Ground Fault Protection for an Ungrounded System

EE5223 Electrical Power System Protection

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Final Draft 4/26/2013

Executive Summary

The purpose of this report is to demonstrate the knowledge of key concepts presented in EE5223 Electrical Power System Protection. This project includes the development of a ground fault protection scheme for an ungrounded system, starting from the basic concepts presented in the course textbook and extending into a detailed implementation and simulation results.

The ground fault protection scheme developed involves an overvoltage relay, connected across broken delta-connected VTs, that monitors zero sequence voltage. Sequence networks and calculations are used to explain the setting of the overvoltage threshold for a single line-to-ground fault. Other fault types are also discussed in terms of what the overvoltage relay will be observing in each case. Implementation details will include ballast resistance selection and relay settings. Also, the common practice of connecting indicating lamps phase-to-phase to determine the faulted phase(s) is modified to provide remote indication. The results of an ASPEN simulation for a given ungrounded system are discussed and compared to hand calculations generated for various fault types. Finally, a conclusion of the system performance is included with directions for future work.

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Statement of Contributions

This project was contributed to by both authors and team members, Adam Heskitt and Hillori Mitchell.

Signed,

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Introduction

The purpose of this term project is to develop a ground fault protection scheme for an ungrounded power system that will ensure adequate protection for a line-to-ground fault and to study how this protection scheme reacts to other fault types (double line-to-ground, line-to-line and three phase). The parameters of this system are based on a client's relaying design report. The protection scheme includes a voltage transformer (VT) connected in wye-grounded to broken-delta configuration and a Basler 59N overvoltage relay. Relay settings and configuration for the overvoltage relay will be determined, as well as the sizing requirements of a ballast resistance. Further, a remote indication scheme will be developed that replaces traditional indicating lamps. Hand calculations will be completed for all fault types in the given system and used to verify the ASPEN OneLiner model of the system.

Background

System Grounding Principles

Proper system grounding is essential in protecting against transient overvoltages that result in significant damage to equipment and/or people working at the substation. Currently, there are various system grounding principles that can be applied and are differentiated by the impedance or lack thereof between the neutral point of the three-phase system and ground. In a high-impedance grounded system a high resistance or inductance is inserted into the ground connection. This limits fault current levels or even negates system capacitance to largely eliminate fault current, respectively. Low-impedance and solidly grounded systems have relatively higher fault currents, but facilitate easier detection of ground faults due to voltage drop along the line. This project focuses on a system that has no intentional ground connection, known as an ungrounded system. Although there is no intentional ground connection the neutral is still coupled to ground via system capacitance [3].

For a ground fault on an ungrounded system, the fault currents remain close to zero as the faulted phase voltage approaches the same potential as ground. The unfaulted phase voltages increase with respect to ground and resulting in an overvoltage condition. These properties lead to a unique method for detecting and protecting against ground faults for an ungrounded system.

Ungrounded System Ground Fault Detection

An example of an ungrounded system is shown in Figure 1 below. The secondary windings of the transformer are connected in delta configuration and the system feeds an ungrounded load. For a single line-to-ground fault, the sequence diagrams would be connected in series as shown. Since the delta-connected transformer represents an open circuit in the zero-sequence diagram, the only path for the fault current to flow through is the system capacitance. This impedance is very high relative to the series system impedances, so the fault current and negative sequence voltage approaches zero while the positive sequence (source voltage) and zero sequence voltages are equivalent [1].

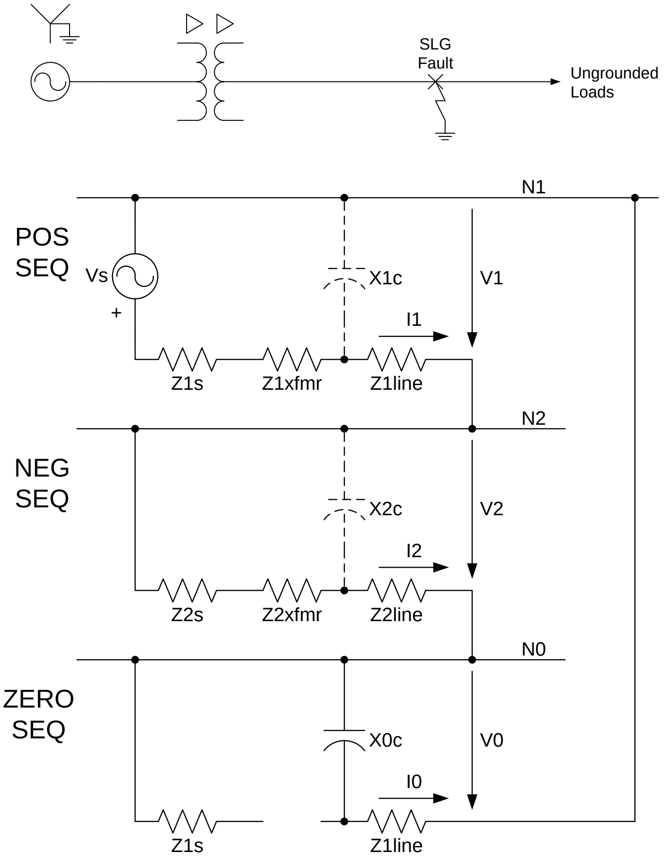

Figure 1: Ungrounded System and Sequence Diagram

Since the fault current is low, a typical ground overcurrent relay is inefficient for detecting ground faults in an ungrounded system. Instead, detection of overvoltage conditions must be relied on to indicate a ground fault. The sequence and phase voltages for a single line-to-ground fault in the same ungrounded system are shown in Figure 2 below. It can be observed that the faulted phase voltage collapses to zero at the fault while the unfaulted phase voltages increase to √3 times their original magnitude, equal in magnitude to the line-to-line voltages. Further, the angle between the two unfaulted phase voltages decreases to 60°. It is interesting to note that the phase-to-phase voltages remain unchanged, which facilitates the continued operation of ungrounded loads. However, the increased phase-to-ground voltages on the unfaulted phases predicate increased insulation levels versus a grounded system. Lastly, the phasor diagrams show that the neutral-to-ground voltage magnitude during a fault approaches that of the phase voltage under typical, unfaulted conditions. This development is the foundation for the following fault detection philosophy and is discussed in [1] and [3].

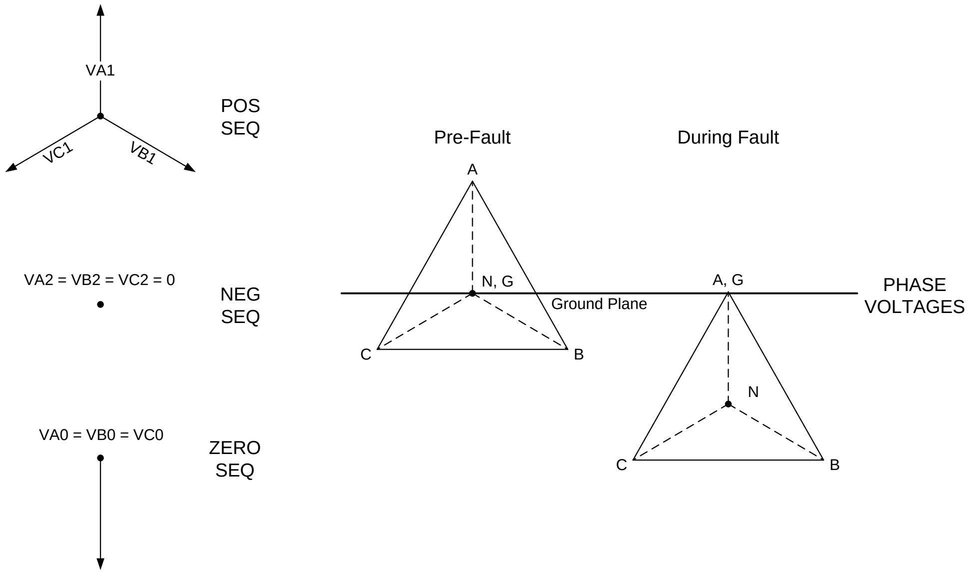

Figure 2: Sequence and Phase Voltages

The obvious approach to detect ground faults in such a system would then be to look for these voltage characteristics. Specifically, by connecting the phase voltages in series in a broken delta connection, the voltage at the break in the delta can be monitored. During a fault, this voltage will increase to three times the regular phase-to-neutral voltage, as shown in Equation 1 below. Accordingly, an overvoltage relay can be connected across the broken delta-connected auxiliary VTs to detect a ground fault.

$$\begin{aligned}
&\boldsymbol{V_{AG} = V_{AN} + V_{NG} = 0} \\
&\boldsymbol{V_{BG} = V_{BN} + V_{NG} = \sqrt{3}\mathrm{V_{LN}}\angle -150^\circ} \\
&\boldsymbol{V_{CG} = V_{CN} + V_{NG} = \sqrt{3}\mathrm{V_{LN}}\angle\ 150^\circ} \\
&\boldsymbol{V_{relay} = V_{AG} + V_{BG} + V_{CG} = 3\mathrm{V_0} = 3\mathrm{V_{LN}}\angle\ 180^\circ}
\end{aligned}$$

Equation 1: Broken Delta Voltage

Existing Voids and Resulting Opportunities

The issues associated with overvoltage ground fault detection for ungrounded system are well studied, with foundational papers dating back to at least 1951 [8]. In the specific case of using a single input overvoltage relay connected across broken delta-connected VTs, most existing voids in capability are inherent to the configuration and system grounding type. For example, detecting where the fault occurs on the faulted line (line end or close in) is difficult due to the low fault current which leads to a constant fault voltage along the line [3]. Similarly, faults other than single line-to-ground are not easily detected by this overvoltage relay. Some authors look past the single line-to-ground fault case and instead develop overcurrent detection and protection methods for a second simultaneous fault, which is typically the more severe fault case in an ungrounded system [6]. Further work is ongoing to study the effects of ferroresonance in VT circuits, which involves sizing the ballast resistance connected in parallel with the overvoltage relay to limit resonance between VT inductance and system capacitance [11], [13], [14]. However, practical rules-of-thumb have long been developed on this subject based on engineering experience [12].

Another existing void is detecting which phase is faulted to ground. A common method used is to connect indicating lamps line-to-line across the broken delta-connected VTs. In this scheme, a darkened lamp would indicate a fault on that phase. This method is limited to local observation, which is only useful if the system is designed to continue to operate for some time in the case of a single line-to-ground fault. Most modern systems would also have a numerical relay monitoring each phase, which could provide the remote communication needed. However, some utilities and engineers still prefer to use the single relay method [15]. Another fault location method involves connecting a signal generator to the zero sequence winding of the transformer [2]. When a fault occurs the relay initiates the signal generator to send a current through the circuit that will then return through the ground network of the fault. This signal allows the relay to determine the electrical distance that the fault occurs away from the relay, thus locating where the fault occurred in the system. A review of the journal article explaining this technique can be found in Appendix I.

The opportunity to develop a method of identifying the faulted phase in an ungrounded system and communicating information to a remote system, without resorting to three-phase voltage sensing by a numerical relay or signal injection, was embraced by the authors. In addition, the voltage sensed by the relay during other types of faults (double line-to-ground, line-to-line, three-phase) will be investigated in order to better understand the system and overvoltage relay reactions.

Proposed Approach and Application

Overview

This report involves the development and implementation of remote indicators in a broken delta ground fault protection scheme for an ungrounded power system. Also, the voltage sensed by an overvoltage relay connected to the broken delta will be explored for each fault scenario and normal operation.

An example ungrounded system will be defined along with its parameters for ASPEN simulation. Next, VT and relay connections will be illustrated, using the Basler 59N as an example. Relay settings and ballast resistance will be recommended based on the system parameters. The implementation details of the remote indicators will be explained, and the testing methodology to explore relay performance during all fault cases and normal operation will be explored. Finally, the results of these tests will be presented.

Example System Development

The first step of implementation for this project is to define a system configuration for study. This system is based on a typical utility's distribution substation, with a two-winding, 120-4.8 kV delta-delta connected transformer. The system one-line diagram is shown in Figure 3 and the system parameters for use in ASPEN are given in Table 1.

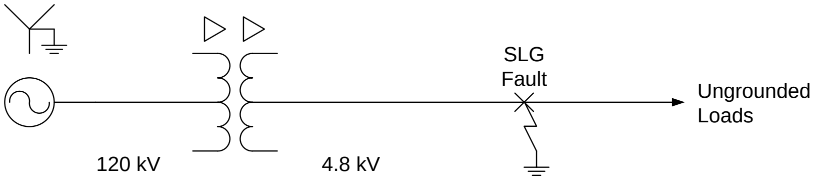

Figure 3: Ungrounded System One-Line Diagram

Table 1: System Parameters

Source (Generator)	
Subtransient	0.27351+j2.51826 Ω
Transient	0.27351+j2.51826 Ω
Synchronous	0.27351+j2.51826 Ω
Neg. Sequence	0.27357+j2.51776 Ω
Zero Sequence	2.8823+j5.62207 Ω
Neutral Imped.	0 Ω
Short Ckt. MVA	3858.4 MVA

Load (Ungrounded)	
Constant Power	10 MW

Transformer	
R	0 Ω
X	.08 Ω
R0	0 Ω
X0	.08 Ω
MVA (per ø)	24 MVA

Line	
R	0 Ω
X	0.1 Ω
R0	0 Ω

X0	0.1 Ω
L	10 mi

Next, the VT and relay configuration are developed based on the system three-line diagram, shown below in Figure 4. The VT ratio is specified to be 4800/120 V, which provides 69.3 V phase-to-neutral voltage to the VT secondaries in normal operating conditions. The total broken delta voltage input to the relay during a ground fault is then 3 x 69.3 V = 208 V, based on Equation 1. Therefore, the relay should be set to a threshold below this value so that the relay will trip when the system voltage increases above the threshold point.

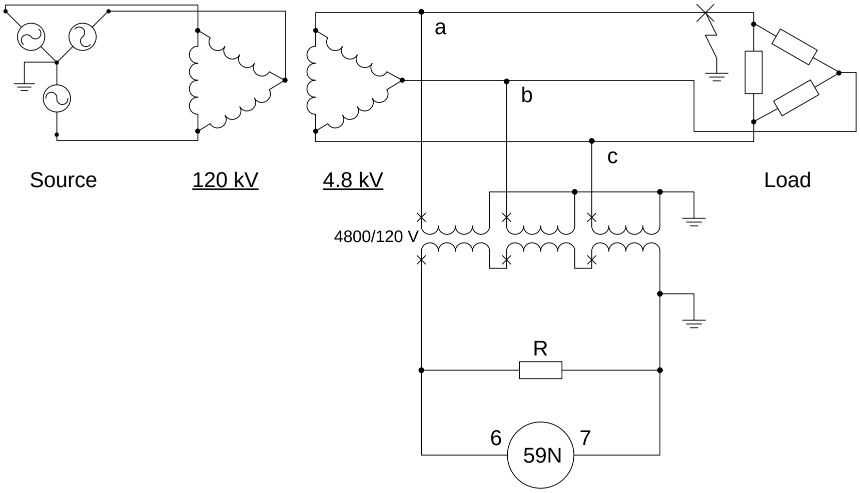

Figure 4: System Three-Line Diagram

Implementation

In order to size the ballast resistance, a method presented in [12] was followed. This method involves sizing the resistor so that the current draw is equal to the continuous current rating of the transformer bank. The VTs chosen in this example project were General Electric type JVW-4, which have a thermal rating of 1500 VA and a voltage ratio of 40:1. With a per-phase secondary voltage of 4800 V/40 = 120 V during a fault, the VT secondary current is then given by Equation 2.

$$\mathbf{I}_{\mathbf{VT,sec,rated}} = \frac{\mathbf{VA}_{\mathbf{VT,1phase}}}{\mathbf{V}_{\mathbf{sec}}} = \frac{\mathbf{1500}}{\mathbf{120}} = \mathbf{12.5}\ \boldsymbol{A}$$

Equation 2: VT Continuous Current Rating

During the fault, the voltage across the ballast resistance will be the same as that across the relay, 208 V according to Equation 1. Therefore the ballast resistance should be 208 V/12.5 A = 16.6 Ω. Since the ground fault might remain for some time, the continuous power rating of the resistor should be at least 208 V x 12.5 A = 2.6 kW.

The Basler BE1-59N Ground Fault Overvoltage Relay is made to address ground fault protection in an ungrounded or high resistance grounded system. Although its main function is to sense overvoltage across the ballast resistance as shown in Figure 4, it also has an optional undervoltage function. The front and rear panels of the relay are shown below in Figure 5, with the terminals connected for this application circled. These figures were provided in [9].

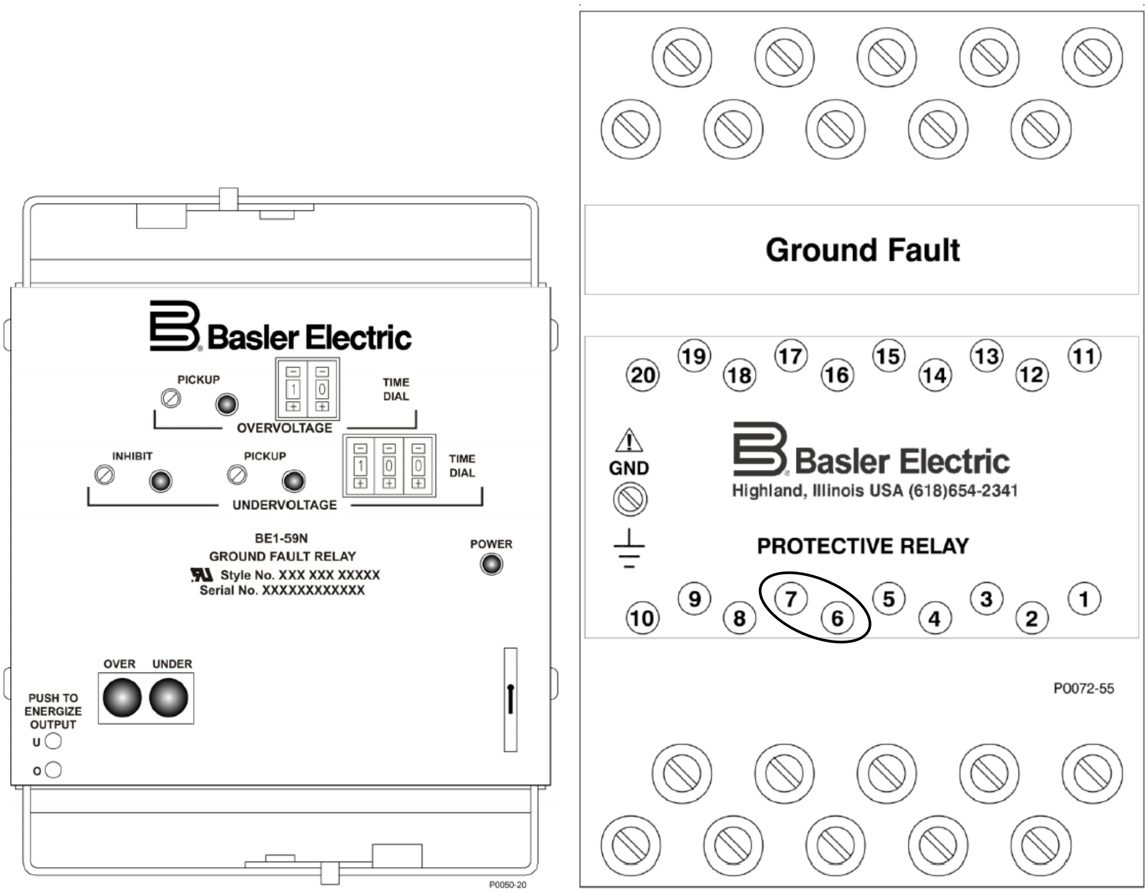

Figure 5: BE1-59N Front and Rear Views

The 59N relay is connected in parallel to the ballast resistance and broken delta VT. The selection of a remote indicator device and its connections to the circuit are then considered. The device chosen for this role is an ABB CVD relay [5]. This relay monitors a voltage across its inputs and closes or opens a contact when the voltage crosses a preset value. In order to replicate the function of local indicating lamps, one of these relays will be connected across each of the three phase VTs secondaries, as shown in

Figure 6. Their output contacts will then be connected to a remote terminal unit or SCADA device to report back to a remote operator.

