GET-6462A

Application Guide
AC Pilot Wire Relaying System
SPD and SPA Relays

CONTENTS

AC PILOT WIRE RELAYING SYSTEM
SPD AND SPA RELAYS

SUMMARY OF FEATURES

Type SPD Relay -

1. High-speed Static Pilot Wire Relay
   - Protection for phase or ground faults.
   - No ac potential source required.
   - Insulating transformer internal.
2. Applicable on Two- or Three-Terminal Lines
3. Excellent Sensitivity on Short Lines.
4. Provision for Sensitive Ground Fault Detection.
   - Input from ground sensor CT.
   - Ideal for resistance grounded systems.
5. High Speed
   - 15 m.s. on heavy faults.
   - 25 m.s. or less on light to moderate faults.
6. Permits High-speed Reclosing.
7. Neutralizing Reactor and Drainage Reactor Available.
8. Case Fully Drawout.

Type SPA Relay -

1. Complete Monitoring of Pilot Circuit.
   - Detects open, shorted, grounded or reversed pilot.
   - LED indication.
2. Transfer-trip Feature Available.
   - One-way or two-way.
3. Complete Isolation of DC Supply.
   - Prevents SPD misoperation from battery ground.
   - Prevents grounded pilot from operating station dc ground monitor.
4. Case Fully Drawout.

APPLICATION GUIDE
AC PILOT WIRE RELAYING SYSTEM
SPD AND SPA RELAYS

INTRODUCTION

The Type SPD relay provides selective high-speed clearing of all faults on a protected line, using a pilot wire circuit to compare line currents at all terminals of the line. Simultaneous clearing at all terminals minimizes damage, permits high-speed reclosing and improves the transient stability of the system.

Since the pilot wire system circulates a current that is a function of the line current, it is similar to current differential relaying. The scheme is easily applied, requires a minimum of system data, and being inherently selective is not affected by the settings of other relays or by changes in the system. The scheme operates on current alone and requires no potential transformers or channel equipment. A separate input to the sequence network can be fed from a ground sensor current transformer to provide sensitive ground fault protection on resistance-grounded systems.

The Type SPA static auxiliary relays provide continuous monitoring of the pilot wire circuit to detect open, shorted, reversed or grounded pilot wires. Models are also available to provide for transfer trip in addition to the monitoring function.

DESCRIPTION AND OPERATING PRINCIPLES
TYPE SPD RELAY

The Type SPD relay is a high-speed static pilot wire relay which provides both phase and ground fault protection for two- or three-terminal transmission or distribution lines. The relaying scheme, which operates on the circulating current principle, is represented by the simplified schematic diagram in Figure 1 for a two-terminal line. The principal functions included in the Type SPD relay, and shown in the schematic diagram, are a phase sequence network, a voltage limiting circuit, a restraint circuit, an operate circuit, and an insulating transformer. In the following paragraphs each of these functions is discussed, and the operating principles of the circulating current scheme are described.

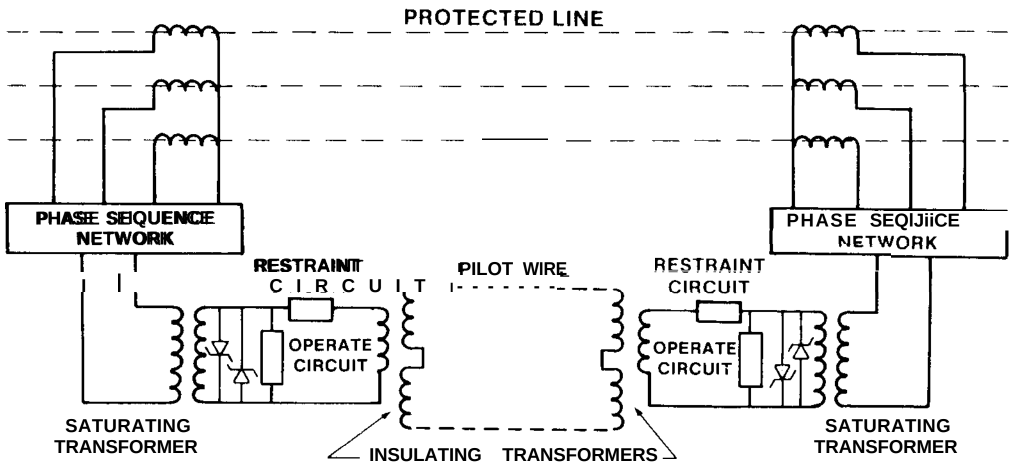


Figure 1. Simplified Functional Diagram of the SPD Relay System

PHASE SEQUENCE NETWORK

The phase sequence network is connected to the current transformers in the three phases as illustrated in Figure 1. This network converts the three phase currents from the line current transformers into a single-phase voltage which is applied to the relay circuits via the saturating transformer.

VOLTAGE LIMITING CIRCUIT

The voltage limiting circuit, which consists of the saturating transformer and zener diodes, limits the relay output voltage that is applied to the pilot circuit via the insulating transformer. This circuit limits the instantaneous peak value of the sequence filter output voltage to 15 volts, and the pilot wire voltage to 60 volts. Thus, for light currents the output of the voltage limiting circuit will be a sine wave, for moderate currents on the order of five times the open-ended pickup of the relay the output will be a clipped sine wave, and for heavy fault currents the output will approach a square wave.

OPERATING AND RESTRAINING CIRCUITS

The sensing circuit responds to a voltage proportional to the current flowing into the pilot wires as a restraining quantity, and to the resulting voltage across the pilot wire pair as an operating quantity. The relative position in the circuit of these restraining and operating functions is shown in the simplified diagram of Figure 1. Pickup for the open pilot wire condition is 3.25 volts across the operate circuit, or 13 volts on the pilot wire side of the insulating transformer.

For the two-terminal line application shown in Figure 1, the relay circuits at the two ends are connected so that during an external fault the voltages applied to the pilot pair at opposite ends are equal in magnitude but reversed in polarity. The voltages are thus additive around the pilot loop, a relatively large current will circulate, and the voltage across the operate circuit will below. The relays will restrain with this condition of high pilot wire current and low pilot wire voltage.

During an internal fault the voltages applied to the pilot pair, although not necessarily equal in magnitude, are essentially in phase and oppose current flow around the pilot loop. Consequently there will be a relatively large voltage and a small current; the static circuitry is designed to operate for this condition.

INSULATING TRANSFORMER

The insulating transformer, which is mounted inside the SPD relay case, acts as an impedance matching device between the relay circuit and the pilot wires. The primary winding is connected to the restraint and operate circuits; the two secondary windings are connected in series across the pilot wires as shown in the functional diagram in Figure 1. The turns ratio is one to four from the relay side of the transformer to the pilot wire side.

STATIC LEVEL DETECTOR LOGIC

Also included, but not shown in Figure 1, is a level detector logic which is part of a printed circuit card. The voltage and current measuring functions are also on this printed circuit card.

The level detector logic consists of a summation amplifier, level detector and timer. The output voltage signals from the restraint and operate circuits are applied to the summation amplifier, as shown in the functional block diagram in Figure 2. The sum-

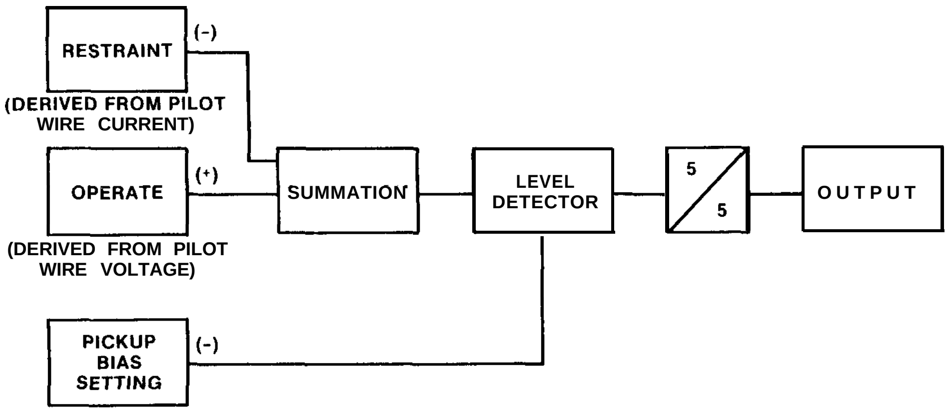


Figure 2. Functional Block Diagram of SPD Pilot Wire Scheme

mation amplifier output is applied to the level detector, the operating point of which is determined by the pickup biassetting. Thesummation amplifier, level detector and timer determine whether the operate quantity exceeds the restraint quantity by more than the pickup bias setting for a time interval longer than the timer setting. When this occurs the 5/5 timer will initiate a trip output. The timer designation 5/5 defines operate and reset times of 5 milliseconds.

Assuming ideal conditions, the output of the restraint circuit always predominates during external faults, whereas during internal faults the output of the operate circuit always predominates.

