CHAPTER IV

DEVELOPMENTS IN SEQUENCE COMPARATORS

4.1 INTRODUCTION :

The phase comparison techniques hitherto reported employ indirect approach of arriving at the required distance relay characteristics. In all of such techniques the mathematical basis of the comparators are first developed. The required characteristics are then plotted on the impedance plane and the necessary inputs are then determined. Corresponding graphical constructions are employed to assist in the selection of necessary inputs. This approach, although ultimately yields the necessary inputs to obtain the required characteristic, however, is not feasible. A more direct approach in the determination of the necessary inputs was, therefore, thoughtnecessary so that the necessary inputs to the comparator can be determined directly from the derived polar characteristic (without going through the complicated mathematical back-up) .

In the present chapter, therefore, a new principle of sequence detection of the derived signals is reported which is based on the direct approach. Further, the sequence detector is reported to detect the sequence of three derived signals and is employed to obtain the conventional quadrilateral characteristic . The comparator provides the necessary flexibility in tailoring the characteristic so as to fit around the fault area of a transmission line with single or double infeed. Two schemes of 3-step quadrilateral characteristics are also fully described and the test results obtained on the relay model constructed in the laboratory during the investigation are presented.

4.2 PRINCIPLE OF THE COMPARATOR :

Fig.4.1 illustrates a typical quadrilateral characteristic on the impedance plane obtained by drawing the line segments passing through the points A, B, C and D. If the impedance vectors Z_{R_1} / K_1 and Z_{R_2} / K_2 are so chosen that their tips coincide with the respective points A and B, then on the basis described in section 3.4.1 , two input signals S_1 and S_2 will be obtained which on comparing for the phase angular difference in a 2-input sine comparator will yield the segment AB. Similarly, the pairs of signals S_2 and S_3 , S_3 and S_4, and S_4 and S_1 will be obtained furnishing the segments BC, CD and DA respectively. The corresponding impedance vectors will be Z_{R_2} / K_2, Z_{R_3} / K_3 and Z_{R_4} / K_4 as shown in fig.4.1 . It is evident that for the segment AB of the characteristic, S_1 must lead S_2 for the tripping to be effective in the shaded region. Similarly, for the successive line segments BC, CD and DA, S_2 must lead S_3, S_3 must lead S_4, and S_4 must lead S_1 . It therefore follows that if the impedance vector seen by the relay should lie inside the

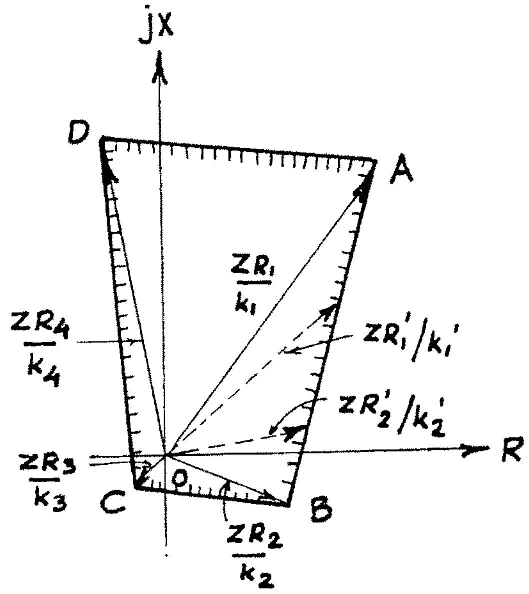


FIG. 4·1 QUADRILATERAL CHARACTERISTIC

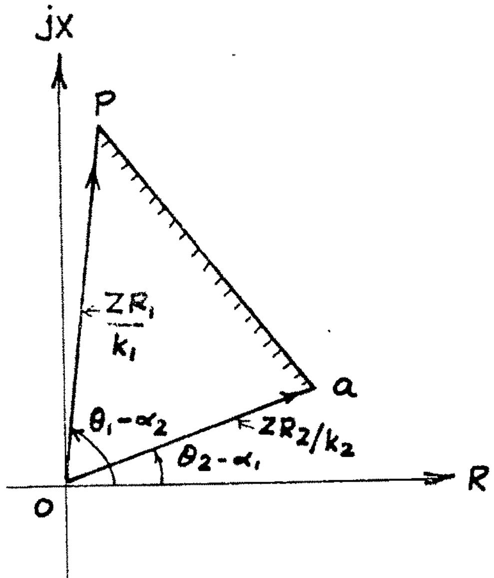


FIG. 4·2 RECTILINEAR CHARACTERISTIC

$$S_1 = K_1 \angle \alpha_1 \, V_L \angle 0 + ZR_1 \, I_L \angle \theta_1 - \phi$$

$$S_2 = K_2 \angle \alpha_2 \, V_L \angle 0 + ZR_2 \, I_L \angle \theta_2 - \phi$$

$$\alpha_1 - \alpha_2 = 180^\circ$$

characteristic, then the sequence of the derived signals must be $S_1 - S_2 - S_3 - S_4$. This sequence, however, will be disturbed if the impedance seen by the relay lies outside the tripping characteristic. Thus the determination of the sequence of the derived signals will provide the necessary discrimination between the legitimate internal faults and the rest of the system conditions.

It is further evident that for the successive line segments of the characteristic the pairs of signals obtained will have one signal in common. This type of comparator will, therefore, need n input signals for n line segments of the closed characteristic.

