DISTANCE MEASURING CONCEPTS SIMPLIFIED

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Introduction

In recent years, we have seen such a flood of esoteric papers on the subject of distance relaying that we may have lost sight of the simplicity and elegance of the traditional concepts and the elemental facts are not receiving the attention they deserve. In emphasizing the effects of digital implementation, load flow, fault resistance, mutual impedance, unsymmetrical impedances, weak sources, ultra high speed, single pole tripping and series capacitors, we denigrate the fundamental measuring concepts that are applied where these influences are not a significant consideration. They do constitute the overwhelming majority of applications. Though these special things are where the interesting analysis and expostulation lie, this paper will focus on some of the basics.

MEASURING QUANTITIES FOR PHASE FAULTS

Considering a simple system with a single source as in figure 1, a 3-phase fault at some point will cause a voltage to exist at some relaying location equal to IZ. A phase-to-phase fault at the same point produces at the relay, a voltage of 2IZ (with the I's, of course, being of different magnitude and the Z's being proportional to the distance to the fault).

BASIC PHASE FAULT DIAGRAM

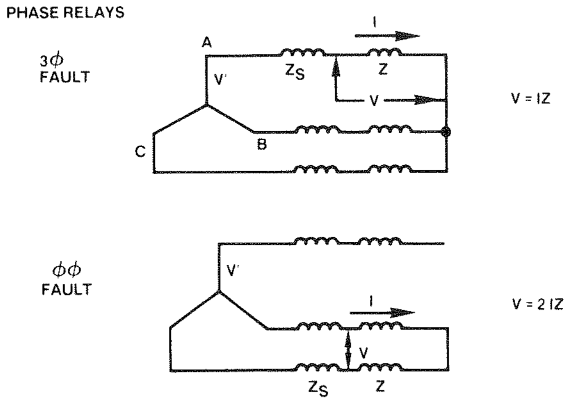


Figure 1

Table I explores the choices possible for comparison. Using wye voltage (phase voltage-to-ground) and wye current would provide a suitable measurement for 3-phase faults but a terrible measurement for phase-to-phase faults because of the fact that wye voltage contains a component not related to the fault. With zero voltage between phases at the fault, there is not, at the fault, zero voltage to ground.

Using delta voltage (phase-to-phase voltage) and wye current, the measurement improves, but still has a 15% difference in the apparent distance to a phase fault at a given location depending on whether a 3-phase or a phase-to-phase fault is involved.

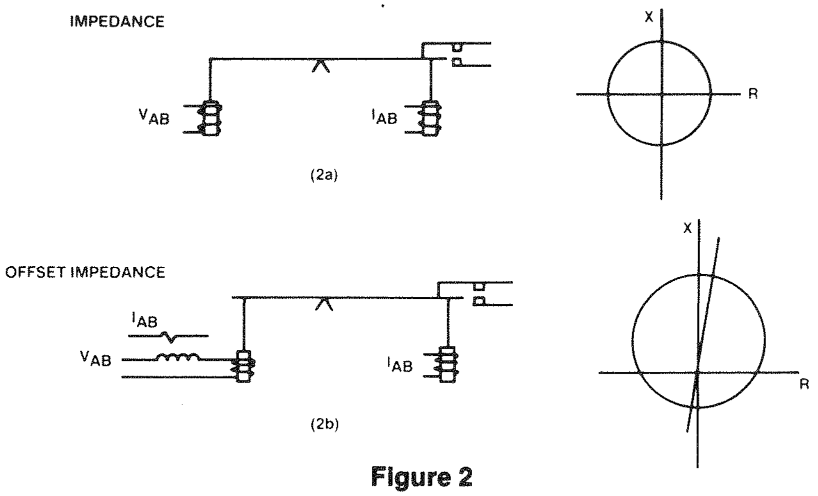
Measurement of distance, using delta voltage and delta current is accurate for both types of phase faults using individual single phase distance units. Figure 2 shows two historical implementations of this concept and, though long since superseded, provide important insight into simple distance measurement. Figure 2a had an impedance characteristic and its balanced-beam operating principle is the origin of the term "balance point." Figure 2b produced an offset impedance characteristic. Using these concepts requires <u>three</u> measuring units (one for each phase combination, AB, BC, CA) to cover all phase fault cases.

