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New Technique in Multi-Input Amplitude Comparator to Generate Quadrilateral Distance Relay, Its Design and Performance

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A new technique in multi-input amplitude comparison is developed. The comparator is found to generate (n—1) characteristics, if 'n' represents the total sinusoidal inputs. The resultant characteristic is the common area of the (n—1) characteristics. Application of this comparator to generate quadrilateral characteristic for distance protection of line is discussed. A relay based on the new technique has been designed and its performance studied. The comparator is found to generate any discontinuous characteristic that could be bound exclusively either by circular arcs or straight lines or a combination of the both.

INTRODUCTION

There appears to be a considerable amount of activity[1-3] particularly during the last few years, in developing distance relay characteristics which more or less fit very snugly around the transmission line fault characteristic so that maloperations due to system condition, other than fault conditions, are brought down to the minimum. So far, three different approaches have been reported to develop such characteristics.

(a) Number of two-input relays with their trip contacts in series to develop final trip out-put[4]. The resultant characteristic generated by this arrangement is the common area of the individual characteristics of the two input relays. The disadvantages of this scheme are:

   (i) Large number of input quantities

   (ii) Large number of two-input relays

   (iii) Loss of reliability and possibility of delayed operation due to a number of independent relays.

(b) Multi-input cosine type phase comparator (coincidence principle or direct phase comparision)[1]. In this case a transistorised 'AND' gate is over-driven (switching action) by a number of sinusoidal input quantities and the output from 'AND' gate is fed to a pulse width detector which finally delivers the trip output. It has been proved that such a relay, say having n number of inputs, is equivalent to $\frac{n(n-1)}{2}$ two-input relay with their trip outputs 'AND' compounded. The resultant characteristic is again constrained as desired. Such a comparator has the advantage of having largest possible two-input comparator contributing to constrain the resultant characteristic. One of the serious disadvantages of this scheme is that any change in one of the inputs affects $(n-1)$ characteristics. Thus independent control of any one of the characteristics is difficult.

(c) Multi-input sine phase comparator (Block spike principle)[5]. In this case, n is the total number of sinusoidal inputs [$(n-1)$ inputs and a sharp pulse, produced by the remaining one input at every instant it passes through its zero value] fed to an 'AND' gate. The out-put from such an 'AND' gate is the indication of trip output. In this case the comparator is equivalent to $(n-1)$ two-input comparators with their trip outputs 'AND' compounded. The scheme has the following advantages and disadvantages.

   (i) No elaborate pulse width detector is required. The output from the 'AND' gate can be made to operate directly a thyristor or a telephone-type relay controlling the breaker.

   (ii) The shape of the characteristics is fixed although independent control of any one of the characteristics is feasible. Only number of inputs should be increased.

   (iii) The comparator generates only $(n-1)$ characteristics, whereas the comparator based on coincidence principle generates $\frac{n(n-1)}{2}$ characteristics.

   (iv) Any stray pulse is likely to maloperate the relay, as expressed by a number of authors[2,6].

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Looking into the various advantages and disadvantages of the above referred scheme, it is felt necessary to investigate whether a suitable comparator technique could be developed that will have the stability and reliability of the coincidence principle and, as well have the flexibility of independent control of the individual characteristics of the sine comparator based on block-spike principles. This paper is the result of such an investigation.

SUGGESTED MULTI-INPUT AMPLITUDE COMPARATOR TECHNIQUE

Let the operating criterion be given by the equation.

$$\begin{array}{lccc} & S_1 & \leqslant & S_2 \\ \text{AND} & S_1 & \leqslant & S_3 \\ \text{AND} & S_1 & \leqslant & S_4 \\ \text{AND} & S_1 & \leqslant & S_5 \\ & \cdot & \cdot & \cdot \\ & \cdot & \cdot & \cdot \\ & \cdot & \cdot & \cdot \\ & \cdot & \cdot & \cdot \\ \text{AND} & S_1 & \leqslant & S_n \end{array}$$

Suitable comparator circuitry, described later, satisfying the above equations will be equivalent to $(n-1)$ two-input comparators with their trip outputs 'AND' compounded.