4.3 MATHEMATICAL BASIS :

On substituting $\alpha_1 - \alpha_2 = \pi$, with $\beta_1 = \beta_2 = 0$ in inequalities (3.7) and (3.8) the resulting inequality will be :

$$X \leqslant - \left[\frac{K_1 Z_{R_2} \sin(\alpha_1 - \theta_2) + K_2 Z_{R_1} \sin(\theta_1 - \alpha_2)}{K_1 Z_{R_2} \cos(\alpha_1 - \theta_2) - K_2 Z_{R_1} \cos(\theta_1 - \alpha_2)} \right] R - \left[\frac{Z_{R_1} Z_{R_2} \sin(\theta_1 - \theta_2)}{K_1 Z_{R_2} \cos(\alpha_1 - \theta_2) - K_2 Z_{R_1} \cos(\theta_1 - \alpha_2)} \right] \quad \ldots.(4.1)$$

Fig.4.2 shows the characteristic represented by the inequality (4.1) .

4.4 SELECTION OF INPUTS WITH THE DIRECT APPROACH :

The direct approach of obtaining the necessary inputs to yield desired characteristic will now be explained. Considering the characteristic of fig.4.1 as the required characteristic the following procedure will be necessary:

Impedance vectors Z_{R_1} / K_1 , Z_{R_2} / K_2 , Z_{R_3} / K_3 and Z_{R_4} / K_4 are required to be drawn from the points A, B, C and D which mark the discontinuities of the characteristic. On choosing K_1 through K_4 arbitrarily, the magnitudes of Z_{R_1} through Z_{R_4} can be fixed from the locations of the points A, B, C and D on the complex impedance plane. The argument of one of the coefficients of V_L (say α_1) can be chosen according to the convenience. The arguments of the remaining successive coefficients (α_2 etc.) can be fixed by employing the condition,

$$\alpha_1 - \alpha_2 = \pi \qquad \ldots (4.2)$$

From the knowledge of α_1 through α_4, the angles of the replica impedances (θ_1 through θ_4) can be immediately selected from the inclinations of the vectors Z_{R_1} / K_1, Z_{R_2} / K_2 , Z_{R_3} / K_3 and Z_{R_4} / K_4 , with the R-axis.

Thus, the knowledge of α_1 through α_4, θ_1 through θ_4, K_1 through K_4 and Z_{R_1} through Z_{R_4} will completely determine the necessary inputs to the comparator to yield the required characteristic of fig.4.1 .

From above it is evident that in arriving at the necessary inputs to obtain the desired characteristic no elaborate mathematical basis or the associated graphical constructions are necessary. The inputs are directly determined from the locations of the discontinuities of the characteristics on the impedance plane.

4.5 SEQUENCE DETECTION RELAY WITH QUADRILATERAL CHARACTERISTIC:

The principle of the detection of the sequence of derived signals explained above will now be employed to obtain the typical quadrilateral characteristic of fig.4.3 .

4.5.1 Input Signals :

The necessary input signals are derived following the procedure outlined in section 4.4 and given in eq.(4.3) .

$$\left.\begin{aligned} S_1 &= -K_1V_L + I_L Z_{R_1} \angle\theta_1 - \phi \\ S_2 &= K_2V_L - I_L Z_{R_2} \angle\theta_2 - \phi \\ S_3 &= -K_3V_L + I_L R_F \angle-\phi \\ S_4 &= K_4V_L \end{aligned}\right\} \quad \ldots\ldots (4.3)$$

S_1 and S_2 are the necessary signals to yield the segment DC of the characteristic. Similarly, S_2 and S_3, S_3 and S_4, and S_4 and S_1 are the necessary pairs of signals to provide the respective line segments BC, OB and OD of the characteristic.

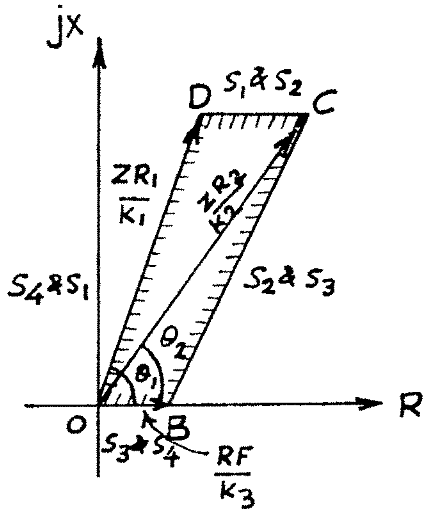


FIG. 4·3 QUADRILATERAL CHARACTERISTIC

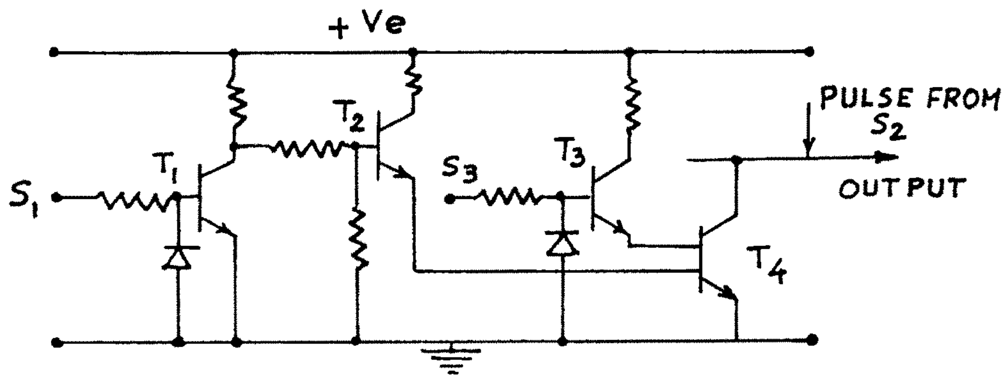


FIG. 4·4 3-INPUT SEQUENCE DETECTOR

4.5.2 <u>3-input Sequence Detector</u> :

The sequence detectors hitherto developed in reference to polyphase relaying[47] or single phase relaying with a view to obtain quadrilateral characteristic[34,35,48] employ flip-flops alongwith certain logic operations in detecting the sequence. This necessitates involved relay circuitry with longer relay operating time in most of the cases.

