CHAPTER VII

A NEW SELF ADJUSTING DISTANCE RELAY

7.1 INTRODUCTION :

A distance relay yielding mho characteristic is inherently directional and comparatively more tolerant towards fault resistance as compared with the relays employing elliptical or quadrilateral characteristics. The resistance component of the impedance seen by a distance relay depends upon diversified factors such as arc current, wind velocity, etc. which any way, are not under control. A self-adjusting feature of the pick-up characteristic will, therefore, be more suitable, where-in the relay characteristic will provide small resistance reach during healthy condition of the system, power swings and faults on the other phase or phases. In the event of a legitimate fault in the protected section the relay will automatically change the shape of the characteristic to take into account the larger fault arc resistance.

The mho relay analysed by Wedepohl[50] used strong polarising voltage from the healthy phase or phase pair to provide self-adjusting feature to the characteristic. During the healthy and over load condition of the system, however, this relay provides conventional mho characteristic which is not desirable. Further, for EHV long lines having low Z_S / Z_L ratios and with the low percentage of polarising voltage derived from the healthy phase or phases the bulging of the characteristic is not at all pronounced. Since the relay used polarising voltage from the healthy phase or phase pair it was ineffective during 3-phase faults. The relay thus appears to be suitable only for faults other than three phase only and further only for H.V.lines with high Z_S / Z_L ratio (of the order of 15 or 20) . To ameliorate these difficulties , therefore, a new self-adjusting relay is reported in the present chapter which does not depend upon the voltage from healthy phase or phase pair in bulging the characteristic and is suitable even for low Z_S / Z_L ratios (of the order of 1 to 2.5). The relay circuitry is fully described and its behaviour during various operating conditions of the system is analysed. The dynamic test results obtained during the investigation are presented in Appendix.

7.2 PRINCIPLE OF OPERATION :

Basically the comparator is the same as that described in Chapter 5, except for the Automatic Gain Controlled Amplifier(AGC) included to realise the self-adjusting feature. Fig.7.1 shows the block-schematic diagram of the first zone relay . System quantities V_L and I_L are applied to the measuring circuits which produce the required signals

