New Ground Directional Elements Operate Reliably for Changing System Conditions

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ABSTRACT

This paper describes a new Ground Directional Relay (GDR) that selects among zero-sequence current-polarized, negative-sequence voltage-polarized, or zero-sequence voltage-polarized directional elements according to system conditions. Application examples illustrate the need for a relay that selects the optimal directional element to increase transmission line protection reliability.

Keywords: Ground Directional Relay (GDR), Directional Element, Zero-Sequence, Negative-Sequence, Current-Polarized, and Voltage-Polarized.

INTRODUCTION

Classical GDRs respond to either negative- or zero-sequence quantities. For these classical GDRs, we must select which sequence quantities to use for each application and particular system operating conditions. After the selection of polarizing and operating quantities, traditional GDRs use these quantities at all times. This restriction may result in directional element misoperation for changing system configurations.

This paper describes a new GDR that selects the best sequence quantities to use for ground faults according to system conditions. It is possible for this new GDR to use a negative-sequence directional element for one fault and a zero-sequence voltage-polarized directional element for the next ground fault. Avoid making choices and compromises by using this new GDR capability. An additional benefit of this new relay is that it does not require user settings.

The Ground Directional Relay consists of a combination of three directional elements:

- Zero-sequence current-polarized (32I).
- Negative-sequence voltage-polarized (32Q).
  Zero-sequence voltage-polarized (32V).

The new relay uses negative- and zero-sequence voltage-polarized directional elements that overcome the dependability and security problems of traditional voltage-polarized elements.

The paper uses system examples to illustrate how this new GDR selects the optimal directional element for each system condition. The results are increased sensitivity, improved security, and setting simplicity.

ELEMENTS OF THE NEW GROUND DIRECTIONAL RELAY (GDR)

The directional elements (32I, 32Q, and 32V) and the selection logic make up the GDR. Following is the description of the directional elements:

Current-Polarized Directional Element (32I)

The 32I element is the traditional current-polarized directional element. Figure 1 shows the simplified block diagram of this element. The analog input quantities to this element are the operating quantity, $3I_0$, and the polarizing quantity, I_{POL} [1]. The 32I element calculates a torque-like product based on the magnitudes and the relative angle of the analog input quantities (Equation 1) when the 32IE bit asserts. The 32I element compares the result of the torque calculation, T, against preset thresholds. If T is positive and above the positive threshold, the F32I bit asserts to declare a forward ground fault. If T is negative and below the negative threshold, the R32I bit asserts to declare a reverse ground fault.

$$T = |I_{POL}| \cdot |3I_0| \cdot \cos(\angle I_{POL} - \angle 3I_0) \qquad \textbf{Equation 1}$$

where:

I_{POL} Polarizing quantity

$3I_0$ Operating quantity: $3I_0 = I_A + I_B + I_C$

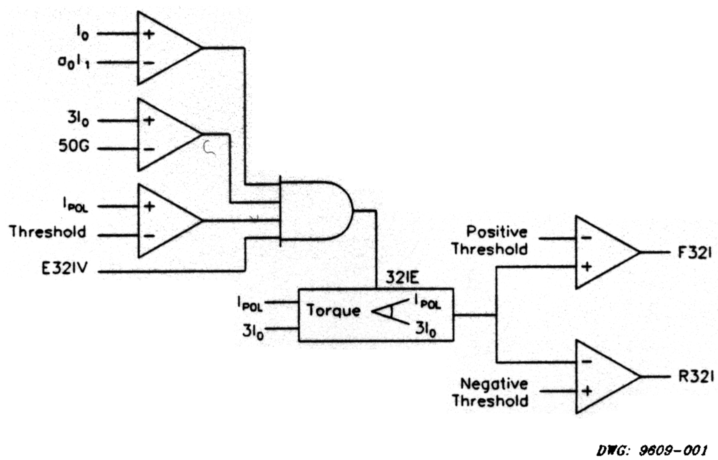

Figure 1: Simplified Block Diagram of the 32I Element

The 32I Enable bit, 32IE, controls this element to increase its security. The 32IE bit asserts when all of the following conditions are true:

- The zero-sequence current, I_0, is greater than the positive-sequence current, I_1, times the a_0 factor ($I_0 > a_0 I_1$).

  The a_0 factor increases the 32I element security for zero-sequence currents, which circulate due to line asymmetries, CT saturation, etc. [2].

- The operating quantity, $3I_0$, is greater than the 50G sensitivity threshold.
- The polarizing quantity, I_{POL}, is greater than the preset sensitivity threshold.

  The relay avoids making erroneous directional decisions for low input current values by comparing $3I_0$ and I_{POL} magnitudes.
- The E32IV programmable variable asserts (logical 1).

The E32IV variable deasserts to identify zero-sequence source isolation [3]. The programmable variable can be set locally or remotely via command or contact input. With this control capability, events that occur locally or in remote parts of the system may control the relay to accommodate new system conditions.

Negative-Sequence Voltage-Polarized Directional Element (32Q)

Figure 2 shows the simplified block diagram of the 32Q element described in Reference [4]. The analog input quantities to this element are the negative-sequence voltage, V_2, and the negative-sequence current, I_2. The 32Q element calculates the negative-sequence impedance, z2, presented to the relay using Equation 2 when the 32QE bit asserts. The element compares z2 against the Z2F and Z2R thresholds. The F32Q bit asserts for forward ground faults, and the R32Q bit asserts for reverse ground faults.

$$z2 = \frac{\mathrm{Re}[V_2 \cdot (1\angle\theta_{L2} \cdot I_2)^*]}{|I_2|^2}$$ **Equation 2**

where:

V_2 Negative-sequence voltage: $V_2 = (V_A + a^2V_B + aV_C)/3$

I_2 Negative-sequence current: $I_2 = (I_A + a^2I_B + aI_C)/3$

Θ_{L2} Line negative-sequence impedance angle

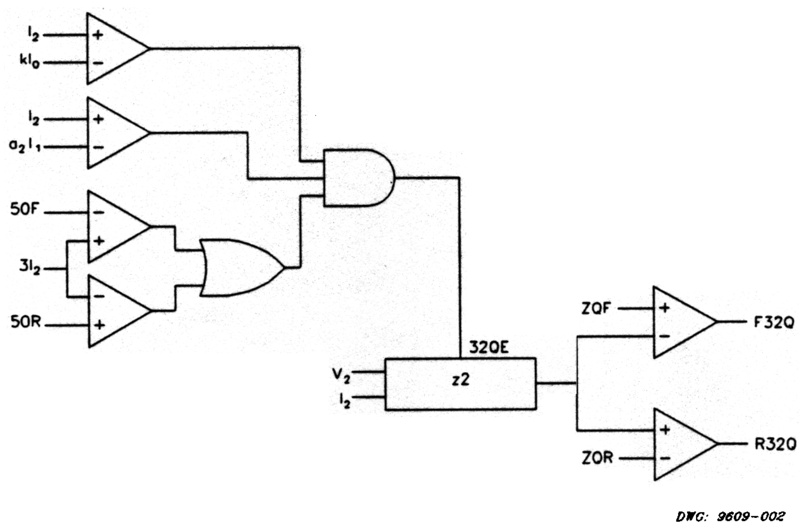

Figure 2: Simplified Block Diagram of the 32Q Element

The 32Q Enable bit, 32QE, asserts when all of the following conditions are true:

- The negative-sequence current, I_2, is greater than the zero-sequence current, I_0, times the k factor ($I_2 > kI_0$).

