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A NEW APPROACH TO ELECTRONIC IMPEDANCE RELAYS

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Abstract

This paper presents a new method for the design of a static impedance relay whose characteristics can be altered using minimum variation of circuit elements. The relay has distinct advantage over the existing relays, in that it does not require either a memory or a special arrangement to detect a close up faults. The relay has the ability to distinguish between real fault and false operations due to power swings.

Introduction

The simplest way of protecting transmission lines and cables against faults is through the use of overcurrent relays. The operation of overcurrent relay depend upon the magnitude of the fault current, which in case of cables and overhead transmission lines operated at low and medium voltage, is higher than the maximum load current. With high and extra-high voltage transmission lines and cables, due to the high value of reactance per unit length, the short circuit current may be equal to or less than the load current. This render the use of overcurrent relays useless.

To overcome the above mentioned problem and to provide protection for transmission lines and cables, the distance or impedance relays are used. The distance relay is an apparatus which can discriminate between healthy and faulty line conditions even with a weak supply and far away faults which may cause fault currents of magnitude less than the load current. The distance protection does not measure the distance but actually the impedance between the relay and the fault.

The basic principle of measurement involves the comparison of the fault current as seen by the relaying point with the voltage at the relaying point, by comparing these two quantities, it is possible to measure the impedance of the line up to the point of fault.

In general a relay detects the change between normal and abnormal conditions by comparing two electrical vector quantities, both of which are derived from the system voltages and currents at a partoicular relay location. Depending on the specific method of comparison all comparators can be grouped as either amplitude or phase comparator.

The general equations for a comparator are:

$$S_1 = K_1 V_L + Z_{R1} I_L$$

$$S_2 = K_2 V_L + Z_{R2} I_L$$

From the above equations, the conventional range of polar characteristics can be obtained using a phase comparator or amplitude comparator, the input signal arrangements necessary to give the various characteristics as follows:

a. Directional characteristic:

$$S_1 = K V_L$$

$$S_2 = Z_R I_L$$

b. Ohm characteristic:

$$S_1 = - K V_L + Z_R I_L$$

$$S_2 = Z_R I_L$$

c. Impedance characteristic:

$$S_1 = - K V_L + Z_R I_L$$

$$S_2 = K V_L + Z_R I_L$$

d. Offset characterstic:

$$S_1 = -K_1 V_L + Z_{R1} I_L$$

$$S_2 = K_2 V_L + Z_{R2} I_L$$

e. Reactance Characteristic:

$$S_1 = -KV_L + Z_R I_L$$

$$S_2 = Z_R I_L$$

f. Mho Characteristic:

$$S_1 = - KV_L + Z_R I_L$$

$$S_2 = KV_L$$

when condition (f) is used, if $V_L = 0.0$, then $S_2 = 0$, there is no protection against terminal faults. This problem is solved using what is known as the polarized Mho relay, by making $S_2 = V_p$, where V_p is the polarizing voltage in phase with V_L but not proportional to it, so that for terminal faults the relay can operate satistactory. As can be seen, the problem now lies in the ability to select a suitable polarizing voltage V_p.

The three basic solutions are adopted in practice, V_p is either derived from the fault voltage V through a resonant circuit tuned to the system frequency (memory) e.g. in "Schlumberger" solid state phase fault distance relay, and in "Siemens" static destance protection or from unfaulted phase through a suitable phase-shifting circuit (sound-phase polarizing) e.g. in ASEA distance relay, alternatively combination of part sound-phase and part faulted-phase polarizing are used [6] and [7].

The last two methods do not solve the problem in the case of 3-phase faults, since this leads to an unpolarized Mho characteristic and operation for close in faults once more become indeterminate.

A Hybrid comparison technique, a combination of amplitude and phase comparison with suitable shapes of line current and voltage to derive the operating and restraining quantities for comparison, may be used for distance protection. The disadvantage is that the inputs to the phase comparator are the outputs from the amplitude comparator and voltage signal. In close-in faults the value of the voltage is near to zero, i.e. the comparator or relay requires a memory action for proper operation.