Characteristics

For the sake of simplicity, a case of five inputs is only considered. The analysis would be extended to any number of input quantities.

Let the five sinusoidal inputs be

$$\begin{aligned} S_1 &= k_1 p + k_2 q \\ S_2 &= k_1 p + k_4 q \\ S_3 &= k_5 p + k_6 q \\ S_4 &= k_7 p + k_8 q \\ S_5 &= k_9 p + k_{10} q \end{aligned}$$

where p and q may each be independently either a current or a voltage, and constants K_1 to K_{10} can have any magnitude and phase that can be realised in a practical circuit. Simple mathematical manipulation and rearrangement, similar to one already reported earlier by Mathews and Nellist[7] would lead to the following four different two-input comparator equations, assuming unity comparator ratio:

$$\left|\frac{w-a}{w-b}\right| = \frac{k_3}{k_1} = r_1 \text{ for pair } S_1, S_2$$

$$\left|\frac{w-a}{w-c}\right| = \frac{k_5}{k_1} = r_2 \text{ for pair } S_1, S_3$$

$$\left|\frac{w-a}{w-d}\right| = \frac{k_7}{k_1} = r_3 \text{ for pair } S_1, S_4$$

$$\left|\frac{w-a}{w-e}\right| = \frac{k_9}{k_1} = r_4 \text{ for pair } S_1, S_5$$

where $a = -\dfrac{k_2}{k_1}$ $\quad b = -\dfrac{k_4}{k_3}$

$$c = -\frac{k_6}{k_5} \quad d = -\frac{k_8}{k_7} \quad e = -\frac{k_{10}}{k_9}$$

$$\text{and } w = \frac{p}{q}$$

If the constants k_1, k_3, k_5, k_7, and k_9 are chosen such that

$$k_1 = k_3 = k_5 = k_7 = k_9$$

then $\quad r_1 = r_2 = r_3 = r_4 = 1$

The four comparator equations will, thus, reduce to straight line equations and the four straight lines will be perpendicular bisectors of the line AB, AC, AD, and AE respectively as shown in Fig 1, where points A, B, C, D, and E are the extremities of the vectors a, b, c, d, and e respectively.

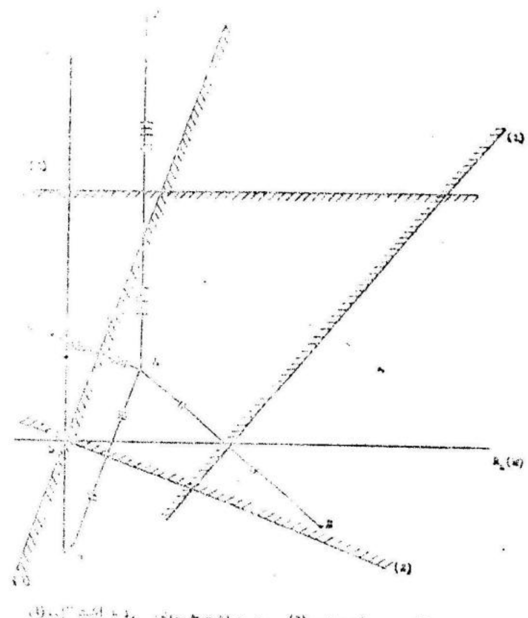


Fig 1 Quadrilateral characteristic developed by five inputs with unity comparator ratio

In general it may be said that any polygonal characteristic could be generated by the proposed multi-input unit ratio amplitude comparator. The number of sinusoidal inputs to the comparator would be one plus the number of sides of the polygon. One of the extremities of vector constants (such as A in Fig 1) will have to be inside the polygon and the rest will be a sort of images of point A across the various sides of the polygon.