TABLE I

MEASURING QUANTITIES	3ϕ	$\phi\phi$	COMMENT
$\frac{V_Y}{I_Y}$	$\frac{IZ}{I} = Z$	$\frac{IZ - j0.5V'}{I} \neq Z$	N.G.
$\frac{V_\Delta}{I_Y}$	$\frac{\sqrt{3}IZ}{I} = \sqrt{3}Z$	$\frac{2IZ}{I} = 2Z$	N.G.
$\frac{V_\Delta}{I_\Delta}$	$\frac{\sqrt{3}IZ}{\sqrt{3}I} = Z$	$\frac{2IZ}{2I} = Z$	OK

NG = Not suitable for both 3ϕ and $\phi\phi$
V_Y = Phase to ground voltage (V_{AG}, etc.)
V_Δ = Phase to phase voltage ($V_A - V_B$, etc.)
I_Y = Phase current (I_A, etc.)
I_Δ = Delta current ($I_A - I_B$, etc.)

BALANCED - BEAM DISTANCE MEASURING UNIT



(2a)

(2b)

Figure 2

Table 1 affords little insight into the use of three-phase measuring units such as that of figure 3. It uses wye current and the characteristics of the voltage triangle on 3-phase faults to judge distance to a fault. It is comparable to the use of wye voltage and wye current for three-phase faults.

Another complementary unit shown in figure 4 is comparable to the use of delta voltage and delta current for all combinations of phase-to-phase faults. These two units of figures 3 and 4 provide accurate measurement of all phase faults, which, prior to the introduction of the concept, required three measuring units (with 3 sets of moving parts, more units to test, more panel space needed, more interconnecting wiring, more trip current to drop targets, and of course more cost).

The overwhelming success of the principle led to its adaptation in solid state varieties of phase distance relaying.

KD-10 3ϕ
DISTANCE UNIT

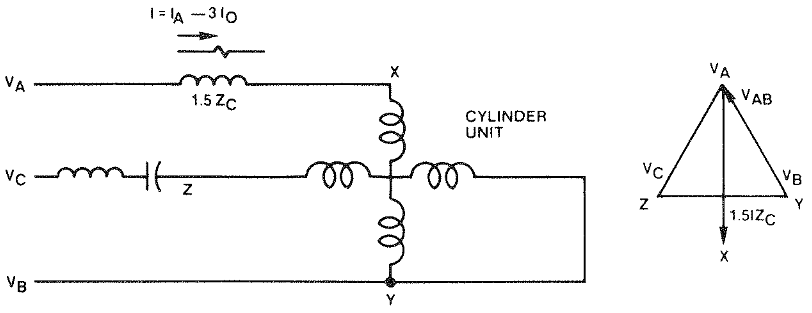


Figure 3

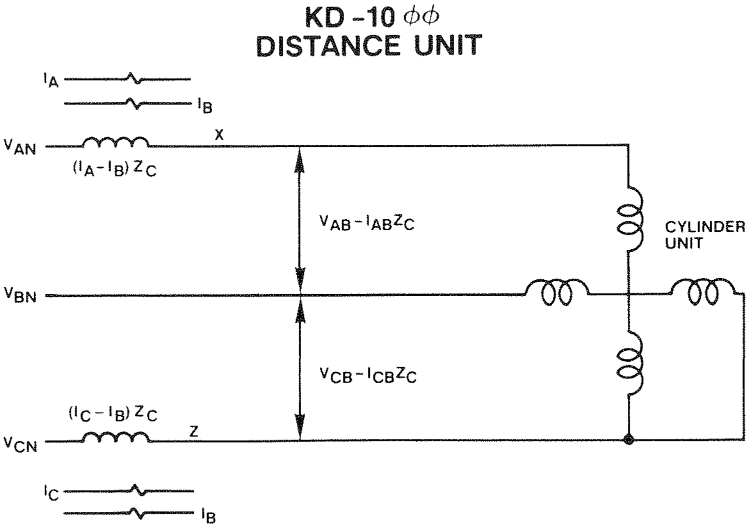


Figure 4

LKD

The solid state equivalent of the electromechanical 3-phase measuring unit is described in figure 5, and it uses delta voltage and current. $I_A - 3I_0$ compensation is used in the KD-10 to assure overlap of the ØØ and 3Ø units in their coverage of ØØG faults. This is required where the ground relay (such as the KDXG) is incapacitated for ØØG faults. In Uniflex, no such blocking takes place.