The 5 milliseconds time-delay following the level detector provides added security during external faults, where conditions might not be ideal because of unequal saturation of the CT's at opposite ends of the line, or because of a phase angle shift between the operate and restraint quantities caused by charging of the shunt capacitance in the pilot wires.

GENERAL

Additional functions included in the Type SPD relay are a regulated dc power supply, an electromechanical output relay, and a target seal-in unit. These and the other functions noted above are shown on the functional block diagram in Figure 3.

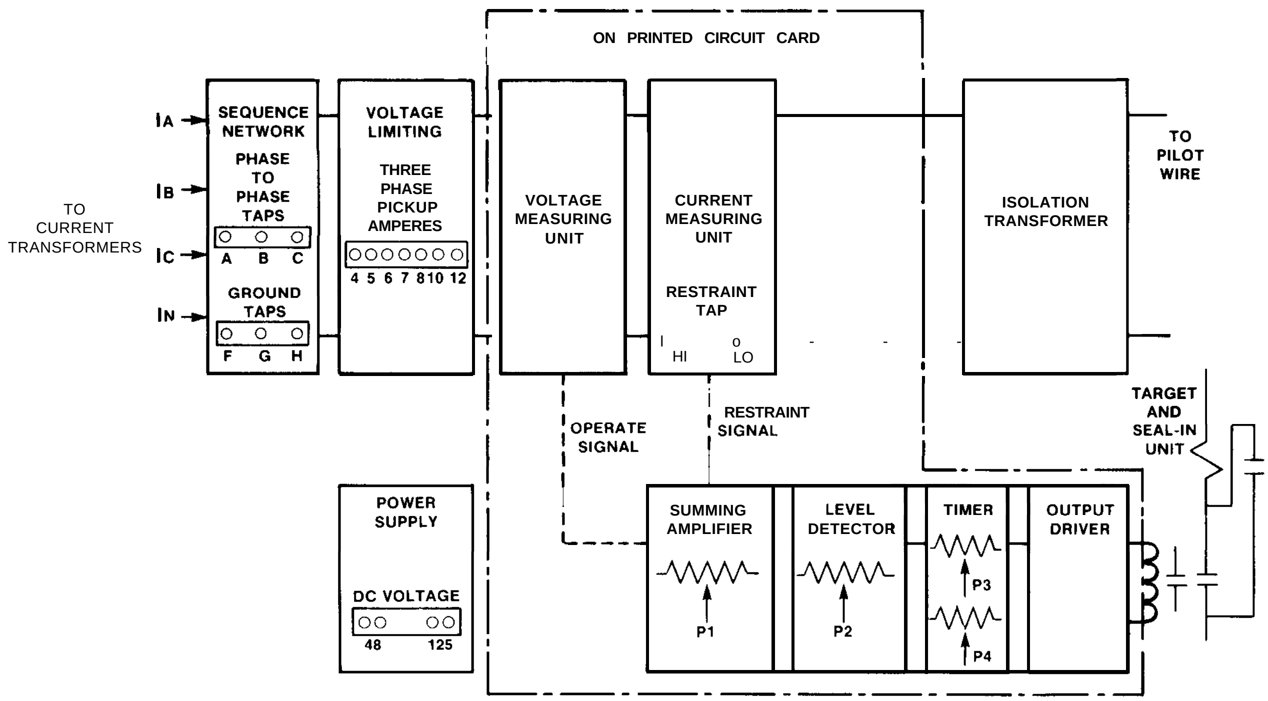


Figure 3. SPD Relay Block Diagram

SETTINGS AND CHARACTERISTICS

CURRENT TAPS

The sensitivity of the relay for the various types of faults is determined by three tap block settings, as well as by the pilot wire length and the number of line terminals. The three tap settings, which can be made from the front of the relay as is apparent from the photograph in Figure 4, are the three-phase pickup tap, the phase-to-phase tap and the ground tap.

The three-phase pickup taps, which are 4,5,6,7,8, 10 or 12 amperes, determine the basic pickup level of the relay. Relay pickup values expressed as multiples of the three-phase pickup tap setting are listed in Table 1 forthevarious phase-to-phaseand ground tap settings with three-phase, phase-to-phase or phase-to-ground faults. The values in the table apply for the theoretical condition of single-end feed and the pilot wires disconnected at the relay terminals. With single-end feed and pilot wires connected to relays at both ends of a two terminal line, the factors in the table would be doubled, neglecting the effect of the pilot wires. The information in Table I, as well as the effect of the pilot wires on relay pickup, is discussed in more detail in the section on APPLICATION.

Table I shows that the phase-to-phase tap position C provides the best sensitivity (lowest pickup) for phase faults, and also the closest agreement between the pickup currents for three-phase and phase-to-phase faults. Since it is true in most cases that the positiveand negativesequence impedances are equal, fault current for a phase-to-phase fault will be 86 percent of the current for a three-phase fault at the same location and with the same system conditions. Thus, use of the C tap assures that the relay will operate for the minimum expected phase-to-phase fault if it operates for the minimum three-phase fault at the same location.

If the three-phase pickup tap is set below maximum possible load with the C tap setting, the relay may operate on some load conditions if the pilot

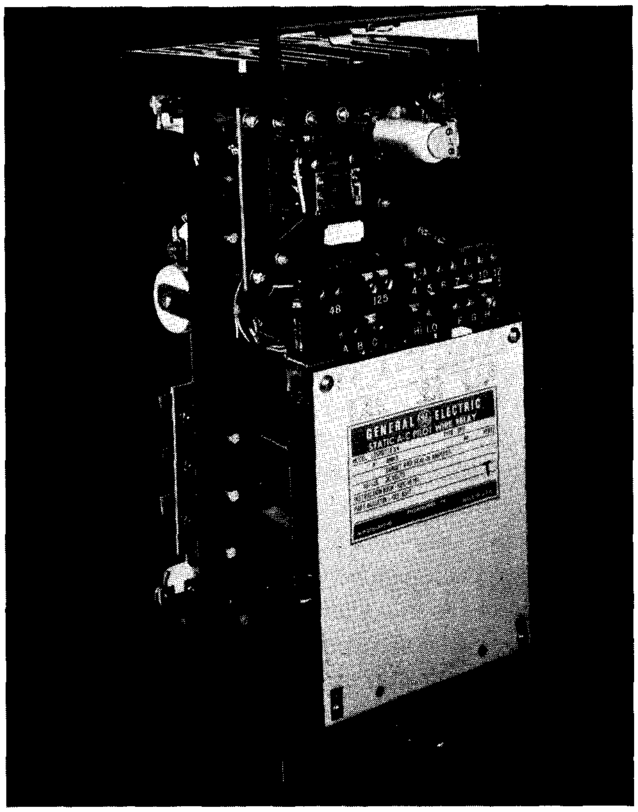


Figure 4. Type SPD Relay, Front View, Removed, From Case

Table 1
Relay Pickup in Multiples of Three-Phase Pickup Tap Setting*

Phase-Phase Tap	Ground Tap	3-Phase Fault	Phase-to-Phase Faults			Ground Faults		
			A-B	B-C	C-A	A	B	C
A	F#	**	1.0	1.0	1.0	1.0	1.8	1.8
A	G	**	1.0	1.0	1.0	.23	.27	.27
A	H	**	1.0	1.0	1.0	.13	.14	.14
B	F#	2.0	.90	.65	.90	2.0	1.2	1.3
B	G	2.0	.90	.65	.90	.23	.27	.27
B	H	2.0	.90	.65	.90	.13	.14	.14
C	F#	1.0	.86	.53	.86	2.4	1.0	1.0
C	G	1.0	.86	.53	.86	.23	.26	.22
C	H	1.0	.86	.53	.86	.13	.13	.13

*Available three-phase pickup taps are 4, 5,6, 7,8, 10 and 12 amperes. Relay pickup forsingle-end feed with the pilot wires disconnected from the relay terminals can be found by multiplying the three-phase current tap setting in amperes times the factor in the table for the particular fault type and the phase-to-phase & ground tap settings.

**When the "A" tap is used the relay will not respond to balanced 3-phase faults.

#When the "F" ground tap is used the relay will not respond to the zero sequence component of fault current, but will respond to the positive and negative sequence components, resulting in the pickup multiple shown in the table.

Refer to Instruction Book GEK-49794 and Apparatus Handbook Section 7278 for further information on the SPD relay.

wires are open circuited. This may be an acceptable risk if the desired three-phase fault sensitivity is to be realized, since the monitoring equipment described in a later section will sound an alarm on an open pilot.

Another approach is to use the B phase-to-phase tap setting, which doubles the pickup for three-phase faults while retaining nearly the same phase-to-phase and ground fault sensitivity, and to utilize other relaying to insure that all three-phase faults are cleared. One possibility is a zone-packaged first-zone distance relay at each end of the line, connected to trip the local breaker and transfer trip the remote breaker via the transferred trip scheme to be described later in the section on the SPA relay. For this scheme to be acceptable, the protected line must be long enough so that the first zone distance units can be set to underreach the remote terminal but overlap the reach setting of the remote distance relay, and an ac potential source must be available.

