SNS COLLEGE OF ENGINEERING

Kurumbapalayam (Po), Coimbatore – 641 107

AN AUTONOMOUS INSTITUTION

Approved by AICTE, New Delhi and Affiliated to Anna University, Chennai

INTERNAL ASSESSMENT EXAMINATION – III ANSWER KEY

VI Semester

B.E – Electrical and Electronics Engineering
19EE605 – Protection and Switchgear

Regulations 2019

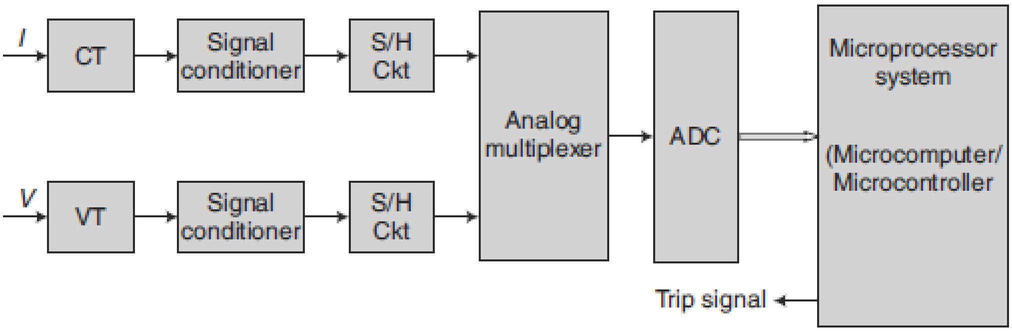
PART - A

<table>
<tr><th>Q.No</th><th>Question</th></tr>
<tr><td>1.</td><td>Interpret the advantages of over current relays over electromagnetic types.
Overcurrent relays offer faster response, higher accuracy, and less susceptibility to mechanical wear compared to electromagnetic relays, enhancing system reliability and reducing maintenance requirements in protection applications.</td></tr>
<tr><td>2.</td><td>Identify the different methods of Numerical distant protection of transmission lines.
Impedance-Based Protection
Reactance Relaying
Mho (Distance) Relaying
Permissive Overreaching Transfer Trip (POTT)
Travelling Wave Protection
Wavelet Transform-Based Protection</td></tr>
<tr><td>3.</td><td>Compare re-striking voltage and recovery voltage.
<table>
<tr><th>Aspect</th><th>Re-Striking Voltage</th><th>Recovery Voltage</th></tr>
<tr><td>Definition</td><td>Voltage that appears across the contacts after arc extinction, causing the arc to re-strike.</td><td>Voltage that appears across the contacts immediately after current zero, during the recovery period.</td></tr>
<tr><td>Occurrence</td><td>Happens after the initial arc is extinguished, often due to the dielectric strength of the medium being insufficient.</td><td>Occurs after the current zero-crossing point when the contacts are re-closing, resulting in the formation of a transient voltage.</td></tr>
<tr><td>Significance</td><td>Can cause damage to equipment and re-ignition of the arc, leading to sustained fault conditions.</td><td>Important in determining the ability of the circuit breaker to withstand transient voltages and safely re-establish insulation.</td></tr>
<tr><td>Mitigation</td><td>Mitigated by using arc extinguishing techniques, such as arc chutes or quenching chambers, to prevent re-striking.</td><td>Managed through appropriate design of circuit breaker components and selection of interrupting medium to withstand recovery voltage without breakdown.</td></tr>
</table></td></tr>
<tr><td>4.</td><td>Give the advantages of SF6 circuit breaker over Air blast circuit breaker.
<table>
<tr><th>Advantages of SF6 Circuit Breakers</th><th>Advantages of Air Blast Circuit Breakers</th></tr>
<tr><td>Superior Dielectric Strength: SF6</td><td>Adequate Dielectric Strength: Air blast circuit</td></tr>
</table></td></tr>
</table>

