Note: See attached duplicate paper by (W), same author showing their schemes for loss of potential?

# DISTANCE RELAYS AND LOSS OF POTENTIAL

BY

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# DISTANCE RELAYS AND LOSS OF POTENTIAL

## 1. INTRODUCTION

The Western Relay Conference typically brings together more than 150 utility engineers associated with protective relaying and the maintained growth in participation at this conference attests to the perceived benefits of collective discussion of common concerns. Loss of potential as it relates to distance relays is often only of academic interest and might be crudely classified as a concern by some and a non concern by others since opinion varies from utility to utility, and even within a given utility from time to time or from region to region. It appears that Loss of Potential relays are applied or not applied as a matter of standard procedure and that individual cases are not examined. This paper is presented on the assumption that such an experienced group might fruitfully conduct a periodic review of the reasons behind the utility concern or non concern as the case may be. The presentation will hopefully be sufficient to stimulate discussion and definitely brief enough to allow time for that discussion which, after all, would be the real benefit. Such an exercise may well result in no changes in classification as concern or non concern, reduced concern or increased concern. From a manufacturers viewpoint the last result and the ensuing retrofit business would be most welcome and thus my objective is identified.

To achieve the aforementioned brevity this discussion is limited to situations where the maximum load current may exceed minimum fault current and hence standard phase overcurrent supervision cannot ensure the desired security for phase distance relays during loss of potential. Benefits and pitfalls are described for a few schemes aimed at providing the desired security.

## 2. VT SECONDARY FAULTS

### 2.1 Secondary Short Circuits

Assuming VT's with wye grounded primary and secondary, Figure 1 illustrates the secondary voltage triangle resulting from a phase A to ground fault. Figure 2 illustrates the collapse of the secondary voltage triangle to a straight line when a secondary phase B to C fault occurs. Normal burden impedance will not modify the voltage triangle resulting from a secondary short.

Figure 3 indicates that, depending on the actual VT equivalent circuit impedances, a fault on one secondary of a dual secondary VT may depress the voltage on the other secondary.

## 2.2 Secondary open circuits

Failure to restore relay potentials after planned interruption is one cause of secondary open circuits. These may also result from accidents or from fuses blowing to clear a secondary fault. Some utilities use molded case breakers to clear all phases when faults occur, and a four pole breaker with the trip circuit wired through the fourth pole has been used. This discussion is restricted to open circuits in one or two secondary phases.

### 2.2.1 One secondary phase open

Based on the reasonable assumption that source impedance can be considered negligible in comparison with secondary circuit burden impedance, Figure 4 illustrates the sequence network connections for one phase open and the possible range of resulting secondary voltage triangles. It is to be noted that the ratio of burden positive sequence impedance to burden zero sequence impedance controls the shape of the resultant triangle. Figure 4(b) is based on the assumption that burden positive and negative sequence impedances are equal and that all network impedances have the same angle.

### 2.2.2 Two secondary phases open

Based on the same assumptions used to present Figure 4, Figure 5 illustrates the variations in secondary voltage as the positive sequence to zero sequence impedance ratio varies.

# 3. RESPONSE OF DISTANCE RELAYS TO LOSS OF POTENTIAL

## 3.1 Preview

There is no pretense at a comprehensive treatment but the following paragraphs illustrate means of evaluating distance relay response to some situations. If it is decided that Zone 1 may undesirably respond to the combined effects of maximum load and loss of potential; some prompt preventive measure is required unless a trip and successful reclose would be considered an acceptable outcome. If analysis indicates that only Zone 2 operation is to be expected then a second zone time delay may be involved which can allow potential failure detection by slower monitoring schemes. On the other hand, response of overreaching pilot relays may result in tripping with very little time delay if repeat or echo circuits are used.

## 3.2 Single Phase Self Polarized Mho Relays

Potential circuit faults or open circuit conditions result in phase shift and/or reductions of some or all of the normal interphase voltages. These voltage changes have an inverse effect on the distance relay reach settings and the maximum sensitivity angle is shifted an amount equal and opposite to the voltage shift from normal.

Figure 6 illustrates the revised R-X diagram characteristics to be expected for the V.T. secondary short circuits considered. When the load impedance plotted to the proper scale on these R-X diagrams falls within the modified characteristic of the distance relay under consideration, that relay can be expected to operate. When a voltage is reduced to zero by a short circuit, the corresponding distance unit reverts to a directional element and can operate transiently due to memory action depending on sensitivity constraints.

## 3.3 Cross Polarized or Polyphase Relays

The Westinghouse KD relay is taken as an example of relays in this class and the three phase and phase to phase units must be separately considered.

Figure 7 provides a graphic technique for predicting KD response to various situations. As with the single phase mho relay, operation depends on the load ohms and the relay setting.

## 3.4 Relays With Mutual Reactors or Replica Impedance

Figure 8 is presented as a reminder that the illustrated single phase self polarized mho relay will be expected not to operate steady state in the current only situation of Figure 8(a) wherein the polarizing voltage circuit is shorted. However, when the voltage circuit is open as in Figure 8(b) input current applied to a mutual reactor can create operating and polarizing quantities to cause relay operation. The effect of other burden as in Figure 8(c) creates an intermediate situation.

## 3.5 Ground Distance Relays

These relays of whatever operating principles can be supervised by load independent zero sequence current level detectors and can readily be made secure against loss of potential. CT circuit abnormalities can result in erroneous zero sequence current and this situation can be accommodated by adding Vo supervision.

3.6 Relay utilitizing deviation signals

Ultra high speed relays based on polarity comparison of current and voltage deviation signals tend to be immune to security problems associated with VT secondary failure because a current deviation coincident with the voltage deviation would be most unlikely. In passing, it can be noted that such operating principles also provide a good measure of immunity to CT circuit perturbations. While relays utilizing such principles are a small percentage of those in service, voltage and current change or deviation detectors have been used for several years and some thought has been given to their use to enhance existing relay security during PT or/and CT circuit abnormalities.

3.7 General

From these few examples, the voltage triangle resulting from a V.T. secondary circuit abnormality is seen to depend upon several factors among which are the type of abnormality and VT burden. The effect on distance relays is seen to further depend on load current, relay settings, relay design, and other burden. This probably accounts for some utility decisions to take preventive measures as a routine standard practice without analysis of each individual case. Prediction, by analytical methods, of distance relay response to secondary short circuits is more straightforward than prediction of response to secondary open circuits yet the latter may be the more severe case. Observations of relay response to actual load and open circuit test situations may be more productive than analytical efforts.

Even should analysis or test indicate the possibility of a problem, the experience of the individual utility will most likely be the deciding factor in the application of any potential circuit monitoring. If a positive decision is made, monitoring of trip circuit supply should include, if possible, the blocking contact of any potential monitoring relay.

The following discussion is intended to outline application considerations relevant to schemes and relays sold or considered by Westinghouse Canada.