The three taps F, G and H determine the relay sensitivity to ground faults. On the H tap, which is the most sensitive, pickup is approximately one-eighth the three-phase pickup tap setting. On the G tap, pickup is approximately one quarter the three-phase pickup tap setting. On the F tap the relay is insensitive to zero sequence current, but will respond to the positive and negative sequence components, resulting in the pickup listed in Table I.

PROVISION FOR SENSITIVE GROUND FAULT PROTECTION

On some resistance grounded systems, neither the G or H tap will provide adequate sensitivity. For such cases an additional input to the sequence network is provided which can be fed from a ground sensor current transformer, as illustrated in Figure 5. With the F tap setting the current pickup with this supplementary ground connection is approximately 0.5 ampere into the relay for the single-end feed condition and an open pilot. The turns ratio of the ground sensor CT must then be selected to provide the desired sensitivity without causing excessive current transformer saturation. This is discussed in more detail in the section on APPLICATION.

DC CONTROL VOLTAGE TAPS

A movable dual link is provided on the upper tap block. It can be set for either 48 or 125 volts dc.

RESTRAINT TAPS

Restraint taps, identified as HI and LO, are provided in the middle of the lower top block, as shown

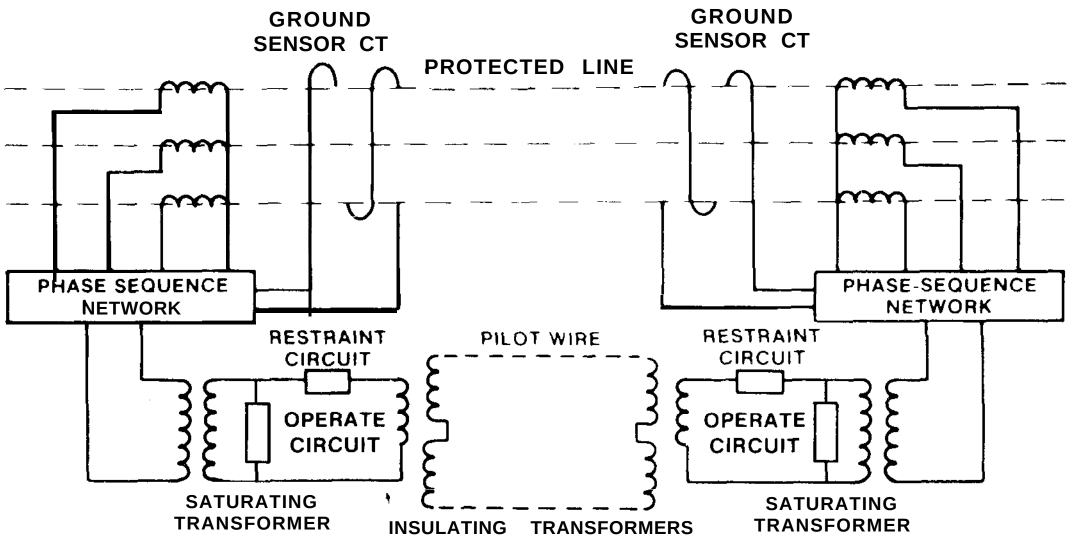


Figure 5. Simplified Functional Diagram of the SPD Relay System With Ground Sensor CT Connection for Resistance Grounded Systems

in Figure 4. The normal setting is the HI tap and all discussion in this bulletin are based on the use of this tap. The LO tap is available for special applications requiring increased sensitivity. Use of the LO tap may result in lower overall security because the ratio of the restraining quantity to the operating quantity will be lower for any system condition.

OPERATING TIMES

Pickup time of the Type SPD relay, expressed as a multiple of pickup, is shown in Figure 6. With heavy fault currents of four times pickup or more, the pickup time will be 15 milliseconds or less.

Dropout time, expressed in terms of fault current prior to the clearing of a fault as a multiple of relay pickup, is shown in Figure 7.

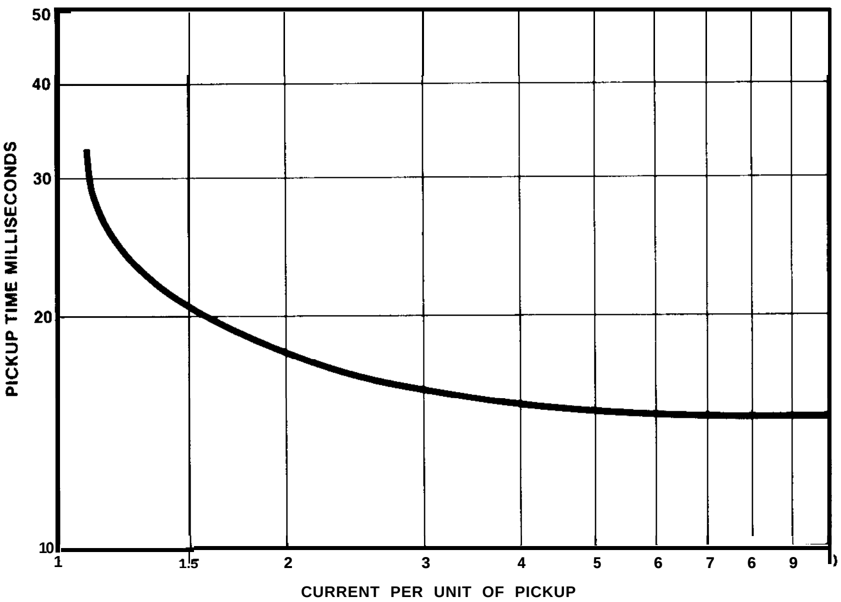


Figure 6. Pickup Time of the SPD Relay Vs. Multiple of Pickup Current

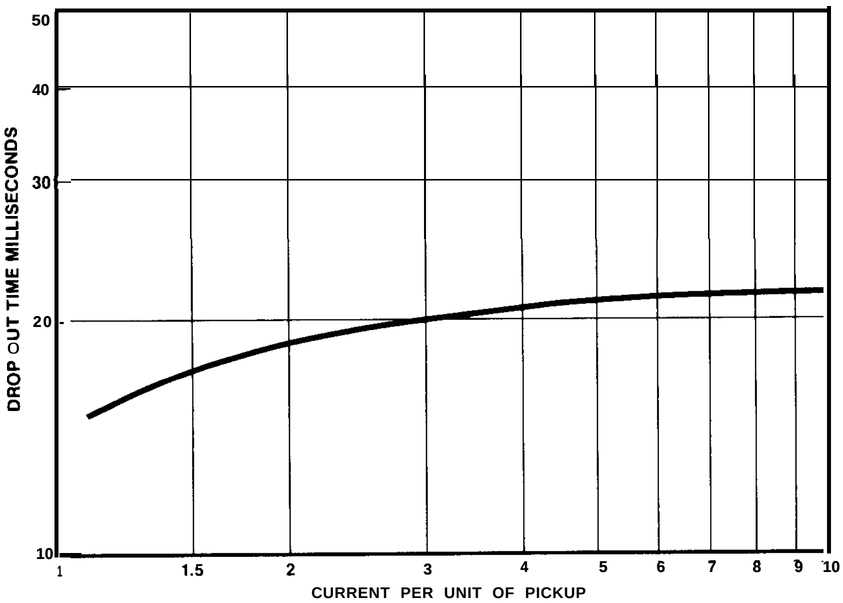


Figure 7. Dropout Time of SPD Relay

APPLICATION

The ac pilot wire system using the type SPD relay provides selective high-speed protection for phase and ground faults on two- or three-terminal lines of short to medium length. The basic scheme requires one SPD relay at each terminal of the protected line and an interconnecting pilot wire pair. Application limitations and determination of relay settings are discussed in the following paragraphs.

THE PILOT WIRES

The pilot is a twisted pair of wires connected between the two (or three) terminals of the protected transmission line. The SPD circuit will impose no more than 60 volts peak on the pilot pair, so the insulation capability of the pilot should be based on the maximum induced voltages that may occur in the pilot circuit, with the proper protection installed. (See section on protection of the pilot).

The limitation on pilot length is determined by the acceptable magnitudes of the loop resistance and the shunt capacitance. For two-terminal lines it is recommended that the series resistance of the pilot loop, including the neutralizing reactor windings if present, not exceed 2000 ohms and that the shunt capacitance be less than 1.5 microfarads. For three-terminal lines the pilot circuit must be in the form of a T connection as shown in Figure 8. It is recommended that the two-way resistance of each leg of the T not exceed 500 ohms, including the neutralizing reactors if present. The resistance of the three legs should be matched as closely as possible by padding one or two of the legs with additional resistance. Resistance matching within one percent or less is desirable. Any mismatch will reduce the security of theschemefor external faults. For example, a mismatch of five percent can produce a signal in one or more of the relays which is 25 percent of that required to cause a misoperation. It is recommended that the total shunt capacitance of the pilot circuit for three-terminal applications be less than 1.8 microfarads. If the value of pilot wire resistance or shunt capacitance exceeds the recommended limitsforeithertwo-orthree-terminal lines, application of the SPD relay may still be possible but the factory should be consulted.