The 3-input sequence detector developed in this section makes use of only a few circuit components and operates faster.

Fig.4.4 shows the basic 3-input sequence detector to detect the sequence of three signals S_1, S_2 and S_3, and fig.4.5 shows the mode of sequence detection. It is evident that the pulse from S_2 will appear as an output only if the sequence is $S_1 - S_2 - S_3$.

This detector will now be employed in obtaining the quadrilateral distance relay characteristic of fig.4.3 .

4.5.3 <u>First Zone Relay</u> :

Fig.4.6 shows the block schematic diagram of the relay providing the characteristic of fig.4.3 . V_L and I_L are applied to the measuring circuits (M) which produce the required signals S_1 through S_4 given by eq.(4.3) .

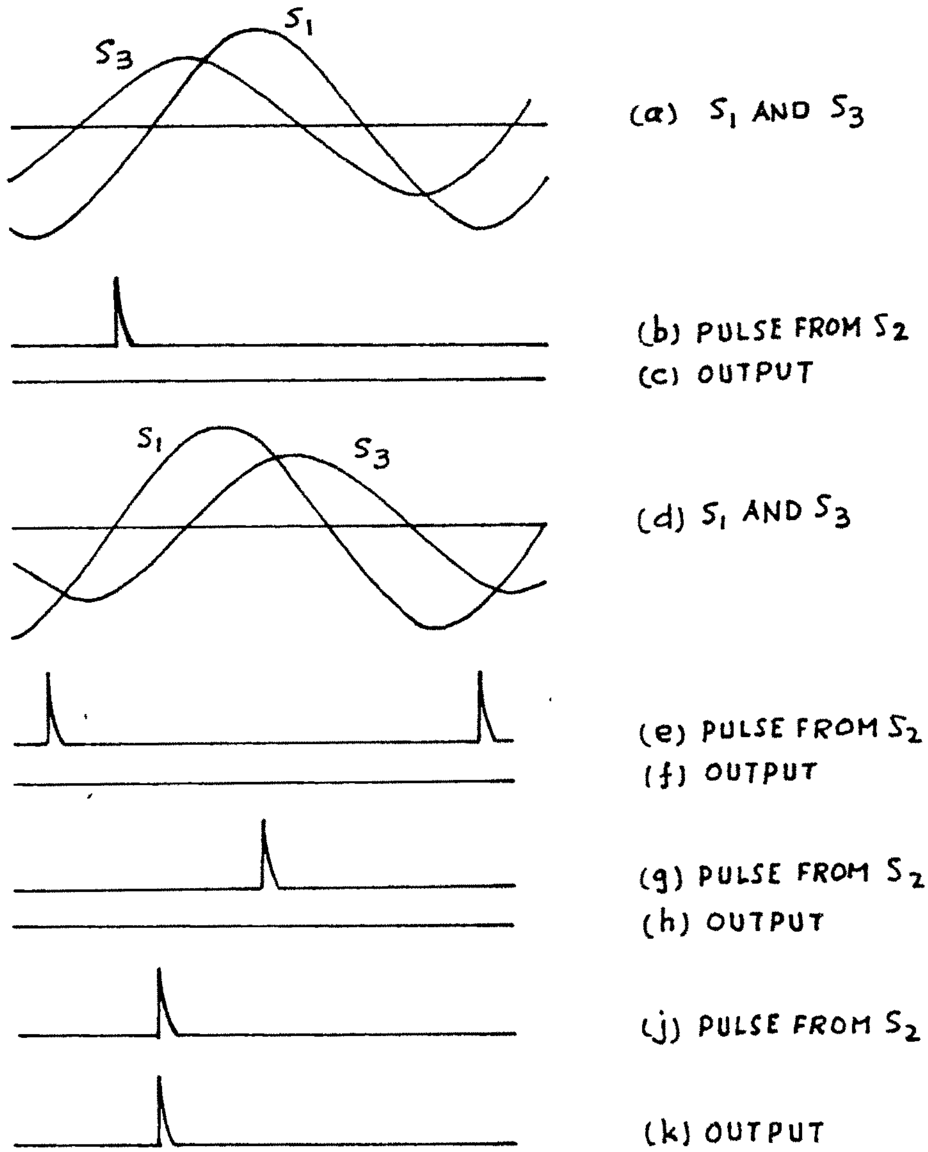


FIG. 4·5 MODE OF DETECTION

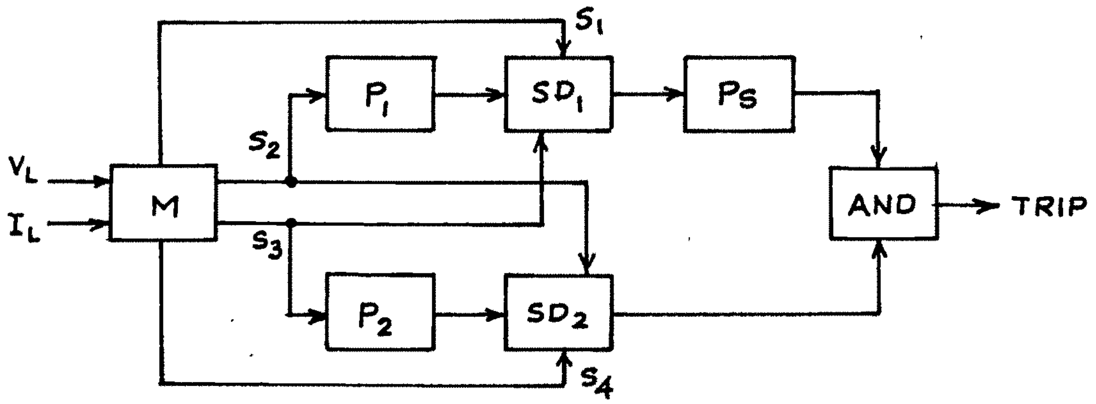


FIG. 4·6 BLOCK-SCHEMATIC DIAGRAM OF THE FIRST ZONE RELAY

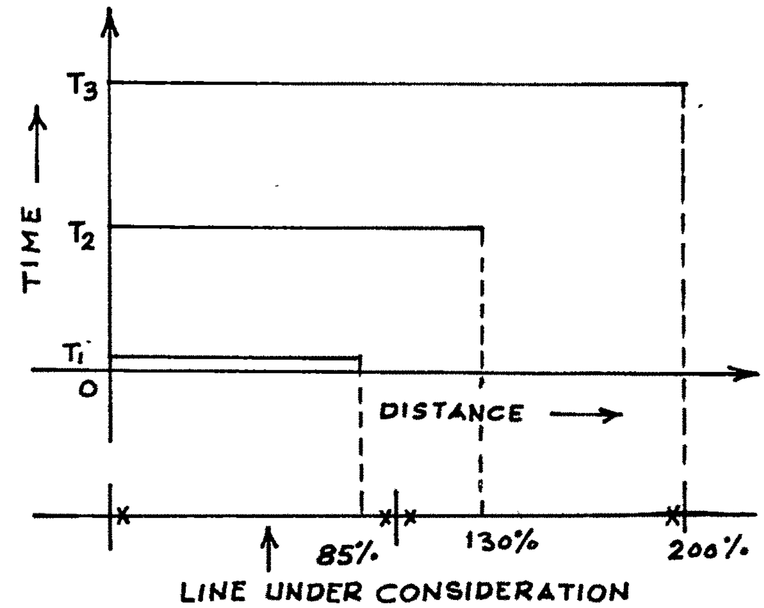


FIG. 4·7 3-STEP SETTINGS

S_2 and S_3 are applied to the respective pulse-forming circuits P_1 and P_2 to obtain the sampling pulses. Sequence detector SD_1 is used to detect the sequence of signals S_1, S_2 and S_3 . Similarly SD_2 is used to detect the sequence of the signals S_2, S_3 and S_4 . The output pulse from SD_1 is stretched by means of pulse stretching circuit (PS) for almost the complete cycle and compared with similar pulse obtained from SD_2 in the final AND gate to obtain the final tripping signal. It follows that the AND gate will provide the output only when the sequence is $S_1 - S_2 - S_3 - S_4$.

The output of the AND gate may be used to trigger a thyristor placed in the trip circuit of the circuit breaker rendering the relay completely static.