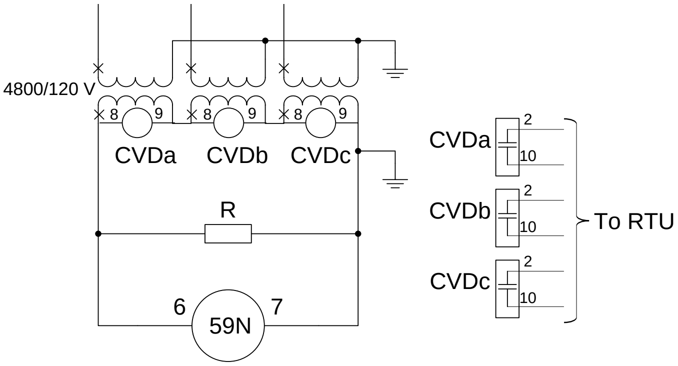

Figure 6: CVD Relay Connections

The operation of the protection scheme designed above will be tested for each fault type using ASPEN. Since OneLiner deals with power system voltages and does not directly simulate control voltages such as that of a VT secondary, the turns ratio is factored in to compare hand calculation results to those of the simulation. While the development of Equation 1 for a single line-to-ground fault was previously provided in the background, hand calculations for other fault types in the ungrounded system are attached in Appendix II. These calculations provide the expected relay voltages for other faults types to be compared with ASPEN results. The following section presents the resulting VT phase voltages and relay voltage for each fault scenario.

Results

This project demonstrated the development of a protection scheme for an ungrounded system through the use of broken delta-connected VTs, a Basler 59N overvoltage relay, and ABB CVD relays as fault indicators. Voltages during all four types of faults were taken from the ASPEN model and are located in Appendix III. To ensure the proposed protection system would operate correctly, hand calculations were performed. These calculations can be found in Appendix II and a summary of the voltages is shown in Table 2 below. Although the ASPEN software does not provide a method for measuring the voltage seen by the relay, the fault voltages of the bus were confirmed to match the hand calculations.

Table 2: Fault Voltage Hand Calculations

Normal Operation Voltages			
Phase A	*Phase B*	*Phase C*	*Relay*
$V_{AG} = \frac{4800}{\sqrt{3}} \angle 0° = 2771 \angle 0°$ V	$V_{BG} = \frac{4800}{\sqrt{3}} \angle -120° = 2771 \angle -120°$ V	$V_{CG} = \frac{4800}{\sqrt{3}} \angle 120° = 2771 \angle 120°$ V	
$V_A = \left(\frac{120}{4800}\right) \cdot V_{AG} = 69.3 \angle 0°$ V	$V_B = \left(\frac{120}{4800}\right) \cdot V_{BG} = 69.3 \angle -120°$ V	$V_C = \left(\frac{120}{4800}\right) \cdot V_{CG} = 69.3 \angle 120°$ V	$V_R = V_A + V_B + V_C = 0$ V
Line-to-Ground Fault			
$V_{AG} = 0$ V	$V_{BG} = 4800 \angle -150°$ V	$V_{CG} = 4800 \angle 150°$ V	
$V_A = 0$ V	$V_B = 120 \angle -150°$ V	$V_C = 120 \angle 150°$ V	$V_R = 208 \angle 180°$ V
Line-to-Line Fault			
$V_{AG} = 2771 \angle 0°$ V	$V_{BG} = 1386 \angle 180°$ V	$V_{CG} = 1386 \angle 180°$ V	
$V_A = 69.3 \angle 0°$ V	$V_B = 34.6 \angle 180°$ V	$V_C = 34.6 \angle 180°$ V	$V_R = 0$ V
Double Line-to-Ground Fault			
$V_{AG} = 4157 \angle 0°$ V	$V_{BG} = 0$ V	$V_{CG} = 0$ V	
$V_A = 104 \angle 0°$ V	$V_B = 0$ V	$V_C = 0$ V	$V_R = 104 \angle 0°$ V
Three Phase Fault			
$V_{AG} = 0$ V	$V_{BG} = 0$ V	$V_{CG} = 0$ V	
$V_A = 0$ V	$V_B = 0$ V	$V_C = 0$ V	$V_R = 0$ V

Based on these findings it was then determined that a Basler 59N overvoltage relay would be able to detect a single line-to-ground fault with a threshold voltage of less than 208 V, or three times the normal phase-to-neutral seen by the VTs. If the threshold were set to less than -104 V (with reversed polarity relative to the previous case) the relay should be able to detect a double line-to-ground fault as well. Further work should test to confirm the relay's use for this specific purpose however.

In order to determine which phase is faulted, auxiliary CVD relays were connected across each phase VT secondary. Based on the results in Table 2, the threshold for these relays to correctly trip and indicate a single faulted phase would be close to zero volts. With a negative crossing threshold set to a few volts for each relay, a remote operator would be able to determine which phases are faulted and distinguish between single line-to-ground, double line-to-ground, and three phase faults. Note, however, that the CVD voltage thresholds would have to be set higher to account for faults further out on the line, where some voltage drop might need to be considered between the bus and the fault.

Conclusion

In summary, the ground fault protection scheme explored in this project was found to be an accurate monitor of single line-to-ground faults in an ungrounded system and might be extended to detect double line-to-ground faults as well. Further, the auxiliary CVD relays are predicted to successfully to locate which phase(s) in the system were affected by the fault and decrease the response time for correcting the fault.

Ungrounded systems are valued as providing continuous operation of medium voltage systems where a power shutdown results in large economic losses. Although the system might continue operation with a faulted phase, ground protection is extremely important for preventing damage to critical equipment and personnel. While conducting research for this project it was found that most of the industry literature available concentrated only on the detection of single line-to-ground faults. However, this is not the only type of fault that can occur within the system and as a result this project evaluated the voltages for all fault types. Lastly, methods for determining the location of the fault in the system through lamps, a signal generator, or fault indication relays were explored to gain insight into a fault situation and increase the reliability of the system.

Recommendations for Continued Work

A proposed area for future work is the development of a lab related to the concepts discussed in this report. The lab would include application-based testing of the proposed overvoltage relay using lab equipment. This would include determining reliability of the relay to trip for the various faults and the coordination of the overvoltage relay with fault indicators. In addition, the lab could also include evaluating how the system would react for varying ballast resistances values during each type of fault.

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Appendix I: Journal Review

Currently, the common ground fault detection methods being used for ungrounded systems are able to detect the presence of a ground fault but do not provide information about the location of where the fault occurred. The article “Fault Locating in Ungrounded and High-Resistance Grounded System” focuses on detecting and locating ground faults in ungrounded and high resistance grounded systems.

For an ungrounded system the fault current is too low for a current monitoring relay to effectively detect the fault. As the authors state there are many ways to detect a ground fault in the system, such as indicator lights connected to each phase, voltmeters, and voltage relays. However, these methods only detect the phase on which the fault occurred and not where the fault was physically located within the system. The first proposed location method includes the installation of a zero-sequence signal generator. When a ground fault is detected the associated relay initiates the signal generator to supply a current through the system that loops back through the grounding network once it reaches the fault. The signal generator is then able to determine the electrical distance from the relay to the fault. To avoid communication problems with other equipment the frequency selected for the signal generator is differs from the power line carrier frequency. Another location method utilizes remote ground-fault indicators (RGFI). The RGFIs are connected to the zero sequence current of a transformer. When a line-to-ground fault occurs the RGFI detects a current through the zero sequence and then provides a physical indication of where the fault occurred. Both location methods were tested for an ungrounded delta connected network and high-resistance network. Although there was error in the measurements the article estimates that roughly 240 hours of work were saved by implementing these location schemes.

Being able to locate a ground fault in a complex system would greatly reduce the service time needed for ground faults in an ungrounded system. One aspect of the first method of location that could be expanded on more is how the relay and the signal generator would be coordinated. For example, future work could address how the signal generator is integrated in relay’s tripping scheme. Also, for method two the authors could look into the benefits of connecting the RGFI to a SCADA system so that the location of the fault is recorded. This would help determine if there is another underlying problem in the system causing the ground faults thus increasing system reliability.

Overall, this article effectively discussed the basic concepts behind ground fault protection in ungrounded systems including the authors’ ideas for locating faults. Some areas of future expansion are adding more industry testing and methods for decreasing the location error. Currently, a utility may not utilize these location methods due to the cost of adding the signal generators or RGFIs. However, this is a methodology that could be beneficial when applied to large systems requiring continuous operation.

Fault Locating in Ungrounded and High-Resistance Grounded Systems

Thomas Baldwin, *Member, IEEE*, Frank Renovich, Jr., *Member, IEEE*, Lynn F. Saunders, *Fellow, IEEE*, and David Lubkeman, *Senior Member, IEEE*

***Abstract*—One of the most common and difficult problems to solve in industrial power systems is the location and elimination of the ground fault. Ground faults that occur in ungrounded and high-resistance grounded systems do not draw enough current to trigger circuit breaker or fuse operation, making them difficult to localize. Techniques currently used to track down faults are time consuming and cumbersome. A new approach developed for ground-fault localization on ungrounded and high-resistance grounded low-voltage systems is described. The system consists of a novel ground-fault relay that operates in conjunction with low-cost fault indicators permanently mounted in the circuit. The ground-fault relay employs digital signal processing techniques to detect the fault, identify the faulted phase, and measure the electrical distance away from the substation. The remote fault indicators are used to visually indicate where the fault is located. The resulting system provides a fast, easy, economical, and safe detection system for ground-fault localization.**

***Index Terms*—Ground-fault location, high-resistance grounding, ungrounded system.**

I. INTRODUCTION

UNGROUNDED and high-resistance grounded industrial power systems have a great advantage; they can operate indefinitely with a ground fault on one phase, eliminating the need for an immediate shutdown. Once the fault is located, the particular circuit can be isolated and the fault cleared at a convenient time, resulting in a controlled, minimized outage. This advantage has tremendous value in many industries, where the instantaneous tripping of faulted circuits to critical processes would result in losses of production, materials, and equipment [1]–[3].

A major problem in operating these systems is locating a ground fault when it occurs. The search may be difficult and time consuming. For one particular manufacturing site studied, approximately half of the faults were quickly located; the other faults required on average four man-hours, and a few faults took 16 or more hours. Small-magnitude fault currents flow in the faulted network due to the leakage (or grounding) capacitance and through the grounding resistor if one is present. The system leakage capacitance is distributed throughout the entire network. It acts as if it were a single lumped capacitance; however, the charging currents can be observed flowing in all branch circuits. Typical fault currents are less than 10 A.

A. Ground-Fault Protection

The original intent of ungrounded systems was to keep the power system operating after the first indication of a ground fault. System maintenance personnel were responsible for locating and correcting the problem before a second ground fault could occur on another phase. When done efficiently and quickly, this approach allows the power system to have nearly continuous operation under most situations. Fault repairs could be conducted during normally scheduled shutdowns. The immediate removal of power to a faulted section upon detection of the first fault defeats the main advantage of high-resistance grounded and ungrounded systems.

Detecting the presence of a ground fault is simple. Techniques using indicator lights, voltmeters, and voltage-sensitive relays have been applied for many years. When one phase is grounded, the phase-to-ground voltage decreases toward zero and the phase-to-ground voltages of the other phases rise. In high-resistance grounded systems, a current-sensitive relay in the grounding resistor circuit may also be used to measure the very small fault current [4].

All these methods for ground-fault detection are nonselective. The faulted phase is identified, but the fault could be anywhere in the network [5]. Because the fault current in high-resistance grounded systems can be similar in magnitude to the charging currents, it is difficult to distinguish between the two. Thus, locating the ground fault is difficult.

B. Ground-Fault Localization

Common methods of localization are: 1) fault isolation by network switching and 2) circuit tracing using a signal injector and a hand-held sensor/detector.

Network switching is the simplest method. The system operator deenergizes one feeder at a time until the fault disappears. Then branch circuits and eventually loads are tested. This identifies the faulted network section. The search process eliminates the continuity of service, which is the advantage of these systems. In practice, the search is postponed until there is a scheduled break in production. Often the search is frustrated by the

Paper PID 01–24, presented at the 2000 IEEE Petroleum and Chemical Industry Technical Conference, San Antonio, TX, September 10–14, and approved for publication in the IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS by the Petroleum and Chemical Industry Committee of the IEEE Industry Applications Society. Manuscript submitted for review September 15, 2000 and released for publication May 11, 2001.

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Publisher Item Identifier S 0093-9994(01)06309-5.

disappearance of the fault when all the manufacturing equipment is shut down. The search is manpower intensive and requires well-trained personnel that are familiar with the entire power system network [5].

Circuit tracing with a superimposed signal is a preferred method for locating a fault. The signal can be supplied in a number of ways. For high-resistance grounded systems, a common signal source is the modulation of the ground-fault current through the grounding resistor. This may be accomplished with a second resistor switched in parallel with the grounding resistor or by shorting out a portion of the grounding resistor. With either method, a pulsing circuit operates a contactor, which switches in a lower resistance for the grounding circuit. This increases the ground-fault current momentarily, enough for detection by ammeters or by a clamp-on detector [1]–[3].

For an ungrounded system, a pulsating electronic signal injector (commonly referred to as a thumper circuit) is attached to the faulted network, and hand-held detectors sense the signal along the faulted circuit. The thumper circuit is an electronic oscillator within the audio frequency range and is coupled between the faulted phase and ground. The signal travels along the fault path, and is detected by a receiver circuit. Such test equipment is portable and only needs to be attached when looking for the fault.

C. Location Problems

The current practices for locating ground faults have certain weaknesses, which have troubled many industrial operations. These weaknesses stem from three conditions that are frequently not considered by the localization methods. They are: 1) intermittent fault conditions; 2) multiple faults on the same phase; and 3) inverted ground faults. Intermittent faults are frequently found in industry when ground faults occur at or near cycled loads, and the fault is on the load side of the controlling contactor. In such circumstances, the fault detection may not even be noted by operations if the duty cycle is low or the fault is on for a very short time. Another type of intermittent fault is encountered during maintenance cycles. A ground fault will be detected, but localization is delayed until the beginning of the maintenance period. With the halting of production, the ground fault disappears. Some time after production recommences the ground fault will reappear as the faulted circuit is reenergized.

The occurrence of multiple faults on the same phase is often found in very large facilities. When this condition does happen, maintenance personnel frequently become confused, unable to isolate the fault by switching methods or encountering myriad detected signals throughout the system. The problem is exacerbated in loop systems. With proper training, the difficulty of multiple faults is diminished, however, much time is consumed until the presence of multiple faults is detected.

Inverted ground faults are those in which the ground reference is outside of the voltage triangle. Fig. 1 illustrates the differences between the inverted ground fault and other ground faults. Inverted ground faults are commonly attributed to arcing faults, where the arcing condition causes a voltage multiplication with respect to ground, and a voltage offset between the system and ground occurs. Inverted ground fault can also appear when there is an unbalanced impedance fault. Fig. 2 illustrates one possible circuit, typical of a motor fault with a broken conductor. In this circumstance, there is an unbalanced loading of capacitance and inductance. The imbalance causes the ground to shift outside of the voltage triangle.

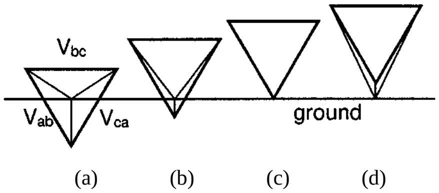


Fig. 1. Ground-fault types. (a) No fault. (b) High-resistance fault. (c) Solidly grounded fault. (d) Inverted ground fault.

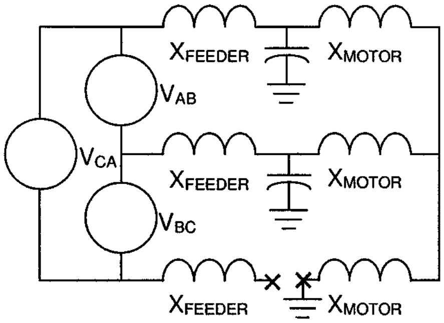


Fig. 2. Motor with a broken conductor fault, causing an inverted ground-fault condition.

Inverted ground faults are difficult to trace. The fault path may contain either an arc or high impedance. Pulse signal methods cannot be used with this fault, because they require a low impedance circuit. Proper detection of an inverted ground fault is necessary.

An additional physical problem with most pulsing-signal search methods is the inability to monitor various locations and wiring methods. Power circuits are often routed in inaccessible locations such as 6–12 m above a factory floor with manufacturing equipment, blocking access via ladders or lifts, thus making it difficult to apply a clamp-on detector. Wiring methods that have grounded protective armor such as rigid conduit and busway may shield the signals from the detectors when the return current path is through the metal casing. This construction forces the signal measurements to be at junction points where the line conductors are accessible.

II. GROUND-FAULT LOCATION

A location technique requires a discernible signal that uniquely identifies a fault location. For ground faults, this signal is the zero-sequence current. Fig. 3(a) shows a simple system with high-impedance grounding, experiencing a ground fault. The sequence-component networks interconnected for the ground fault are illustrated in Fig. 3(b). The grounding resister and the leakage capacitance limit the fault current and, hence, the zero-sequence current.

The new technique seeks to provide a substitute zero-sequence current, without losing the current-limiting benefit. A sufficient zero-sequence current is obtained by placing an ideal current source between points J and K of Fig. 3(b).

