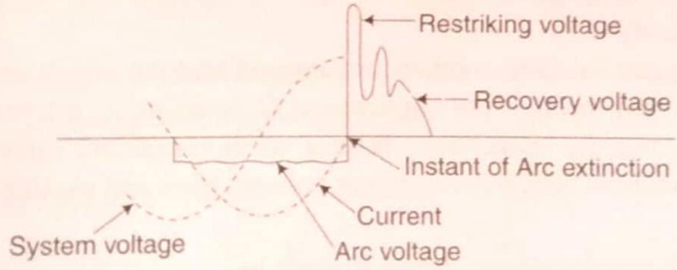


Fig. 14.7 *Restriking and recovery voltage*

14.5.1 Expression for Restriking Voltage and RRRV

breaker, the capacitance C being short-circuited by the fault. Hence, the circuit o
Fig. 14.8(b) becomes completely reactive and the fault current is limited entirely b
inductance of the system.

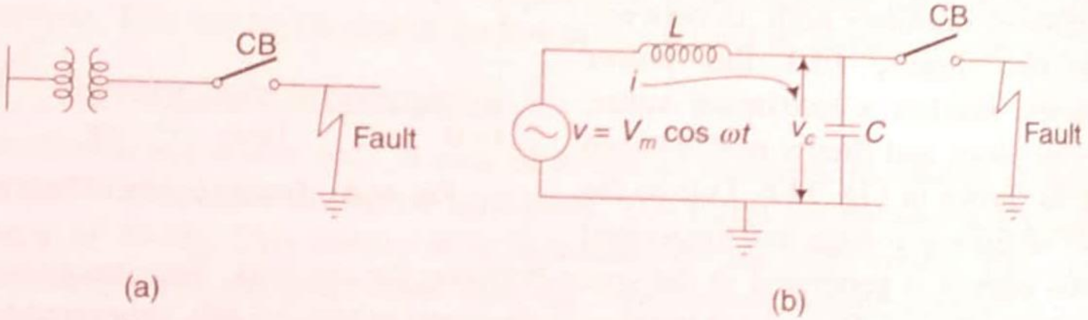


Fig. 14.8 *(a) Fault on a feeder near circuit breaker (b) Equivalent electrical circuit for analysis of restriking voltage*

The fault is cleared by the opening of the circuit breaker contacts. The parting o
the circuit breaker contacts does not in itself interrupt the current because an arc i

The mathematical expression for the transient condition is as follows:

$$L\frac{di}{dt}+\frac{1}{c}\int i\,dt = V_m \cos \omega t \tag{14.3}$$

Immediately after the instant of arc extinction, the voltage across the capacitance (v_c) which is the restriking voltage, oscillates at the natural frequency given by Eq. (14.1). Since the natural frequency oscillation is a fast phenomenon, it persists for only a small period of time. During this short period which is of interest, the change in the power frequency term is very little and, hence negligible, because $\cos \omega t \approx 1$. Hence the sinusoidally varying voltage $V_m \cos \omega t$ in Eq. (14.3) can be assumed to remain constant at V_m during this short interval of time i.e., the transient period.

Substituting $V_m \cos \omega t \approx V_m$, the Eq. (14.3) can be written as

$$L\frac{di}{dt}+\frac{1}{c}\int i\,dt = V_m \tag{14.4}$$

$$i = \frac{dq}{dt} = \frac{d(cv_c)}{dt} \tag{14.5}$$

where, v_c = voltage across the capacitor = Restriking voltage

Therefore,

$$\frac{di}{dt} = \frac{d^2(cv_c)}{dt^2} = c\frac{d^2v_c}{dt^2} \tag{14.6}$$

$$\frac{1}{c}\int i\,dt = \frac{q}{c} = v_c \tag{14.7}$$

Substituting these values in Eq. (14.4), we get

$$LC\frac{d^2v_c}{dt^2} + v_c = V_m \tag{14.8}$$

Taking Laplace Transform of both sides of Eq. (14.8), we get

$$LCS^2v_c(s) + v_c(s) = \frac{V_m}{s}$$

where, $v_c(s)$ is the Laplace Transform of v_c.