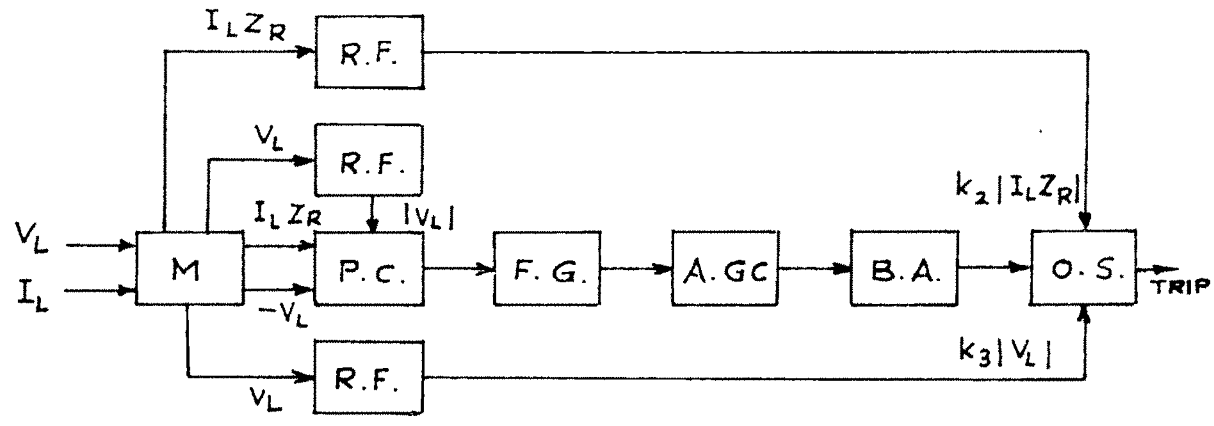


FIG. 7·1 BLOCK-SCHEMATIC DIAGRAM OF THE RELAY

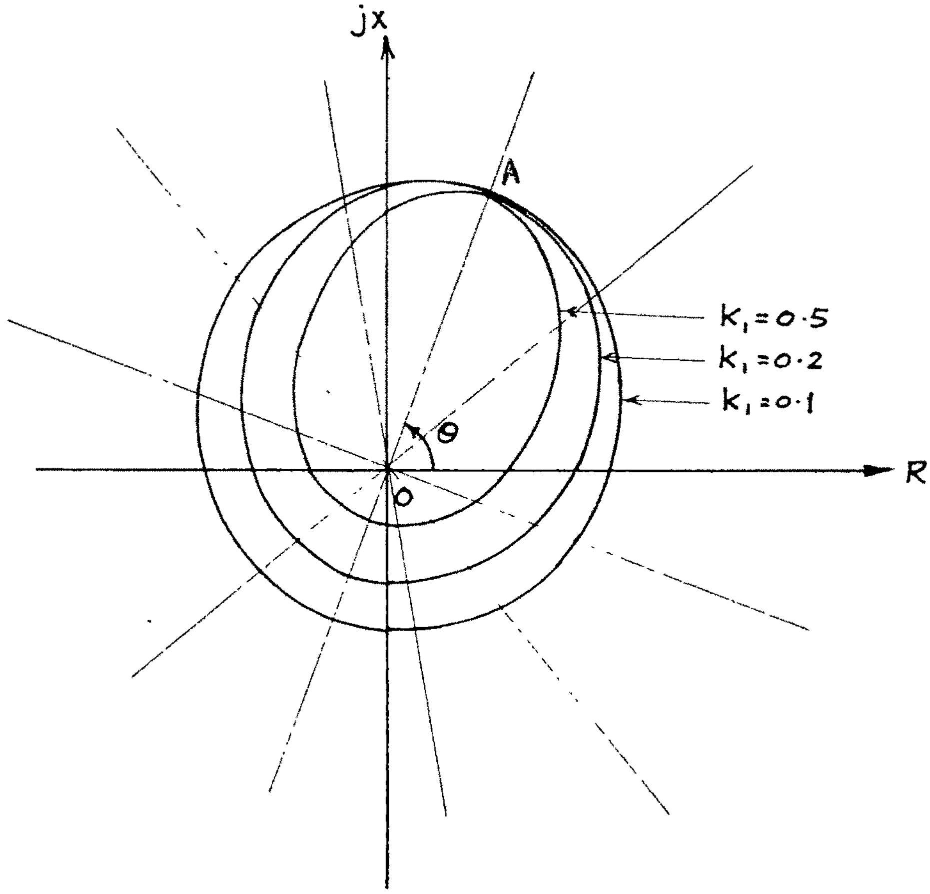


FIG 7·2 ELLIPTICAL CHARACTERISTICS

$k_2 = 1{\cdot}0;\ k_3 = 0{\cdot}25$

$I_L Z_R$ and $-V_L$ for the purpose of phase comparison and V_L, and $I_L Z_R$ and V_L respectively for the d.c. biassing of the phase comparator and final amplitude comparison after adequate rectification and filtering. The function generator provides the voltage across the capacitor C placed in the former given by

$$e_c = K_1 \mid V_L \mid [1-\cos(\theta - \phi)] \qquad \ldots\ldots (7.1)$$

Voltage e_c is compared with $K_2|I_L Z_R|$ and $K_3|V_L|$ in the amplitude comparator such that the latter issues a tripping signal when

$$K_1|V_L| \; [1-\cos(\theta - \phi)] \leqslant K_2|I_L Z_R| - K_3|V_L| \quad \ldots(7.2)$$

or

$$Z_L \leqslant \frac{K' Z_R}{1-K'' \cos(\theta-\phi)} \qquad \ldots. (7.3)$$

where $K' = K_2/(K_1+K_3)$ and $K'' = K_1/(K_1+K_3)$

Constants K_2 and K_3 represent the potentiometer settings. It may be noted that K_1 was treated as a constant in the inequality(5.4) which is same as (7.3). Under such circumstances, as shown, the inequality(5.4) represented an ellipse enclosing the origin of the impedance plane. For changes in the system parameters K_1 was a constant yielding a steady characteristic that did not change.

If, however, K_1 is converted to a function of some system quantity (say V_L) then the resulting tripping characteristic will also depend upon the actual value of that quantity.

Fig.7.2 gives the plots of the inequality(7.3) with specific values of K_2 and K_3, K_1 being the parameter. It may be observed that the characteristics are ellipses enclosing the origin. Further, the reduction in K_1 increases the resistance reach of the characteristic accommodating more fault resistance. Finally, all the curves pass through the point A, corresponding to the adjusted reach of the relay making latter measure correctly except for the transient over-reach due to current offsets.

It may be noted that the values of K_2 and K_3 given in fig.7.2 are by no means the only values. In fact any suitable values could be assigned to them to obtain in conjunction with K_1, any desired eccentricity (reach on R-axis) and the reach of the relay (along $\theta = \emptyset$) .

Since K_1 is the coefficient of V_L, it is evident that the relay acquires the self-adjusting feature. The method of making K_1 dependent on V_L will now be explained.

It may be observed from fig.7.1 that e_c is applied to the output stage(O.S.) for the final amplitude comparison through the A.G.C. Fig.7.3 shows the circuit of the automatic gain controlled amplifier, employed for the