has excellent dielectric properties, allowing for compact design and higher voltage ratings.	breakers rely on air as the interrupting medium, which has lower dielectric strength compared to SF6.
High Interruption Capability: SF6 circuit breakers can interrupt high magnitude fault currents efficiently without generating large arc voltages.	Limited Interruption Capability: Air blast circuit breakers have lower interruption capacity compared to SF6 circuit breakers, especially for high-voltage applications.
Lower Maintenance Requirements: SF6 circuit breakers require less maintenance due to the absence of arc-extinguishing contacts, reducing downtime and operational costs.	Regular Maintenance Needed: Air blast circuit breakers require frequent maintenance of arc-extinguishing contacts and compressors, leading to higher maintenance costs and downtime.
Compact Size: SF6 circuit breakers are more compact and lighter compared to air blast circuit breakers, making them suitable for installations where space is limited.	Larger Footprint: Air blast circuit breakers are bulkier and require more space for installation due to the need for compressors and air storage tanks.

5.	**Define the term “rate of rise of recovery voltage”.** The "rate of rise of recovery voltage" (RRRV) indicates the rapidity with which voltage across circuit breaker contacts escalates following current interruption, a vital parameter for safeguarding insulation integrity and ensuring system reliability in electrical networks.

PART - B

6.a	**Discuss the neat block diagram of different methods of numerical distance protection of transmission line.**  Fig. 11.26 *Block diagram of a typical numerical distance relay* Distance protection is a widely used protective scheme for the protection of transmission and sub-transmission lines. It employs a number of distance relays which measure the impedance or some components of the line impedance at the relay location. Since the measured quantity is proportional to the distance (line-length) between the relay location and the fault point, the measuring relay is called a distance relay. A distance protection scheme which incorporates numerical distance relays for the protection of lines is known as a numerical distance protection scheme or numerical distance

protection. In a numerical distance relay, the analog voltage and current signals monitored through primary transducers (VTs and CTs) are conditioned, sampled at specified instants of time and converted to digital form for numerical manipulation, analysis display and recording. The voltage and current signals in the form of discrete numbers are processed by a numerical filtering algorithm to extract the fundamental frequency components of the voltage and current signals and make trip decisions. The extraction of the fundamental frequency components from the complex postfault voltage and current signals that contain transient dc offset component and harmonic frequency components, in addition to the power frequency fundamental components, is essential because the impedance of a linear system is defined in terms of the fundamental frequency voltage and current sinusoidal waves.

6.b Distinguish briefly about the various comparators in detail.

tor	Application	Advantages	Disadvantages
Electromechanical Relay	Overcurrent protection, directional protection	Reliable, robust, simple design	Slow operating speed, susceptible to mechanical wear
Solid-State Relay	Overcurrent protection, voltage protection	Faster operating speed, no moving parts	Limited current and voltage ratings, susceptible to electrical noise
Microprocessor-Based Relay	Multifunction protection (overcurrent, overvoltage, frequency, etc.)	Programmable, customizable settings, advanced communication capabilities	Complex programming, higher initial cost
Digital Comparator	Voltage and current comparison	High accuracy, fast response	Requires external analog-to-digital converters, sensitive to noise
Optical Comparator	Current comparison in high-voltage applications	Isolation from high voltages, immune to electromagnetic interference	Limited bandwidth, may require calibration
Differential Relay	Protection against internal faults in transformers and generators	Sensitive to small current imbalances, provides selective tripping	Complex setup, may require CT saturation compensation
Amplitude Comparator	Overcurrent protection, differential protection	Simple design, easy to implement	Limited to comparing magnitudes, may not detect phase differences
Phase Comparator	Differential protection, synchronism check	Detects phase differences, accurate for phase comparison	More complex design, requires precise phase measurements, sensitive to phase shifts

7.a **Derive the expression to find the critical value of resistance to be connected across the circuit breaker contacts.**

14.6 RESISTANCE SWITCHING

To reduce the restriking voltage, RRRV and severity of the transient oscillations, a resistance is connected across the contacts of the circuit breaker. This is known as resistance switching. The resistance is in parallel with the arc. A part of the arc current flows through this resistance resulting in a decrease in the arc current and increase in the deionisation of the arc path and resistance of the arc. This process continues and the current through the shunt resistance increases and arc current decreases. Due to the decrease in the arc current, restriking voltage and RRRV are reduced. The resistance may be automatically switched in with the help of a sphere gap as shown in Fig. 14.9. The resistance switching is of great help in switching out capacitive current or low inductive current.