## 4. High Speed Potential Comparison Schemes

Any disagreement between the secondary voltage of normally identical sources can be used to detect the problem in less than 8 msec, to identify the defective source, initiate an alarm, and block voltage sensitive protection or control associated with the defective source. Normally identical sources include the output of dual secondary VT's, the output of duplicate VT's, and the voltages on both sides of VT secondary fuses. For all such schemes, one must consider situations where failure to block, improper blocking, or erroneous alarms might occur.

### 4.1 Dual Secondary VT's

With reference to Figure 9(a), the equivalent circuit of a three winding transformer should be considered to see if a close in fault on one VT secondary may depress the other secondary voltage enough to cause distance relays on both secondaries to operate. If so, momentary cross blocking may be useful and is available.

Furthermore, if the voltage on both secondaries is sufficiently depressed, there may not be enough voltage difference to cause immediate operation of the comparator relay. In such a case, secondary impedance can be increased by a resistor equal to required difference voltage divided by VT short circuit current. This added resistor should not be high enough to cause unacceptable VT errors with normal burden.

The added resistor plus normal lead resistance and VT short circuit impedance must also not permit loss of directionality of a compensator type distance relay on a close in reverse fault with maximum protected line infeed. Figure 10 illustrates an example of this concern.

If possible, addition of VT secondary circuit resistance would be avoided.

### 4.2 Burden Considerations. Duplicate VT's or Dual Secondary VT's

In Figure 9(b) duplicate VT's are illustrated but this can be considered equivalent to dual secondary VT's if the ratio $Z_L/Z_H$ in Figure 3 is high and we have no concern that a fault on one secondary can depress the voltage on both secondaries.

Figure 4(a) illustrates that, in the case of a single secondary phase open, the resulting open phase voltage is dependent on burden impedance $Z_1/Z_0$ ratio. It would be possible to have a close in primary SLG fault on the same phase as is open on one VT secondary. Unless the burden $Z_1/Z_0$ ratio is controlled we could have a comparator type relay decide, on the basis of voltage magnitudes during a primary system fault, that the sound secondary is defective and undesirable blocking would result.

To avoid problems of this sort, we can consider the following:

4.2.1 Use a 3 pole breaker in place of fuses so that a single fuse cannot open. This does not take care of accidental open circuits.

4.2.2 Adjust burden impedance so that $Z_1=Z_0$ approximately, and thus the open phase voltage will go to zero as shown in Figure 4(b).

4.2.3 Utilize a relay which will latch up at the first indication of a VT secondary problem.

4.2.4 Another burden consideration involves the use of auxiliary VT's on only one of the two secondaries being compared. In this case the concern is that with main VT's on the line side of the breaker, line energization can cause magnetizing inrush into auxiliary VT's. Signifigant inrush currents could cause enough secondary voltage difference (5 volts in one case) to cause protection blocking at the instant of an unsuccessful reclose.

Peak auxiliary VT magnetizing inrush times the total secondary circuit source impedance should be below the detection level of the comparator being used. The deliberate addition of secondary series resistance would exacerbate inrush problems.

4.3 Trip and Reclose

When a line fault is cleared, line side VT secondary voltages may go to zero and restore balance. Thus any indication of VT secondary problem could be reset to be re-established at the time of reclose. Again, the cross block feature which momentarily blocks both primary and standby protection would be highly undesirable since the reclose might be unsuccessful. Thus latch up and manual reset feature must also be included along with cross blocking.

4.4 Voltage Across Fuses

Figure 11 is a special case of comparing two normally identical potential sources.

With this arrangement, some of the foregoing considerations cease to be relevant. Burden is usually of no concern nor is performance during power system primary faults. Prompt acknowledgement of alarms and prompt trouble correction eliminate realistic concern about reset when the line is tripped.

This approach is used on the assumption that the primary cause of VT secondary open circuits is fuse blowing due to test accidents. From figure 11 it is obvious that a VT secondary fault will not result in comparator action until after a fuse has opened to create an unbalance. Thus, operate time is measured from when the VT secondary fuse opens. This scheme has been the most commonly and consistently applied. We have no reports of false blocking or failure to block and such schemes have been in use for 15 years.

5. <u>ZERO SEQUENCE Voltage and NOT Zero Sequence Current</u>

This type of scheme has been widely used with a time delay in the order of one half second. A relay intended to reach a block decision in the order of 10 milliseconds and not block for a close in fault involving ground is also available. Blocking occurs if $3V_o$ exceeds 20 volts and $3I_o$ is less than 1 amp.

5.1 VT Secondary Short Circuits

This approach can be expected to detect VT secondary short circuits involving ground. Faults not involving ground will not be detected until after a secondary fuse has opened. There will be no response to three phase shorts or opens.

5.2 Burden Considerations

Figure 12 illustrates a significant difference between a VT secondary SLG fault as in Figure 12(b) and an open phase as in Figure 12(c).

In the case of the SLG fault, the positive and negative sequence magnetizing impedance of the wye-broken corner delta aux VT's is shunted by the system and main VT source impedances. In the case of the open phase, any aux VT secondary zero sequence current is limited by aux VT positive sequence magnetizing impedance. The relay includes fixed resistive loads shown dotted in Figure 12(c) to ensure that an adequate shunt will be available to ensure operation even if no other main VT secondary burden is present.

However, since the VA burden of the 3Vo detector in the relay is not zero, this detector will be more sensitive to 3Vo resulting from main VT secondary ground faults than to 3Vo resulting from main VT secondary open circuits. The reverse would be a more desirable state of affairs.

5.3 Zero Sequence Source Impedance

The response to 3Vo of 20 secondary volts or more and 3Io less than 1 secondary amp implies an equivalent zero sequence source impedance of 20 secondary ohms or less. Because of sensitivity variation as described in 6.2 above, a zero sequence source impedance 15 secondary ohms or less is to be preferred in the interest of protection dependability.

5.4 Reset can occur when a line is open and line side VT's are used.

5.5 Logic Breakdown - Line Side VT's

There are situations where 3Vo can be detected on sound VT secondaries and no 3Io will be detected simultaneously. These situations involve line side VT's and open line breakers. Reliability of protected line relaying is NOT involved but nuisance local or remote alarms may be a concern and a delay in any remote alarm is desirable.

5.5.1 Sequential Ground Fault Clearing

As shown in Figure 13, one line end clears and the zero sequence voltage at the fault is applied to the relay at the open end.

5.5.2 Post Fault Transients

Figure 14 shows a higher frequency decaying transient after a ground fault was cleared on a 500 kV system.