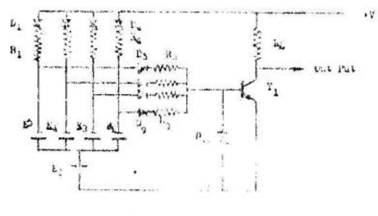
For protection of transmission line, quadrilateral characteristic is considered as ideal since it just fits into the fault characteristic. Fig 1 has deliberately been drawn as quadrilateral to show such an application. It now simply remains to choose p and q, the system input quantities, as voltage and current at the distance relay location to convert the so called 'w-plane' to the familiar 'z-plane' or the R-X diagram.

For the sake of showing definite application to particular type of distance relay, constants r_1 to r_4 were chosen as unity. In the most general case the polygon could be bound exclusively either by arcs or straight lines, or a combination of arcs and straight lines, almost at will, by suitable choice of scaler constants r_1 to r_n.

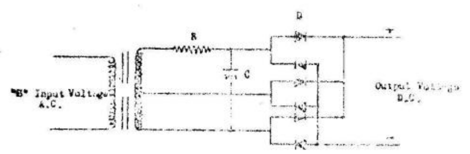
Comparator Circuitry

The circuitry, in principle, satisfying the basic comparator equation, is shown in Fig 2. Fig 2(a) shows transistorised multi-input 'AND' gate, normally in the conducting state, driven by the bias resistance R_1 to R_4. The 'AND' gate will deliver trip output only when all the gate inputs (E_2-E_1), (E_3-E_1) .. are simultaneously negative. Thus, to develop trip output, the following should be satisfied.

	E_1	$\leq$	E_2
AND	E_1	$\leq$	E_3
.	.		.
.	.		.
.	.		.
AND	E_1	$\leq$	E_n



2 (a) AND Gate



2 (b) Rectifier circuit

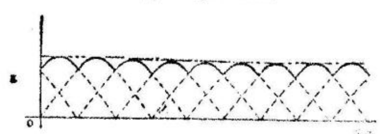


Fig 2 (c) D C output voltage wave form

Fig 2(b) shows how to develop the dc voltages E_1 to E_n from the basic sinusoidal inputs S_1 to S_n. The single phase input is split into three phase and then rectified by the three phase full wave rectifier bridge circuit; because of phase splitting no filtering is necessary and, thus, fast response is ensured. The ripple content is as small as about 4.2% and can be considered as negligible. Replacing dc voltages E_1 to E_n by sinusoidal inputs S_1 to S_n the above equation reduces to the desired comparation criterion. Successful operation of a circuitry very similar to this, except with an additional element of tunnel diode across the base emiter junction has already been reported[8] in simpler case of two inputs. No malo-perations are reported and the operating time is found to be very small.

DESIGN AND PERFORMANCE

In order to apply the principle of the criterion explained in the previous section, to generate a relay with quadrilateral characteristic, a transmission line was considered with an impedance of 20 Ω at 65°. Arc resistances at the end of the zone and at relay locations were taken as 6 Ω and 4 Ω respectively. Desired characteristic is shown in Fig 3.

From the figure the magnitudes and phases of the

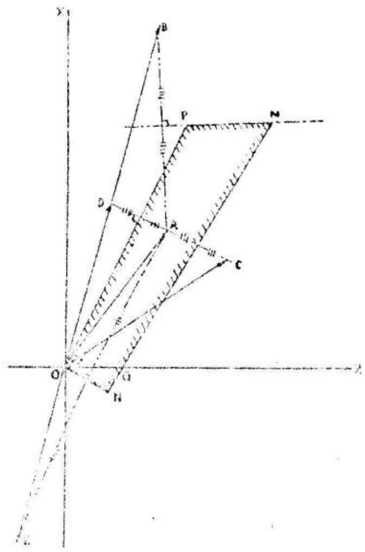


Fig 3 Desired quadrilateral characteristic

respective vector were measured as under:

$\bar{a} = \overline{OA} = 12.2 \angle 54°$
$\bar{b} = \overline{OB} = 24.2 \angle 76°$
$\bar{c} = \overline{OC} = 14.0 \angle 34°$
$\bar{d} = \overline{OD} = 12.0 \angle 76°$
$\bar{e} = \overline{OE} = 12.0 \angle 76°$

COMPENSATOR

Compensator is essentially an air-gap transformer with current energized primary winding. On secondary induced voltage appears which is proportional to the magnitude of current. Phase angle relation between the primary and secondary quantities is a function of parameters of the compensator circuit, namely resistance and inductance. With a suitable combination, the desired vector quantities could be obtained. It has been shown in the vector diagram in Fig 4.

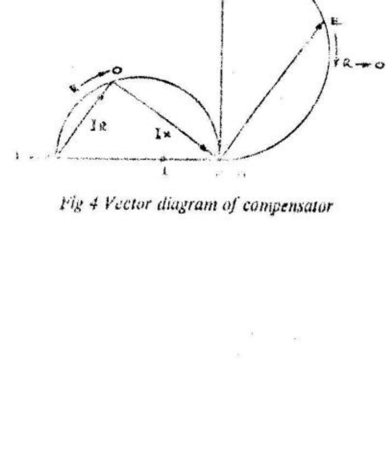


Fig 4 Vector diagram of compensator

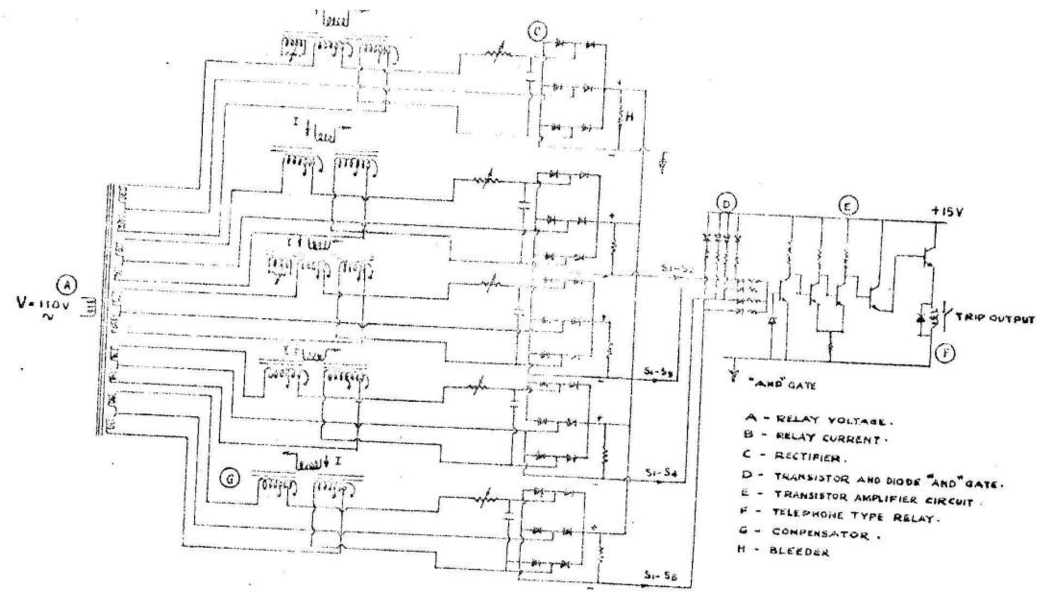


Fig 5 Circuit diagram of the designed relay

The relay input quantities, S_1 to S_6, were obtained by proper vector addition and subtraction of the quantities from relay voltage. Complete relay circuit is shown in Fig 5.

PERFORMANCE TESTS

The following tests were performed:

(a) Polar characteristic

(b) Relay sensitivity

(c) Relay operating time

Figs 6, 7 and 8 show the test results and are self-explanatory.