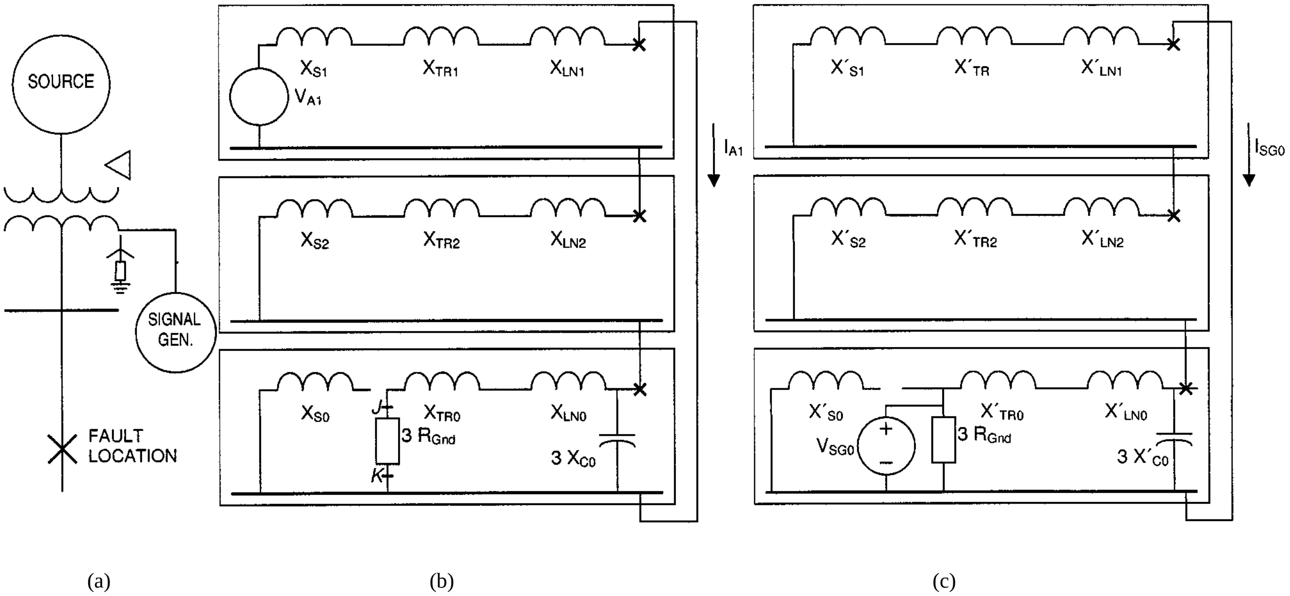


Fig. 3. (a) Simple power system with transformer and feeder and a ground fault on one phase at the end of the feeder. (b) Symmetrical component impedance network of the network. (c) Same impedance network viewed from the zero-sequence signal generator perspective.

The principles of superposition show that the current from the positive-sequence source has not changed, but the current flow in the network is the sum of the currents from each source. The zero-sequence current can be made distinct by a change in frequency from the fundamental power system frequency.

Fig. 3(c) is the resulting sequence-component circuit diagram for the distinct-frequency zero-sequence fault-signal current. The total impedance seen by the current source is of the same order of magnitude as the total ground-fault impedance of a solidly grounded system. Hence, a relatively small current (1–5 A) flows in the fault circuit with a small impedance voltage (less than 50 V). The zero-sequence current level is selected to provide adequate detection and measurement.

The transformation from sequence components to phase components provides the current flow in each conductor within the network. Summing the three phase currents at any point in the network gives the residual current. For feeders and branch circuits between the signal source and the fault location, the residual current is nonzero. Indeed, for a radial network, the residual current will equal the source current magnitude. In all other nonfaulted branch circuits, the residual current will be zero. Because of the low-impedance voltage, the current flow in the leakage capacitance is negligible.

The zero-sequence current flow during a ground fault permits a variety of techniques for locating the fault location. Impedance computation of the zero-sequence voltage and current provides an approximation of the distance from the measurement location to the fault. Zero-sequence current transformer arrangements and residual current transformers provide detection of the current signal along the faulted circuit. The signal detection and measurement are similar to that of detection and measurement for solidly grounded systems, but the response and control actions are indication and data recording instead of fault isolation by tripping circuit breakers or blowing fuses.

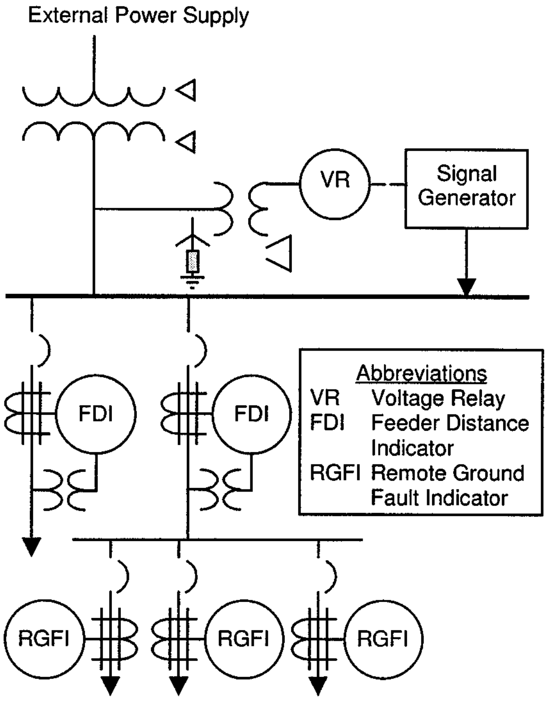


Fig. 4. Ground-fault system architecture for a simple system.

III. Location System

A ground-fault location system has been implemented in a manufacturing facility with ungrounded delta systems and high-resistance grounded systems. The system provides detection of ground faults, the zero-sequence fault-signal current, impedance/distance measurements to the fault, and fault-path indication for the feeders and branch circuits.

The ground-fault location-system architecture is shown in Fig. 4. It consists of the following devices:

- digital substation relay;
- zero-sequence signal generator;
- remote ground-fault indicators.

The function and operation of each of the devices will be discussed next.

A. Digital Substation Relay

A digital relay monitors the substation's bus voltages and the feeder currents to detect ground faults and provide initial data about the ground fault's location. Specifically, the relay indicates the type of fault: ground fault or inverted fault; the faulted phase; the substation feeder on which the fault is located; and the electrical distance from the substation to the fault.

The three-phase substation voltages are monitored with respect to ground. A relative-voltage comparison algorithm is used to detect a ground-fault condition and identify the faulted phase. This algorithm checks for inverted-ground conditions, as locating these faults must be handled in a different manner. The relative-voltage philosophy of this algorithm also guards against false ground-fault detection due to supply voltage problems on the primary side of the substation transformer, such as voltage sags, loss of one or more phase voltages, or opened phase conductor (or fuse).

To detect the presence of a possible ground fault, the relay uses an algorithm that monitors an unbalanced voltage condition [4]. The unbalanced voltage is found by summing the three line-to-ground voltage phasors as follows:

$$V_{\text{Unbalance}} = V_{AN} + V_{BN} + V_{CN}. \quad (1)$$

If the unbalanced voltage exceeds a given threshold, the relaying algorithm continues by identifying the fault type. The algorithm uses a relative comparison of the line-to-line voltages with the line-to-ground voltages. When the line-to-ground voltage drops below a threshold constant α, multiplied with the magnitude of the line-to-line voltage, then a ground fault is detected on that particular phase

$$V_{LN} < \alpha \; |V_{LL}| \quad (2)$$

where

$$0 < \alpha < \frac{1}{\sqrt{3}}.$$

To discriminate between a ground fault and an inverted ground fault, a test checks to see if any two of the three line-to-ground voltages exceed the line-to-line voltages by another threshold constant β. If so, then an inverted ground-fault condition is detected

$$V_{LN} > \beta |V_{LL}| \quad (3)$$

where

$$1 < \beta < 1.5.$$

By using relative comparisons based on the line-to-line voltages, power supply problems, which can lead to false ground-fault detection, are recognized and appropriate blocking actions are taken.

On detection of a valid ground fault, the relay activates the zero-sequence signal generator, providing a nonfundamental frequency current to the fault. Voltage and current transducers provide measurements to the relay for determining the impedance from the substation to the fault location. In addition, the relay indicates the feeder on which the fault has occurred by monitoring the current transducers that are located on the feeders leaving the substation. The complete fault measuring sequence happens within several power-frequency cycles, after which the relay deactivates the signal generator, records the fault event, and activates the ground-fault target on the relay's front panel. The relay continues to monitor the fault until it is removed, either by corrective action or by being an intermittent fault. A record of the fault clearing is added to the event history, and the ground-fault target is adjusted to indicate that a fault has occurred, but it is presently cleared.

By utilizing a zero-sequence impedance/ground distance algorithm [6], the feeder circuit impedance is computed. With stored feeder parameters, an estimate of the distance to the fault is obtained.

B. Zero-Sequence Signal Generator

The signal generator provides a low-amperage ac current to the fault circuit. The signal is coupled to the power distribution network such that the current flow to the fault consists only of a zero-sequence component. The return path for the current is through the ground system. The signal frequency is selected to be different and distinguishable from the power-line frequency. An appropriate range is 10–50× the fundamental power frequency. Odd harmonic power frequency values should be avoided, as many nonlinear loads also produce odd harmonic currents. During a fault, these harmonic currents may flow through the fault path, and making it difficult to take accurate measurements of the signal's magnitude.

From the power-line frequency perspective, the signal generator appears to both the ungrounded and high-resistance grounded system as an ideal current source operating at another frequency (or an open circuit). From the signal generator frequency perspective, the ground-fault circuit consists of the low-impedance paths of the positive-, negative-, and zero-sequence circuits in parallel with the high-impedance elements of the zero-sequence circuit, as in Fig. 3(c). Hence, the signal generator supplies a current for a low-impedance current loop starting from the substation, along the supply feeders, to the fault location, and back through the grounding network.

The signal generator is controlled by the substation relaying system. With the detection of a ground fault, the digital relay activates the signal generator. The signal generator injects the current signal into the power system network for several milliseconds, long enough for the digital relay to monitor the signal flow as it leaves the substation and goes to the fault. After the relay has determined the supplying feeder to the fault and the electrical distance, the signal generator removes the current injection and waits until the relay detects a change in the fault condition or the power system operator initiates a request to reactivate the remote ground-fault indicators.

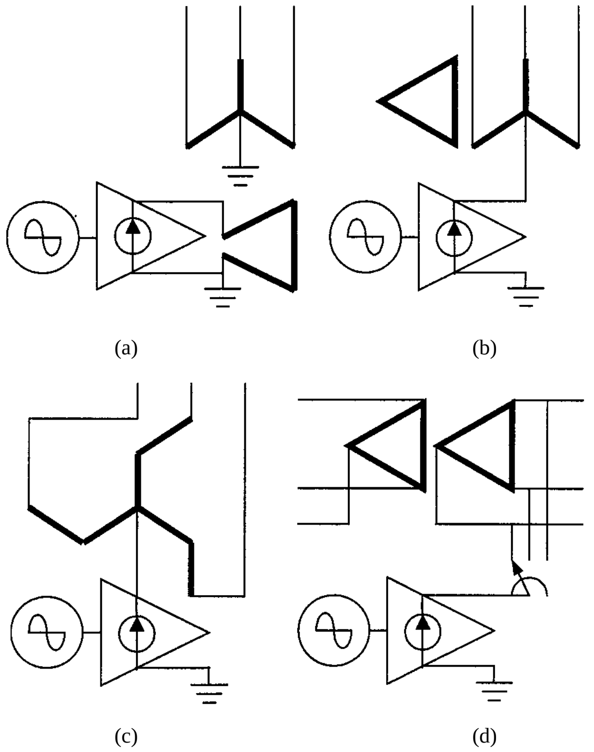

(a) (b) (c) (d)

Fig. 5. Signal generator interfaces to the power system. (a) Open delta/wye auxiliary transformer connection. (b) Wye/delta auxiliary transformer connection. (c) Zig-zag auxiliary transformer connection. (d) Circuit-switching method using the main power transformer.

The signal generator may be coupled to the three-phase power system using several techniques. The direct approach is to use a zero-sequence three-phase auxiliary transformer interface. Fig. 5(a)–(c) shows an open-delta/wye, wye/delta, and zig-zag transformer connection. An indirect technique for coupling the signal generator to the power system is to use the main supply transformer and a phase-conductor selector switch. This circuit is shown in Fig. 5(d). The selector switch is positioned to the phase with the ground fault. The current signal back flows into the transformer and across the windings to the other two phases. The low impedance of the power system source causes little interaction to the current signal. Technically, the selector switch is unnecessary; however, in practice the selection of the faulted phase insures that the impedances as seen by the generator and relay are approximately the same for whichever phase has the fault.

In practice, a servo-amplifier, configured as a current source, may serve as the output stage of the signal generator. When looking into the output terminal, the circuit sees a high-impedance source. With the addition of a 60-Hz *LC* blocking filter, the signal generator appears as a high-impedance circuit branch to ground.

C. Remote Ground-Fault Indicator

In the industrial distribution-system environment, the number of feeders, branch circuits, and loads can be enormous. The major issue associated with applying a technology at the substation for monitoring a network condition is identifying on which branch circuit or at which load, an event has happened. Additional information is necessary to identify the faulty branch circuit or load. Remote sensors located on the branch circuits and nearby loads provide the necessary information to bracket the fault to within a manageable circuit section.

The specifications for the remote sensors may vary widely for different industrial environments. However, the most important requirements include low cost, ease of installation and maintenance, and accurate and reliable performance of the desired function. The primary function of the sensor is to detect the presence of the zero-sequence current-injection signal on the power circuit. The signal flows with a nonzero summation of all the phase conductor currents only between the signal generator and the ground fault. With the detection of a residual current flow through the sensor, an annunciation is made either through communication to a central data collection and/or local indication. Because ground faults do not require immediate tripping of the protective circuit breaker, indication is the only function of the device.

In this ground-fault location system, the individual load feeders and branch circuits are each monitored by a device similar in nature to a 50G device, an instantaneous overcurrent relay. The device, the Remote Ground-Fault Indicator (RGFI) is an electronic indicator connected to the secondary of a zero-sequence current transformer to sense 1–15 A on the primary circuit.

The RGFIs that are positioned in the ground-fault circuit between the substation's zero-sequence signal generator and the ground fault will all give indication of the fault, as illustrated in Fig. 4. Each branch circuit or load feeder should employ a RGFI, as one would apply overcurrent protection. Coordination between the devices is not necessary or performed.

The RGFI is most sensitive to the frequency of the signal generator. At that particular frequency, the device will give indication with as little as 1 A of current flow on the primary circuit. The device is constructed using a core balance (residual current) current transformer. All the line conductors are fed through the opening of the current transformer. Hence, the device monitors the sum of all the current flowing in the line conductors.

At the power-line frequency, the indicator has a minimum current threshold making it immune to the leakage capacitance charging currents that flow from all parts of the network during a fault. Selectivity is accomplished using the induced secondary voltage of the current transformer. The core steel of the current transformer has a very flat saturation characteristic on the B-H curve. Hence, the transformer can only support a given burden, and any additional burden quickly diminishes the secondary current. The frequency of the injected current signal is at least 10× higher than the power-system frequency. The burden that a transformer can support depends on the maximum induced voltage, which is a function of the core's saturation of the magnetic flux density and the frequency of the flux. That is,

$$E = 4.44\, f\, n\, A\, B_{\max} \tag{4}$$

where

E induced secondary winding voltage;

f frequency of the flux and the voltage;

n number of turns in the secondary winding;
A cross-sectional area of the core;
$B_{\max}$ peak value of the flux density.

The induced voltage of the injected current signal is $10\times$ larger than that of the power-frequency charging currents. The current transformer's burden is designed to cause core saturation at the power frequency, but not at the injected-current frequency. The overall effect is that the current transformer has a smaller turns ratio (I_2/I_1) at the power frequency than at the injected-signal frequency.

The flat core-saturation characteristic serves another useful purpose. Because of the potential of two simultaneous ground faults on separate phases and feeders, the indicator must be capable of withstanding very large fault currents. Depending on the operating voltage and substation configuration, the fault-current magnitudes range from 10 to 60 kA. During these fault conditions, the core saturation limits the energy that passes into the secondary circuit.

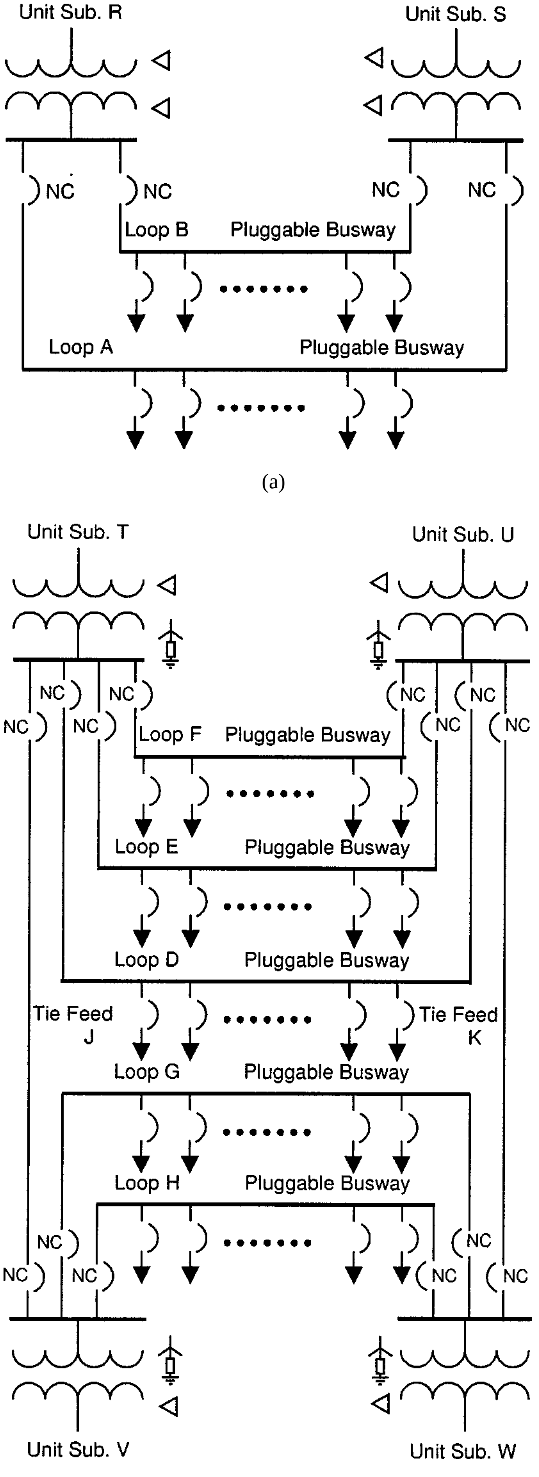
IV. TEST CASES

An industrial manufacturing site with several 480-V distribution systems was selected to test the ground-fault location system. The first test was conducted on an ungrounded delta-connected system with two loop feeders and two unit substations. A second test was conducted on a high-resistance grounded system with five loop feeders, two tie lines, and four unit substations. One-line diagrams for both of these distribution systems are shown in Fig. 6. The loads supplied by the systems are resistance spot-welding units. Faults are intermittent in nature, happening on the load side of the welding control units. The feeders provide service to the welders via busway and bus plugs. Standard operating practice is to keep all of the circuit breakers closed.