## 6. Current Operated Schemes

The foregoing paragraphs have outlined various Loss of Potential schemes and limitations of these schemes, some of which have seen many years of apparently successful application. Some of these shortcomings, now obvious, at one time seemed subtle. Others can be handled with proper application consideration but future circuit changes may cause problems where none existed originally. All schemes described thus far are amenable to monitoring of the status of the blocking output but the result is a race between proper blocking and improper distance relay operation, and the application of high speed relaying to long heavily loaded lines will continue to be a concern to some utilities. There are therefore grounds for seeking improvement and one can look to the equivalent of zero sequence overcurrent supervision which eliminates races, is immune to load current effects, and allows the secure application of relatively slow potential monitoring schemes. Zero sequence current is a deviation signal as is negative sequence current and both provide immunity to load current. Negative sequence segregation, networks with an assured transient output for three phase faults can be built. Similarly composite sequence networks can be built with an assured transient output for any fault. This transient output can be used with a pulse stretcher to supervise phase and ground distance relays. Experimental relays have been built with no response to 10 amp positive sequence steady state but reliably closing a supervising contact within 5 milliseconds of a 1 amp change in the positive sequence current.

## Conclusion

It is not intended that this paper should designate the subject as a concern or as a non conern. Rather it is expected that such designation will result from consideration and discussion of this paper. If Loss of Potential is a concern, there are means available to handle the problem.

The ratio of VT positive to zero sequence impedance is seen to influence the voltage triangle resulting from open fuses. Mixtures of low and high VA burden relays merit consideration from this point of view.