In this paper, the proposed schemes are described to obtain Mho, offset Mho, Reactance and Blinder by using Hydbrid comparator which is a combination of phase and amplitude comparator, The advantages of this scheme are that few number of signals are needed and there is no mixing between voltage and current signals. In fact only current signals are used as will be seen hereby.

2. Principle of Mho Relay Characteristic [8]

The Mho relay generally is known as an admittance relay because its characteristic is a straight line on the admittance diagram. The Mho relay is clearly directional. When the characteristic is plotted on the R/X diagram it will be a circle whose circumference passes through the origin.

In Fig. (1) length AB corresponds to the length of the line to be protected which could be equal to the relay setting if the relay characteristic angle is the same as the line angle $\theta = \varphi$

In the general case;
Line protected = Relay setting x Cos $(\theta - \varphi)$
Hence AB = AD x Cos $(\theta - \varphi)$

2.1 Mho Characteristic Using Hybrid Comparator

In Fig. (2) Z_R is the relay setting (replica impedance) , its phase angle is θ and Z is the impedance of the protected line or short circuit impedance whose phase angle is φ . The equation of Mho unit is as follow;

$Z \leq Z_R \cos(\theta - \varphi)$. Which represents a circle of diameter Z_R and passes through the origin. The impedance characteristic of the Mho relay is therefore a circle passing through the origin. To obtain this condition, two input amplitude comparator is used as shown in Fig.(3);

Operating input $S_I = I_L \cdot Z_R \cdot \cos(\theta - \varphi)$
Restraining input $S_V = V$
Tripping condition occur when $S_I \geq S_V$
Hence

$$I_L \cdot Z_R \cdot \cos(\theta - \varphi) \geq V$$
$$I_L \cdot Z_R \cdot \cos(\theta - \varphi) \geq I_L \cdot Z$$
$$Z_R \cdot \cos(\theta - \varphi) \geq Z$$

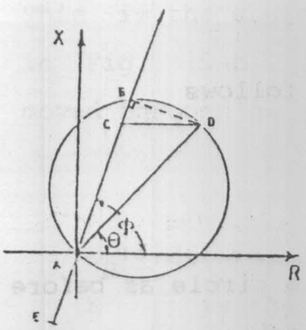


Fig.(1) General form of Mho.

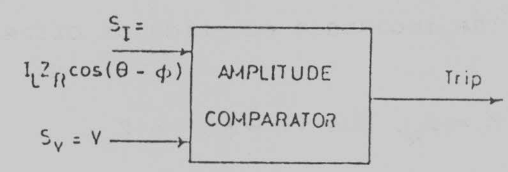


Fig.(3) Block diagram of Mho characteristic.

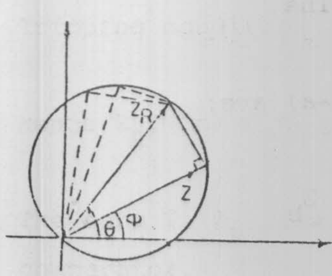


Fig.(2) Mho characteristic.

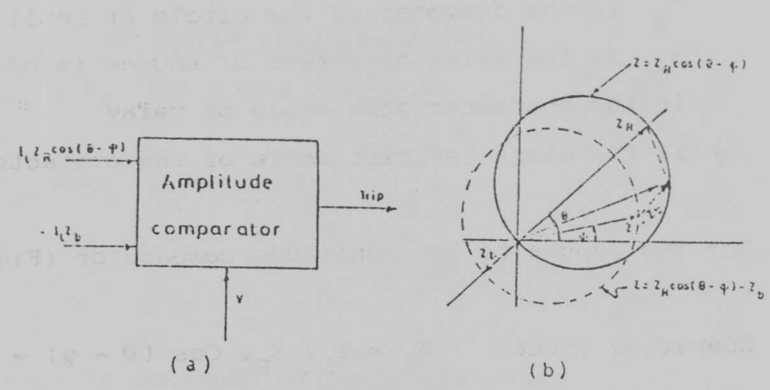


Fig.(4) a- Block diagram of offset-Mho unit

b- Offset-Mho characteristic

The term I_L . Z_R. Cos $(\theta - \varphi)$ is obtained by using an auxiliary phase comparator.