  In the event that the 32Q and 32V elements have sequence currents above their minimum current sensitivity thresholds, the relay selects the 32Q element if $I_2 > kI_0$. This check assures that the relay uses the most robust analog quantities even if the relay sensitivity settings are not optimized.

- The negative-sequence current, I_2, is greater than the positive-sequence current, I_1, times the a_2 factor ($I_2 > a_2I_1$).

  The a_2 factor increases the 32Q element security in the same way the a_0 factor increases the 32I element security.

- The negative-sequence current, $3I_2$, is greater than the 50F or 50R sensitivity threshold. The relay avoids making erroneous directional decisions for low input values of $3I_2$ by requiring that $3I_2$ be greater than the 50F or 50R threshold.

Zero-Sequence Voltage-Polarized Directional Element (32V)

The 32V element is the zero-sequence analogy of the 32Q element. The differences between the 32V and 32Q elements are:

- The analog input quantities.

  The 32V element uses zero- instead of negative-sequence quantities.

- The a_0 factor.

  The circulating zero-sequence currents, which are due to line asymmetries, are typically less than the circulating negative-sequence currents for most phase conductor configurations [2]. Thus, the a_0 factor is usually smaller than the a_2 factor. Because of this fact, we can set the 32V element more sensitively than the 32Q element in nontransposed line applications where CT saturation is not a possibility.

Equation 3 shows the algorithm used to calculate z0. The 32V element makes directional decisions in the same way as the 32Q element. The element compares z0 against the Z0F and Z0R thresholds to assert F32V (forward fault) or R32V (reverse fault) depending on the direction of the ground fault. Figure 3 shows the simplified block diagram of the 32V element.

$$z0 = \frac{\mathrm{Re}[3V_0 \cdot (1\angle\theta_{L0} \cdot 3I_0)^*]}{|3I_0|^2} \qquad \textbf{Equation 3}$$

where:

V_0	Zero-sequence voltage:	V_0	$= (V_A + V_B + V_C)/3$
I_0	Zero-sequence current:	I_0	$= (I_A + I_B + I_C)/3$
Θ_{L0}	Line zero-sequence impedance angle		

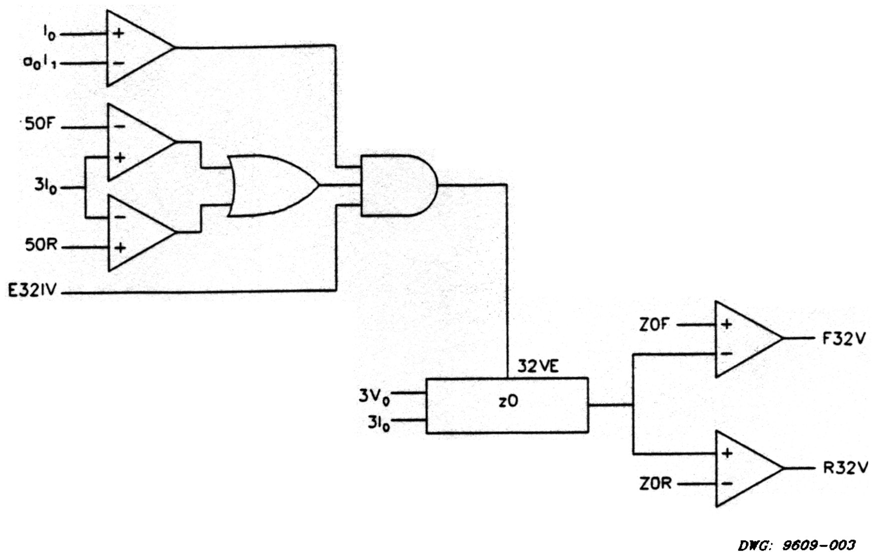

Figure 3: Simplified Block Diagram of the 32V Element

The 32V Enable bit, 32VE, controls this element. The 32VE asserts when all of the following conditions are true:

- The zero-sequence current, I_0, is greater than the positive-sequence current, I_1, times the a_0 factor ($I_0 > a_0 I_1$).
- The residual current, $3I_0$, is greater than the 50F or 50R sensitivity threshold.
- The E32IV programmable variable asserts (logical 1).

The GDR uses the status of the 32IE, 32QE, and 32VE bits in the relay priority logic to select the optimal directional element to run. This priority logic is explained later in this paper.

32Q AND 32V ELEMENT OPERATION FOR GROUND FAULTS

The way that the 32Q and 32V elements declare forward and reverse ground faults is similar. Let us examine the 32Q element operation for forward and reverse ground faults in a two-source system. Figure 4 shows the relay negative-sequence voltage, V_2, and negative-sequence current, I_2, for a ground fault at the remote terminal. I_2 is the current contribution from the local end. Notice that the primary current I_2 is flowing in at the CT polarity mark. At the relay location, $V_2 = - I_2 Z_{S2}$. If the negative-sequence impedance angles, $\angle Z_{S2}$ and θ_{L2}, are the same, the calculated z2 quantity is $z2 = - | Z_{S2} |$

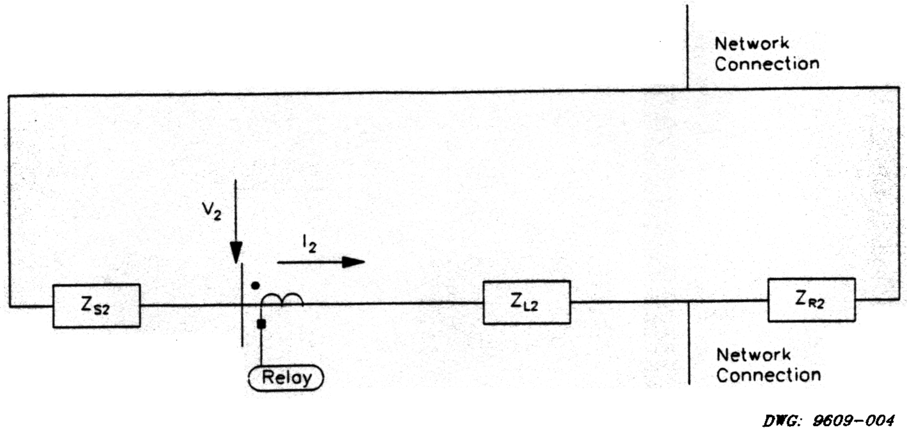

Figure 4: Relay Negative-Sequence Voltage, V_2, and Negative-Sequence Current, I_2, for a Ground Fault at the End-Of-Line

What are the relay analog input quantities and the z2 result for a ground fault behind the relay? Figure 5 shows the relay quantities, V_2 and I_2, for this reverse fault. The polarity of V_2 is the same as for forward ground faults. For reverse faults, the relay current I_2 is the contribution from the remote end. The primary current I_2 is flowing out at the CT polarity mark. At the relay location, $V_2 = I_2(Z_{L2} + Z_{R2})$. If the angles, $\angle(Z_{R2} + Z_{L2})$ and θ_{L2}, are the same, the calculated z2 is $z2 = | Z_{L2} + Z_{R2} |$.