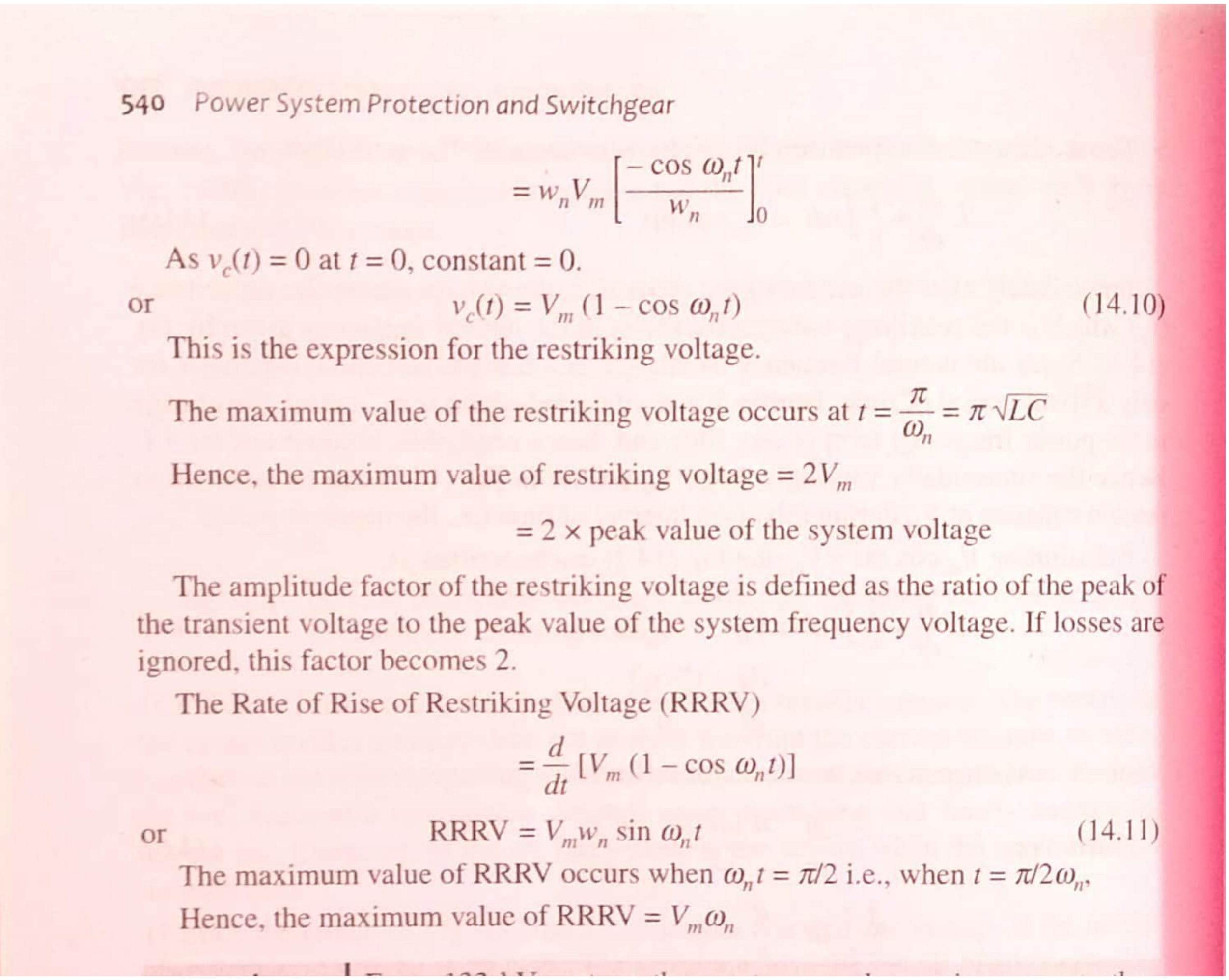
Other terms are zero as initially $q = 0$ at $t = 0$