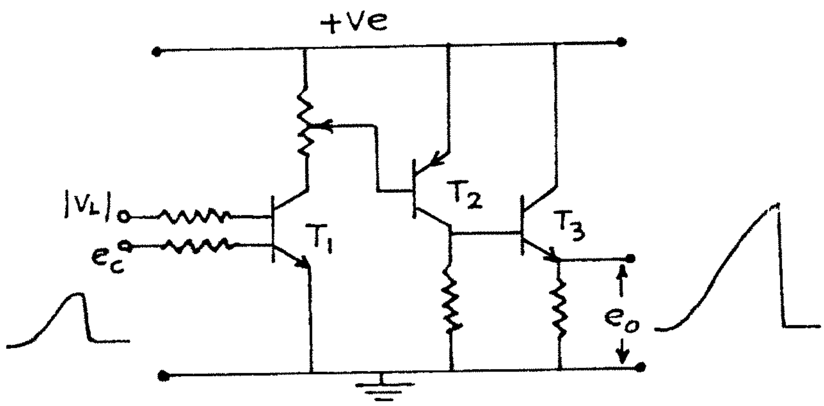


FIG. 7·3 A.G.C. WITH BUFFER AMPLIFIER

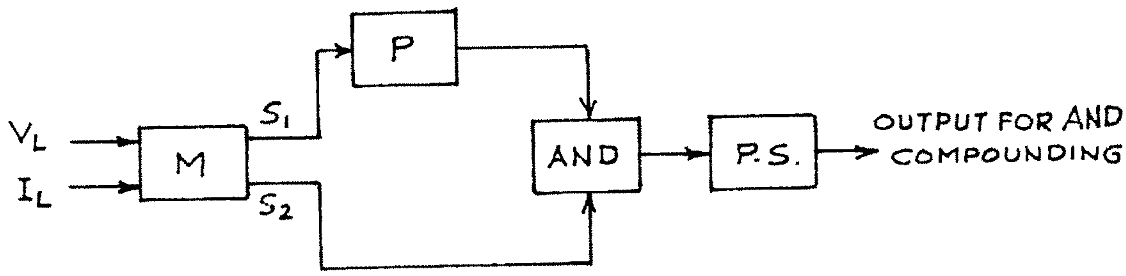


FIG. 7·4 DIRECTIONAL UNIT

purpose, followed by the buffer amplifier stage. The A.G.C. stage uses complementary transistors. The operating point of the first stage is shifted by means of a biassing voltage $|V_L|$ so as to change the gain of the amplifier. It is evident that the output of the emitter follower circuit will be the amplified voltage $K_1 e_c$, wherein K_1 will depend on $|V_L|$ (Plates 7.1 and 7.2) .

7.3 DIRECTIONAL CHARACTERISTIC :

It may be noted that the relay described in the previous section is non-directional (fig.7.2). To prevent the relay operating in the events of reverse faults, therefore, it is necessary to employ a directional unit. A directional characteristic can be easily obtained by either phase comparison or amplitude comparison. Since a block-spike scheme provides fastest measurement of the direction, it is employed here to obtain the required directional characteristic.

The block-schematic diagram of the directional unit is shown in fig.7.4 . Quantities V_L and I_L are applied to the measuring circuits (M) which produce the required signals S_1 and S_2 of eq.(7.4)

$$\left.\begin{aligned} S_1 &= V_L \angle -90^o \\ S_2 &= I_L Z_R \angle \theta - \phi \end{aligned}\right\} \quad \ldots. \; (7.4)$$

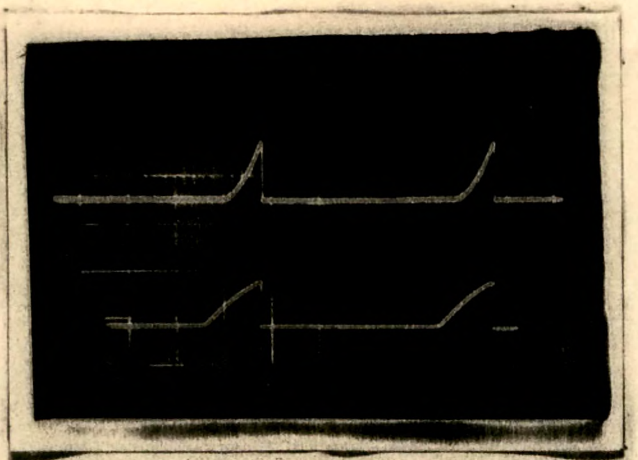


Plate 7.1 Output of A.G.C.
with smaller e_c

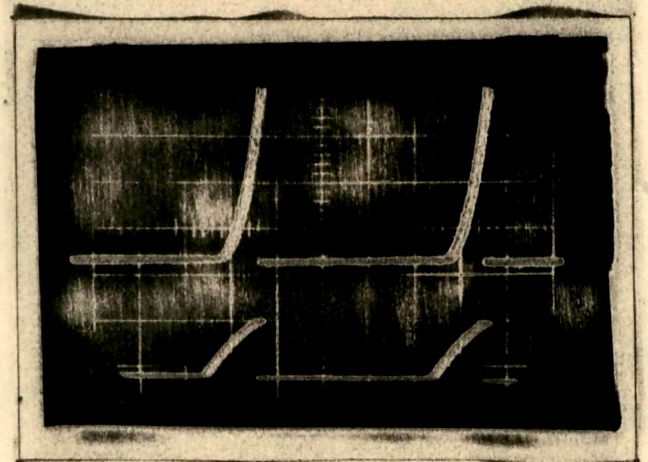


Plate 7.2 Output of A.G.C.
with larger e_c

A pulse is obtained from S_1 at its zero cross-over when it changes its sign from negative to positive (P). This pulse is compared with S_2 in the phase comparator which is an AND gate. The output pulse of the AND gate follows the directional characteristic which is superimposed over the self-adjusting characteristic of fig.7.2 as shown in fig.7.5 by AND compounding with the output of the comparator of section 7.2. To facilitate the AND compounding, a pulse stretching circuit (P.S.) is employed (fig.7.4).

7.4 RELAY ANALYSIS :

The behaviour of the relay during various conditions of the system will now be considered.

