HYBRID CHARACTERISTICS
IN
DISTANCE RELAYING

By

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A Dissertation
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CERTIFICATE

Certified that the dissertation entitled HYBRID CHARACTERISTICS IN DISTANCE RELAYING which is being submitted by Sri T. Subba Rao in partial fulfilment for the award of the Degree of Master of Engineering in POWER SYSTEMS of University of Roorkee is a record of student's own work carried out by him under my supervision and guidance. The matter embodied in this dissertation has not been submitted for the award of any other Degree or Diploma.

This is further to certify that he has worked for a period of 11 (Eleven) months from December 64 to October 1965 for preparing dissertation for Master of Engineering Degree at the University.

Signature

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Dated 14·11·65

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Roorkee SUBBA RAO

SYNOPSIS

The conventional distance relays which are in use till now, have got straight line and circular characteristics represented on R-X diagram. The development of static relays made it possible to construct relays with new types of characteristics like elliptical hyperbolic and still complicated characteristics. This dissertation is an attempt to investigate into the experimental requirements needed to obtain these characteristics and their applications. Performance requirements of relays for application to long transmission lines and problems arising out of the modification of impedance seen by relays in multi-terminal lines have been discussed and the use of these new characteristics is shown. A static distance relay with adjustable elliptical and hyperbolic characteristics using rectifier bridges has been constructed and experimental curves are given. There are some definite fields of application for these new characteristics and the use of transistor circuits permits to construct relays with omnibus characteristics to cope with the increase in length of lines and the number of interconnections.

CONTENTS

INTRODUCTION

The protection of transmission lines is one of the most important, difficult and interesting branches of the relaying art. One should appreciate the fact that the majority of the faults occurs on transmission lines rather than on buses or apparatus. The following are the types of protection employed for transmission lines:

a) Over-current protection
b) Distance protection
c) Pilot wire protection
d) Carrier relaying, with and without distance relays.

For a long time it was the practice to apply over current relays for the protection of lines. It is because the over-current relays are simplest in application, reliable in operation and cheapter in cost. But with the increasing demand for power and increasing growth and complexity of systems it became difficult or say impossible to obtain selectivity with the slow speed overcurrent relays, because of the problem of choosing time settings which are correct under all conditions. Even when the selectivity is achieved the operating time of some of the relays is unnecessarily long.

Sufficiently quick clearance of short circuits within the limits of the protected section and the back up protection of the following sections together with the relatively low cost of distance protection has enabled the widespread extension of the distance principle as the basic and back-up forms for the high voltage networks, especially when there are a large number of sections and several supply sources. The pick up characteristics of distance relays used namely impedance, reactance and Mho relays can be represented by straight lines or circles when plotted on R-X diagram. The relay operates when the tip of the impedance vector which is determined by the ratio of voltage and current applied to its terminals is placed within the limits of the region.

Distance relays with these characteristics were satisfactory for the protection of any types of line. But due to the increased use of longer and more heavily loaded transmission lines operating at or near the stability limit and increase in the number of interconnections, demands for greater reliability of service, and switching arrangements utilising a minimum number of circuit breakers, the problem of protection presents an even greater challenge to the ingenuity of relay engineers. The existing distance relays with straight line or circular characteristics cause increasing incorrect operations. Development of static comparators using vacuum tubes, transistors and rectifier bridge comparators made possible to construct distance relays with elliptical, hyperbolic and still complicated characteristics. The elliptical characteristic covers very narro-w tripping area represented in R-X diagram and will strictly envelope the over all assembly of operating points of the defective line and will not run the risk of including zones of healthy operation.

Investigations to obtain the elliptical distance relay characteristics have been started in 1954, by Grevenko and others (19). They have shown that with three inputs fully rectified and applied to the three coils of moving coil rela elliptical characteristic can be obtained. It is however possible to use only a single coil relay and simplify the circuit which has been done by the author.

With the use of transistor circuits there is a great flexibility in constructing relays with omnibus characteristics to suit any application in High Voltage interconnected networks.

CHAPTER I

DISTANCE RELAYS WITH CONVENTIONAL CHARACTERISTICS AND THEIR APPLICATIONS

CHAPTER - I

DISTANCE RELAYS WITH CONVENTIONAL CHARACTERISTICS AND THEIR APPLICATIONS:

1.1 - Characteristics of Distance Relays in the Impedance and Admittance Planes

The conventional distance relays till now used have got straight line or circular characteristics when drawn in the impedance plane. The relay operates if the tip of the impedance vector which is determined by the ratio of voltage and current applied to the relay terminals, is placed within the limits of the region of the complex plane limited by the relay characteristic. When the tip of the impedance vector is moved to another part of the complex plane, the relay does not operate if this part is outside the limits of the characteristic in question.

Considering the operating characteristics drawn in the complex impedance plane, we can distinguish the following main types of relays.

1. Non-directional distance relay with a circular characteristic with the centre at the origin called impedance relay.
2. A directional distance relay with a circular characteristic, passing through the origin called Mho relay or admittance relay.
3. Distance relay with a displaced circular characteristic of general form in the impedance plane.

4. The non-directional distance relay with a straight line characteristic parallel to the R-axis in the impedance plane called Reactance Relay.

The characteristics of these distance relays are shown in Fig. (1) both in the impedance plane and admittance plane.

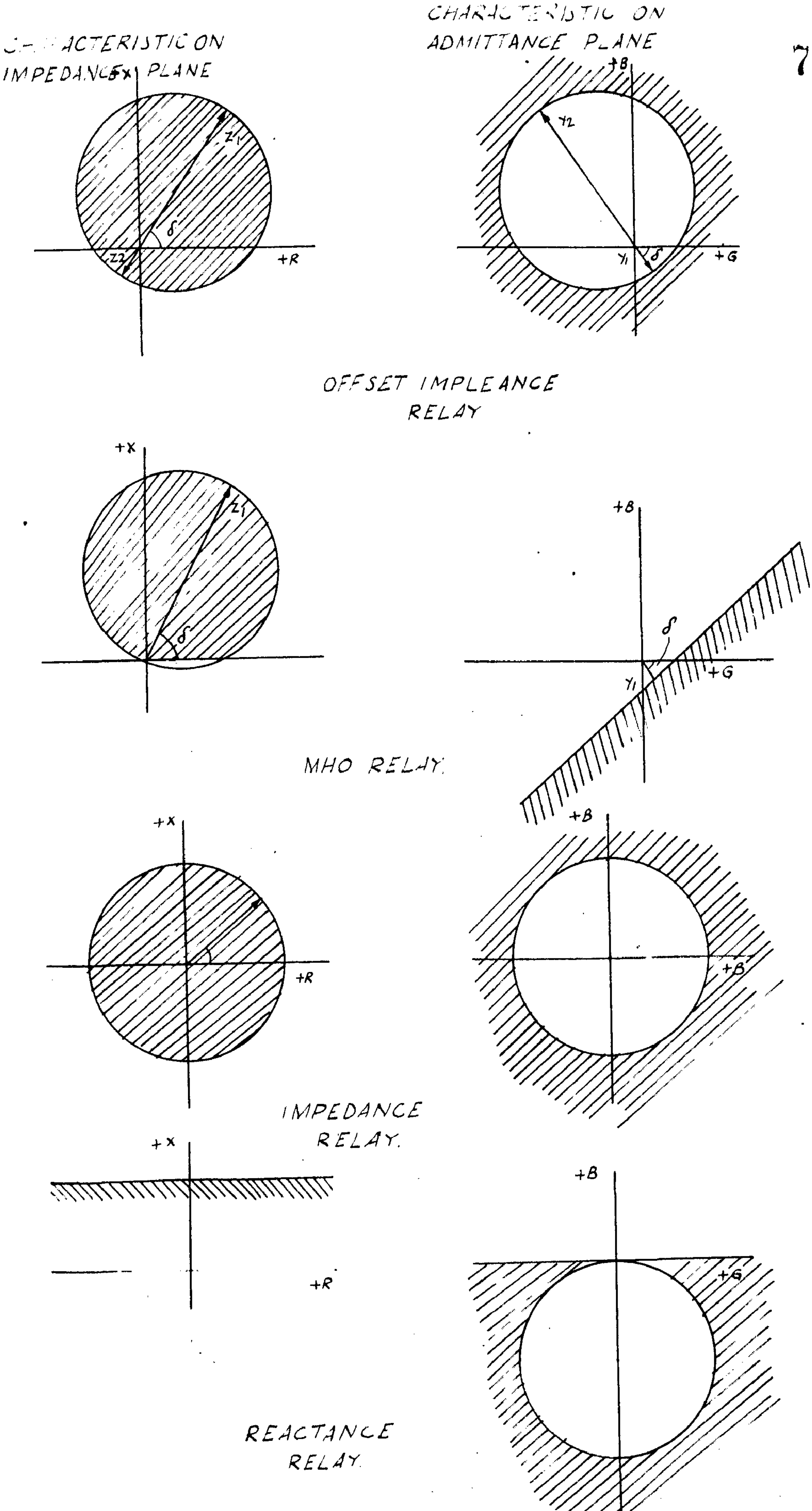
These characteristics are obtained by the comparison of the voltage and current by electromechanical principles.

1.2. General Impedance Equation of an Electromagnetic Relay

The operation of any electromagnetic relay involves the resultant torque produced in the element by the application of a current and/or voltage and the interaction of current and the voltage. In the case of a distance measuring element, the resultant torque at the balance point must be equal to zero and the following general equation(1) may be written to express the fact:

$$+ K_v V^2 - K_i I^2 - K_{iv} IV \cos(\phi_v - \phi_i - \psi) = 0 \quad .....(1{\cdot}1)$$

in which the first term is indicative of the torque produced by the voltage alone tending to open the contacts and the second term is indicative of the torque produced by the current alone tending to close the contacts, and the third term indicates the interaction torque in which the angle ψ is the vector angle between current and voltage at which this interaction torque is maximum.



OFFSET IMPLEANCE RELAY

MHO RELAY.

IMPEDANCE RELAY.

REACTANCE RELAY.

FIG. 1

Equation (1) may be expressed in terms of Z, the effective impedance presented to the relay, by dividing by $K_v I^2$,

$$Z^2 - \frac{K_{iv}}{K_v} Z \cos(\phi_z - \psi) = \frac{K_i}{K_v} \quad .....(1\cdot 2).$$

Equation (2) may be transformed into the following form by the addition of $\frac{K_{iv}}{2K_v}$ to both sides.

$$Z^2 + \frac{K_{iv}}{2K_v} - \frac{K_{iv}}{K_v} Z \cos(\phi_z - \psi) = \left[\frac{\sqrt{K_{iv}^2 + 4 K_i K_v}}{2K_v}\right] \quad (1\cdot 3)$$

Equation (3) will be recognised as the equation of a circle expressed in terms of the polar coordinates Z and ϕ_z. The radius of this circle is $\sqrt{K_{iv}^2 + 4 K_i K_v}/2 K_v$ and its centre is located at a distance $K_{iv}/2 K_v$ from the origin at the angle ψ, from the reference vector.

Equation (2) is a quadratic and may be solved for Z, giving the following expression:

$$Z = \frac{K_{iv}}{2 K_v} \cos(\phi_z - \psi) \pm \frac{\sqrt{K_{iv}^2 \cos^2(\phi_z - \psi) + 4 K_i K_v}}{2 K_v} \quad .(1\cdot 4)$$

By the proper evaluation of constants, equation(4) may be made to assume the following forms which are characteristic of the various types of distance relays. That is by supplying with proper input quantities, the unit can be made to give an operating characteristic of any of the conventional distance relays.

1.2.1 - Impedance Relay

$$K_{iv} = 0$$

Substituting in equation(1.4).

$$Z = \sqrt{\frac{K_i}{K_v}} = K \text{ (Constant)}. \quad --(1.5)$$

The operating characteristic of this relay is shown in Fig. (2) is a circle with origin as centre and radius equal to $K = \sqrt{\frac{K_{iv}}{K_v}}$

1.2.2. - Reactance Relay:

$$K_v = 0 \qquad \psi = 90^\circ$$

Substituting in equation).

$$Z = \frac{K_{iv}}{2K_v}\cos(\phi_z - \psi) \pm \frac{K_{iv}\cos(\phi_z - \psi)}{2K_v}\left[1 + \frac{4K_i K_v}{K_{iv}^2\cos^2(\phi_z - \psi)}\right]$$

$$= \frac{K_{iv}}{2K_v}\cos(\phi_z - \psi) \pm \frac{K_{iv}}{2K_v}\cos(\phi_z - \psi)\left[1 + \frac{4K_i K_v}{2K_{iv}^2\cos^2(\phi_z - \psi)} + \cdots\right]$$

$$= \frac{K_{1v}}{2K_v} \cos(\phi_z - \psi) \pm \left[\frac{K_{1v}}{2K_v} \cos(\phi_z - \psi) + \frac{4K_1}{4K_{1v} \cos(\phi_z - \psi)} \right]$$

$$= \frac{K_1}{K_{1v} \cos(\phi_z - \psi)}$$

$$= \frac{K_1}{K_{1v} \sin\phi_z} \quad \text{when} \quad \psi = 90^\circ$$

$$= \frac{K}{\sin \phi_z} \quad \text{where} \quad \frac{K_1}{K_{1v}} = K$$

or $Z \sin \phi_z = K$

or $X = K$. ---.(1·6)

In other words, this relay has an operating characteristic ~~such that all impedance~~ such that all impedance radius vectors whose heads lie on this characteristic have a constant X- component The operating characteristic for this relay is a straight line parallel to resistance axis and is at a distance of $K = \frac{K_1}{K_{1v}}$ as shown in fig. (8).

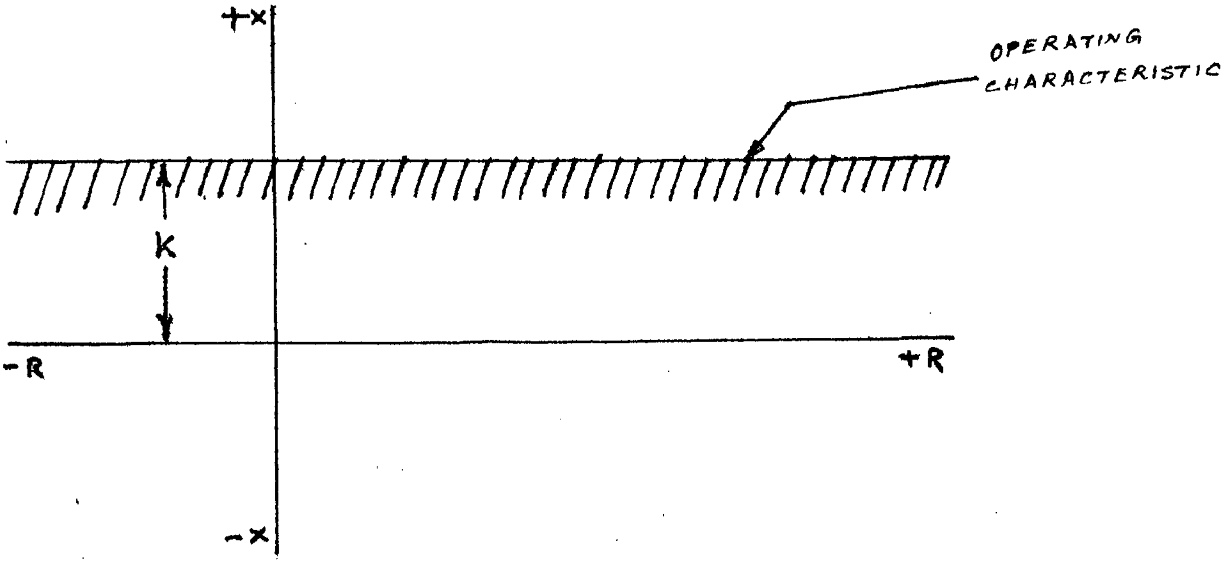


Fig. 8. Characteristic of Reactance Relay

The significant thing about this characteristic is that the resistance of the impedance has no effect on the operation of the relay; the relay responds solely to the reactance component.

1.2.3. Mho Relay or Admittance Relay:

$$K_i = 0$$

From equation (1·3),

$$Z = \frac{K_{iv}}{2K_v}\,\mathrm{Cos}\,(\phi_s - \psi) \pm \frac{K_{iv}\,\mathrm{Cos}(\phi_s - \psi)}{2K_v}$$

$$= \frac{2K_{iv}}{2K_v}\,\mathrm{Cos}(\phi_s - \psi)$$

$$= \frac{K_{iv}}{K_v}\,\mathrm{Cos}\,(\phi_s - \psi)$$

$$= K\,\mathrm{Cos}\,(\phi_s - \psi) \quad \text{- - - -} \quad (1{\cdot}7)$$

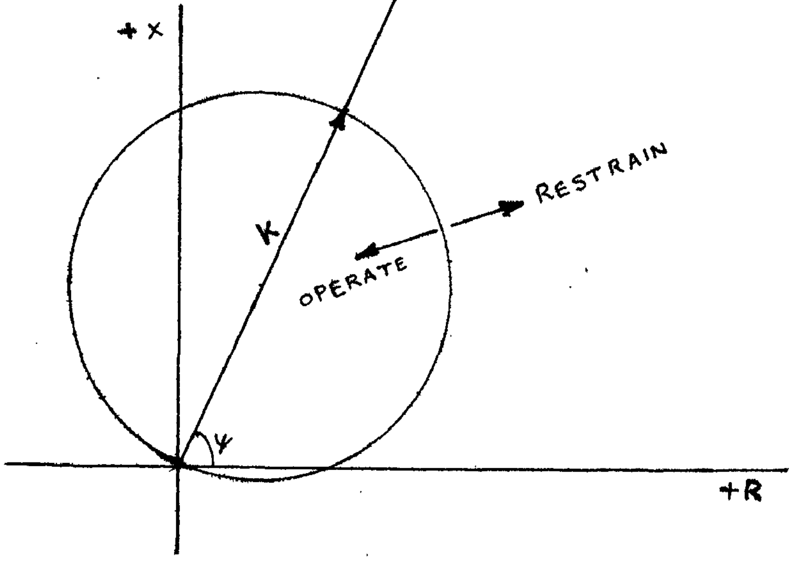


Fig. (4) Characteristic of a 'Mho' Relay

1.3. Applications and limitations of Impedance, Reactance and Mho Relays:

1.3.1. Impedance Relay:

As it has already been shown that the operating characteristic of an impedance relay is a circle with centre as origin and the relay would operate for any impedance falling within the circle, it follows that the relay itself cannot discriminate between internal and external faults.

For example, in the fig.(5), let AB represent one line and AC, a second line in series. Then with a relay located at A, the line AB would represent a transmission line in front of the relay and AC a transmission line behind the relay.

As it is necessary in most applications to discriminate between these two lines, it is essential to add a directional relay to limit the relay operation to one line. The characteristic of this relay is represented by the line D-D so that the relay is now capable of operation only for faults occuring within the shaded portion of the circle.

1.3.2. REACTANCE RELAY:

Since the reactance relay measures only the reactance and ignores the resistance component, it is indispensible for very short lines where the arc resistance may be comparable with the line impedance. Like the impedance relay, the reactance relay requires a directional unit; this unit will be usually of the mho type. The reactance relay is applicable to lines not subject to overload or power swing conditions which represent an impedance low enough to across the relay characteristic. Whether this will occur can be found only by calculation of the swing impedance. Reactance type relays have also become the standard preference in most countries for protection against ground faults owing to the high resistance component often found in ground faults(2)(3)

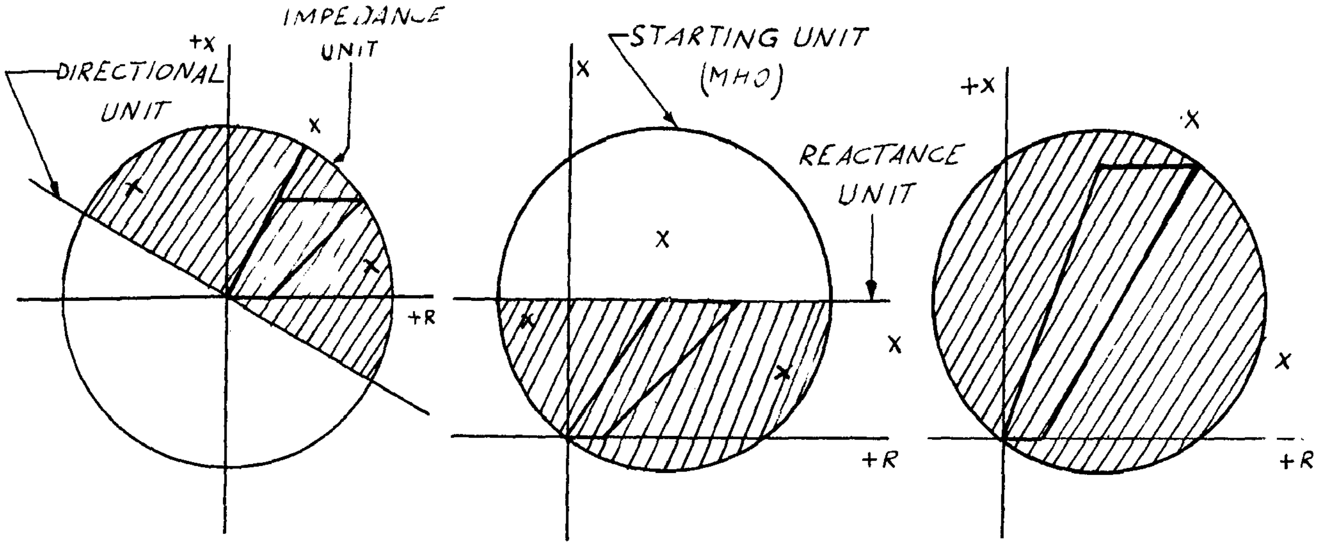
1.3.3. Mho Relay:

The mho characteristic is suited ideally for protecting long or heavily loaded transmission lines because it is less likely to trip on power swings than the conventional reactance or impedance relays(4) Another desirable feature is that a relay for phase faults should operate only on faults involving the phase pair with which the relay is associated. All other faults or system conditions should not affect it. In fig.(6) it can be seen that the large tripping area of the impedance characteristics of the impedance and reactance relays shows that these relays are susceptible to power swings and faults in other phases (denoted by asteriks) where as the snug fit of the Mho circle around the fault area shown in fig. 6(C) indicates that the Mho relay effectively prevents the tripping for power swings and for any faults but those for which the relay is set to operate.

The fact that the Mho unit combine sensitive directional action with accurate ohmic measurement means that one Mho unit does what two conventional units did before. This not only eliminates the contact races that can occur between the directional element and the measuring element but obviously simplifies the circuits to which the relay is applied.

The Mho relay has got limitation for application to short lines, because on very short lines, even with memory action the torque is likely to be low during second zone fault after the memory action has expired.

Arc resistance also places a limit on the shortness of a line to which the Mho unit can be applied. Arc resistance increases as the current decreases and becomes more effective on short lines. This is in the same direction as the other



(a)

(b)

(c)

THE RELAYS TRIP IN THE SHADED AREA

CROSSES ARE CONDITIONS FOR WHICH TRIPPING IS UNDESIRABLE

FIG. 6

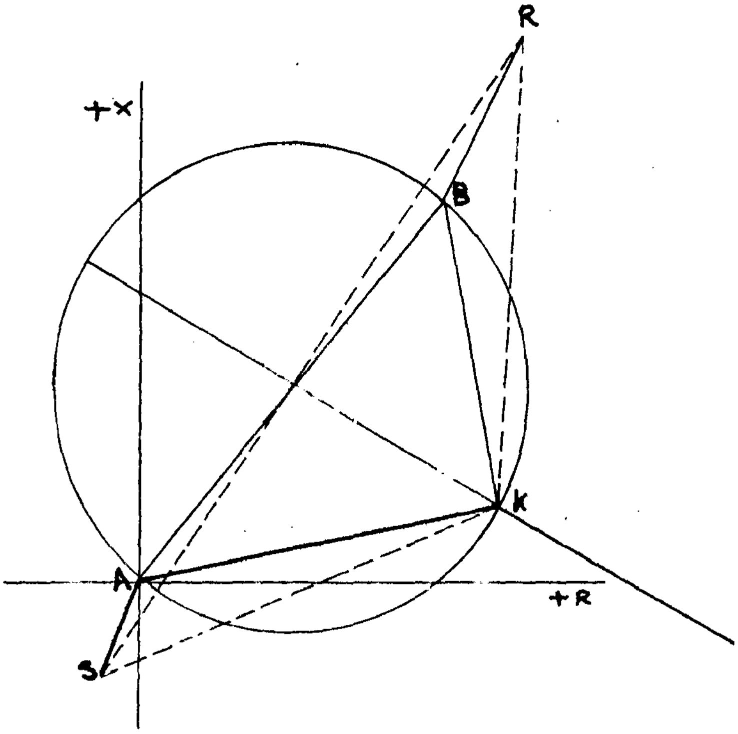


FIG. 7

limitation of minimum voltage to provide adequate torque.

1.6. BEHAVIOUR DURING POWER SWINGS:

It is said that a Mho relay will permit larger power swings than other impedance or reactance relays without any false operation. The maximum power swing angle that the Mho characteristic will allow without false operation can be found geometrically as shown in fig.

Referring to fig.(7)AB is the impedance of the protected section, SA is the system impedance beyond terminal A and BR is the system impedance beyond terminal B.

Draw a perpendicular through the mid point of RS. From K where it cuts the relay characteristic draw lines to R, S, A and B. RKS is the angle O_0 between the generated EMF's at R and S at which the relay at A will operate. BKA is the angle O between the terminal voltages at A and B at which the relay at A will trip and AK is the impedance it sees.

The power swing locus is shown as a straight line. This implies equal generated electromotive forces and no line capacitances. The swing impedance locus for other cases is discussed in chapter VI.

If the phase angle of the Mho characteristic is made same as that of the impedance of the line the latter becomes a diameter of the circular Mho characteristic. Hence from the diagram, it can be seen that the maximum power swing angle between terminal voltages that is allowed by the Mho relay without tripping is 90°. And if the circular characteristic is made slightly lagging (to accomodate for arc resistance) the power swing allowed will be still less than 90°.

The ideal requirements of a relay is that it should not trip on power swings from which the system would be likely to recover that is roughly upto a power swing angle of 110 degrees between the voltages at the ends of the line. This means that even the Mho characteristic will be large enough to trip un-necessarily on power swings because even at 90° degrees, the power swing locus will enter the operating characteristic of the Mho relay and thus trip the line un-necessarily.

CHAPTER II

DEVELOPMENT OF STATIC RELAYS

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In view of the widespread interest in electronic devices of all kinds, it is not surprising that protection engineers have developed a keen interest in electronic protective relays. This interest however has not resulted in general enthusiasm for such relays because many relay engineers are thoroughly satisfied with electromagnetic relays. On the other hand some operators would welcome a complete line of electronic relays. Some of the latter group have been inclined to attribute the lack of interest in electronic relays to, what is to them a reactionary attitude.