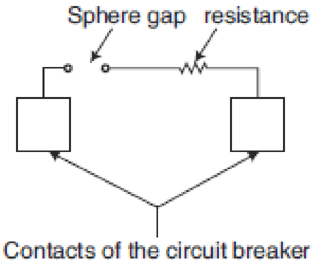


Fig. 14.9 *Resistance switching*

The analysis of resistance switching can be made to find out the critical value of the shunt resistance to obtain complete damping of transient oscillations. Figure 14.10 shows the equivalent electrical circuit for such an analysis.

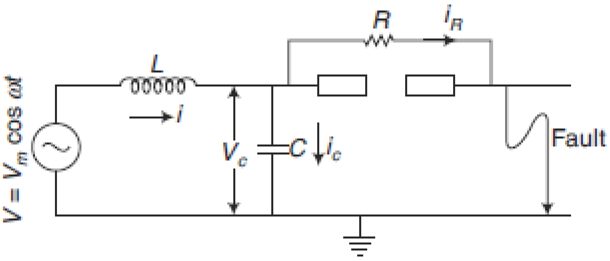


Fig. 14.10 *Circuit for analysis of resistance switching*

As the period of transient oscillations is very small, the change in the power frequency term during this short period is very little and hence negligible, because $\cos \omega t \approx 1$. Hence, the sinusoidally varying voltage $V_m \cos \omega t$ can be assumed to remain constant at V_m during the transient periods, i.e., $V_m \cos \omega t = V_m$.

Hence, the voltage equation is given by

$$L\frac{di}{dt}+\frac{1}{C}\int i_C\,dt = V_m \quad \text{and} \quad i = i_c + i_R$$

Therefore, the above equation becomes

$$L\frac{d(i_c+i_R)}{dt}+v_c = V_m$$

or

$$L\frac{di_c}{dt}+L\frac{di_R}{dt}+v_c = V_m \tag{14.12}$$

$$i_c = \frac{dq}{dt} = \frac{d(Cv_c)}{dt}$$

Therefore,

$$\frac{di_c}{dt} = \frac{d^2(Cv_c)}{dt^2} = C\frac{d^2v_c}{dt^2} \tag{14.13}$$

$$\frac{di_R}{dt} = \frac{d(v_c/R)}{dt} = \frac{1}{R}\frac{dv_c}{dt} \tag{14.14}$$

Substituting these values in Eq. (14.12), we get

$$LC\frac{d^2v_c}{dt^2}+\frac{L}{R}\frac{dv_c}{dt}+v_c = V_m \tag{14.15}$$

Taking Laplace Transform, of both sides of Eq. (14.15), we get

$$LCS^2v_c(S)+\frac{L}{R}S\,v_c(S)+v_c(S) = \frac{V_m}{s}$$

Other terms are zero, as $v_c = 0$ at $t = 0$

or

$$LCv_c(S)\left[S^2+\frac{1}{RC}S+\frac{1}{LC}\right] = \frac{V_m}{s}$$

or

$$v_c(S) = \frac{V_m}{SLC\left[S^2+\frac{1}{RC}S+\frac{1}{LC}\right]} \tag{14.16}$$

For no transient oscillation, all the roots of the equation should be real. One root is zero, i.e. $S = 0$ which is real. For the other two roots to be real, the roots of the quadratic equation in the denominator should be real. For this, the following condition should be satisfied.