7.4.1 Healthy And Over-Load Conditions Of The System :

Fig.7.6 shows a typical two-machine system under consideration. The relay placed at C in the section CD is set to protect against faults upto point F in the first zone, which corresponds to about 80 percent of the length of section CD.

During the healthy and over load conditions of the system V_L will have nominal value. Current I_L may assume any value from very small to above full load. Since the initial setting of K_1 is done in reference to the value of V_L for the faults at F, it is evident that during healthy

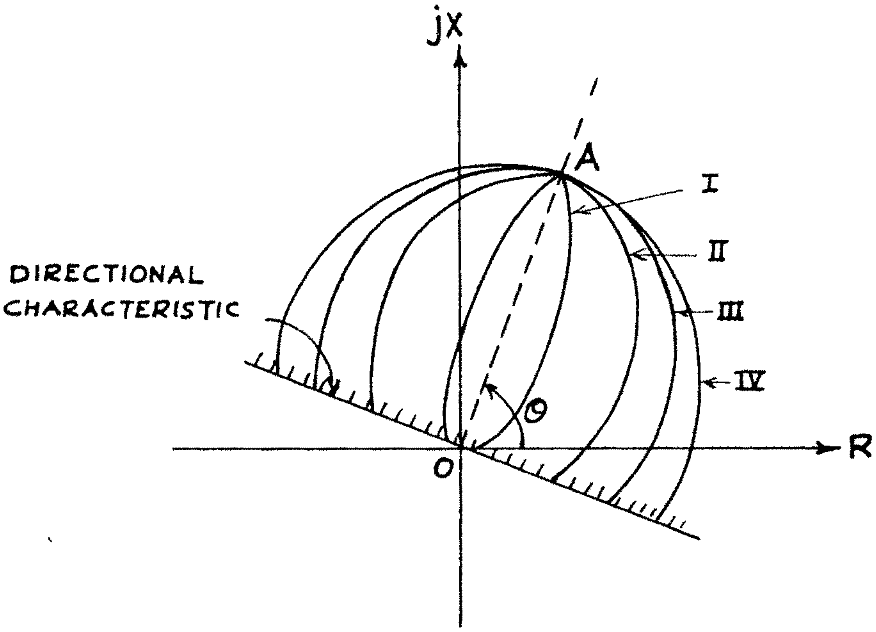


FIG. 7·5 SELF - ADJUSTING AND DIRECTIONAL CHARACTERISTICS

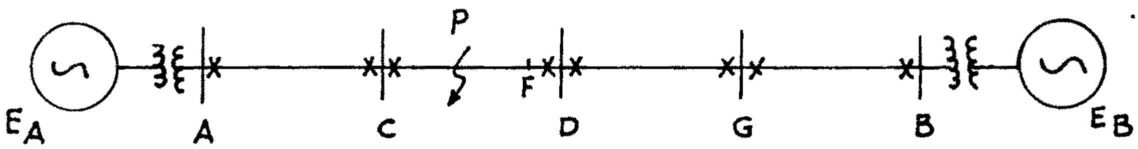


FIG. 7·6 TWO MACHINE SYSTEM

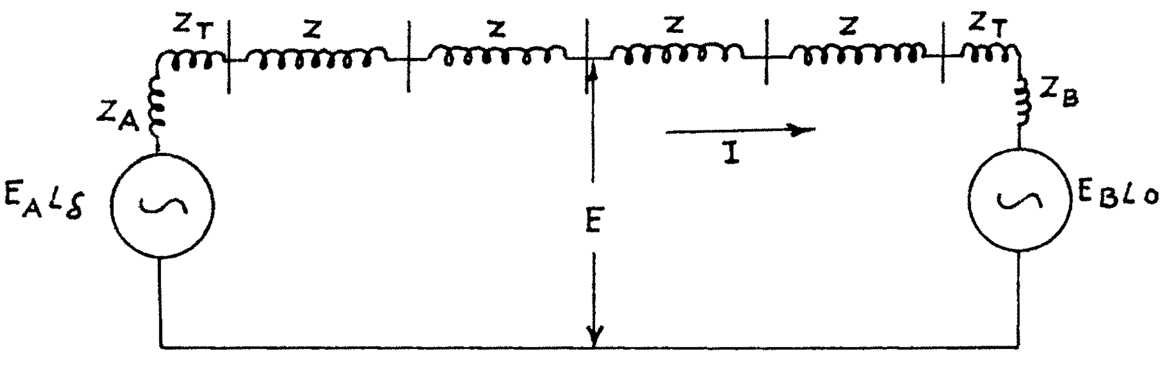


FIG. 7·7 EQUIVALENT CIRCUIT

a-nd over-load conditions of the system K_1 will be larger than the set value. This will result in larger eccentricity of the characteristic i.e. a very small resistance reach of the characteristic.

Characteristic I in fig.7.5 is a probable characteristic of the relay during healthy conditions and over-loading of the system. It is apparent that the relay will have no tendency to trip.

