CHAPTER VI

EFFECT OF POLARISATION ON COMPARATOR MODELS

6.1 INTRODUCTION :

Over and above the relaying signals necessary for the purpose of measurement of the distance of the fault point from the relay location, the distance relays are required to be supplied with the polarising signals to provide the directional feature to the characteristic so as to respond correctly to the direction of fault current flow. The polarising signal may be derived from the voltage of the faulted phase or phases, but for low fault infeed conditions, and particularly for faults close to the relay location, the faulty phase voltage may be reduced in amplitude below that is necessary for correct relay operation. To avoid an incorrect measurement or a failure to measure on this account, the practice is either to supplement the signal derived from the faulted phase or phases by additional ones derived from healthy phases, or , to use resonant circuits. The present day distance comparators inherently use sensitive comparator elements, thereby increasing the sensitivity of the measurement. Hence the magnitude of the polarising signal needed will be very small compared to the nominal voltage reference (about 2 to 5 percent). The extent to which these additional signals affect protection operation is dependent on the magnitude and phase of the additional signals relative to the signals derived from the faulty phase voltage. The actual characteristic is influenced by the choice of the supplementary signals and by the actual fault conditions encountered since these determine the significance of the chosen supplimentary signal in relation to the signals derived from the voltage of faulted phases.

The purpose of the present chapter is, therefore, to consider the effect of different levels of polarisation with varying generation conditions on the comparator models described in the previous chapters. In the present chapter, therefore, the effect of polarisation is shown on the composite distance relay characteristic, quadrilateral characteristic and the directional characteristic obtained employing the Multi-input phase comparator, sequence comparator and 2-input sine comparator (to be employed in conjunction with hybrid comparator discussed in subsequent chapter) .

6.2.1 Multi-Input Phase Comparator :

The signals necessary to derive the composite relay characteristic of fig.3.10 employing unsymmetrical sine comparison limits are

$$\left.\begin{aligned} S_1 &= [-K_1V_L + I_LZ_R \angle\theta - \phi] \angle 90^\circ \\ S_2 &= I_LZ_R \angle\theta-\phi \\ S_3 &= K_3V_L \end{aligned}\right\} \quad \ldots. (6.1)$$

Signals S_1 and S_2 are the operating and restraining signals respectively providing the necessary resistance and reactance reaches of the characteristic, while S_1 and S_3 are the similar signals providing the segments of the restricted mho characteristic embodying the directional feature.

The relay characteristic is likely to loose the directional feature when the signal S_3 is reduced below the threshold level of relaying. The signal S_3, is, therefore, augmented by a signal S_p derived from the healthy phase or phases.

$$S_3' = K_3 V_L + S_p \qquad \ldots. \ (6.2)$$

The signal S_p can be expressed as

$$S_p = K_p \angle\alpha_p \, V_L + I_L Z_p \angle\theta_p \qquad \ldots. \ (6.3)$$

Equation (6.2) can further be written as

$$S_3' = K_3 V_L + K_p \angle\alpha_p \, V_L + I_L Z_p \angle\theta_p$$

$$= K_3' \, V_L + I_L Z_p \angle\theta_p \qquad \ldots. \ (6.4)$$

where $K_3' = K_3 + K_p \angle \alpha_p$

In general the forward reach is determined by Z_R / K_1 while the apparent reach in the fourth quadrant of the impedance plane corresponds to Z_p / K_3'. For a given forward reach the complete characteristic can be derived from the knowledge of Z_p and K_3'. These depend upon type and level of polarisation, the fault condition as well as the system parameters. These parameters for earth faults and for line to line fault conditions for different types of polarisation are given in Tables 1 and 2 respectively (for a single end feed condition).

In these two tables the coefficient K_R is chosen such that on phase shifting the supplementary polarising signal derived is in phase with the faulty phase component.

Table 3 gives the parameters Z_p and K_3' for a condition of fault infeeds from both ends of the circuit.

6.2.2 Relay Polar Characteristics :

Typical polar characteristics with polarisation from the healthy phase(s) are presented in fig.6.1, 6.2 and 6.3 for different source to line impedance ratios and levels of polarisation. Fig.6.1 is for the case of a 25 mile, 132 kV line fed from one end and for a line to line fault between phases Y and B. The polarising voltage is derived from the line voltage V_{YR} . Fig.6.2 corresponds to the case of a line to ground fault on phase R with polarisation derived from line voltage V_{YB} . Fig.6.3 shows the effective polar characteristics for a double infeed case for the same line. The fault considered was a line to line fault between phases Y and B. The fault level at the relay end considered was 5000 MVA and the remote end fault level was 1000 MVA, pre-fault power being exported at relay end.

TABLE 1

PARAMETERS OF R-E EARTH FAULT RELAY CHARACTERISTICS

Polarising Signal: Faulty Phase Component	Polarising Signal: Supplementary Component S_p	K'_3	Z_p
$K_3 V_R$	$K_R V_B$	$K_3 + \lvert K_R \rvert$	$\dfrac{\lvert K_R \rvert \; Z_Z \left\{ 2 + \dfrac{Z_{S_o}}{Z_S} + a^2 \left(1 - \dfrac{Z_{S_o}}{Z_S} \right) \right\}}{\left(2 + Z_{L_o} / Z_L \right)}$
$K_3 V_R$	$K_R V_{BY}$	$K_3 + \sqrt{3} \lvert K_R \rvert$	$\sqrt{3} \lvert K_R \rvert \; Z_S (2 + Z_{S_o} / Z_S) \Big/ (2 + Z_{L_o} / Z_L)$
$K_3 V_R$	$K_R V_{RB}$	$K_3 + \sqrt{3} \lvert K_R \rvert$	$\dfrac{\sqrt{3} \lvert K_R \rvert \; (Z_S \angle -60^\circ + Z_{S_o} / Z_S)}{2 + Z_{L_o} / Z_L}$

TABLE 2

PARAMETERS OF Y-B PHASE FAULT RELAY CHARACTERISTICS

Polarising Signal			
Faulty phase component	Supplementary component S_p	K_3'	Z_p
$K_3 V_{YB}$	$K_{YB} V_R$	$K_3 + \frac{1}{\sqrt{3}} \mid K_{YB} \mid$	$\frac{1}{\sqrt{3}} \mid K_{YB} \mid Z_S$
$K_3 V_{YB}$	$K_{YB} V_{YR}$	$K_3 + \mid K_{YB} \mid$	$\frac{\sqrt{3}}{2} \mid K_{YB} \mid \angle -30^\circ\ Z_S$

TABLE 3

PARAMETERS OF Y-B PHASE FAULT RELAY CHARACTERISTICS (INFEED FROM BOTH ENDS)