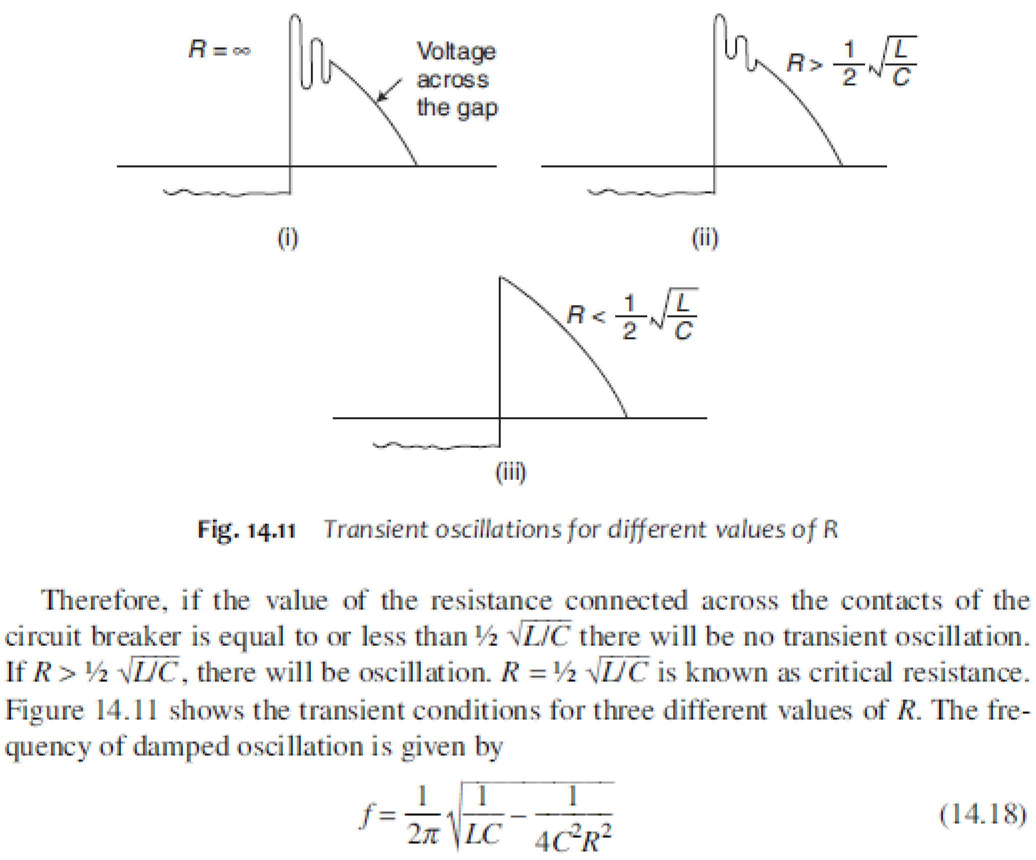
$$\left[\left(\frac{1}{2RC}\right)^2-\frac{1}{LC}\right]\geq 0 \quad \text{or} \quad \frac{1}{4R^2C^2}\geq\frac{1}{LC}$$

or

$$\frac{4}{LC}\leq\frac{1}{R^2C^2} \quad \text{or} \quad R^2\leq\frac{LC}{4C^2}$$

or

$$R^2\leq\frac{1}{4}.\frac{L}{C} \quad \text{or} \quad R\leq\frac{1}{2}\sqrt{\frac{L}{C}} \tag{14.17}$$