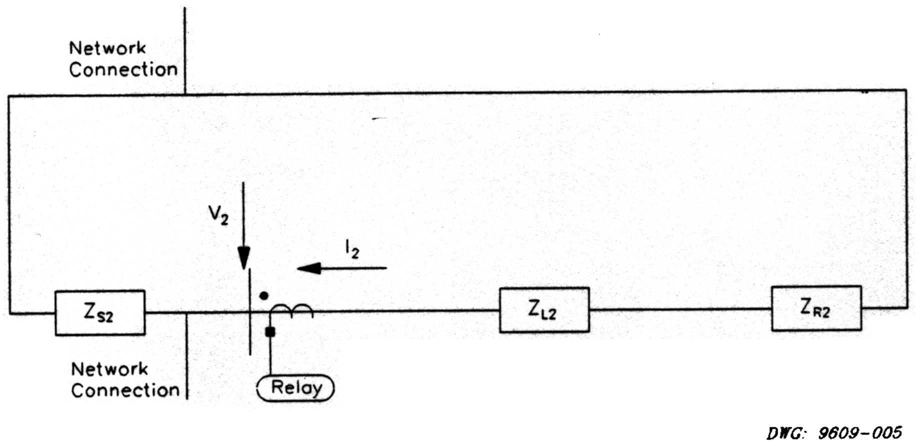

Figure 5: Relay Negative-Sequence Voltage, V_2, and Negative-Sequence Current, I_2, for a Ground Fault Behind the Relay

After the z2 calculation, the relay compares z2 against the forward and reverse thresholds (Z2F and Z2R, respectively) to make the fault direction declaration. The Z2F threshold must be greater than the maximum z2 result for forward faults (Z2F > z2). The Z2R threshold must be less than the minimum z2 result for reverse faults (Z2R < z2). The 32V element does identical comparison of z0 with thresholds Z0F and Z0R.

One of the advantages of the 32Q and 32V elements is that the element sensitivity does not depend on the voltage magnitude at the relay location. For this reason, the elements can be applied in very strong systems where the magnitudes of V_2 and V_0 are very small.

WHICH TO SELECT: NEGATIVE- OR ZERO-SEQUENCE?

The question of which element to select is a difficult one to answer for many applications, since the answer depends upon system configuration and fault location. The new GDR simplifies the answer: let the relay decide.

To see why choosing one element over the other is beneficial, let us look at the relay negative- and zero-sequence currents for the single-line-ground (SLG) fault on the two source system shown in Figure 6.

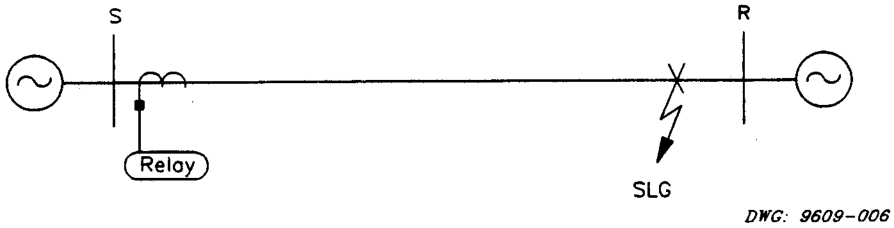

Figure 6: SLG Fault at the End-of-Line on a Two-Source System

Figure 7 shows the sequence network connections for this SLG fault. I_{2R} is the relay negative-sequence current, I_{0R} is the relay zero-sequence current, and I_{0T} is the total zero-sequence current. Equations 4 and 5 show how to calculate these I_{2R} and I_{0R} currents.

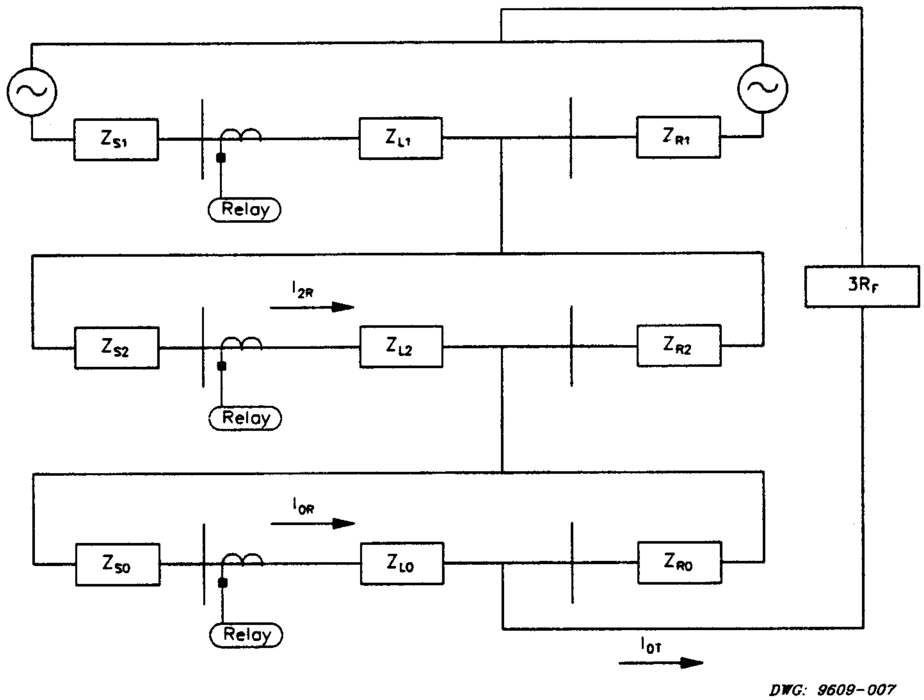

Figure 7: Sequence Network Connections for an SLG Fault at the End-of-Line. I_{2R} and I_{0R} are the Relay Negative- and Zero-Sequence Currents

$$I_{2R} = I_{0T}\left(\frac{Z_{R2}}{Z_{S2} + Z_{L2} + Z_{R2}}\right)$$ **Equation 4**

$$I_{0R} = I_{0T}\left(\frac{Z_{R0}}{Z_{S0} + Z_{L0} + Z_{R0}}\right)$$ **Equation 5**

From Equations 4 and 5, notice that the ratio of the remote source impedance to the total impedance of the corresponding sequence network determines which current is the biggest, I_{2R} or I_{0R}. These impedance ratios may change with system operating conditions.

For example, if Z_{R0} is small, the 32Q element can be more reliable than the 32V element since there is more I_2 than I_0 for the relay to utilize. Conversely, if Z_{R2} is very small, the 32V element may be more reliable than the 32Q element for similar reasons. If the remote negative- or zero-sequence source impedance (Z_{R2} or Z_{R0}) changes (due to switching), so do the magnitudes of I_2 and I_0.

Proper selection of the directional element may depend on system operating conditions.

Challenging Ground Directional Element Applications

Following are three examples of transmission line protection applications which benefit from this new GDR. These examples demonstrate the need for using the optimal directional element to match the system configuration.

Example 1: Delta-Connected Tapped Load Desensitizes the 32Q Element

The delta-connected tap load shown in Figure 8 requires that each relay use two separate ground fault directional elements to achieve maximum sensitivity: one for forward ground faults and the other for reverse ground faults. Each element must use different sequence quantities.

Let us examine the effect of this tap load on the directional elements of Relay 2 for the reverse SLG fault identified as SLG 1 in Figure 8. Figure 9 shows the sequence network connections for this fault.