Polarising Signal: Faulty phase component	Polarising Signal: Supplementary component S_p	K_3'	Z_p
$K_3 V_{YB}$	$K_{YB} V_R$	$K_3 + \frac{\lvert K_{YB}\rvert(\alpha Z_{S_1} + Z_{S_2} + Z_L)}{\sqrt{3}(Z_{S_1} + Z_{S_2} + Z_L)}$	$\frac{\lvert K_{YB}\rvert Z_{S_1}(\alpha Z_{S_1} + Z_{S_2} + Z_L)}{\sqrt{3}(Z_{S_1} + Z_{S_2} + Z_L)}$
$K_3 V_{YB}$	$K_{YB} V_{YR}$	$\frac{K_3 + \lvert K_{YR}\rvert \angle 150^\circ}{\sqrt{3}} \times \left\{ a^2 - \frac{(\beta - 1)(a^2 - a) Z_{S_1}}{2(Z_{S_1} + Z_{S_2} + Z_L)} - \frac{\alpha Z_{S_1} + Z_{S_2} + Z_L}{Z_{S_1} + Z_{S_2} + Z_L} \right\}$	$Z_{S_1} \left\{ \frac{a^2 - (a^2 - a)(\beta Z_{S_1} + Z_{S_2} + Z_L)}{2(Z_{S_1} + Z_{S_2} + Z_L)} - \frac{\alpha Z_{S_1} + Z_{S_2} + Z_L}{Z_{S_1} + Z_{S_2} + Z_L} \right\}$

$\alpha = V_{S_2} / V_{S_1}$, $\beta = (2a^2 + \alpha) / (a^2 - a)$

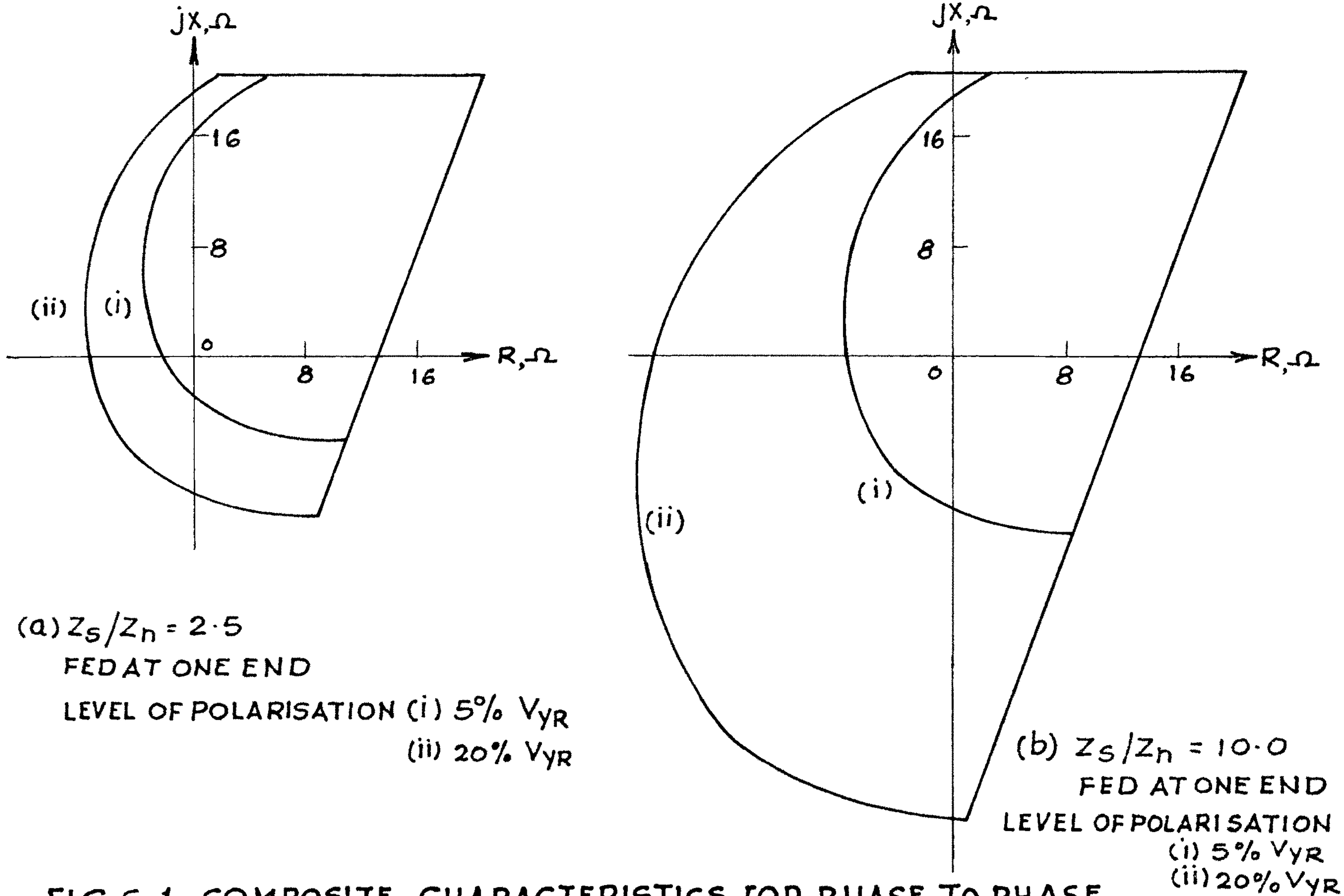
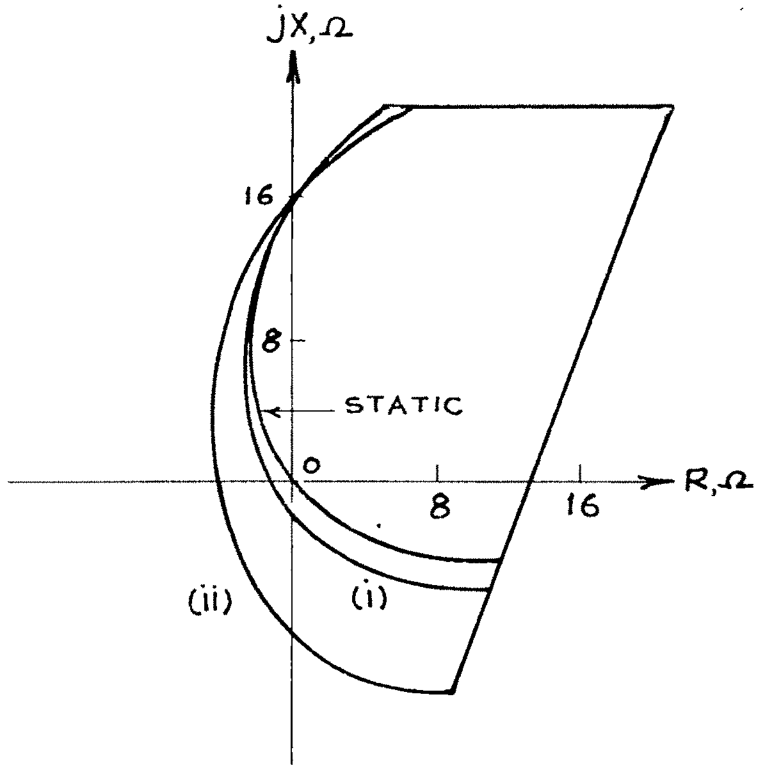


FIG. 6·1 COMPOSITE CHARACTERISTICS FOR PHASE TO PHASE FAULT RELAYS ON PHASES Y AND B.