4.6 THREE STEP DISTANCE RELAY SCHEMES :

A common form of distance protection scheme employed for transmission line protection takes the form of a 3-zone time distance arrangement, the first zone being set for instantaneous operation, whilst the second and third zones provide the delayed back-up feature. The representative values for distance setting are : 1st zone - 80 percent, 2nd zone - 100 percent of the protected section + 20 to 40 percent of the neighbouring section, 3rd zone- 100 percent of one section and the entire neighbouring section. The typical time delays are : 1st zone- no intentional time delay, 2nd zone - 0.5 to 1.0 second, and 3rd zone - 1.0 to 2.0 seconds.

In this section three step distance relay schemes are described which obtain the characteristics suggested as being nearest to the ideal i.e. directional quadrilateral. These characteristics are obtained by employing the sequence comparison technique.

4.6.1 3-Step Characteristics With Single Fault Detector :

In the present section two schemes of 3-step distance measurement are described which employ single relay unit for operation under all three zones, the necessary time delays being obtained by means of timers energised by the rate of rise of current circuit.

Scheme 1 :

Fig.4.7 illustrates typical 3-step settings and fig.4.8 illustrates the 3-step quadrilateral characteristics on the complex impedance plane. In changing the zone reach setting of the relay from zone 1 to zone 2 and from zone 2 to zone 3 the reach on both resistance and reactance axes are simultaneously increased.

Fig.4.9 illustrates the block-schematic diagram of the 3-step relay. System quantities V_L and I_L are applied to the measuring circuits which produce the required