2.1. ADVANTAGES OF ELECTRONIC RELAYS:

The following are the advantages of static relays over electromagnetic relays.

a) Low burden on current transformers and voltage transformers.

b) Absence of mechanical inertia and 'bouncing' contacts

c) Very fast operation.

d) Flexibility in the building up of the relays with most complicated operating characteristics.

Static Relays can be divided broadly into two categories:

a) Relays using Vaccuum tubes

b) Relays using transistors.

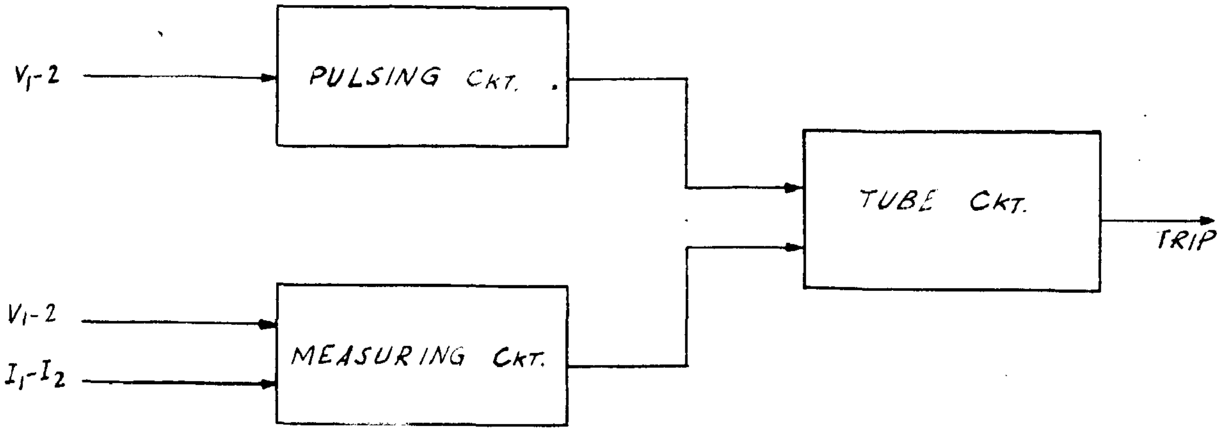
2.2. RELAYS USING VACCUM TUBES:

Proposals for electronic relays are not new and references relating to their application to power system protection may be found in the literature from 1927 onwards. In that year(5) Fitzgerald published a paper describing a scheme for an electronic pilot relay system to overcome the limitations of pilot wires when operating over considerable distances. This scheme was abandoned because of the short life and the high cost of the tubes available at that time, but a somewhat similar scheme (6) is now in active use as the phase comparison relay. Fitzgerald's was the first well known application of electronic protective relays.

In 1934, Rolf Widroe(7) described electronic circuits for most of the common types of protective relays using thyratron tubes. A thyratron, when a certain value of voltage applied to its grid does not fire but when once the voltage is raised above a given threshold it will fire. This principle is used to produce relays such as undervoltage, over-voltage, power directional and distance relays. Input circuits consisting of transformers, metal rectifiers and linear R, L, C circuit components for summation and comparison of the input quantities and always a single output voltage is applied to the thyratron grid.

In 1938( ) in the United States, a laboratory sample of electronic reactance relay was built and tested, but at that time the electromagnetic reactance relay was fully adequate for the needs of the industry and no steps were taken to put the electronic relay into production.

Macpherson, Warrington and McConnell(8) in 1948, published a paper describing an electronic Mho relay. The 'Mho' characteristic is obtained by comparing the line voltage with line current at the moment of line voltage maximum. The complete unit consisted of three basic elements, a pulsing circuit, a measuring circuit and a tube circuit as shown in block diagram below.



The function of the pulsing circuit is to generate a pulse at the moment of the line current maximum. The pulse is used to overcome a large grid bias and permit a tube to conduct. The measuring circuit will compare the line voltage with line current. It consists of a transformer supplied with line to line voltage and a transductor supplied with the corresponding line currents. The tube circuit is the sensitive element which is responsive to signals from both the measuring circuit and the pulsing circuit. The tube circuit also initiates the tripping signal to the circuit breaker when the impedance being measured falls below that for which the relay is set to operate. The operating equation of the relay has been shown to be,

$$K E_{max} \text{Sin } wt = K' I_{max} \text{Sin } (wt + \theta - \phi) \quad \ldots \quad (2.1)$$

considering the moment the line voltage maximum, where the measuring takes place i.e. $wt = 90^\circ$.

$$K E_{max} = K' I \cos(\phi - \theta)$$

$$\text{or} \quad Z = \frac{K'}{K} \cos(\phi - \theta) \quad - - - (2.2)$$

which is the polar equation of a Mho circle.

It is also stated that the relay may be made to have reactance characteristic by causing the measuring moment to occur at the instant of line current zero.

The field experience with this type of relay is described by Barnes and Macpherson in 1953.(9)

Loving in 1949(10) described electronic circuits to perform complete relaying functions, ex. distance, directional, over-current etc. In 1954, Bergseth(11) published a paper on direct phase comparison distance relay using a diode coincidence circuit while in the same year Kennedy(12) described an electronic carrier relaying scheme using no electromagnetic relays at all, even tripping being performed by the use of a heavy duty thyratron.

However there are certain limitations( ) with static relays using thermionic tubes like the requirement of special power supplies for valve heaters and provision of appreciable voltages for valve anodes and electrode bias.

2.3. RELAYS USING TRANSISTORS:

The heavy power supplies required for thermionic valves, together with the increased confidence in transistors have attracted the attention of protective engineers to the desirability of building relays with transistors.

A substantial body of literature already exists on transistorised relays. In 1956, Colin Adamson and Wedepohl of Manchester college of technology described a Mho relay with junction transistors(13) The block diagram of the circuit used is shown in fig.(8·b).

V_1 and V_2 are derived from system voltage and current. The coincidence circuit is such that it produces a rectangular output voltage, the duration of which is the period during which both the voltages V_1 and V_2 are both instantaneously positive. The integrating circuit converts this voltage block into a triangular wave form, the peak amplitude of which is a measure of the duration of coincidence. The level detector is a circuit which produces an output voltage pulse when its input voltage attains a pre-determined level.

The circuit represented by the block diagram is adjusted in such a way that for a phase displacement of 90 degrees (electrical) between voltages V_1 and V_2, the peak voltage attained in the integrating circuit is just sufficient to operate the level detector, and for phase displacement greater than 90 degrees, it is insufficient to cause operation. The schematic circuit of direct phase comparison relay described is shown in fig.(8·a).

When T_1 and T_2 are switched off simultaneously, the capacitor C commences to charge according to the law.

$$v_c = - V_c (1 - e^{-t/CR})$$

CR is so arranged that when $t = 5$ millisec. (0.25 cycle) $v_c = - V_b'$; thus the voltage on the condenser counteracts the effect of the bias V_b' on T_3, and T_3 switches on, causing the operation of the relay P. As soon as either V_1 or V_2

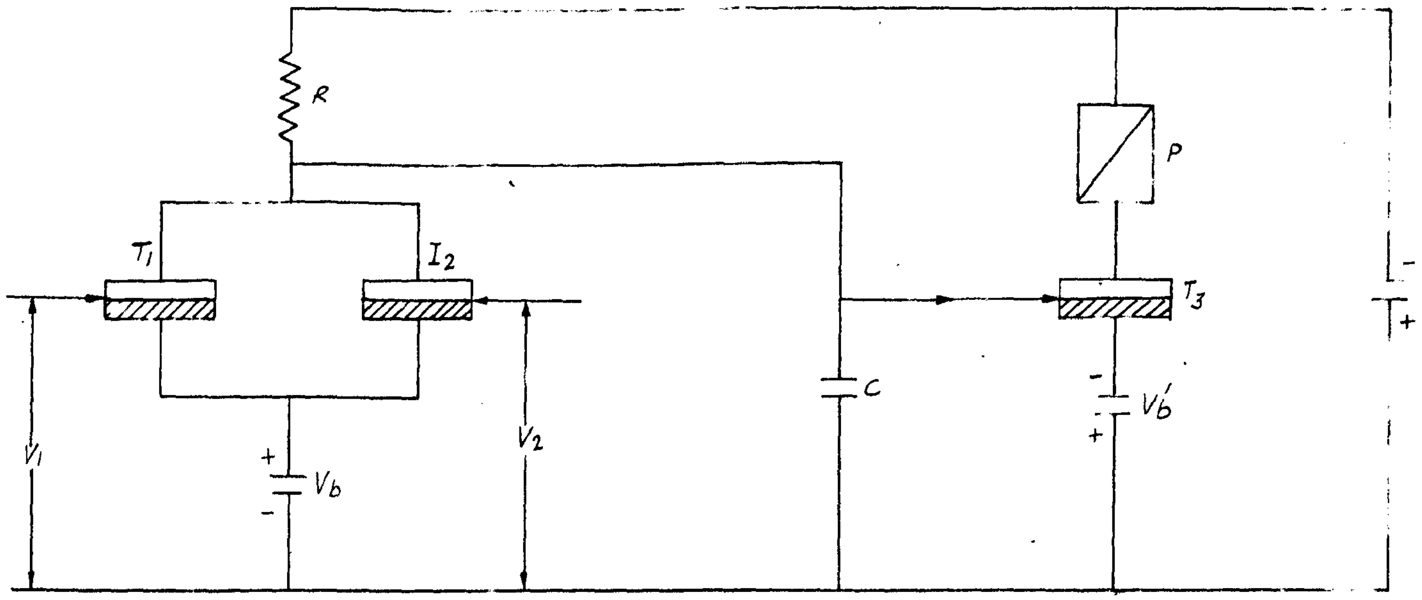

R
P
T1
I2
T3
C
Vb
Vb'
V1
V2
+
-
+
-
-
+

FIG. 8 (a)

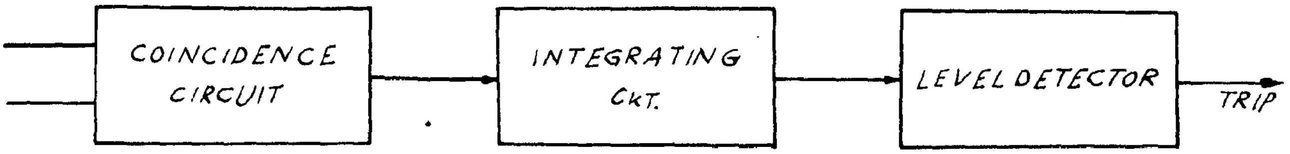

COINCIDENCE CIRCUIT
INTEGRATING CKT.
LEVEL DETECTOR
TRIP

FIG. 8 (b)

becomes zero or negative, C discharges. It is thus necessary for V_1 and V_2 to be simultaneously positive for more than 90 electrical degrees; this corresponds to a phase displacement between V_1 and V_2 of less than 90° before operation can occur.

But the distance relay with above principle found to be affected greatly by D.C. transients that the relay over-reaches. The same authors later published a modified form of above type(14), which they claimed to be free from maloperation due to D.C. transients. In this, the block diagram of which is given below, (FIG 9) consists of two identical phase comparators energised with V_1, V_2 and $-V_1$, $-V_2$ respectively. The outputs from the two comparators are fed to the coincidence circuit arranged so that an output signal is generated only when both comparators indicate a fault simultaneously.

In 1962, Fabrikant, a Russian Engineer published about a transistorised phase comparator(15). The difference between this and the circuit given by Adamson is that the time of coincidence of the input electrical quantities is compared with non-coincidence time, not with a specified time. It is claimed that false operation is less likely during transients, large power input signals are permissible and the system is less affected by ambient temperature. The system is however more complicated.

However it is only in one field, electronic protection has been successfully applied, that is in carrier relaying. The reason is that carrier relaying has accomplished a solution for highly difficult problem of comparing conditions at the ends of a transmission system where economically it was not possible by other means. The literature on this aspect is quite extensive(5)(6) (16) (17)

The life of transistors is, at present, unknown, although it is claimed that their operating life at normal rating will be many times that of conventional thermionic valves and that their shelf life is almost indefinite. Progress and developments in transistors is rapidly bringing their rating and power into a situation where they will be of real practical value in the design and development of new protective gear systems and relays.

CHAPTER III

MULTI-INPUT COMPARATOR CIRCUITS FOR DISTANCE RELAYS

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3.1. REVIEW:

Investigations into the working of multi-input comparators have been only of recent origin, as the first investigation in this field seems to have been initiated by Hoel(18) in 1950.

He has shown that for a moving coil relay with three or more coils energised from fully rectified currents i_1, $i_2 \ldots i_n$, i_n, the relay operates according to the equation,

$$\pm|i_1| \pm |i_2| \pm |i_3| \pm \text{--------} \pm |i_n| = 0 \quad ..(3\cdot1)$$ in the ideal case.

The $\pm$ sign indicates that the rectifiers are connected either in operate or restraint condition. In this way relays with elliptical, hyperbolic or more complex characteristics can be obtained. Based on this theory, a practical relay appears to have been developed in 1956(19)(20). It gave an elliptical characteristic and the expression for the torque was given as

$$T = K \; | IZ_R | - |V_R - \frac{I Z_R}{2} (1 - C)| - |V_R - \frac{I Z_R}{2}(1 + C)| - \quad (3\cdot2)$$

where V_R and I are short circuit voltage and current at the relay terminals referred to secondary terminals.

Z_R = Impedance of the protected section referred to the relay input terminals.

C = eccentricity of the ellipse.

If we put $\dfrac{Z_R (1 - C)}{2} = Z_1$

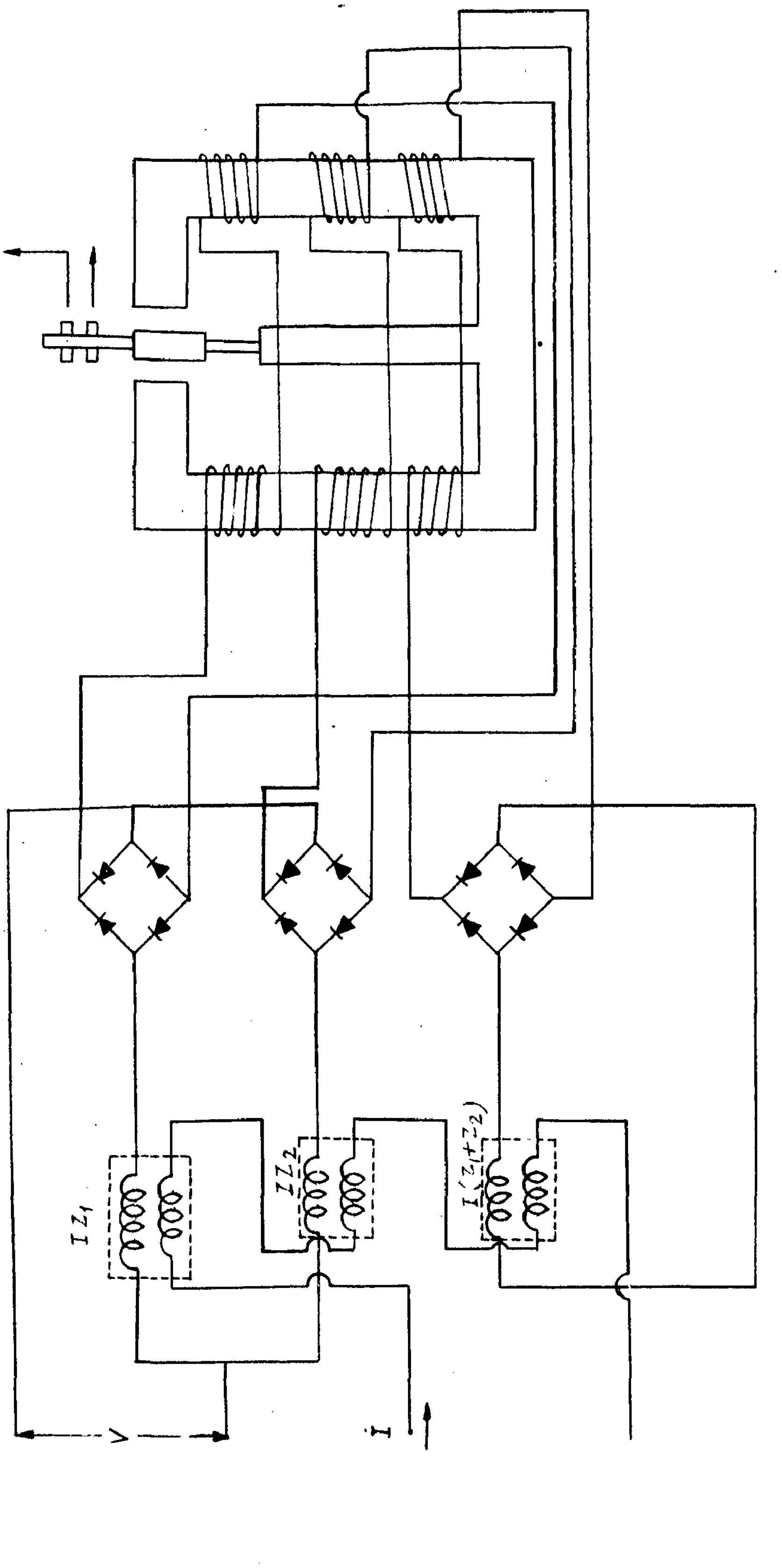


FIG. 10.

and $$\frac{Z_R(1+C)}{2} = Z_2$$

Then $Z_R = Z_1 + Z_2$

Equation (2) can be written as

$$T = K \ |I(Z_1 + Z_2)| - |V_r - IZ_1| - |V_r - IZ_2| \qquad \ldots(3{\cdot}3)$$

The circuit used by Gaevenko(19) consists of three full wave rectifier bridges, the outputs of which are fed to the three coils of a moving coil relay as shown in Fig. (10).

The inputs to the three rectifier bridges are proportional to the quantities represented in the equation (3·3).

The outputs of the three rectifier bridges is to be completely smoothened out without introducing time delay and for this purpose split phase circuits and polyphase rectifier bridges(21) were used. Relays with oval and other special characteristics appears to have been developed using non-linear elements.

Investigations into the working of multi-input comparators were continued by Wedepohl(22). The two main types of multi-input comparators that were investigated by Wedepohl were (1) The three input transistor phase comparator (2) The three input rectifier bridge comparator. In Wedepohl's view ''Complex characteristics may be obtained with relative ease with the relay circuits described above (multi-input comparators)''

3.2.1. - Three Input Transistor Phase Comparator:

This is shown in Fig.11(a) using three transistors. The three inputs are V_1, V_2 and V_3. It is necessary for V_1, V_2 and V_3 to be instantaneously positive for more than quarter of a cycle, for the relay to operate. As soon as one or more of the three inputs signals becomes negative, coincidence ceases. A large number of characteristics were obtained as 'Mho' 'Ohm' and directional characteristic with inputs of the form,

$$V_1 = I\,Z_R - V$$

$$V_2 = V \underline{|\alpha}$$

$$V_1 = I\,Z_R \text{ or } I\,Z_R'$$

The characteristics one of which is shown in Fig. 11 (b) consisted of arcs of circle and straight lines forming discontinuous polar curves.

3.2.2 - Three Input Rectifier Bridges Comparator:

This is shown in Fig. 12(a) using three rectifier bridges. The three inputs are i_1, i_2 and i_3 and the input transistor is cut off when the output is zero. Hedepohl analysed this circuit in terms of an equivalent 4 input phase comparator using transistors where the equivalent inputs should be:

$$i_a = i_1 + i_2 + i_3$$

$$i_b = i_1 - i_2 - i_3$$

$$i_c = i_1 + i_2 + i_3$$

$$i_d = i_1 - i_2 + i_3$$

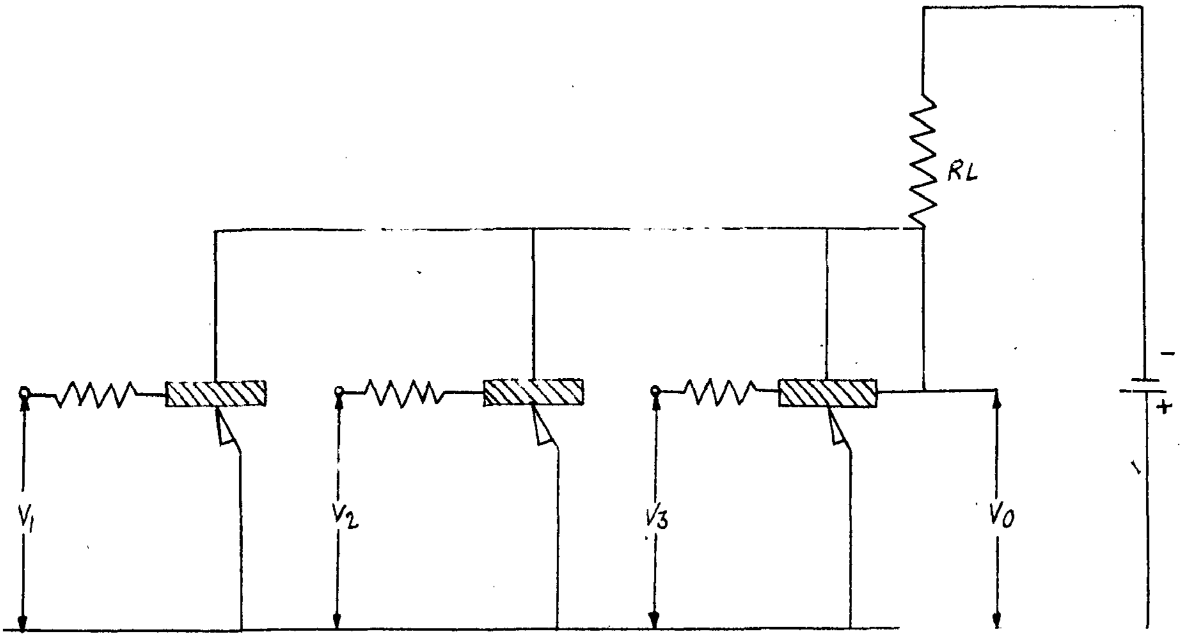


FIG.11(a) THREE INPUT TRANSISTOR PHASE COMPARATOR

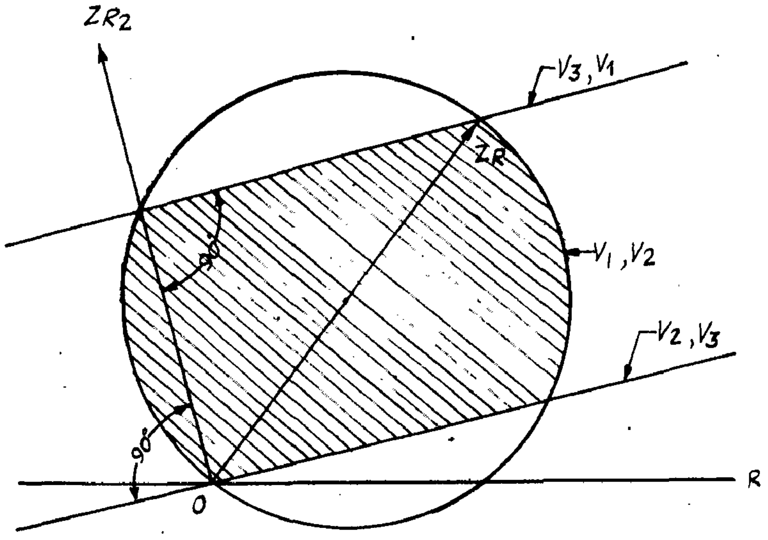


FIG.11(b) ONE OF THE CHARACTERISTICS OBTAINED WITH THE COMPARATOR

This equivalent circuit is shown in Fig. 12(b). Output is produced only when all the four inputs are simultaneously positive. The six signals to be compared in amplitude are,

i) $(I_2 + I_3)$, I_1 ;   ii) $(I_1 + I_2)$, I_3

iii) $(I_1 + I_3)$, I_2 ;   iv) $(I_1 - I_2)$, I_2

v) $(I_1 - I_2)$, I_3 ;   vi) $(I_2 - I_3)$, I_1

where capital I represents rms magnitude of currents i_1, i_2 and i_3. The characteristics would have a common area bounded by the six 2-input characteristics with inputs of the form

$$I_1 = 2I\,\underline{/45^\circ}$$

$$I_2 = \frac{V}{R}$$

$$I_3 = I - \frac{V}{R}$$

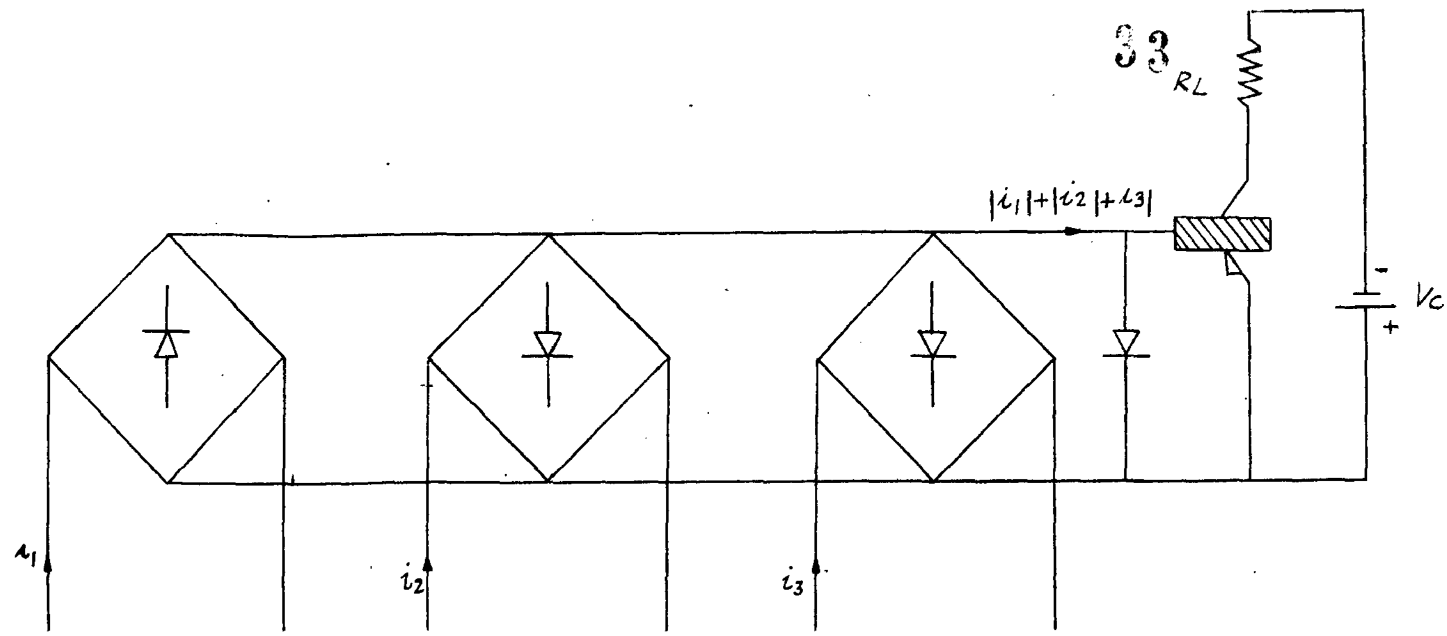
One of such characteristics is shown in Fig. 12(c)

3.3.1 - Conic Characteristics for Distance Relays:

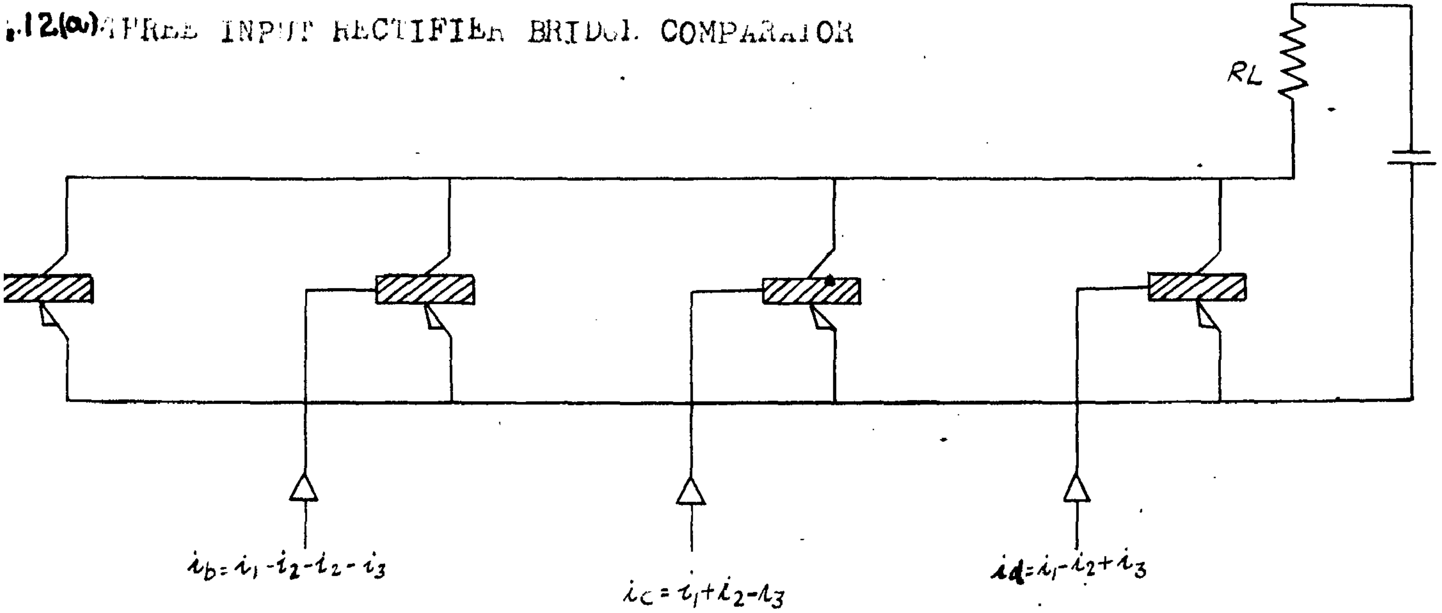
The application of multi-input comparator circuits for the distance relays with special characteristics has been investigated by [illegible] Rao (23). It is found that by combining the outputs of phase comparator and amplitude comparators, any type of conic characteristics can be obtained for distance relays.