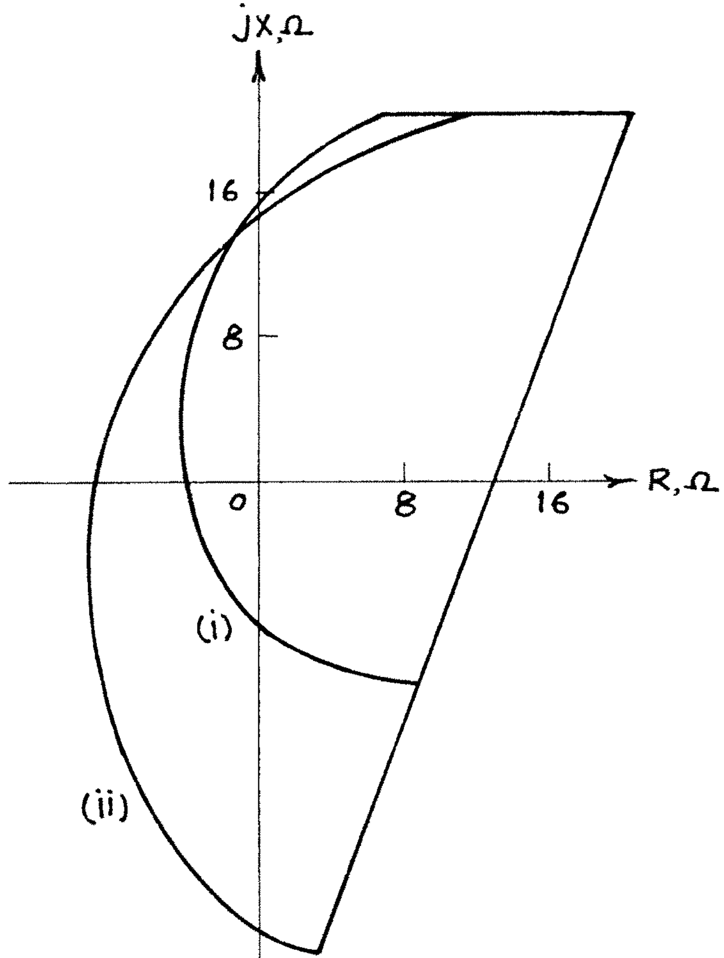


(a) $Z_s/Z_n = 2 \cdot 5$

FED FROM ONE END

LEVEL OF POLARISATION (i) 5% V_{BY}

(ii) 20% V_{BY}



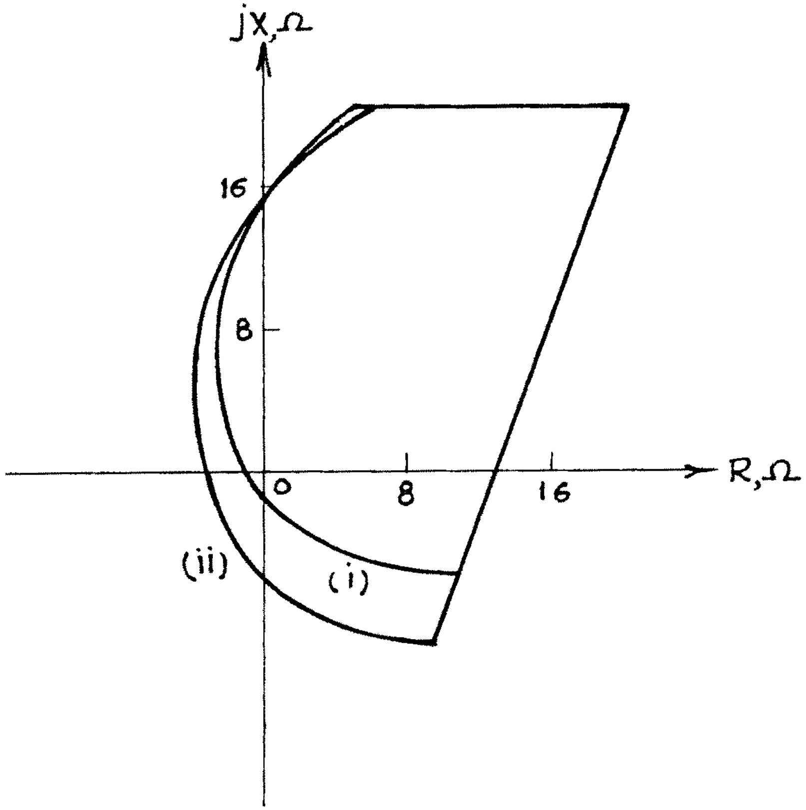
(b) $Z_s/Z_n = 10 \cdot 0$

FED FROM ONE END

LEVEL OF POLARISATION (i) 5% V_{BY}

(ii) 20% V_{BY}

FIG. 6·2 COMPOSITE CHARACTERISTICS OF PHASE TO EARTH FAULT RELAY ON PHASE R

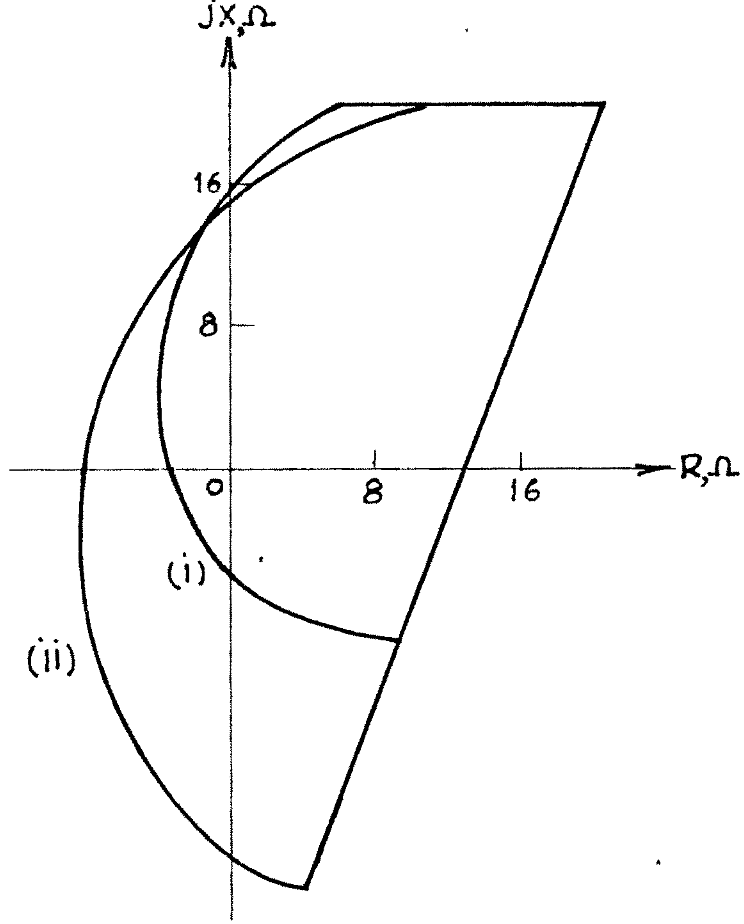


(a) $Z_S/Z_n = 2\cdot5$

FED AT BOTH ENDS

LEVEL OF POLARISATION (i) 5% V_R

(ii) 20% V_R



(b) $Z_S/Z_n = 10\cdot0$

FED AT BOTH ENDS

LEVEL OF POLARISATION (i) 5% V_R

(ii) 20% V_R

FIG. 6·3 COMPOSITE CHARACTERISTICS FOR PHASE TO PHASE FAULT RELAY ON PHASES Y AND B. PREFAULT POWER EXPORTED AT THE RELAY END $\frac{V_{S1}}{V_{S2}} = 1\cdot05\angle30^\circ$