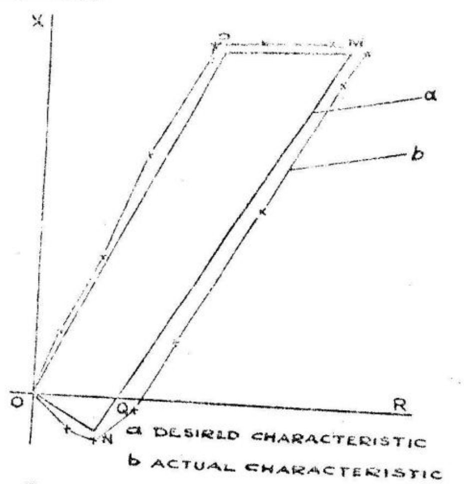


Fig 6 Comparison of the desired characteristic with the actual characteristic

CONCLUSION

A new technique in multi-input amplitude comparison has been developed. In order to develop a characteristic of n sides, the total number of inputs are $(n+1)$. The resultant characteristic could be bound exclusively either by circular arcs or straight line or combination of both. Independent control of each characteristic is feasible. A simple application to generate quadrilateral characteristic to fit in the transmission line fault characteristic is discussed. A relay has been designed and its performance studied.

Static Polar Characteristics

It is seen that the theoretical and actual characteristics practically coincide. This relay could be used as a three-step distance relay by changing the reactance characteristic to a suitable value.

Relay Sensitivity

The relay is found to operate very satisfactorily upto the value of $\frac{Z_S}{S_L}$ equal to 6.5. Operating time of relay is very small and it is constant.

V A Consumption

From the view point of burdon consideration, the comparator has definite limitation since large amount of VA is lost in the phase splitting network rather than being available to operate the transitor gate.

'AND' Gate

The suggested 'AND' gate does not give false tripping under the following conditions:

(a) When there is failure in the current and potential transformer circuit.

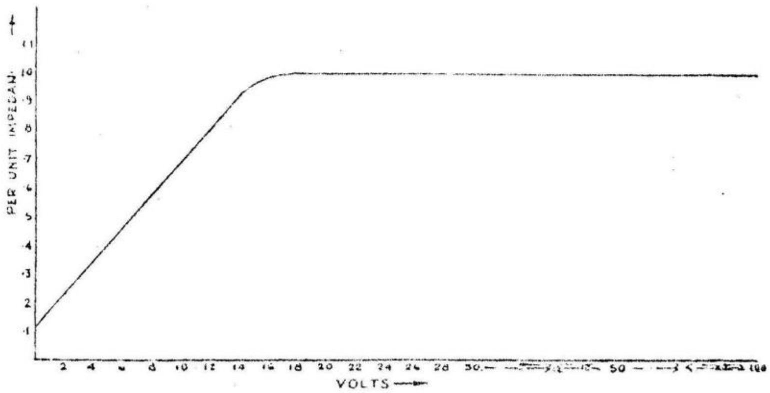


Fig 7 Relay sensitivity curve

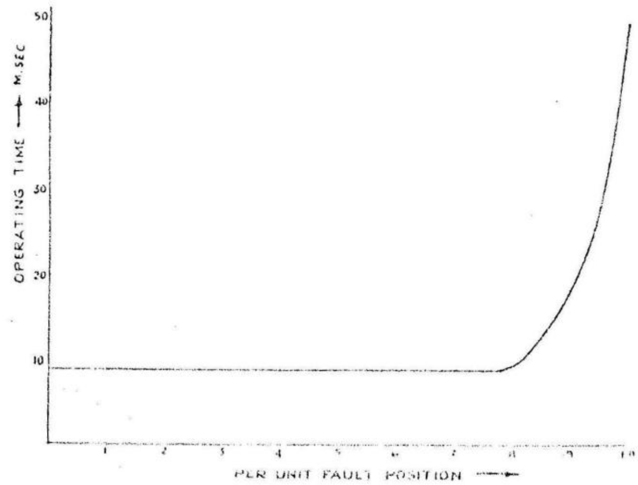


Fig 8 Fault position against operating time

(b) If the transistor emitter and collector, under abnormal condition, are short-circuited.