In the first test, remote ground-fault indicators were placed at 16 welding control units between the bus plug and the power-input side of the controls. A registered target on the indicator would signal that a ground fault occurred within the control station, the cables running to the welder, or the welder itself. A review of fault histories indicated that almost all faults happen between the control station and the welder.

At the unit substations, current transformers were placed on the four ends of the feeders near the circuit breakers. On one substation bus, potential transformers were placed to measure the line-to-ground voltages. The measurements were sent to a computer with a data acquisition system. The computer executed a fault location algorithm and controlled the zero-sequence generator. The output of the signal generator was connected to the same substation bus. Faults were staged at the loads on various phases. The fault location estimates and the physical site of the fault are given in Table I. The physical site distances are also estimates based on the floor location of the fault. The total conductor lengths of feeders A and B are 1400 and 1158 ft, respectively.

The absolute error distance and percentage is extremely good in the first test. A maximum error of 21 ft was recorded, which translates into finding a fault among three to five loads. This was accomplished by: 1) having a loop system with measurements at both ends of the loop; 2) using the same equipment to measure the feeders' electrical distance prior to staging the ground faults; and 3) modeling the feeders as three line segments of cable and busway.



(a)

(b)

Fig. 6. Two test systems. (a) Ungrounded delta-connected network. (b) High-resistance grounded network.

In the second test, a permanent installation of remote indicators, signal generator, and relay was located on a five-feeder high-resistance grounded system. All 185 welding loads were

TABLE I
TEST CASES ON AN UNGROUNDED LOOP DISTRIBUTION SYSTEM

Case	Feeder and Distance				Faulted	Abs. Error	Percent
No.	Actual		Predicted		Phase	Distance	Error
1	A	470	A	460	A	10 ft	0.71
2	A	553	A	561	B	8 ft	0.57
3	A	587	A	598	B	11 ft	0.79
4	A	595	A	616	C	21 ft	1.50
5	A	638	A	643	C	5 ft	0.30
6	A	697	A	700	B	3 ft	0.21
7	A	733	A	733	A	0 ft	0.00
8	A	794	A	802	C	8 ft	0.57
9	A	946	A	943	C	3 ft	0.21
10	A	1008	A	1000	A	8 ft	0.57
11	B	534	B	515	C	19 ft	1.64
12	B	559	B	538	C	21 ft	1.81
13	B	665	B	675	A	10 ft	0.86
14	B	722	B	724	C	2 ft	0.17
15	B	887	B	874	A	13 ft	1.12

TABLE II
TEST CASES ON A HIGH-RESISTANCE GROUNDED LOOP DISTRIBUTION SYSTEM

Case	Feeder and Distance				Abs. Error	Percent
No.	Actual		Predicted		Distance	Error
1	D	305	D	208	97	8.28
2	D	655	D	517	138	11.78
3	E	325	E	374	49	4.75
4	E	475	E	404	71	6.89
5	F	356	F	376	20	1.61
6	F	406	F	370	36	2.89
7	G	245	G	314	69	4.62
8	G	374	G	401	27	1.81
9	G	395	G	437	42	2.81
10	G	465	G	426	39	2.61
11	G	465	G	454	11	0.74
12	G	514	G	533	19	1.27
13	G	675	G	780	105	7.03
14	G	675	G	814	139	9.30
15	G	700	G	628	72	4.82
16	H	544	H	518	26	2.26
17	H	544	H	584	40	3.48
18	H	566	H	498	68	5.91

fitted with remote ground-fault indicators. The conductor lengths of the five loop feeders are $\mathrm{D} = 1171$ ft, $E = 1031$ ft, $F = 1246$ ft, $G = 1494$ ft, and $H = 1151$ ft. Faults were staged at various locations. Results of some fault tests are listed in Table II.

The results from the second test show greater error than the first. The largest distance error is 139 ft, which translates into a fault within three 45-ft sections of welding loads. There are two main sources of errors in this test: 1) the impedance measurements rely on good voltage measurements of the current signal (the voltage is only measured at the bus with the zero-sequence signal generator; the voltage at the other three buses in this case are estimated) and 2) the physical distances of the busway are suspected as undocumented extra turns and detours are made to circumnavigate building supports and tall equipment (the high-resistance grounding is not suspect in the errors.

The permanent installation of the second system has completed three months of operation in which 120 naturally occurring faults have been recorded. The primary benefit has been the reduction in fault search time by the electricians. Plant management conservatively estimates that 240 h of labor have been saved, and faults are being repaired within an 8-h work shift.

V. CONCLUSIONS

This paper has presented a new approach to locating ground faults for ungrounded and high-resistance grounded systems. The system approach couples information from a relay located at a unit substation and remote ground-fault detectors to indicate the fault phase, the supply feeder to the fault, an estimate of the fault distance, and the branch circuit or connected load with the fault. A zero-sequence signal generator that operates at a distinct frequency other than the power-line frequency provides a circuit path and signal to aid in locating the ground fault. From the signal-generator viewpoint, the fault network behaves like a solidly grounded system. However, from the power-line viewpoint, the system has not changed from being an ungrounded or resistive grounded network.

The ground-fault location system is capable of location intermittent faults and multiple faults. It can detect and distinguish inverted ground faults.

The remote ground-fault indicator or detector is a robust device that gives indication of a ground fault on a particular circuit. It is sensitive in detecting small zero-sequence currents, but able to withstand large fault currents.

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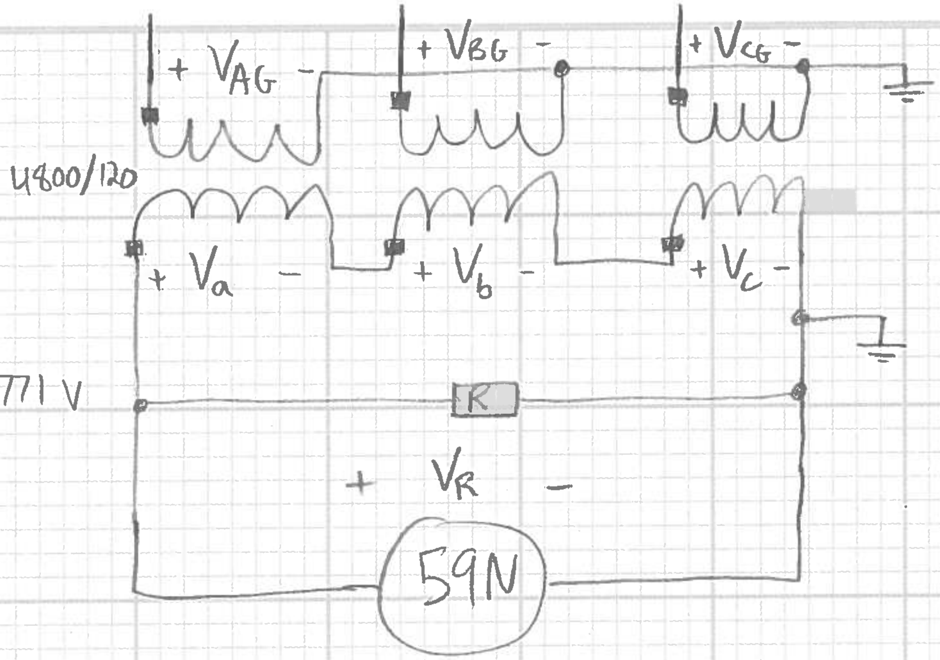
Appendix II: Hand Calculations

BLACK & VEATCH

Owner
Plant
Unit
Project No.
File No.
Title
Computed By
Date 20
Verified By
Date 20
Page of



$|V_{LL}| = 4800\ V$

$|V_{LN}| = \frac{4800}{\sqrt{3}} = 2771\ V$

Normal Operation

$V_{AG} = \frac{4800}{\sqrt{3}} \angle 0° = 2771 \angle 0°\ V$ $V_{BG} = \frac{4800}{\sqrt{3}} \angle -120° = 2771 \angle -120°\ V$ $V_{CG} = \frac{4800}{\sqrt{3}} \angle 120° = 2771 \angle 120°\ V$

$V_a = \frac{120}{4800} \cdot V_{AG} = 69.3 \angle 0°\ V$ $V_b = \frac{120}{4800} \cdot V_{BG} = 69.3 \angle -120°\ V$ $V_c = \frac{120}{4800} \cdot V_{CG} = 69.3 \angle 120°\ V$

$V_R = V_a + V_b + V_c = 69.3 \angle 0° + 69.3 \angle -120° + 69.3 \angle 120° \boxed{= 0\ V}$

SLG (A-phase)

☑ Verified w/ ASPEN

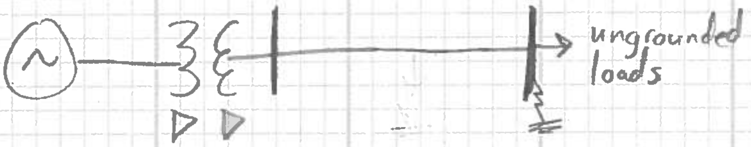
$V_{AG} = 0\ V$ $V_{BG} = 4800 \angle -150°\ V$ $V_{CG} = 4800 \angle 150°\ V$

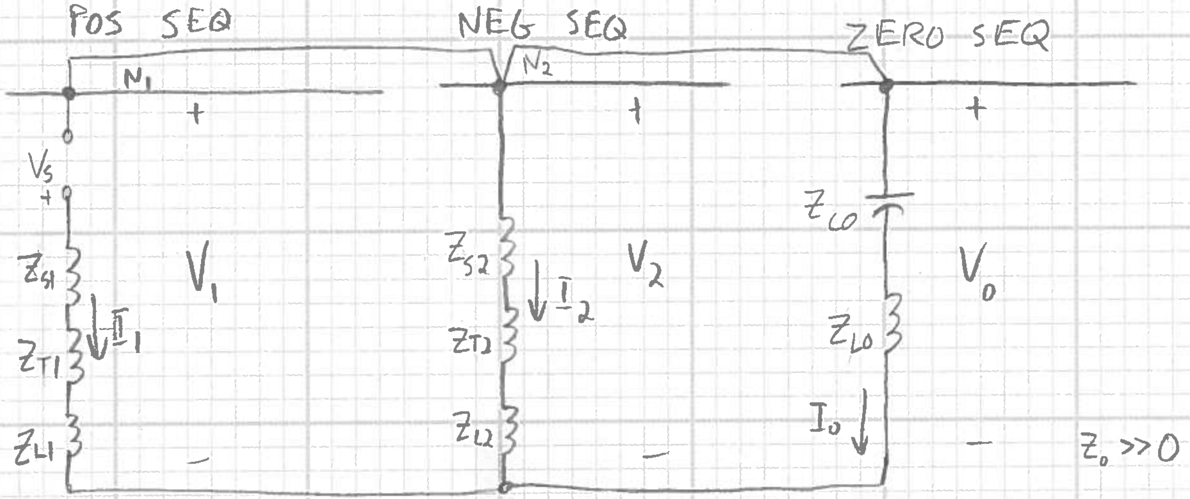
$V_a = 0\ V$ $V_b = 120 \angle -150°\ V$ $V_c = 120 \angle 150°\ V$

$V_R = V_a + V_b + V_c = 0 + 120 \angle -150° + 120 \angle 150° \boxed{= 208 \angle 180°\ V} = 3\, V_{LN} \left(\frac{120}{4800}\right)$

DLG (B, C - phase)

- assume bolted fault





$Z_1 = (0.27351 + j2.51826) + j0.08 + j0.1 = 0.27351 + j2.69826$

$Z_2 = (0.27357 + j2.51776) + j0.08 + j0.1 = 0.27357 + j2.69776$

$V_1 = V_2 = V_0$

$I_0 \approx 0$ b/c Z_0 is high

$I_1 = -I_2$

$V_{AG} = V_1 + V_2 + V_0 = 3V_1 = 1.5\angle 0°$ p.u.

$V_1 = V_2 = V_s \left(\frac{Z_2}{Z_1 + Z_2}\right) = 1.0 \left(\frac{0.27357 + j2.69776}{0.54708 + j5.39602}\right) = 0.5\angle 0°$ p.u

$V_{BG} = V_{CG} = 0$ p.u.

$V_{AG} = \frac{4800}{\sqrt{3}} \times 1.5\angle 0° = 4157\angle 0°$ V

☑ verified w/ ASPEN

$V_a = 104\angle 0°$ V

$V_R = V_a + V_b + V_c \boxed{= 104\angle 0° \text{ V}}$

BLACK & VEATCH

Owner

Plant Unit

Project No. File No.

Title

Computed By

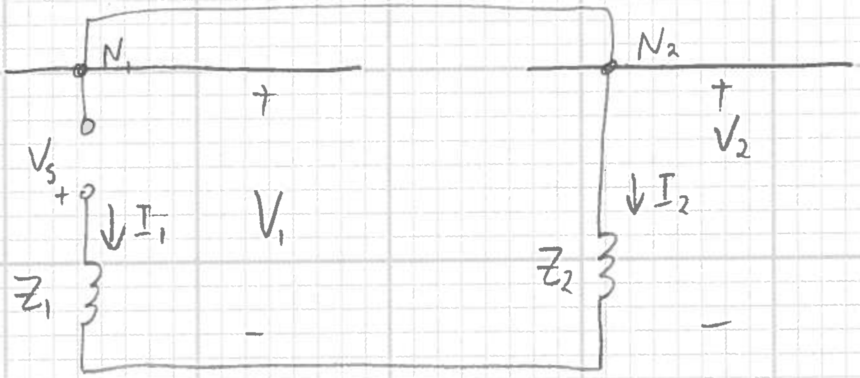
Date 20

Verified By

Date 20

Page of

L-L (B, C-phase)



$I_1 = -I_2$

$a = 1\angle 120°$

$V_1 = V_2 = V_s\left(\frac{Z_2}{Z+Z_2}\right) = 0.5\angle 0°$ p.u.

$V_{AG} = V_1 + V_2 = 1.0\angle 0°$ p.u $= \frac{4800}{\sqrt{3}}\angle 0° = 2771\angle 0°$ V

$V_{BG} = 0.5\angle -120° + 0.5\angle 120° = 0.5\angle 180°$ p.u. $= 1386\angle 180°$ V

$V_{CG} = 0.5\angle 120° + 0.5\angle -120° = 0.5\angle 180°$ p.u. $= 1386\angle 180°$ V

☑ verified w/ ASPEN

$V_a = 69.3\angle 0°$

$V_b = 34.6\angle 180°$

$V_c = 34.6\angle 180°$

$V_R = V_a + V_b + V_c \boxed{= 0\text{ V}}$

DO NOT WRITE IN THIS SPACE

BLACK & VEATCH

Owner ____________ Computed By ____________

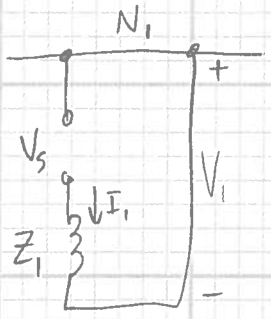
Plant ____________ Unit ____________ Date ____________ 20____

Project No. ____________ File No. ____________ Verified By ____________

Title ____________ Date ____________ 20____

____________ Page ______ of ______

3PH



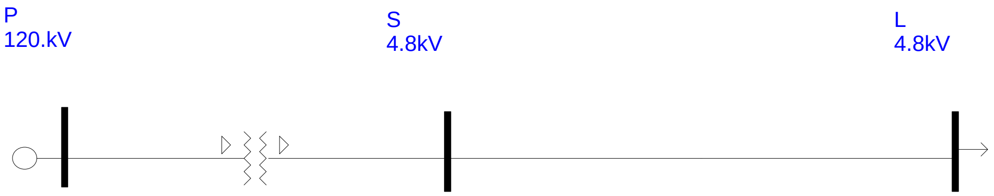
$V_1 = 0$

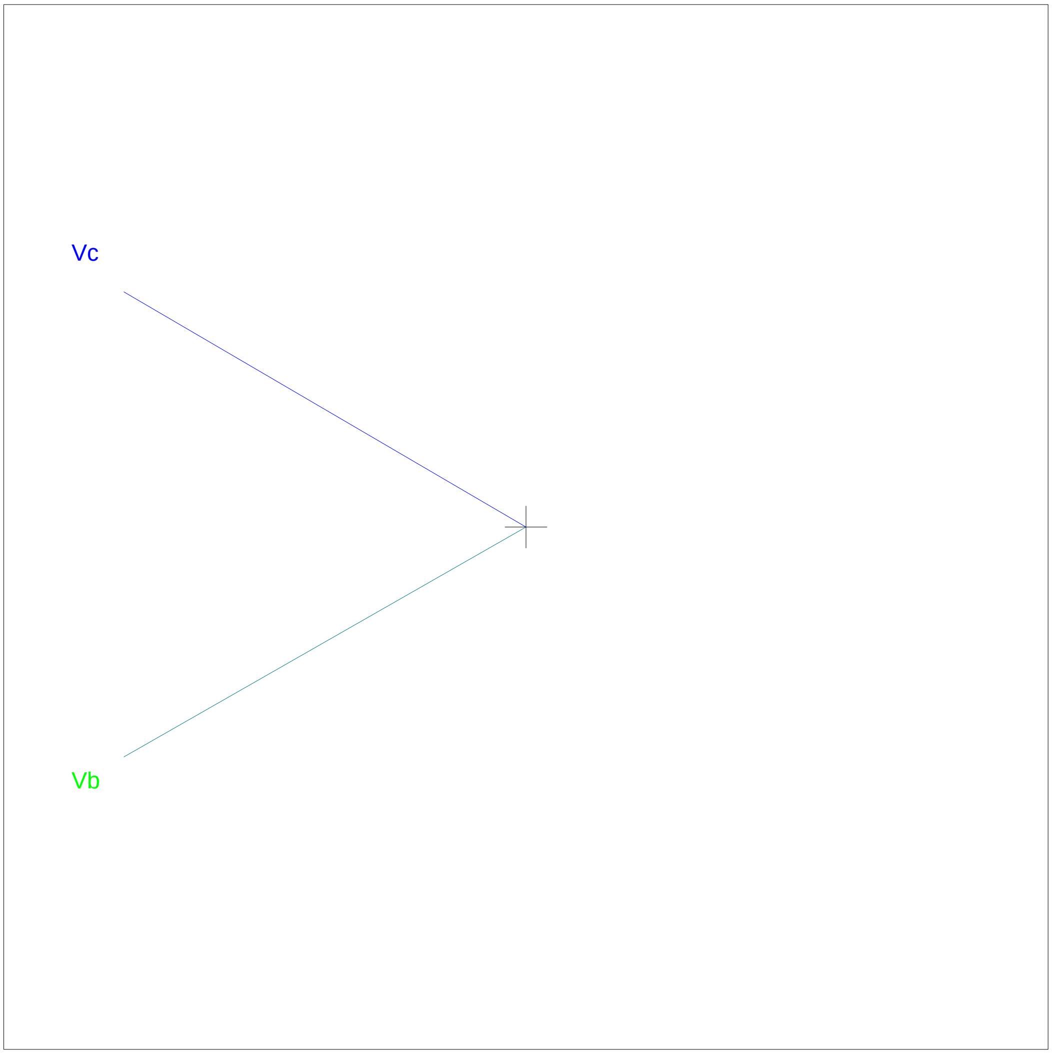
$V_{AG} = V_{BG} = V_{CG} = 0$

$V_R \boxed{= 0\,V}$

☑ verified w/ ASPEN

Appendix III: ASPEN Simulation Results





Fault Description:

1. Bus Fault on: 0 S 4.8 kV 1LG Type=A

Solution at: 0 S 4.8kV.