Pilot loop resistance can be based on information supplied by the communication utility if the pilot is leased, or it can be calculated knowing the wire size and length of the pilot run, using dc resistance data published in wire tables. Pilot loop resistance can also be determined by direct measurement from one end with the remote end shorted for two terminal lines, or from each terminal to a short at the junction of the T for three terminal lines. This should be a dc measurement since the shunt capacitance will influence an ac measurement.

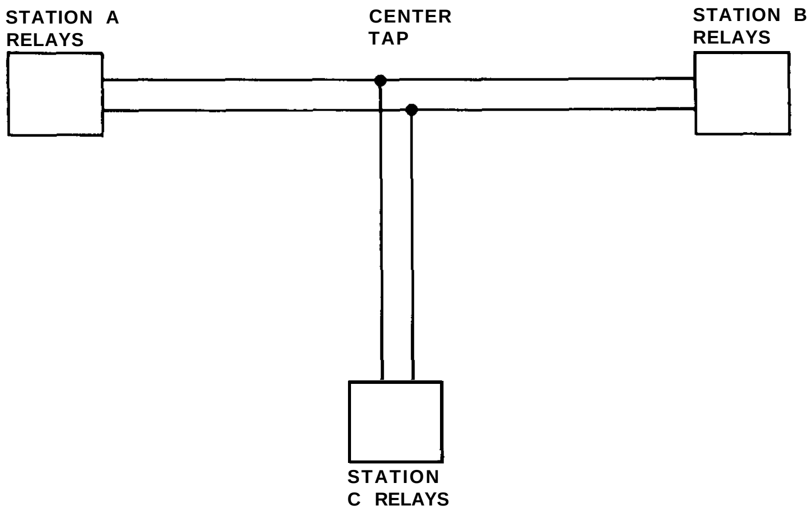


Figure 8. Pilot Wire Connections for Three Terminal Lines

The shunt capacitance can be determined either by calculation or measurement. However, measurement is preferred unless the pilot is under the complete control of the user, since it is sometimes the practice of communication utilities to tap an existing pilot wire. This practice can result in an open section of pilot wire beyond one or both stations that will add to the shunt capacitance, as illustrated in Figure 9. If the value of shunt capacitance is supplied by the communication utility it must be the total shunt capacitance, including the effects of any open sections beyond either terminal.

Pilot wire resistance in excess of the values noted above will reduce the current flowing in the pilot, and hence in the restraint circuit of the SPD relays. In the limit, the condition of an open-circulated pilot would be approached where the relays will operate on external faults, or heavy load if it is above the 3-phase pickupsetting. Shunt capacitance in excess of the listed values tends to reduce the relay sensitivity, and in the limit would approach the short-circuited condition where the relays will not operate.

RELAY SENSITIVITY AND SETTINGS

The sensitivity of the SPD relay for the various types of faults is determined by the three-phase pickup tap setting, phase-to-phase tap setting and ground tap setting, as well as by the pilot wire length and number of line terminals. The relay pickup in per of the three-phase tap setting is given in Table I for the different phase and ground tap settings and various types of faults, with single-end feed and the pilot wires disconnected from the relay terminals.

In the following discussion it is assumed that operation of the relay on load flow with an open pilot is not acceptable, and that the scheme should detect all three-phase faults on the protected line. If the SPD relay is to be secure against operation with an open pilot and maximum load flow, with margin, the relay three-phase current pickup from Table I should be at least 1.25 times the maximum expected balanced load current. If the SPD relay is to operate for any fault on the protected line, with margin, the minimum fault current for each type of fault should be at least 1.33 times the relay pickup for the particular type of fault. The following discussion is based on the use of the high-restraint (HI) tap setting. As previously noted, a low-restraint tap is also available for special applications requiring increased sensitivity, but use of the "LO" tap may result in lower overall security.

The following setting procedure is suggested:

A. If it is assumed that it is desired to trip for all three-phase faults as well as all unbalanced faults on the protected line, the C phase-to-phase tap should be selected.

B. Determine the value of I_T from equation 2,

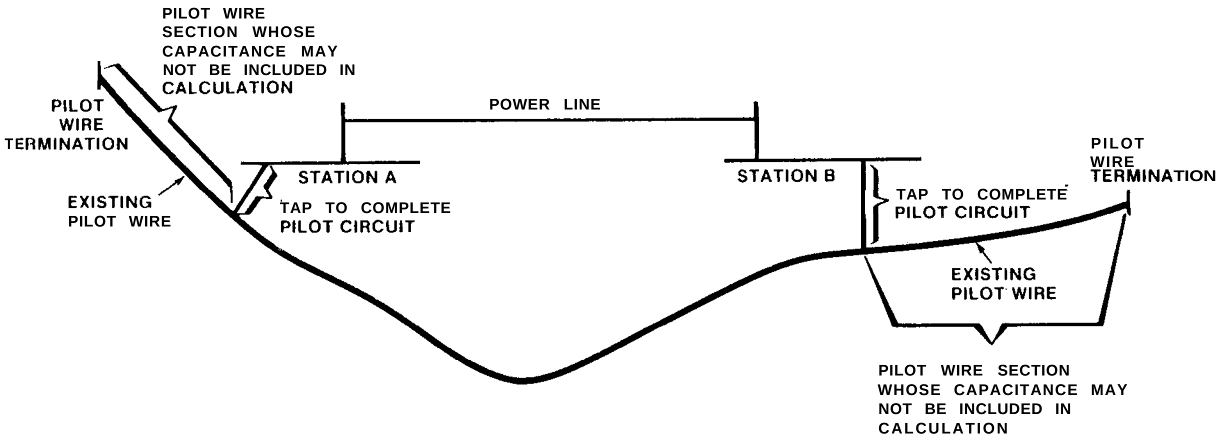


Figure 9. Typical Situation Where Pilot Wire Capacitance May Be Greater Than Calculated Value.

assuming it is desired that the relay not trip with an open pilot and maximum load:

$$I_T = 1.25 \left[\frac{I_L}{M} \right] \qquad (2)$$

where:

I_T = minimum theoretical three-phase pickup tap; use next higher available three-phase pickup tap (T).

I_L = maximum load current

M = multiplier for phase-to-phase tap (1.0 for C tap from Table 1)

C. Check that the three-phase pickup tap T determined in **B** satisfies equation (3):

$$T \leq 0.75 \left[\frac{I_F}{MNP} \right] \qquad (3)$$

where:

T = three-phase pickup tap setting (determined in **B)**

I_F = minimum 3-phase fault current at fault location, sum of contributions from all terminals

P = factor from Figure 10 for total capacitance of pilot wire ("near-end" curve)

M = multiple for phase-to-phase tap (1.0 for C tap)

N = number of line terminals

If the current tap T determined in **B** satisfies equation (3), proceed to step **D** below. If the selected current tap T does not satisfy equation (3), the relay as set may not detect the minimum three-phase fault on the protected line. The user then has two options:

(a) Reduce the T tap setting until equation (3) is satisfied, recognizing that an open pilot may now cause the relay to trip with load flow near maximum.

(b) LeaveT at the setting determined in **B,** and resort to other relaying to protect for the possible minimum three-phase fault.

As suggested previously, if the line impedance is sufficient and a potential source is available, zone-l distance relays could be used as the other relaying in conjunction with the transferred trip feature of the SPA relays. In either case, proceed to step **D,** using the T tap finally selected.