Power drain is negligible.

ACKNOWLEDGMENT

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DISCUSSION

Srinivasa Murthy:

. The present trend among relay designers (distance relay) is to minimise the number of transactors used and make input circuitry as simple as possible. It is also expressed in many papers, that transactors are the main source of errors, if proper matching is not done. From the above considerations, the relay presented by the authors looks out of tune, with the present progress in the area.

Since the paper does not discuss the type of testing equipment used to find out the dynamic performance of the relay, it is difficult to appreciate the significance of test results such as accuracy and sensitivity in a practical situation. When compared to the multi-input phase and comparators, the relay does not possess any advantage. The transient performance of the scheme is inferior to that of multi-input phase comparison based on polarity coincidence principle as the rectifier case used to average the signals will be an additional source of error.

2. The authors have noted that ripple content is about 4.2%. Since they are comparing n-independent signals, it is quite possible that errors due to ripple content in various signals may be non-compensating and may give rise to a large accumulated error. Whether this case is considered. Contrary to the author's assumption, this error is not insignificant.

3. If an attempt is made to reduce the ripple content by having filters, the transient performance of the relay will be very unsatisfactory. Then how could this type of comparison compare with the versatile phase comparators where no need for rectifiers and filters exists?

4. The title 'New Multi-input Amplitude Comparison' also raises some questions. Here the comparator compares only two signals viz the smallest in magnitude of n-inputs and a threshold voltage. But multi-input amplitude comparison implies that a single comparator does the job of comparing all signals with a reference voltage. This is not so.

Authors:

1. Static relays generating a straight line or a circular characteristic needs a minimum of one transactor, but to generate any discontinuity in the relay polar characteristics, it is an accepted fact, more transactors are required. This is not considered as a disadvantage, since the advantages of improved polar characteristics are considerable.

Only static tests on the relay were performed, since no dynamic test bench was available during the course of investigation. The proposed relay has an advantage of controlling any one of the segments of quadrilateral distance relay independently which is not the case with multi-input phase comparator based on coincidence principle, whereas the multi-input sine comparator is prone to maloperate on stray pulses due to system switching etc.

No claim at improved transient performance has been made, since no such tests were made.

2. The ripple content of 4.2% is not considered large and no serious errors were caused in the polar characteristics.

3. Use of filters to reduce ripple will predominently cause delay in operation rather than anything else.

4. The authors believe the title appropriate, since the basic comparator delivers trip output when all the four relaying quantities (called the operating inputs) are simultaneously more than one relaying input (called the restraining quantity)

B S Palki :

1. The boundaries of the characteristic correspond to the perpendicular bisectors of lines AB, AC and AE where A, B, C, D and E are extremities of vectors a, b, c, d and e. Thus implicit in the technique used is the necessity for an accurate control over vectors d and e, responsible to give directional property to the relay. Any error either in magnitude or angle in these makes the relay either non-directional or shifts its position from origin. In such a case do the authors recommend such relay to be used as a measuring unit of a distance relay?

In contrast the phase comparators exhibit an inherent directional property.

2. A desirable shape of quadrilateral characteristic is one with extension in second quadrant also. This might require phase shift of more than 90° in current circuits, which cannot be obtained by transactors. In addition, a general quadrilateral characteristic requires phase shifts in current circuits far removed from line angle. Will such requirements not impair the transient performance of the relay?

3. The theory requires amplitude comparison of absolute values of two signals. The ripple content present in the rectified outputs may introduce errors which can be as high as 12% in the case. In such a case, do the authors recommend the relay for first zone measurement?

Perhaps this is one of the reasons why amplitude comparators are used for starter relays as in the case of type RXZF of ASEA

4. Using block average or block spike methods with symmetrical/unsymmetrical limits of comparison it is possible to obtain characteristics like quadrilateral, only with three signals as compared to 5 signals used in this case.