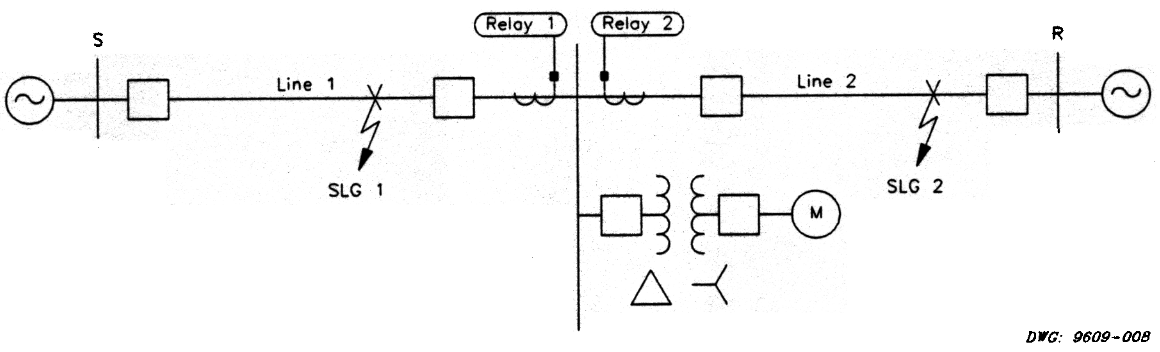

Figure 8: System One-Line Diagram Showing Tapped Load, SLG 1 Fault on Line 1, and SLG 2 Fault on Line 2 (faults are not simultaneous)

From Figure 9, notice that the load impedance shunts positive- and negative-sequence current around Relay 2 (but not Relay 1). This shunting of negative-sequence current by $Z_{\lambda 2}$ desensitizes the 32Q element of Relay 2 (but not Relay 1). For SLG 1, the ratio of I_{2R2} to I_{2R1} is less than one.

In the limit, as $Z_{\lambda 2}$ approaches infinity, this ratio approaches one. Equation 6 illustrates this ratio in terms of negative-sequence impedances:

$$\frac{I_{2R2}}{I_{2R1}} = \left(\frac{Z_{\lambda 2}}{Z_{\lambda 2} + Z_{2L2} + Z_{R2}} \right) \qquad \textbf{Equation 6}$$

Let $X = \dfrac{Z_{\lambda 2}}{(Z_{2L2} + Z_{R2})}$ and substitute X into Equation 6. Equation 7 shows the result of this substitution.

$$\frac{I_{2R2}}{I_{2R1}} = \frac{X}{(X+1)} \qquad \textbf{Equation 7}$$

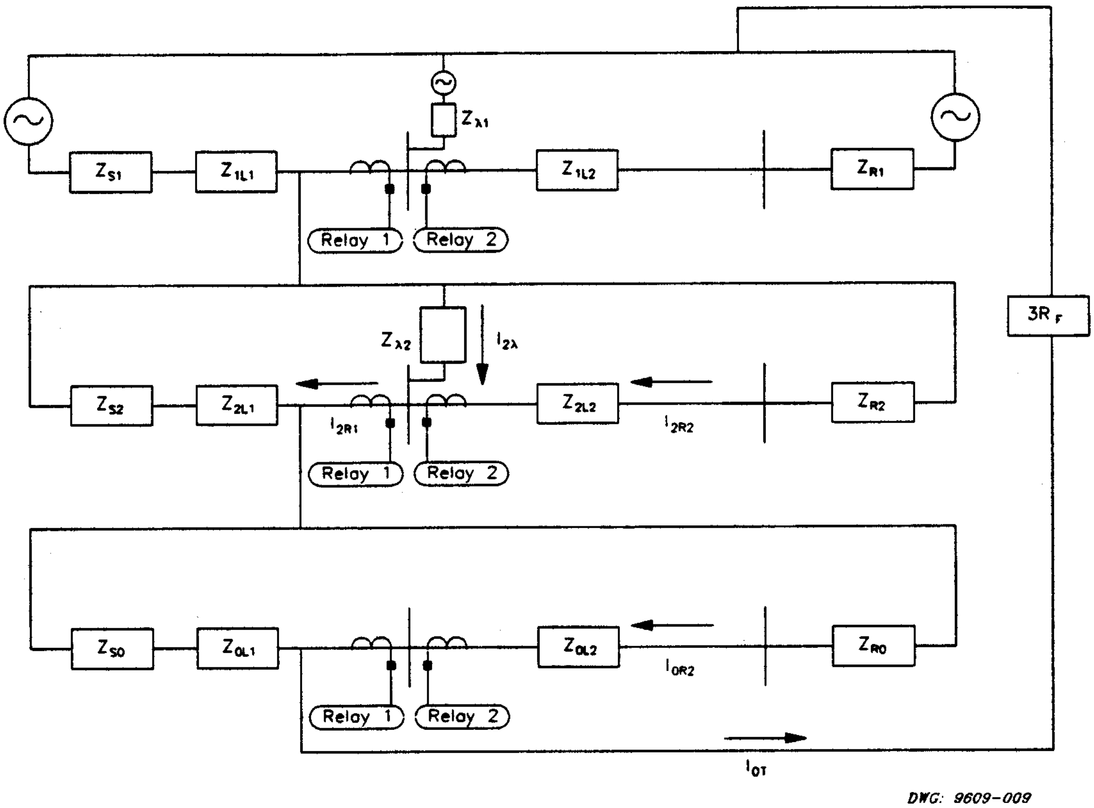

Figure 9: Sequence Network Connections for SLG 1 Fault

As X increases toward infinity, the ratio shown in Equation 7 approaches one, and the 32Q element sensitivities of Relays 1 and 2 are almost equal for SLG 1.

From Figure 9, notice that the zero-sequence impedance network does not include the load impedance. Because the load impedance does not shunt zero-sequence current, Relay 1 and Relay 2 see the same zero-sequence current.

To illustrate that there is more I_{0R2} than I_{2R2}, we can use Equations 8 and 9 to calculate the ratio of I_{2R2} to I_{0R2}.

$$I_{0R2} = I_{0T}\left(\frac{Z_{S0} + Z_{0L1}}{Z_{S0} + Z_{0L1} + Z_{0L2} + Z_{R0}}\right)$$ **Equation 8**

$$I_{2R2} = I_{0T}\left(\frac{Z_{\lambda 2}\left(Z_{S2} + Z_{2L1}\right)}{\left(Z_{S2} + Z_{2L1}\right)\left(Z_{\lambda 2} + Z_{2L2} + Z_{R2}\right) + Z_{\lambda 2}\left(Z_{2L2} + Z_{R2}\right)}\right)$$ **Equation 9**

Let us assume that Source R is a transformer such that $Z_{R0} = Z_{R2}$. To simplify this example further, assume that $Z_{S0} = 3Z_{S2} = Z_{0L1}$, $Z_{S2} = Z_{2L1}$, and $Z_{0L2} = 3Z_{2L2}$. Using these assumptions and the definition of X shown earlier, we can now calculate the ratio of I_{2R2} to I_{0R2} in terms of system impedances. Equation 10 shows this ratio.

$$\frac{I_{2R2}}{I_{0R2}} = \frac{X\left(6Z_{2L1} + 3Z_{2L2} + Z_{R2}\right)}{6Z_{2L1}\left(1 + X\right) + 3X\left(Z_{2L2} + Z_{R2}\right)}$$ **Equation 10**

Table 1 shows the I_{2R2}/I_{0R2} ratio for five different loads and five different combinations of line and source impedances for the system shown in Figure 9.

Table 1: I_{2R2}/I_{0R2} Ratio for Different X and System Impedance Values

X	Case 1	Case 2	Case 3	Case 4	Case 5
1	0.42	0.51	0.56	0.6	0.82
5	0.47	0.82	0.76	0.87	0.92
10	0.48	0.89	0.79	0.92	0.93
20	0.48	0.93	0.81	0.95	0.94
50	0.49	0.95	0.83	0.97	0.95

Case #	Z_{2L1}	Z_{2L2}	Z_{R2}
1	1 Ω	1 Ω	10 Ω
2	10 Ω	1 Ω	1 Ω
3	1 Ω	1 Ω	1 Ω
4	10 Ω	10 Ω	1 Ω
5	1 Ω	10 Ω	1 Ω

Note: All impedances have the same angle and are listed in secondary ohms.