D. Check that the T tap finally selected satisfies equation (4), assuming that the G ground tap setting is used:

$$T \leq 0.75 \left[\frac{I_S}{BNP} \right] \qquad (4)$$

where:

T = three-phase pickup tap setting

I_S = minimum internal single-phase-to-ground fault current, sum of contributions from all terminals

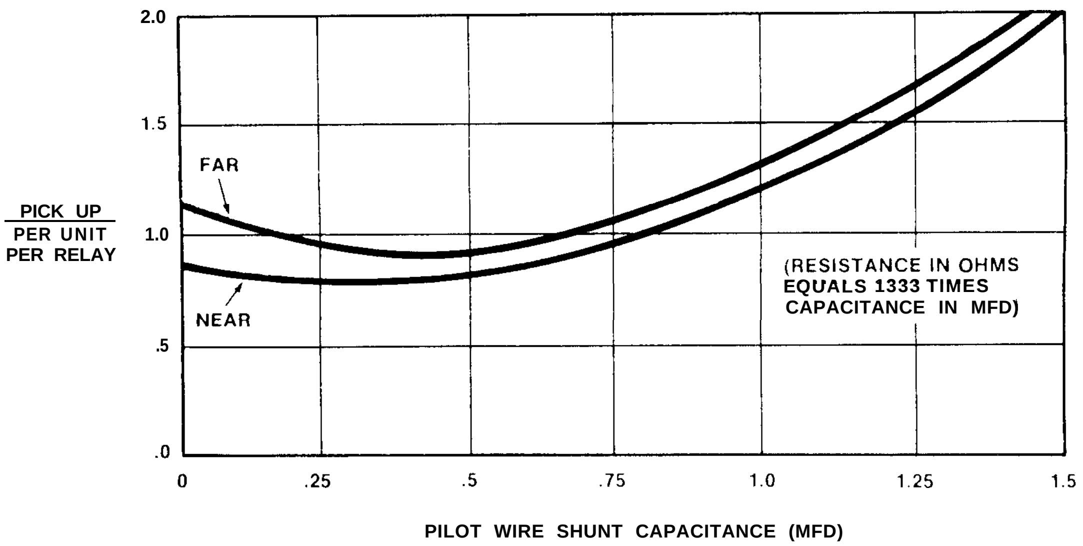


Figure 10. Effect of Pilot Wire Shunt Capacitance On SPD Pickup

B = multiplier from Table I for the phase and ground tap positions, and B0/ fault

P = factor from Figure 10 for actual capacitance of pilot wire (use "near-end" curve)

N = number of line terminals

If equation (4) is not satisfied with the G ground tap, check again using the H tap. If equation (4) is still not satisfied, refer to the following section on use of the ground sensor connection.

The three-phase pickup amperes tap, the phase-to-phase tap, the ground tap and the restraint tap must be set in the same position in the relays at all terminals of the protected line.

GROUND SENSOR CONNECTION

On applications where the required sensitivity on single-phase-to-ground faults is not realized, the ground sensor CT connection shown in Figure 5 should be considered. This condition will typically be encountered on resistance grounded systems, where the ground fault current is primarily determined by the grounding resistor. In such cases the ground fault current is substantially less than the phase fault current, and there will be little difference between the minimum and maximum ground fault currents.

A current transformer of relay accuracy may be used as the ground sensor. The turns ratio should be selected so that the current into the relay is at least 2 amperes with minimum ground fault current and no more than 12 amperes with maximum ground fault current. The SPD static relay is well suited for application with CTs typically used as the ground sensor. For example, calculations have shown that with the 50/5ground sensor used in General Electric Power/Vac switchgear, the SPD relaying system will perform correctly for secondary ground fault currents within the 2 to 12 ampere limits noted above. Other CTs from available ratios of 100/5, 200/5 400/5 or 800/5 may also be used as the ground sensor to provide a secondary current in the 2 to 12 ampere range.

Relay pickup with this ground sensor input will be approximately 0.5 amperes into the relay, for the 4 ampere three-phase pickup tap position and the open pilot condition noted in Table I. When the ground sensor is used the ground tap must be in the F position.

DESCRIPTION AND OPERATING PRINCIPLES TYPE SPA PILOT MONITORING RELAYS

The Type SPA relays are static pilot wire auxiliary relays designed primarily for use with the SPD pilot wire system to provide continuous monitoring of the pilot wire circuit for the detection of open, shorted, reversed or grounded pilot wires. The basic pilot monitoring installation requires a master, or transmitting, relay at one terminal and a receiving relay at the other terminal, or terminals, of the pilot circuit. Models of the SPA are also available to provide a direct transfer trip feature, either unidirectional or bidirectional, in addition to the pilot monitoring functions. The four available SPA models are listed in Table II. Descriptions of each model and the schemes are included in the following paragraphs.

Table II

Model*	Monitor		Transfer Trip Functions	U-C Detect.	O-C Detect.	Ground Detect.
	Transmit.	Rec.				
SPA11A	X			X	X	X
SPA11B	X		X	X	X	X
SPA12A		X		X		
SPA1 28		X	X	X		

*Refer to Instruction Book GEK-65512 and Apparatus Handbook Section 7278 for further information on the SPA relays.

FEATURES

In the transmitting or sending end relays, solid state detection circuits operate undercurrent (UC), overcurrent (OC) and ground (GND) units, each with output contacts and associated light emitting diode (LED). In the receiving end relays the solid state circuit operates an undercurrent unit with alarm contacts and LED. Powerforthesolidstatedetection circuits and monitoring current is provided by an isolated dc power supply. This isolation of the dc source prevents a ground in the battery supply from beingreflectedintothepilotwirecircuitandpossibly causing a misoperation of the SPD scheme.

PILOT MONITORING

A typical installation of the pilot monitoring scheme is illustrated by the simplified functional diagram in Figure 11. This scheme requires a transmitting end relay, model SPA11A, and a receiving end relay, model SPA12A. The scheme operates by circulating a low-level current of approximately 0.75 milliamperes dc through the pilot wire circuit. This current is initiated by the power supply in the transmitting end relay and circulates through the relay circuit at the receiving end. It provides the reference to determine whether the pilot circuit is open or shorted. With normal pilot wires the undercurrent units in both the transmitting end and receiving end relays will be held in the operated position by the 0.75 ma circulating current. This normal circulating current is not sufficient to cause operation of the overcurrent unit in the transmitting end relay.

Since the transmitting and receiving end monitoring relays are effectively in series with the pilot wire loop, it is necessary to provide a low-impedance bypass for the ac current circulated between the SPD relays at each end. This system-frequency bypass is provided by capacitors mounted internally in the SPA relays and connected in parallel with the relay circuit, as shown in Figure 11.

OPEN PILOT

An open circuited pilot wire will cause the monitoring current to fall to zero. The undercurrent units (UC) in both the transmitting and receiving end relays will drop out, the UC contacts will close, and the LED indicators for the UC function will light.

SHORTED PILOT

A shorted pilot loop will result in an increase in the monitoring current at the transmitting end, and a

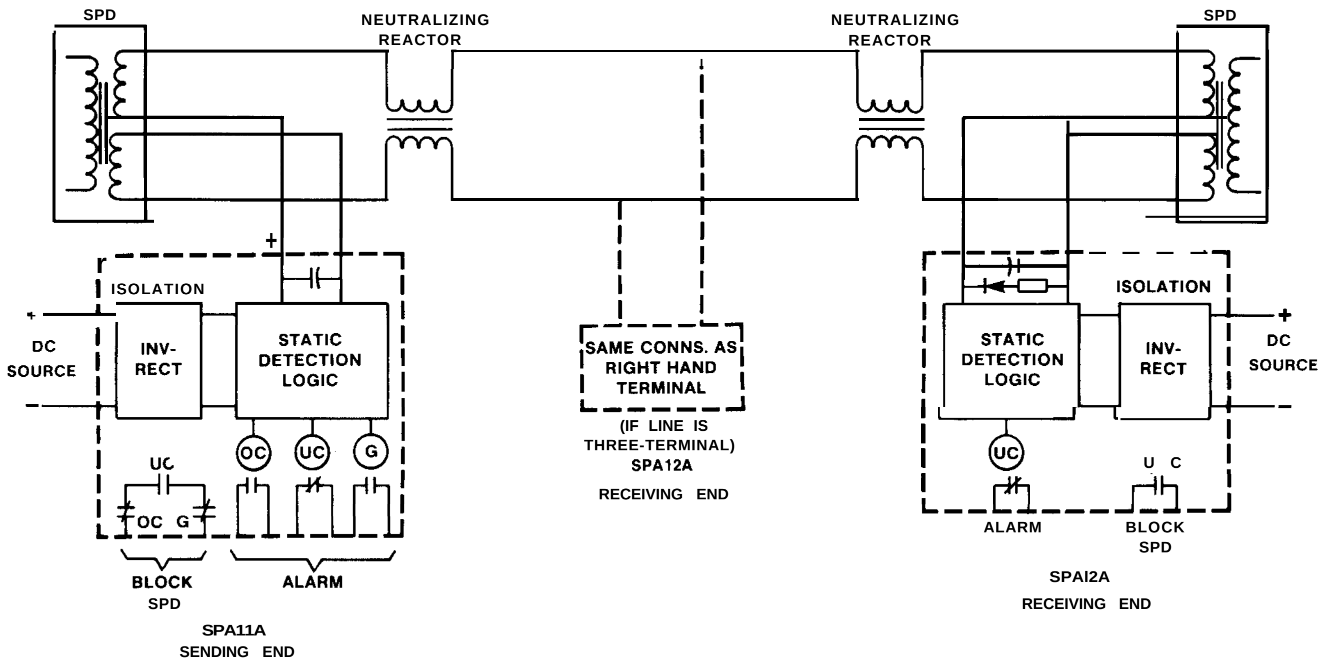


Figure 11. Simplified Functional Diagram — SPA Relays, Monitoring Only

decrease in the current at the receiving end. The increase in current at the transmitting end will result in operation of the overcurrent unit and the associated LED. The current at the receiving end will decrease to zero for a short circuited pilot, causing the undercurrent unit to drop out. A short circuit on the pilot is the extreme case for the overcurrent condition. The overcurrent unit in the transmitting end relay will pickup for circulating currents of 1.35 milliamperes or more.