It can be seen that the effect of polarisation on the Multi-input phase comparator model is to make the characteristic enclose the origin of the impedance plane. The effect is more pronounced for higher level of polarisation and higher source/line impedance ratio. It may be observed that the reach on the resistance axis remains unchanged. Further from fig.6.2 and 6.3 it may be observed that the high source/line impedance ratio alongwith high level of polarisation (20 percent) may make the relay under reach for solid faults at the far end of the protected line section. However, as pointed out earlier, the level of polarisation needed for sensitive solid state relays is quite low(less than 5 percent) the under reaching of relays under such conditions is quite improbable.

From the foregoing, it would appear that the directional feature of the relay has been lost, since the origin is enclosed by the relay characteristic. This interpretation follows from the fact that negative impedance in the forward sense and positive impedance with reverse power flow are normally identified. This assumption is, however, not valid. In the case of reverse power flow, the relay input equations change, owing to the new vector relationship between voltage and current. Typically, in case of Multi-input phase comparator the equations become

$$\left.\begin{aligned} S_1 &= [-K_1V_L - I_LZ_R\angle\theta-\phi]\ \angle 90^\circ \\ S_2 &= -I_LZ_R\angle\theta-\phi \\ S_3 &= K_3' V_L - I_LZ_p\angle\theta_p-\phi \end{aligned}\right\} \quad \ldots.(6.5)$$

The polar characteristic for a 132 KV, 25 mile feeder fed at both ends with fault level of 5000 MVA at the relay end and 1000 MVA at the remote end during reverse fault condition is shown in fig.6.4. The level of polarisation is 20 percent. It may be seen that the characteristic is totally different from that for forward power flow. In particular, the origin lies outside the relay characteristic, which is almost entirely in the third quadrant of the impedance plane, thereby rendering the relay completely directional.

6.3.1 Sequence Comparator :

The signals necessary to obtain a directional quadrilateral characteristic of fig.6.5 are :

$$\left.\begin{aligned} S_1 &= -K_1V_L + I_LZ_{R_1}\angle\theta_1-\phi \\ S_2 &= K_2V_L - I_LZ_{R_2}\angle\theta_2-\phi \\ S_3 &= -K_3V_L + I_LZ_{R_3}\angle\theta_3-\phi \\ S_4 &= K_4V_L \end{aligned}\right\} \quad \ldots.(6.6)$$

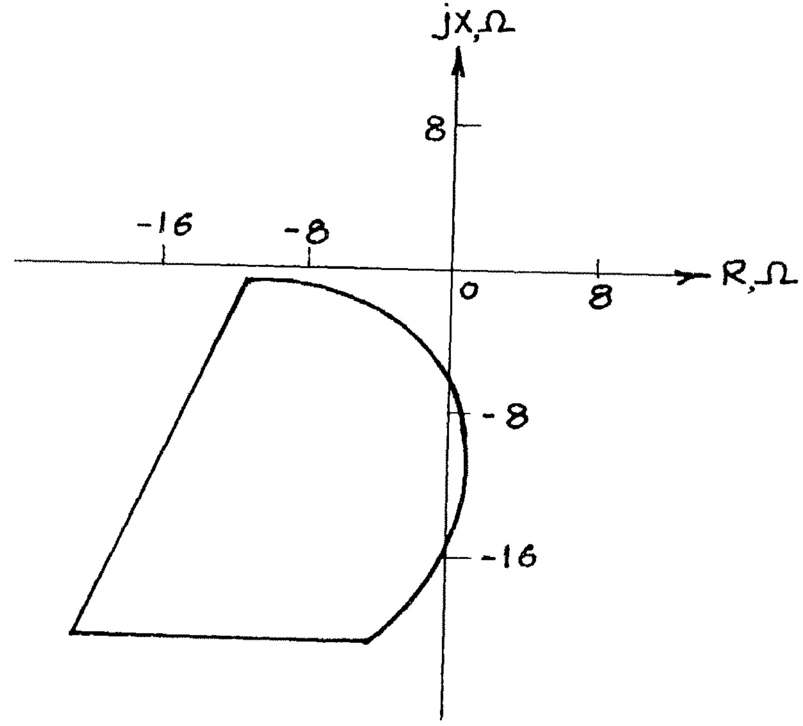


FIG. 6·4 COMPOSITE CHARACTERISTIC DURING REVERSE FAULTS. FAULT LEVEL AT RELAY END 5000 MVA; FAULT LEVEL AT REMOTE END 1000 MVA.

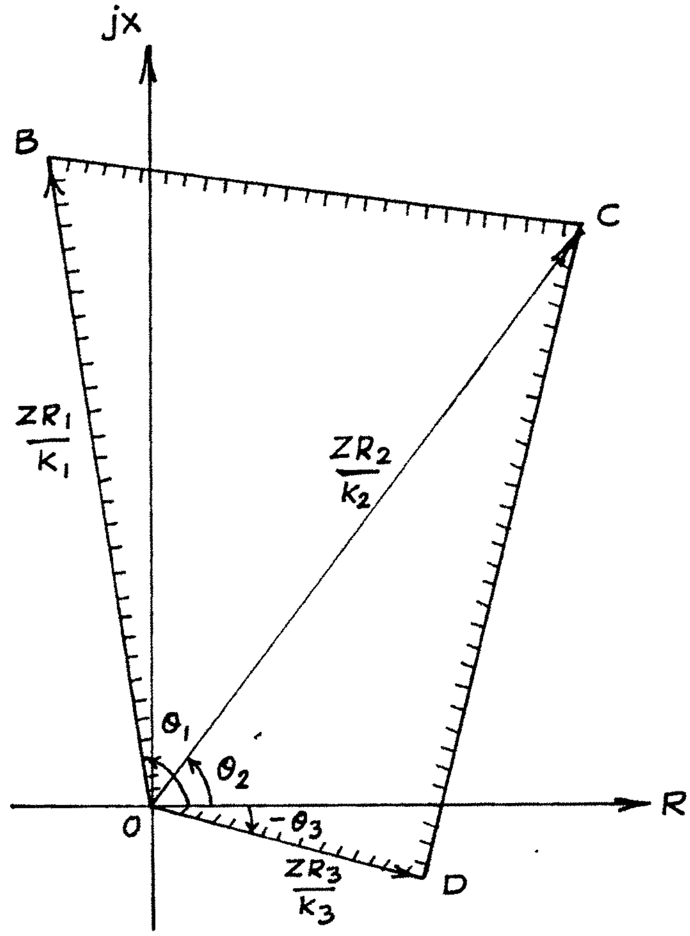


FIG. 6·5 DIRECTIONAL QUADRILATERAL CHARACTERISTIC

Signals S_3 and S_4 are responsible for yielding the segment OD of the characteristic . Similarly signals S_4 and S_1 provide the segment OB. Signals S_1, S_2 and S_3 determine the resistance and reactance reaches of the characteristic in the forward direction of power flow.