2.2 Offset Mho Characteristic Using Hybrid Comparator

2.2.1 First Method [9]

The impedance equation of offset Mho unit is as follows

$$Z = Z_R . \cos(\theta - \varphi) - Z_b$$

As shown in Fig. (4-b) the characteristic is a circle as before except that it is moved through an impedance Z_b , where ;

Z_R is the diameter of the circle or replica impedance

Z_b is the value of offset or source impedance

θ is the characteristic angle of relay

φ is the characteristic angle of the protected line

The two inputs to the amplitude comparator (Fig. 4-a) are;

Operating input $S_I = I_L . Z_R . \cos(\theta - \varphi) - I_L . Z_b$

Restraining input $S_V = V$

Tripping condition occurs when $S_I \geq S_V$

Hence $Z_R . \cos(\theta - \varphi) - Z_b \geq Z$

The term $I_L . Z_R . \cos(\theta - \varphi)$ is obtained by using auxiliary phase comparator.

2.2.2 Second Method [10]

The impedance equation of offset Mho relay will be

$$Z = Z_R \cdot \cos(\theta - \varphi) + K$$

This is the equation of circle of radius K and centre $Z_R \angle \theta$ as shown in Fig. (5-b). The impedance characteristic of offset Mho relay is moved through an impedance of $(K - Z_R)$ where ;

$Z_R \angle \theta$ determines the position of the center of the circle.
K is the radius

The inputs to the amplitude comparator (Fig. 5-a) are;
Operating input $S_I = I_L \cdot Z_R \cdot \cos(\theta - \varphi) + I_L \cdot K$
Restraining input $S_V = V$
Tripping condition occurs when $S_I \geq S_V$

Hence $Z_R \cdot \cos(\theta - \varphi) + K \geq Z$

The term $I \cdot Z_R \cdot \cos(\theta - \varphi)$ is obtained by using the phase comparator.

In Figs (3,4a,5a) amplitude comparators used to obtain the required Mho and offset Mho characteristics.

2.3 Auxiliary Phase Comparator

The phase comparator shown in (Fig. 6) has two inputs:

$S_1 = I.\ Z_R\ \underline{|\theta - \varphi}$

$S_2 = V.\ \sin w\ t$

To obtain the required output $I.\ Z_R \cos(\theta - \varphi)$ from this comparator the input voltage signal $V \sin(w\ t)$ to the comparator must be shifted in phase of $\sin(\theta - \varphi)$ as shown in Fig. (6).
In the above auxilary phase compator, it should be noted that the amplitude of the input voltage signal S_2 is ineffective and only its phase relation to the S_1 signal is of importance.

2.4 Close Up Fault

Under close up fault conditions, i.e. close in 3-phase fault conditions, the value of the relay voltage is almost zero (V = 0) thus the input signal, to the comparator, proportional to the voltage is lost. This condition does not represent a problem when using an amplitude comparator. Using a hybrid comparator, the occurence of a close up fault will pose a problem due to the loss of the voltage signal which is required for the operation of the auxiliary phase comparator to obtain $I_L.\ Z_R.\ \cos(\theta - \varphi)$. This problem was tackled previously by different manufacturs either by using a memory circuit which memorises the V(t) before the fault as in the case of PDPS Schlumberger or by increasing the sensitivity of the relay to operate down to 0.1 % of the normal operating voltage as in some types produced by ASEA