	 **Fig. 14.11** *Transient oscillations for different values of R* Therefore, if the value of the resistance connected across the contacts of the circuit breaker is equal to or less than $\frac{1}{2}\sqrt{L/C}$ there will be no transient oscillation. If $R > \frac{1}{2}\sqrt{L/C}$, there will be oscillation. $R = \frac{1}{2}\sqrt{L/C}$ is known as critical resistance. Figure 14.11 shows the transient conditions for three different values of R. The frequency of damped oscillation is given by $$f = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{1}{4C^2R^2}} \qquad (14.18)$$
7.b	**Describe the principle constructional features of all types of air blast circuit breaker. Give its advantages and disadvantages.** In air blast circuit breakers, compressed air at a pressure of 20-30 kg/cm2 is employed as an arc quenching medium. Air blast circuit breakers are suitable for operating voltage of 132 kV and above. They have also been used in 11 kV–33 kV range for certain applications. At present, SF6 circuit breakers are preferred for 132 kV and above. Vacuum circuit breakers are preferred for 11 kV–33 kV range. Therefore, the air blast circuit breakers are becoming obsolete. An air-blast circuit breaker may be either of the following two types. **(i) Cross-blast Circuit Breakers** In a cross-blast type circuit breaker, a high-pressure blast of air is directed perpendicularly to the arc for its interruption. Figure 14.21(a) shows a schematic diagram of a cross-blast type circuit breaker. The arc is forced into a suitable chute. Sufficient lengthening of the arc is obtained, resulting in the introduction of appreciable resistance in the arc itself. Therefore, resistance switching is not common in this type of circuit breakers. Cross-blast circuit breakers are suitable for interrupting high current (up to 100 kA) at comparatively lower voltages. **(ii) Axial-blast Circuit Breakers** In an axial-blast type circuit breaker, a high-pressure blast of air is directed longitudinally, i.e. in line with the arc. Figure 14.21(b) and (c) show axial-blast type circuit breakers. Figure 14.2.1(b) shows a single blast type. Whereas Fig. 14.21(c) shows a double blast type or radial blast type. Axial blast circuit breakers are suitable for EHV and super high voltage application. This is because interrupting chambers can be fully enclosed in porcelain tubes. Resistance switching is employed to reduce the transient overvoltages. The number of breaks depends upon the system voltage, for example, 4 at 220 kV and 8 at 750 kV. Air-blast circuit breakers have also been commissioned for 1100 kV system.

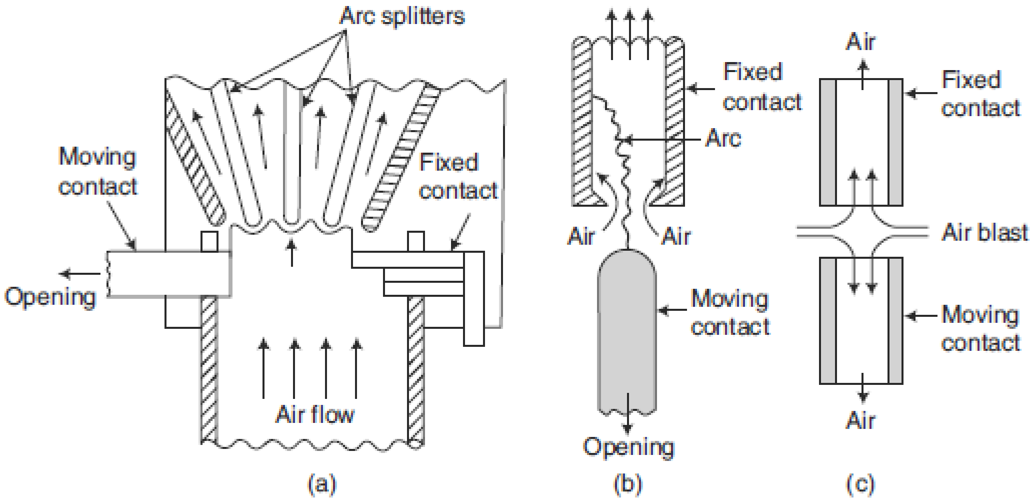


Fig. 14.21 *(a) Cross-blast circuit breaker (b) Single blast type axial-blast circuit breaker (c) Double blast type (or radial-blast type) axial-blast circuit breaker*

PART - C

8.a **Analyze a complex power system scenario and recommend appropriate settings for a static overcurrent relay to achieve optimal coordination with other protective devices.**