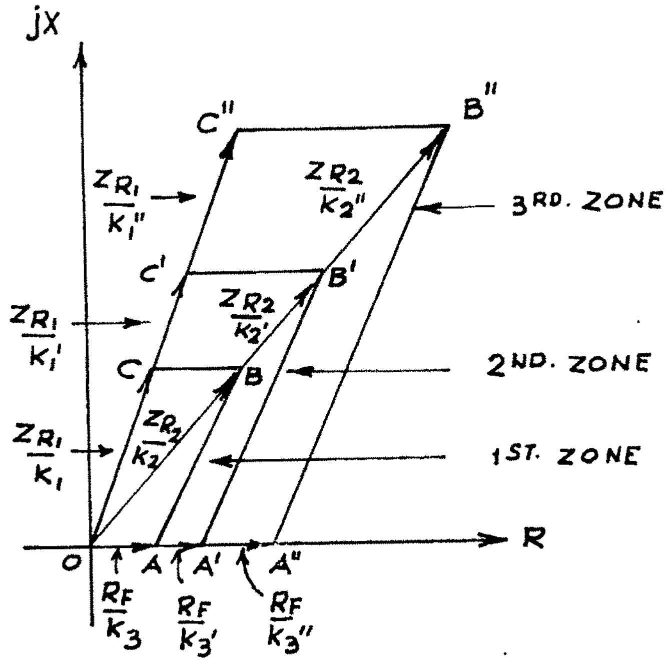


FIG. 4.8 3-STEP QUADRILATERAL CHARACTERISTICS

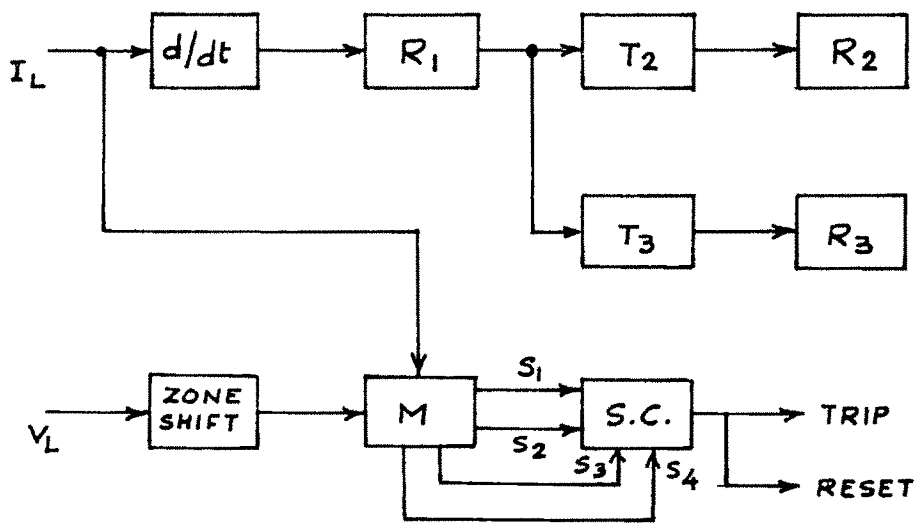


FIG. 4·9 BLOCK-SCHEMATIC DIAGRAM OF THE 3-STEP RELAY signals S_1 through S_4 given by eq.(4.3) . With the proper choice of the constants K_1 through K_4 the relay is initially set to operate for first zone faults.

For the 2nd zone faults the inputs to the sequence comparator are altered to change the zone reach in accordance with eq.(4.4) .

$$
\left.\begin{aligned}
S_1 &= -K_1' V_L + I_L Z_{R_1} \angle\theta_1 - \phi \\
S_2 &= K_2' V_L - I_L Z_{R_2} \angle\theta_2 - \phi \\
S_3 &= -K_3' V_L + I_L R_F \angle - \phi \\
S_4 &= K_4 V_L
\end{aligned}\right\} \quad \ldots\ldots (4.4)
$$

To effect the necessary changes from K_1, K_2 and K_3 to K_1', K_2' and K_3' respectively typical contact arrangement of fig.4.10 is employed. dI / dt unit (fig.4.9) is used to operate reed relay R_1, the auxiliary contacts of which are used to facilitate the starting of the timer circuits T_2 and T_3 . After the completion of the second zone time delay, the timer T_2 operates the reed relay R_2, the auxiliary contacts of which make the necessary changes in the inputs to the sequence comparator. Similarly, the reed relay R_3 is employed to change the reach of the relay from zone 2 to zone 3 after the operation of the timer T_3.

In short, for first zone faults the sequence comparator is supplied with the inputs given by eq.(4.3) .

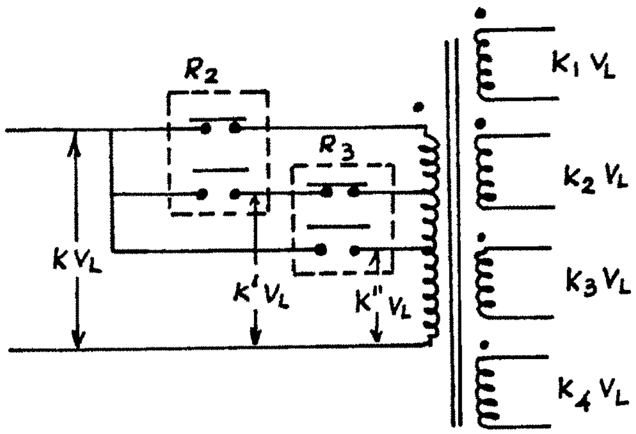


FIG. 4·10 CONTACT ARRANGEMENT FOR ZONE SHIFTING.

In the event of faults in the 2nd and 3rd zones, the dI / dt unit starts both the timing circuits T_2 and T_3. For the faults in zone-2 , the timer circuit T_2 operates reed relay R_2 which alters the inputs to the sequence comparator in accordance with eq.(4.4) and sets the relay in its 2nd zone. Similarly in the event of third zone faults the reed relay R_3 switches the comparator in to its third zone of distance measurement after the 3rd zone time delay.

Scheme 2 :

Fig.4.11 illustrates typical 3-step quadrilateral characteristics in which the zone reach settings for the 2nd and 3rd zone are effected by altering only the reactance reach.

Fig.4.12 illustrates the measuring circuit of the relay along with the necessary contact arrangements for the zone shifting. Initially the relay is supplied with the signals S_1 through S_4 given by eq.(4.3) setting the relay for the first zone faults. For the 2nd and 3rd zone faults the inputs to the sequence comparator are altered in accordance with eq.(4.5) and (4.6) respectively.