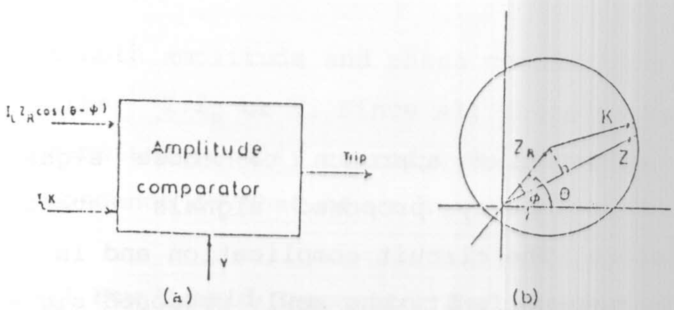


Fig.(5) a - Block diagram of offset-Mho unit
b - Offset-Mho characteristic

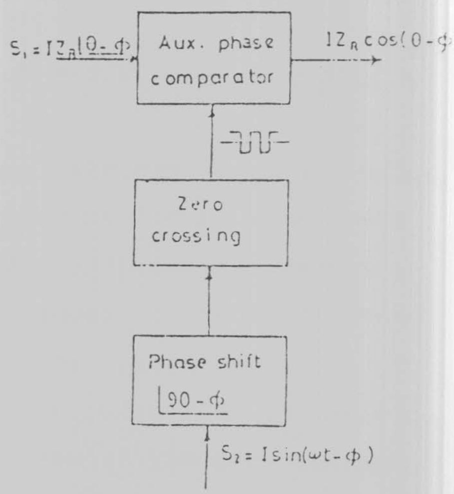


Fig.(7) Inputs IZ, I

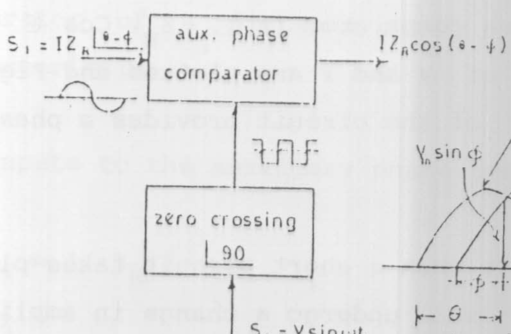


Fig.(6) Inputs IZ, V

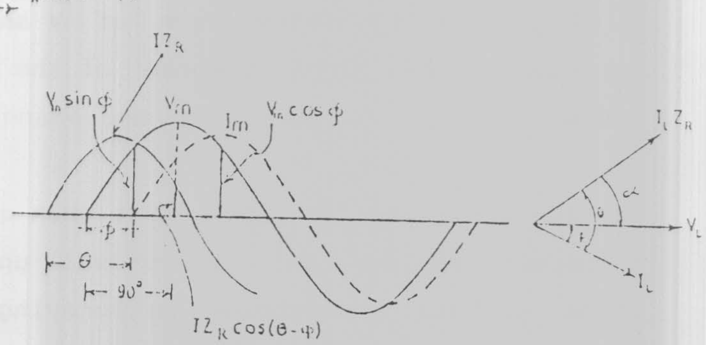


Fig.(8) Wave form of V and I

3. New Signals to Phase Comparator

Figure (7) shows an auxiliary phase comparator with the following two-input signals

$$S_1 = I.\ Z_R \underline{|\theta - \varphi}$$

$$S_2 = I.\ \mathrm{Sin}\ (w\ t - \varphi)$$

The signals represent an alternative approach to those signals previously application of these newly proposed signals have the advantage of reducing used before. The circuit complication and in the same time avoid problem of close-up fault, the newly proposed signal S_2 is not equal to V but in phase with it. At short circuit the value of current is lagging the voltage by an angle φ , so if the current signal is used as S_2 and shifted by $(90^{\circ} - \varphi)$ it will be in phase with the voltage signal and then using zero crossing. The output from the auxiliary phase comparator is I. Z_R. Cos $(\theta - \varphi)$. In Fig. (8) the wave form of V and I are plotted and Figure (9) represents the block diagram of the circuit provides a phase shift $(90^{\circ} - \varphi)$.

It is important to note that when a short circuit takes place the transient voltage and current will undergo a change in amplitude or phase or both. The problem of decaying of the D.C. transient current component if the circuit due the effect of short circuit has been delt with through the use of the replica impedance.

In voltage comparison the line voltage at the relay location is compared with the voltage drop across an impedance which is replica of the impedance of the protected line section on a secondary basis. For a fault at the end of the protected section the line voltage at the relay is produced by the line current flowing through the impedance of the protected section. Consequently, the transient behaviour should be identical to that of the voltage produced by the same current flowing through the replica impedance provided that the system impedance is homogeneus.