To obtain the adequate directional feature of the characteristic during dynamic conditions the signal S_4 is augmented by a polarising signal derived from the healthy phase or phases. The signal S_4 can be written as

$$S_4 = K_4' V_L + I_L Z_p \angle\theta_p - \phi$$

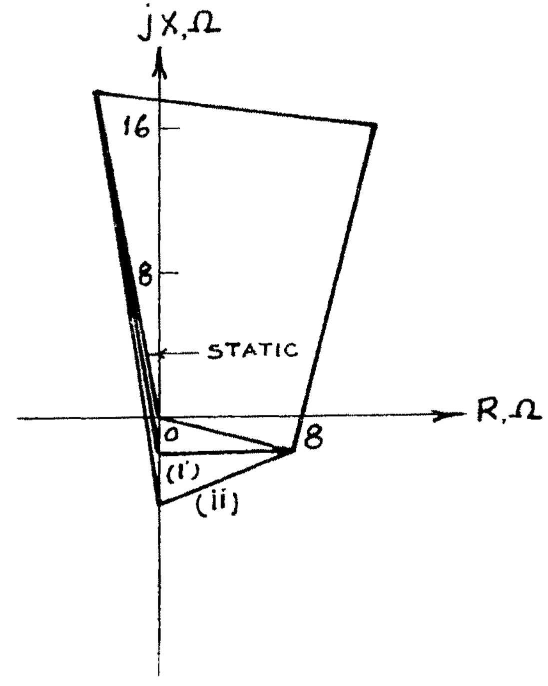
$$= K_4' V_L - I_L Z_p \angle\theta_p' - \phi \qquad \text{.... (6.7)}$$

where $\theta p' = \theta_p - 180^o$

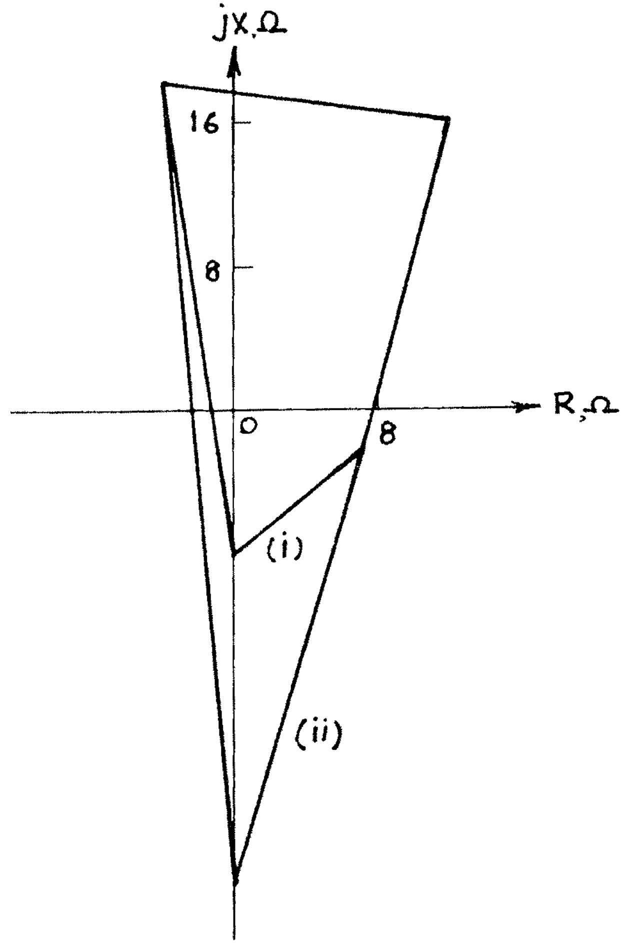
The presence of $I_L Z_p$ term in the Eq.(6.7) makes the relay enclose the origin of the impedance plane.

6.3.2 Polar Characteristics :

Fig.6.6 represents typical polar characteristics for a 25 miles, 132 kV line fed from one end for a R-E fault . The polarising voltage is derived from the healthy phase voltage V_{BY}. Both 5 percent and 20 percent levels of polarisation are considered with different source/line impedance ratios. Fig.6.7 represents the polar characteristics of phase to phase fault relays on phases Y-B with similar system conditions and polarisation levels. Fig.6.8 represents