3.3.2 - Elliptical Impedance Characteristics with Directional Bias

A new type of rectifier phase comparator has been



.12(a)·THREE INPUT RECTIFIER BRIDGE COMPARATOR



.12(b)·EQUIVALENT TRANSISTOR PHASE COMPARATOR

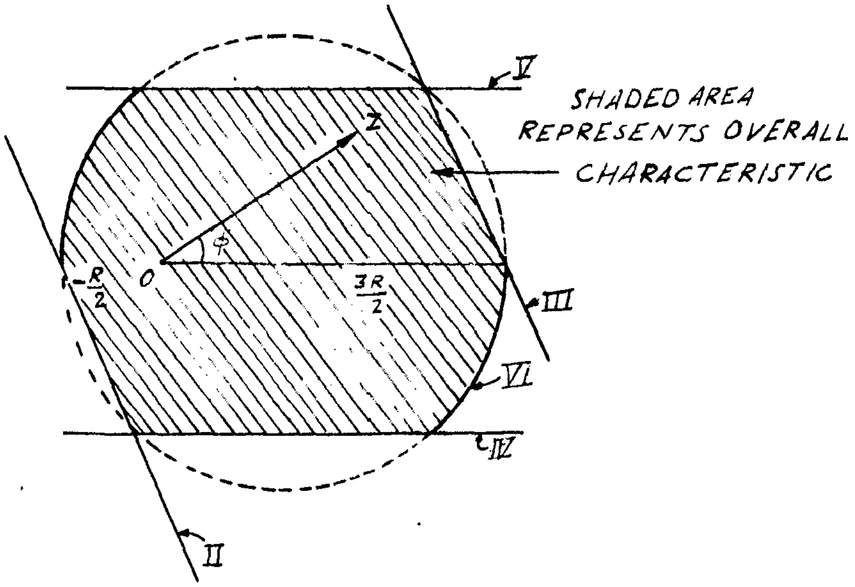


FIG.12(C)·ONE OF THE CHARACTERISTICS OBTAINED WITH [illegible] investigated by him, the output of which is proportional to the cosine of the phase angle between the two input signals.

In an amplitude comparator working as an impedance relay, the inputs are $I\,Z_R$ and V_r where V_r is the fault voltage. The torque is zero when $|I\,Z_R| = |V_r|$. The output of this comparator is compared with the output of the rectifier phase comparator whose output is equal to $I.\ V_r \text{ Cos } \theta$.

For amplitude comparator, torque is zero when

$$|I| = \left|\frac{V_r}{Z_R}\right| \qquad \text{and}$$

$$T = |I| - \left|\frac{V_r}{Z_R}\right|$$

for phase comparator,

$$T = \left|\frac{V_r}{Z_L}\right| \text{Cos } \theta$$

where Z_L is the impedance (assumed linear) in the operating signal element of the phase comparator.

The criterion for operation therefore is,

$$|I| - \left|\frac{V_r}{Z_R}\right| + \left|\frac{V_r}{Z_L}\right| \text{ Cos } \theta = 0 \ \ldots\ldots (34).$$

putting

$$\frac{V_r}{I} = Z_L = \sqrt{R^2 + X^2}$$

$$K = \frac{Z_R}{Z_L} = \frac{I_L}{I_R}$$

$$R^2(1 - K^2) - 2K \cdot Z_R \cdot R + X^2 = Z_R^2 \quad \ldots\ldots\ldots (\;)$$

which can be put in the form:

$$\left[R - \frac{K Z_R}{(1 - K^2)}\right]^2 + \frac{X^2}{(1 - K^2)} = \frac{Z_R^2}{(1 - K^2)^2} \quad \ldots\ldots (3.5).$$

is the equation of the ellipse whose centre (intersection of major and minor axes) is shifted from the origin in the positive direction by $\frac{K Z_R}{(1 + K^2)}$ and whose major axis is $= \frac{2 Z_R}{(1 - K^2)}$ and minor axis $= \frac{2 Z_R}{\sqrt{1 - K^2}}$

Thus by varying the value of $K = \frac{Z_A}{Z_B}$, the relay can be made to have different operating characteristics like circle, ellipse, parabola and hyperbola. Fig. (13) shows the complete circuit. And Fig. (14) shows the types of characteristics obtained for varying from 0 to 1.

3.3.3. - Elliptical 'Mho' Characteristics With Directional Bias

In the previous section, the relay considered is inherently an impedance relay and hence the characteristics will not pass through the origin. If the inputs to the amplitude comparator are $\left(\frac{I}{2}\right)$ and $\left(\frac{V_r}{Z_R} - \frac{I}{2}\right)$, then all the characteristics will pass through the origin and the relay will thus be inherently directional.

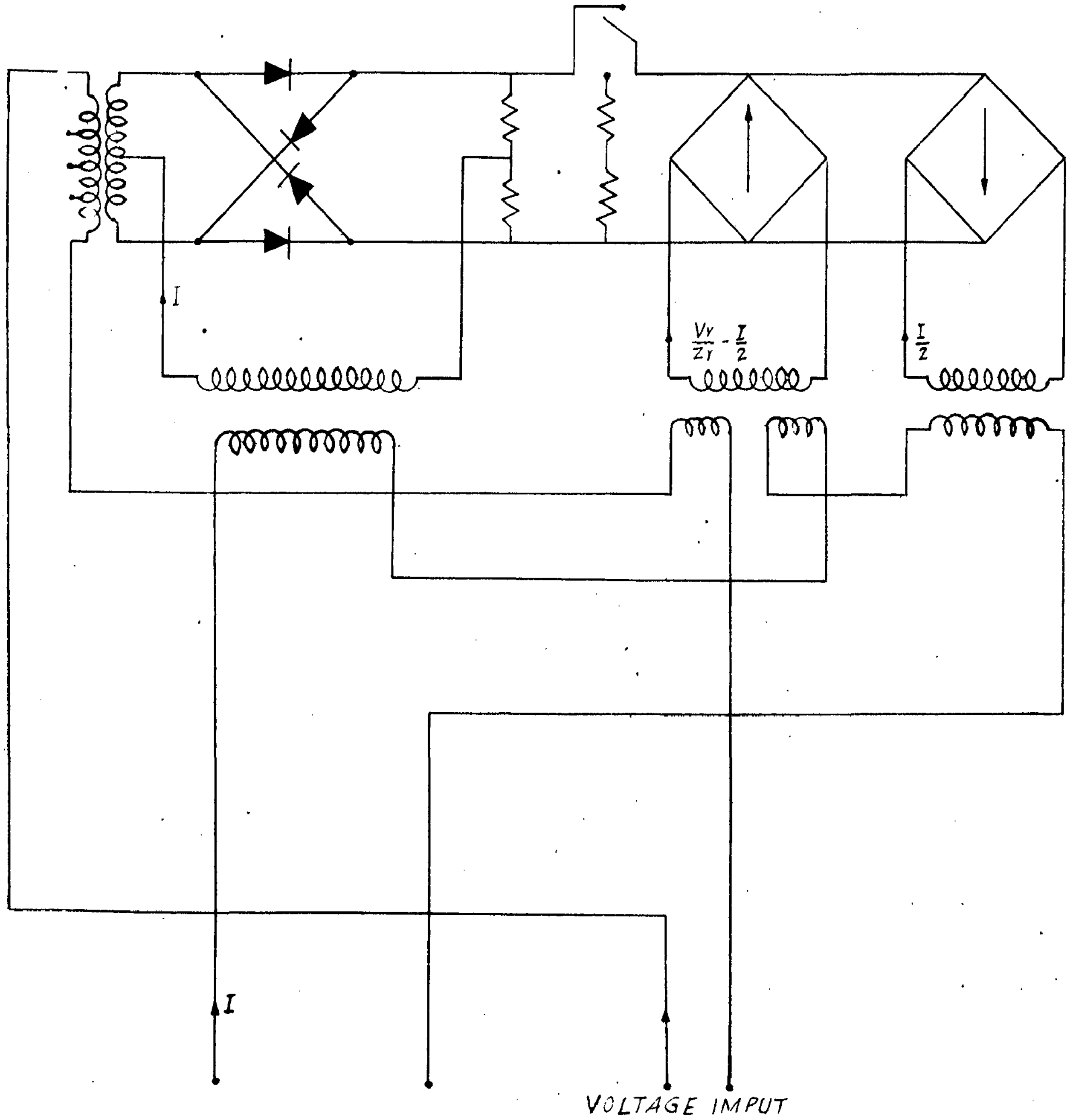
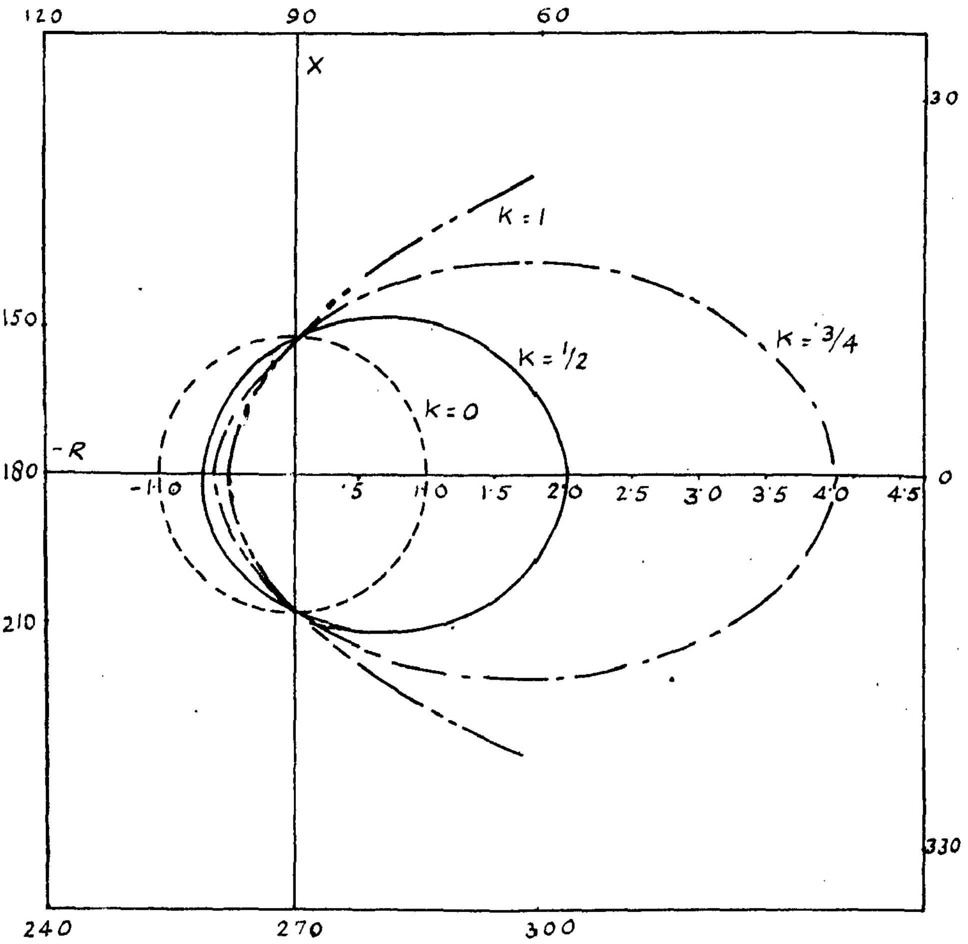


FIG. 13.



FIG· 14· CHARACTERISTICS OBTAINED BY VARYING VALUE OF K.

The equation for operation is:

$$\left[x - \frac{\omega_n}{2(1-k)}\right]^2 + \frac{y^2}{(1-k^2)} = \frac{\omega_n^2}{4(1-k^2)} \quad --- (3\cdot6)$$

Equation (3.6) is the [illegible] [illegible] ellipse whose centre [illegible] shifted from the origin by $p = \dfrac{\omega_n}{2(1-k)}$

and whose major axis is:

$$\frac{\omega_n}{(1-k)} \qquad \text{and}$$

minor axis $= \omega_n \sqrt{\dfrac{1+k}{1-k}}$

[illegible] this [illegible] ellipse passes through the origin [illegible] the [illegible] [illegible] is [illegible] directional.

[illegible] [illegible] of the [illegible] this scheme [illegible] [illegible] [illegible] [illegible] the D.C. output [illegible] necessarily also [illegible] [illegible] control over the eccentricity of the curves [illegible] [illegible] possible in the previous scheme.

CHAPTER IV

STATIC DISTANCE RELAYS WITH ELLIPTICAL AND HYPERBOLIC CHARACTERISTICS USING RECTIFIER BRIDGE AMPLITUDE COMPARATOR

CHAPTER - IV

STATIC DISTANCE RELAY WITH ELLIPTICAL AND HYPERBOLIC CHARACTERISTICS USING RECTIFIER BRIDGE AMPLITUDE COMPARATOR

4.1 - Rectifier Bridge Amplitude Comparators

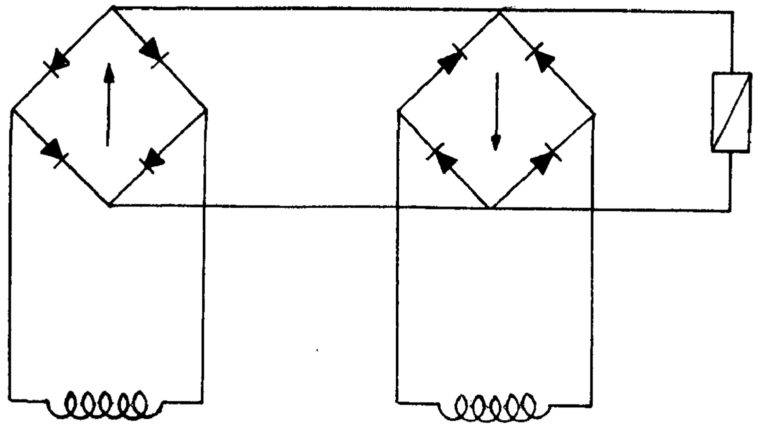
Rectifier bridge comparators are being increasingly used in the field of protective relaying. They may be arranged as either amplitude comparators or phase comparators. The former type have become very popular and are in wide use in U.K., U.S.A. and continental Europe (21) (24) (25).

4.1.1. - Types of Connections

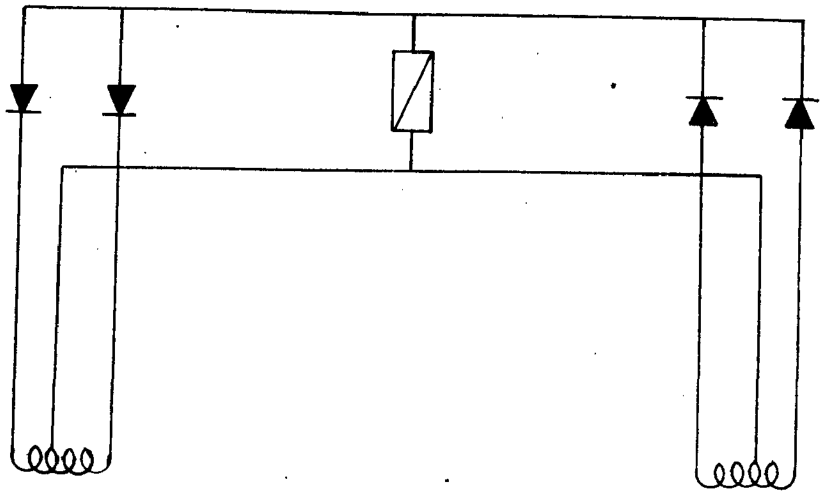
The three main types of rectifier bridge comparator circuits are shown in Fig. (15). Out of these, the Graetz connection is most widely used while the split phase connection is used only where a smooth D.C. output is needed, without introducing inductive - capacitance smoothing filters. The midpoint connection is very rarely employed. Since Graetz type of rectifier bridge comparator circuit is employed it is only necessary to discuss the operation of this type.

Basically, the Graetz type of rectifier bridge comparator consists of two full wave rectifiers connected in series opposing as shown in Fig. (16), a polarized moving coil relay (MC) being connected across two rectifiers as shown.

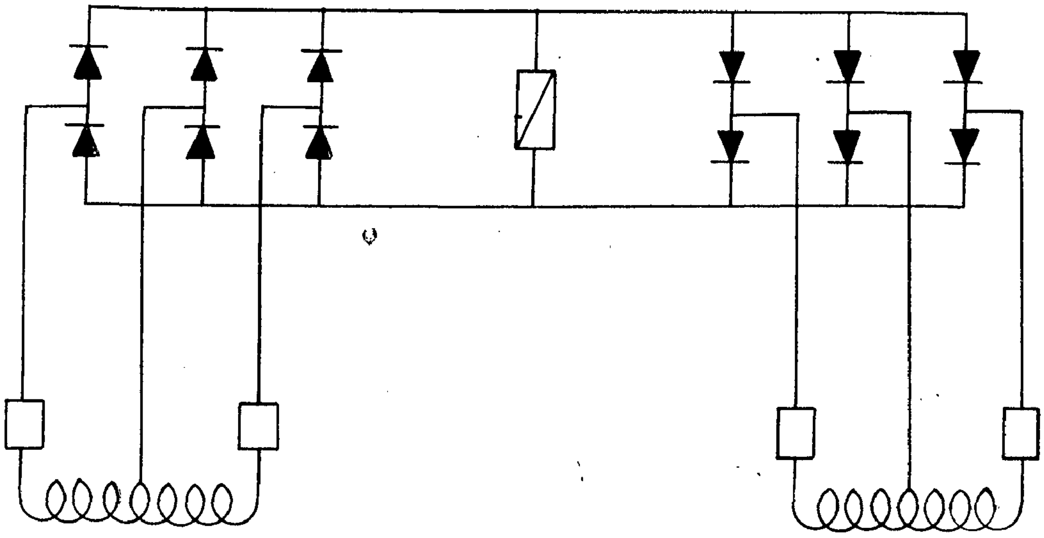
The advantage of this type of connection is that the sensitivity of the relay is highest at low currents which is a desirable characteristic. This is because at low-current



(a) GRAETZ CONNECTION



(B) MID POINT CONNECTION



(C) SPLIT PHASE CONNECTION.

FIG. 15.

all the spill current flows through the relay, whereas only a small fraction of this spill current flow through the relay at higher values of input currents.

This can be explained with Fig. In Fig. (16), when only restraining input is given to the relay, the value of i_r is small, this entire current flows through the moving coil relay in the blocking direction and the relay restrains. As this value of i_r is increased further, the current through the relay increases until the voltage across the moving coil relay reaches $-2 V_t$, where V_t is the threshold voltage of one rectifier element. After this, the rectifiers of bridge (1) will conduct, and all the excess current will flow through these rectifiers. The current through the relay will consist of flat topped half waves as shown in Fig. (17).

The reverse is true if bridge 1 is only energised, the voltage drop across the relay will now be V in the reverse direction than before, and the current through the relay will be in the operating direction. When the voltage across the two relays reaches a value of $+ 2 V_t$, the surplus, current from bridge 1 will spill over through the rectifier bridge 2.

4.1.2 Behaviour Under Ideal Conditions(26).

When both i_o and i_r are present the relay voltage will be a unidirectional wave, which will have a peak of $\pm 2 V_t$, the sign depending on which of the two currents sources is larger. When $i_o = i_r$, the relay voltage is zero at every instant as shown in Fig. (17). When i_o and i_r are not in phase, the voltage across the relay will be a square wave of double the fundamental frequency and if the two currents are equal in magnitude, the relay voltage will be a square wave with equal positive and negative components giving zero average voltage over one half cycle of the fundamental voltage wave; the polarised relay operating on the average to its terminals therefore develops no torque, since the average voltage over one cycle of the positive and negative components of this square wave is each equal to V_t. Here it has been assumed that the voltage developed across the polarised relay by each input current individually with the other bridge rectifier disconnected is large compared to 2 V_t.

The comparator characteristics for the transition point from positive through zero to negative voltage when the two currents are in phase is shown in Fig.(18·a). Here the transition is very sharp, but in the case where i_o and i_r are not in phase, the transition is less sharp as indicated in Fig.(18·b).

4.1.3. Relay Impedance and Sensitivity of the Scheme

i) When the two currents are in phase the current through the relay is equal to the difference between the two input currents, until the voltage across the relay reaches ± $2V_t$. After this there will be no further increase in the relay current- this is true whatever may be the impedance of the relay, but the maximum possible relay current is inversely proportional to the relay impedance. The sensitivity is thus highest when the input currents are in phase.

ii) When the two input currents are out of phase the relay current depends on the average differential voltage and the relay impedance. Where the input currents are sufficiently

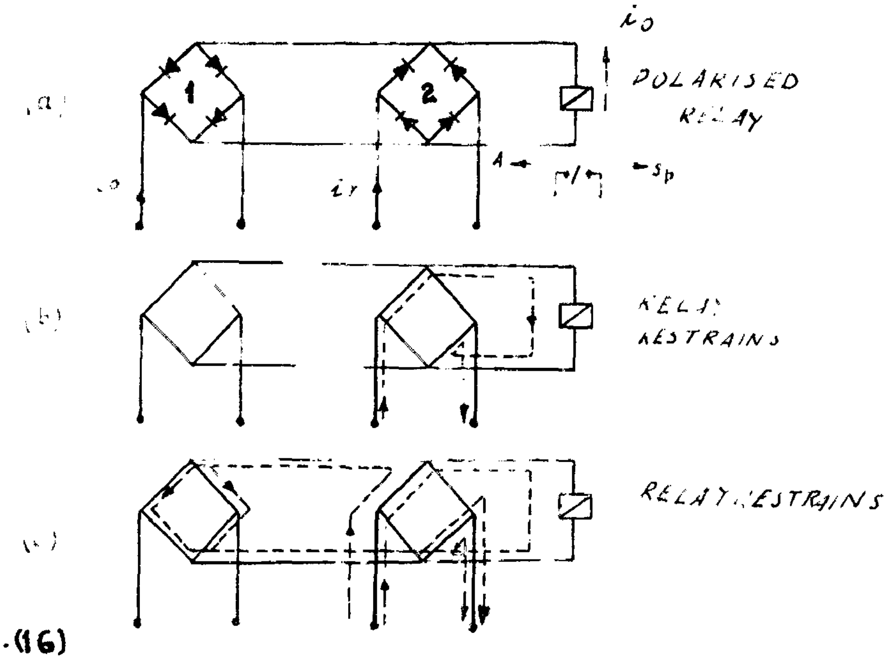
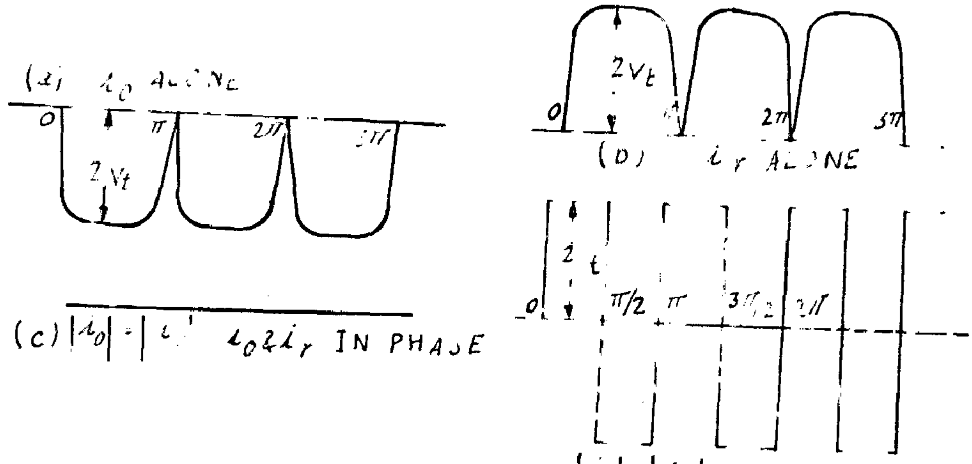


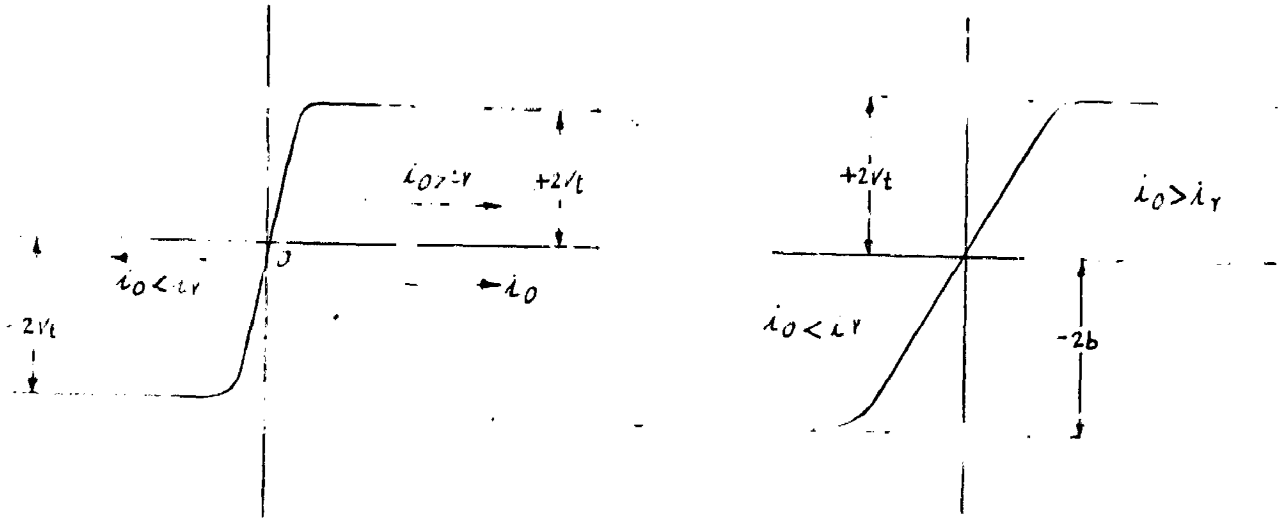
FIG.(16)



(c) $|i_o| = |i_r|$ i_o & i_r IN PHASE

(d) $|i_o|$ $|i_r|$ i_o & i_r OUT OF PHASE

FIG.(17)



RECTIFIER BRIDGE CHARACTERISTIC WHEN IMPUTS ARE IN PHASE.

b) RECTIFIER BRIDGE CHARACTERISTIC WHEN i_o & i_r ARE OUT OF PHASE.