In both amplitude and phase comparators $(I.Z_R - V)$ are compared with either $I.Z_R$ or V. Since all these terms contain the primary current transient equally reproduced, it cancels out in the measurement if the impedance is that of a homogenous system [11].

3.1 New Hybrid Comparator for Mho and Offset Mho

The heart of distance relay is the measuring unit which compares the current and voltage in each of the phase to phase and phase to ground circuit. Figure (10) shows a proposed measuring element i.e. hybrid comparator of a distance relay which has a Mho or Offset Mho characteristic.

The inputs to the auxiliary phase comparator are,

$$S_1 = I.\ Z_R$$
$$S_2 = I$$

The output is $I.\ Z_R.\ \text{Cos}\ (\theta - \varphi)$

The inputs to amplitude comparator are;

$$S_3 = -\ I\ .\ Z_b$$

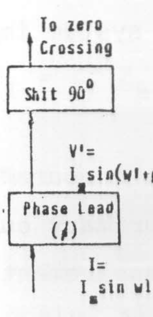


Fig.(9): Block diagram of shifter (90-φ)

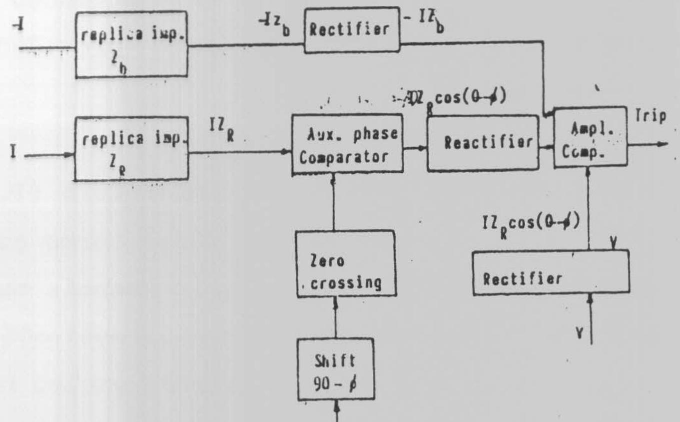


Fig. (10) Block diagram to obtain Mho, offset-Mho characteristic (measuring element)

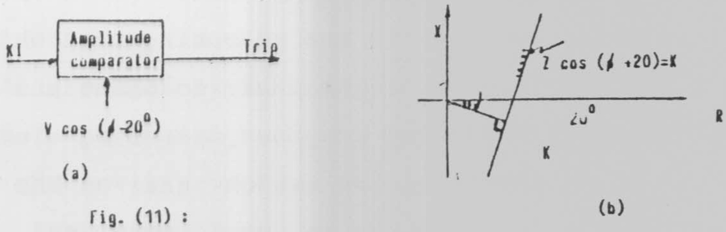


Fig. (11) :
a. Block diagram of blinder unit
b. Characteristic blinder for θ = -20°

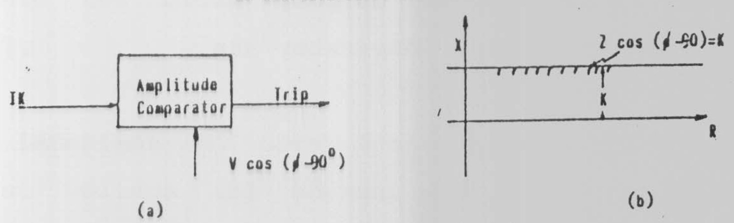


Fig. (12) : a. Block diagram of reactance unit
b. Characteristic reactance

$S_4 = V$

$S_5 = I \, . \, Z_R . \, \text{Cos} \, (\theta - \varphi)$

Tripping condition occurs when $I . \, Z_R . \, \text{Cos} \, (\theta - \varphi) - I \, . Z_b \geq V$

The above equation represents the operating condition for a relay having an offset Mho characteristic.