or

$$v_c(s)\,[LCS^2 + 1] = \frac{V_m}{s}$$

or

$$v_c(s) = \frac{V_m}{s(LCS^2+1)} = \frac{V_m}{LCS\left(s^2+\frac{1}{LC}\right)}$$



$$= w_n V_m \left[\frac{-\cos \omega_n t}{w_n}\right]_0^t$$

As $v_c(t) = 0$ at $t = 0$, constant = 0.

or
$$v_c(t) = V_m (1 - \cos \omega_n t) \qquad (14.10)$$

This is the expression for the restriking voltage.

The maximum value of the restriking voltage occurs at $t = \dfrac{\pi}{\omega_n} = \pi\sqrt{LC}$

Hence, the maximum value of restriking voltage $= 2V_m$

$= 2 \times$ peak value of the system voltage

The amplitude factor of the restriking voltage is defined as the ratio of the peak of the transient voltage to the peak value of the system frequency voltage. If losses are ignored, this factor becomes 2.

The Rate of Rise of Restriking Voltage (RRRV)

$$= \frac{d}{dt}[V_m (1 - \cos \omega_n t)]$$

or
$$\text{RRRV} = V_m w_n \sin \omega_n t \qquad (14.11)$$

The maximum value of RRRV occurs when $\omega_n t = \pi/2$ i.e., when $t = \pi/2\omega_n$,

Hence, the maximum value of RRRV $= V_m \omega_n$

Q.3

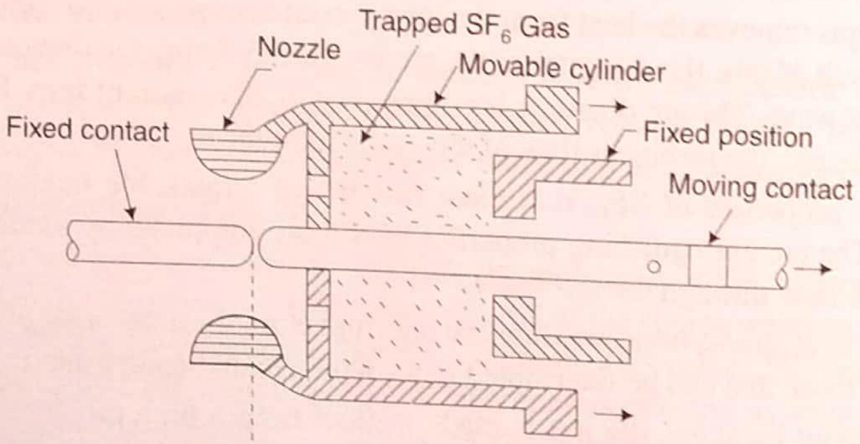
(ii) Puffer-type (Single-pressure Type) SF$_6$ Circuit Breaker In this type of circuit breaker the SF$_6$ gas is compressed by the moving cylinder system and is released through a nozzle during arc extinction. This is the most popular design of SF$_6$ circuit breaker over wide range of voltages from 3.3 kV to 765 kV.