JMC/pl

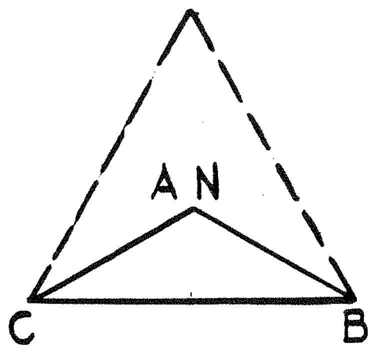


__Figure 1__

A to G Fault On
V.T. Secondary

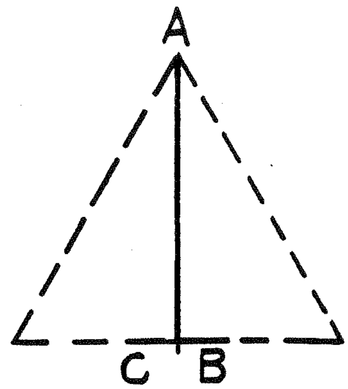


__Figure 2__

B to C Fault On
V.T. Secondary

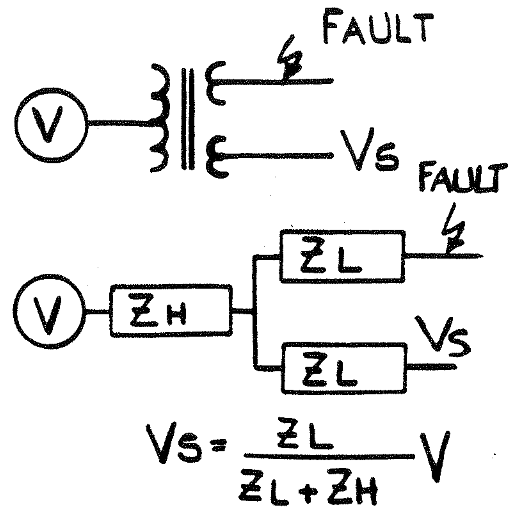


__Figure 3__

Dual Secondary V.T.
Equivalent Circuit

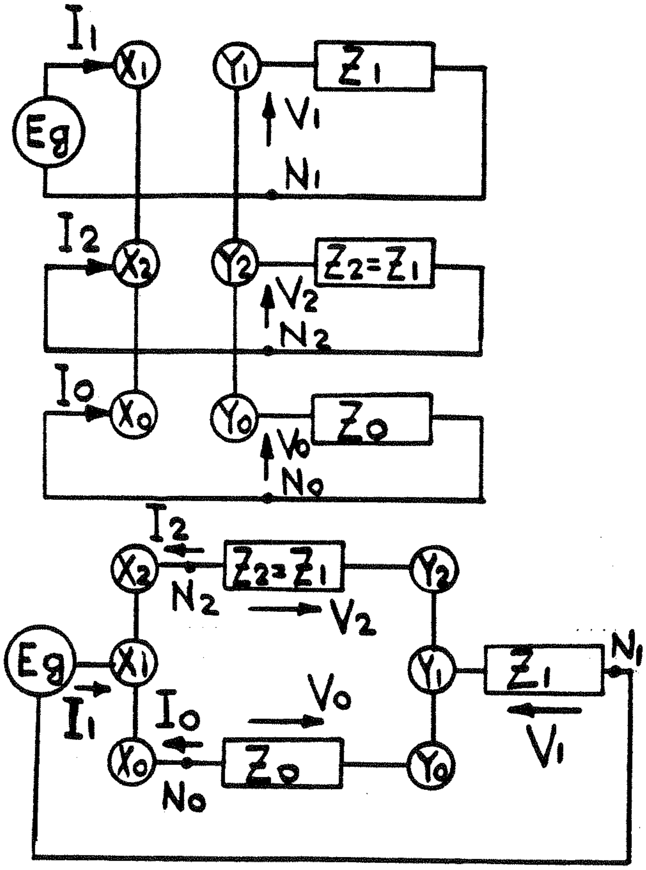


__Figure 4(a)__ Phase A Open
Burden $Z_1$, $Z_2$, $Z_o$

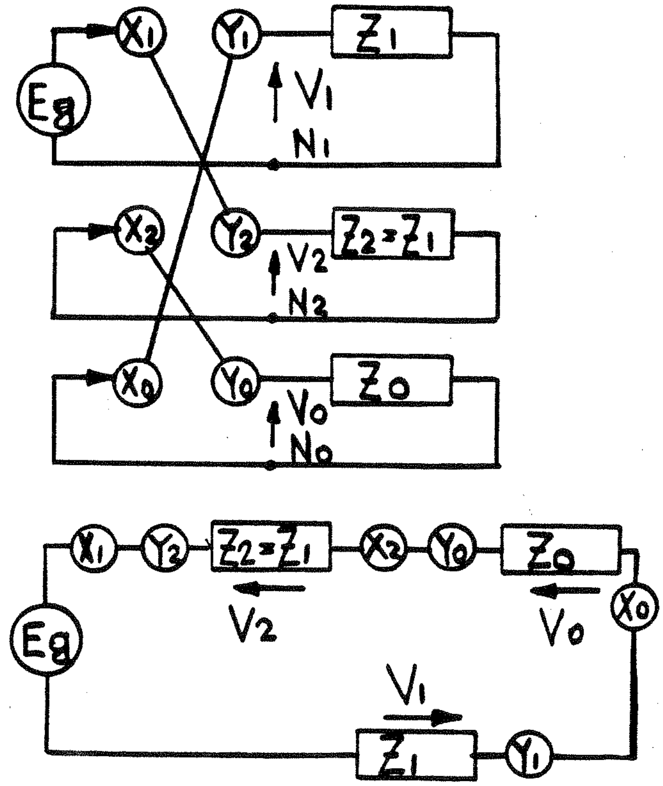


__Figure 5(a)__ Phase B & C Open.
Burden $Z_1, Z_2, Z_o$

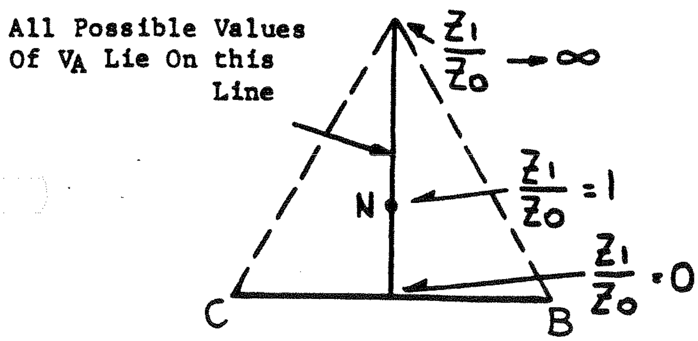


__Figure 4(b)__ Phase A Open

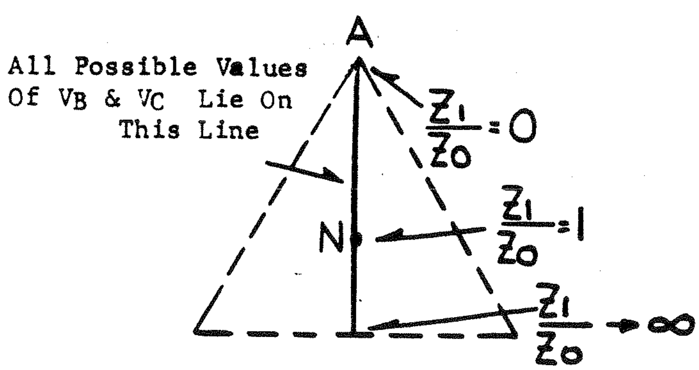


__Figure 5(b)__ Phases B & C Open

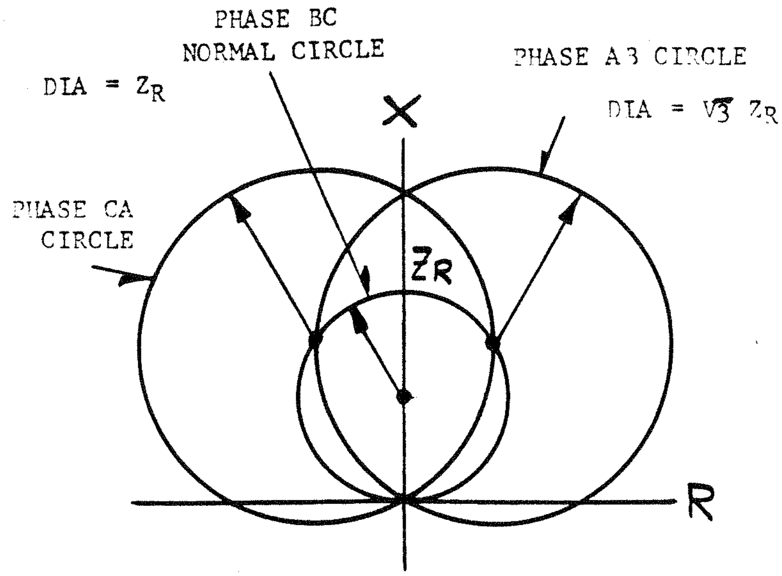


Figure 6(a) SELF POLARIZED MHo RELAY
REVISED R-X CHARACTERISTICS
A TO G FAULT ON VT SECONDARY

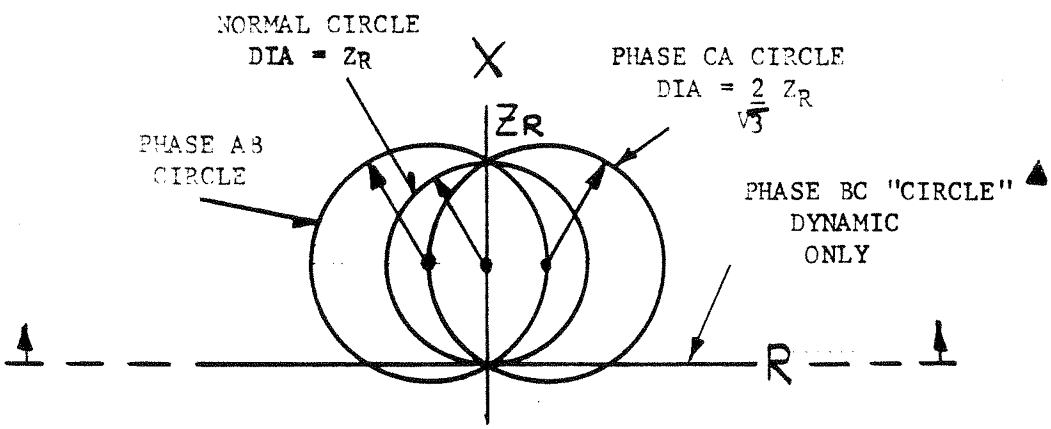


Figure 6(b) SELF POLARIZED MHo RELAY
REVISED R-X CHARACTERISTICS
B TO C FAULT ON VT SECONDARY
▲ PHASE BC ELEMENT BECOMES A MOMENTARY DIRECTIONAL ELEMENT. ZERO TORQUE @ 90° to $Z_R$

Figure 6 Graphical Method for determining single phase mho relay response to V.T. secondary faults. If load ohms $Z_1$ is plotted on RX diagram and falls within any circle the corresponding element will operate.

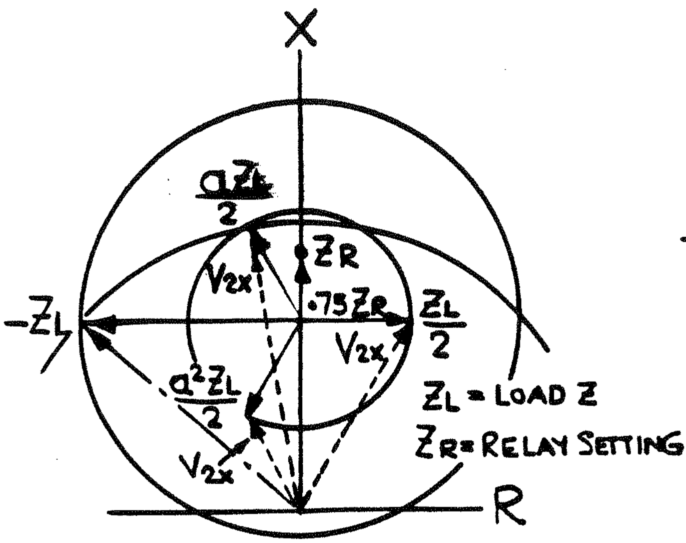


Figure 7(a) KD 3Ø Unit With SLG Fault On V.T. Secondary

| Fault | VIX | V2X |
|---|---|---|
| A - G | $0.75\ Z_R - Z_L$ | $0.75\ Z_R + 0.5\ Z_L$ |
| B - G | " | $0.75\ Z_R + a(0.5\ Z_L)$ |
| C - G | " | $0.75\ Z_R + a^2(0.5\ Z_L)$ |