7.4.2 Power Swings :

To appreciate the effect of power swings on the relay characteristic, the equivalent circuit of the two-machine system of fig.7.6 is drawn in fig.7.7 . The voltage at the relay location is given by

$$E = (1-m)E_A \angle\delta + E_B \angle 0 \qquad \text{....(7.5)}$$

where E_A and E_B are the voltage back of transient reactances of machines A and B respectively and δ is the angular difference between them which varies during the power swings. Factor m is used to represent the relay location. Since the shape of the relay characteristic is dependent on $|V_L|$ controlling the gain of A.G.C. it is only necessary to consider eq.(7.5). For simplicity E_A and E_B are considered equal in magnitude and for various values of m the swing loci are drawn in fig.7.8 . Since $\delta = 120^o$ is sufficiently large for the system to loose stability[51] the loci are plotted only upto that value.

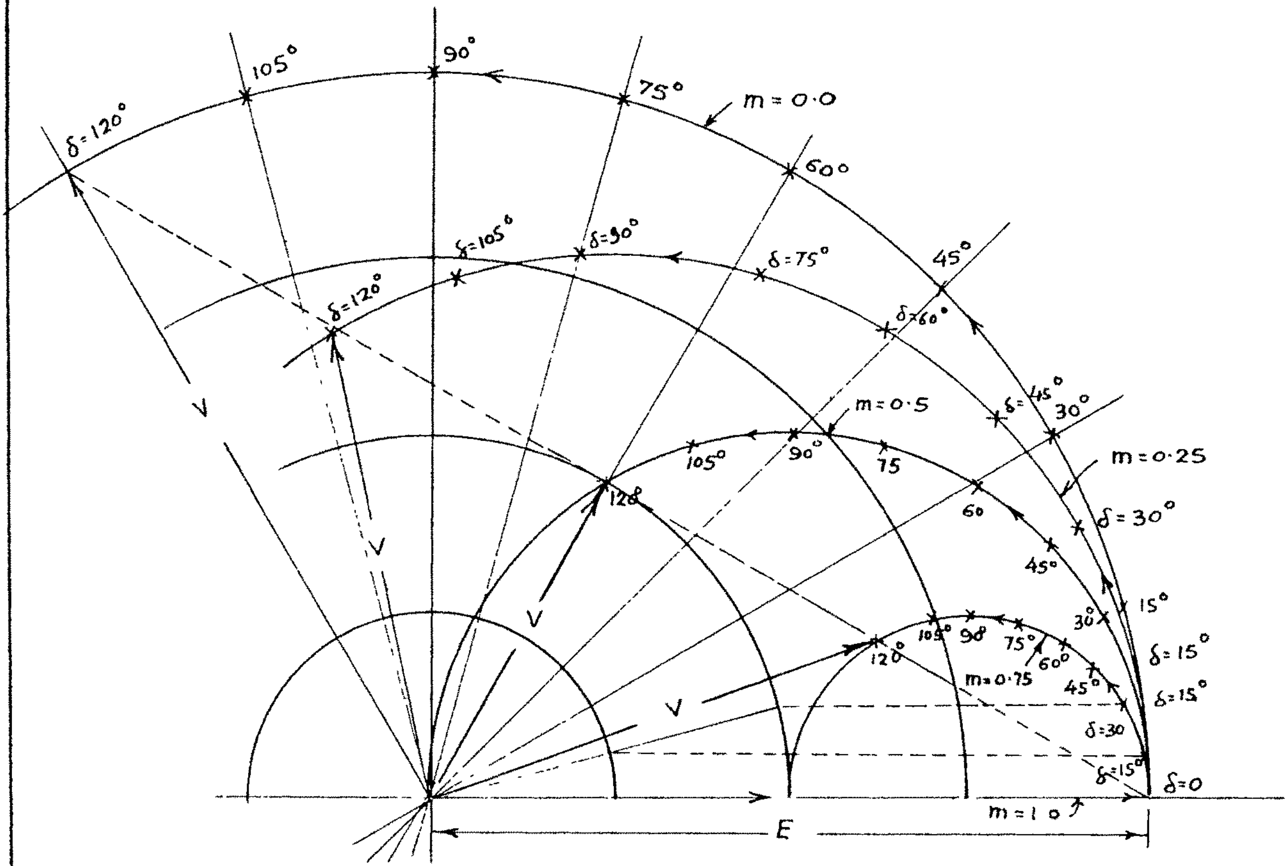


FIG. 7·8 VOLTAGES AT VARIOUS RELAY LOCATIONS DURING POWER SWINGS
($E_A = E_B = E$)