Double pressure type SF$_6$ circuit breaker

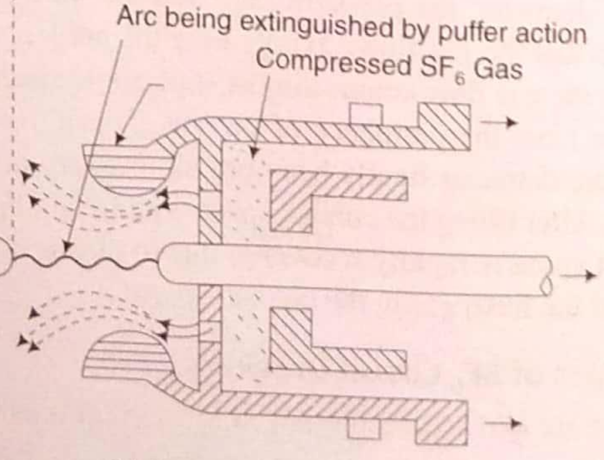
This is the early design of SF$_6$ circuit breakers which employed a double pressure system. In this system, SF$_6$ gas at high pressure of 14 to 18 atmospheric pressure stored in a separate tank is released into the arcing zone to cool the arc and build up the dielectric strength of the contact gap after arc extinction. Its operating principle is similar to that of air-blast circuit breakers. Because of their complicated design and construction due to the requirement of various auxiliaries such as gas compressors, high pressure storage tank, filters and gas monitoring and controlling devices, this type of circuit breakers have become obsolete.

Puffer-type SF$_6$ circuit breaker

This type of circuit breakers are also sometimes called single-pressure or impulse type SF$_6$ circuit breakers. In this type of breakers, gas is compressed by a moving cylinder system and is released through a nozzle to quench the arc. This type is available in the voltage range 3.3 kV to 765 kV.



(a) Closed position



(b) Open position

Fig. 14.24 Puffer-type

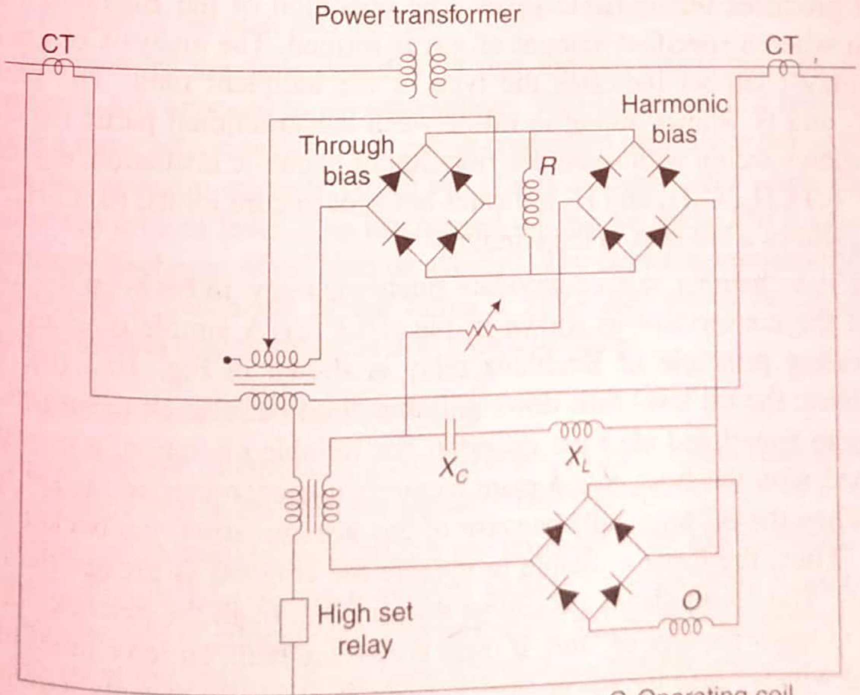
Q.4

overheating, and ultimately trips the transformer circuit breakers.