From these observations, we see that the 32V element provides Relay 2 with more sensitivity than the 32Q element does for reverse SLG faults because I_{0R2} is bigger than I_{2R2}.

Before deciding to use the 32V element for all ground fault directional decisions, compare the 32V and 32Q element sensitivities at Relay 2 for an SLG fault near Source R on Line 2 (shown as SLG 2 in Figure 8).

For this example, let us assume that Source R is a strong zero-sequence source. Thus, Z_{R0} is smaller than the sum of the remaining zero-sequence impedances ($Z_{S0} + Z_{0L1} + Z_{0L2}$) shown in Figure 10. Equation 11 shows that I_{0R2} is small because Z_{R0} is small.

$$I_{0R2} = I_{0T}\left(\frac{Z_{R0}}{Z_{S0} + Z_{0L1} + Z_{0L2} + Z_{R0}}\right) \quad \textbf{Equation 11}$$

Although I_{0R2} is small, the 32V element still may indicate fault direction correctly. However, at Relay 2, I_{2R2} is greater than I_{0R2}. Thus, the 32Q element provides better sensitivity than the 32V element does for SLG faults in front of Relay 2 and should be used instead.

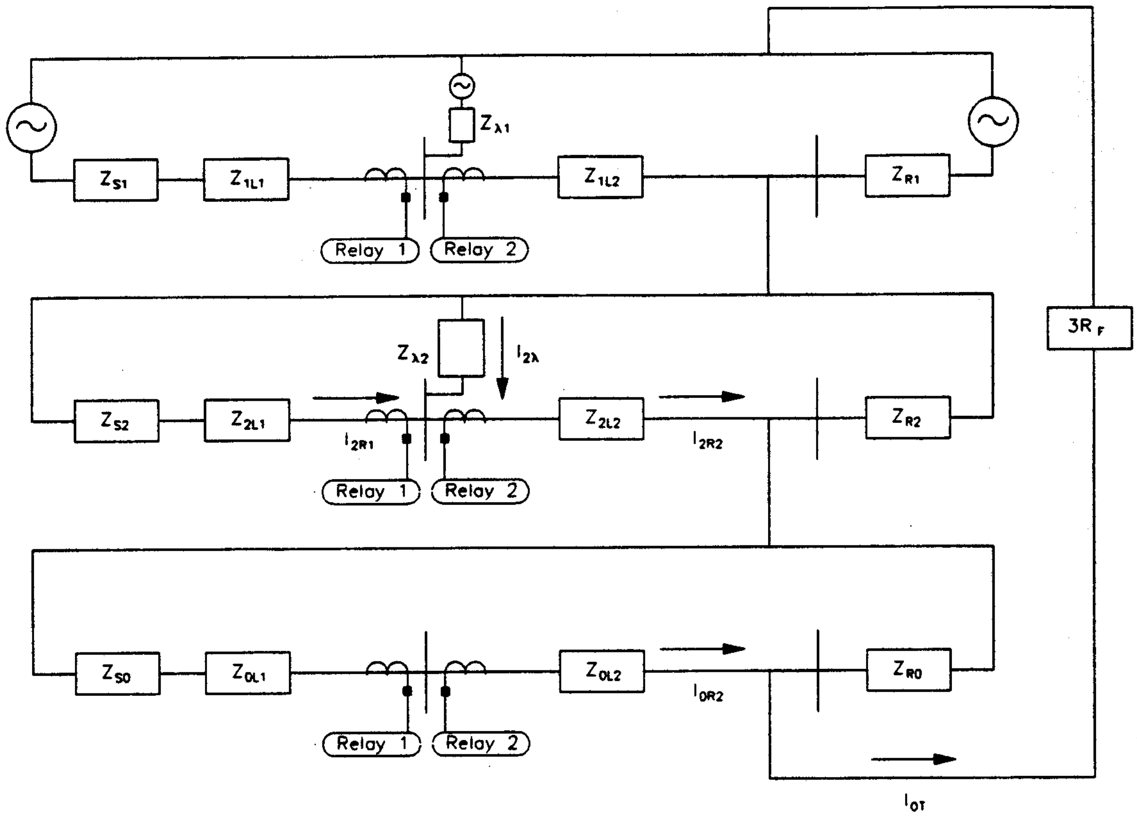

Figure 10: Sequence Network Connections for SLG 2 Fault

The information presented above shows that the optimum ground directional elements arrangement for Relays 1 and 2 is to have the 32V element make reverse ground fault decisions and have the 32Q element make forward fault directional decisions.

Example 2: Changing System Configuration Defeats the 32Q Element

Consider next the looped station application shown in Figure 11. In this example, assume all zero-sequence sources are strong sources of equal strength. Under normal operation, the station bypass switch is open, and Breakers A and B are closed. With this station configuration, it is very desirable to use the 32Q element for all directional decisions since this element delivers more sensitivity than the 32V element does for remote ground faults (due to the infeed from the strong zero-sequence remote sources).

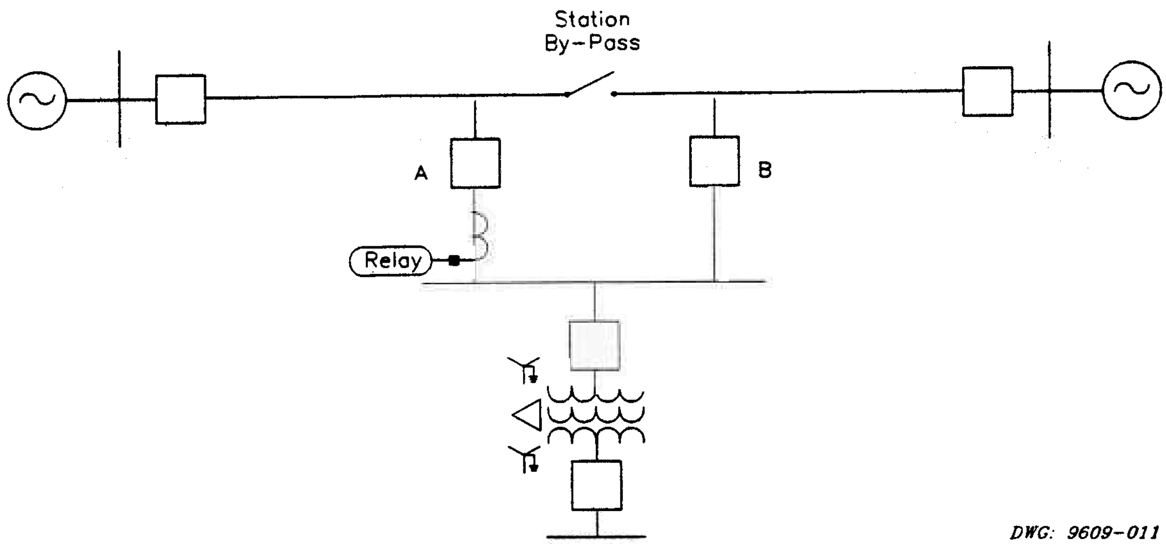

Figure 11: Looped Station/Tapped Station System One-Line Diagram

After closing the station bypass switch (while keeping Breaker A closed), we can isolate Breaker B and still deliver power to the now tapped station. With the station configured as a tap, there is only a zero-sequence source behind the relay for forward faults. The 32Q element is now defeated for forward SLG faults due to the lack of negative-sequence current available to the relay. For this station configuration, the only viable ground directional element choices are either 32V or 32I. The 32I element requires a reliable polarizing source. If this source is not available, we must then use the 32V ground directional element.