FIG.(18)

large, the square wave output of the comparator can be considered as an ideal square wave as in fig. (17). As already stated, for equal input currents the average voltage over one cycle of the positive and negative components of this square wave is each equal to V_t.

4.8. Applications of Rectifier Bridge Amplitude Comparators.

4.8.1. Amplitude Comparator Working as an Impedance Relay.

The characteristic of an impedance relay on R-X diagram, as already explained in chapter I is a circle with its centre at origin. The characteristic equation can be written as,

$$|Z_L| = |Z_1| \quad .. \quad (4\cdot 1)$$

Where Z_L is the impedance vector of the line from the relay point to the fault and Z_1 is called the replica impedance (which is an external impedance in the relay circuits).

Multiplying equation (4·1) by I

$$|I\ Z_L| = |I\ Z_1|$$

$$\text{or} \quad |V_F| = |I\ Z_1| \quad .. \quad (4\cdot 2)$$

because $I\ Z_L = V_F$ where V_F is the fault voltage of the relay.

$$\text{or} \quad \left| \frac{V_F}{Z_1} \right| = |\ I\ |$$

Therefore inputs to the amplitude comparator working as an impedance relay are I and $\frac{V_F}{Z_1}$.

The circuit of an amplitude comparator working as impedance relay is shown in fig. (18·6).

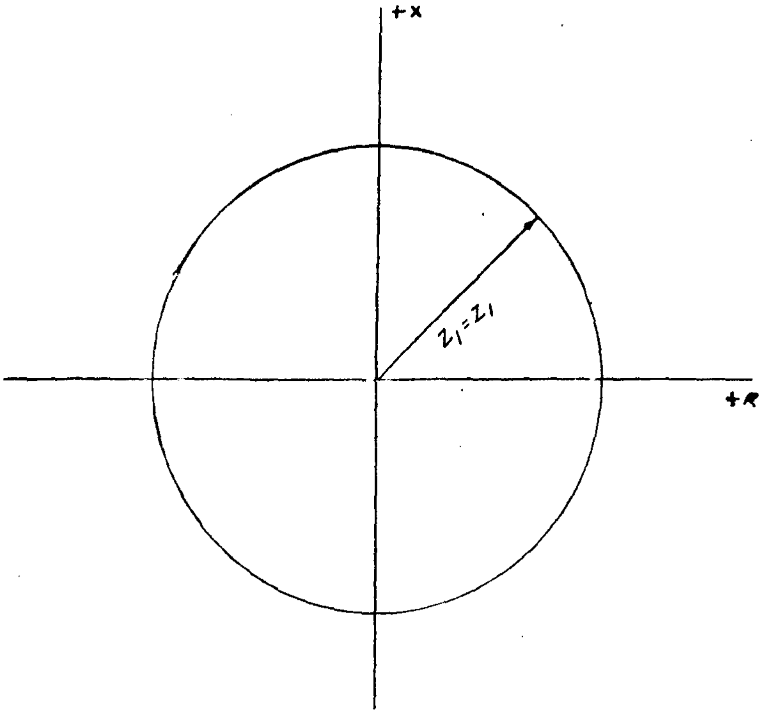


FIG. 19(a).

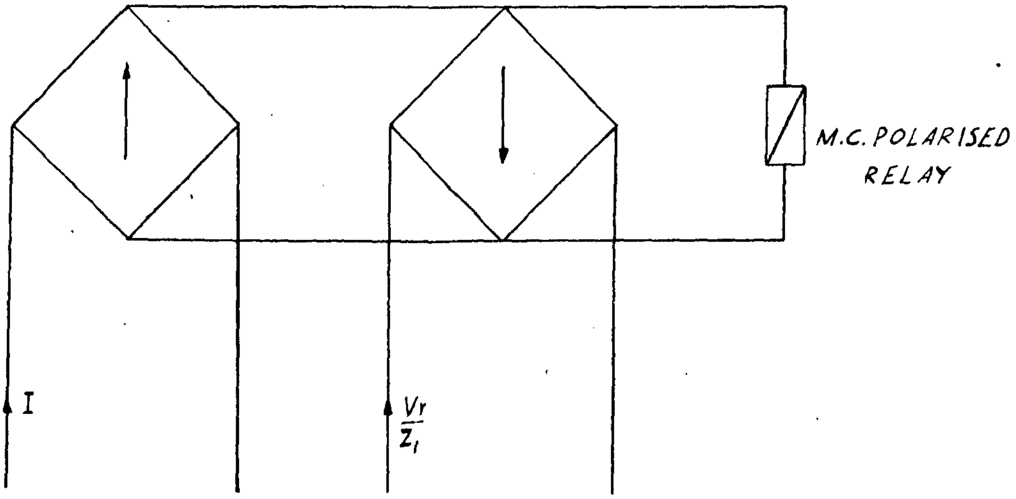


FIG. 19(b). AMPLITUDE COMPARATOR AS AN IMPEDANCE RELAY

4.2.2. Amplitude Comparator Working as an Admittance (Mho) Relay:

The characteristic of a Mho relay on R-X diagram is a circle passing through origin and so the characteristic equation can be written as,

$$|Z_L - \frac{Z_1}{2}| = |\frac{Z_1}{2}| \quad .. \quad (4\cdot3)$$

Where Z_1 is the diameter of the characteristic circle and represents the reach of the relay in the direction of maximum torque angle.

Multiplying equation (4·3) by I,

$$|I Z_L - I \frac{Z_1}{2}| = |I \frac{Z_1}{2}|$$

or $$|V_R - \frac{I Z_1}{2}| = |\frac{I Z_1}{2}| \quad .. \quad (4\cdot4)$$

or converting into current equation -

$$|\frac{V_R}{Z_1} - \frac{I}{2}| = |\frac{I}{2}|$$

Hence the inputs to the amplitude comparator working as Mho relay are $\frac{V_R}{Z_1} - \frac{I}{2}$ and $\frac{I}{2}$

The circuit diagram of amplitude comparator as a Mho relay is shown in fig.(20).

4.3. Distance Relay with Elliptical and Hyperbolic characteristics

4.3.1. Characteristic Equation of a Distance Relay with Elliptical Operating Characteristics

The principle utilised is that the sum of the distances of any point on the ellipse from the focii is a constant and is equal in magnitude to the length of major axis.

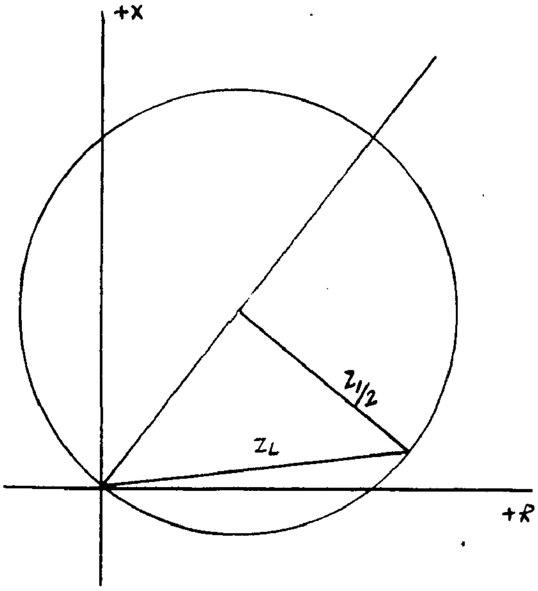


FIG. 20(a).

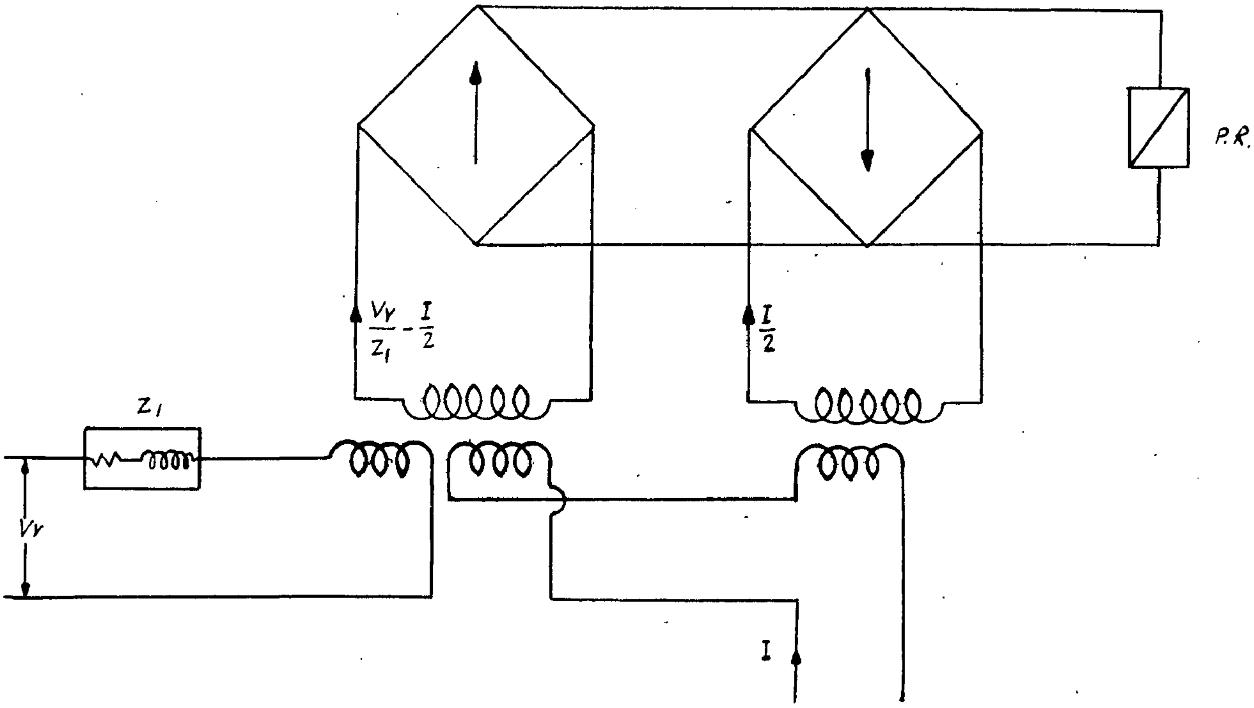


FIG. 20(b) AMPLITUDE COMPARATOR AS A MHO RELAY

Referring to fig.(21), let Z_1 and Z_2 represent the vectors the tips of which coincide with the focii of the ellipse drawn on R-X diagram, and let 2a represent the length of major axis of ellipse.

Then the elliptical characteristic of the distance relay is expressed in general case as,

$$|Z_L - Z_1| + |Z_L - Z_2| = |2a| \quad .. \quad (4.5)$$

If the characteristic is passing through the origin as in fig. (21) the length of major axis is equal to the sum of the distances from the origin to the focii.

Therefore,

$$|Z_L - Z_1| + |Z_L - Z_2| = |Z_1 + Z_2| \quad .. \quad (4.6)$$

Multiplying equation (4.6) throughout by I, then

$$|I\,Z_L - I\,Z_1| + |I\,Z_L - I\,Z_2| = |I\,(Z_1 + Z_2)| \quad .. \quad (4.7)$$

putting $I\,Z_L = V_F$ as before, we can write,

$$|V_F - I\,Z_1| + |V_F - I\,Z_2| = |I\,(Z_1 + Z_2)| \quad .. \quad (4.8)$$

Dividing throughout by $(Z_1 + Z_2)$, to convert into current equation,

$$\left|\frac{V_F}{Z_1+Z_2} - I\,\frac{Z_1}{Z_1+Z_2}\right| + \left|\frac{V_F}{Z_1+Z_2} - I\,\frac{Z_2}{Z_1+Z_2}\right| = |\,I\,| \quad ... \quad (4.9)$$

Hence for a 3-input amplitude comparator working as distance relay with elliptical operating characteristic, the three inputs will be, $\left(\frac{V}{Z_1+Z_2} - I\,\frac{Z_1}{Z_1+Z_2}\right)$, $\left(\frac{V_F}{Z_1+Z_2} - I\,\frac{Z_2}{Z_1+Z_2}\right)$ and (I)

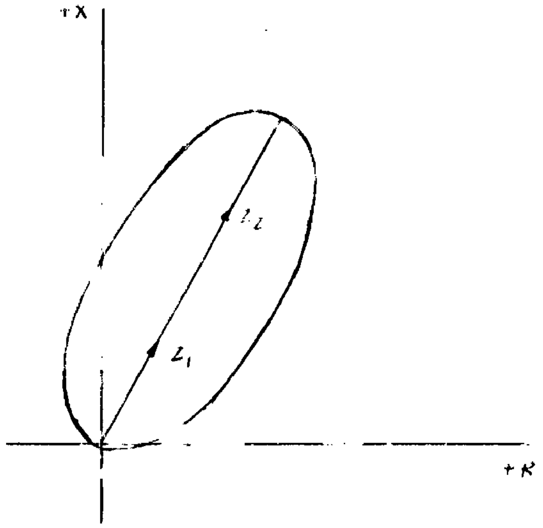


FIG. 21.

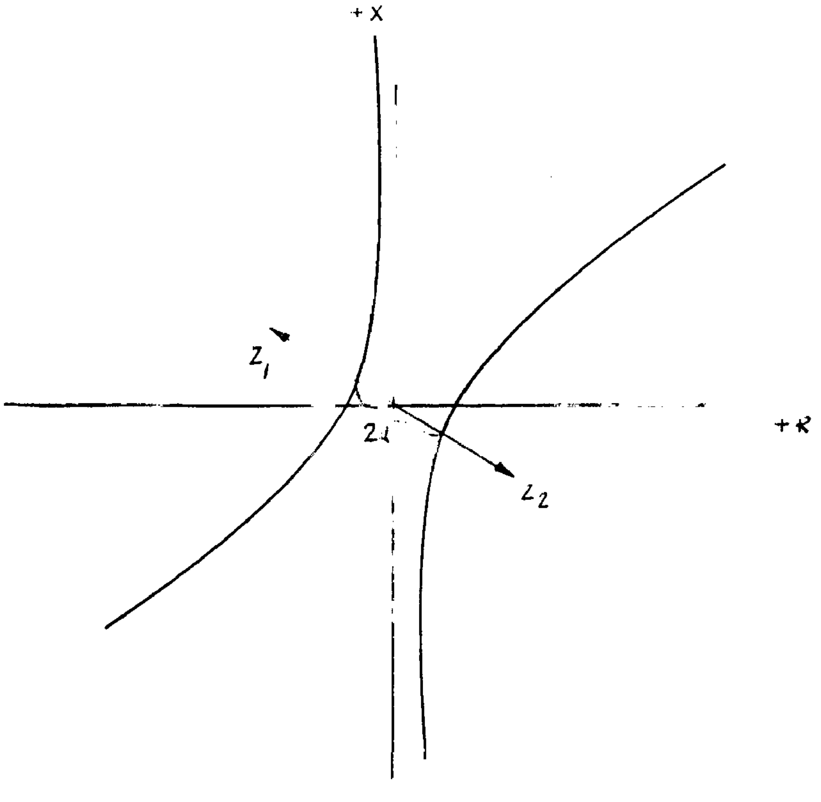


FIG. 22.

The schematic circuit diagram employed is shown in fig.(23).

4.3.2. Characteristic equation of a Distance Relay with Hyperbolic Characteristics.

The principle utilised is the property of the hyperbola that the difference of the distances from any point on the hyperbola to the focii is a constant and equal to the length of transverse axis. (i.e. the distance between the two vertices).

Referring to fig. (22), let Z_1 and Z_2 represent vectors the tips of which coincide with the focii of the hyperbola drawn on R-X diagram and let 2a represent the length of transverse axis.

We can write the equation for the right and left branches of hyperbola as-

$$|Z_L - Z_1| - |Z_L - Z_2| = |2a| \quad .. \quad (4.10)$$

$$|Z_L - Z_2| - |Z_L - Z_1| = |2a| \quad .. \quad (4.11)$$

Multiplying throughout by I and putting $I Z_L = V_r$ as before,

$$|V_r - I Z_1| - |V_r - I Z_2| = |2aI| \quad .. \quad (4.12)$$

$$|V_r - I Z_2| - |V_r - I Z_1| = |2aI| \quad .. \quad (4.13)$$

or

$$\left|\frac{V_r}{2a} - I\frac{Z_1}{2a}\right| - \left|\frac{V_r}{2a} - I\frac{Z_2}{2a}\right| = |I| \quad .. \quad (4.14)$$

$$\left|\frac{V_r}{2a} - I\frac{Z_2}{2a}\right| - \left|\frac{V_r}{2a} - I\frac{Z_1}{2a}\right| = |I| \quad .. \quad (4.15)$$

Hence for a three input amplitude comparator working as distance relay with hyperbolic characteristic the inputs are

$$\left(\frac{V_r}{Z_a} - \frac{I Z_1}{Z_a}\right); \left(\frac{V_r}{Z_a} - \frac{I Z_2}{Z_a}\right) \text{ and } (I)$$

The schematic circuit diagram employed is shown in fig.(23).

6.6. Description of Circuit Diagram:

Part 1 of the circuit is the measuring circuit. The inputs to the measuring circuit are V_r (fault voltage at the relay) and fault current I.

The ratios of the current transformers are marked on the circuit diagram. The three outputs of the measuring circuit are fed to the three rectifier bridges connected in parallel. The D.C. output of this Comparator circuit is fed to triggering circuit (explained in detail later). The output from the triggering circuit is applied to the polarised moving coil relay.

6.6.1. Triggering Circuit:

It has been explained already that the output of a rectifier bridge amplitude comparator will be a square wave when the two inputs to the comparator are not in phase. When the two inputs are equal in magnitude but are not in phase, the voltage across the relay will be a square wave of double the fundamental frequency with equal negative and positive components, give the zero average voltage. Since the moving coil relay is a high speed relay, it responds to both positive and negative pulse, and the operation of the relay will not be well defined.

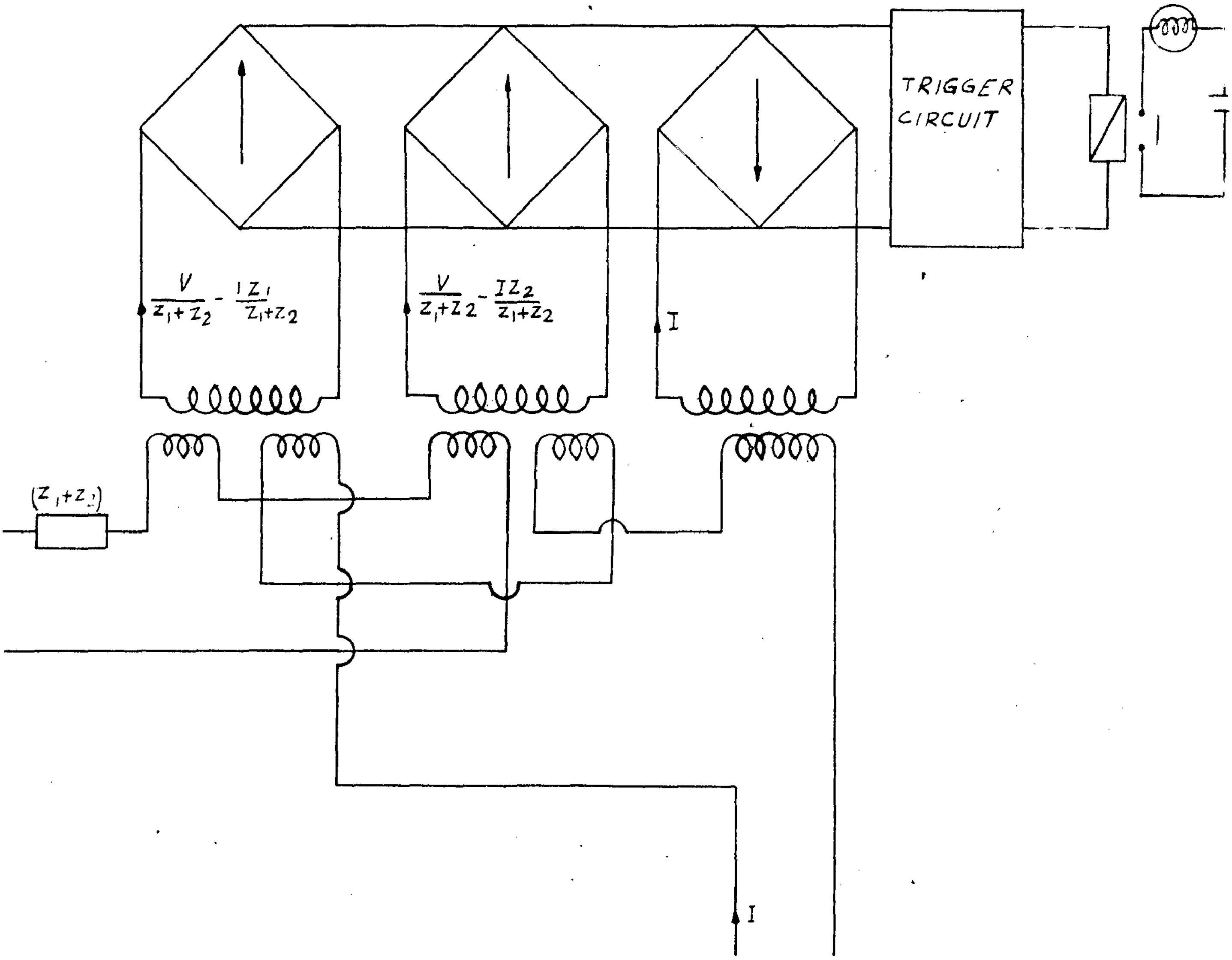


FIG. (25) SCHEMATIC DIAGRAM OF RELAY.

Hence the output of the comparator is applied to a level detector circuit, which in turn triggers a bistable circuit, as soon as the positive half of the input wave exceeds 5 milliseconds.

The complete circuit is shown in fig.(24).

C.C.1.1. Level Detector:(29)

The function of the level detector circuit is to trigger as soon as the positive half of the input wave exceeds 5 milliseconds, and giving a negative pulse in the output stage. The circuit is shown in fig. (24).

The emitters of Transistors T_2 and T_3 are connected through a common resistor R_{e23}. As long as the voltage V_c is lower than certain value V_p (the pick-up voltage) transistor T_3 is fully conducting due to negative voltage applied to its base, while transistor T_2 is biased to cut-off by the voltage drop across the common emitter resistance R_{e23}.

The input voltage V_{in} to the level detector is obtained from the rectifier bridge comparator such that the operating current makes the base of T_1 positive with respect to the emitter. When base of T_1 is zero or positive, transistor T_1 stops conduction, and the voltage $-V_{cc}$ starts to charge the condenser 'C' and V_c starts to raise exponentially depending upon the time constant $C(R_{b2} + R_{c1})$ of charging circuit.

As soon as the voltage reaches the pick up value, T_2 starts to conduct and its collector voltage starts to rise. This rise of voltage is transferred to the base of T_3 and reduces its emitter and collector currents.