10.2.4 Protection against Magnetising Inrush Current

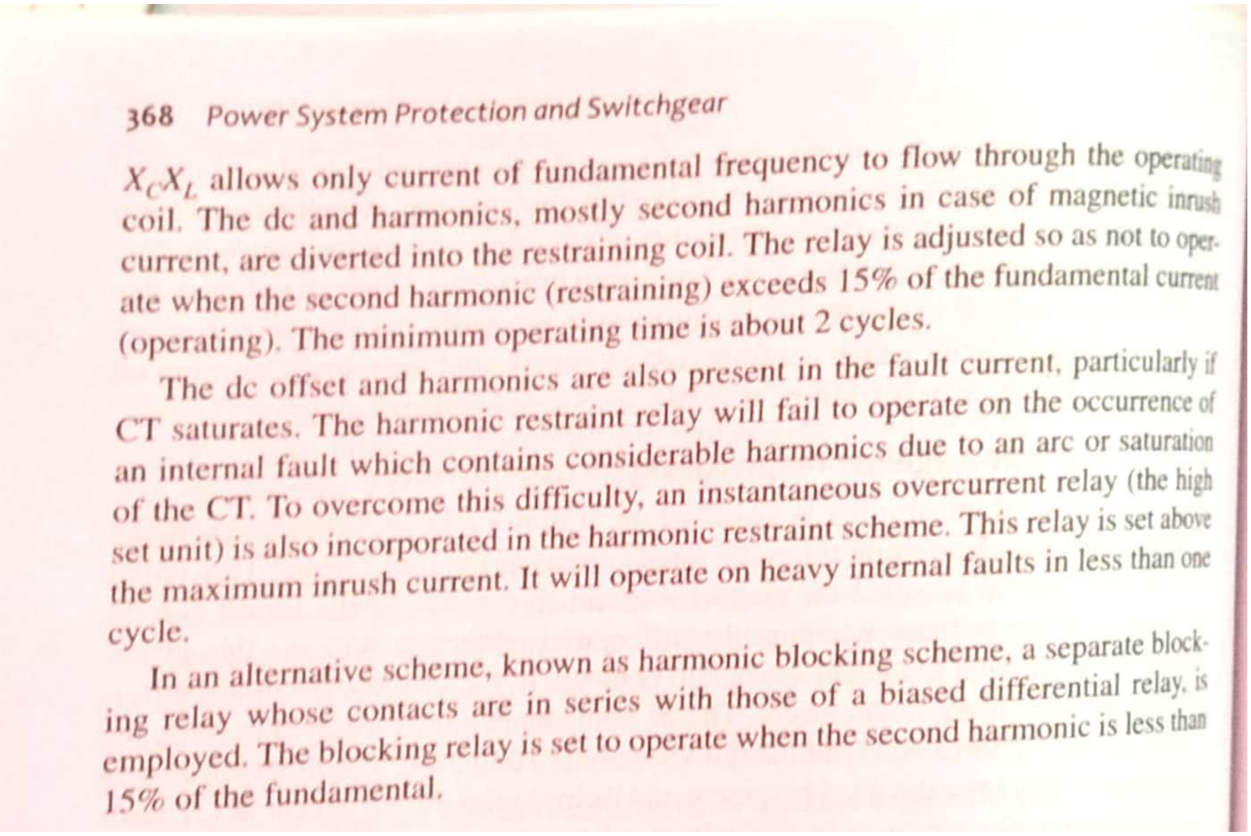
When an unloaded transformer is switched on, it draws a large initial magnetising current which may be several times the rated current of the transformer. This initial magnetising current is called the magnetising inrush current. As the inrush current flows only in the primary winding, the differential protection will see this inrush current as an internal fault. The harmonic contents in the inrush current are different than those in usual fault current. The dc component varies from 40 to 60%, the second harmonic 30 to 70% and the third harmonic 10 to 30%. The other harmonics are progressively less. the third harmonic and its multiples do not appear in CT leads as these harmonics circulate in the delta winding of the transformer and the delta connected CTs on the *Y* side of the transformer. As the second harmonic is more in the inrush current than in the fault current, this feature can be utilised to distinguish between a fault and magnetising inrush current.

Figure 10.2 shows a high speed biased differential scheme incorporating a harmonic restraint feature. The relay of this scheme is made insensitive to magnetic inrush current. The operating principle is to filter out the harmonics from the differential current, rectify them and add them to the percentage restraint. The tuned circuit



O-Operating coil
R-Restraining coil

Fig. 10.2 *Harmonic restraint relay*



$X_C X_L$ allows only current of fundamental frequency to flow through the operating coil. The dc and harmonics, mostly second harmonics in case of magnetic inrush current, are diverted into the restraining coil. The relay is adjusted so as not to operate when the second harmonic (restraining) exceeds 15% of the fundamental current (operating). The minimum operating time is about 2 cycles.