(i) Instantaneous Overcurrent Relay

The current derived from the main CT is fed to the input transformer which gives a proportional output voltage. The input transformer has an air gap in the iron core to give linearity in the current/voltage relationship up to the highest value of current expected, and is provided with tappings on its secondary winding to obtain different current settings. The output voltage of the transformer is rectified through a rectifier and then filtered at a single stage to avoid undesirable time delay in filtering so as to ensure high speed of operation. A limiter made of a zener diode is also incorporated in the circuit to limit the rectified voltage to safe values even when the input current is very high under fault conditions. A fixed portion of the rectified and filtered voltage (through a potential divider) is compared against a preset pick-up value by a level detector and if it exceeds the pick-up value, a signal through an amplifier is given to the output device which issues the trip signal. The output device may either be a static thyristor circuit or an electromagnetic slave relay.

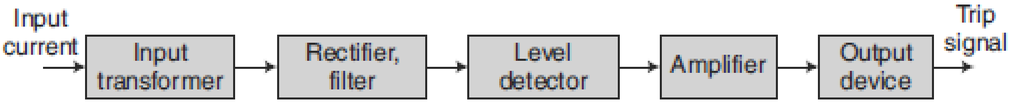


Fig. 5.22 *Block diagram of static instantaneous overcurrent relay*

(ii) Definite Time Overcurrent Relay

The input current signal derived from the main CT is converted to a proportional voltage signal by the input transformer and then rectified, filtered and compared with the preset threshold value of the level detector (1). If the voltage exceeds the preset threshold value, the level detector gives an output voltage, thereby the charging of the capacitor C of the RC timing circuit starts. As soon as the voltage across the capacitor exceeds the preset threshold value (VT) of level detector (2), a signal through the amplifier is given to the output device which issues the trip signal. Potentiometers P1 and P2 are used for current setting and time setting, respectively

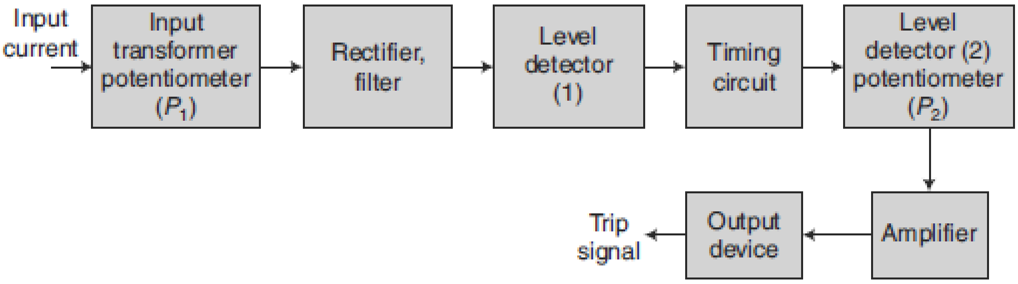


Fig. 5.23 *Block diagram of definite time overcurrent relay*

(iii) Inverse-time Overcurrent Relay

The operating time of the inverse-time overcurrent relay decreases with increasing fault current. For this relay with inverse-time characteristic, the charging of the capacitor of timing circuit takes place from a voltage proportional to current