Figure 6 shows the operational amplifier implementation of the identical measuring concept as is used in the electromechanical phase-to-phase unit. Using this principle, preserves all of the advantages previously enjoyed, like this single unit:

a) being highly directional for zero voltage faults, requiring no memory action circuit

b) responding to all 3 of the combinations of ØØ (phase-to-phase) faults and complementing the 3-phase unit for all 3 of the combinations of ØØG (phase-to-phase-to-ground) faults

c) responding to all close-in (roughly 1/3 of set reach) ØG (phase-to-ground) faults

d) requiring no out-of-step blocking, and

e) being able to trip for ØØ faults occurring during out-of-step.

UNIFLEX LKD 3ϕ DISTANCE UNIT

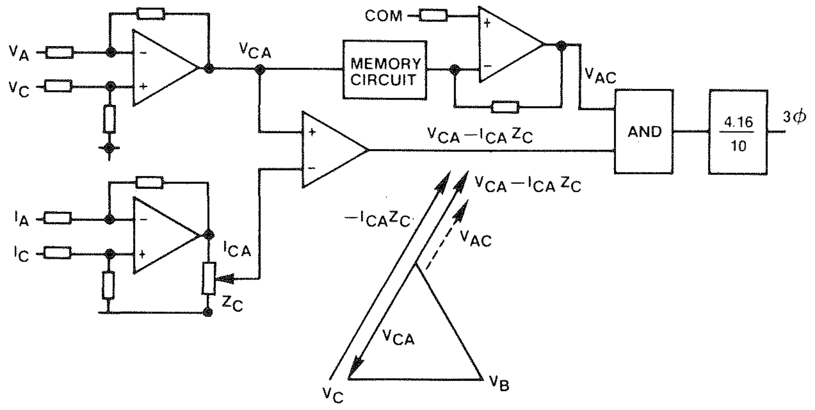


Figure 5

UNIFLEX LKD $\phi\phi$ DISTANCE UNIT

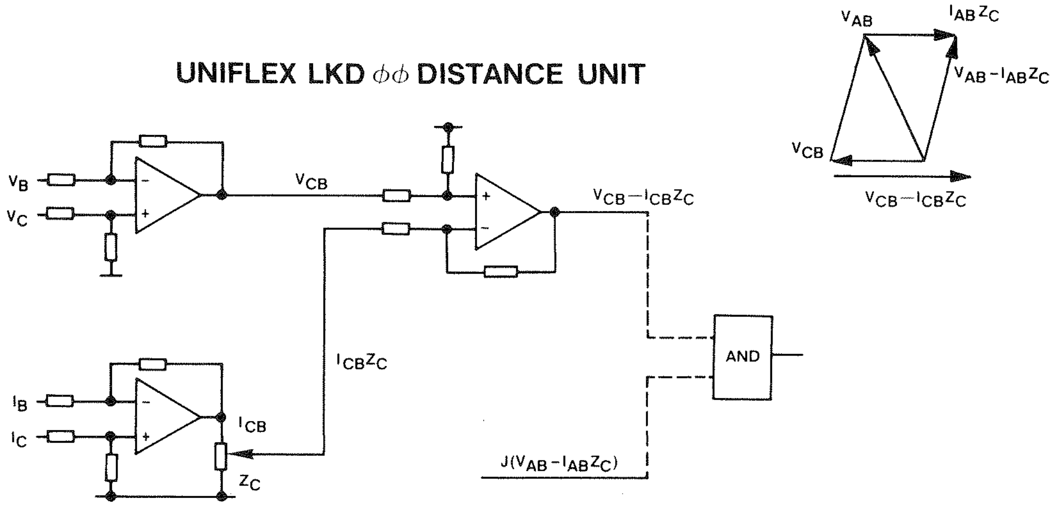


Figure 6

LD-1

Another useful concept that employs delta voltage and delta current for the distance measurement for phase faults is described by figure 7. Here speed is a pivotal influence because it is used as a carrier start element. Block sequence relays develop operating and polarizing quantities. Depending on which of these quantities leads the other, operation or restraint is produced.

For faults appearing inside the characteristic operating circle of the relay, the operating voltage leads the polarizing voltage. Operation (and carrier starting) takes place. For normal conditions or for faults appearing outside the characteristic circle, the polarizing voltage leads the operating voltage.