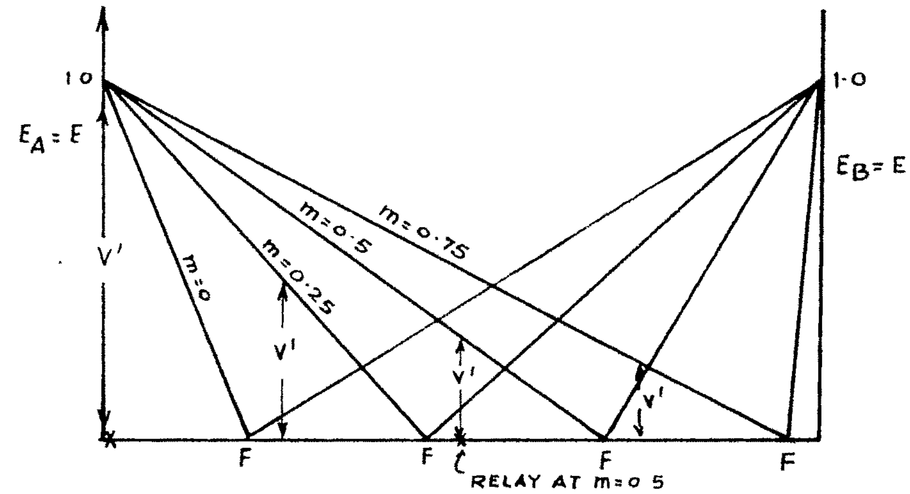


FIG 7·9 VOLTAGES AT VARIOUS RELAY LOCATIONS DURING FAULTS
AT 80% OF THE RESPECTIVE SECTIONS ($E_A = E_B$)

In fig.7.9 for each value of m, the values of the voltages set to protect 80 percent of the corresponding sections (V') are shown. From figs. 7.8 and 7.9 the ratios of the voltages measured by the relays at different locations to the corresponding set values are calculated and drawn against the relay location in fig.7.10. From fig.7.10 it is evident that during power swings the relay will either yield the characteristic in accordance with the initial settings ($m = 0$, $\delta = 120^{o}$) or provide the characteristics with extremely small resistance reach rendering the relay inoperative.

7.4.3 Effect of Faults On Relays On Unfaulted Phase(s) :

The conventional distance relaying schemes on unfaulted phase(s) may trip undesirably when faults take place on other phases, particularly when such faults are close to the relay locations[52]. The effects of various types of faults on the self-adjusting relays on the unfaulted phases will now be considered.

GROUND FAULT RELAYS :

To measure correctly the positive sequence impedance of the line up to the point of fault, these relays are supplied with phase to neutral voltages and the sum of corresponding phase and compensated neutral currents. The behaviour of the self-adjusting relay under this condition

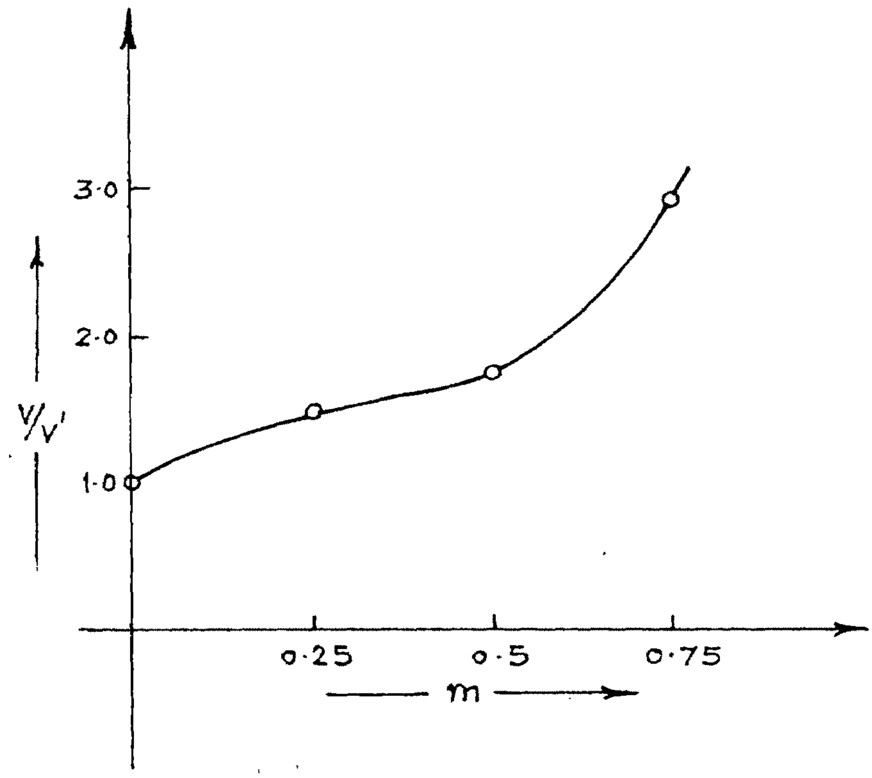


FIG. 7·10 PLOT OF $\frac{V}{V'}$ V/S m

will be analysed considering the effect of fault on the phase to neutral voltage, V_L.

<u>Line To Ground Faults</u> :

Considering the system of fig.7.6, the voltage measured by the ground fault relay (at C) on unfaulted phase b during a line to ground fault on phase a at P will be given by[52]

$$V_b = \frac{E_p \left[(a^2-a)Z_2 - CZ_1' + (a^2-1)Z_o + C_o Z_o' + 3a^2 R_F \right]}{Z_1 + Z_2 + Z_o + 3 R_F} \quad ..(7.6)$$

where Z_1, Z_2 and Z_o are the positive, negative and zero sequence impedances respectively viewed from the point of fault. Z_1' and Z_o' are the positive and zero sequence impedances respectively measured up to the point of fault from the relay location. C is the fraction of the total positive sequence current which flows through the relay. Factor C can assume any value between 0 and 1 depending upon the location of the fault and the feeding from the two ends, A and B. Factor C_o is the fraction for the zero sequence currents, similar to C and E_p is the prefault emf .