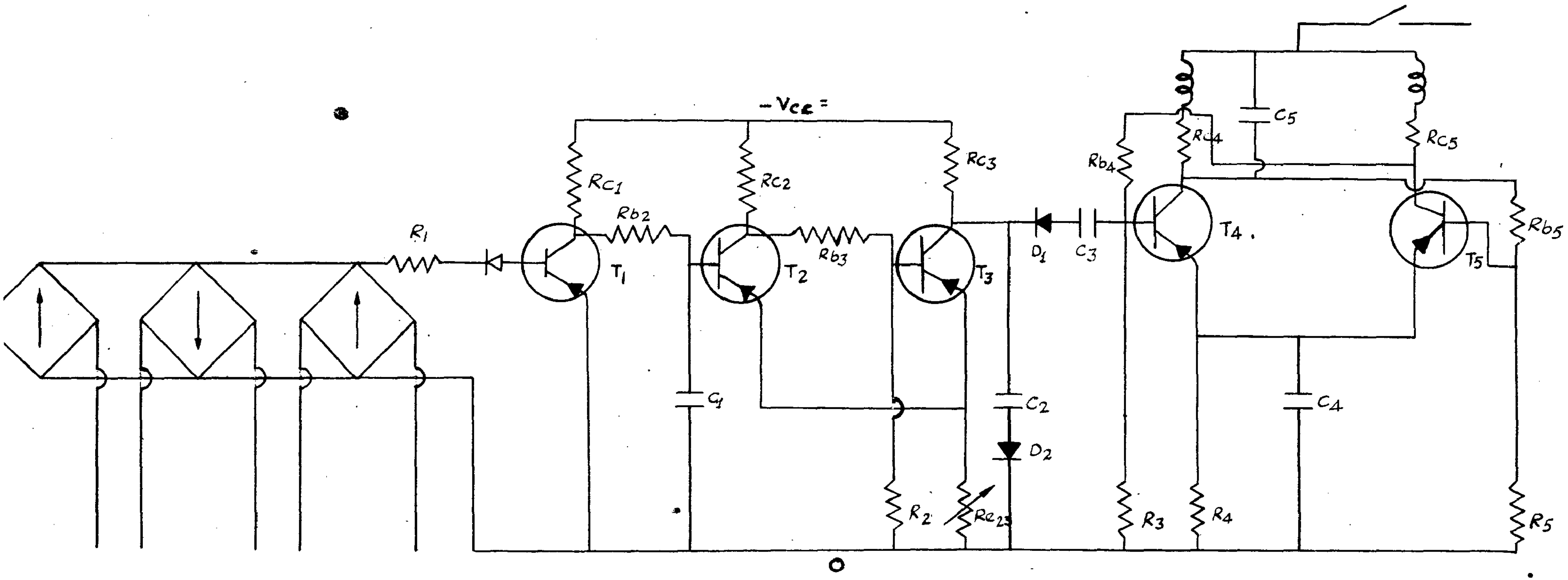


FIG. (24) · LEVEL DETECTOR AND BISTABLE CIRCUIT.

$R_1 = 1 k\Omega$
$R_{c1} =$
$R_{b2} = 2 k\Omega$
$R_{c2} = 10 k\Omega$
$R_{b3} = 30 k\Omega$
$R_2 = 50 k\Omega$
$R_{c3} = 5.7 k\Omega$
$R_{e23} = 1 k\Omega$
$C_1 = 0.5 \mu F$
$C_2 = 2 \mu F$
$C_3 = .01 \mu F$
$R_3 = 10 k\Omega$
$R_4 = 560 \Omega$
$R_{c4} = 1 k\Omega$
$C_4 = 2 \mu F$
$C_5 = 1 \mu F$
$R_{c5} = 1 k\Omega$
$R_{b4} = 4.7 k\Omega$
$R_{b5} = 4.7 k\Omega$
$R_5 = 10 k\Omega$

This reduction in emitter current of T_3 pushes T_2 further to conduction with rise in its collector current which is again transferred to the base of T_3 and cycle is repeated. If during this action gain is greater than unity, the circuit will suddenly change to other state of stability where T_2 is fully conducting and T_3 is cut off. When T_3 is cut-off, a negative voltage suddenly appears across the collector and emitter of transistor T_3 which is applied to the bistable circuit.

By choosing proper values for R_{e1}, R_{b2} and C, V_e can be made to reach V_p if the base of T_1 remains at positive or zero potential for more than 5 milliseconds.

4.4.1.2. Bistable Circuit:

This circuit has got two states of stability in either of which one transistor is fully conducting and the other is cut-off and can remain in one of these states indefinitely.

The circuit may be triggered from one state to the other state by applying either a positive pulse to the base of the conducting transistor to turn it OFF or a negative pulse to the base of nonconducting transistor to turn it ON. The latter usually demands less energy.

In the circuit shown initially when switch K is closed, transistor T_4 is cut off and T_5 will be conducting. The time constant of T_4 is made purposely larger than that of T_5 so that collector voltage of T_5 will rise at a higher rate than that of T_4. This is essential because when switch K is closed both transistors T_4 and T_5 race in conduction.

The rise of voltage of T_5 is transferred to the base of T_4 and opposes its tendency to conduct, this further reduces the rate of rise of voltage of T_4 and the process is cumulative with the result that T_5 will be driven rapidly to full conduction while T_4 remains cut-off.

When a negative pulse from the level detector is applied to the base of T_4, the circuit is triggered to the other state, i.e. T_4 conducting and T_5 is cut-off. To reset, the H.T. supply is switched off and then switched on again so that the original ~~state of~~ state of stability is established.

The whole trigger circuit, will thus be triggered when the positive half of the input wave (output of rectifier bridge comparator) is more than 5 milliseconds, i.e. when the operating current is more than the restraining current.

4.4.2. Polarised Moving Coil Relay:

In an electromagnetic relay such as an induction cup unit, perfect characteristics can be obtained with reasonable burdens, because it uses the torque comparison and the work done to close the contacts has got no effect on the magnetic fluxes which produces the torque. In static relays, on the other hand, the comparison is made electrically, in a network and good characteristics are obtained only if the burden imposed by the tripping device is negligible compared with the power in the network.

The most sensitive electromagnetic tripping relays are of the moving coil or moving iron types, polarised by a permanent magnet. In the present case a polarised moving coil relay is used as a tripping devices.

Ofcourse at present time, controlled silicon rectifiers are available with sufficient capacity to trip the breaker having a trip coil current of 40A at 250 V for 60milliseconds, but their cost is too high.

4.4.3. Calculation of C.T. Ratios:

It was proposed originally to design the relay suitable for testing in the High speed relay test panel, designed and developed by T.S.M. Rao in the power system laboratory(27) A transmission line of 132KV, of 100 miles is represented in the relay test panel by the suitable impedances which are adjustable. The schematic diagram of the test panel is shown in fig.(25).

If a fault is created the middle of the line as shown in the diagram, the maximum impedance between the relaying point and the fault point is 20 ohms. The primary of the C.T. connected to the line, has got 90 turns and the secondary turns are variable from 5 turns to 485 turns in steps of 5. The P.T. connected has got a ratio of 440V/110V.

If the maximum current that can be drawn from P.T. so that it will not be burdened excessively is 500mA,

Then,

$$(Z_1 + Z_C) = Z_r = \frac{110}{0.5} = 220 \text{ ohms}$$

Assuming C.T. primary turns = 90 (This can be varied from 5 to 405 turns).

$$\text{C.T. Ratio used} = \frac{300}{90}$$

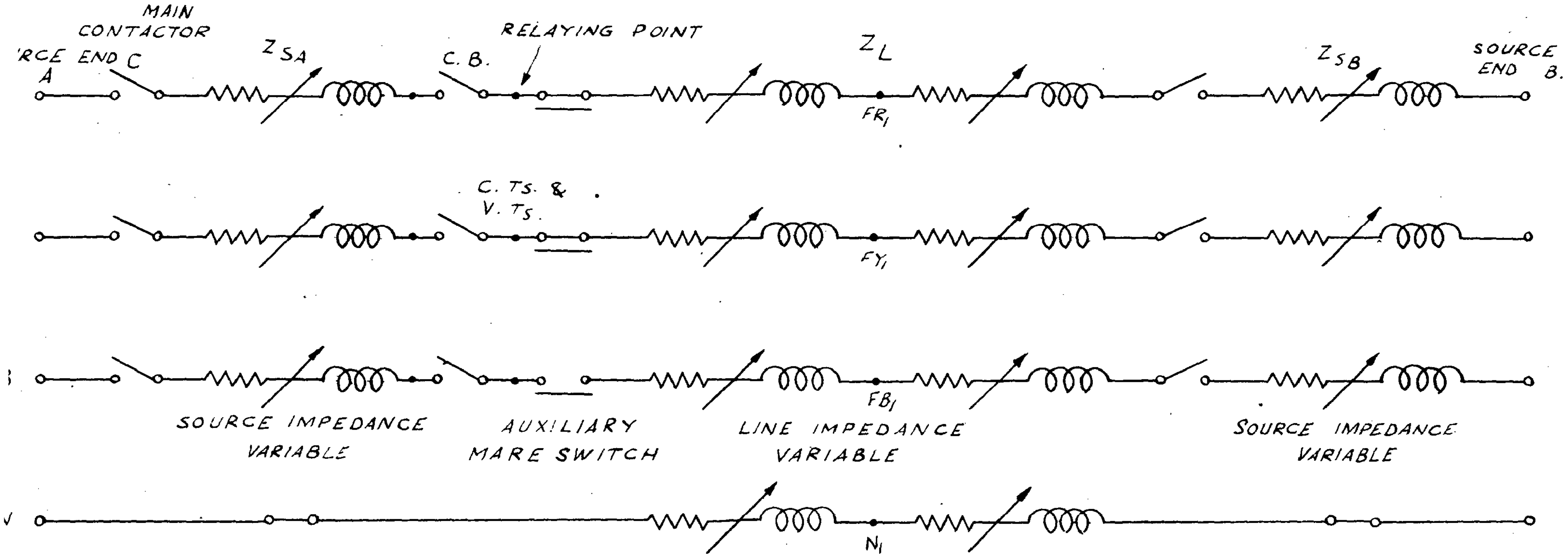


FIG. 25. SCHEMATIC DIAGRAM OF HIGH SPEED RELAY TEST PANNEL

$\therefore$ Impedance seen by the relay

$$= 20 \times \frac{200}{60} \times \frac{100}{400} = \frac{50}{3} \simeq 17$$

But Z_r = 220 ohms.

$\therefore$ Aux C.T. ratio $= \frac{220}{17}$ = 13 say (13).

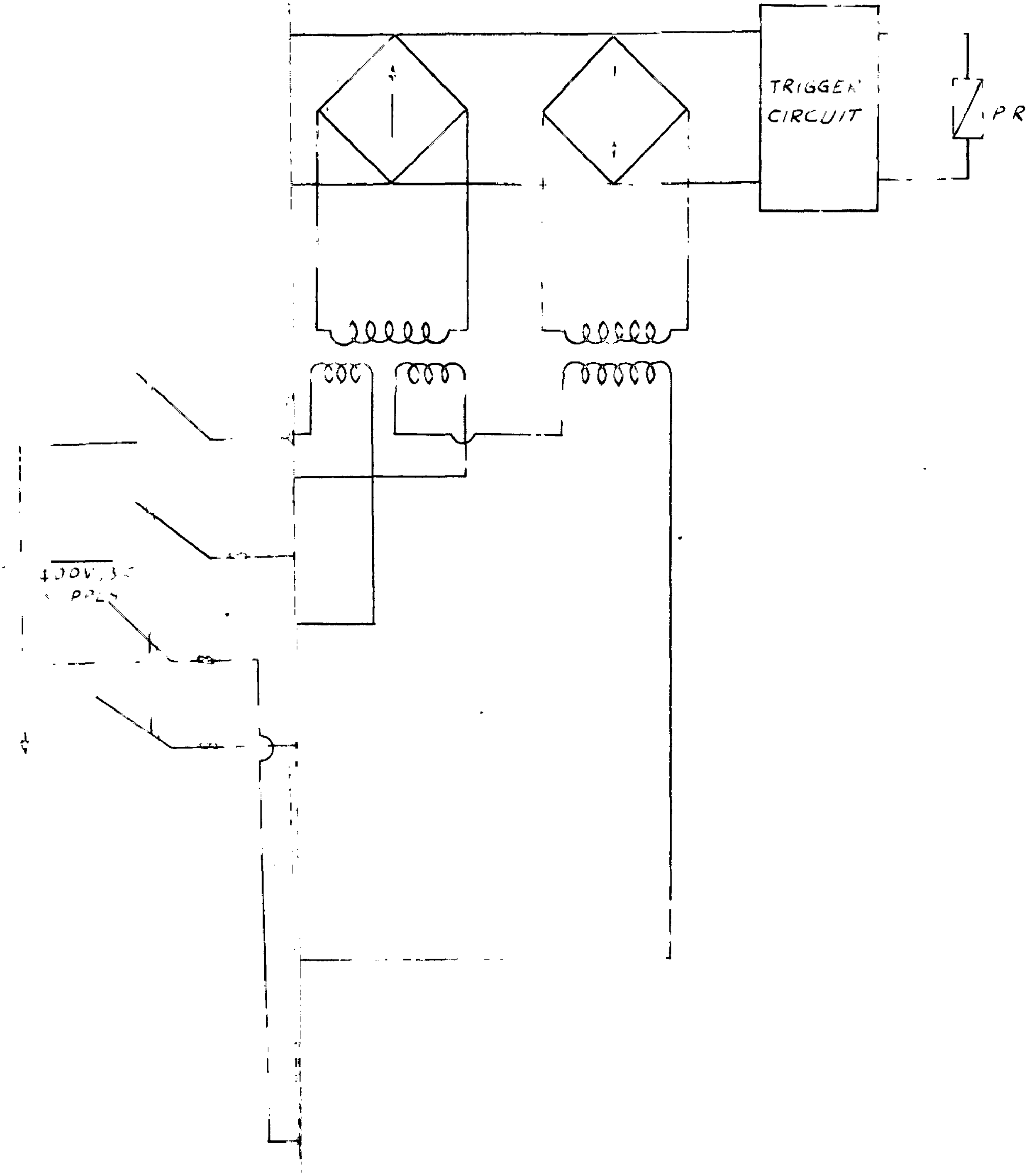
The Aux. C.T.(1) is provided with tappings so that C.T. ratio can be varied from 8 to 20.

4.8. Experimental Results:

4.8.1. Test Circuit Employed:

The circuit employed is shown in fig.(26). All voltage sources were transformed into current sources. The reach of the relay can be adjusted by varying the impedance (Z_R). In the circuit employed Z_R is shown to be as only resistance, but usually in practice it will be an impedance, the phase angle of which will decide the maximum torque angle. In that case all the characteristics shown will merely be rotated without changing the shape of the characteristic in each case.

Phase shifting between the inputs i_o and i_r is obtained by using a phase shifter in the circuit. A 3-phase induction regulator with primary and secondary separated instead of connecting both in series, is used as a phase shifter. The phase angle of the secondary voltage with respect to the primary voltage can be varied, by varying the position of the rotor.



TERISTIC

6.5.2. Operating Characteristics obtained by Test Results.

6.5.2.1. Elliptical characteristics:

The elliptical operating characteristics obtained by test results are shown in fig. (27) to (32)

Eccentricity of the characteristic curve

$$e = \frac{Z_2 - Z_1}{Z_1 + Z_2} = \frac{Z_2}{Z_1 + Z_2} - \frac{Z_1}{Z_1 + Z_2}$$

Therefore eccentricity can be adjusted by changing the values of $\frac{Z_1}{Z_1+Z_2}$ and $\frac{Z_2}{Z_1+Z_2}$ i.e. by changing the ratios of C.Ts. (1) and (2).

The characteristic can be made off set from the origin by suitably adjusting the ratios $(\frac{Z_1}{Z_1+Z_2})$ and $(\frac{Z_2}{Z_1+Z_2})$ as shown in fig. (28) to (32).

6.5.2.2. Hyperbolic Characteristics:

The hyperbolic characteristics drawn from test results are shown in fig. (33). The curvature of the hyperbola can be varied by suitably adjusting the ratios $(\frac{Z_1}{Z_a})$ and $(\frac{Z_2}{Z_a})$ as shown.

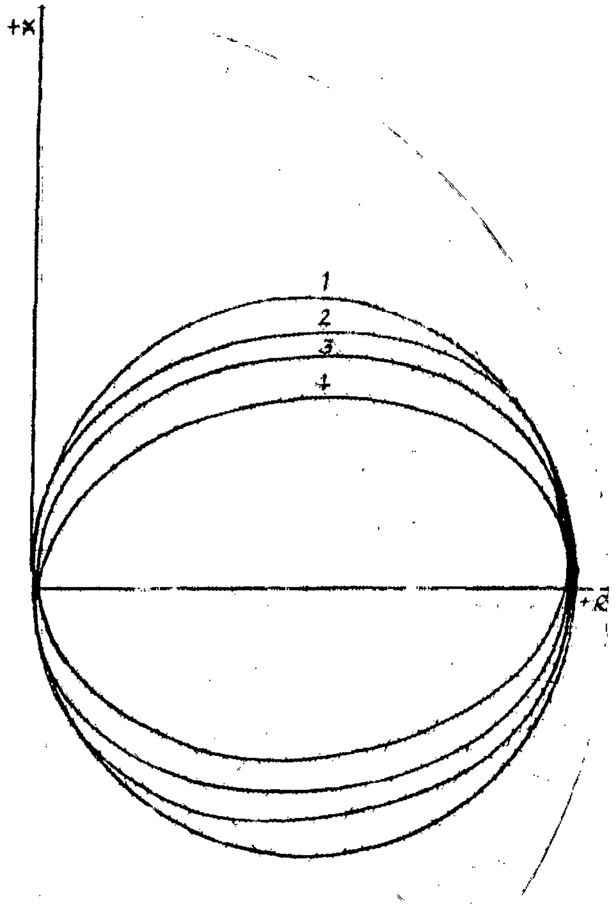


FIG. 27. ELLIPTICAL CHARACTERISTICS

1. e = 0
2. e = 0·333
3. e = 0·667
4. e = 0·833

ALL THE CHARACTERISTICS PASSES THROUGH ORIGIN.

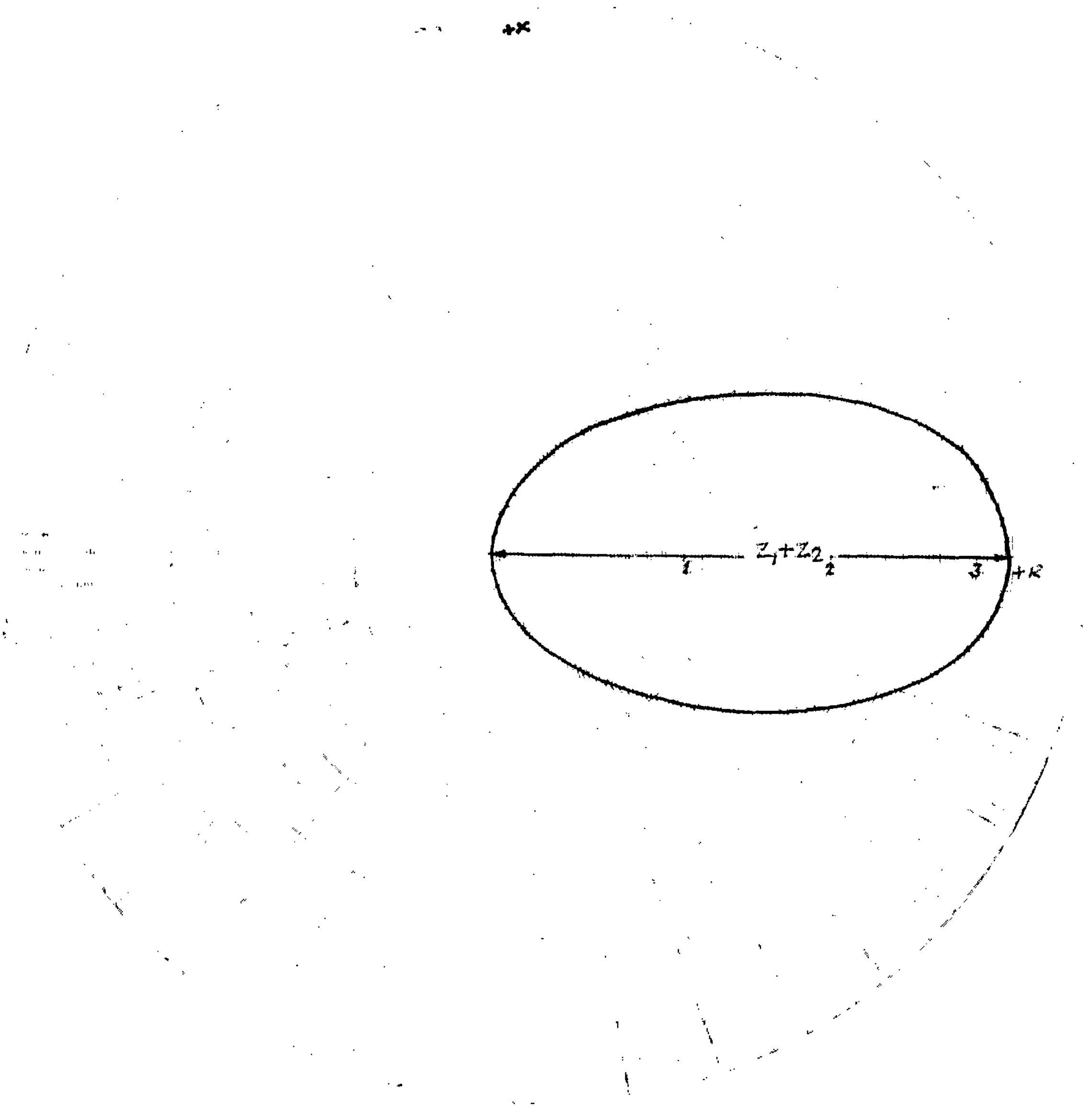


FIG. 28.

$$\frac{Z_1}{Z_1+Z_2} = 0 \qquad \frac{Z_2}{Z_1+Z_2} = \frac{5}{6} = 0.833$$

$e = 0.833$ ONE FOCUS OF ELLIPSE IS AT ORIGIN

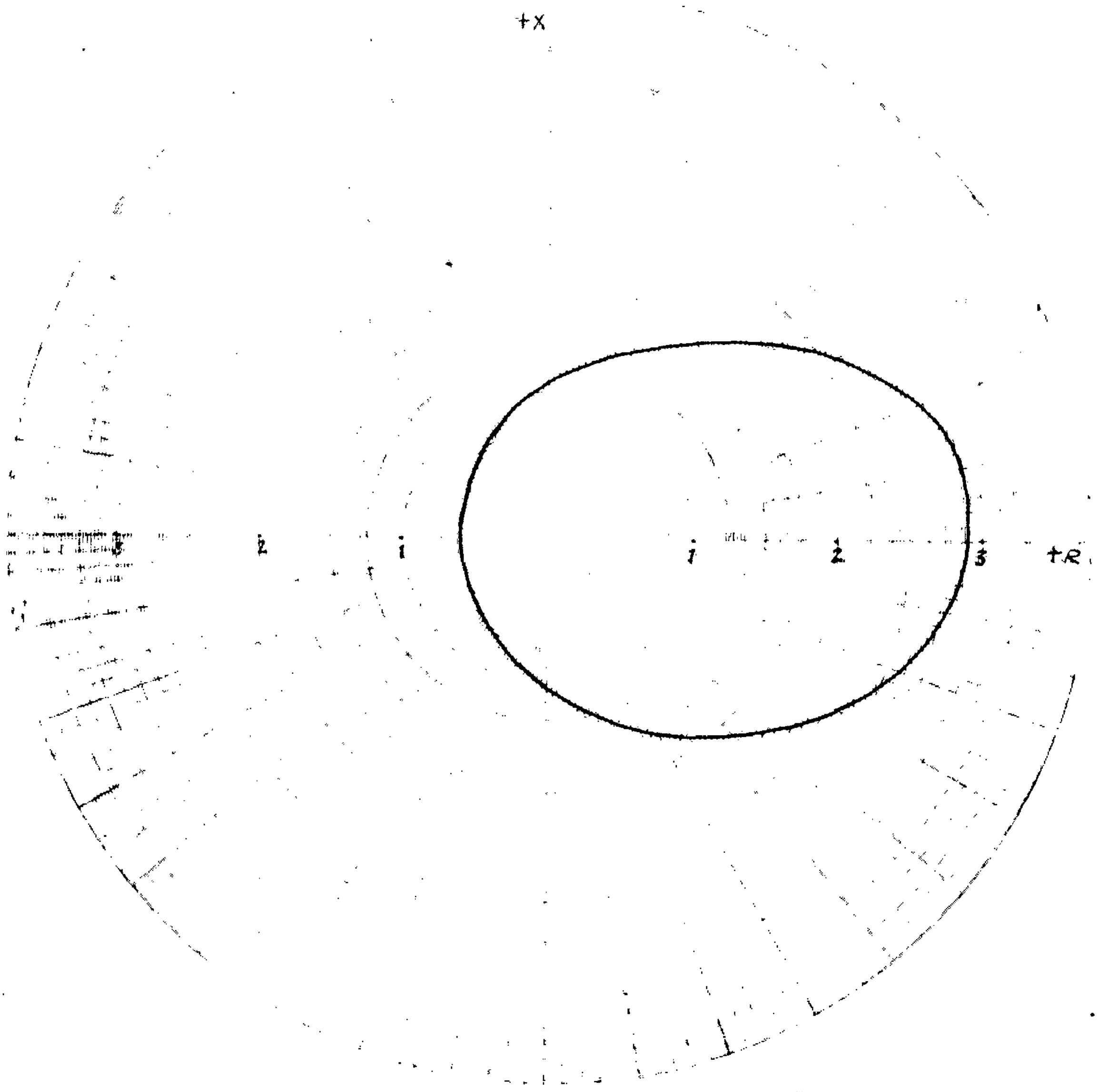


FIG. 29.