If $Z_b = 0$, the relay has a Mho characteristic

where $Z_R \lfloor \theta$ is the replic impedance

θ is the relay characteristic angle

I is the fault current

V is the fault voltage

3.2 OHM Characteristic by Using Hybrid Comparator [12]

The impedance equation of Ohm characteristic is as follows:

$Z . \cos \, (\theta - \varphi) = K$ which represents a straight line depending on the value of θ

If $\theta = 90^{o}$, it will be reactance characteristic

If $\theta = -20^{o}$, say, it will be blinder characteristic as shown in Figs. (11,12)

3.2.1 Blinder Characteristic

Assume $\theta = -20^{o}$ the equation will be ;

$Z.\ \cos(\varphi + 20^\circ) = K$

$V.\ \cos(\varphi + 20^\circ) = I.K$

The inputs to amplitude comparator as shown in Fig. (11-a) are;

Operating input $S_I = I.K.$

Restraining input $S_V = V.\ \cos(\varphi + 20^\circ)$

Tripping condition occurs when $S_I \geq S_V$

The blinder characteristic is shown in Fig. (11-b), such a relay has been used as a blinder for preventing other protective relays during swings.

3.2.2 Reactance Characteristic

The equation of reactance characteristic is as follow:

$Z.\ \cos(\varphi - 90^\circ) = K$

$I.Z.\ \cos(\varphi - 90^\circ) = I.K$

The input signals to the amplitude comparator, are;

operating input $S_I = I.K$

restraining input $S_v = I.Z.\ \cos(\varphi - 90^\circ)$

The tripping condition occurs when $S_I \geq S_V$

The block diagram and characteristic of the reactance unit are shown in Fig. (12-a, 12-b)

4. Mho, Offset Mho, Reactance and Blinder Relay

Fig. (13) shows the detailed circuit diagram of a relay whose characteristic can be either that of a Mho, offset Mho, Reactance or Blinder

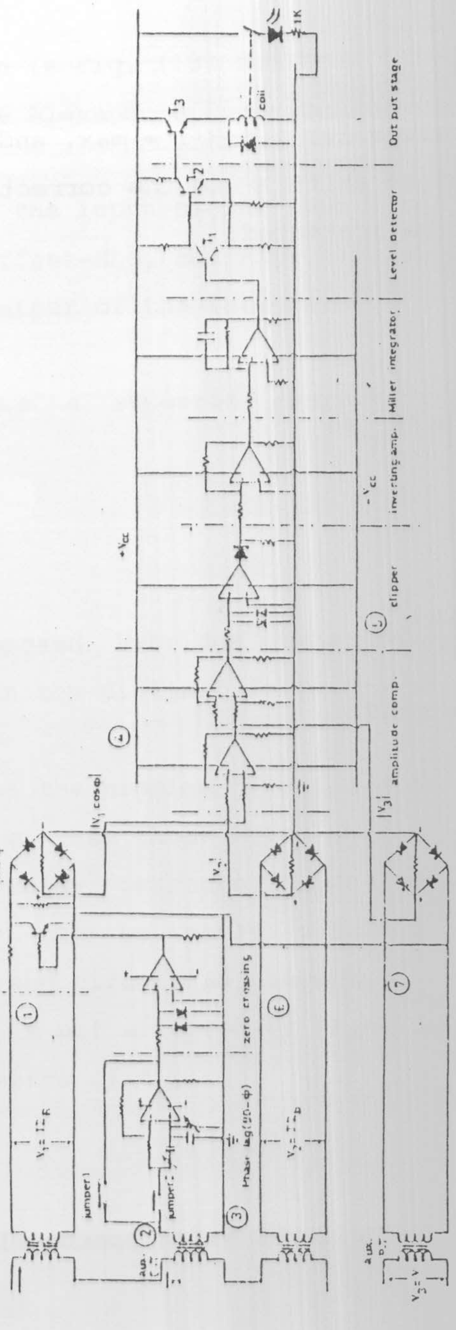


Fig.(13) Detailed circuit of measuring element of Mho-offset Mho, Reactance and Blinder Relays.

a. As Mho Relay

Jumper 1 is disconnected

Jumper 2 is connected

Z_b = zero

Use phase shifter as phase lag i.e R'_3 = max. and R_3 is variable, so as to adjust the phase shift φ to the correct value corresponding to that of the line to be protected.

b. As Offset Mho Relay

The same as in Mho but $Z_b \neq 0$

c. As Reactance Relay

Jumper 1 is connected

Jumper 2 is disconnected

$Z_b = 0$

d. As Blinder Relay

Jumper 1 is disconnected

Jumper 2 is connected

$Z_b = 0$

Use phase shifter as phase lead i.e $R_3 = 0$ and R'_3 is variable, to obtain the required φ as stated before.