3Ø Unit Operates If $\overline{V_{2X}} > \overline{V_{1X}}$

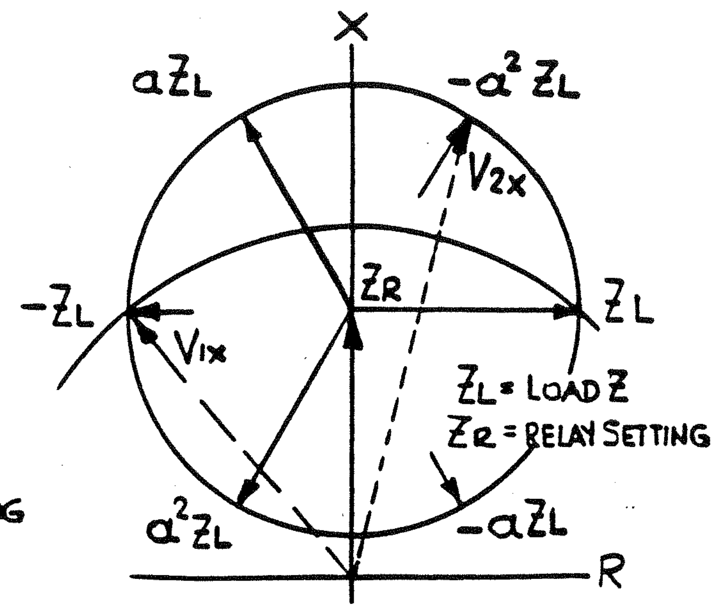


Figure 7(b) KD 3Ø Unit With Ø Ø Fault On V.T. Secondary

| Fault | V1X | V2X | |
|---|---|---|---|
| BC | $Z_R - Z_L$ | $Z_R - Z_L$ | ▲ |
| CA | " | $Z_R - aZ_L$ | |
| AB | " | $Z_R - a^2Z_L$ | ✱ |

3Ø Unit Operates if $\overline{V_{2X}} > \overline{V_{1X}}$

✱ $V_{1X}$, $V_{2X}$ Phasors Drawn for AB FLT

▲ No Steady State Operation For BC FLT

Dynamic Operation if $Z_R > \frac{2}{3} \frac{Z_L}{\cos(\phi - \theta)}$

$\phi$ = ∠ of $Z_R$

$\theta$ = ∠ of $Z_L$

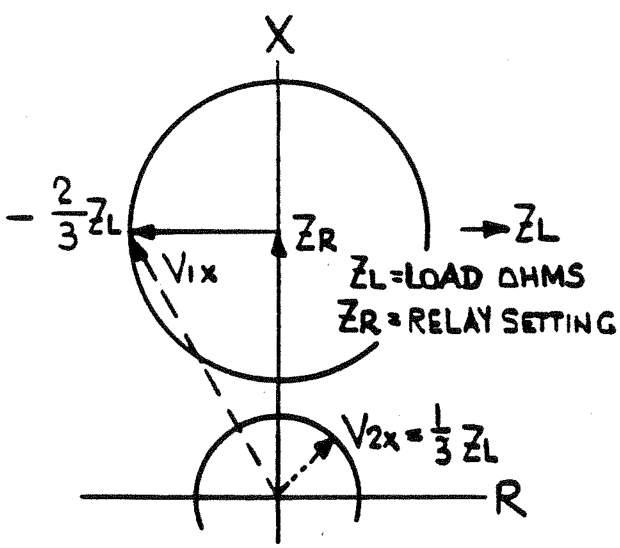


Figure 7(c) KD Ø - Ø Unit With SLG Fault On V.T. Secondary

$V_{1X} = Z_R - \frac{2}{3} Z_L$; $V_{2X} = \frac{1}{3} Z_L$ Any SLG Fault

Ø - Ø Unit Operates If $\overline{V_{2X}} > \overline{V_{1X}}$

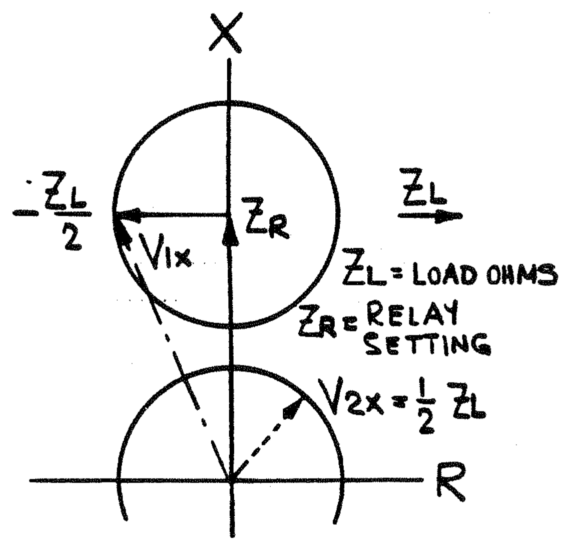


Figure 7(d) KD Ø - Ø Unit With Ø - Ø Fault On V.T. Secondary

$V_{1X} = Z_R - \frac{1}{2} Z_L$; $V_{2X} = \frac{1}{2} Z_L$ Any Ø - Ø Fault

For Operation $\overline{V_{2X}} > \overline{V_{1X}}$

Figure 7 Graphical Method for determining KD relay response to V.T. secondary faults by phasor additions of relay setting $Z_R$ and load ohms $Z_L$ in accordance with specific equations for $V_{1X}$ and $V_{2X}$ as presented.

In all examples $Z_L$ has been represented as Unity Power factor and $Z_R$ angle is 90°.