GROUNDED PILOT

The ground indicating unit in the transmitting end relay is normally dropped out. A ground on either pilot wire, below 10,000 ohms, will causetheground unit to operate and the ground LED to light.

REVERSED PILOT

A polarity sensitive circuit in the receiving end relays provides indication of a reversed pilot wire. For the reversed pilot condition sufficient current is bypassed around the undercurrent detection circuit to cause the UC unit to drop out. Furthermore, as a result of the decrease in resistance at the receiving end, the monitoring current increases sufficiently to operate the overcurrent function at the transmitting end. These indications are the same as would occur during a shorted pilot.

TRIP BLOCKING

The SPA relays for both the transmitting and receiving ends include contact circuits for the optional supervision of the SPD trip circuit. At the transmitting end, this consists of normally closed contacts of the OC and ground units, and a normally open contact of the UC unit, all connected in series. At the receiving end a normally open contact of the UC unit is used. At user discretion, these contacts can be connected in series with the SPD trip circuit to block that circuit when an abnormal pilot condition is detected.

TRANSFER TRIPPING

On some applications the user may wish to use the pilot circuit to send a transfer trip signal in one or both directions. Table II lists the SPA models required when transfer tripping is involved. These relays include all the monitoring functions previously described for the transmitting and receiving end relays. In addition they include a transfer trip initiating auxiliary unit (TTA) and a receiving auxiliary unit (TT).

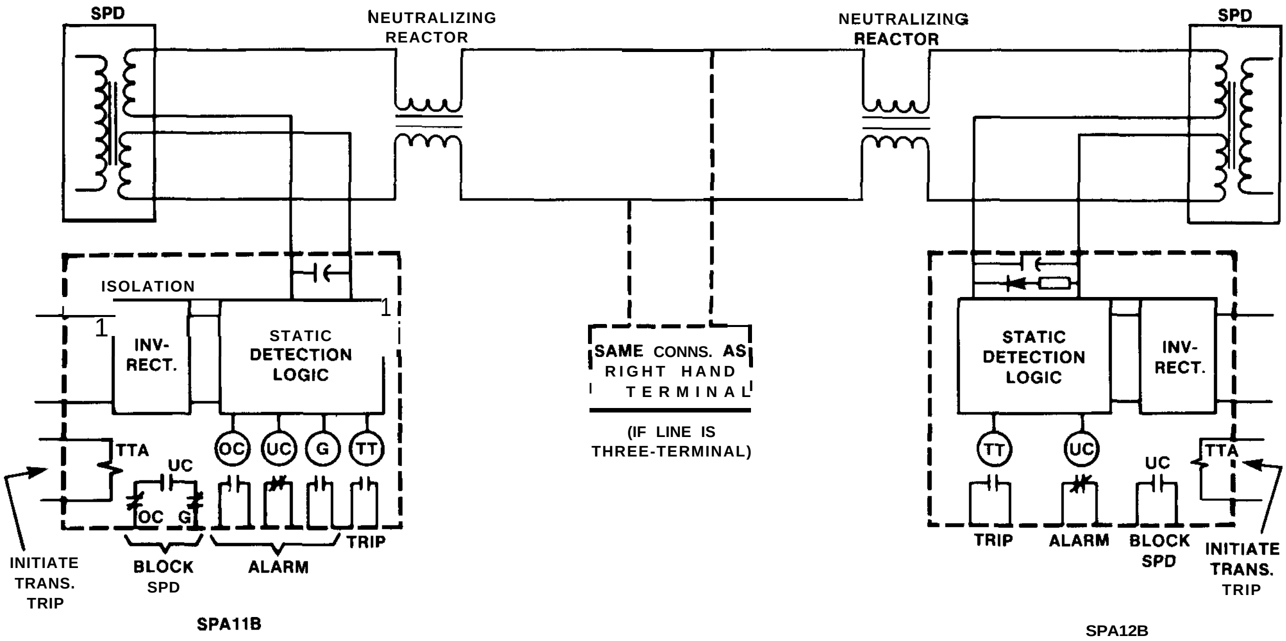


Figure 12. Simplified Functional Diagram - SPA Relays, Monitoring and Two-Way Transferred Trip

A typical installation of the pilot monitoring scheme, with two-way transfertripping, is illustrated by the simplified functional diagram in Figure 12. The transfer trip signal is initiated by energizing the coil of the TTA auxiliary unit. Closure of the TTA contacts reverses the polarity of the dc voltage applied to the pilot wires. Reversal of thevoltage polarity causes operation of the receiving auxiliary unit (TT) in the SPA relays at both the local and remote terminals of the pilot wire.

The same SPA models are used in a one-way transfer trip application. Referring to Figure 12, the TT unit contacts are not used at the initiating end and the TTA unit coil circuit is not connected at the receiving end.

THREE-TERMINAL LINES

Application of the monitoring/transfer trip schemes to three-terminal lines is represented by the dashed connections in Figures 11 and 12, which show the addition of the third terminal. The only difference in the circuit is that a link in the receiving end relays must be placed in the "three-terminal" position.

CHARACTERISTICS

Detection levels of the undercurrent units (UC) in the transmit and receiving end relays are listed in Table III:

Table III
UC Unit Detection Levels

Relay	Line Terminals	UC Level
SPA1 1A or -B	2	0.53 ma or less
SPA11A or-B	3	0.43 ma or less
SPA1 2A or -B	2	0.53 ma or less
SPA12A or-B	3	0.21 ma or less

Operating current of the overcurrent unit (OC) in the transmit end relay is 1.35 ma.

The ground unit in the transmit end relay will operate, and the GND LED will light, when the resistance to ground from either conductor of the pilot pair falls below 10,000 ohms.

No field adjustments are necessary in the SPA relays to realize these operating characteristics. The only settings required at the time of installation are the dc voltage selectors, 48 or 125 volts, the target seal-in unit tap setting when transfer tripping is involved, and the selector in the receiving end relays for two- or three-terminal lines.

OPERATING TIMES

The operating times of the undercurrent, overcurrent, and ground detection circuits are intentionally made slow to override transient disturbances. The times will vary depending on conditions on the primary system and the severity of the abnormal condition on the pilot wire. Thevalues listed in Table IV are approximate:

Table IV
Operating Times

Unit	Pilot Condition	Detection Time	Restore Time
UC	Open Circuit	0.3 Sec.	2 Sec.
OC	Short Circuit	0.3 Sec.	0.7 - 2 Sec.
GND	Ground	0.3 - 0.5 Sec.	0.4 - 0.8 Sec.

In Table IV detection time of each unit is the time to close its contact after the occurrence of the pilot condition listed in the table. The restore time is the time to reopen the contact after the condition listed in the table is removed and normal circuit conditions are restored.

For transfer trip installations, the operating time is defined as the time between energizing theTTA unit at one end and the closure of the TT unit contact at the other end. This time will vary slightly with the length of the Pilot wire, as listed in Table V.

Table V
Transfer Trip Times

Pilot Resistance	Operate* Time	Reset* Time
0 Ohms	4 cyc.	6 Cyc.
2000 Ohms	5 cyc.	6 Cyc.

*60 Hz base.

The transfer trip operating times are virtually independent of station battery voltage variations.

PROTECTION OF THE PILOT WIRES AND ASSOCIATED EQUIPMENT

The most likely source of difficulty in an ac pilot wire relaying scheme is the pilot circuit itself. Because the pilot circuit extends over a considerable distance it is exposed to a number of hazards which can interfere with the proper operation of the scheme, or can cause damage to the pilot circuit and the associated equipment. The more common hazards are:

1. Rise in station ground potential.
2. Induced voltages.
3. Lightning.

The sources of thesevoltage disturbancesand the various devices available to minimize their effects have been described in a continuing series of technical papers, guides and standards, listed in the bibliography. The user should review these references for a more comprehensive discussion of pilot wire protection.

GROUND POTENTIAL RISE

A substantial voltage rise can occur at the substation ground mat relative to the remote ground potential. This voltage rise can cause excessive insulation stresses on the pilot wire relay, the pilot wire monitoring relay, the pilot wires, and between the pilot wires and other conductors in the same cable.

As illustrated in Figure 13, the typical condition resulting in ground potential rise is a single-phase-to-ground fault on the power system. With ground current flowing through the Station A ground mat, there will be a voltage difference between this mat and the remote ground potential. The magnitude of this voltage will depend on the magnitude of the current and on the impedance between the station ground and the remote ground. The value of the ground current is usually available from system fault studies. The determination of the impedance between the mat and the remote ground has been the subject of a number of papers listed in the bibliography which describe means of determining the impedance by either calculation or test.