Practical Results

The relay shown in Fig. (13) has been tested using the test equipment available in the Alexandria Distribution Company for relay testing.

Fig. (14) shows the input signal wave forms (S_1,S_2) when the relay is used as offset-Mho, and Fig. (15) shows the output wave forms at the input and output of the integrator.

The relay shows a superrior characteristics when used in different modes.

Conclustion

The newly proposed Hybridge type relay using the signal $IZ_R \cos(\theta - \varphi)$ has the distinct following advantages:

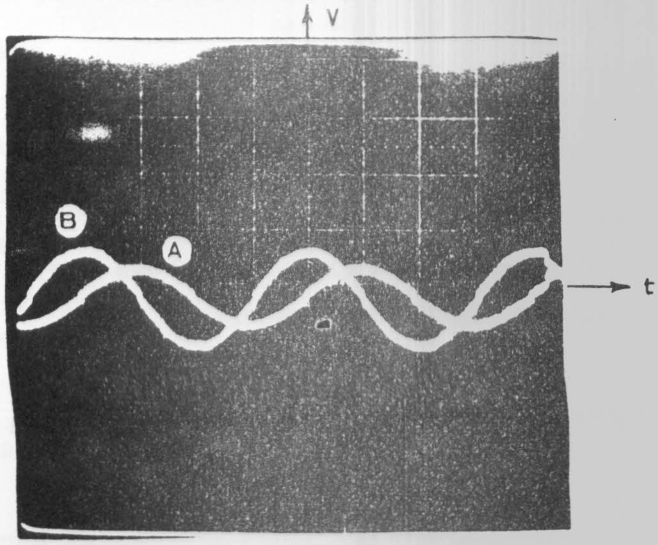
1. It overcomes the problem of using polarizing voltage.
2. It is simpler than those types using memory elements.
3. Different relay characteristics Mho, Offset Mho, Blinder, and Reactance can be easly obtained by minimum alteration in connection and circuit adjustment.
4. The relay is not affected by transients caused to power swing due to the presence of Z_R.

References

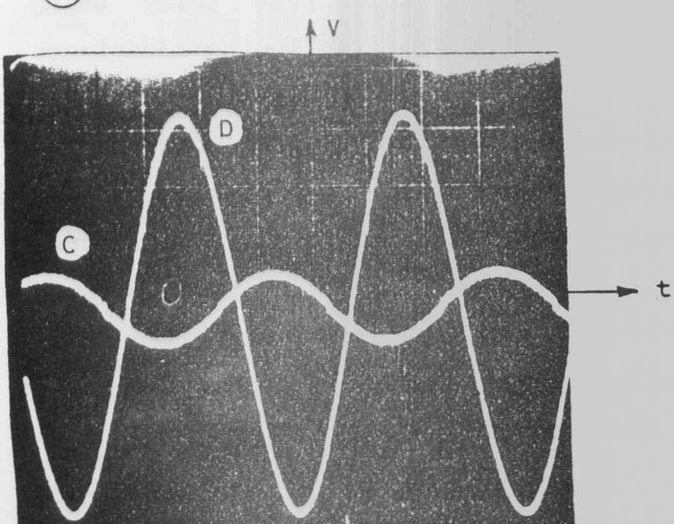
[1] Minimum Impedance Relay Description 26/110 E-2b/ph 8-12-63 BBC.