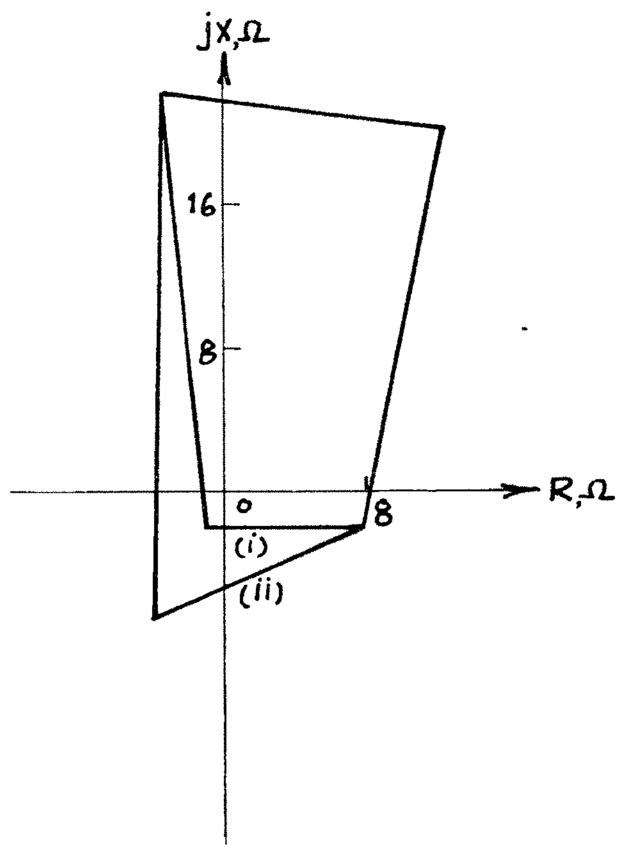


(a) $Z_S/Z_n = 2 \cdot 5$
FED FROM ONE END
LEVEL OF POLARISATION (i) 5% V_{BY}
(ii) 20% V_{BY}

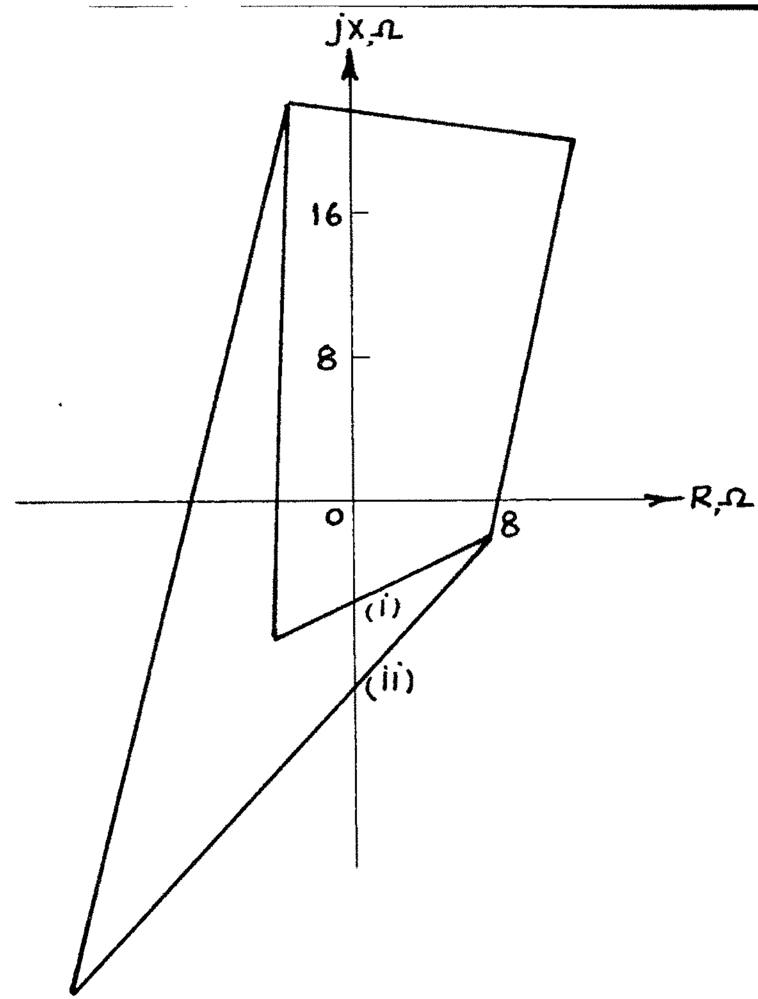


(b) $Z_S/Z_n = 10 \cdot 0$
FED FROM ONE END
LEVEL OF POLARISATION (i) 5% V_{BY}
(ii) 20% V_{BY}

FIG. 6·6 QUADRILATERAL CHARACTERISTIC OF PHASE TO EARTH FAULT RELAY ON PHASE R

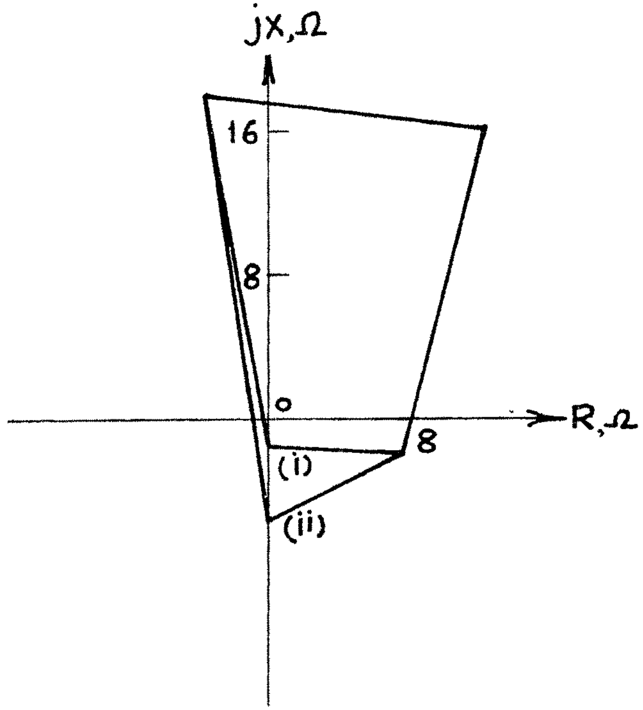


(a) $Z_S/Z_n = 2\cdot5$
FED FROM ONE END
LEVEL OF POLARISATION (i) 5% V_{YR}
(ii) 20% V_{YR}

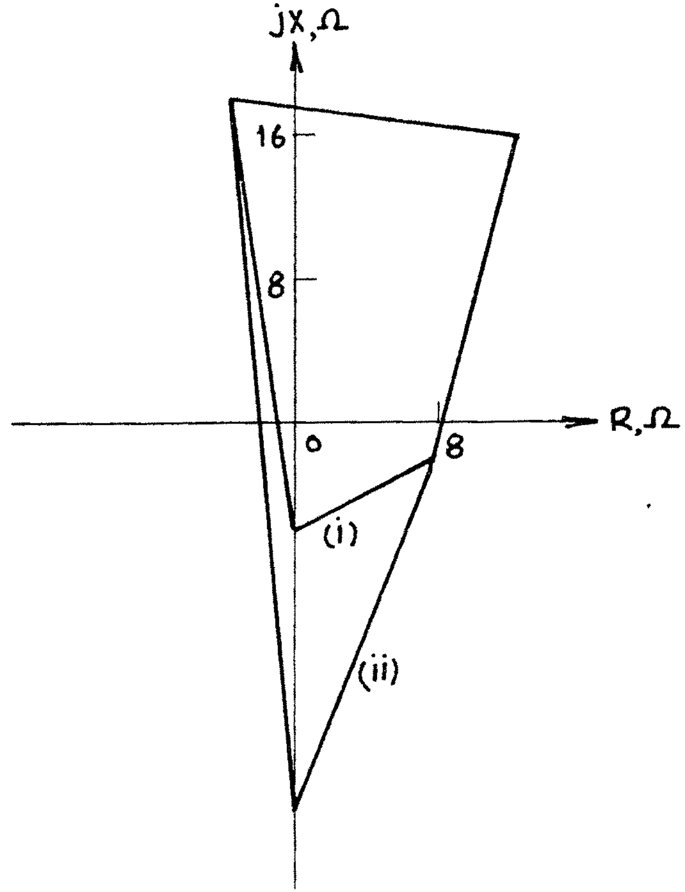


(b) $Z_S/Z_n = 10\cdot0$
FED FROM ONE END
LEVEL OF POLARISATION (i) 5% V_{YR}
(ii) 20% V_{YR}

FIG. 6·7 QUADRILATERAL CHARACTERISTICS OF PHASE TO PHASE FAULT RELAYS ON PHASES Y AND B.



(a) $Z_S/Z_n = 2 \cdot 5$
FED FROM BOTH ENDS
LEVEL OF POLARISATION (i) 5% V_R
(ii) 20% V_R



(b) $Z_S/Z_n = 10 \cdot 0$
FED FROM BOTH ENDS
LEVEL OF POLARISATION (i) 5% V_R
(ii) 20% V_R

FIG. 6·8 QUADRILATERAL CHARACTERISTICS FOR PHASE TO PHASE FAULT RELAYS ON PHASES Y AND B. PRE-FAULT POWER EXPORTED AT THE RELAY END $\frac{V_{S1}}{V_{S2}} = 1 \cdot 05 \angle 30^\circ$

the case of a 25 mile, 132 kV line fed from both the ends, prefault power being exported at the relay end. The fault level at relay end is considered to be 1000 MVA while that at the remote end is 5000 MVA.