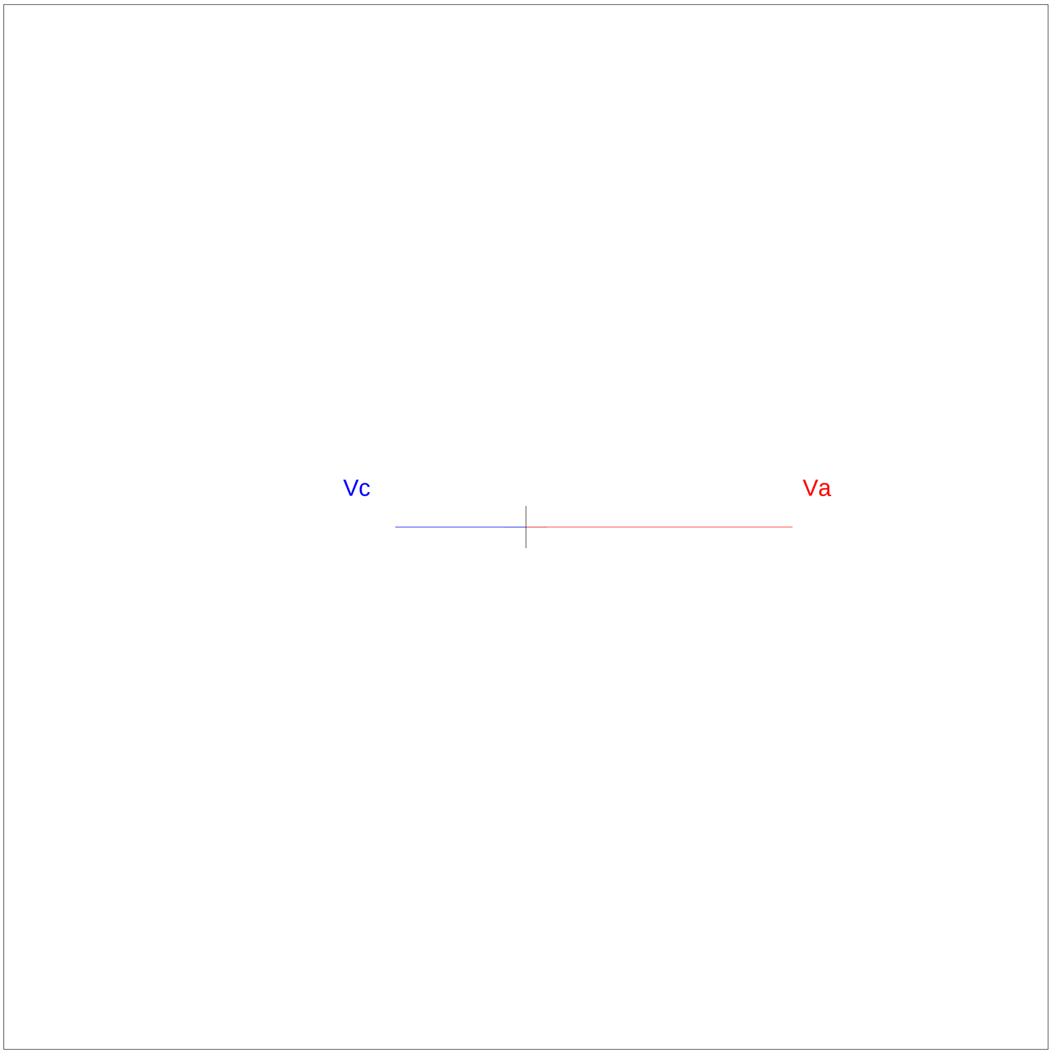
Voltages (kV) at this bus:

Va = 0.00@-0

Vb = 4.80@-150

Vc = 4.80@150

Reference: System



Fault Description:

1. Bus Fault on: 0 S 4.8 kV LL Type=B-C

Solution at: 0 S 4.8kV.

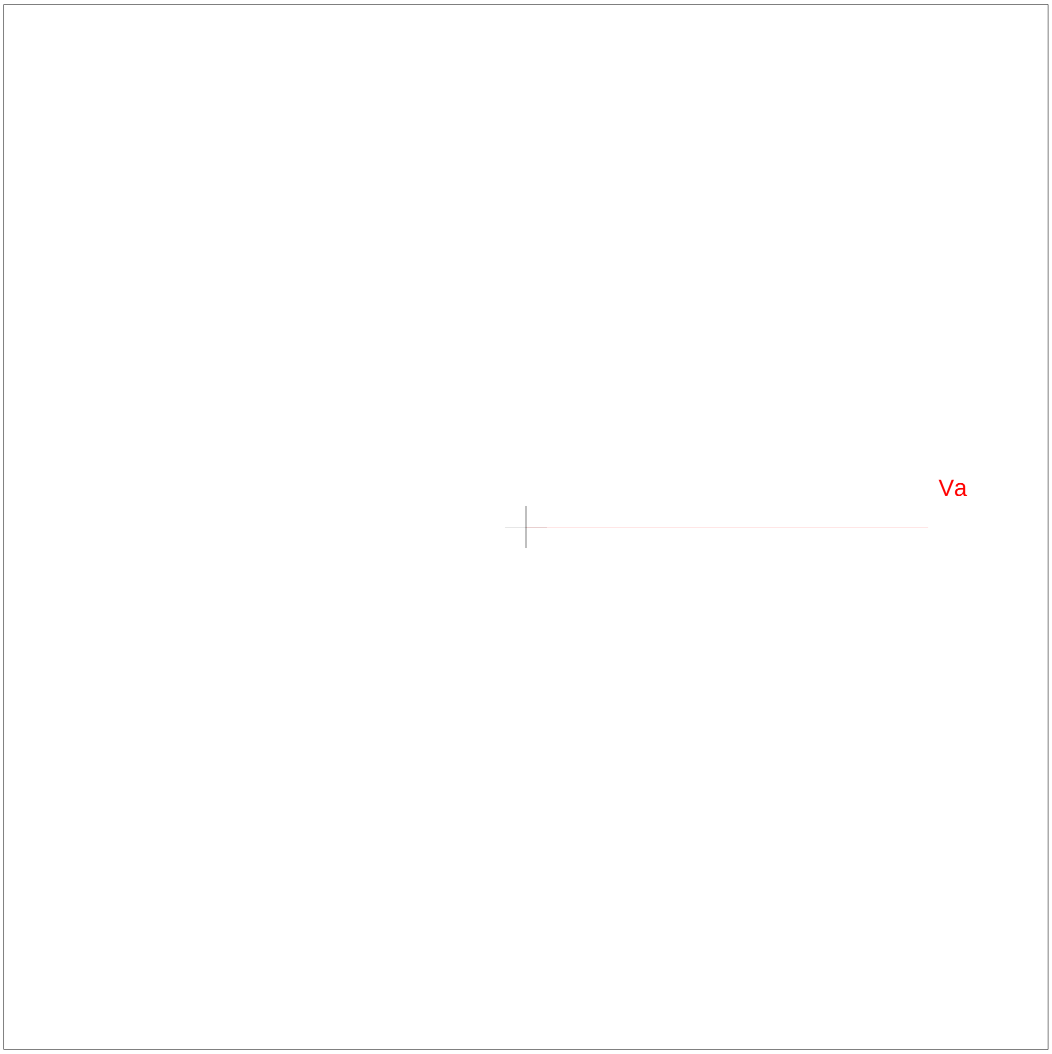
Voltages (kV) at this bus:

Va = 2.77@0

Vb = 1.39@-180

Vc = 1.39@-180

Reference: System



Fault Description:

1. Bus Fault on: 0 S 4.8 kV 2LG Type=B-C

Solution at: 0 S 4.8kV.

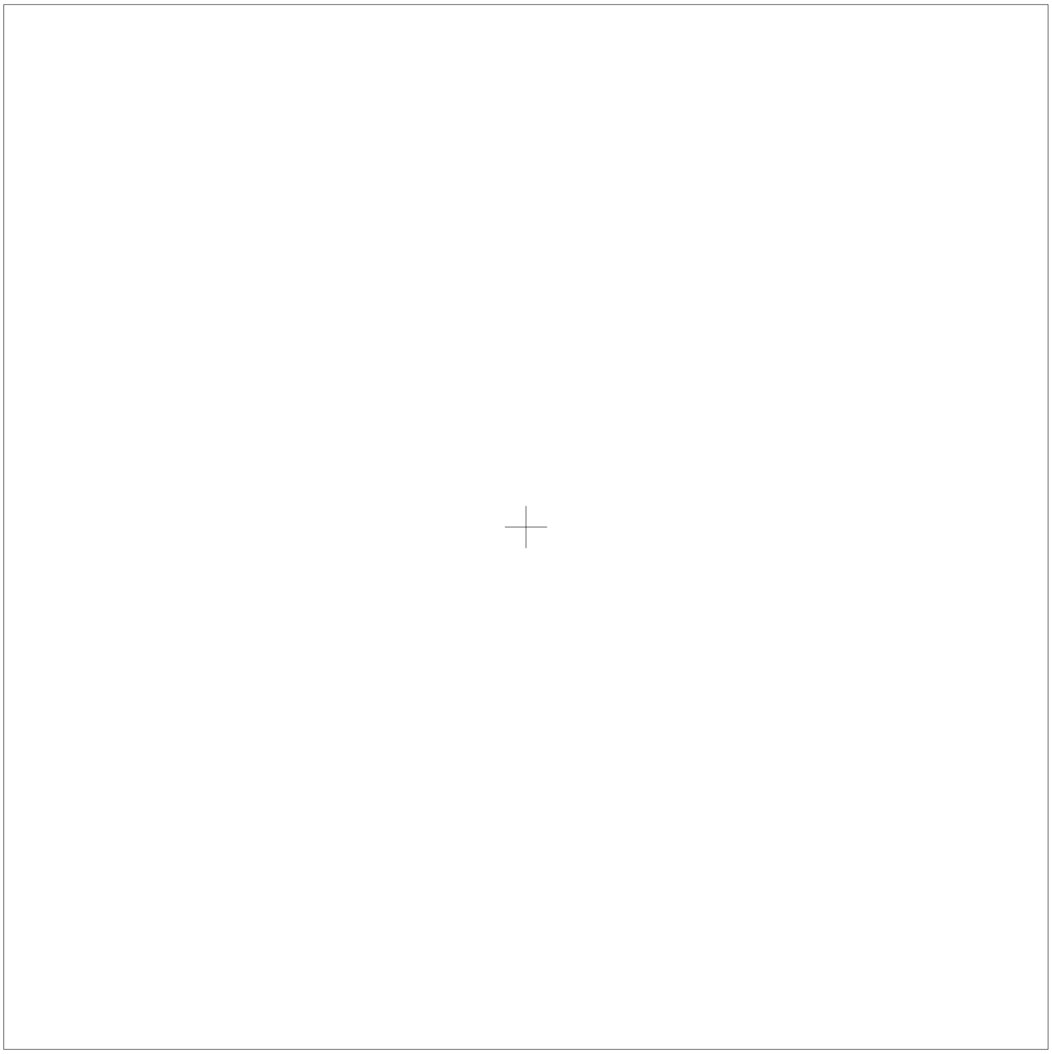
Voltages (kV) at this bus:

Va = 4.16@0

Vb = 0.00@0

Vc = 0.00@0

Reference: System



Fault Description:

1. Bus Fault on: 0 S 4.8 kV 3LG

Solution at: 0 S 4.8kV.

Voltages (kV) at this bus:

Va = 0.00@28

Vb = 0.00@-92

Vc = 0.00@148

Reference: System

BE1-59N GROUND FAULT OVERVOLTAGE RELAY

The BE1-59N Ground Fault Overvoltage Relay provides sensitive protection for ungrounded and high resistance grounded systems.

ADVANTAGES

- Provides 100% stator ground fault protection.
- 100/120 Vac or 200/240 Vac nominal sensing input.
- Four sensitivity ranges for overvoltage are available: 1-20 and 10-50 Vac for a 100/120 Vac input and 2-40 and 20-100 Vac for a 200/240 Vac input.
- Four sensitivity ranges for undervoltage are available: 0.1-2.5 Vac and 0.5-12 Vac for a 100/120 Vac input and 0.2-5 Vac and 1-24 Vac for a 200/240 Vac input.
- Instantaneous, definite, and inverse time characteristics.
- 40 dB harmonic filtering.
- Low sensing input burden.
- Power supply status contact.
- Qualified to the requirements of
  - — IEEE C37.90.1-1989 and IEC 255 for surge withstand capability;
  - — IEC 255-5 for impulse.
- UL recognized per Standard 508, UL File #E97033.
- Gost R certified; complies with the relevant standards of Gosstandart of Russia.
- Five year warranty.

ADDITIONAL INFORMATION

INSTRUCTION MANUAL

Request publication 9171400990

STANDARDS, DIMENSIONS & ACCESSORIES

Request bulletin SDA

Basler Electric
P. O. BOX 269 HIGHLAND, ILLINOIS 62249, U.S.A. PHONE 618-654-2341 FAX 618-654-2351

APPLICATION

PURPOSE

The available fault current for single-phase-to-ground Faults is very limited for ungrounded systems and systems that are grounded through a high resistance. This current limiting reduces the possibility of extensive equipment damage, and eliminates the need for a neutral breaker by reducing the fault current below the level required to sustain an arc.

But it remains important to detect and isolate single-phase- to-ground faults in order to prevent their evolution into more dangerous faults such as phase-to-phase-to-ground and three-phase-to-ground faults. Sensitive voltage relays can be used to detect ground faults where the fault current is very small. The BE1-59N is especially suited to the task.

HIGH RESISTANCE GROUNDING

A common method of grounding an ac generator is to connect a distribution transformer between the neutral of the generator and the station ground. The distribution transformer's primary voltage rating is equal to, or greater than, the generator's rated line-to-neutral voltage. The distribution transformer secondary is rated at 200/240 Vac or 100/120 Vac, and a resistor is connected across the secondary winding. When reflected through the transformer, the resistor is effectively a high resistance.

$$R_P = R_S \mathrm{\ X\ } N^2$$

where R_P is the effective primary resistance
R_S is the actual value of the secondary resistor
N is the turns ratio of the distribution transformer

Available single-phase-to-ground fault current at the generator terminals is greatly reduced by the high effective resistance of the distribution transformer and secondary resistor. The distribution transformer provides isolation for the protection scheme and reduces the voltage to a convenient level.

The BEI-59N ground fault overvoltage relay is connected across the secondary resistor to detect the increase in voltage across the distribution transformer caused by a ground fault in the generator stator windings. A ground fault at the generator terminals will result in rated line-to-neutral voltage across the transformer primary, while ground faults near the neutral will result in lower voltages. The overvoltage relay set point must be higher than any neutral voltage caused by normal unbalances in order to avoid nuisance trips. This will allow a certain percentage of the stator windings to go unprotected by the overvoltage relay. The overvoltage relay function typically protects 90 to 95% of the generator stator windings.

The BEI-59N ground fault overvoltage relay monitors the fundamental frequency (50 or 60 Hz) voltage that accompanies a ground fault, and is insensitive to the third harmonic voltage present during normal operation.

One hundred percent protection of the generator stator windings is obtainable with the optional overlapping undervoltage element. The undervoltage element is tuned to measure the third harmonic voltage, which is present in the generator neutral under normal operating conditions. The undervoltage element detects the reduction of the normal third harmonic voltage that accompanies a ground fault near the neutral point of the generator.

An undervoltage inhibit feature is included with the third harmonic undervoltage element. This feature supervises the operation of the ground fault relay to prevent operation during startup and shutdown by monitoring the generator terminal voltage.

UNGROUNDED SYSTEMS

The BEI-59N ground fault overvoltage relay is used to detect ground faults on ungrounded three-phase-three-wire systems. The relay is connected as shown in Figure 1. A set of voltage transformers is wired with a grounded wye primary and a broken delta secondary. The BEI-59N is connected across the broken delta. It is often necessary to connect a resistor across the broken delta to avoid ferroresonance.

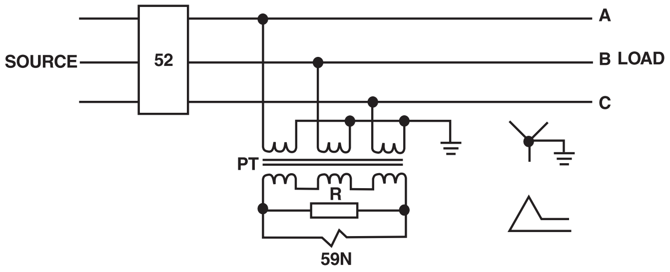


Figure 1 - Ungrounded 3-Phase, 3-Wire System

APPLICATION, continued

Grounded wye/broken delta voltage transformers act as zero sequence filters by summing the three phase voltages. Under normal conditions this sum is zero. When a ground fault occurs, the BEI-59N ground fault overvoltage relay will detect the presence of the secondary zero sequence voltage ($3V_0$).

The BEI-59N ground fault overvoltage relay greatly reduces the risk of equipment damage by detecting and isolating the first ground to occur on an ungrounded system.

SPECIFICATIONS

FUNCTIONAL DESCRIPTION

The specifications on these pages define the features and options that can be combined to exactly satisfy an application requirement. The block diagram (Figure 2) illustrates the overall operation of the relay.

INPUTS

Nominal sensing input ratings, defined by the style number, are 100/120 or 200/240 Vat with a maximum burden of 2 VA single-phase at nominal 50/60 Hz. The maximum continuous voltage rating is 360 Vat for 100/120 Vat nominal, and 480 Vat for 200/240 Vat nominal.