With the station configured as a tap, it is still important for the directional element of the relay shown in Figure 11 to declare fault direction. For example, given an SLG fault near either line end, the zero-sequence source of the tapped load desensitizes the ground protection of the remote terminal. By tripping Breaker A, we remove the tap zero-sequence infeed.

For the relay shown in Figure 11, the ideal directional element arrangement is to use the 32Q element when the station is looped and use the 32V (or 32I) element when the station is configured as a tap.

Example 3: Removal of the Zero-Sequence Polarizing Source

Figure 12 shows a system with two sources and Substation T between them. Substation T has a wye-delta-wye transformer. The wye transformer connections are solidly grounded. Let us analyze the performance of Relay 1 located at Substation T when the transformer is in and out of service.

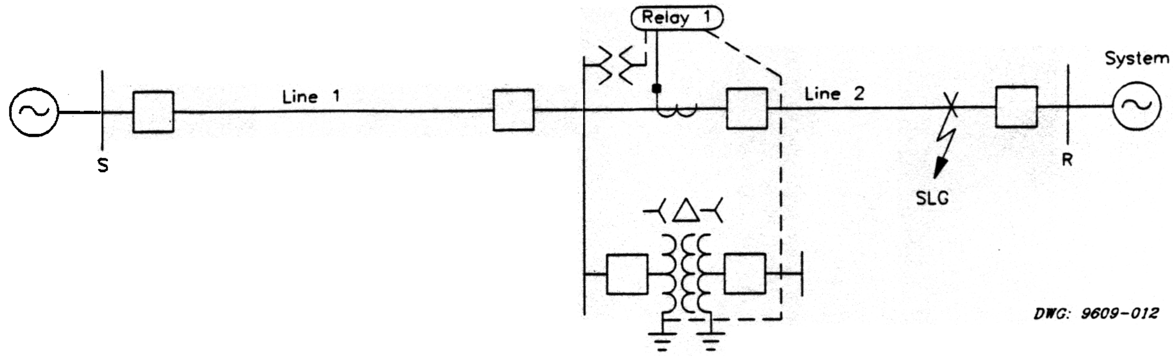

Figure 12: The 32I and 32Q Elements Provide Reliable Fault Direction Declarations

The sequence network connections (Figure 13) show the relay negative-sequence current, I_{2R}, the relay zero-sequence current, I_{0R}, the transformer zero-sequence current, I_{0X}, and the total zero-sequence current, I_{0T}, for an SLG fault at the end of Line 2 when the transformer is in service. For this operating condition, we can calculate I_{2R} and I_{0R} using Equations 12 through 15.

$$I_{2R} = I_{0T}C_2 \qquad \textbf{Equation 12}$$

$$C_2 = \frac{Z_{R2}}{Z_{S2} + Z_{2L1} + Z_{2L2} + Z_{R2}} \qquad \textbf{Equation 13}$$

$$I_{0R} = I_{0T}C_0 \qquad \textbf{Equation 14}$$

$$C_0 = \frac{Z_{R0}}{\frac{(Z_{S0} + Z_{0L1})Z_{T0}}{Z_{S0} + Z_{0L1} + Z_{T0}} + Z_{0L2} + Z_{R0}} \qquad \textbf{Equation 15}$$

C_2 and C_0 are the negative- and zero-sequence current distribution factors. The C_0 factor depends on the transformer impedance Z_{T0}. As Z_{T0} approaches zero, C_0 approaches $Z_{R0}/(Z_{0L2} + Z_{R0})$, while C_2 does not change. If the Z_{T0} impedance is such that C_0 is greater than C_2, then I_{0R} is going to be greater than I_{2R}.

When I_{0R} is greater than I_{2R}, the 32I element detects ground faults with higher fault resistance than does the 32Q element. When the transformer is in service, the transformer grounding connections provide a reliable zero-sequence polarizing source.

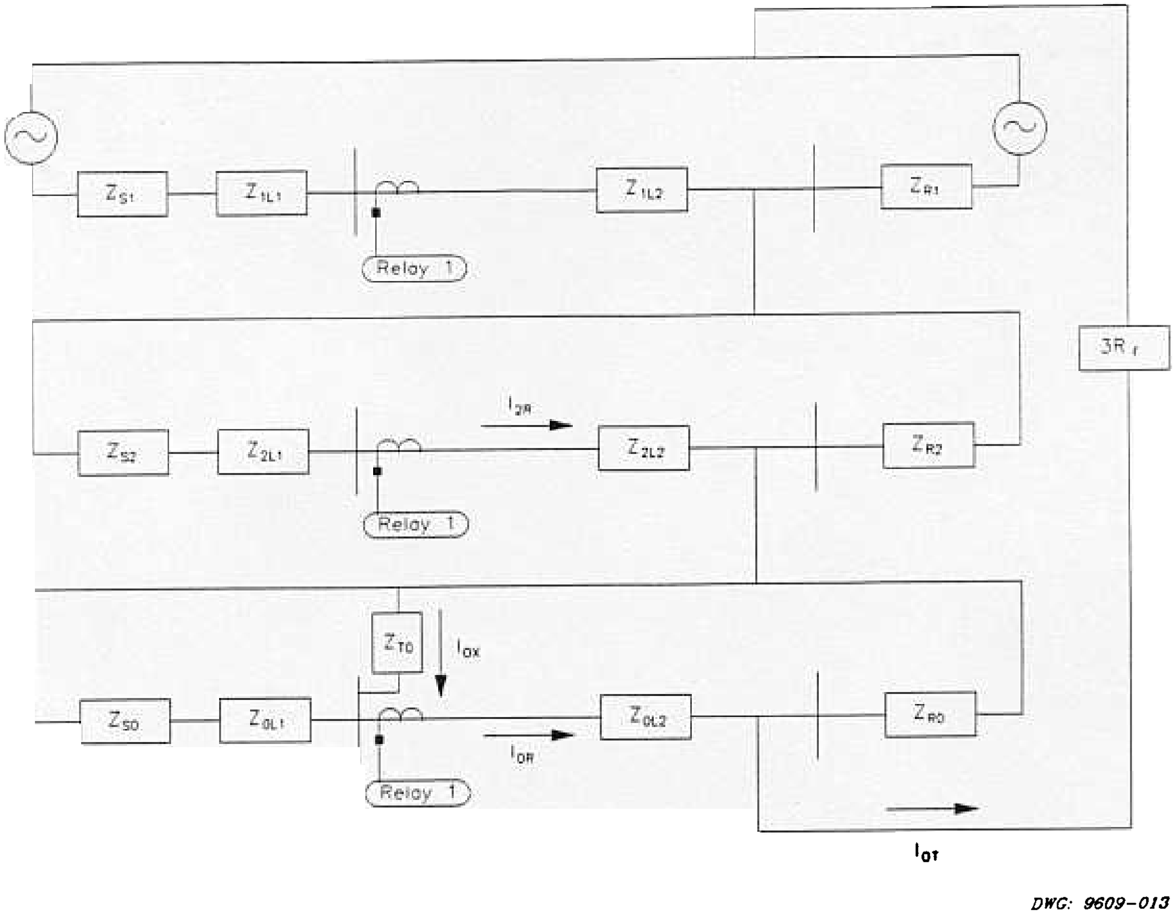

Figure 13: I_{0R} is Greater Than I_{2R}, Due to the Zero-Sequence Current Contribution from the Transformer, I_{0X}

What happens if the transformer at Substation T is out of service? Removing the transformer from service opens the zero-sequence polarizing-current path (Figure 14). We cannot use the 32I element with the transformer out of service.