$$\frac{Z_1}{Z_1+Z_2} = 0 \qquad \frac{Z_2}{Z_1+Z_2} = 0{\cdot}667$$

$e = 0{\cdot}671$ ONE FOCUS OF ELLIPSE IS AT ORIGIN

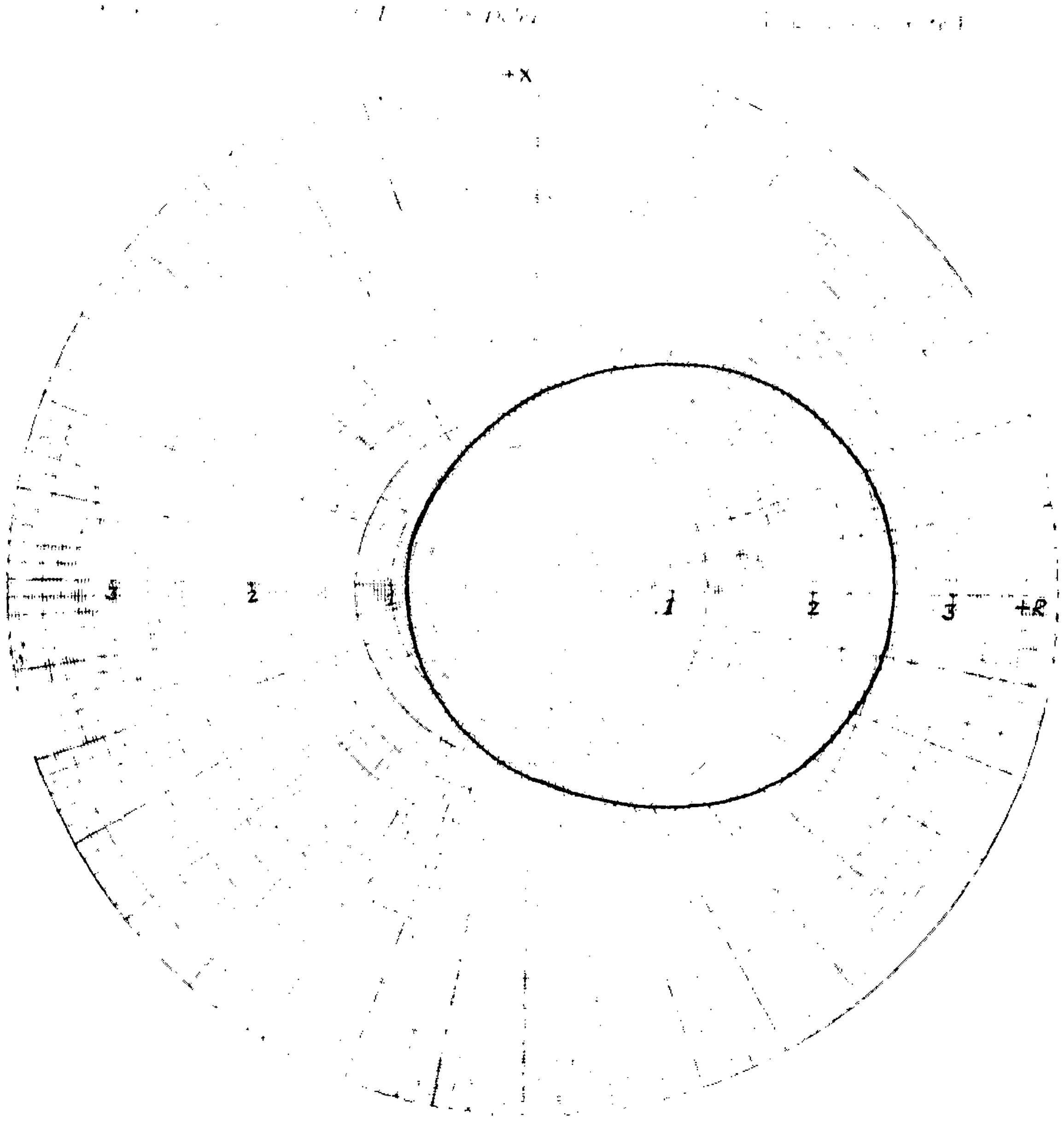


FIG. 30

$\frac{Z_1}{Z_1+Z_2} = 0.5$ $\qquad$ $\frac{Z_2}{Z_1+Z_2} = 0\cdot5$

$e = 0\cdot5$ ONE FOCUS OF ELLIPSE AT ORIGIN

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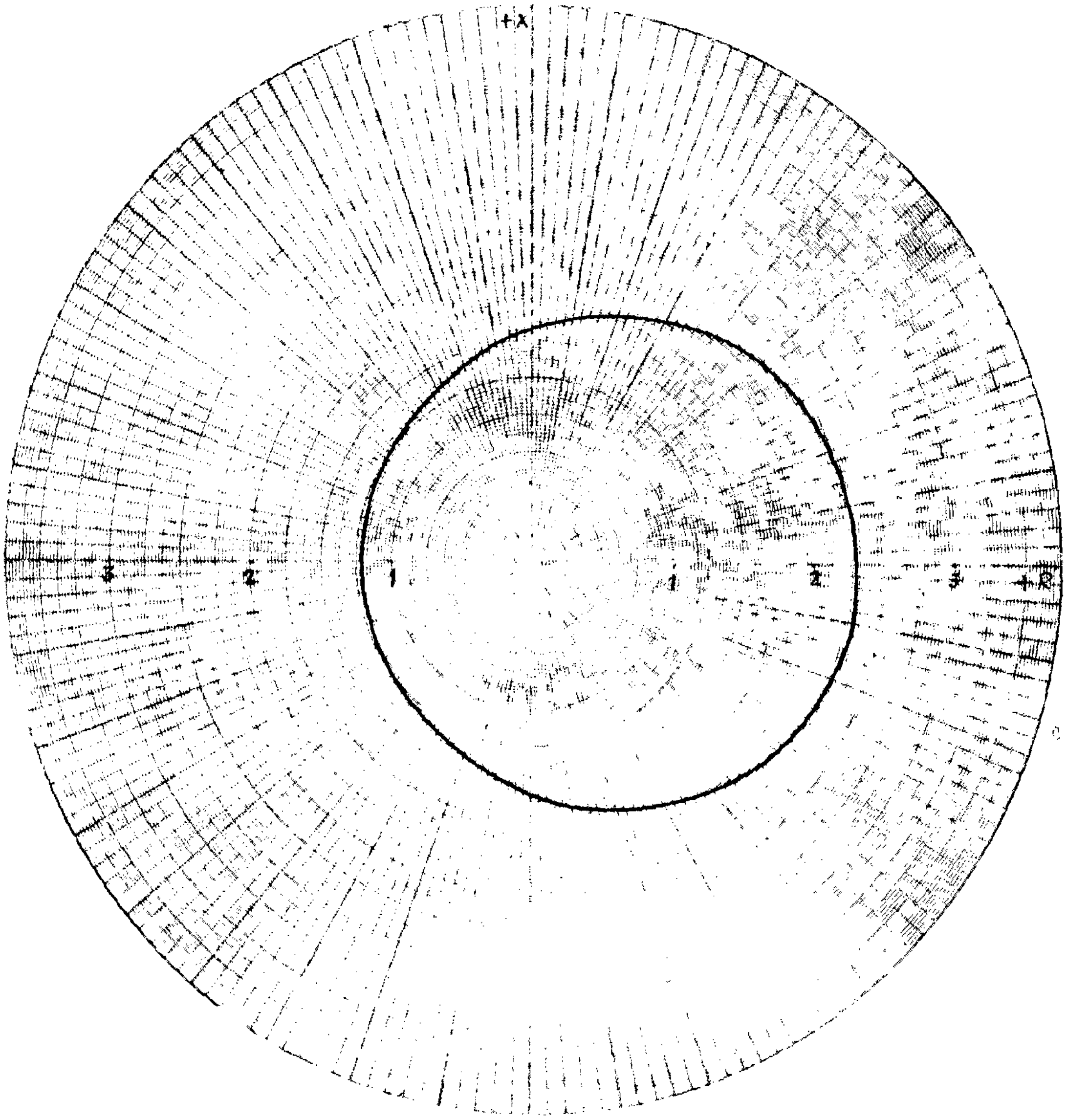


FIG. 31

$$\frac{Z_1}{Z_1+Z_2} = 0 \qquad \frac{Z_2}{Z_1+Z_2} = 0.333$$

$e = 0.167$ ONE FOCUS OF ELLIPSE AT ORIGIN

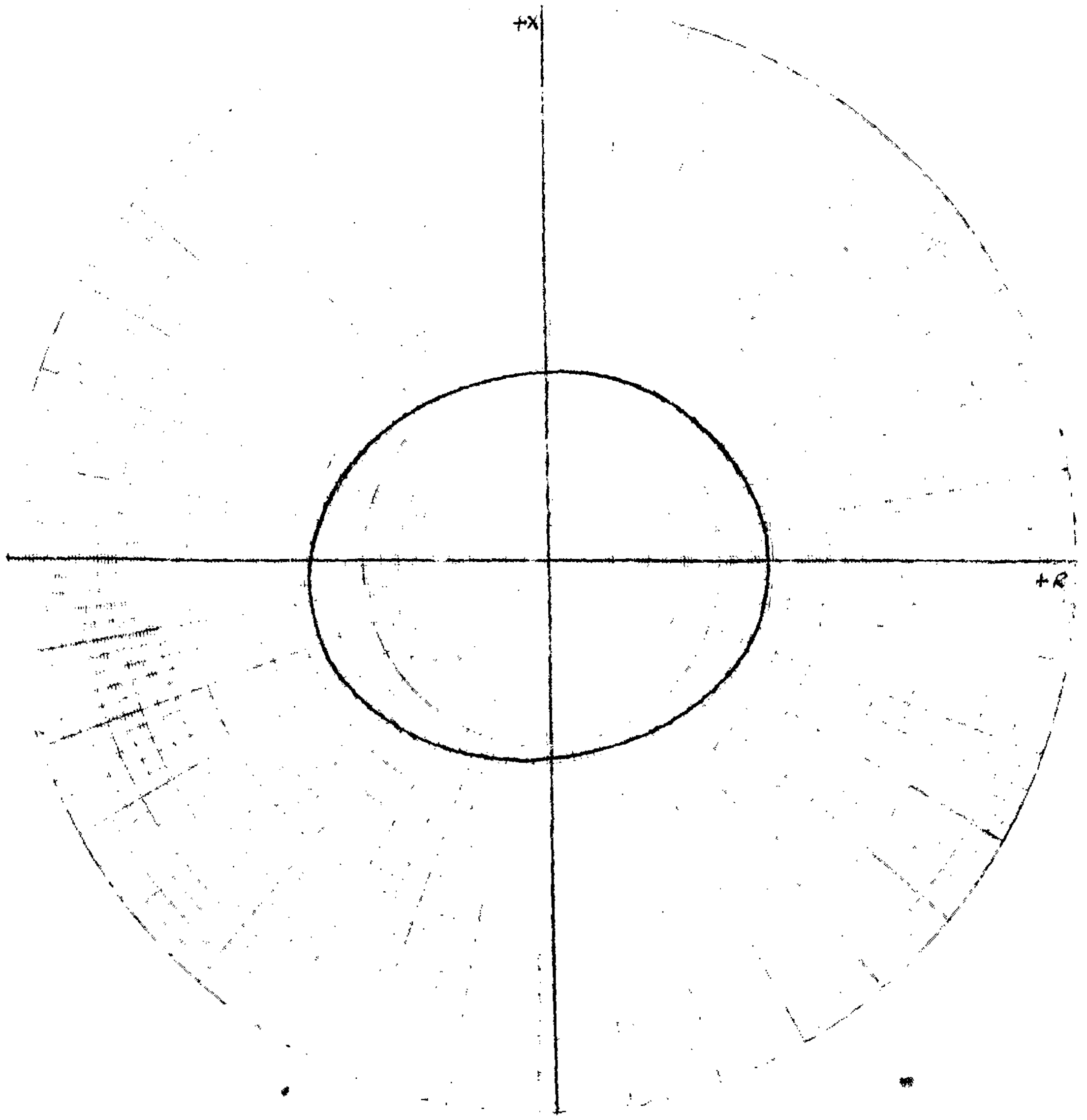


FIG. 32.

$e = 0167$ ONE FOCUS COINCIDING WITH ORIGIN

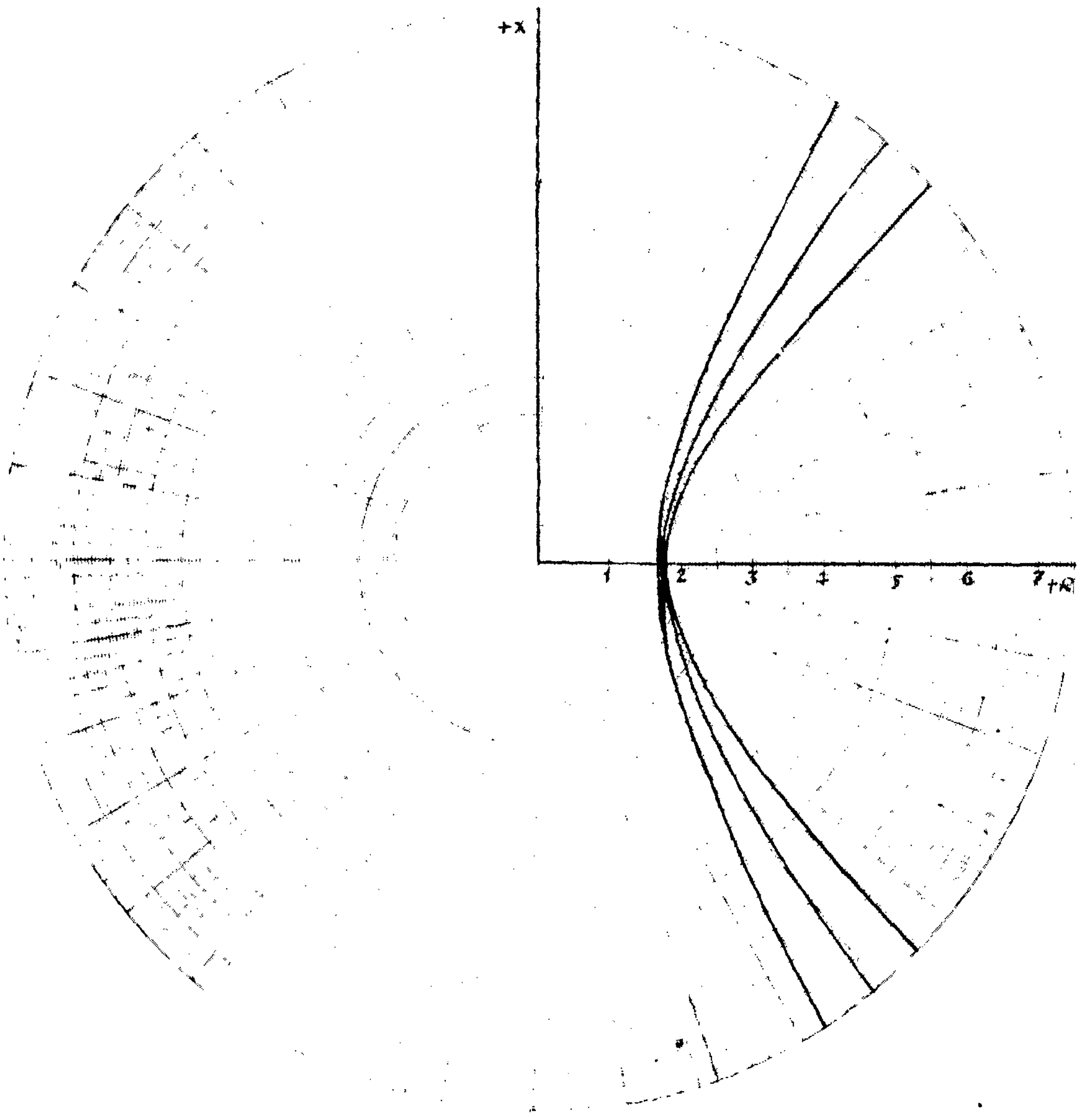
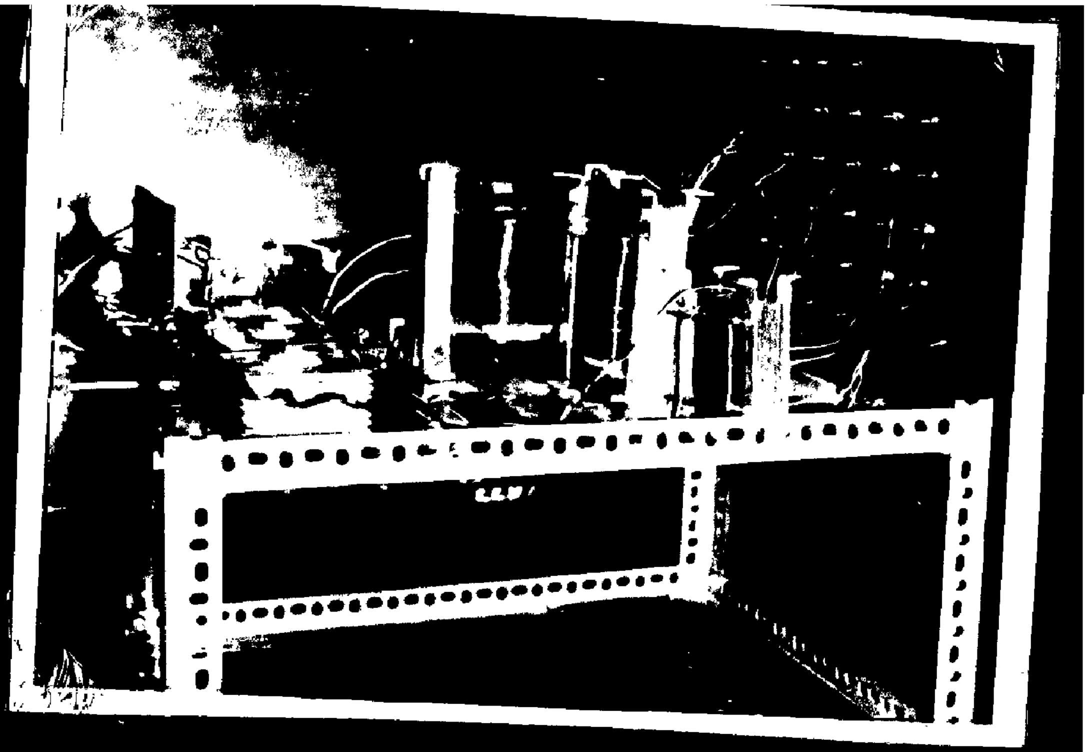
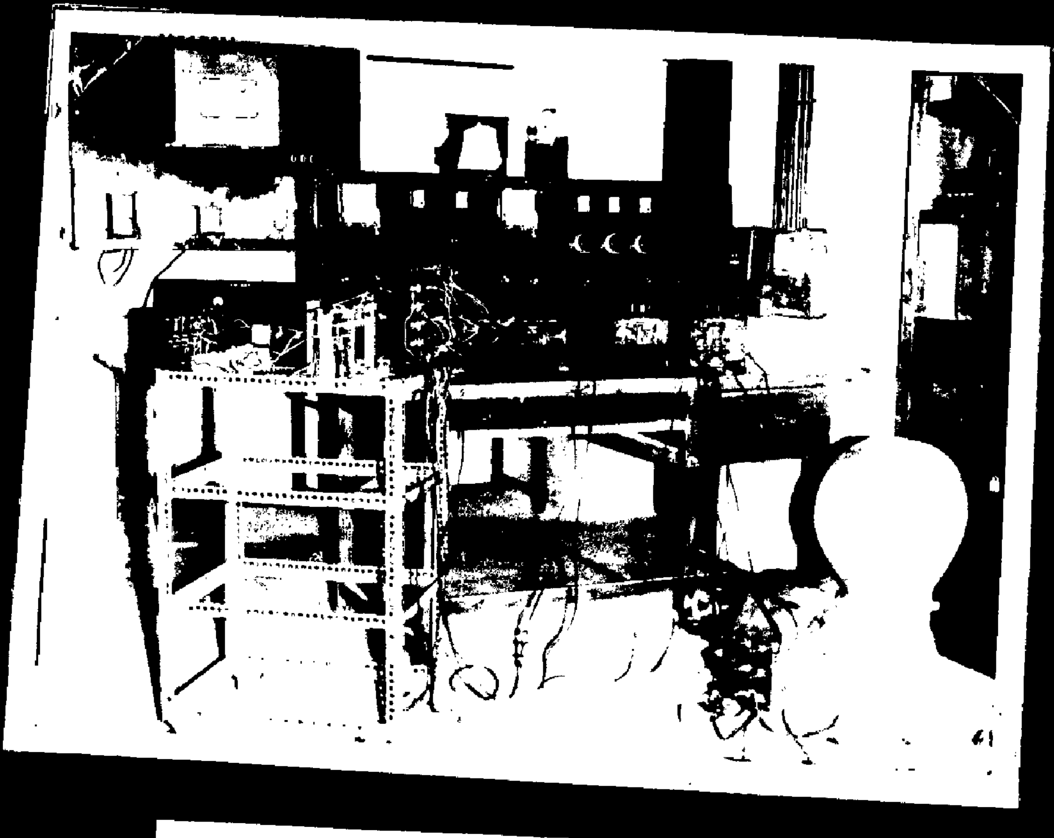


FIG. 33 HYPERBOLIC CHARACTERISTICS



PHOTOGRAPH OF RELAY ASSEMBLY



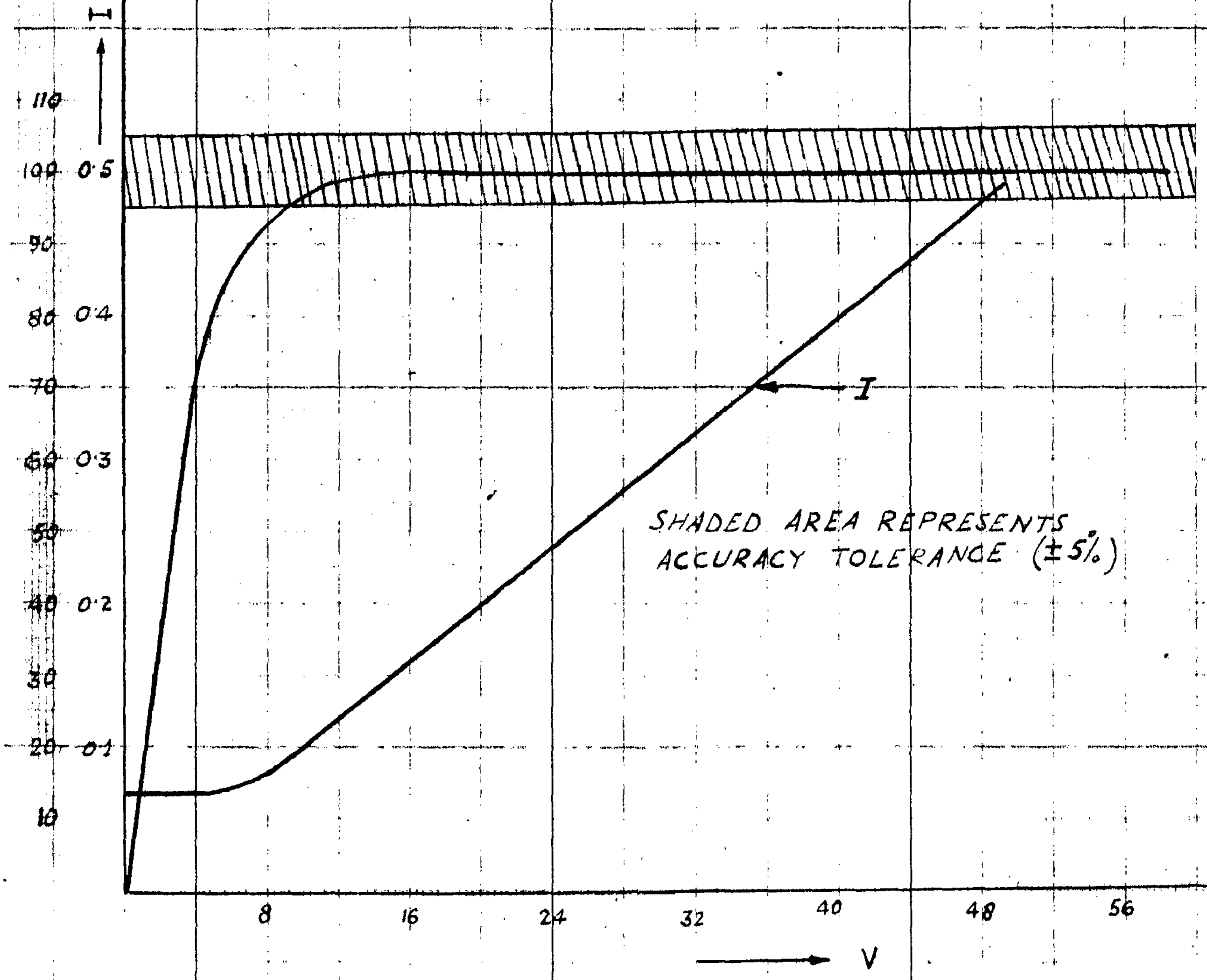
SET UP FOR AUTOMATIC TESTING
OF RELAY

4.5.3. Voltage/Reach Curve:

Fig.(34) represents the relay voltage/reach curve. The relay maintains an accuracy of measurement within ±5% down to 8 volts. Thus the relay will be applicable to transmission lines where the value of source, line impedance, ensured that the voltage drop to the point of fault would be no less than 8 volts secondary. This minimum voltage will appear only when the fault is very close to the bus.

This accuracy is quite satisfactory than electromagnetic relays.

ACCURACY CURVE



SHADED AREA REPRESENTS ACCURACY TOLERANCE (±5%)

FIG. 34.

4.5.4. Characteristics of Rectifier Used:

The Forward and reverse characteristics of selenium rectifier used are shown in fig.(55). The threshold voltage of each rectifier is about 1 volt. The scale of the reverse current has been purposely enlarged in comparison with the forward current, because it is of such a low order.

FORWARD AND REVERSE CHARACTERSTIC
OF SELENIUM RECTIFIER USED.

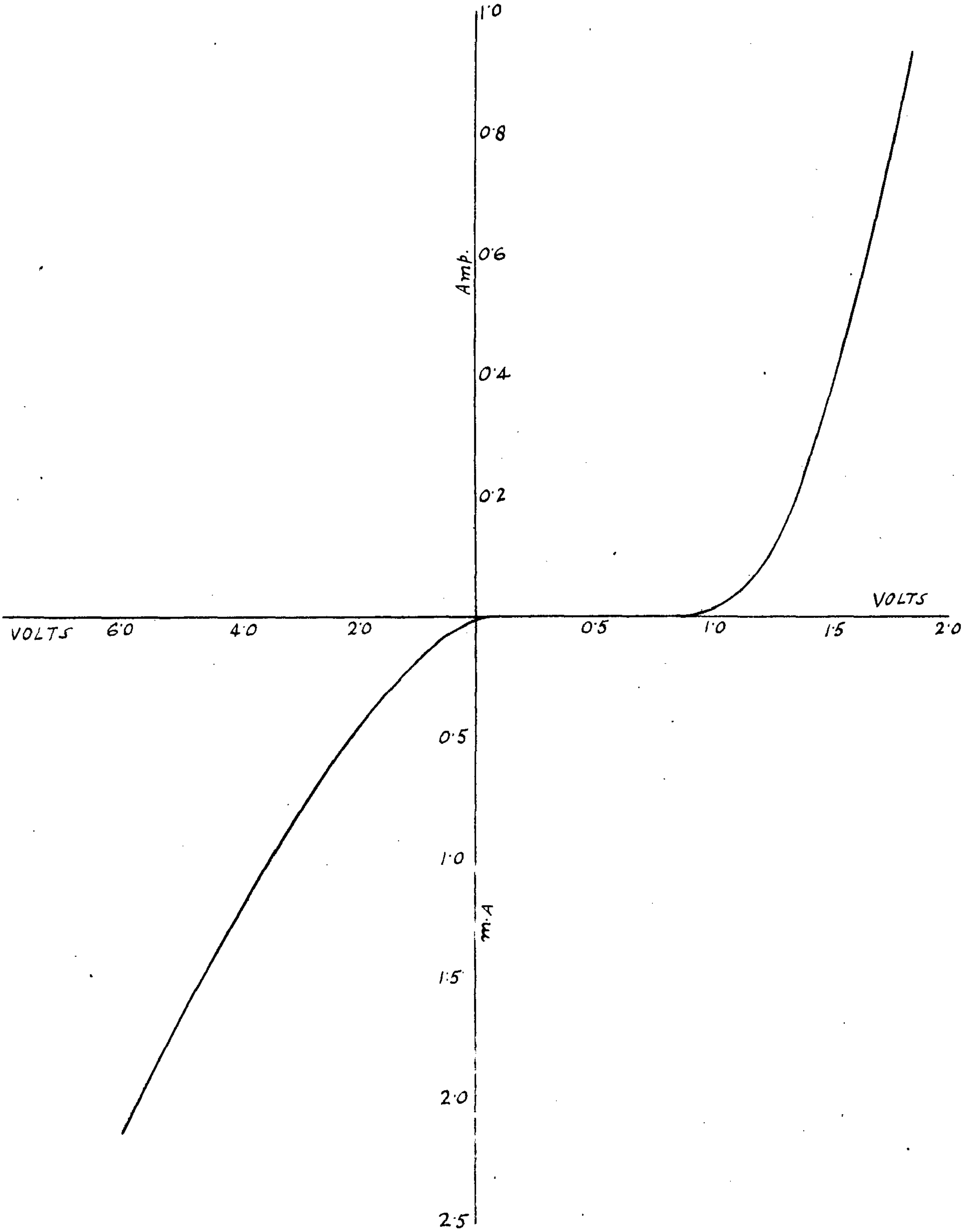


FIG. 35.