Overvoltage Sensing

In a typical application, the BEI-59N Ground Fault Overvoltage Relay monitors the voltage across a resistor in the generator's grounding circuit. The voltage across the resistor is supplied to the sensing transformer in the relay.

The derived secondary voltage is applied to an active filter to obtain the fundamental component of the input voltage. If this voltage exceeds the OVERVOLTAGE PICKUP (controlled at the front panel), an LED illuminates, and an internal signal is developed that may be employed three different ways, depending upon the timing option selected.

1. The overvoltage output relay is energized instanta neously.
2. A definite time delay (optional) is initiated whose period is determined by the front panel TIME DIAL over a range or 0.1 to 99.9 seconds. At the expiration of the time delay, the overvoltage output contacts close.
3. An inverse time delay (optional) is initiated whose period is determined by two factors:
   a. Magnitude of the overvoltage condition (±2% or 100 mV or whichever is greater for the 120 Vac pickup range or ±2% or 200 mV for the 240 Vac pickup range), and
   b. Selection of a particular response curve by the front panel TIME DELAY over the range of 01 to 99 (±5% or 25 mSec, whichever is greater) (Reference Figure 4.)

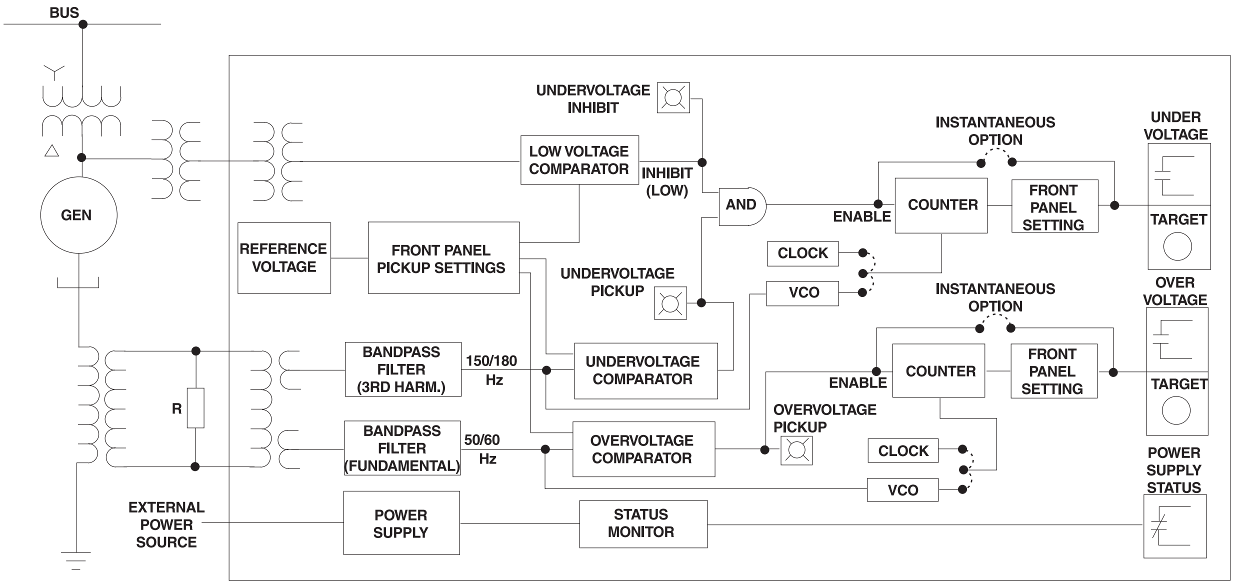


Figure 2 - Functional Block Diagram

P0010-5
12/12/01

SPECIFICATIONS, continued

Undervoltage Sensing Option

The undervoltage option is sensitive to the third harmonic (150 Hz or 180 Hz) voltage at the generator neutral, and insensitive to the fundamental frequency (50 or 60 Hz). The undervoltage measuring element determines within 5 cycles if the third harmonic voltage is less than or greater than the UNDERVOLTAGE PICKUP setting on the front panel. If less than, the UNDERVOLTAGE LED will illuminate, and an internal signal is developed which may be employed three different ways, depending upon the timing option selected.

1. The undervoltage output relay is energized instantaneously.
2. A definite time delay is initiated whose period is determined by the front panel TIME DIAL over a range or 0.1 to 99.9 seconds. At the expiration of the time delay, the undervoltage output contacts close.
3. An inverse time delay is initiated whose period is determined by two factors:
   a. Magnitude of the undervoltage condition (±2% or 100 mV or whichever is greater for the 120 Vac pickup range or ±2% or 200 mV for the 240 Vac pickup range), and
   b. Selection of a particular response curve by the front panel TIME DIAL over the range of 01 to 99 (±5% or 25 mSec, whichever is greater) (Reference Figure 3.)

Undervoltage Inhibit

When the undervoltage measuring element is selected, an undervoltage inhibit circuit is included to monitor the generator terminal voltage. When the terminal voltage is less than the UNDERVOLTAGE INHIBIT setting on the front panel, the undervoltage sensing option is inhibited to prevent relay operation during start-up or shutdown of the generating unit.

The UNDERVOLTAGE INHIBIT range is continuously adjustable from 40 to 120 Vac for the 100/120 Vac sensing input, and 80 to 240 Vac for the 200/240 Vac input.

PICKUP ACCURACY

Relay pickup will not vary from its setting more than as follows for variations in input power or operating temperature within the specified limits.

For 120 Vac sensing range: ±2.0% or 100 millivolts, whichever is greater.

For 240 Vac sensing range: ±2.0% or 200 millivolts, whichever is greater.

DROPOUT RATIO

Overvoltage and undervoltage elements reset within 2.0% of their actual pickup level within seven cycles.

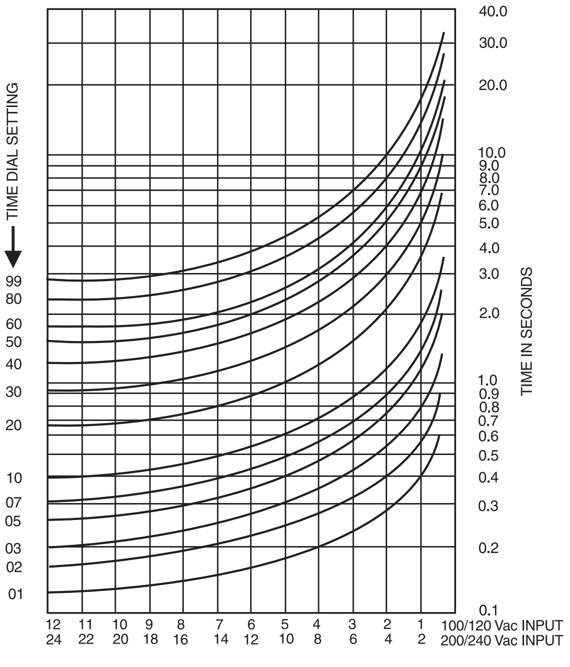


Figure 3 - Undervoltage Inverse Time Curve

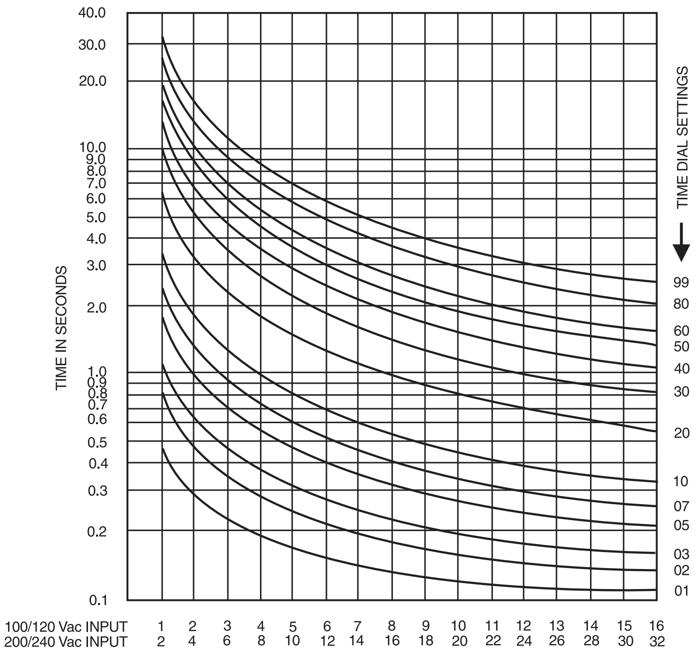


Figure 4 - Overvoltage Inverse Time Curve

SPECIFICATIONS (continued)

TIMING ACCURACY

Definite time is adjustable from 00.1 to 99.9 seconds, in steps of 0.1 seconds. Accuracy is within 2.0% or 100 milliseconds, whichever is greater.

Inverse time is adjustable from 01 to 99 in increments of 01. The setting defines a curve as illustrated in Figures 3 and 4. Inverse timing is accurate within ±5% or 25.0 milliseconds, whichever is greater, for any combination of time dial and pickup setting.

POWER SUPPLY

One of five power supply types may be selected to provide internal operating power. They are described in Table 1.

Table 1 - Power Supply Options

Type	K	J	L*	Y	Z
Nominal Voltage	48Vdc	125Vdc 120 Vac	24Vdc	48Vdc 125 Vdc	250 Vdc 240 Vac
Burden	3.4 W	3.6 W 22.1 VA	3.5 W	3.4 W 3.6 W	3.7 W 37.6 VA

*The type L power supply initially requires 14 Vdc to begin operation. Once operating, the input voltage may be reduced to 12 Vdc and operation will continue.

POWER SUPPLY STATUS OUTPUT

A normally closed output relay is provided, whose contact remains open when energized by the presence of nominal voltage at the output of the power supply. If the power supply voltage falls below requirements, the power supply status output relay will de-energize, closing its contact. A shorting bar is included in the relay case so that the status output terminals can provide a remote indication that the BE1-59N relay has been withdrawn from its case or taken out of service by removing the connection plug.

OUTPUTS

Output contacts are rated as follows:

Resistive
120 Vac - Make, break, and carry 7 Aac continuously.
250 Vdc - Make and carry 30 A for 0.2 s, carry 7 A continuously, break 0.3 A.
500 Vdc - Make and carry 15 A for 0.2 s, carry 7 A continuously, break 0.3 A.

Inductive
120 Vac, 125 Vdc, 250 Vdc - Break 0.3 A (L/R = 0.04).

Push-to Energize Output Switches

Momentary pushbuttons accessible by inserting a 1/8-inch diameter non-conducting rod through the front panel. Pushbuttons are used to energize the output relays in order to test system wiring.

TARGET INDICATORS

Electronically latched, manually reset target indicators are optionally available to indicate closure of the trip output contacts. Either internally operated or current operated targets may be specified. Internally operated targets should be selected when normally closed (NC) output contacts are specified. When current operated, the minimum rating is 200 mA through the trip circuit. The output circuit is limited to 30A for 1 s, 7A for 2 min, and 3A continuously.

SURGE WITHSTAND CAPABILITY

Qualified to IEEE C37.90.1-1989, Standard Surge Withstand Capability Test and IEC 255, Impulse Test and Dielectric Test.

MECHANICAL

Operating Temperature

-40°C (-40°F) to +70°C (+158°F)

Storage Temperature

-65°C (-85°F) to +100°C (+212°F)

Case Size: S1.

Weight

13.6 pounds (6.17Kg) maximum.

Shock

Withstands 15 G in each of three mutually perpendicular planes without structural damage or performance degradation.

Vibration

Withstands 2 G in each of three mutually perpendicular planes, swept over the range of 10 to 500 Hz for a total of six sweeps, 15 minutes for each sweep, without structural damage or performance degradation.

CONNECTIONS

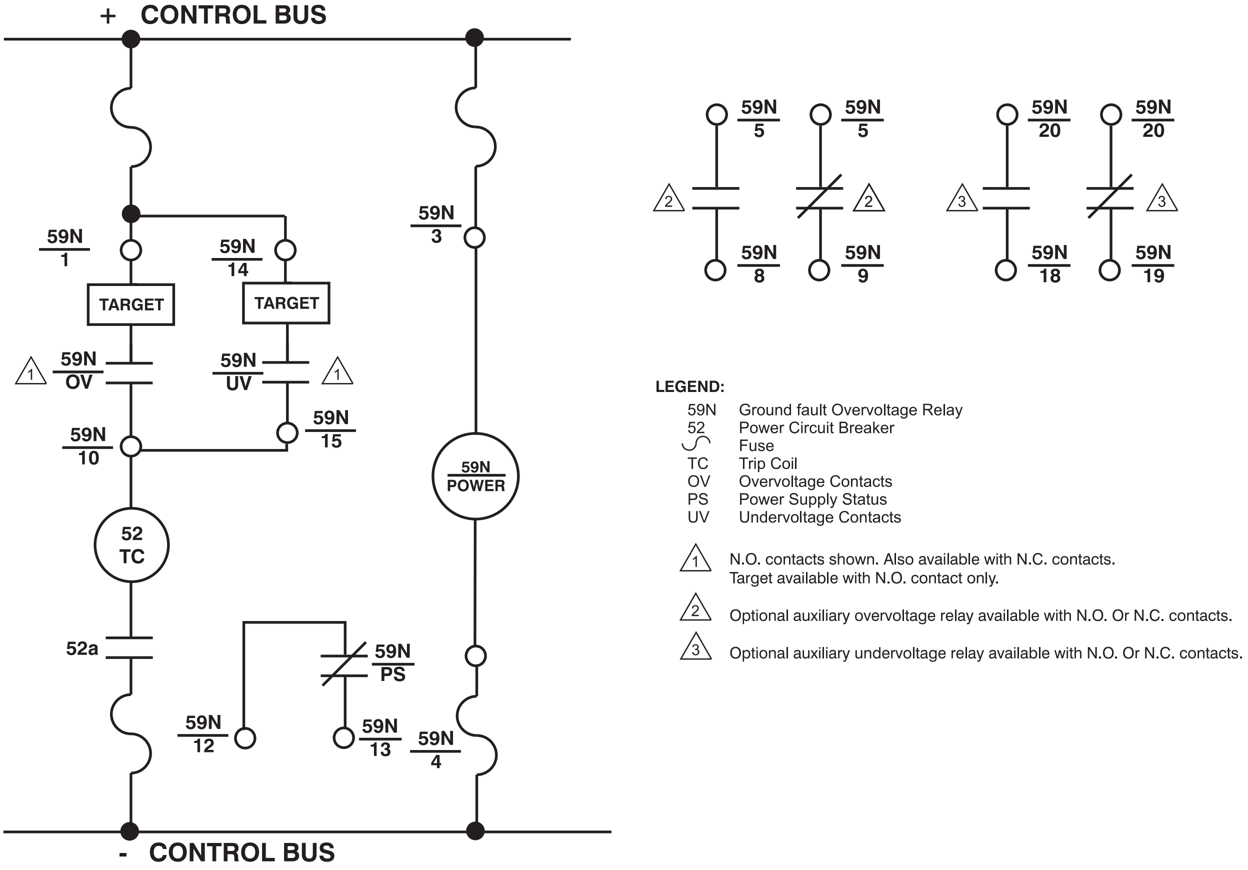
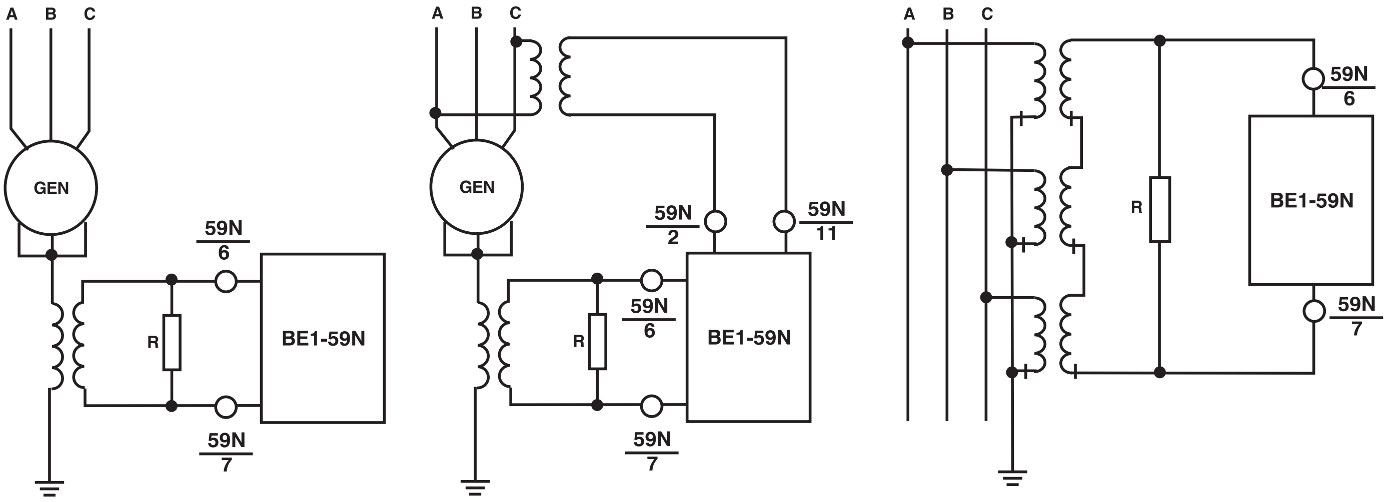


Figure 5 - Typical Control Circuit Connections



Ground Fault Overvoltage

Overlapping Ground Fault
(Undervoltage and Overvoltage)

Ungrounded System

Figure 6 - Voltage Sensing Connections

ORDERING

MODEL NUMBER

BE1-59N Ground Fault Overvoltage Relay

STYLE NUMBER

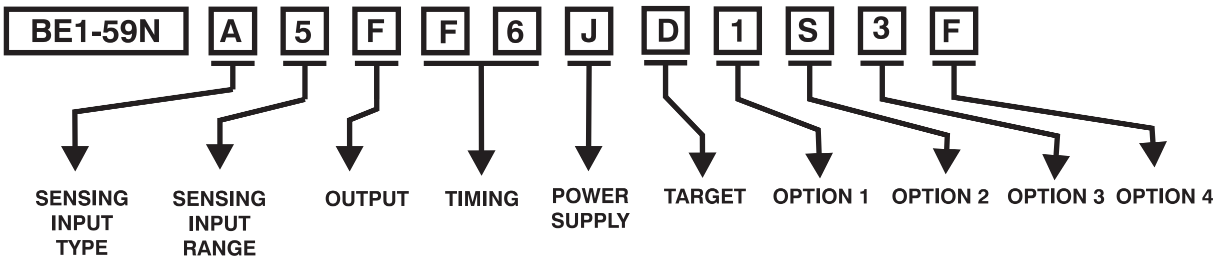
The style number appears on the front panel, drawout cradle, and inside the case assembly. This style number is an alphanumeric combination of characters identifying the features included in a particular unit. The sample style number below illustrates the manner in which the various features are designated. The Style Number Identification Chart (page 8) defines each of the options and characteristics available for this device.