If the zero- and negative-sequence source impedances have the same values, I_{2R} is going to be greater than I_{0R} for an end-of-line SLG fault because Z_{0L1} is greater than Z_{2L1}. When I_{2R} is greater than I_{0R}, the 32Q element is more reliable than the 32V element.

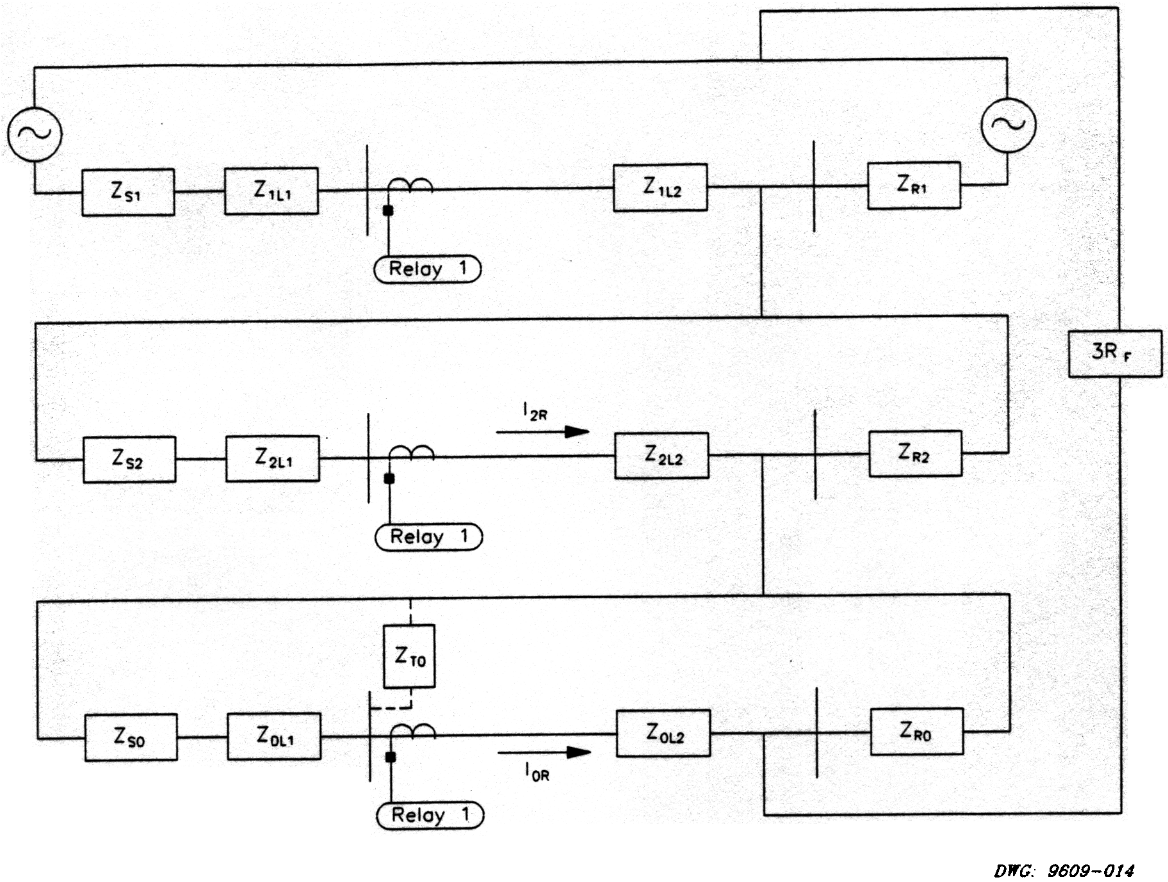

Figure 14: When the Transformer is Out of Service, I_{2R} is Greater Than I_{0R} Because Z_{0L1} is Greater Than Z_{2L1}

Assuming that the relay has both current- and voltage-polarizing sources, the ideal solution in this application is to select:

32I when the transformer is in service.

32Q or 32V, depending on the magnitudes of I_{2R} and I_{0R}, when the transformer is out of service.

Selecting The Optimal Directional Element

As explained in previous sections and examples, each of the three directional elements (32I, 32Q, 32V) has advantages and disadvantages for various system conditions. The relay selects the optimal directional element for a particular system configuration according to the selected processing sequence and the enable variables (32IE, 32QE, 32VE).

Selecting Among the Three Directional Elements

The assignments in the EL1G, EL2G, and EL3G variables determine the directional element processing sequence. Assign 32I, 32V, or 32Q elements to these variables in the desired sequence. For example, assigning EL1G=32I, EL2G=32Q, and EL3G=32V sets the element processing sequence as 32I first, 32Q next, and 32V last. OFF is a setting option for any priority variable. OFF allows you to defeat a particular directional element when the required element inputs are not available or you simply do not want to use a particular element.

Figure 15 shows the GDR processing sequence. The relay looks first at the EL1G variable. If EL1G is not set to OFF, the logic checks the enable variable of the element assigned to the EL1G priority variable. If the enable variable asserts (indicating healthy inputs for that element), the relay uses the output of that element to declare fault direction. If EL1G=OFF or if the enable of the selected directional element does not assert, the relay logic checks the next priority variable EL2G, and repeats the same process.