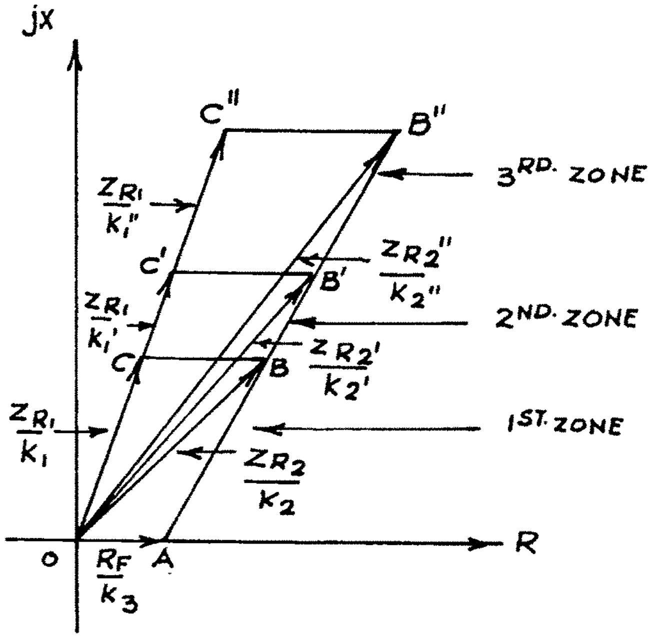


FIG. 4·11 3-STEP QUADRILATERAL CHARACTERISTICS

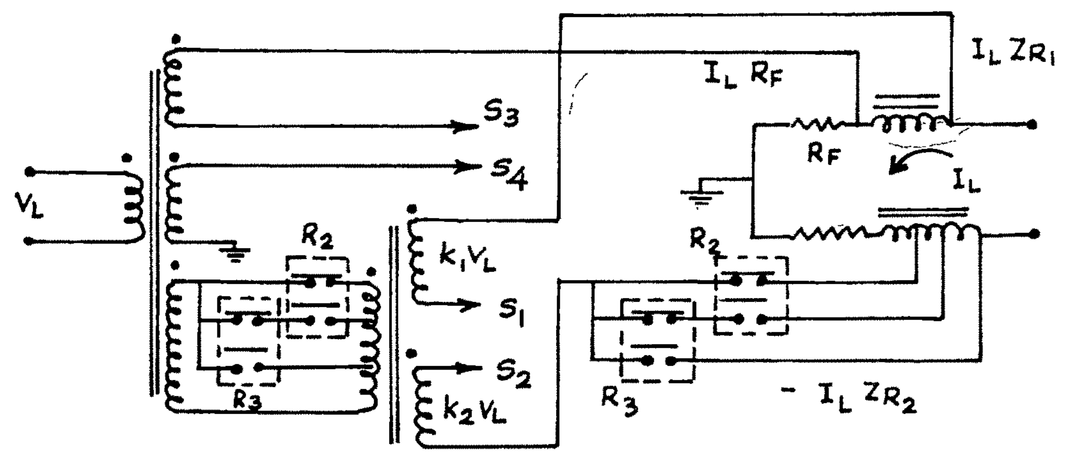


FIG. 4·12 MEASURING CIRCUIT WITH CONTACT ARRANGEMENT

$$
\left.\begin{aligned}
S_1 &= -K_1' V_L + I_L Z_{R_1} \angle \theta_1 - \phi \\
S_2 &= K_2' V_L - I_L Z_{R_2}' \angle \theta_2' - \phi \\
S_3 &= -K_3' V_L + I_L R_F \angle -\phi \\
S_4 &= K_4 V_L
\end{aligned}\right\} \quad \ldots\ldots (4.5)
$$

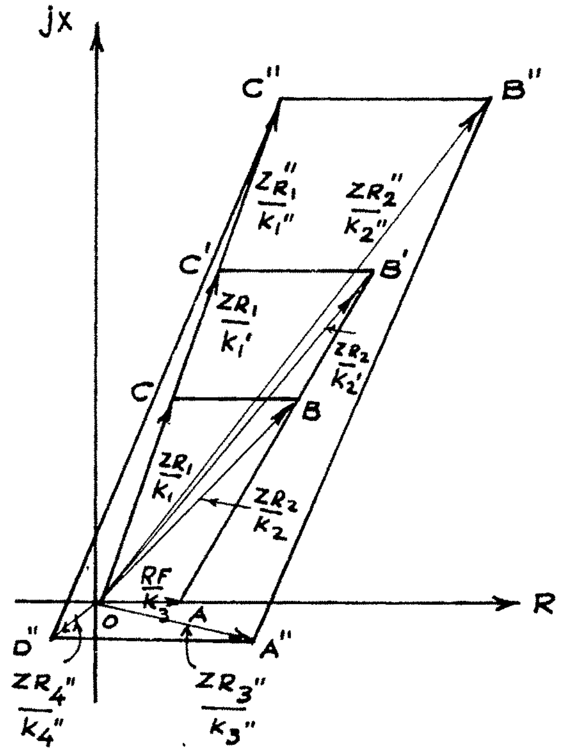
$$
\left.\begin{aligned}
S_1 &= -K_1'' V_L + I_L Z_{R_1} \angle \theta_1 - \phi \\
S_2 &= K_2'' V_L - I_L Z_{R_2}'' \angle \theta_2'' - \phi \\
S_3 &= -K_3 V_L + I_L R_F \angle -\phi \\
S_4 &= K_4 V_L
\end{aligned}\right\} \quad \ldots\ldots (4.6)
$$

In this case also the rate of rise of current unit is used to start the timers T_2 and T_3. The auxiliary contacts of R_2 and R_3 (as shown in fig.4.12) are used to switch the relay from its first zone setting to 2nd and 3rd zone settings respectively.