SAMPLE STYLE NUMBER: A5FF6JD1S3F

The style number above describes a BE1-59N Ground Fault Overvoltage relay having the following features.

Sensing Input Type	(A)	Single-phase
Sensing Input Range	(5)	120 Vac, 60 Hz (nominal) with 1-20 Vac pickup range
Output	(F)	Two NO output relays: one for the overvoltage function and one for the undervoltage function
Timing	(F6)	Inverse for the overvoltage function: definite time for the undervoltage function
Power Supply	(J)	125 Vdc and 100/120 Vac
Target	(D)	Two (one for each function), current operated
Option 1	(1)	Undervoltage element
Option 2	(S)	Push-to-energize outputs
Option 3	(3)	Two NO auxiliary output relays (one per function)
Option 4	(F)	Semi-flush mounting

NOTE: The description of a complete relay must include both the model number and the style number.



SAMPLE STYLE NUMBER ILLUSTRATED

HOW TO ORDER:

Designate the model number followed by the complete Style Number.

BE1-59N Style Number ☐☐☐ ☐☐☐☐☐☐☐☐

Complete the Style Number by selecting one feature from each column of the Style Number Identification Chart and entering its designation letter or number into the appropriate square. (Two squares are used to indicate time delay characteristics.) All squares must be completed.

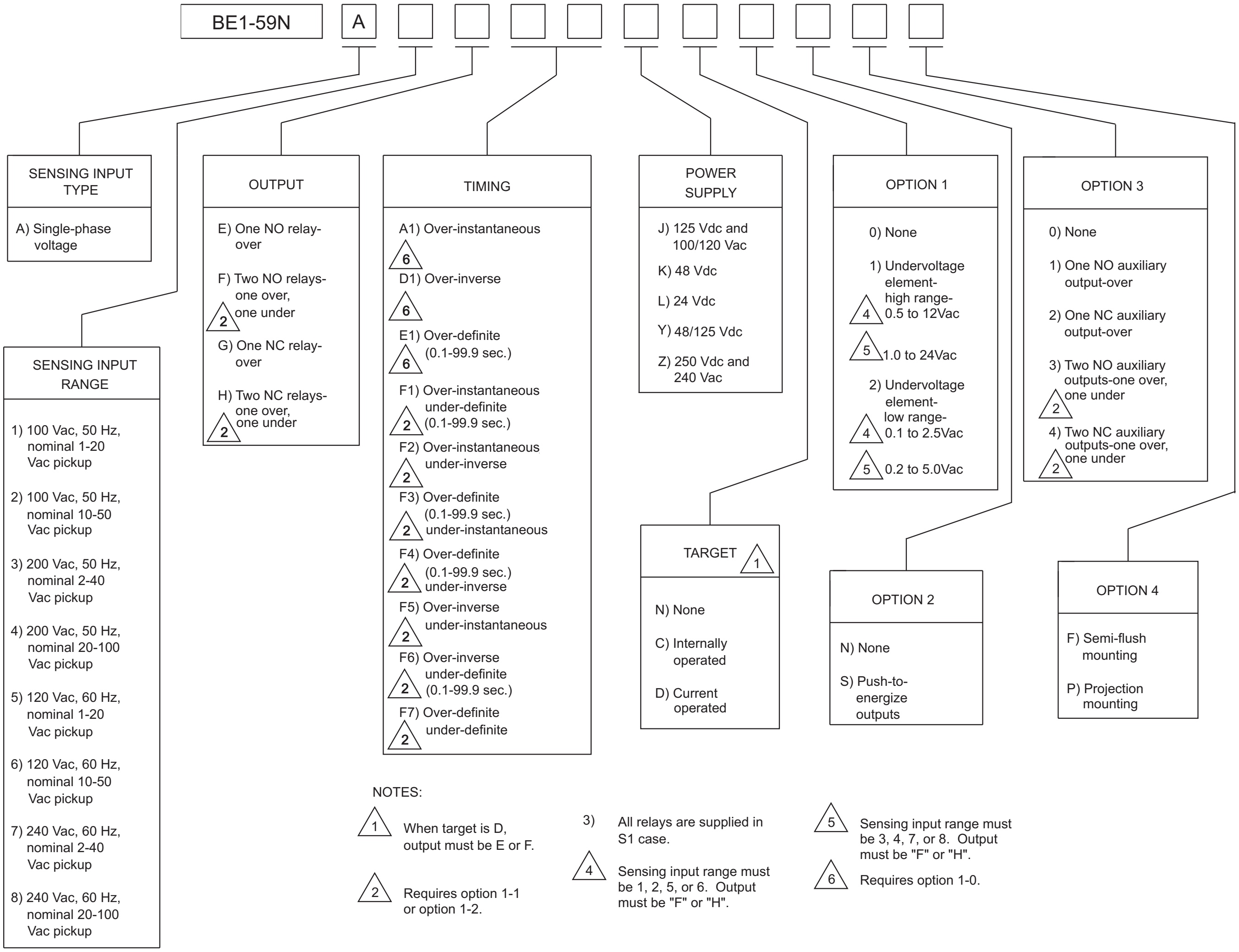
STANDARD ACCESSORY:

The following accessory is available for the BE1-59N Ground Fault Overvoltage Relay.

Test Plug

The test plug (Basler part number 10095) provides a quick, easy method of testing relays without removing them from their case. The test plug is simply substituted for the connection plug. This provides access to the external stud connections and to the internal circuitry.

STYLE NUMBER IDENTIFICATION CHART



BE1-59N A ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

SENSING INPUT TYPE
- A) Single-phase voltage

SENSING INPUT RANGE
- 1) 100 Vac, 50 Hz, nominal 1-20 Vac pickup
- 2) 100 Vac, 50 Hz, nominal 10-50 Vac pickup
- 3) 200 Vac, 50 Hz, nominal 2-40 Vac pickup
- 4) 200 Vac, 50 Hz, nominal 20-100 Vac pickup
- 5) 120 Vac, 60 Hz, nominal 1-20 Vac pickup
- 6) 120 Vac, 60 Hz, nominal 10-50 Vac pickup
- 7) 240 Vac, 60 Hz, nominal 2-40 Vac pickup
- 8) 240 Vac, 60 Hz, nominal 20-100 Vac pickup

OUTPUT
- E) One NO relay-over
- F) Two NO relays-one over, one under △2
- G) One NC relay-over
- H) Two NC relays-one over, one under △2

TIMING
- A1) Over-instantaneous △6
- D1) Over-inverse △6
- E1) Over-definite (0.1-99.9 sec.) △6
- F1) Over-instantaneous under-definite (0.1-99.9 sec.) △2
- F2) Over-instantaneous under-inverse △2
- F3) Over-definite (0.1-99.9 sec.) under-instantaneous △2
- F4) Over-definite (0.1-99.9 sec.) under-inverse △2
- F5) Over-inverse under-instantaneous △2
- F6) Over-inverse under-definite (0.1-99.9 sec.) △2
- F7) Over-definite under-definite △2

POWER SUPPLY
- J) 125 Vdc and 100/120 Vac
- K) 48 Vdc
- L) 24 Vdc
- Y) 48/125 Vdc
- Z) 250 Vdc and 240 Vac

TARGET △1
- N) None
- C) Internally operated
- D) Current operated

OPTION 1
- 0) None
- 1) Undervoltage element-high range-
  - △4 0.5 to 12Vac
  - △5 1.0 to 24Vac
- 2) Undervoltage element-low range-
  - △4 0.1 to 2.5Vac
  - △5 0.2 to 5.0Vac

OPTION 2
- N) None
- S) Push-to-energize outputs

OPTION 3
- 0) None
- 1) One NO auxiliary output-over
- 2) One NC auxiliary output-over
- 3) Two NO auxiliary outputs-one over, one under △2
- 4) Two NC auxiliary outputs-one over, one under △2

OPTION 4
- F) Semi-flush mounting
- P) Projection mounting

NOTES:

△1 When target is D, output must be E or F.

△2 Requires option 1-1 or option 1-2.

3) All relays are supplied in S1 case.

△4 Sensing input range must be 1, 2, 5, or 6. Output must be "F" or "H".

△5 Sensing input range must be 3, 4, 7, or 8. Output must be "F" or "H".

△6 Requires option 1-0.

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Printed in U.S.A.

CVD Relay

Effective: January 1996

NEW INFORMATION

CAUTION

Before putting relays into service, remove all blocking which may have been inserted for the purpose of securing the parts during shipment, make sure that all moving parts operate freely, inspect the contacts to see that they are clean and close properly, and operate the relay to check the settings and electrical connections.

1.0 APPLICATION

These relays are used to initiate switching or control operations when the line voltage rises above a preset value or falls below a preset value. Thus the relay is a contact making voltmeter with high and low voltage contacts.

2.0 CONSTRUCTION AND OPERATION

2.1 Voltage Unit

The voltage unit operates on the induction disc principle. A main coil located on the center leg of an "E" type laminated structure produces a flux which divides and returns through the outer legs. A shading coil causes the flux through the left leg (front view) to lag the main pole flux. The out-of-phase fluxes thus produced in the air gap causes torque on the disc which moves to a position in its travel that corresponds to the voltage applied to the electromagnet. The disc will remain in this position until the applied voltage is changed at which time, the disc will move to a new position that corresponds to the new voltage.

2.2 Indicating Contactor Switch (ICS)

The indicating contactor switch is a small dc operated clapper type device. A magnetic armature, to which leaf-spring mounted contacts are attached, is attracted to the magnetic core upon energization of the switch. When the switch closes, the moving contacts bridge two stationary contacts, completing the trip circuit. Also during this operation, two fingers on the armature deflect a spring located on the front of the switch, which allows the operation indicator target to drop. The target is reset from the outside of the case by a push rod located at the bottom of the case.

The front spring, in addition to holding the target, provides restraint for the armature and thus controls the pickup value of the switch.

3.0 CHARACTERISTICS

3.1 Voltage Unit

The type CVD relay has adjustable lower and raise voltage contacts that can be set around a calibrated scale. The moving contacts will assume a position corresponding to the voltage applied to the relay and will stay in that position until the voltage changes. If the voltage changes either gradually or suddenly, the contact will assume a new position corresponding to the change unless the travel is limited by the setting of the adjustable contacts.

The voltage unit has inverse timing; that is, the greater the change in voltage, the faster the relay contact will travel. If the voltage on the voltage unit is barely sufficient to close the contacts, the contact resistance at this light pressure may reduce the voltage on the time-delay unit sufficiently to cause a substantial increase in the time. If the voltage change is 1/2 to 1 volt greater than that required to barely close the voltage unit contacts, this effect is negligible.

3.2 Trip Circuit

The main contacts will close 30 amperes at 250 volts dc and the seal-in contacts of the indicating contactor switch (ICS) will carry this current long enough to trip a circuit breaker.

The indicating contactor switch (ICS) has two taps that provide a pickup setting of 0.2 or 2 amperes. To change taps requires connecting the lead located in front of the desired setting by means of a screw connection.

4.0 ENERGY REQUIREMENTS

See Table I.

5.0 SETTINGS

5.1 Voltage Unit

These are independent relay adjustments. These are the high voltage and low voltage contact settings as described under Section 3, Characteristics.

5.2 Indicating Contactor Switch (ICS)

No setting is required on the ICS unit except the selection of the 0.2 or 2.0 ampere tap setting. This selection is made by connecting the lead located in front of the tap block to the desired setting by means of the connecting screw.

6.0 INSTALLATION

The relays should be mounted on switchboard panels or their equivalent in a location free from dirt, moisture, excessive vibration, and heat. Mount the relay vertically by means of the four mounting holes on the flange for semi-flush mounting or by means of the rear mounting stud or studs for projection mounting. Either a mounting stud or the mounting screws may be utilized for grounding the relay. The electrical connections may be made directly to the terminals by means of screws for steel panel mounting or to the terminal studs furnished with the relay for thick panel counting. The terminal studs may be easily removed or inserted by locking two nuts on the stud and then turning the proper nut with a wrench.

For detailed FT Case Information refer to I.L. 41-076.

7.0 ADJUSTMENTS AND MAINTENANCE

7.1 Acceptance Check

a. Contacts
Set the left-hand adjustable contact in the center of the scale and adjust the voltage until the moving contact just makes. Set the left-hand contact back out of the way and bring the right-hand contact up until the contacts just make. The pointer should be within 1/32 inch of where the left-hand pointer was.

b. Calibration Check
Check the scale markings by setting either of the two contacts at a value marked on the scale, then alternately apply this voltage ±5%. Contacts should make and break respectively.

TABLE I
60 CYCLE BURDEN OF THE CVD RELAY AT CONTINUOUS RATING

Range	Continuous Rating	Burden	Power Factor Angle †	Watts
15 - 60	65 volts	7.85 VA	70°	2.68
30 - 120	132 volts	7.85 VA	70°	2.68
40 - 160	176 volts	7.85 VA	70°	2.68
80 - 320	352 volts	7.85 VA	70°	2.68
105 - 135	148 volts	16.5 VA	78°	3.43
180 - 320	254 volts	16.5 VA	78°	3.43
210 - 270	296 volts	16.5 VA	78°	3.43

† Degrees current lags voltage.

8.0 CALIBRATION

8.1 Voltage Unit

a. Contacts
Apply sufficient voltage to the relay to make the disc float in the center of its travel. Move both of the adjustable contacts until they just make with the moving contacts. If the contact pointers do not meet at the same point on the scale, adjust the follow on both stationary contacts. Approximately the same follow should be in each of the adjustable stationary contacts.

b. Calibration Check
The adjustment of the spring tension in calibrating the relay is most conveniently made with the damping magnet removed.

Set either of the adjustable stationary contacts in the center of its travel and apply this voltage to the relay. Wind up the spiral spring by means of the spring adjuster until the stationary contact and moving contact just makes.

Check the other scale markings by setting the adjustable contact on these markings and applying the corresponding voltage to the relay. The contacts should make within ±5% of scale markings.

c. Time-Curve
Adjust the permanent magnet keeper to calibrate for the operate times (±5%) given in Table II.

8.2 Indicating Contactor Switch (ICS)

Close the main relay contacts and pass sufficient dc current through the trip circuit to close the contacts of the ICS. This value of current should not be greater than the particular ICS setting being used. The indicator target should drop freely.

For proper contact adjustment, insert a.030” feeler gauge between the core pin and the armature. Hold the armature closed against the core pin and gauge and adjust the stationary contacts such that they just make with the moving contact. Both stationary contacts should make at approximately the same time. The contact follow will be approximately 1/64” to 3/64”.

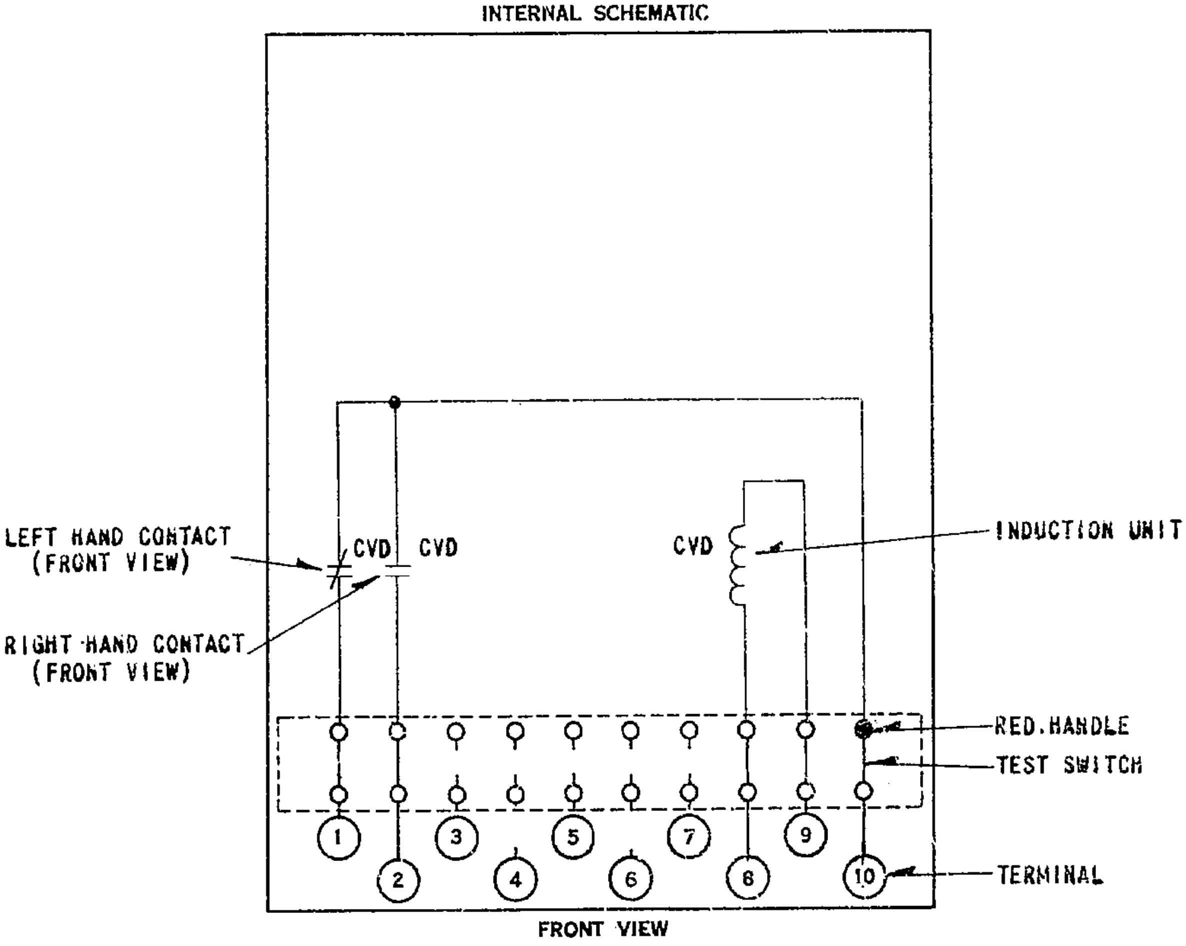
9.0 RENEWAL PARTS

Repair work can be done most satisfactorily at the factory. However, interchangeable parts can be furnished to the customers who are equipped for doing repair work. When ordering parts, always give the complete nameplate data.