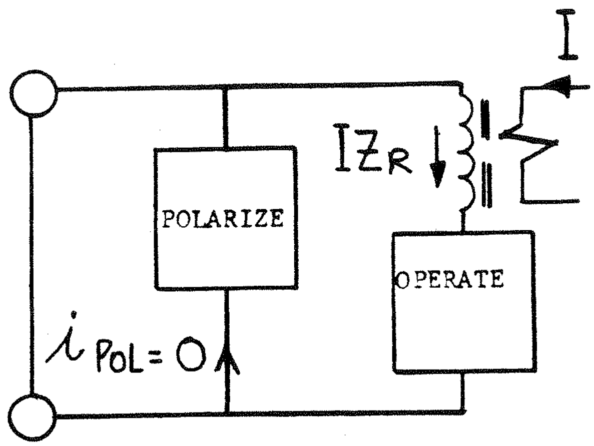


Figure 8(a) Short Circuit

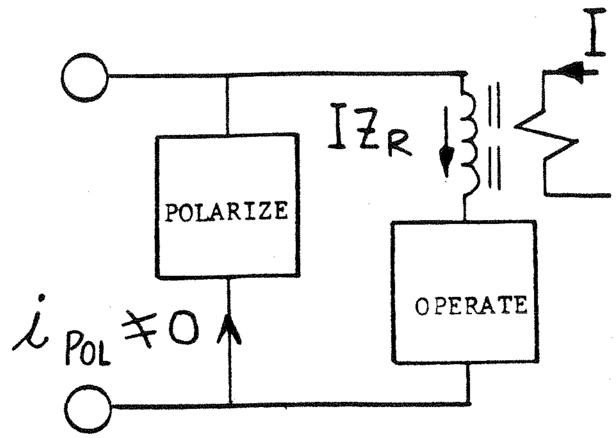


Figure 8(b) Open Circuit

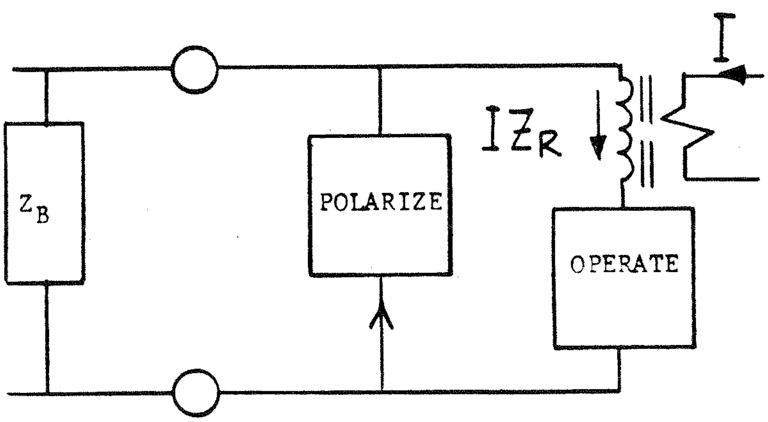


Figure 8(c) Open Circuit - External Burden

Figure 8 Examples of Distance Relays With Zero Applied Voltage

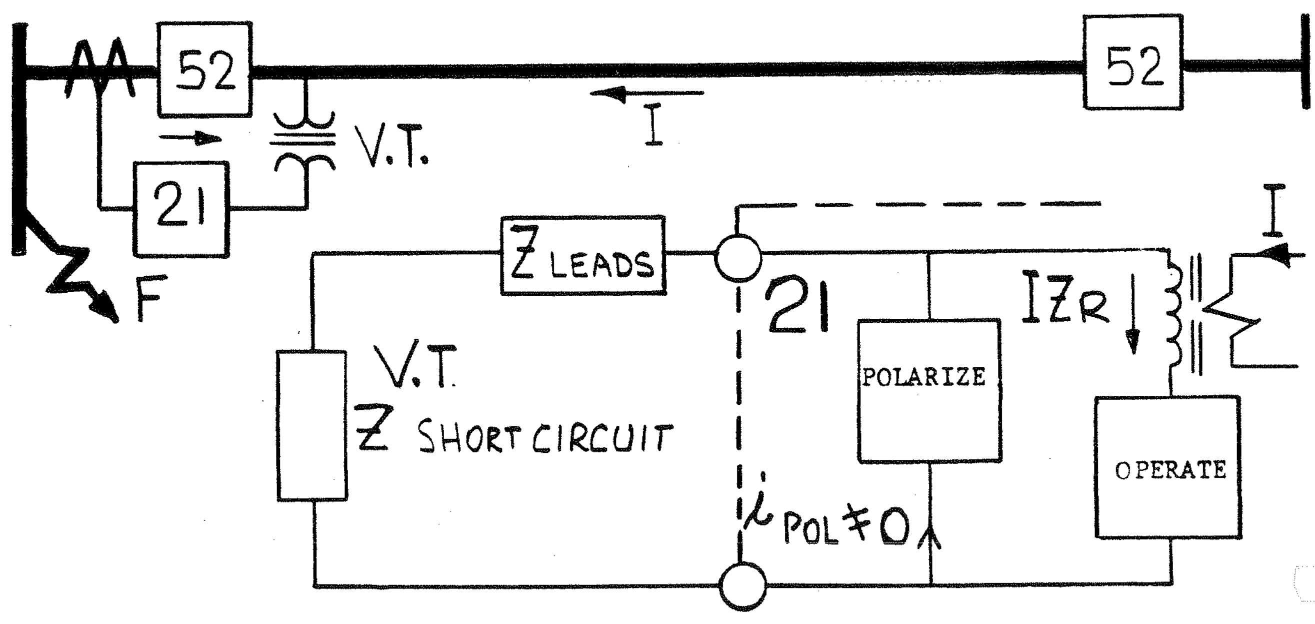


Figure 10 Close-In Reverse Fault

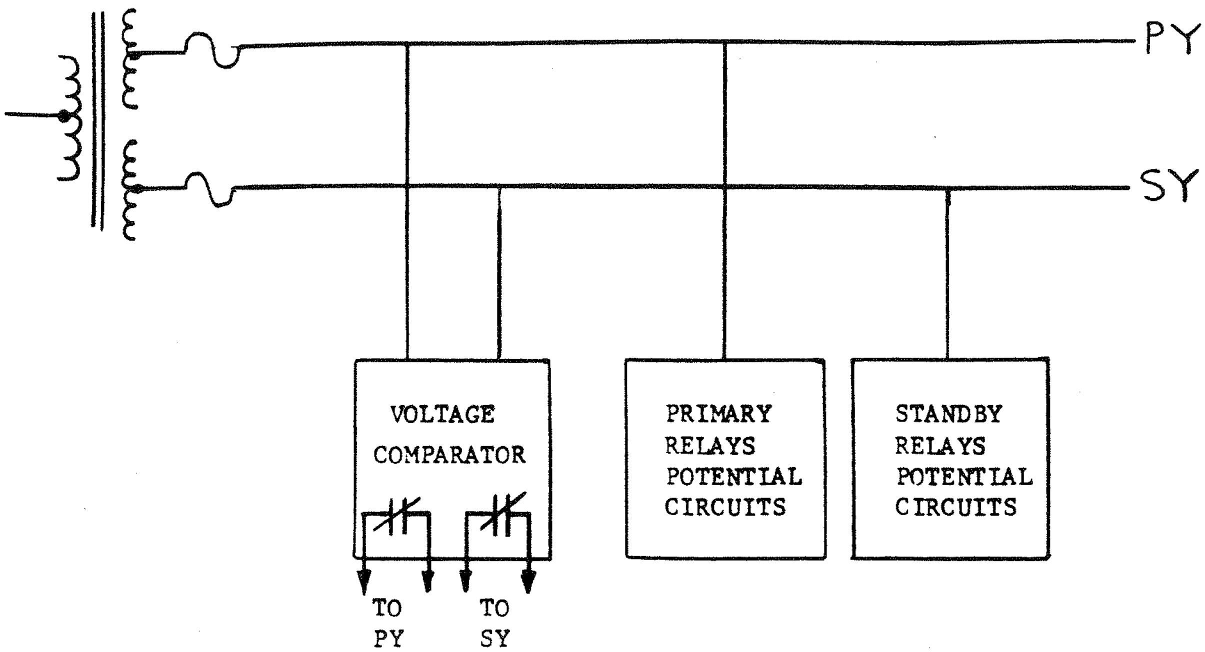