The dc offset and harmonics are also present in the fault current, particularly if CT saturates. The harmonic restraint relay will fail to operate on the occurrence of an internal fault which contains considerable harmonics due to an arc or saturation of the CT. To overcome this difficulty, an instantaneous overcurrent relay (the high set unit) is also incorporated in the harmonic restraint scheme. This relay is set above the maximum inrush current. It will operate on heavy internal faults in less than one cycle.

In an alternative scheme, known as harmonic blocking scheme, a separate blocking relay whose contacts are in series with those of a biased differential relay, is employed. The blocking relay is set to operate when the second harmonic is less than 15% of the fundamental.

Q.5

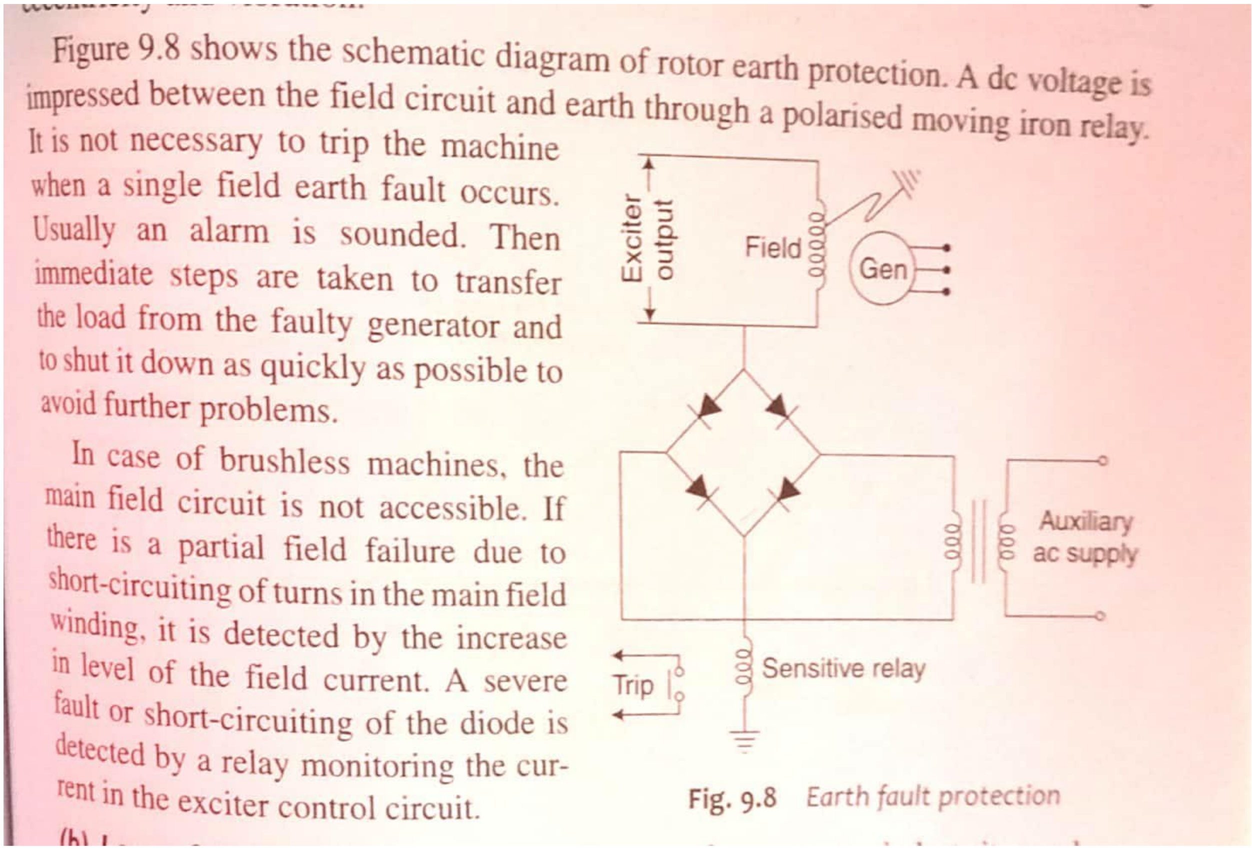


Figure 9.8 shows the schematic diagram of rotor earth protection. A dc voltage is impressed between the field circuit and earth through a polarised moving iron relay. It is not necessary to trip the machine when a single field earth fault occurs. Usually an alarm is sounded. Then immediate steps are taken to transfer the load from the faulty generator and to shut it down as quickly as possible to avoid further problems.

In case of brushless machines, the main field circuit is not accessible. If there is a partial field failure due to short-circuiting of turns in the main field winding, it is detected by the increase in level of the field current. A severe fault or short-circuiting of the diode is detected by a relay monitoring the current in the exciter control circuit.