Figure 8 shows the digital pattern to be used to identify the operating voltage/polarizing voltage (each squared from their sinusoidal wave-shapes) relationship. Only the positive half cycles are shown. A similar comparison is made on the negative half cycles to assure high speed.

PHASOR DIAGRAMS AND R-X DIAGRAM
FOR BLOCK SEQUENCE CONCEPT
(3ϕ FAULT)

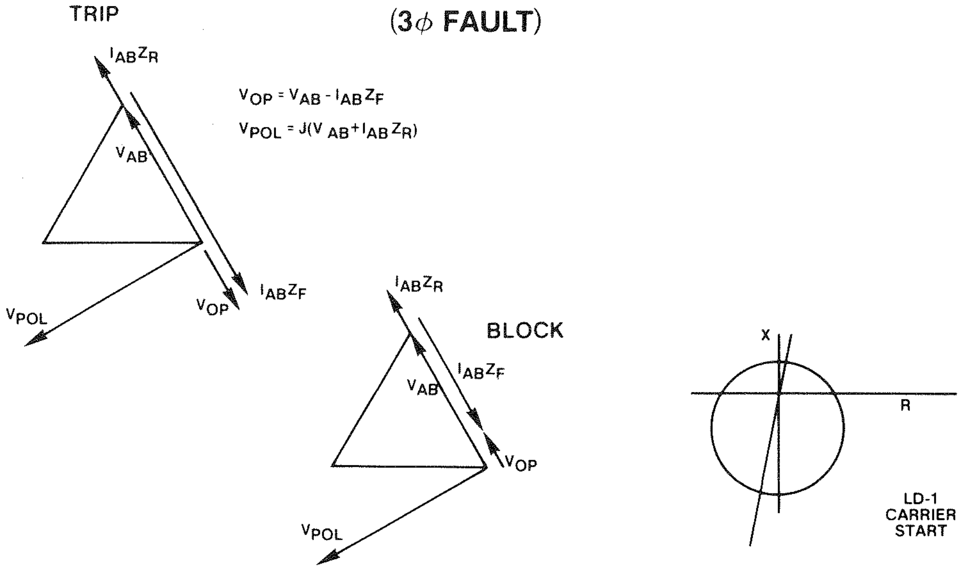
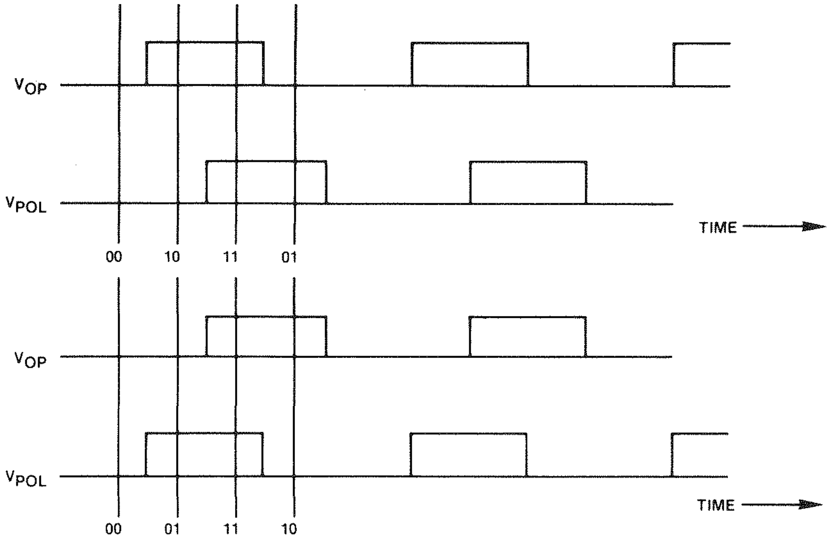


Figure 7

LD-1 CARRIER START



BLOCK SEQUENCE SENSING BY DIGITAL TECHNIQUE
(00, 10, 11, 01 OPERATES)
(00, 01, 11, 10 BLOCKS)

Figure 8

MEASURING QUANTITIES FOR GROUND FAULTS

Appendix I describes the difficulties of measuring the distance to a ground fault. Comparison of zero sequence voltage and current fails miserably because the ratio is source impedance not line impedance.

Comparison of phase voltage with phase current also fails. Modification of phase current by zero sequence current does allow this combination to be used. It requires three individual measuring units, one for each phase, and is used in single-pole trip and ground reactance step distance applications. For other applications, a simpler zone-packaged arrangement can be applied using the magnitude comparison concept described in Appendix II.