Figure 9(a) Dual Secondary V.T.'s

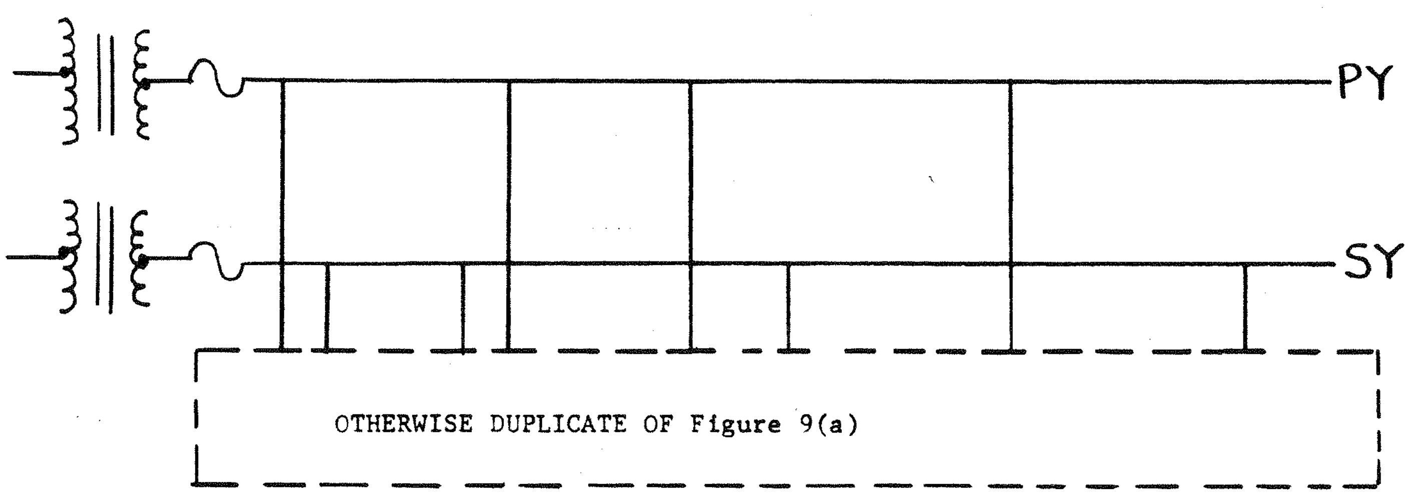


Figure 9(b) Duplicate V.T.'s

Figure 9 Comparison of Normally Identical Potential Sources

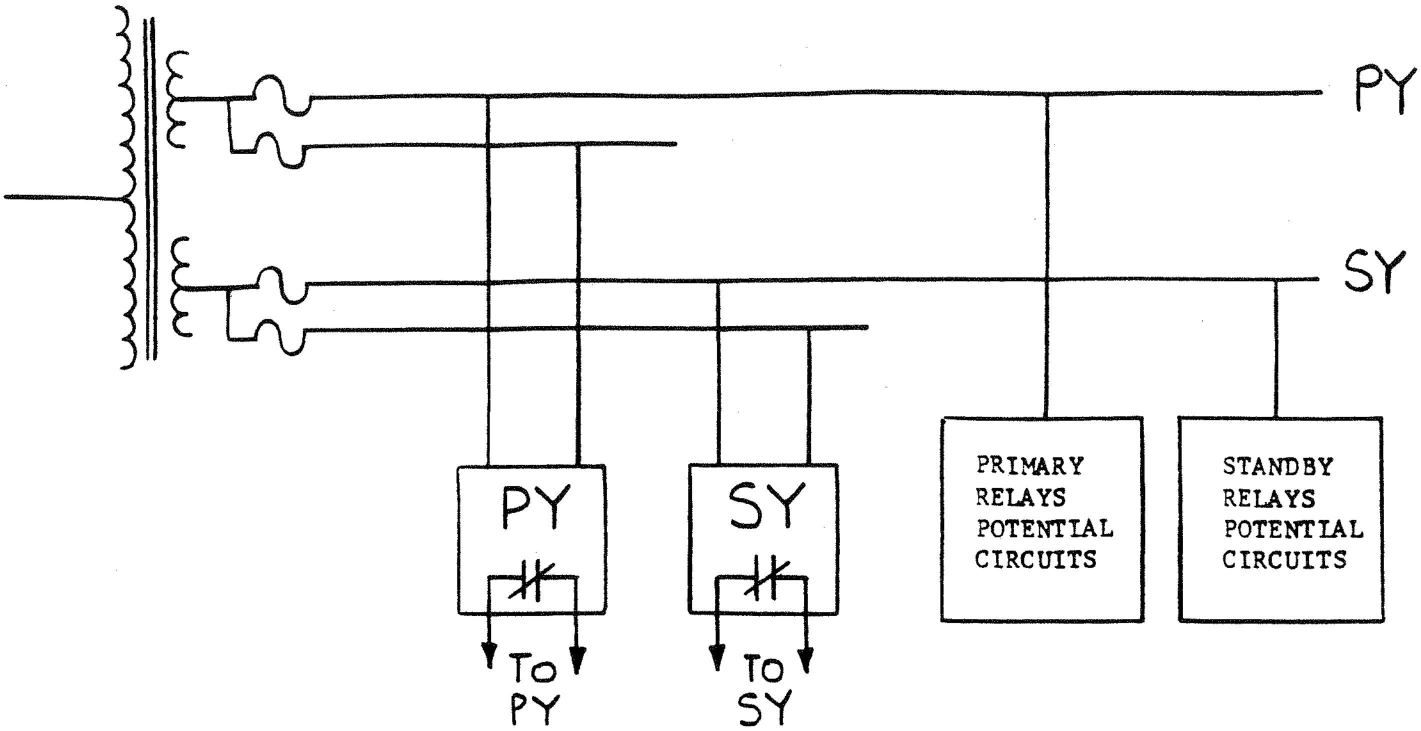


Figure 11 Normal Application Of Voltage Comparators To Detect Fuse Failure

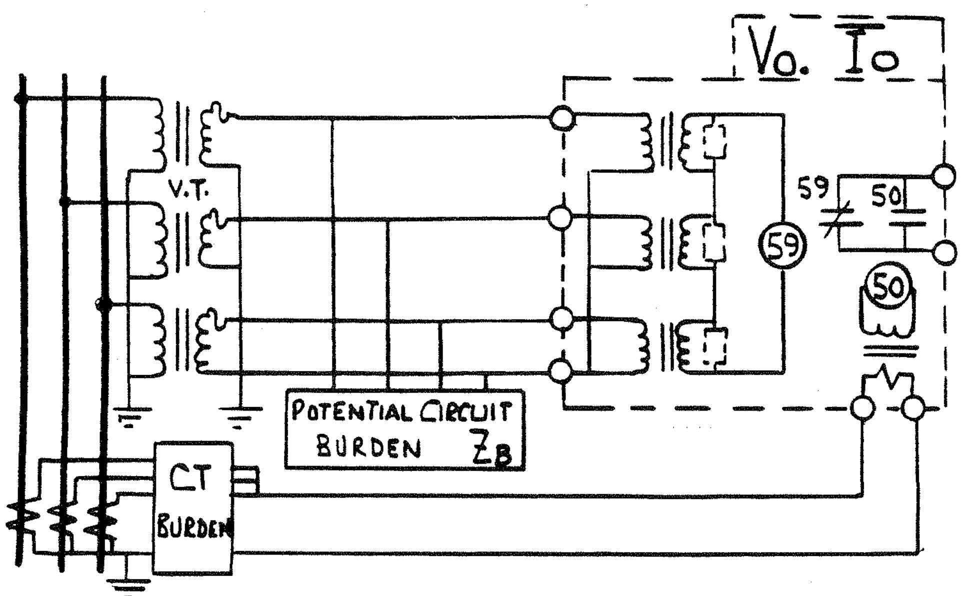


Figure 12(a) Basic Vo.Io AC Connections

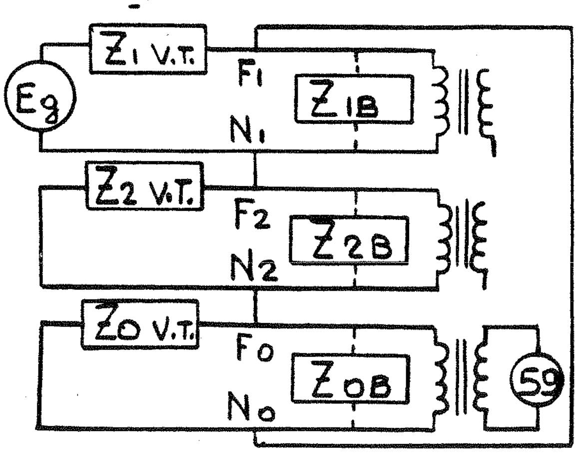


Figure 12(b) A-G Fault On V.T. Secondary