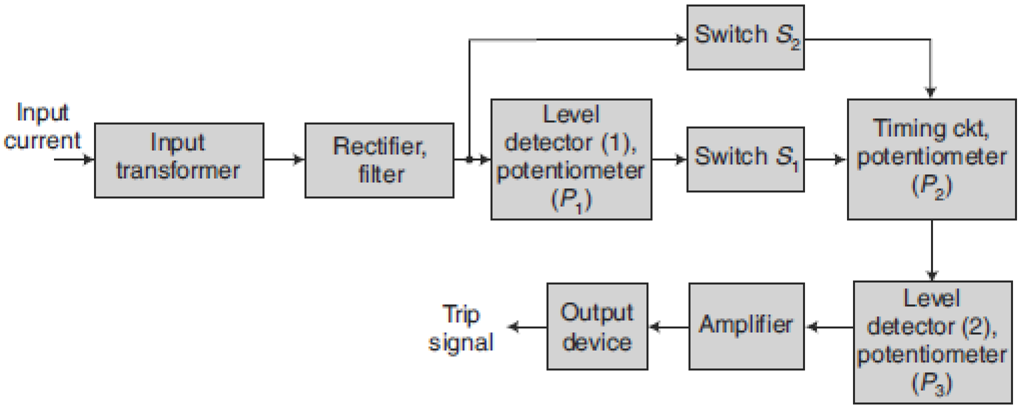


Fig. 5.24 *Block diagram of inverse-time overcurrent relay*

(iv) Directional Overcurrent Relay

The directional overcurrent relay incorporates a directional unit which responds to power flow in a specified direction. The directional relay senses the direction of power flow by means of a phase difference (f) between voltage (V) and current (I). When f exceeds a certain predetermined value and the current is above the pick-up value, the directional overcurrent relay operates. The directional relay is a double actuating quantity relay with one input as current I from CT and the other input as voltage V from VT.

In case of electromagnetic directional overcurrent relays, discrimination is affected when voltage drops down to very low values under fault conditions. In static directional relays, this problem is less serious because the static comparators used in these relays are inherently very sensitive and they can give reliable performance up to 1% of system voltage which is well within the minimum fault voltage.

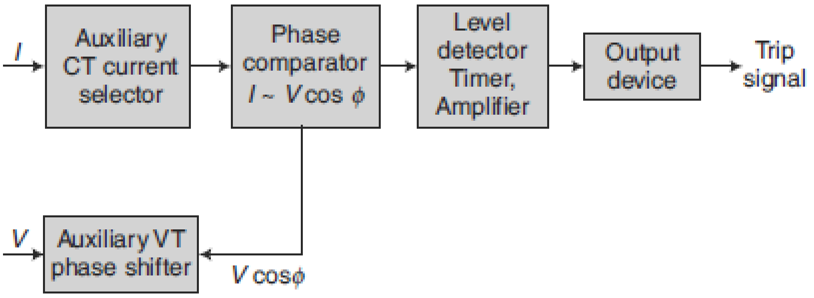


Fig. 5.25 *Simplified block diagram of static directional overcurrent relay*

8.b **For a 132 kV system, the reactance and capacitance up to the location of the circuit breaker is 3 ohms and 0.015 μF, respectively. Calculate the following:**

(a) The frequency of transient oscillation

(b) The maximum value of restriking voltage across the contacts of the circuit breaker

(c) The maximum value of RRRV

(a) The frequency of transient oscillation

$$L = \frac{3}{2\pi 50}, \quad f = 50, \text{ the system frequency}$$

$$= \frac{3}{100\,\pi} = 0.00954 \text{ H}$$

$$f_n = \frac{1}{2\pi\sqrt{LC}}$$

$$= \frac{1}{2\pi\sqrt{0.00954 \times 0.015 \times 10^{-6}}}$$

$$= \frac{10^5}{2\pi \times 1.1962} = \frac{10^5}{7.5241} = 13.291 \text{ kHz}$$

(b) The restriking voltage

$$v_c = V_m\,[1 - \cos \omega_n t]$$

The maximum value of the restriking voltage = $2V_m$

$$= 2 \times \frac{132}{\sqrt{3}}\sqrt{2} = 215.56 \text{ kV}$$

(c) The maximum value of RRRV = $\omega_n V_m$

$$= 2\pi f_n \times \frac{132}{\sqrt{3}} \times \sqrt{2} \times 1000$$

$$= 2\pi \times 13.291 \times 1000 \times \frac{132}{\sqrt{3}} \times \sqrt{2} \times 1000 \text{ V/s}$$

$$= 9010.45 \times 10^6 \text{ V/s} = 9.01045 \text{ kV}/\mu\text{s}$$