INPUT WAVE FORMS FOR OFFSET-MHO RELAY

Refer to Fig.(13)



Ⓐ IZ_R } (2 V/cm)
Ⓑ I



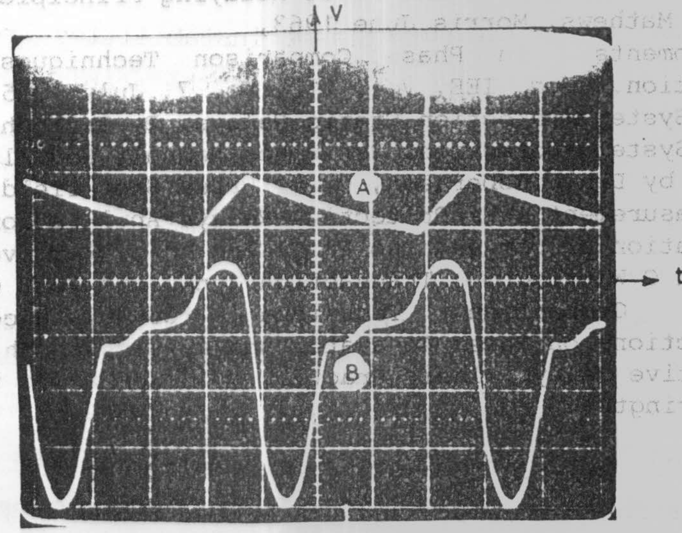
Ⓒ IZ_b (2 V/cm)

Ⓓ V (0.2 V/cm)

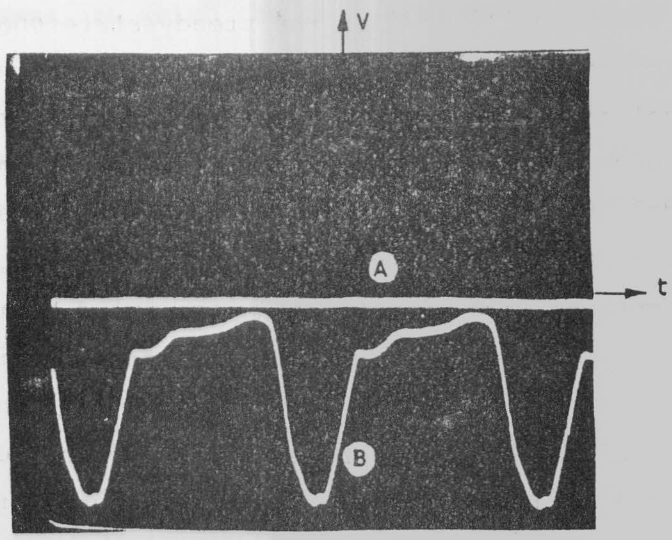
Fig. (14)

RESULTS OF OFFSET - MHO RELAY

Refer to Fig.(13)



Trip condition (Time scale 5 ms)



No trip condition (Time scale 5 ms)

(A) Out put wave-form of Miller integrator (Voltage scale 2 V/cm)

(B) Out put wave-form of amplitude comparator (Voltage scale 0.2 V/cm)

Fig.(15)

[2] BBC Brown Bouveri Technical Fundamentals H.V Distance Relay and Protective Schems.
[3] Polarized Mho Distance Relay, New Apprpach to the Analysis of Practical Characteristic. Proc. IEE, Vol. 12, No. 3, March 1965,
[4] Static Mho Distance and Pilot Relaying Principles and Circuits, Dewey, Mathews, Morris June 1963,
[5] Developments in Phase Comparison Techniques for Distance Protection. Proc. IEE, Vol. 112, No. 7, July 1965.
[6] Power System Protection Static Relays, By Ts Madhava Rao.
[7] Power System Protection, Reference Manual, Reyrolle, protection. Edited by Denis Robertson, Oriel Press Stockfield.
[8] GEC Measurement 1982 Protective Relays Applications Guid.
[9] Application of Ohm and Mho Priciples to protective relays, A.r Van C Warrington, Transaction June 1964 Vol. 65
[10] Hybrid Comparison Technique for Distance Relay, IEEE transactions on Power Apparatus and systems March/April 1971.
[11] Protective Relays, Their Practic, volume one and two By R.A. Van C. Warrington.