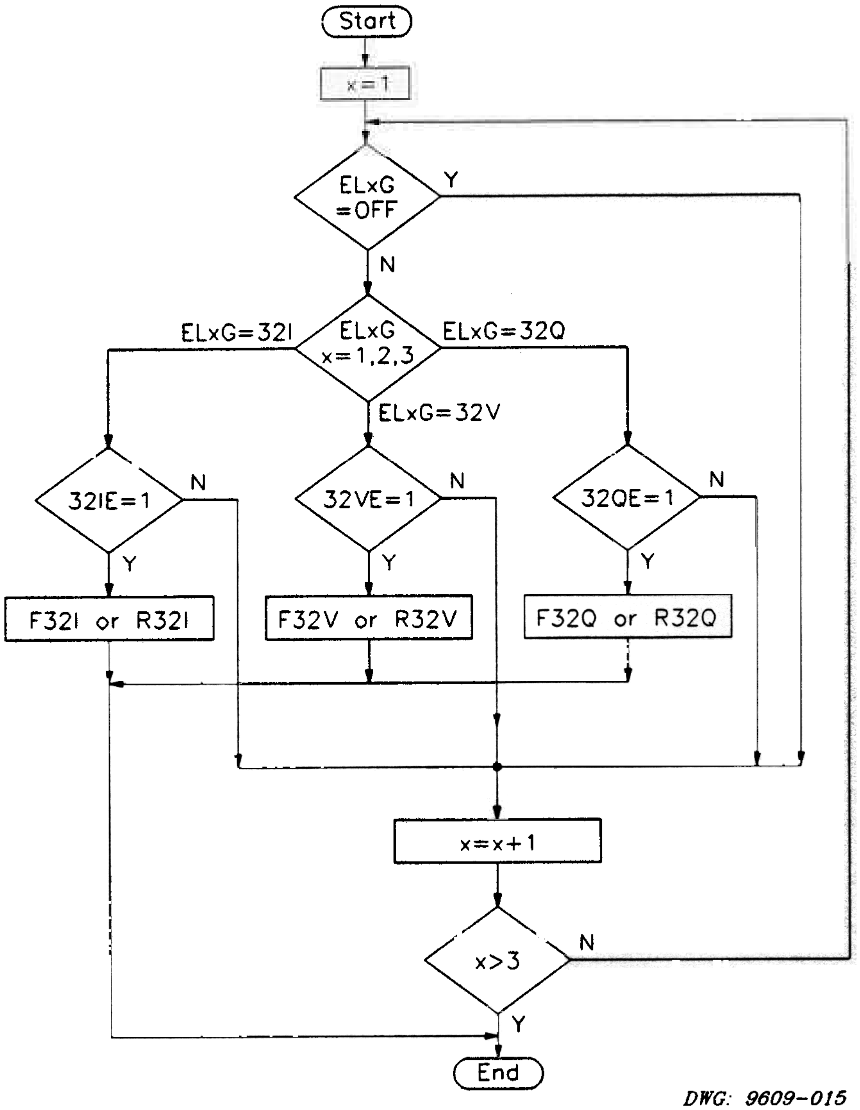

Figure 15: Ground Directional Relay Processing Sequence

Figure 16 shows the processing sequence when EL1G=32I, EL2G=32Q, and EL3G=32V. This sequence works for the majority of system configurations.

With this processing sequence, the relay uses 32I when I_{POL} and $3I_0$ are above the sensitivity thresholds. If the currents do not exceed these thresholds, the 32IE variable does not assert. The relay then proceeds to the 32Q element and checks the status of 32QE. If 32QE does not assert, the relay next checks the status of 32VE. The relay uses the k factor in the 32QE variable to select the most reliable sequence current, I_2 or I_0, in making the directional decision.

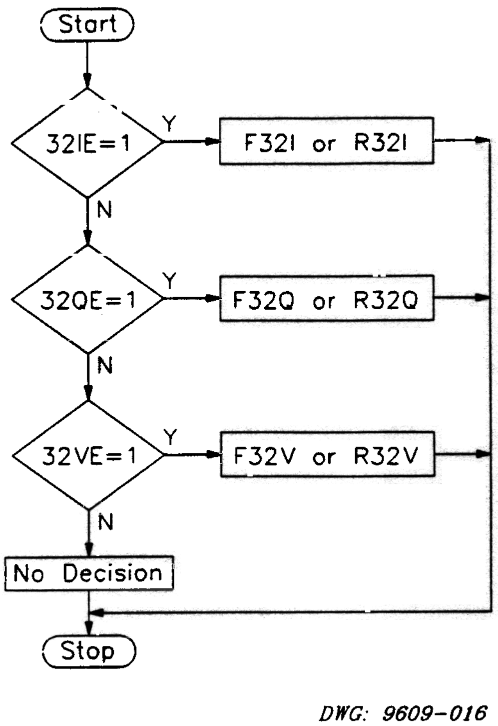

Figure 16: Ground Directional Relay Processing Sequence When EL1G=32I, EL2G=32Q, and EL3G=32V

GROUND DIRECTIONAL RELAY AUTOMATIC SETTING MODE

In the automatic setting mode, the GDR provides settings for the 32Q and 32V directional elements. This feature simplifies the relay setting procedure.

The relay selects the most suitable settings from given system parameters. For example, the relay uses the line impedance parameters to set the Z2F, Z2R, Z0F, and Z0R thresholds used in the 32Q and 32V elements.

Figure 17 shows the calculated sequence impedances, z2 and z0, for forward and reverse faults. If we assume infinite sources at both line ends, the line impedance separates the calculated impedances for forward and reverse faults. To safely discriminate between forward and reverse faults, we can set the forward and reverse thresholds at one-half of the corresponding sequence line impedance. The relay sets Z2F to $Z_{L1}/2\ \Omega$, and Z2R to $Z_{L1}/2+0.1\ \Omega$. Z0F and Z0R are set the same as Z2F and Z2R except the relay uses the zero-sequence line impedance, Z_{L0}, instead of the positive-sequence line impedance, Z_{L1}. These voltage directional element threshold settings guarantee that the relay makes the correct directional decisions for any source switching conditions.

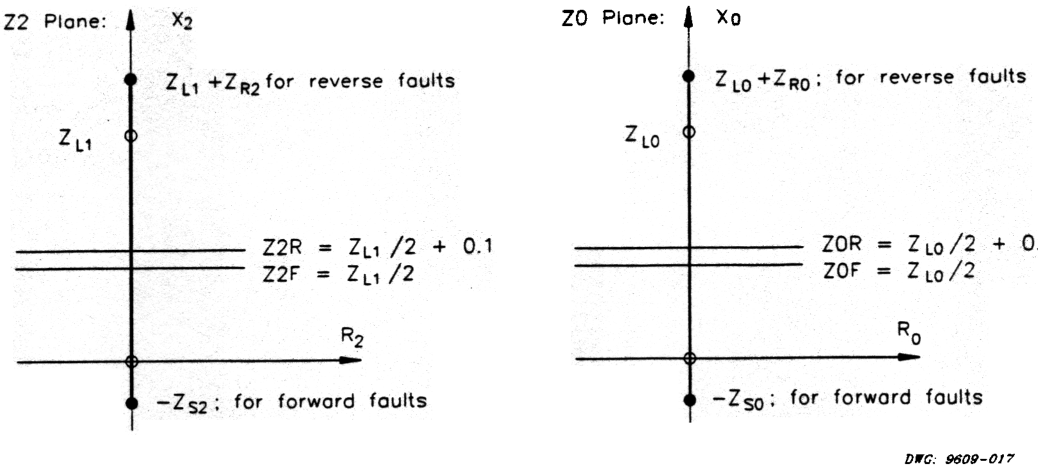

Figure 17: Zero- and Negative-Sequence Impedances for Forward and Reverse Faults

The relay automatic mode sets the a_0 and a_2 factors to 0.1. These conservative settings make the directional elements secure under almost all transmission line configurations while allowing sensitive settings for 50F and 50R. The relay automatic selection mode sets 50F to 0.5 A and 50R to 0.25 A. The 50R setting is more sensitive for reverse faults than forward faults. For example, Directional Comparison Blocking (DCB) schemes require more sensitive reverse elements than forward elements.

SUMMARY

1. All reliable directional elements require supervision. In this paper, we discuss the supervision logic required for ground directional elements and how the relay uses the outputs of this logic to select the optimal ground directional element to match system conditions.

2. Each of the directional elements included in the new GDR has advantages and disadvantages. For example, the zero-sequence directional elements must be blocked and negative-sequence directional elements enabled during zero-sequence source isolation conditions with zero-sequence mutual coupling.

3. Delta-connected tap-load can severely desensitize a negative-sequence directional element for reverse ground faults. For these applications, the 32V element is more sensitive than the 32Q element because I_0 is greater than I_2 at the relay location.

4. For these same delta-connected tap-load applications, when the forward remote terminal is a strong zero-sequence source, a negative-sequence directional element is the best choice for forward ground fault detection because I_2 is greater than I_0 at the relay location.

5. When using the 32I element, the proper polarizing source must be available to the relay. If the source is not available, the GDR automatically selects the next directional element.

6. Selecting a fixed directional element for all system conditions may sacrifice protection reliability and sensitivity. This new GDR element concept overcomes the restriction of selecting quantities from one sequence network to detect all ground faults.

7. Automatic directional element selection and settings make the relay easy to apply.

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Note: U.S. Patents cover the ground directional element discussed in this paper.

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