The diagram in Figure 14 represents a typical voltage profile of the potential difference between the pilot cable and ground during a single-phase-to-ground fault. As is apparent from the plot, the potential of earth near the pilot wire cable tends to be at the remote ground potential for most of the length of the pilot run. Hence, if the cable is not grounded it will assume a potential near that of the remote ground because of the capacitive coupling. Thus the potential rise of the station ground mat results in a significant voltage difference between the station ground mat and the pilot cable with its connected station equipment. If this voltage difference be-

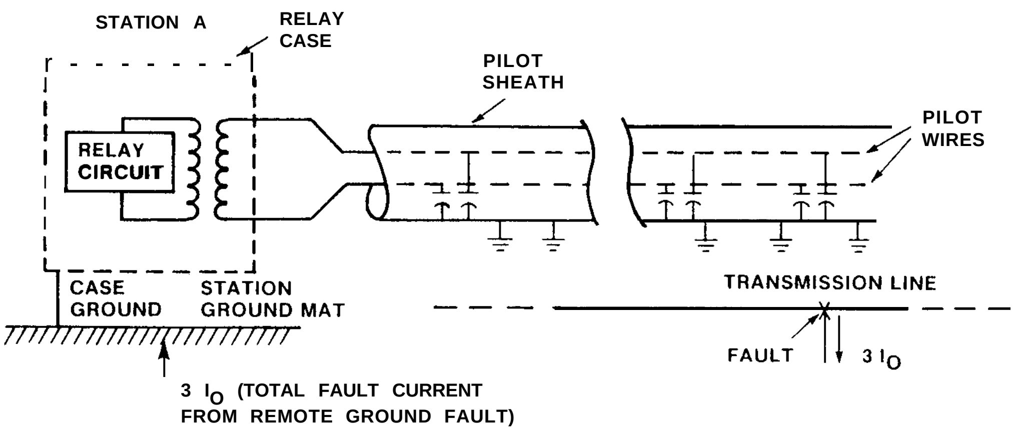


Figure 13. Situation Causing Station Ground Mat Potential Rise

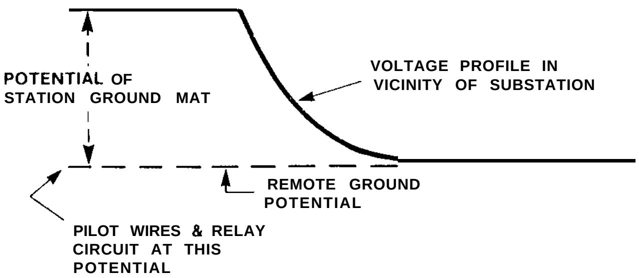


Figure 14. Typical Ground Potential Profile During A Single-Phase-to-Ground Fault

comes too great, there is danger to personnel and the possibility of damage to the pilot wire relays, the connected equipment and the pilot wire itself. If this voltage difference exceeds 600 volts, protection of the pilot wires is usually necessary since this is the continuous voltage insulation level of theconnected relays, terminal boards, panels and standard telephone cables.

The usual method of protecting against excessive station ground potential rise is to install a neutralizing reactor in the pilot wire circuit as shown in Figure 15. The windings of the neutralizing reactor present a low impedance to the normal circulating current of the wire pilot scheme (i.e., transverse voltage signals) since the currents in the two windings will flow in opposite directions. Consequently, the transverse signal is opposed only by the leakage reactance of the neutralizing reactor windings.

On the other hand, a common mode voltage difference, as a the result of the station ground potential rise, will attempt to force current through the two windings in the same direction and will therefore be opposed by the magnetizing impedance of the neutralizing reactor. The capacitors connected to ground at the midpoint of the SPD insulating transformer and the stray capacitance to ground of the pilot wires complete the path for the reactor magnetizing current resulting from the potential difference between station ground and remote ground. Since most of the voltage drop from this circulating magnetizing current will appear across the reactor windings, the relays and pilot connections on the station side of the reactor will be elevated in potential to essentially the same level as the station ground mat, as illustrated by the voltage profile in Figure 15.

The voltage profile also reveals that the neutralizing reactor itself and a section of the pilot wire cable adjacent to the station may still be subjected to excessive voltage stresses during a station ground potential rise. For this reason a neutralizing reactor that can withstand the full ground potential rise

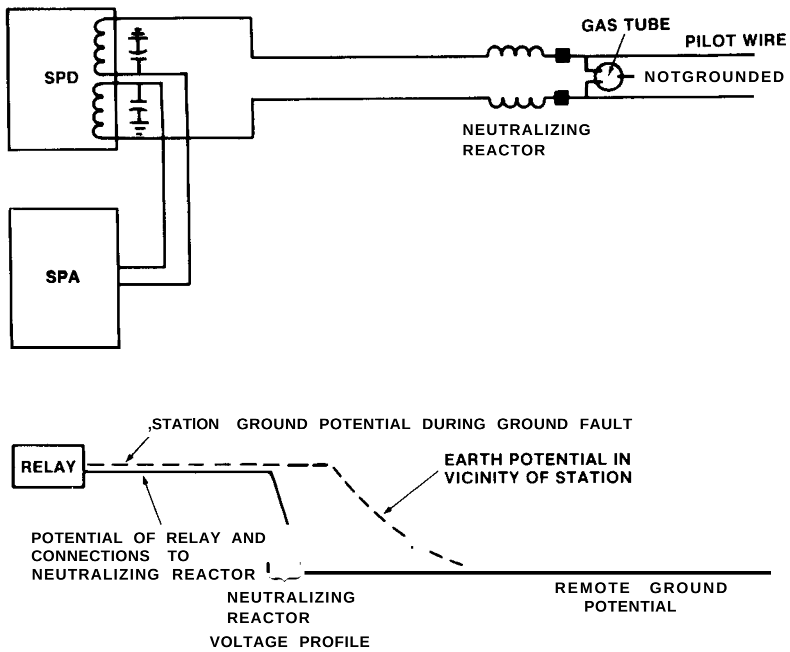


Figure 15. Typical Application of Neutralizing Reactors, With Voltage Profile

should be selected. A neutralizing reactor with a 4kV withstand capability, including the capacitors and resistors for the ground connection, and an ungrounded gaseous discharge tube, is available from General Electric. The purpose of the gaseous discharge tube is explained in a following section on lightning effects. If the expected potential rise exceeds the withstand rating of standard pilot wire cable, then a pilot wire with a higher voltage rating should be installed from the neutralizing reactor to a splice point outside the zone of influence of station ground potential.

INDUCED VOLTAGES

Disturbances from induced voltages usually have their source in the power circuits themselves, either during faults on the line being protected by the pilot wire scheme, or on adjacent lines. This inductive coupling can result in induced voltages in the transverse (or differential) mode, or in the common (or longitudinal) mode.

If the magnetic flux of the faulted line links one wire of the pilot pair less than the other, then an induced voltage in the transverse mode will appear as a voltage between the two wires. If the flux links both wires of the pilot pair and not theground return path, then the induced voltage is known as common mode and results in a voltage from both wires to the common ground reference plane.

TRANSVERSE MODE INDUCED VOLTAGES

Since a voltage resulting from the transverse mode of induction is between the two wires of the pilot pair, it appears as an operating voltage to the SPD relays. If it exceeds the voltage required to operate the SPD, which is 13 volts with no restraint current present, an incorrect trip can result. Consequently it is essential that transverse mode induced voltages be held to a minimum. An effective means of minimizing transverse mode induced voltage between the wires is to use a twisted pair for the pilot.

COMMON MODE INDUCED VOLTAGES

Coupling between the pilot pair and an adjacent power line carrying fault current may result in a common mode (or longitudinal) induced voltage. Generally this induced voltage results from a ground fault and can usually be determined with sufficient accuracy by multiplying the maximum ground fault current by the zero sequence mutual impedance between the power circuit and the pilot circuit. The neutralizing reactor, described in the section on ground potential rise and shown in Figure 15, will protect the relays, terminal blocks, and pilot wires up to the reactor from damage by such induced voltages. If it is determined that the common mode induced voltage on the other side of the neutralizing reactor can exceed the insulation capability of the pilot wires, a mutual drainage reactor with gaseous discharge tube can be installed as shown in Figure 16. If it is deemed necessary to provide a mutual

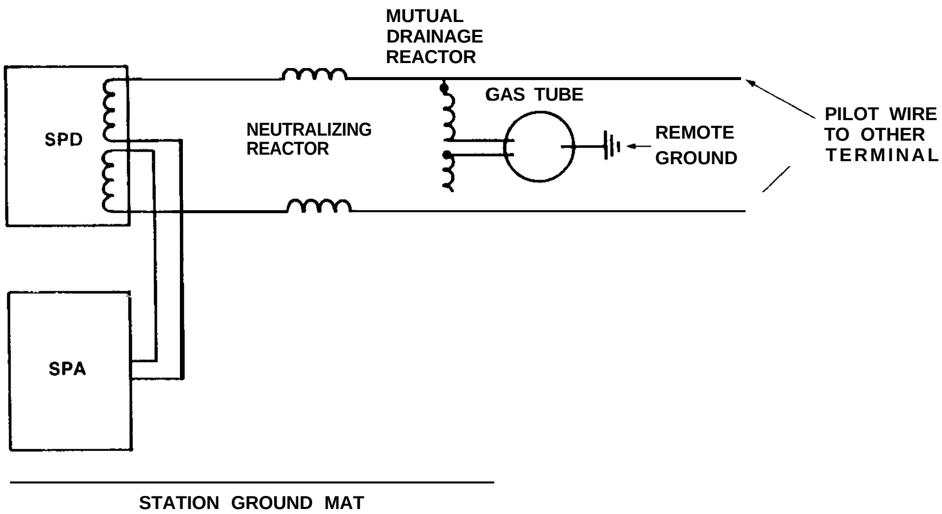


Figure 16. Typical Use of Mutual Drainage Reactor and Gas Tube

drainage reactor, as well as the neutralizing reactor, then the gas tube associated with the drainage reactor should be remotely grounded at a point outside the zone of influence.