To appreciate the role of eq.(7.6) in deciding the shape of the characteristic, typical values were assumed for the system impedances. A programme was run on digital computer where C_o and C were varied for selected fault locations. The ratios of $| V_b / E_p |$ so obtained are given in Appendix alongwith the fault locations(m), C_o and C.

It may be noted from the Appendix that for the close-in faults the ratio $|V_b / E_p|$ falls only slightly from 1.0. The relay on b phase will therefore measure a larger voltage than the set value (V') during this condition and provide an extremely small resistance reach, rendering the relay completely stable.

Phase to Phase Faults :

It is more convenient in this case to consider faults on phases b and c, the relay being protecting a-phase from earth faults. The relay on phase 'a' will measure line to neutral voltage V_{an}, for faults on phases b and c, given by[52]

$$V_{an} = \left[\frac{2Z_2 + R_F}{Z_1 + Z_2 + R_F} \right] E_p \qquad \ldots.(7.7)$$

Since $Z_1 \backsimeq Z_2$, it is evident from eq.(7.7) that the relay will provide the characteristic similar to that provided for healthy and over-load conditions (with extremely small resistance reach). The relay will,therefore, have no tendency to operate.

PHASE TO PHASE FAULT RELAYS :

For the protection of lines against phase to phase faults, the relays are supplied with the delta voltages and the difference of phase currents.

Line To Ground Faults :

For the ground faults on phase a, the delta voltage measured by the b-c relay will be [52]

$$V_{b-c} = \frac{(a^2-a)\ (2Z_2 + Z_o + 3R_F)\ E_p}{(Z_1 + Z_2 + Z_o + R_F\ )} \qquad \text{.... (7.8)}$$

Since $Z_1 \simeq Z_2$ and $(a^2-a) = -j\sqrt{3}$, V_{b-c} will be greater than E_p. The relay will therefore provide extremely small resistance reach of the characteristic rendering it inoperative during this type of faults.

Phase to Phase Faults :

It is convenient in this case to consider the faults on phases b and c. The voltage measured by the phase to phase fault relays on phases a and b will be given by [52]

$$V_{ab} = \left[\frac{(a-a^2)\ CZ_1' + 3Z_2 + R_F(1-a^2)}{Z_1 + Z_2 + R_F}\right] E_p \qquad \text{...(7.9)}$$

Clearly V_{a-b} in eq.(7.9) will be greater than E_p for faults anywhere on the line, C assuming any value between 0 and 1. The a-b relay will, therefore, have no tendency to trip.

7.4.4 Faults On The Protected Phase(s) :

The behaviour of the self-adjusting relays during the faults on the protected phase(s) will now be considered.

External Faults :

The first zone relays are usually set to protect about 80 to 85 percent of the line section under consideration. Length OA in fig.7.5 can be considered as the impedance that the relays at C will measure for metallic short circuits at F(fig.7.6), which corresponds to 80 percent of the length of section CD. For faults beyond F, the relays will provide smaller resistance reach on the characteristic. Neglecting the transient over reach, the impedance seen by the relay will lie outside the characteristic for the fault beyond F. The relays, will, therefore, have no tendency to trip.

Reverse Faults :

During the reverse faults on the system the self-adjusting relay comparators will have the tendency to provide larger resistance and reactance reaches of the characteristics (in the reverse direction) particularly when the faults are close-in. Any attempt by this comparator to trip the breakers, however, will be ameliorated by the directional unit.

Internal Faults :

The eccentricity of the elliptical characteristics can be adjusted so as to accommodate the expected maximum values of the fault resistance for the faults occurring at F in the system of fig.7.6 (the relay being at C). For faults anywhere between the relay location (C) and the point F, the value of $|V_L|$ supplied to A.G.C. will be less than that for the faults at F. The characteristic of the relay will, therefore, provide larger reach on the resistance axis (small eccentricity) accommodating more fault resistance.

7.5 SELECTION OF K_1, K_2 AND K_3 TO YIELD DESIRED CHARACTERISTICS :

The selection of K_1, K_2 and K_3 in the comparator to yield desired characteristics to suit particular protective requirements will now be considered.

7.5.1 Selection of K_1 :

It is evident from section 7.2 that the shape of the characteristic depends upon the value of K_1 which is dependent on the gain of the A.G.C. stage. The peak value of the voltage across the capacitor placed in the function generator (fig.7.5) is given by

$$e_{c_i} = C_1 |V_L| \left[1 - \cos(\theta - \phi)\right] \qquad \text{.... (7.10)}$$

where c_1 is a constant. The voltage e_{c_i} is applied to the A.G.C. amplifier to obtain the amplified e_{c_i} given by

$$e_c = K\, e_{c_i}$$

$$= C_1 K\, |V_L| \left[1 - \cos(\theta - \phi)\right] \qquad \text{.... (7.11)}$$

where K is the stage-gain which depends on the value of V_L. Voltage e_c given by (7.11) when compared with $K_2|I_L Z_R|$ and $K_3|V_L|$ in the amplitude comparator in accordance with (7.2) gives the self adjusting characteristic. It is evident, therefore, that