SDG

The SDG implementation of this concept is shown in figure 9. $(V_{A1}+V_{A2}) - (I_{A1} + I_{A2}) Z_C$ is segregated out of $V_{AG} - I_A Z_C$ by the simple expedient of allowing the secondary neutral of the transformer to float. In the rudimentary circuit form V_{WO} greater than V_{XN}(or V_{YN} or V_{ZN}) causes a transistor to turn on and trip.

SDG BASIC CIRCUIT

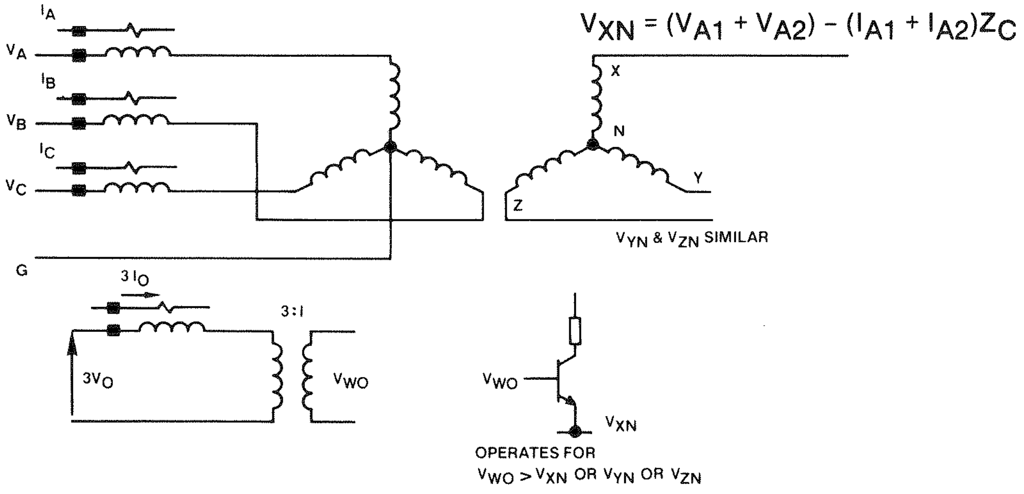


Figure 9

LDG

Figure 10 describes how the identical distance measuring concept is implemented in the LDG relay with operational amplifiers. By setting Z_C for the desired reach, a ground fault, in the proper direction, within that reach will cause the relay to have an output.

High resistance ground fault accommodation is realized with the LDG, using the logic shown in figure 11. With all switches closed, directional unit operation alone is allowed to produce pilot tripping (provided the channel information confirms the need to trip) for 50 milliseconds. It is then cut off for external faults to allow time coordinated backup tripping based on distance unit operation, supervised or not as desired, by the same directional unit. By this concept, the Uniflex system with LDG ground distance relaying is able to overcome the usual ground fault resistance limitation and to recognize internal high resistance ground faults it would otherwise not detect.

Also the control by the directional unit removes the setting limitation of twice line impedance imposed on the SDG predecessor relays. Any setting within the range of the LDG can now be used without regard to the protected line impedance.