Methods are available to obtain the above characteristics using a single multi-input comparator.

Therefore the statement that above methods require a large number of signals and comparators is not correct.

In fact ASEA's latest version of static distance relay with quadrilateral characteristic type RAZOG makes use of phase comparison technique based on block average method.

Authors :

1. The authors agree with the conclusions drawn by the discusser. For the first zone unit, the phaser C could be shortened, in which case, the first zone high speed unit will positively maintain directional feature. The third zone unit could be made to enclose the origin, in which case, it will lose its directional feature but without any serious consequences since it has a delayed operation because of the timer.

2. Getting a voltage shifted by more than 90° with respect to current is not a serious problem as shown in Fig 9.

3. The authors do not know the figure of 12% error due to 4.2% ripple has been arrived at. As pointed out

, the ripple does not pose a serious problem. discusser may refer to Reference 8, where no ious problem has been mentioned.

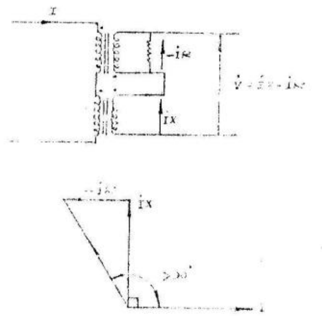

Fig 9 Shifting voltage with respect to current

4. The authors have reservations about the block-spike method as mentioned in the paper. Using a block-average method, it is possible to get a discontinuity in the polar characteristics if unsymmetrical limits of comparison are used, but the authors consider the circuitry for constraining the phase angle margins unreliable. The authors are unable to comment on ASEA's RAZOG quadrilateral distance relay, since details are not available.

S S Gangakhedkari

1. Refer Fig 4—compensator circuit

Division of total current I in the branches R and X are shown equal to total current, which is not correct. The vector diagram also has not shown the direction of currents such that the voltage vectors I_1 R and I_x X are equal to the output voltage E.

2. Refer Fig 5—the final circuit diagram

The author mentions that shorting of collector and emitter will not affect the operation of the relay. Suppose the collector and amitter of the amplifier circuit gets shorted. Will not the relay operate?

In the same way, will not open circuiting of input transistor of the multivibrator circuit cause the relay to operate?

3. Please explain the relation of quantities S_1-S_2, S_1-S_3 etc to the fault impedance measured.

Authors :

1. Phasorialy $\bar{I} = \overline{IR} + \bar{I}_x$, similarly I_R has rightly been shown in phase with E and I_x lagging by 90°, E being the voltage across the parallel combination of R and X. The authors do not see any anomaly.

2. In Fig 5, the basic 'AND' gate has 5 transistor stages. The first and the third transistors are 'ON' whereas the rest are 'OFF'. The shorting or breakdown of collector-emitter of any of the off-transistors will result in mal-operation of the relay. Such risk, although remote, is taken.

3. Phasors S_1 to S_6 are all functions of Z_r. For example $S_1 = Z_r - a$, $S_2 = Z_r - b$ and so on. The phasors a and ba and thus S_1 and S_2 will decide the disposition of line PM on the R-X diagram.

P V Dakshinamoorthy :

1. Will the authors elaborate the test arrangement adopted by them explaining how far actual conditions are simulated in their tests?

2. What is the transient overreach of the relay? Does it maloperate for transients due to external faults near the reach point.

3. As the speed of the relay is indicated as less than 10 ms what are the precautions taken by the authors to prevent maloperation due to switching spikes both in the primary and in the d c circuits?

4. What is the variation of relay operating time with varying Z_S/Z_L ratio

Authors :

The transient performance of the relay was not investigated due to non-availability of dynamic relay test bench. The operating time of the relay was found to be around 10 ms for faults within 80 percent of the reach point and for Z_S/Z_L upto 6. For faults beyond 80 percent of the reach and range factor more than 6, the operating time increased.