It can be observed that in all the cases the origin is enclosed by the relay characteristics. Further, polarisation does not affect the settings on resistance and reactance axes. Finally, higher level of polarisation and higher source/line impedance ratio give marked elongation of the characteristics in the third and fourth quadrants of the impedance plane.

6.4.1 Hybrid Comparator :

The hybrid comparator (presented in Chapter 7)yields self-adjusting elliptical characteristic. This characteristic, however,is non-directional. A directional characteristic is, therefore, superimposed over the self-adjusting elliptical characteristic. The necessary inputs to a 2-input sine comparator to yield directional characteristic are

$$\left.\begin{aligned} S_1 &= K_1 V_L \angle 90^\circ \\ S_2 &= I_L Z_R \angle \theta - \phi \end{aligned}\right\} \quad \ldots. (6.8)$$

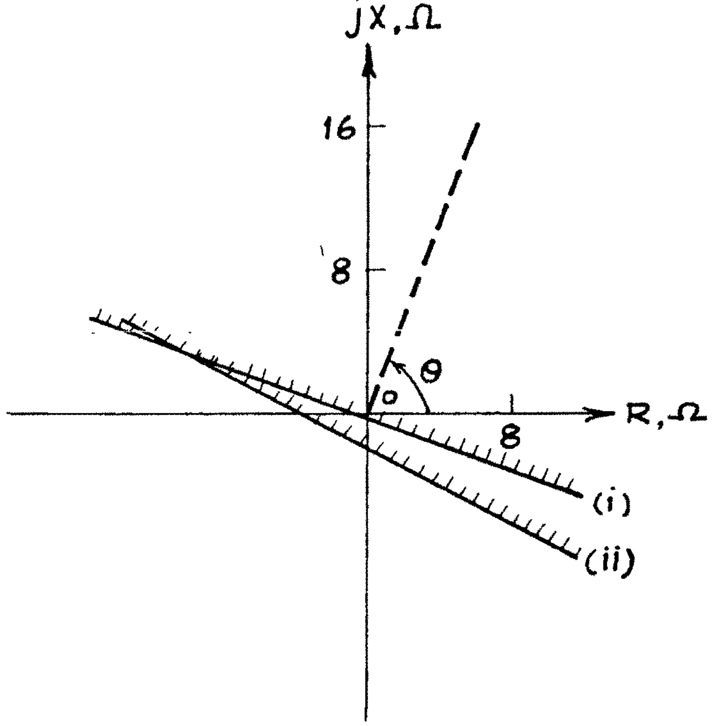
The operating signal S_1 is augmented by a polarising signal derived from healthy phase or phases to acquire directional feature during dynamic conditions. The signal S_1 can be written as :

$$S_1 = K_1' V_L \angle\alpha_1 + I_L Z_p \angle\theta_p - \phi \quad \ldots. (6.9)$$

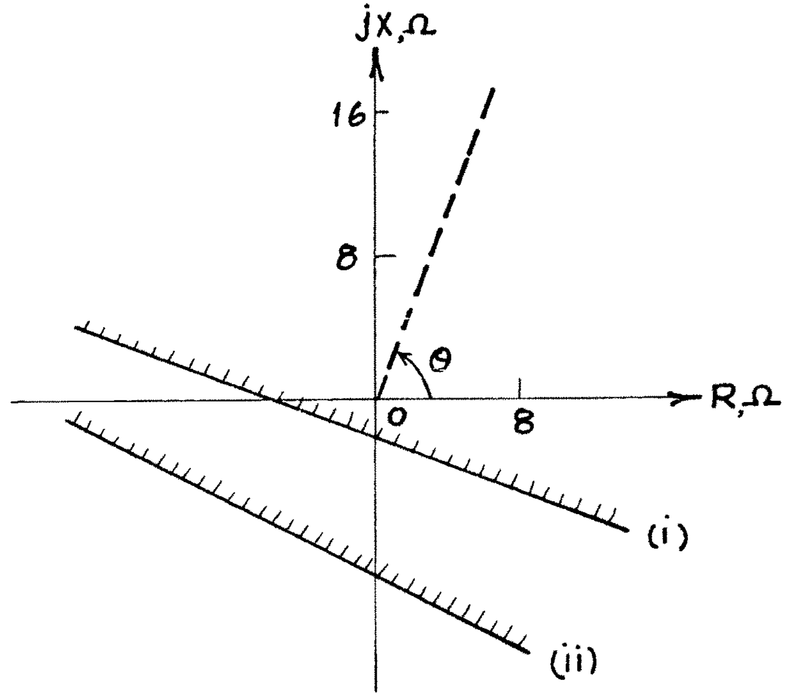
6.4.2 Polar Characteristics :

Fig.6.9 represents polar characteristics for a 25 mile, 132 kV line fed from one end for faults between phases Y and B. The polarising signal is derived from the healthy phase voltage V_R . Both 5 percent and 20 percent polarisation levels are considered with different source/line impedance ratios. Fig.6.10 represents polar characteristic for R-E fault relay with similar system conditions and polarisation levels. The polarising voltage in this case is derived from phases B and Y. Fig.6.11 represents the case of 25 mile, 132 kV line fed from both ends, prefault power being exported at the relay end. The fault level at the relay end is considered to be 1000 MVA while that at remote end is 5000 MVA.

It can be observed that the origin is enclosed in all the cases. The reach on the resistance axis(which is chiefly decided by the self-adjusting elliptical characteristic) remains unaffected by the polarisation of directional characteristic.