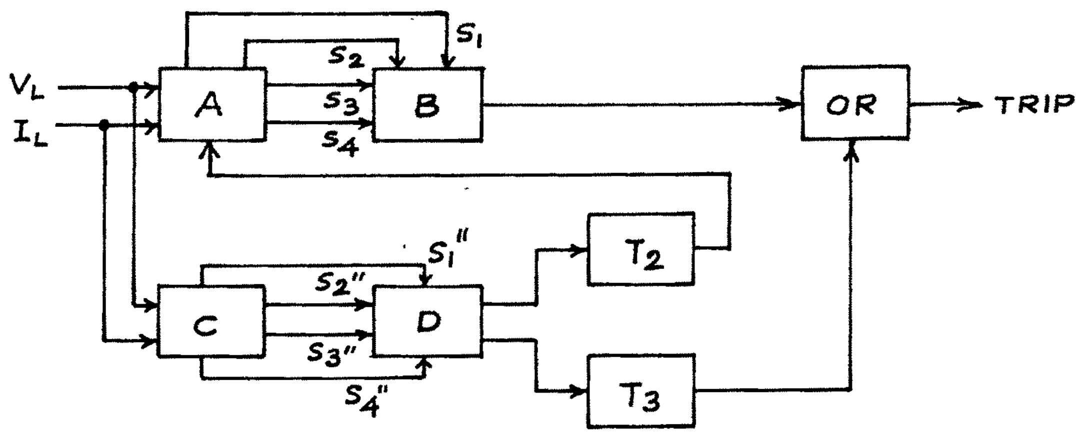
4.6.2 Third Zone Monitored Relay Scheme :

In this section a three-step distance relay arrangement is explained in which an exclusive third zone unit is employed, its output being utilised for monitoring carrier transmission and for energising timer circuits for change over from first zone to second zone.

The typical characteristic provided by a third zone monitored relay is illustrated in fig.4.13(a). Fig.4.13(b)



(a) TYPICAL 3-STEP CHARACTERISTICS



A. MEASURING CIRCUIT WITH ZONE SHIFTING ARRANGEMENT.

B. 1ST. AND 2ND. ZONE SEQUENCE COMPARATOR.

C. MEASURING CIRCUIT FOR THIRD ZONE.

D. 3RD. ZONE SEQUENCE COMPARATOR.

(b) BLOCK-SCHEMATIC DIAGRAM OF THE RELAY

FIG. 4.13 THIRD ZONE MONITORED RELAY SCHEME illustrates the block-schematic diagram of the relay. As soon as the third zone unit sees an impedance in any of the three zones, it gives an output signal energising the timer circuits T_2 and T_3 . The timer T_3 produces the trip signal after the third zone time delay through the output OR logic. The timer T_2 facilitates the change of setting of the relay from first zone to second zone after the second zone time delay. The third zone sequence comparator receives the signals given by eq.(4.7) for the correct setting of third zone (non-directional).

$$\left.\begin{aligned} S_1'' &= -K_1'' V_L + I_L Z_{R_1}'' \angle\theta_1'' - \phi \\ S_2'' &= K_2'' V_L - I_L Z_{R_2}'' \angle\theta_2'' - \phi \\ S_3'' &= -K_3'' V_L + I_L Z_{R_3}'' \angle\theta_3'' - \phi \\ S_4'' &= K_4'' V_L - I_L Z_{R_4}'' \angle\theta_4'' - \phi \end{aligned}\right\} \quad \ldots. (4.7)$$

In short, for a fault in the third zone the timer T_3 provides an output after the third zone time delay, for a fault in the second zone, an output is provided when the timer T_2 changes the setting of the composite first and second zone unit from the first to the second zone; and for a fault in the first zone, an output is straightaway provided. The input to the composite two zone units are as follows :

(a) Before timer T_2 operates ,

$$\left.\begin{aligned} S_1 &= -K_1V_L + I_LZ_{R_1}\angle\theta_1 - \phi \\ S_2 &= K_2V_L - I_LZ_{R_2}\angle\theta_2 - \phi \\ S_3 &= -K_3V_L + I_LR_F\angle{-\phi} \\ S_4 &= K_4V_L \end{aligned}\right\} \quad \ldots\ldots (4.8)$$

(b) After timer T_2 operates :

$$\left.\begin{aligned} S_1 &= -K_1' V_L + I_LZ_{R_1}\angle\theta_1 - \phi \\ S_2 &= K_2' V_L - I_LZ_{R_2}'\angle\theta_2' - \phi \\ S_3 &= -K_3V_L + I_LR_F\angle{-\phi} \\ S_4 &= K_4V_L \end{aligned}\right\} \quad \ldots\ldots (4.9)$$

Thus the relay provides an output with the three zone characteristics, alongwith the respective time delays associated with the individual zone characteristics.

4.7 PERFORMANCE TESTS :

The relay described in the previous sections was constructed for the first zone and tested during steady-state conditions only. Fig.4.14 shows the complete relay circuit for the first zone and fig.4.15 shows the static characteristic of the relay obtained during the investigation.