CHAPTER V

APPLICATIONS OF DISTANCE RELAYS WITH ELLIPTICAL AND HYPERBOLIC CHARACTERISTICS

CHAPTER V

APPLICATION OF DISTANCE RELAYS WITH ELLIPTICAL AND HYPERBOLIC CHARACTERISTICS

5.1. RELAYING PROBLEMS ON LONG TRANSMISSION LINES

Upto a certain length of transmission line, conventional distance relays will readily distinguish internal faults for which the line should be opened and external faults, load conditions and power swings for which the line should not be opened. This distinction is based on the magnitude of the impedance or reactance of the line as it appears to the relay$^{(\quad)}$. This impedance will be referred to hereafter as the input impedance and is determined by the current and voltage existing at the relay location.

The magnitude of the input impedance will distinguish clearly between internal and external faults for any length of lines, but as longer lines are considered the difference in impedance between load and fault conditions becomes less and may even be reversed$^{(28)}$.

Although there is little difference in impedance magnitude during fault and load conditions on very long lines, there is fortunately, a considerable difference in phase angle. During load conditions, the heavy charging current component tends to make the input impedance having a leading power factor, whereas during an internal fault much of the line capacitance is short circuited and the input impedance will be lagging considerably.

5.2. Input Impedance During an Internal Fault.

When supplied with proper currents and potentials, the relay associated with the faulted conductor or conductors measures the positive sequence impedance of the line between the relay and the fault including any arc or contact resistance(30) of the fault. The impedance and arc resistance measured by the relays not directly associated with the fault differs from the true impedance by an amount which depends on the type of fault.

As an illustrious example the impedance seen by the three phase relays connected to phases 1-2, 2-3 and 3-1, for a fault between phases 2-3 is shown in fig.(36).

The line A-B is a vector representing the true (positive sequence) impedance of the protected transmission line where as F is the fault location. The lines A S and B L represent the total system impedance behind the relay and beyond the protected line respectively and can easily be calculated from a knowledge of the short circuit currents at the terminals A and B, deducting the current that flows through the line. For the sake of simplicity all the impedances of the system are considered to be of the same phase angle, that is, the system is homogeneous and points S, A, B and L are on the same straight line.

The impedance measured by the relay in the faulted phases 2-3 (neglecting arc resistance) is represented by the line A F, which is the phase to neutral positive sequence impedance of the lin between the relay and the fault as is referred to as the true impedance. The phase 3-1 relay sees an impedance which is leading the true impedance and phases 1-2 relay, lagging impedance and arc as shown in the diagram.

The area Z_{23}' is the input impedance area for the relay in phases 2-3, Z_{3-1}' is that impedance seen by the relay connected to phases 3-1 and Z_{12}' is by the relay in phases 1-2. The arc resistance is expressed as $R_a/2$ instead of R_a because

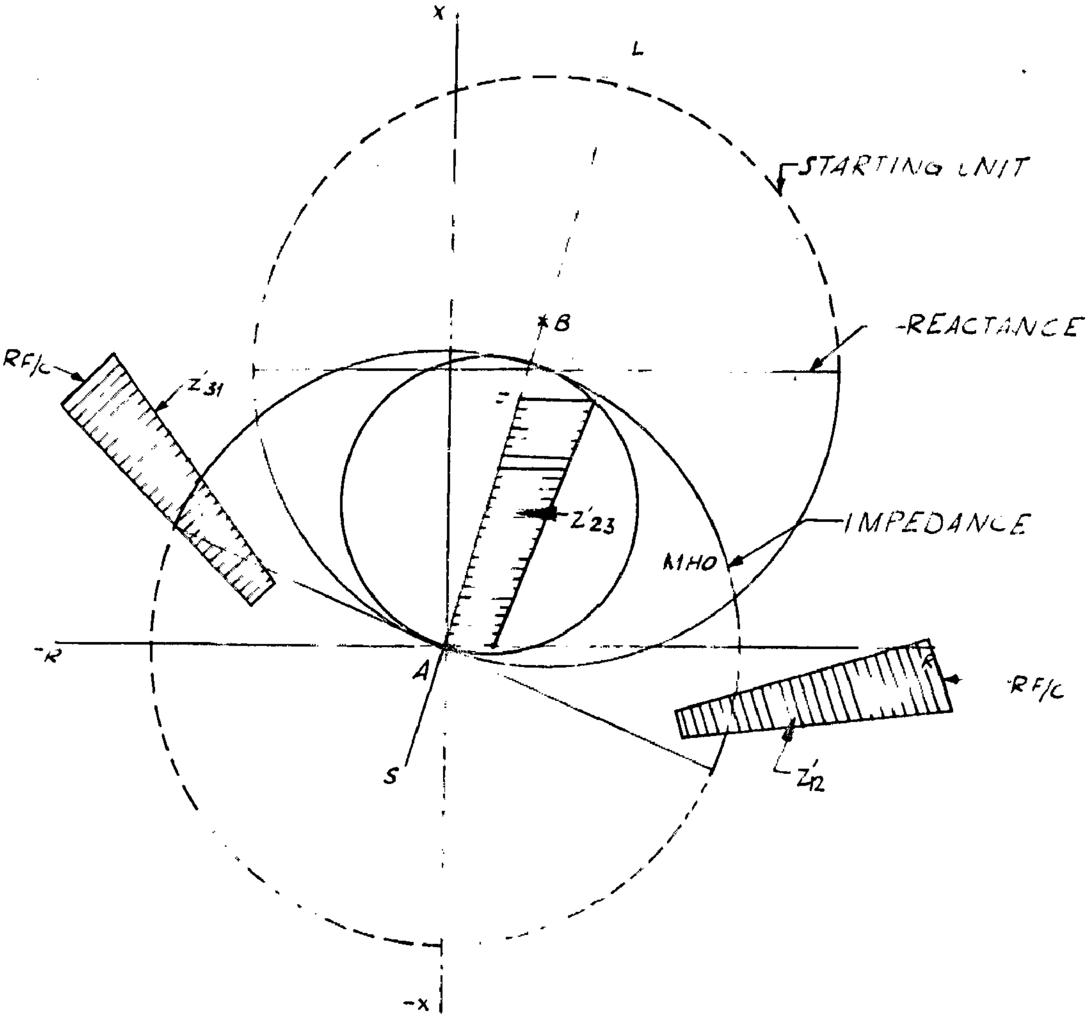

X
L
STARTING UNIT
B
REACTANCE
RF/C
Z'31
Z'23
IMPEDANCE
MHO
-R
A
R
RF/C
S
Z'12
-X

FIG. 36.

only a fraction C of fault current flows through the relay, the rest comes from the line section on the other side of the arc.

6.3. Impedance seen by Relays during Power Swings(31):

The locus of the impedance seen by relays during power swings for the equal system voltages at both ends of the line is a straight line (. The swing impedance locii for a simple 2-machine system shown in fig.(37(a)· are plotted in fig.(37·(b)·) for the condition $L_{A/L_{B}} = 1$.

If the two generators are in phase with each other, the current is zero, and therefore the apparent impedance is infinite. But if the generators are 180° apart, the voltage becomes zero at the middle of the line and therefore there appears to be a three-phase short circuit at that point ($n = \frac{1}{2}$).

When the voltages at the 2-ends of the system are not equal, the swing impedance locii, as seen by relays will be circular (Fig.37(b)) instead of straight lines (   ). Then the impedance will never become infinite.

6.4. Performance of Distance Relays with Conventional Characteristics

In fig.(38), the typical load impedance circle for an interconnected system is shown and the tripping characteristics of impedance, reactance and Mho relays. It can be seen that the third zone of the conventional impedance relay set to operate in back-up time upto D would also operate on the maximum load.

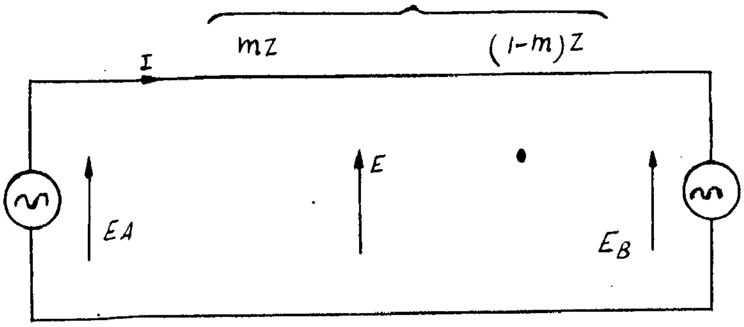


FIG. 37(a)

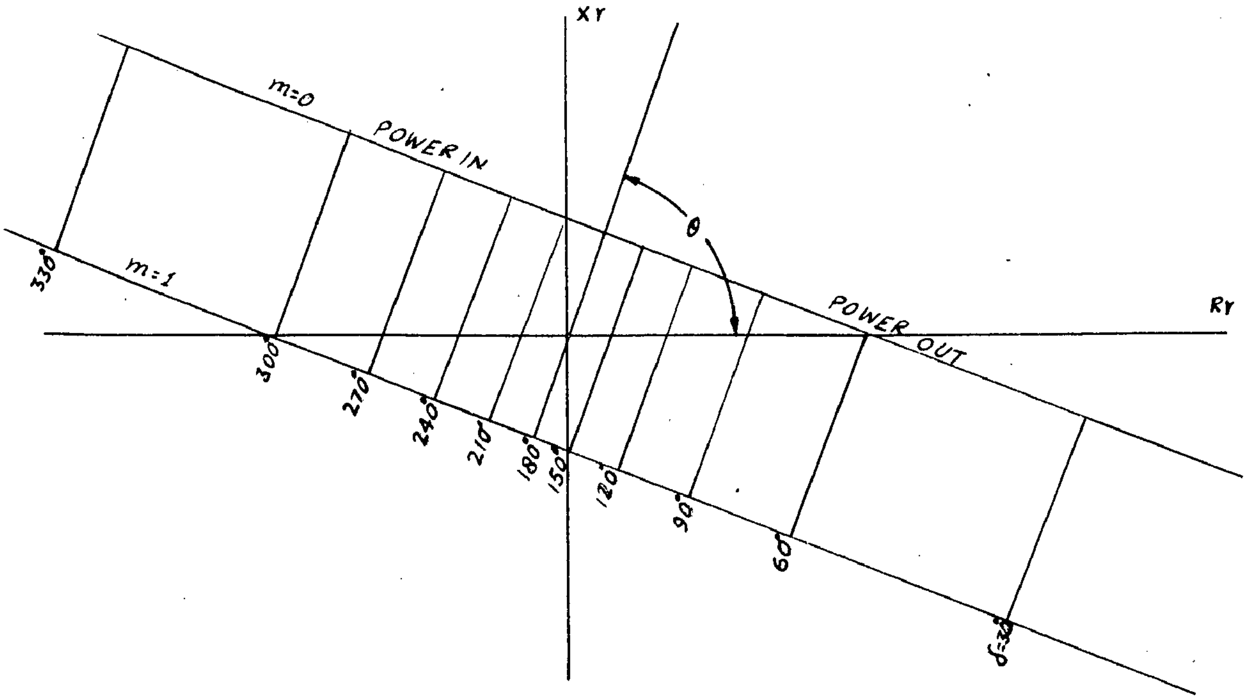


FIG. 37(b)

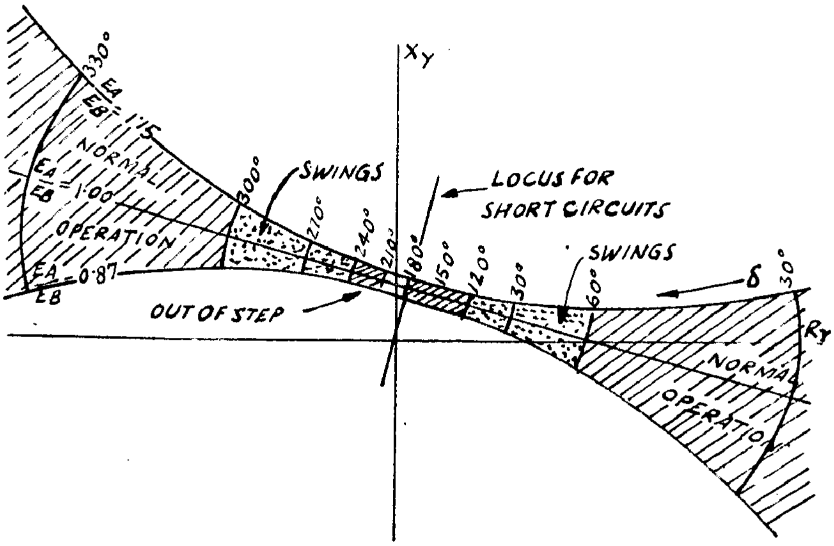


FIG. 37(c)

A further margin of impedance would be required to take care of the drifting apart of the two generating sources during the period of reclosure, because of the leading and lagging and speeding up and lagging and, leading generation and slowing down, otherwise the relays would trip on the reduced impedance condition caused by the two stations swinging apart before reclosure.

To overcome the difficulties of long transmission lines, the problem is therefore to design relays, which will(32),

1. Trip instantaneously for faults upto A, including arc resistance.
2. Trip on out-of-step conditions and swings from which the system will not recover.
3. Not trip on loads upto the steady state power limit.
4. Trip in delayed time upto D, for back up protection.
5. Not trip on swings from which the system would be likely to recover that is roughly upto $\delta = 110^\circ$.
6. Provide carrier blocking for external faults.

Items 1, 2, and 5 require that the relays should trip instantaneously for conditions within the area A - A' 120 degrees - B - B' 240° degrees. A circle fits very well around these points (see fig. 38) the centre of the circle on the line impedance A B, about 60 degrees leading the R - axis, though it also includes some loads which should be excluded under item (3). Such a circle is the characteristic of a directional relay with a voltage restraint. It is the characteristic of a Mho relay.

6.6. Methods of Obtaining Tripping Areas:

Items 4, 5 and 6 require also a relay combination which will operate within the shaded area of fig.(38).

5.5.1. Reducing Tripping Area of Relay Characteristic with blinders

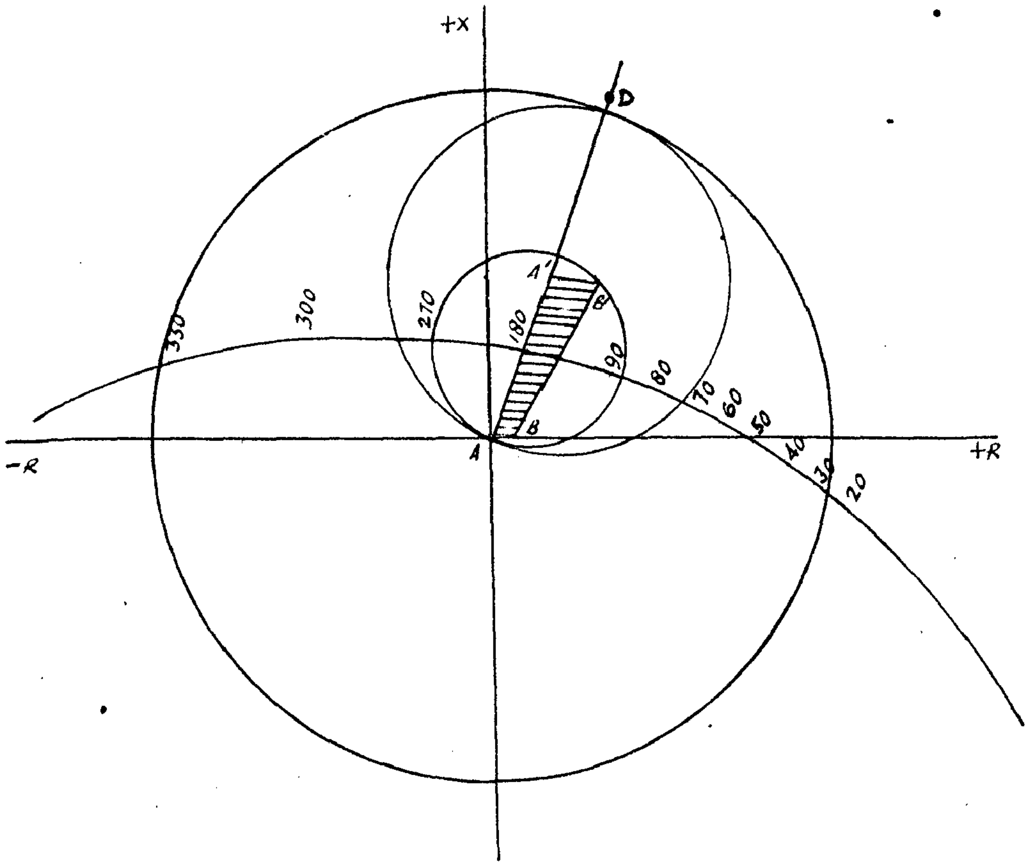
The method adopted in one case (Kansas - Nebraska interconnection) is to use two ohm units called blinders in conjunction with one Mho unit (see fig.39). By connecting the contacts of two ohm units in series with impedance unit and a timing unit back up protection with delayed tripping occurs in the lightly shaded area as shown in the fig.(39) which disposes of items 4 and 6.

In reference to items 3 and 5, by connecting the contacts of the ohm units in series with those of Mho unit, the value of δ at which tripping occurs can be accurately controlled by the setting of the ohm units; otherwise this limit is determined by the Mho unit, whose setting is based on the length of the line and hence cannot be adjusted. The Mho unit would prevent tripping on swings upto $\delta = 75^\circ$, but about 110° would be required to provide sufficient margin for power swings, especially after instantaneous reclosure of the breakers following the fault.

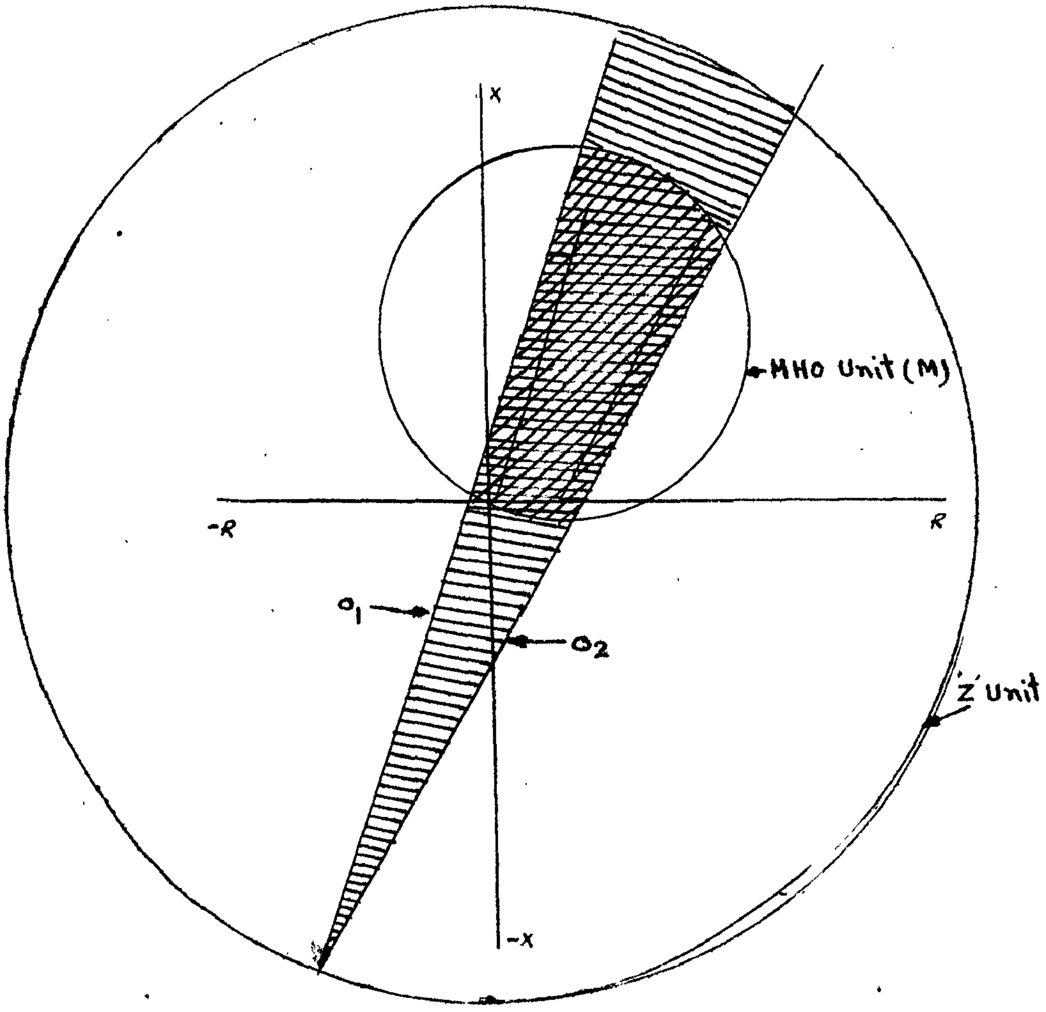
Usually 20° and 30° are chosen for the ohm units. The 20° characteristic can be as close to impedance vector as desired, but the closer it is, the lower the ohmic pick up and hence the higher the potential burden.

The 30 degree characteristic has to allow for the maximum arc voltage, which will be during minimum generation and single-end feed.

The above scheme requires three relays for each phase and there will be three contacts in series in the trip circuit. As the number of contacts in series is increased, the reliability


+X
D
A'
B
B
A
180
270
300
330
90
80
70
60
50
40
30
20
-R
+R

FIG·38·


X
MHO Unit (M)
-R
R
O_1
O_2
Z Unit
-X

FIG·39·

will be decreased.

5.5.2. Use of Second Zone Impedance Relays.(33)

Fig. (40·a) shows a possible combination of relays for application to long lines. In this, a displaced circular characteristic is used which does not include the origin. The diameter of such a circle will be smaller than that of either an impedance or Mho unit of the same reach and consequently it will cover smaller angular range in the direction of swing impedance locus.

5.5.3. Use of Relays with Circular Characteristics of large Diameters.

Another method utilises a directional element and two elements having circular characteristics of large diameter as shown in fig.(40·b). The latter elements perform the function of blinders, but because their circles intersect, no other distance element is required to limit the reach on faults.

This provides good coverage in the direction of fault impedance, and restriction in the direction of load current and swings.

5.5.4. Distance Relay with Elliptical Operating Characteristics

Attempts to produce the distance relays with characteristics which will closely cover the fault impedance area lead to the design of relays with elliptical characteristics. An elliptical characteristic will closely follow the fault area and hence the impedance during swings and overloads will not fall within the operating characteristic and hence will not be susceptible for operation during swings and overloads.

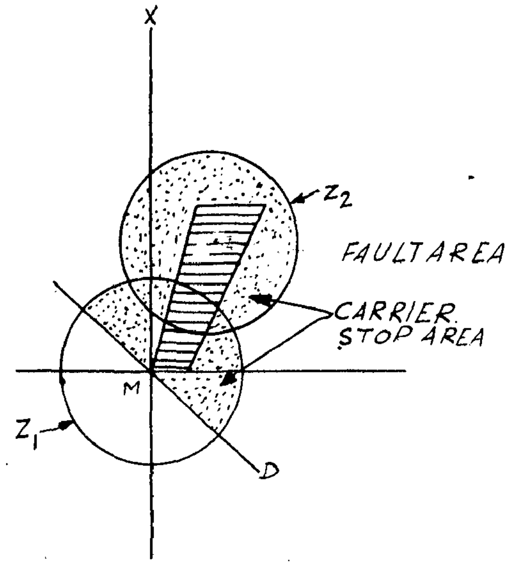


FIG. 41(a).

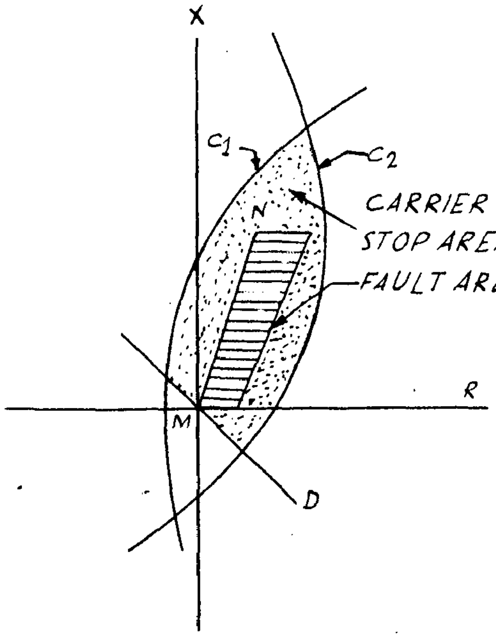


FIG. 41(b).

An elliptical characteristic would have considerable advantages and could be thought of as roughly equivalent to a Mho unit interlocked with two blinders. Assuming all of the individual relay units had equal reliability the relay with elliptical characteristic would be more reliable as it would have only one contact in the trip circuit, where as the equivalent scheme would have three contacts in series in the trip circuit.