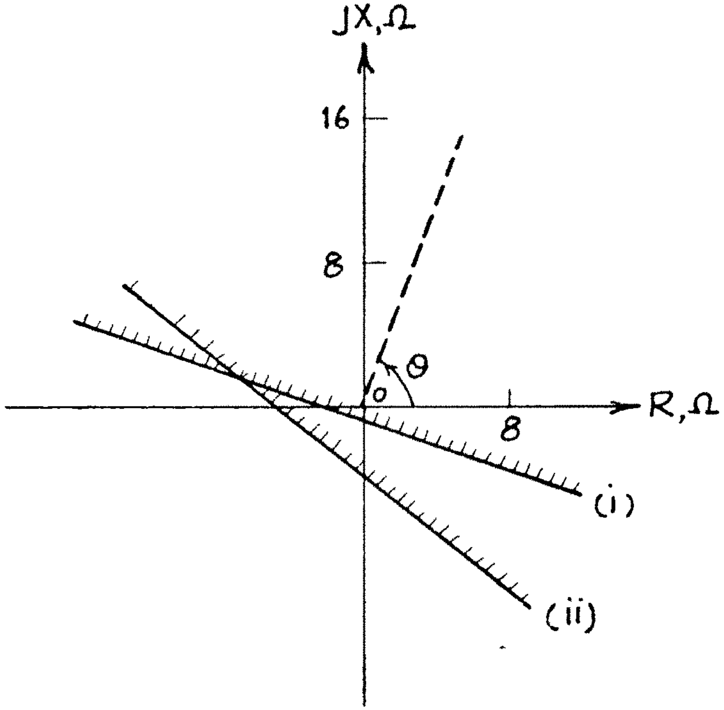


(a) $Z_S/Z_n = 2 \cdot 5$
FED FROM ONE END
LEVEL OF POLARISATION (i) 5% V_R
(ii) 20% V_R

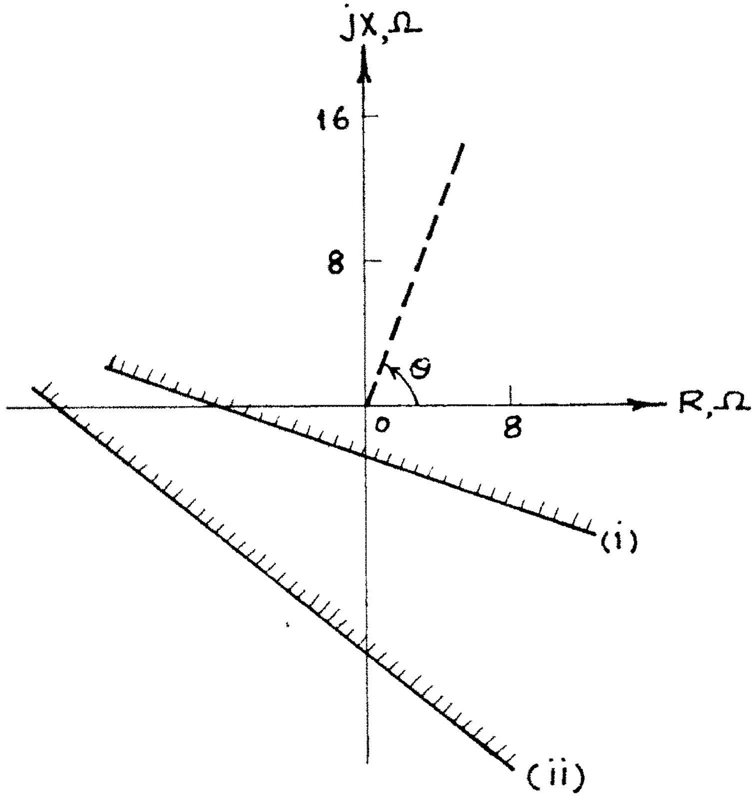


(b) $Z_S/Z_n = 10 \cdot 0$
FED FROM ONE END
LEVEL OF POLARISATION (i) 5% V_R
(ii) 20% V_R

FIG. 6·9 DIRECTIONAL CHARACTERISTIC OF Y-B PHASE TO PHASE FAULT RELAY

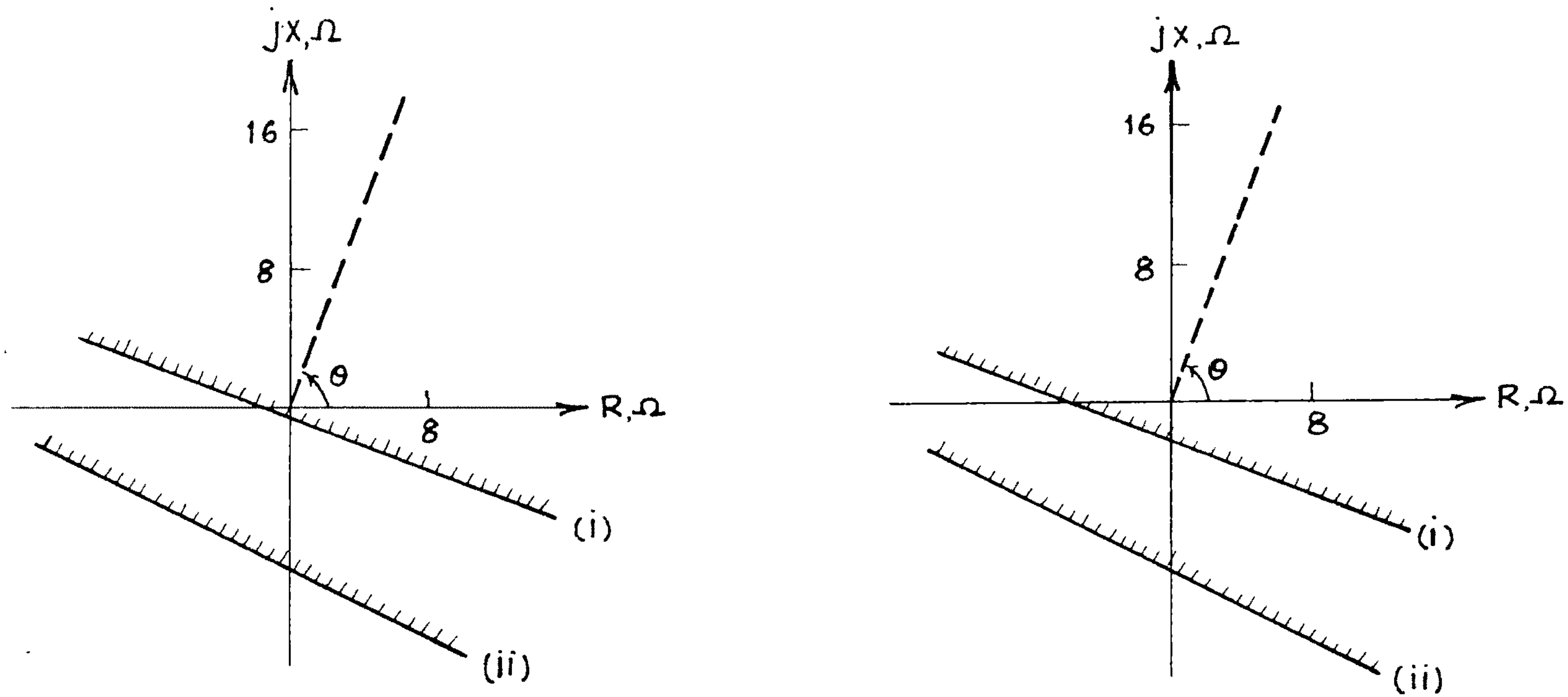


(a) $Z_S/Z_n = 2\cdot5$
FED FROM ONE END
LEVEL OF POLARISATION (i) 5% V_{BY}
(ii) 20% V_{BY}



(b) $Z_S/Z_n = 10\cdot0$
FED FROM ONE END
LEVEL OF POLARISATION (i) 5% V_{BY}
(ii) 20% V_{BY}

FIG. 6·10 DIRECTIONAL CHARACTERISTIC OF PHASE TO EARTH FAULT RELAY ON PHASE R



(a) $Z_s/Z_n = 2\cdot5$
FED AT BOTH ENDS
LEVEL OF POLARISATION (i) 5% V_R
(ii) 20% V_R

(b) $Z_s/Z_n = 10\cdot0$
FED AT BOTH ENDS
LEVEL OF POLARISATION (i) 5% V_R
(ii) 20% V_R

FIG. 6·11 DIRECTIONAL CHARACTERISTIC FOR PHASE TO PHASE FAULTS ON PHASES Y AND B. PREFAULT POWER EXPORTED AT THE RELAY END $\frac{V_{S1}}{V_{S2}} = 1\cdot05\angle30^\circ$