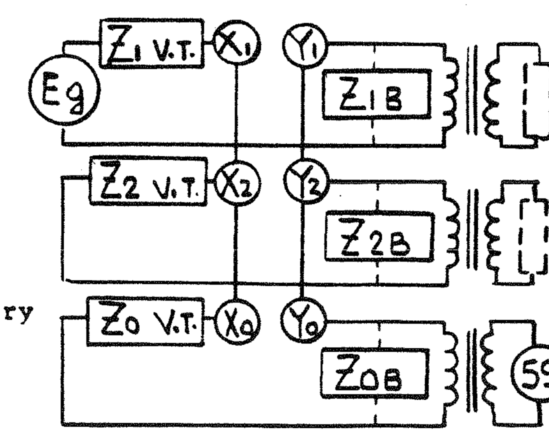


Figure 12(c) Phase A Open On V.T. Secondary

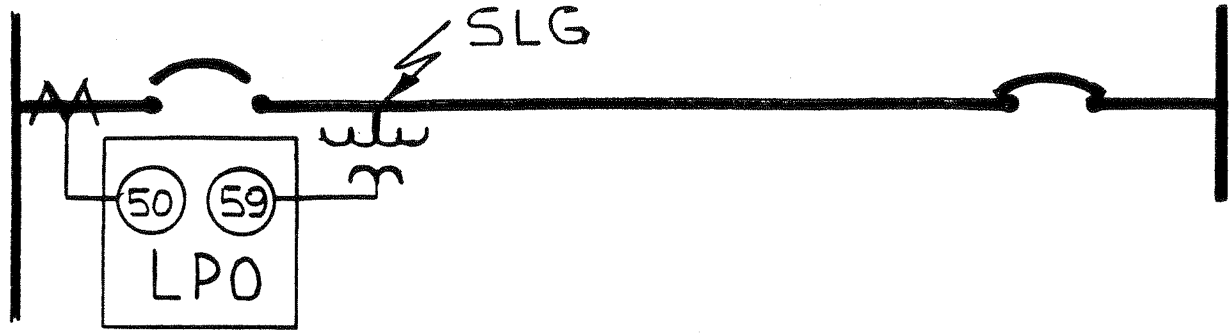


Figure 13

Fault Cleared One End Only
LPO Logic 3Vo. $\overline{3Io}$ Satisfied
Time Delay Required to Avoid False Alarm

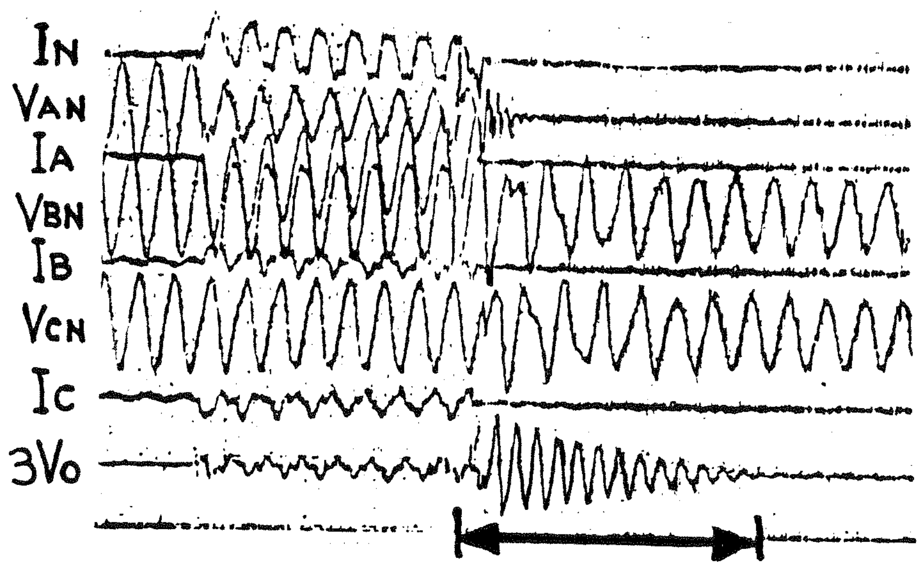


Figure 14

Staged 500 KV A G Fault
Cleared Via Repeat Circuit
Note Post Fault 3Vo Transient
Shunt Compensated Line