Fig. 9.8 *Earth fault protection*

Q.6

10.2.2 Percentage Differential Protection

Percentage differential protection is used for the protection of large power transformers having ratings of 5 MVA and above. This scheme is employed for the protection of transformers against internal short circuits. It is not capable of detecting incipient faults. Figure 10.1 shows the schematic diagram of percentage differential protection for a $Y - \Delta$ transformer. The direction of current and the polarity of the CT voltage shown in the figure are for a particular instant. The convention for marking the polarity for upper and lower CTs is the same. The current entering end has been marked as positive. The end at which current is leaving has been marked negative.

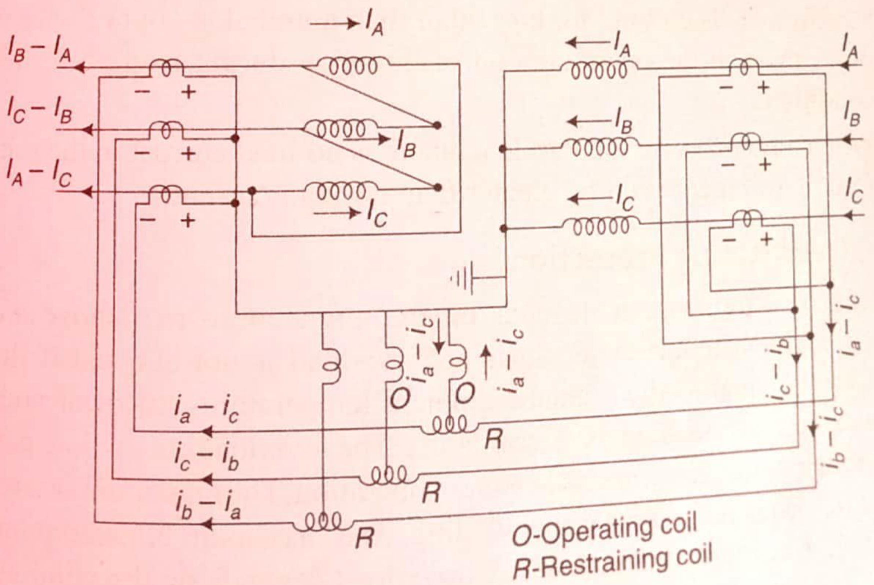


Fig. 10.1 *Percentage differential protection for $Y - \Delta$ connected transformer*

O and R are the operating and restraining coils of the relay, respectively. The connections are made in such a way that under normal conditions or in case of external faults the current flowing in the operating coil of the relay due to CTs of the primary side is in opposition to the current flowing due to the CTs of the secondary side. Consequently, the relay does not operate under such conditions. If a fault occurs on the winding, the polarity of the induced voltage of the CT of the secondary side is reversed. Now the currents in the operating coil from CTs of both primary and secondary side are in the same direction and cause the operation of