LDG BASIC CIRCUIT

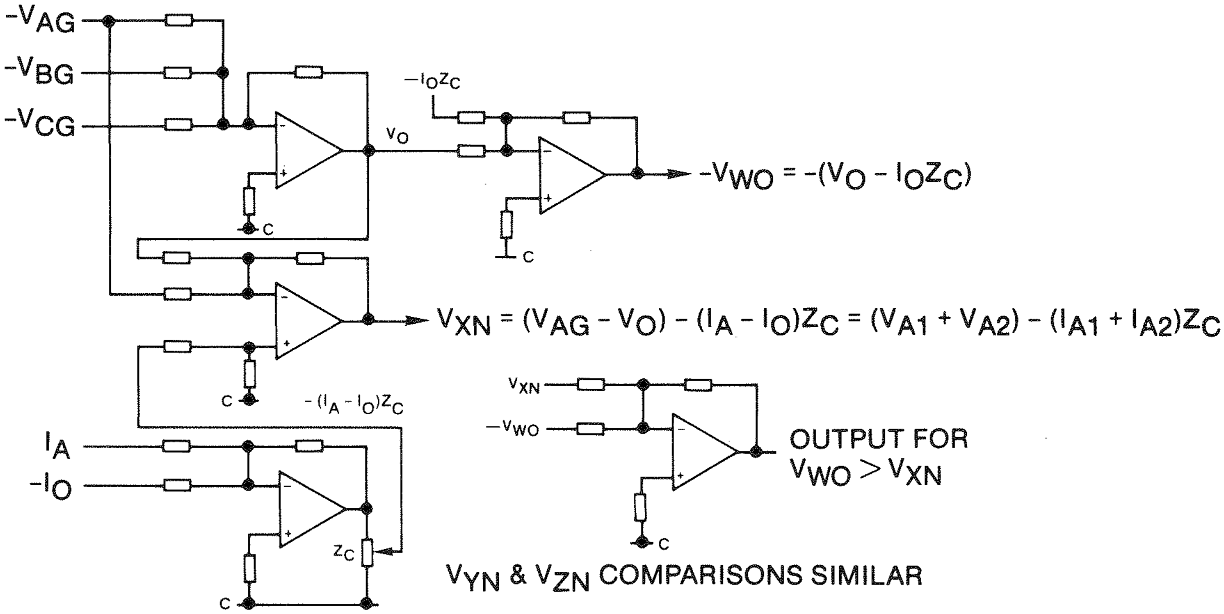


Figure 10

LDG DIRECTIONAL UNIT LOGIC

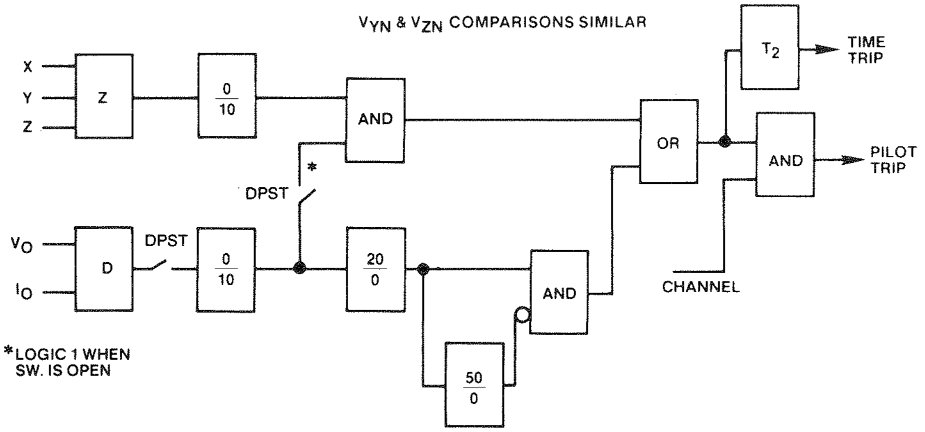


Figure 11

Ground distance relays are inherently designed for phase-to-ground fault recognition. They generally over reach their reach setting (see a fault to be nearer than it actually is) for ØØG faults because the apparent impedance is (for a BCG fault for example) in its simplest form:

$Z_{1L}+(3I_0R_G)/(I_B+KI_0)$ where Z_{1L} is positive sequence impedance from the relay location to the fault, I_B and I_0 are the faulted phase and zero sequence relay currents, R_G is fault resistance to ground and K is $(Z_{0L}-Z_{1L})/\ Z_{1L}$. Figure 12 shows the effect of I_B+KI_0 leading $3I_0$. The effect of the fault resistance, R_G, is to produce a lagging component in the apparent impedance. Pre fault load flow can aggravate this effect. The LDGZ zone 1 relay has a circuit, figure 13, that shortens the reach of the relay by approximately 25 percent rather than blocking for ØØG faults to guard against this overreach tendency.

OVERREACHING EFFECT CAUSED BY FAULT RESISTANCE FOR BCG FAULT.