TABLE II

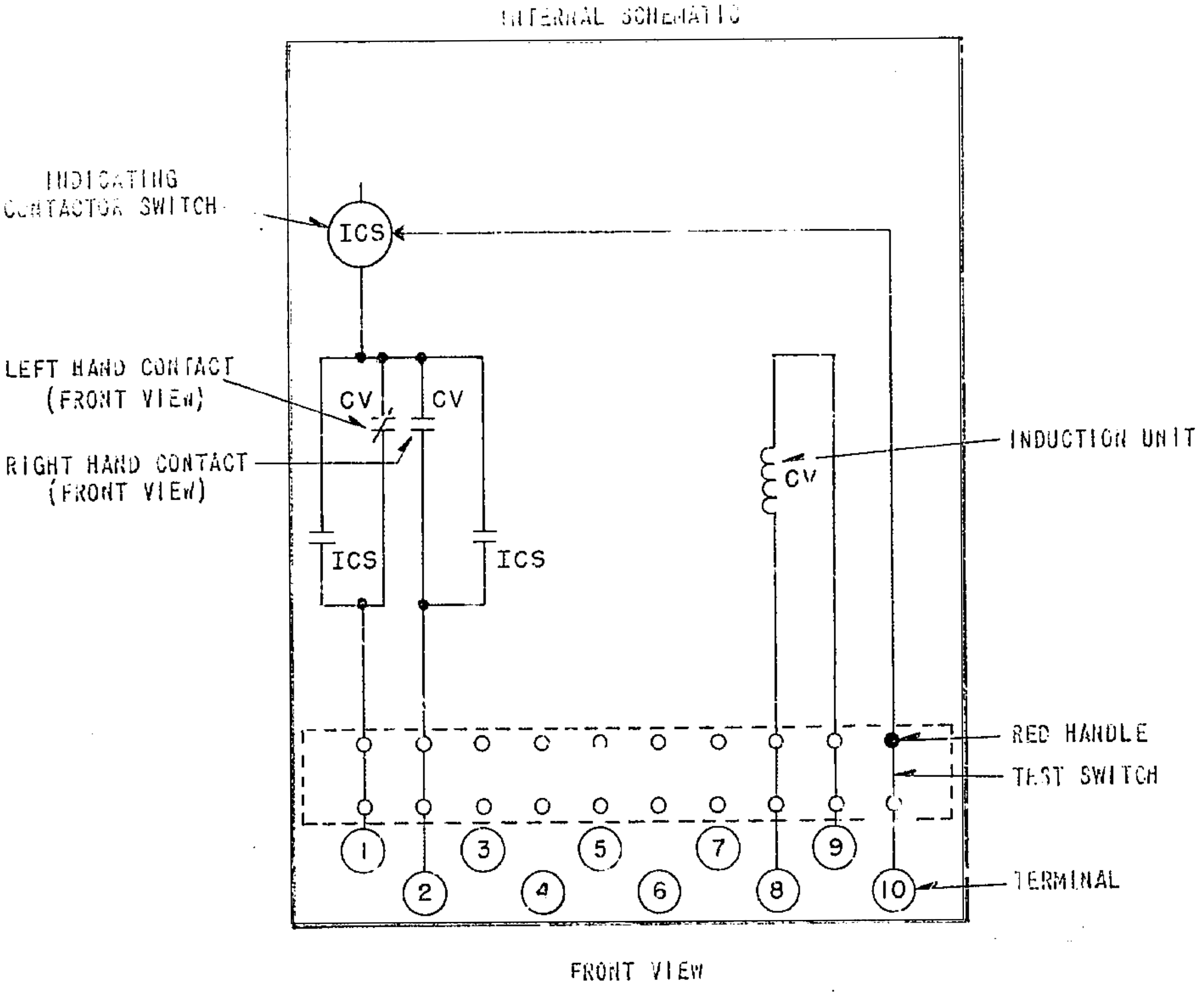
Relay Rating (Volts)	Under Voltage Contact Setting	Over Voltage Contact Setting	Test Voltage From	Test Voltage To	Operate Time (Seconds)
15 - 60	15	34	0	68	1.9
30 - 120 (1.5 sec.)	40	120	65	0	1.5
30 - 120 (2.0 sec.)	66	80	66	120	2.0
40 - 160	40	91	0	182	1.9
80 - 320	80	182	0	364	1.19
105 - 135 [†]	117	123	120	130	7.5
180 - 230	234	246 240	240 220	260	7.5
210 - 270 [†]	200	210 205	205 188	222	7.5

[†] Allow relay to heat for 30 minutes.



Sub 1
184A176

Figure 1. Type CVD Voltage Relay in Type FT-11 Case



Sub 1
184A793

Figure 2. Type CVD Voltage Relay with ICS Unit in Type FT-11 Case

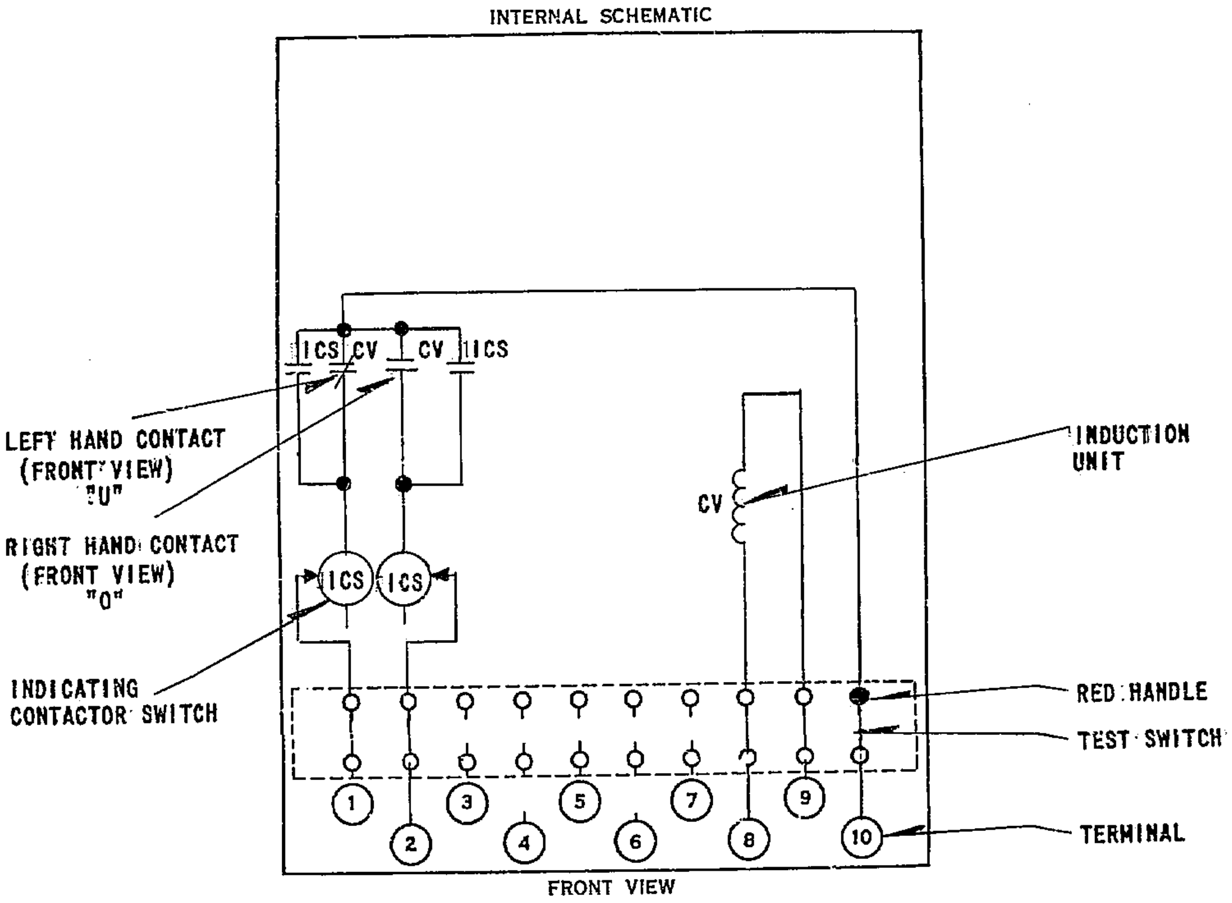


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Figure 3. Type CVD Voltage Relay with Two (2) ICS Units in Type FT-11 Case

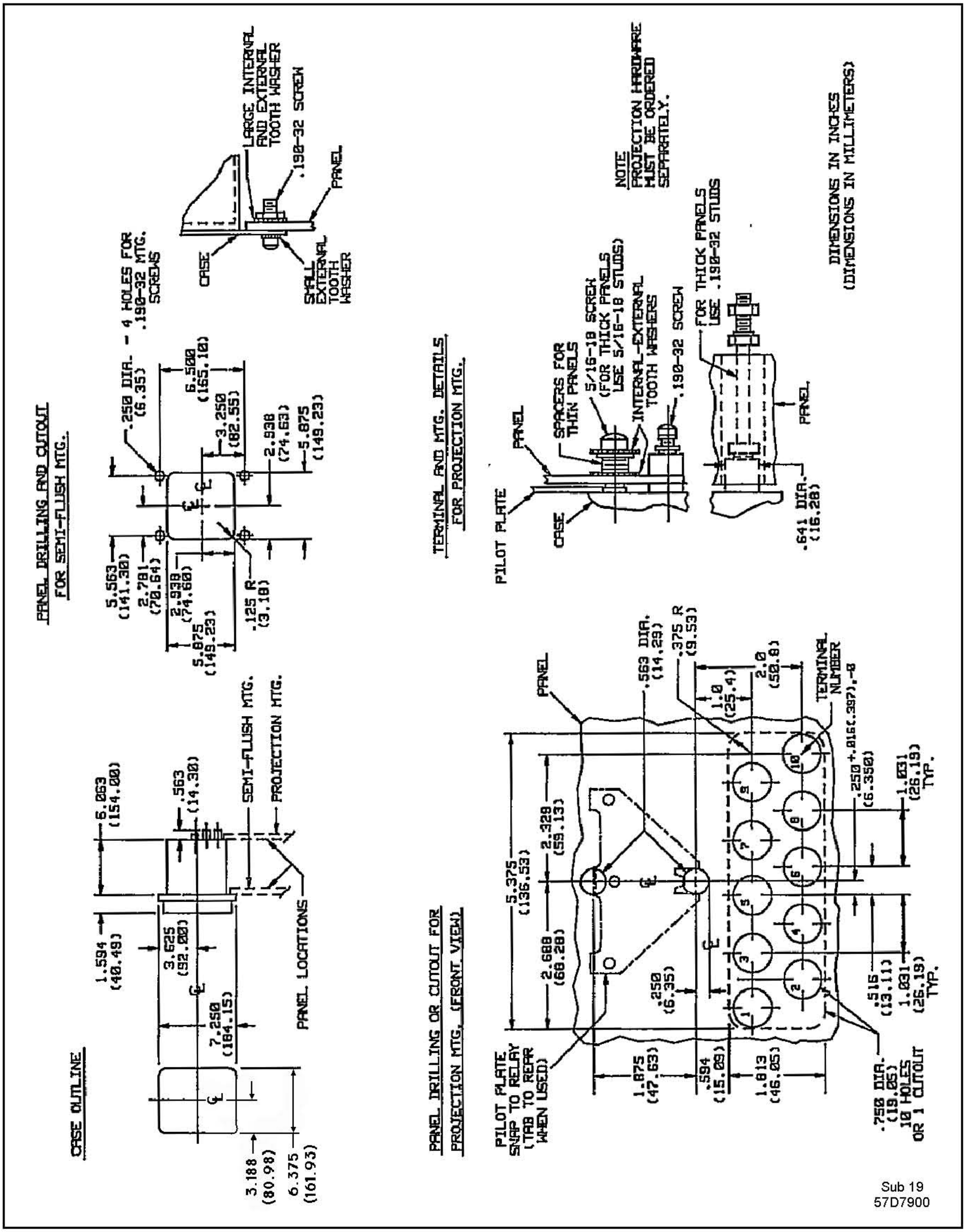

Figure 4. Outline and Drilling Plan for CVD Relay in Type FT-11 Case.

IL 41-201.3 - New Information

ABB Inc.

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Coral Springs, Florida 33065

Telephone: +1 954-752-6700
Fax: +1 954-345-5329

www.abb.com/substation automation

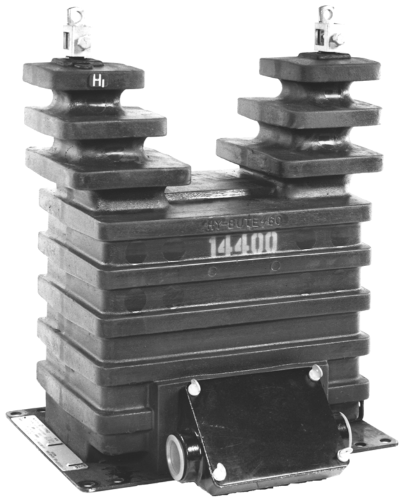
2,400 V to 14,400 V BIL 75 kV to 110 kV
Outdoor Voltage

JVW-4/JVW-5

60 Hz

AVAILABLE

When choosing your GE Instrument Transformer, don't forget to explore the benefits of using GE's 0.15 accuracy class AccuBute line. See page 2.10.



JVW-4 -5, two-bushing model

Application

Designed for outdoor service; suitable for operating meters, instruments, relays, and control devices.

Thermal Rating (Volt-Amperes)

55°C Rise above 30°C Ambient 1500

ANSI Meter Accuracy Classification, 60 Hz

Operated at rated voltage
  W, X, M, Y, Z; all models 0.3
  ZZ; all models 1.2
Operated at 58% of rated voltage ②
  W, X, M, Y; all models 0.3
  Z; all models 1.2
Burden impedance as at rated voltage, but operated at 58% of rated voltage ③
  W', X' M', Y', Z'; all models 0.3

Weight - Shipping/Net

(approximate, in pounds)

Transformer 120/105

Reference Drawings

JVW-4

Accuracy Curve at
120 Secondary Volts, 60 Hz 9689241659
Excitation Curves:
  60:1 & 70:1 9689241591
  100:1 & 120:1 9689241629
Outline Drawing; Two-Bushing
Transformer 9932529
Wiring Diagram .... refer to page 42, figure 5

JVW-4/JVW-5 DATA TABLE

Line-To-Line Circuit Voltage For Permissible Primary Connection				Transformer Rating ①		Catalog Number		
						JVW-4	JVW-5	
						BIL 75 kV	BIL 110 kV	
Δ	Y	Y Only	GY Only ④	Primary Voltage	Ratio	Two-Bushing Model	Single-Bushing Model	Two-Bushing Model
2,400	2,400	4,160	---	2,400	20:1	**764X030011**	---	---
4,200	4,200	7,280	---	4,200	35:1	**764X030012**	---	---
4,800	4,800	8,320	---	4,800	40:1	**764X030013**	---	---
7,200	7,200	---	---	7,200	60:1	**764X030014**	---	---
---	---	---	7200 ⑤	7,200	60:1	---	**765X030051**	**765X030042**
---	---	---	8400 ⑥	8,400	70:1	---	**765X030052**	**765X030044**
12,000	12,000	12,000	---	12,000	100:1	---	---	**765X030045**
14,400	14,400	14,400	---	14,400	120:1	---	---	**765X030046**

Notes:

① For continuous operation, the transformer-rated primary voltage should not be exceeded by more than 10%. Under emergency conditions, over-voltage must be limited to 1.25 times the transformer primary-voltage rating for two-bushing models, and 1.40 times the rating for single-bushing models.

② Applies to transformers connected Y-Y on a circuit in which the line-to-line voltage is the same as the transformer-rated primary voltage. In each case, the transformer is operated with reduced voltage and reduced excitation (58% of normal). In determining the accuracy classification under such conditions, the Volt-Ampere rating of the burden is maintained constant, regardless of the transformer secondary voltage.

③ The prime symbol (') is used to signify that these burdens do not correspond to standard ANSI definitions.

④ Single-bushing design with removable grounding strap.

⑤ 12,470 in Y configuration.

⑥ 14,560 in Y configuration.

JVW-5

Accuracy Curve at 120 Secondary Volts, 60 Hz	9689241659
Excitation Curves:	
60:1 & 70:1	9689241591
100:1 & 120:1	9689241629
OutlineDrawings:	
Two-Bushing Model	9932529
Single-Bushing Model	9932530
Wiring Diagram	refer to page 42, figure 5

Accessories	Catalog Number
Mounting Hardware	
"L" Mounting Brackets	8944634002
Channel Bracket	5466227001
Suspension Hooks	8944630001
Secondary Conduit Box	9689897001

Construction and Insulation

Please refer to General Product Information, item 1.4.

Core and Coils

Please refer to General Product Information, item 3.8.

Primary
Terminals

Please refer to General Product Information, item 4.6.

Secondary
Terminals

Please refer to General Product Information, item 4.18.

Ground Terminal

Please refer to General Product Information, item 4.23.

Conduit Box

Please refer to General Product Information, item 12.1.

Polarity

Please refer to General Product Information, item 7.2.

Baseplate and Mounting

Please refer to General Product Information, items 5.3, 5.15, and the Applications Information Section of this volume.

Nameplate

Please refer to General Product Information, item 6.4.

Rating Identification

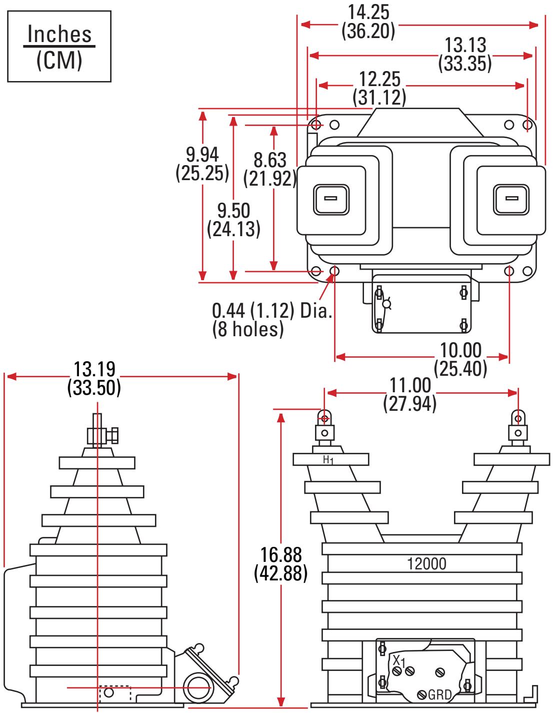
Please refer to General Product Information, item 13.1.

Maintenance

Please refer to General Product Information, item 10.1 and pages 24-27.

Note:

1. Voltage transformers of this type are available for use in 50 Hz applications in many ratings. However, Industry Standard IEEE 57.13 to which we test transformers does not apply at 50 Hz. Customers who order voltage transformers for 50 Hz application should provide an accuracy specification including Burden VA and Power Factor. If an accuracy specification is not made available, the transformer(s) will be tested at 60 Hz with test burdens as defined in IEEE 57.13 for 60 Hz application.



JVW-4/JVW-5 mechanical dimensions