6.5.2. Application of Hyperbolic Characteristics as Blinders.

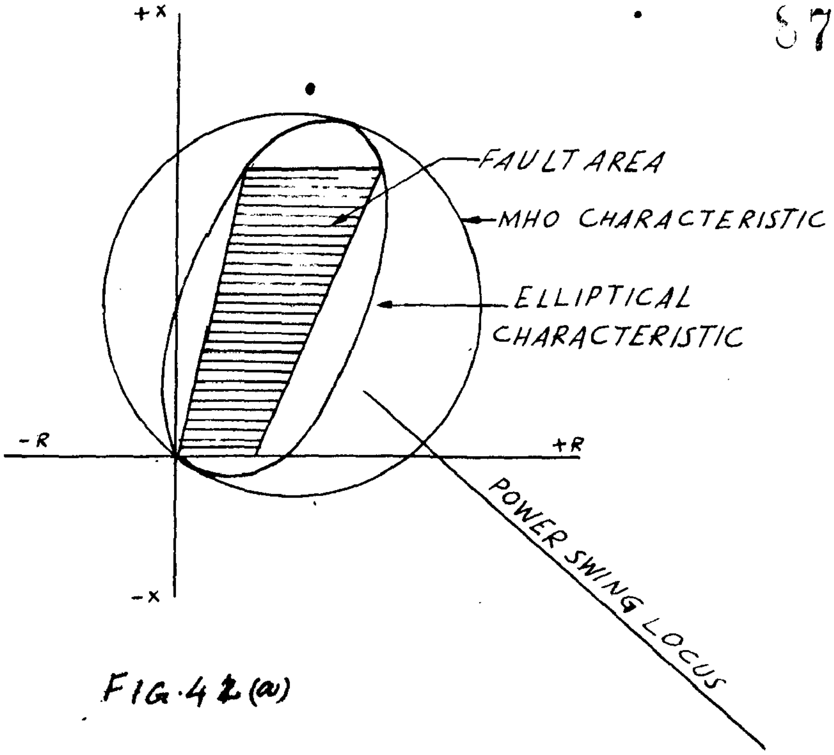
The limitation of the operating field of a distance relay of any type can be achieved by the addition of a distance blocking relay which distinguishes a defined part of the complex plane. Blocking of a Mho relay by the two ohm units (straight line characteristics) has been described already. The two branches of a hyperbola can also be employed for blocking the Mho relays.

The use of blocking distance relay with hyperbolic characteristics will be an improvement over the use of ohm relays with straight line characteristics because a hyperbolic characteristic will fit closely with the fault area (including the faults with resistance).

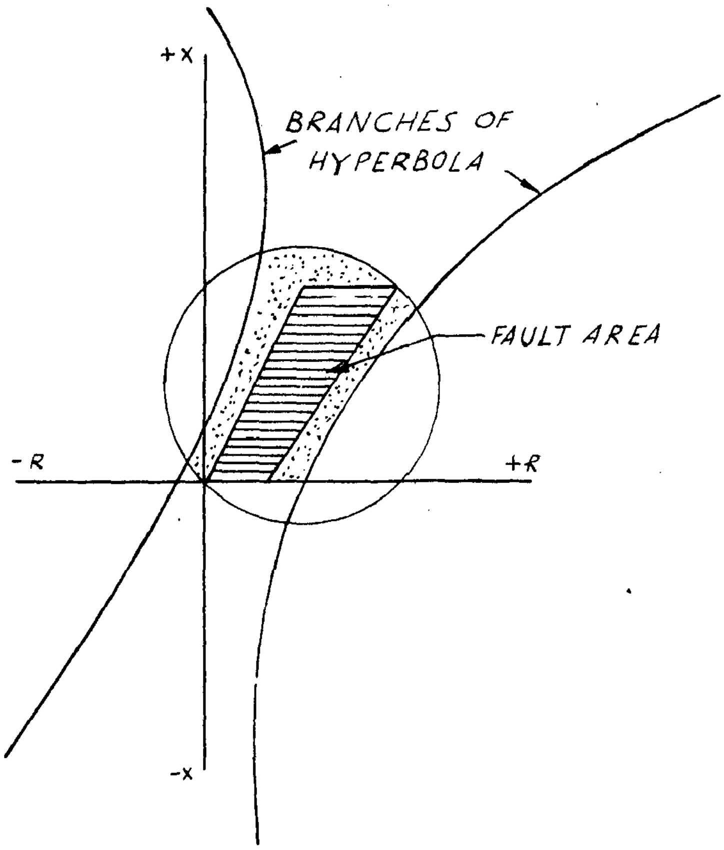
6.6. Problem of Setting the Starting Unit for Long Lines

In the 3-zone distance protection, zones 1 and 2 are for preserving continuity of service and zone 3 is essentially back-up.

Zone 2 is not to cover the whole of the neighbouring section. Zone 2 must be set for atleast $Z_1 + ½ Z_1'$ ohms where Z_1 is the impedance of the protected section and Z_1' is the impedance



FIG·42(a)



FIG·42(b)·

of the next section and U is the maximum ratio $\frac{I_R + I_F}{I_R}$ of the total current entering the next section to the amount flowing through the protected ~~next~~ section.

Until recent years system conditions were fairly simple so that back-up protection was effectively provided by the relays at the next station towards the source with enough time delay to permit the relay in the faulted circuit to clear the first fault, if operable. The increase in the number of inter-connections and power infeed points in recent years has reduced the fault current in the circuits, other than the faulted circuit, so that remote back-up relaying is becoming increasingly difficult, at the same time loads are becoming more important and hence demanding better service continuity.

5.6.1. Back-Up with Reversed Off-set Mho Relays.

Where the limitation of the back-up reach of distance relays is mostly due to the line length, an improvement in their operation can be obtained by locating the zone 3 unit at the other end of the line section and reversing its direction. Referring to fig. (42) the third step of the distance relay normally provides remote back-up for faults in section B C if the breaker at B fails to trip.

Now this back-up can equally well be provided by reversing the third zone unit at B so that it covers section B C. This arrangement not only reduces the impedance seen by the back-up relay by the impedance of section AB but also maintains power supply to tapped loads in section A B.

6.6.2. Elliptical Characteristic for Zone 3 Unit:

The back-up provided by the reversed-off-set third zone relay is local back-up since this back-up relay has the same A.C. and D.C. supplies as the relays it is backing up so that it may fail for the same cause.

This difficulty can be ameliorated by using distance relay with elliptical characteristic for the third zone unit, which will enable it to have a shorter impedance reach along the R-axis than along the X-axis.

On the question of remote versus local back-up protection the following statement from the 1960 C.I.G.R.E. publication No.334 page 38 can be quoted.

" Answers to Questionnaires on Back-up protection-Remote back-up. This is the cheapest and simplest form of back-up protection. It is entirely independent of local supplies, wiring etc. and is essential where there is no bus protection. On the other hand it is unreliable where local power infeed raises the impedance seen by the back-up relay to that of maximum load conditions. An elliptical R - X characteristic is helpful."

6.7. Protection of Multi-terminal lines:

Multi-terminal inter-connected systems have become more prevalent because of economic factor involved. System planners are applying increasing pressure on the relay engineer on the basis that the best possible relaying system cannot cost as much as an additional circuit breaker and possibly an additional section of transmission circuit(34). Inspite of the ingenuity of relay engineer, it is impossible to relay some systems.

5.7.1. Effect of infeed. Apparent Impedance(35):

In multi terminal lines, the modification of system impedance seen by distance relays imposes a great difficulty of satisfying conflicting requirements by suitable characteristics and settings. This is explained for a simple 3-terminal line shown in fig. (43)(a).

The voltage at terminals of A = $I_A . Z_{AD} + (I_A + I_C)Z_{DF}$

current through relay at A = I_A

Apparent impedance seen by relay at A

$$= \frac{I_A . Z_{AD} + (I_A + I_C)Z_{DF}}{I_A}$$

$$= Z_{AD} + \left(\frac{I_A + I_C}{I_A} \right) Z_{DF}$$

$$= Z_{AD} + Z_{DF} \left(1 + \frac{I_C}{I_A} \right)$$

and $Z_{DF} \left(1 + \frac{I_C}{I_A} \right)$ is called the apparent impedance of the line section DF to the relay at A.

Hence the infeed from terminal C causes the line from A to D, as viewed from A to appear to be longer than it really is. An N-terminal short line can easily thus appear to be a very long line.

5.7.2. Sequential Tripping(36):

Due to this increased apparent impedance caused by infeed, the relays at terminals A to be able to see the fault F near terminal B, they may have to be set so sensitively that even a minor swing between terminals A and C may cause the tripping of the breaker at terminal A.

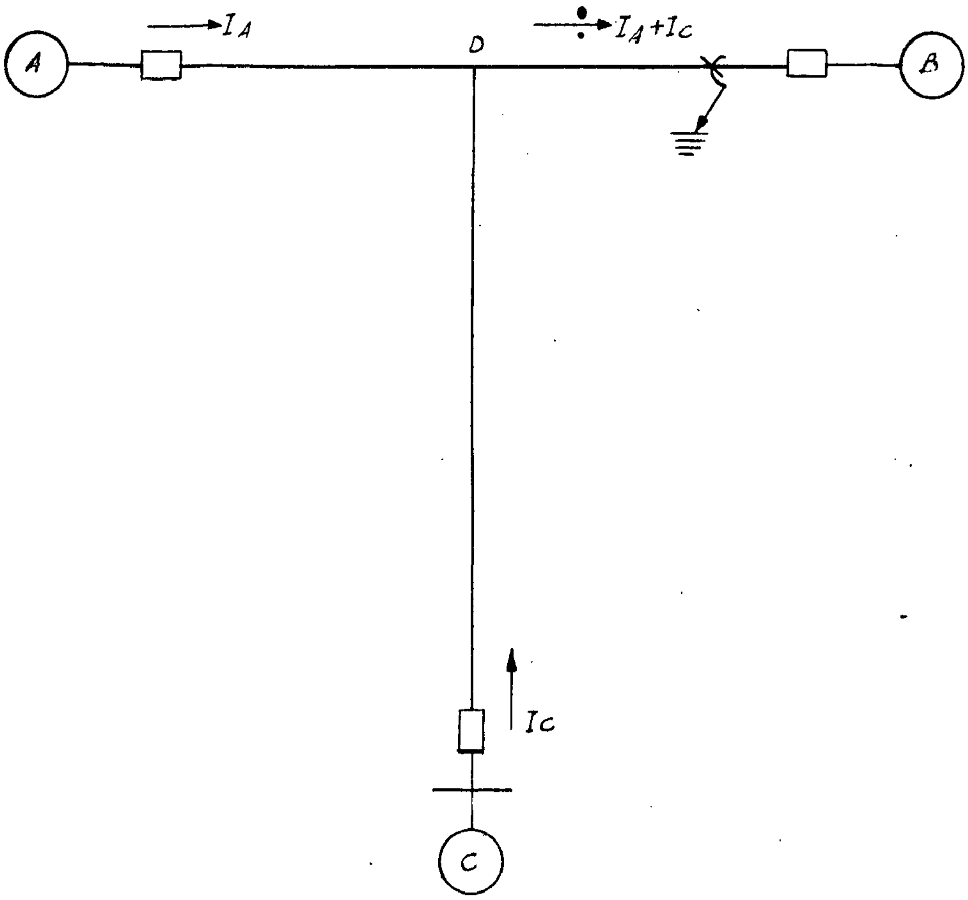


FIG. 43(a).

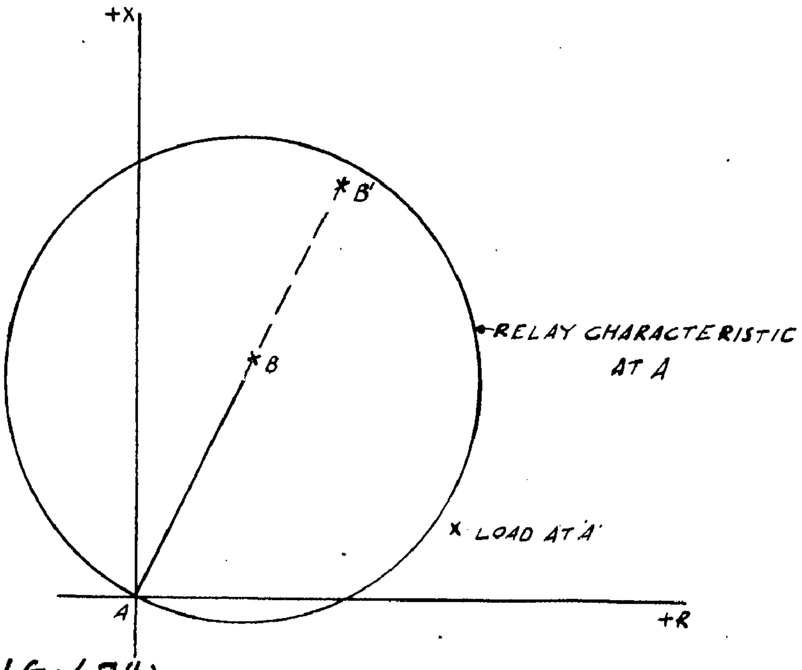


FIG. 43(b).

A B = IMPEDANCE SEEN WITH NO INFEED FROM C

A B' = IMPEDANCE SEEN WITH INFEED FROM C

One solution to the above problem is to use sequential tripping. The relay characteristic at A must be contracted to a smaller size, to permit a reasonably good load carrying ability. The circuit breaker at C is allowed to trip first when the fault impedance jumps from AB' to AB i.e. into the relay characteristic at A. Then relay at A can see the fault and open the breaker at A.

8.7.3. Problems in Sequential Tripping

Generally sequential tripping is quite tolerable, but occasionally there will be other problems such as the following.

i) High speed reclosing of the line may have to be delayed because of sequential tripping.

ii) Impedance type carrier starting is intolerable as illustrated in fig. (44).

If the fault is moved towards D from B, there will be a series of fault locations, which will appear to be in the area B''. The carrier start relay at A will start a blocking signal, but the carrier - stopping relay will not be able to stop the carrier. There will then be no carrier trip any where. The problem can be avoided by carrier-starting with reversed off-set Mho relay. There is then no internal fault condition for which carrier can start without being stopped.

iii) If it is desired to block tripping during out-of-step conditions, there is another problem not taken care of by the carrier starting means as given above, in which out-of-step blocking is set up. If there is

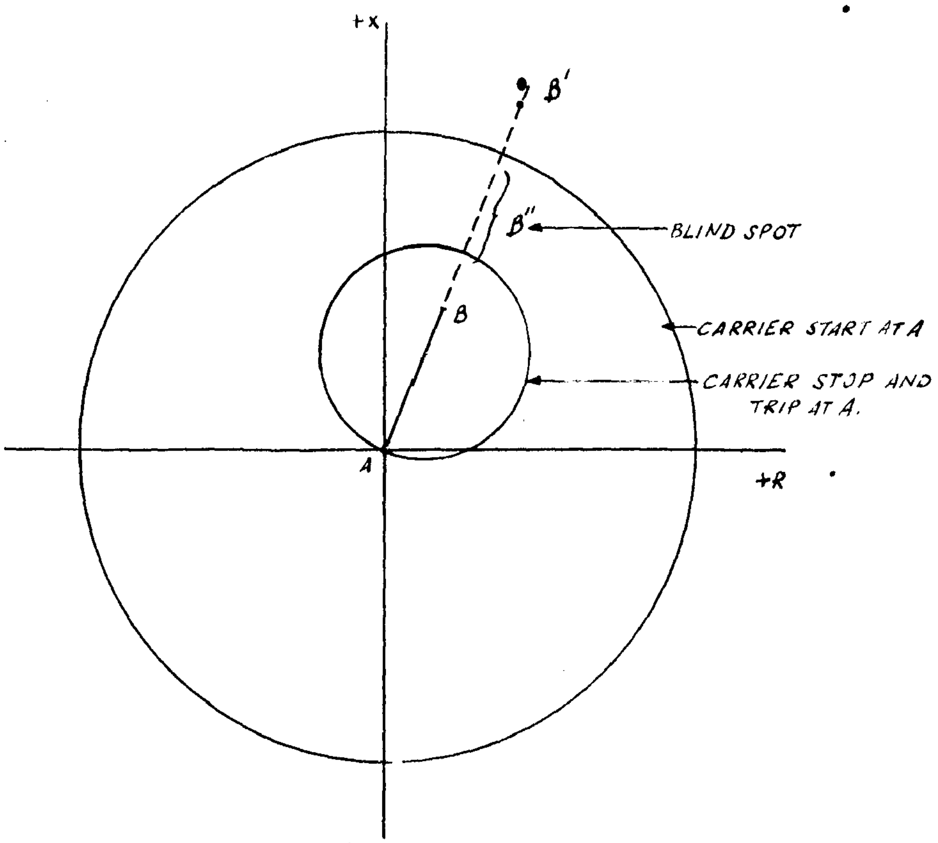


FIG. 44(a).

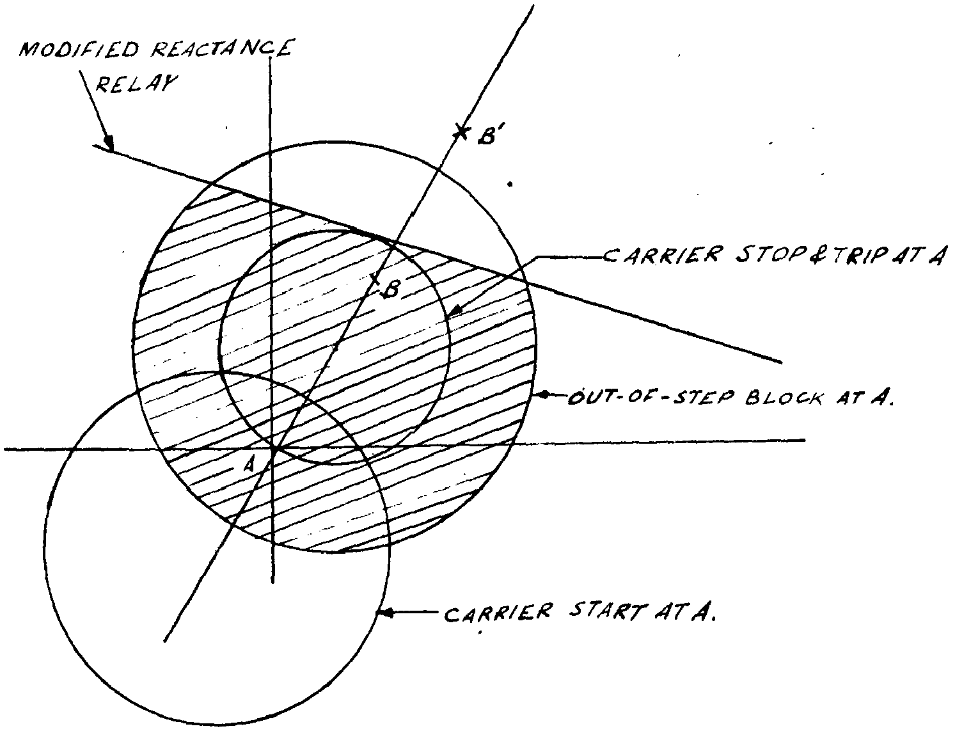


FIG. 44(b).

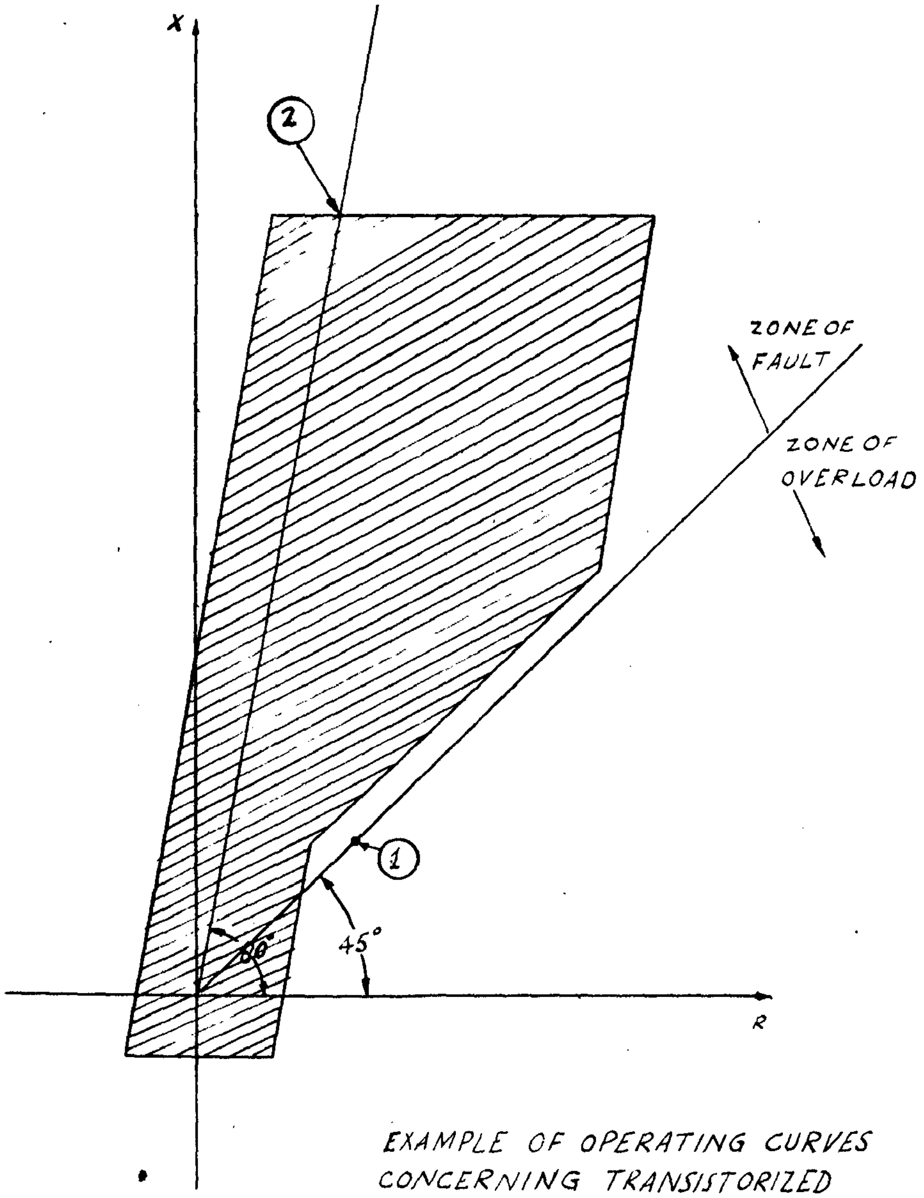
a time delay of several cycles between the operation of the out-of-step block at A and carrier stop and trip at A. Here again a fault near B may appear to be in the area D', and will set up out-of-step block at A. This situation has been avoided in a few applications by means of an extra relay unit E (a modified reactance relay). The out-of-step block area is shown shaded.

8.7.4. Methods of avoiding Sequential Tripping

It may be desirable to obtain high speed tripping for all ~~time~~ line faults and yet not permit tripping during a swing unless there is actual out-of-step condition. The only way of achieving this end is to narrow down the tripping area of the relay characteristic in the direction of swing locus. The tripping area of the relay characteristic should be reduced to the actual fault characteristic. Various schemes have been used to approach that, (1) by the use of ohm blinders to limit the area of Mho relay characteristic (2) to use two relays with circular characteristic, one circle being off-set from the origin (3) the use of Relay with elliptical characteristic

Investigations for new types of characteristics for application to High Voltage interconnected networks has led to the types of characteristics for distance relays which will exactly cover the fault area, so that it allows maximum permissible over load and at the same time operating for minimum fault current.

A transistorised relay has been developed in Belgium(38) having a characteristic similar to that shown in fig.145.



EXAMPLE OF OPERATING CURVES CONCERNING TRANSISTORIZED IMPEDANCE RELAYS.

FIG. 45.

POINT 1. THE POINT OF PERMISSIBLE LIMITING OVERLOAD IMPEDANCE

POINT 2. THE POINT OF MAXIMUM SENSITIVITY FOR BACK-UP PROTECTION.

The operating zone adopted is ideal because it includes any operation under the severest conditions of over-load whilst nevertheless, retaining very broad vision of faults even if there is an arc resistance.

The C.I.G.R.E. committee set up for discussing the problems of protection of multi-terminal lines expressed the following opinion-

" The difficulties related to satisfactory setting of distance relays in interconnection networks have been known for a certain time, but upto the present time the problem has only been acute in several particular cases which were relatively rare."

" On account of the increase in short circuit powers and also of the increase in the number of stations tapped from the interconnected line the difficulties are becoming accentuated and more general."

After giving the various possible solutions for such cases, the conclusion of the report is as follows-

" The problem regarding the starting principle of distance relays should be solved as soon as possible having regard to the present acute state of the question.

It would appear that the possibilities arising from the use of electronic techniques could supply appreciable improvements in a short time having regard to the flexibility observed in the building up of the most complicated operating characteristics."

CONCLUSION

With increasing confidence on the behaviour of electronic components, static relays are gaining universal acceptance. With static comparators, there is a great flexibility, to obtain the required type of operating characteristic. The static distance relay constructed with rectifier bridge comparators can be adjusted to have either circular (impedance or Mho) elliptical or hyperbolic characteristic.

The scheme used by the author has got the following advantages over other schemes described.

1) In the circuit used by Gaevenko, smoothing of the D.C. output is necessary without introducing time delays and for this purpose split phase circuits and polyphase rectifier bridges are employed, where as no such smoothing is necessary in the present case.

2) Single winding polarised moving coil relay is used in the output stage, because the comparison of input quantities is done electrically, where as in the scheme used by Gavenko, three winding moving coil relay has to be used and the comparison of the input quantities is done magnetically. Not only the cost will be high but also the power consumption will be large.

3) In the circuit employed by T.S.M. Rao, for changing the eccentricity of the operating curve, the value of K $(= \frac{Z_R}{Z_L})$ has to be changed. This also changes the reach of the relay and hence the adjusting of

the eccentricity of the operating characteristic is not flexible. Where as in the present case, the adjustment of the eccentricity of the characteristic is independent of the adjustment of the reach of the relay.

4. In the circuit used by T.S.M. Rao, because of the mutual effect between amplitude and phase comparators, there will be a bulging of the operating characteristic, which in the present case does not appear.

The relay maintains an accuracy of ± 5 percent upto a minimum fault voltage of 8 volts applied to the relay, which is quite satisfactory.

The use of a distance relay with hyperbolic characteristics will be as a blocking relay for the Mho characteristic. For this purpose the operating characteristic should cover both branches of hyperbola. To achieve this two relays may have to be used each relay having a characteristic covering one branch of hyperbola.

Alternatively, a single relay can be constructed to satisfy both the equations (4.14) and (4.15) simultaneously.

Distance relays with very narrow tripping area are necessary for application to long transmission lines and in this respect an elliptical characteristic will be more appropriate. Investigations to construct relays with operating characteristic exactly following the fault impedance area, for application to long lines where the minimum fault current is less than the maximum load current, are going on.

The characteristic for the starting unit for application in high voltage interconnected networks, developed in Belgium will satisfy these requirements. This is possible only with transistorised relay circuits.

Though the transistor relays may not replace simpler types of electromagnetic relays, they may be accepted for relays with complicated operating characteristics which are possible only with transistorised relays.

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