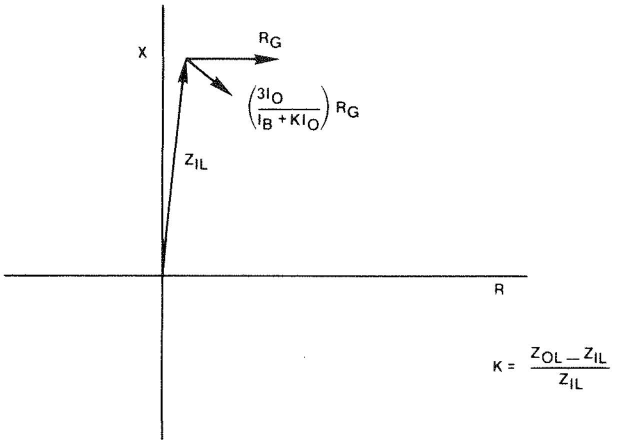
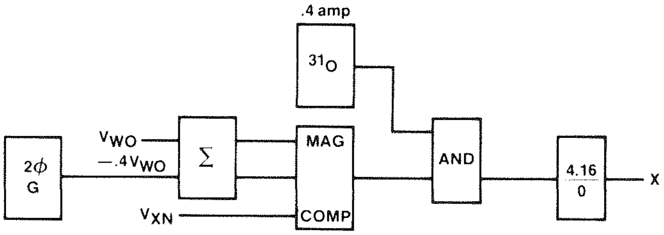


Figure 12

LDGZ 21N-1



V_{YN} & V_{ZN} COMPARISONS SIMILAR

Figure 13

Internal faults near the balance point can produce short coincidence pulses out of the comparison circuit, causing small, but undesired, reach shortening. The LDGZ relay contains the circuitry of figure 14. It assures fast, secure tripping for faults near the balance point and avoids the longer tripping time produced by those relays that use inverseness as a security measure.

LDGZ LOGIC

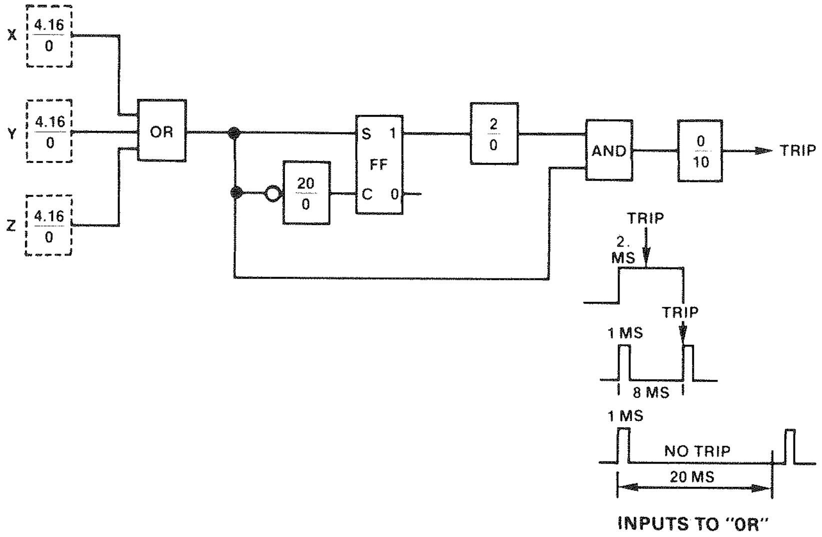


Figure 14

Table II shows the various concepts and considerations that are incorporated in the Uniflex distance measuring units.

TABLE II

UNIFLEX DISTANCE UNITS

Relay	Function	Mag. Comp	Block Coinc.	Block Seq.	ØØG	2 Count W/Switch	D Unit W/Switch	*Setting Recomm.
LD-1	21S			X				
LKD	21P		X					
LDZ	21-1		X					VT'S 90% PCA-5 85%
LDG	21NP	X					X	
LDGZ	21N-1	X			X	X		VT'S 90% PCA-5 80%

*Note: Other higher performance devices such as the PCMX and PCA-7 allow settings identical to those for VT's. Devices with transient performance similar to the PCA-5 such as the PCA-8 allow settings similar to those for PCA-5.

Appendix I
GROUND DISTANCE RELAYS

METHOD 1

$$Z = \frac{V_{A0R}}{I_{A0R}} = Z_{0S} \qquad \text{N.G.}$$

METHOD 2

$$V_{AGR} = V_{A1R} + V_{A2R} + V_{A0R} = \text{A-PHASE-TO-GROUND VOLTAGE AT RELAY}$$

$$V_{AGR} = I_{A1R}Z_{1L} + I_{A2R}Z_{2L} + I_{A0R}Z_{0L}$$

$$\frac{V_{AGR}}{I_{AR}} = \frac{I_{A1R}Z_{1L} + I_{A2R}Z_{2L} + I_{A0R}Z_{0L}}{I_{A1R} + I_{A2R} + I_{A0R}}$$

$$\frac{V_{AGR}}{I_{AR}} = \frac{Z_{1L}\left(I_{A1R} + I_{A2R} + I_{A0R}\frac{Z_{0L}}{Z_{1L}}\right)}{I_{A1R} + I_{A2R} + I_{A0R}} \qquad \text{N.G.}$$