$$K_1 = KC_1 \qquad \text{.... (7.12)}$$

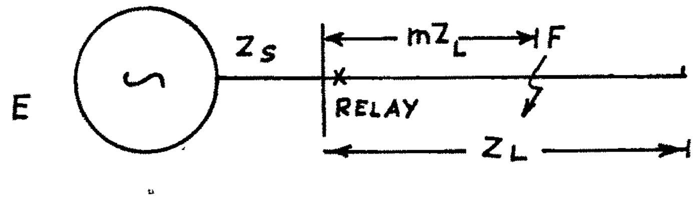
To arrive at the proper choice of K_1 it is necessary to determine both C_1 and K for the relay under consideration. Both C_1 and K for the relay developed during the laboratory investigation are determined and presented in the Appendix. For the relay under consideration and using the method of Least Squares the variation of K_1 with $|V/E|$ can be approximately written as :

$$K_1 = -0.043 + 0.196\,|V/E| + 0.135\,|V/E|^2 \qquad \text{....(7.13)}$$

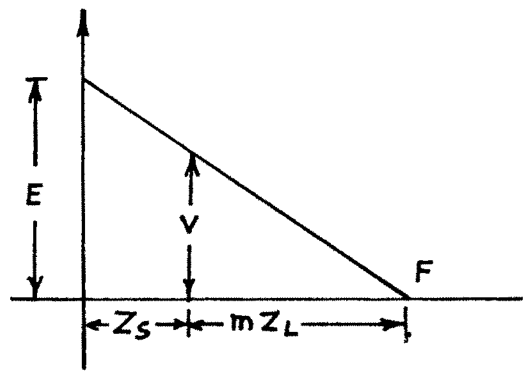
To appreciate the effect of source/line impedance ratio and location of fault on the shape of the characteristic, the system of fig.7.11 is considered. The value of K_1 is set for the farthest fault (at 80 percent of the length of the line) with maximum generation ($Z_S / Z_L = 1.0$). The value of $|V/E|$ under this condition is found to be 0.444 p.u.

7.5.2 Selection of K_2 and K_3 :

The values of K_2 and K_3 will depend upon the eccentricity of the characteristic required for the farthest



(a) SYSTEM UNDER CONSIDERATION



(b) VARIATION OF VOLTAGE AT THE RELAY LOCATION

FIG. 7-11 SYSTEM UNDER CONSIDERATION FOR RELAY SETTING fault in the protected section. The values of K_1 (corresponding to initial setting) and K''(eccentricity) when substituted in (7.3) will furnish the value of K_3. The constant K_2 may be chosen as equal to K_3 .

7.5.3 Effect of Z_S / Z_L Ratio And Fault Location On The Shape Of The Characteristic :

To determine the effects of Z_S / Z_L ratio and the fault location on the shape of the characteristic a computer programme was run. The considered parameters and the results of the computer programme obtained are presented in the Appendix.

7.6 PERFORMANCE TESTS :

The relay described in section 7.2 was constructed and tested for both steady-state and dynamic conditions. Plate 7.3 shows a typical printed card of the relay (front view) and plate 7.4 shows its rear view . The results obtained during the testing are presented in the Appendix.

It is clear from the tests that the relay has sufficiently low transient over-reach(less than 7.5 percent) for an adequately large source/line impedance ratio. Further the relay maintains good accuracy for the entire range of operation.

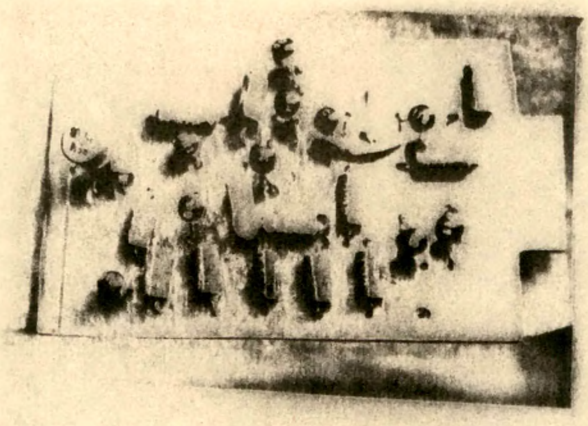


Plate 7.3 Typical Printed Card
(Front View)

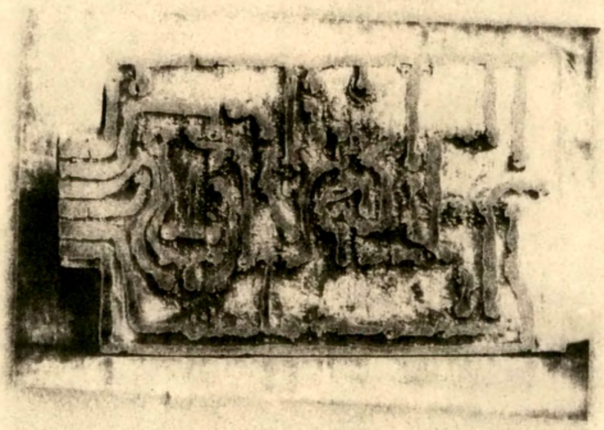


Plate 7.4 Typical Printed Card
(Rear View)