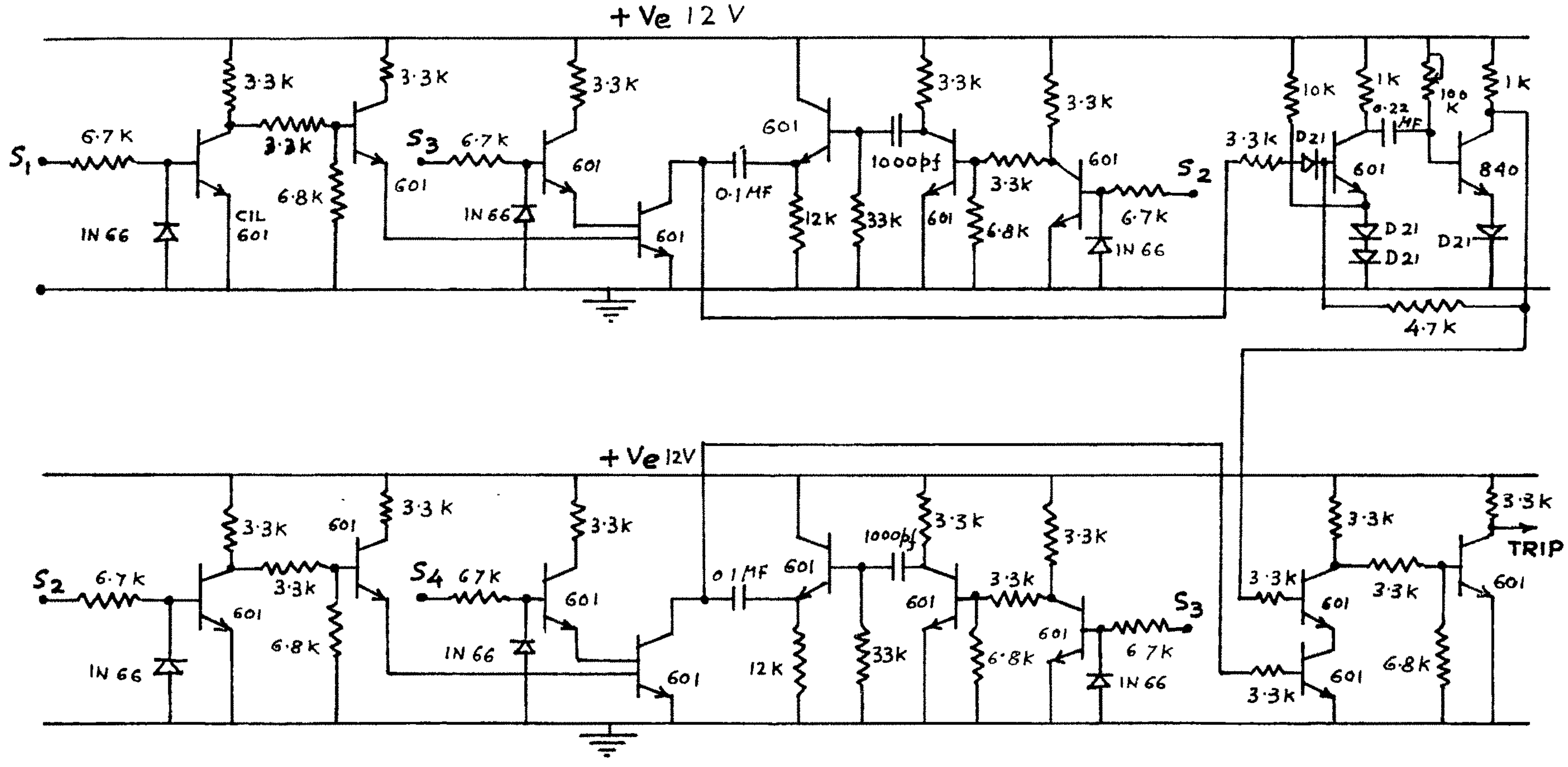


FIG. 4·14 COMPLETE RELAY CIRCUIT FOR QUADRILATERAL CHARACTERISTIC

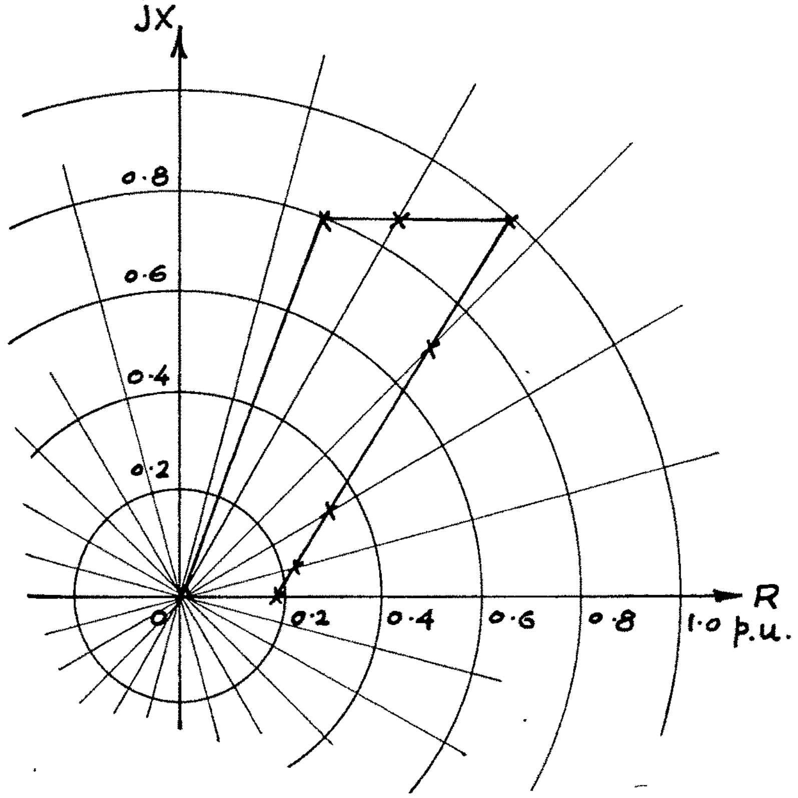


FIG. 4·15 STATIC POLAR CURVE