METHOD 3

$$\frac{V_{AGR}}{I_{AR} + \left(\frac{Z_{0L} - Z_{1L}}{Z_{1L}}\right) I_{A0R}} = \frac{Z_{1L}\left(I_{A1R} + I_{A2R} + \frac{Z_{0L}}{Z_{1L}} I_{A0R}\right)}{I_{A1R} + I_{A2R} + \frac{Z_{0L}}{Z_{1L}} I_{A0R}} = Z_{1L} \qquad \text{OK}$$

SEQUENCE NETWORK INTERCONNECTION FOR ϕG FAULT

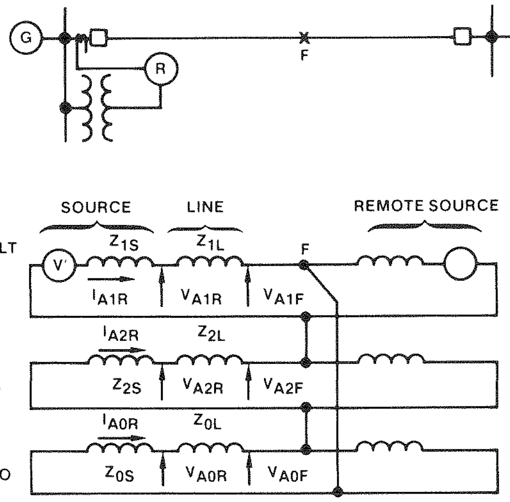


Figure 15

Appendix II

MAGNITUDE COMPARISON GROUND DISTANCE RELAY

SEE FIGURE 15

At the fault $V_{A1F} + V_{A2F} + V_{A0F} = 0$ (1)

and $|V_{A1F} + V_{A2F}| = |V_{A0F}|$ (2)

Also $V_{A1F} = V_{A1R} - I_{A1R} Z_{1L}$ (3)

$V_{A2F} = V_{A2R} - I_{A2R} Z_{2L}$ (4)

$V_{A0F} = V_{A0R} - I_{A0R} Z_{0L}$ (5)

Adding (3) and (4) and using $Z_{1L} = Z_{2L}$

$$V_{A1F} + V_{A2F} = (V_{A1R} + V_{A2R}) - (I_{A1R} + I_{A2R}) Z_{1L} \quad (6)$$

The magnitude of this sum is then equal to $|V_{A0F}|$. This is true for any phase-to-ground fault that is away from the relay location by an impedance, Z_{1L}.

If now we develop in a relay at R, values $V_{A1R} - I_{A1}Z_C$ and $V_{A2R} - I_{A2}Z_C$ and add them, we will have a quantity:

$V_{XN} = (V_{A1R} + V_{A2R}) - (I_{A1R} + I_{A2R})Z_C = (V_{AR} - V_{A0R}) - (I_{AR} - I_{0R}) Z_C$ (7)
where Z_C is the setting of the relay
Also a value:
$V_{W0} = (V_{A0R} - I_{A0R}Z_{0C})$ (8)
is developed (again using only the local quantities at R).

From the similarity of (7) and (8) to (6) and (5) it can be seen that, a ØG fault occurring where $Z_C = Z_{1L}$ and Z_{0L} will cause V_{W0} to equal V_{XN}. A fault closer to the relay location (in the trip direction) will cause V_{W0} to exceed V_{XN}. A farther fault will cause V_{XN} to exceed V_{W0}. Similar quantities V_{YN} and V_{ZN} are generated for detection of ground faults in phases B and C. If V_{W0} exceed the least of these, it is identified as a fault within the "reach setting" of the relay. This is the LDG and SDG magnitude comparison concept.

Conclusion

This paper has reviewed some very old distance measuring concepts and described their modern adaptations. A considerable body of refinement has been necessary to provide the speed and security that has come to be expected, while at the same time taking advantage of those superb qualities the basic measuring concepts have provided in the past. Each distance function has unique demands, and the Uniflex distance measuring concepts have been adapted to fulfill them.