If the pilot pair is in the same cable as other communication circuits, care must be taken that the intercircuit withstand voltages are not exceeded. An effective method of minimizing intercircuit voltages is to protect each circuit in a similar manner at the same location, thus assuring that at no point will there be significant voltage differences.

LIGHTNING

Control equipment in substations is generally so well shielded against severe voltage surges caused by lightning that direct protection may not be necessary. The pilot wire system differs from other control equipment in that it runs over a considerable distance from one substation to another and hence is exposed to lightning. Lightning induced voltages may exceed the pilot insulation capability, and if this is possible, lightning arrestors may be applied as needed as typified by Figure 17. The protection provided by the arresters should coordinate with the insulation withstand capability of the neutralizing reactor and the pilot pair. It is essential that the arresters reseal with nominal ac and dc currents flowing in the pilot pair. It is for this reason that lightning arresters rather than carbon blocks are recommended. The arresters should be remotely grounded outside the zone of influence so that they do not operate on a ground potential rise, since the neutralizing reactors protect against this condition.

As shown in Figure 17, a gas tube is usually connected from wire to wire of the pilot pair when arresters are used. The purpose of this gas tube, which is supplied with the neutralizing reactor, is to short the two wires together should one arrester fire and not the other. This will prevent a high voltage between the pilot pair which could cause a false trip by the SPD relay during arrester discharge. It is essential that the gas tube be left ungrounded so that it does not provide a path to the ground.

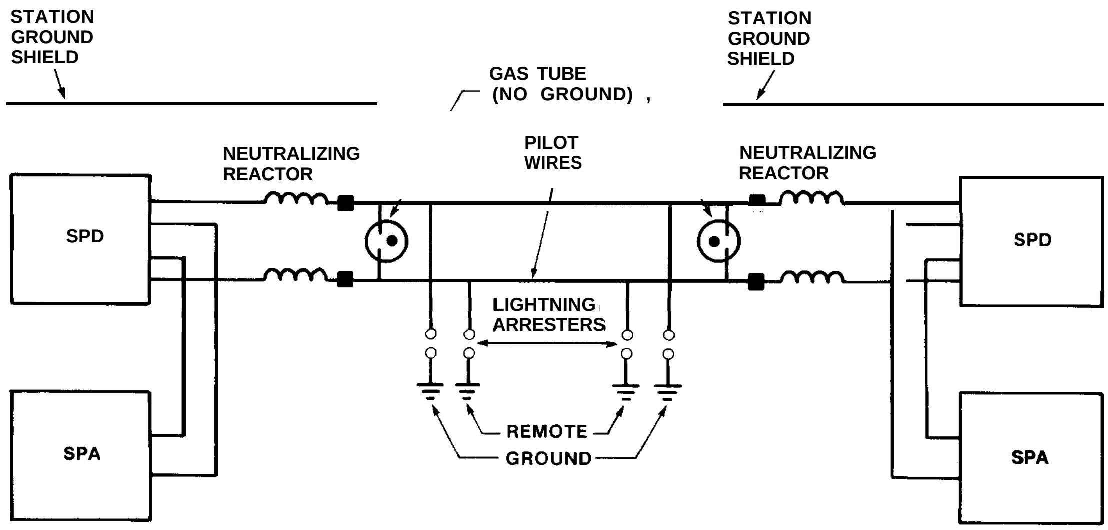


Figure 17. An Illustration of Possible Surge Protection

ELEMENTS OF THE PILOT WIRE SYSTEM

The elements of the ac wire pilot scheme and their functions, which were discussed in detail in earlier sections. are summarized in Table VI. As is apparent from the table the major components of the system, some of which are supplied by the user, are the following:

1. Pilot wire relay, type SPD, and associated equipment.
2. Pilot pair and surge limiting equipement.
3. Pilot monitoring relay, Type SPA
4. Neutralizing reactor and associated equipment.
5. Mutual drainage reactor.

Of these five elements the first two, the pilot wire relay and pilot pair, are of course essential to the operation of the basic scheme. The pilot monitoring relays, while not essential to the operation of the scheme, are usually included because of their value in detecting open, shorted, grounded or reversed pilot pairs. The neutralizing reactor should be used when data is not available to verify that ground potential rise and/or common mode induced voltages on the pilot pair are within the insulation capability of the pilot wires and connected equipment. The mutual drainage reactor is used when protection beyond that provided by the neutralizing reactor is required to protect against common mode induced voltages.

The SPD-SPA pilot wire relaying system is designed to keep to a minimum the number of units that must be ordered and mounted. The SPD11A relay includes, in addition to the relay itself, an external test switch, ammeter, and meter range-changing transformer, thus providing the facilities required for the basic pilot wire relaying scheme and for the ac testing of the system. The pilot wire pair, and lightning arresters for surge protection, are supplied by the user.

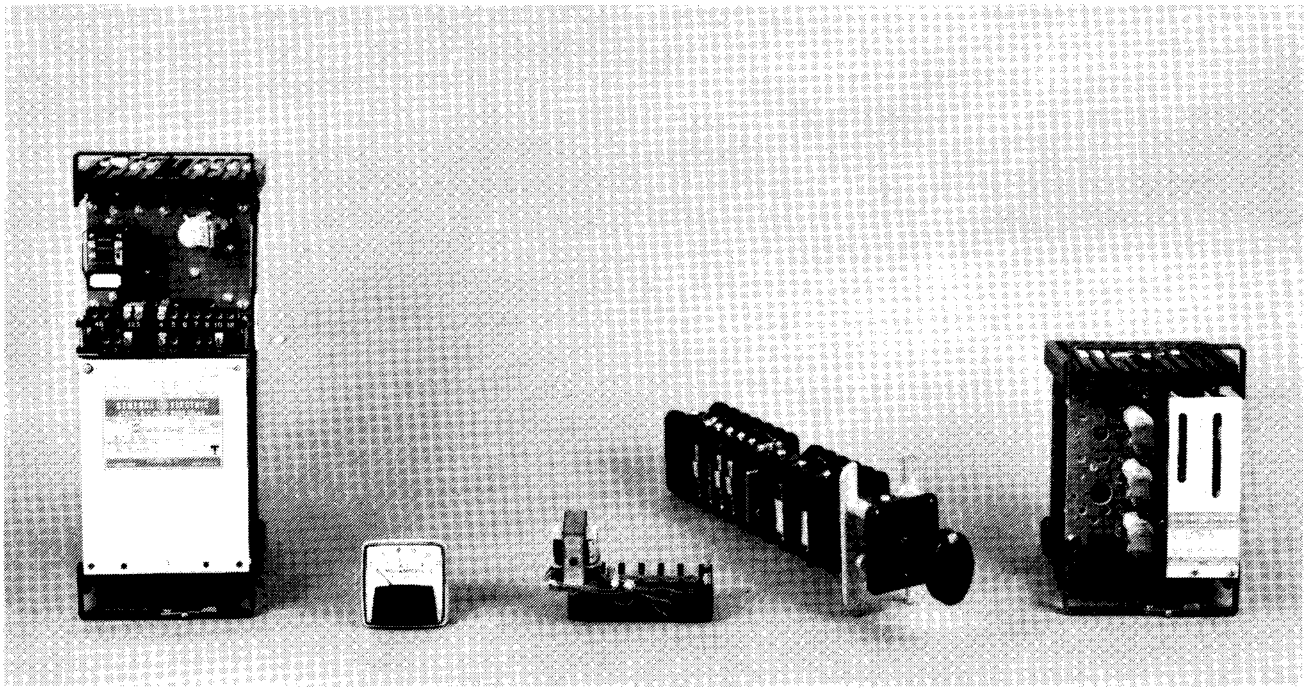
The SPA relays, one per line terminal, provide the transmitting or receiving functions for pilot monitoring, and can be supplied with or without transferred trip capability. The relay type numbers for these various functions are listed in Table II. Each of these relays includes the auxiliary units and resistors to provide the specified functions, as well as an internally mounted capacitor to bypass the ac circulating pilot current around the dc circuits. In previous schemes this ac bypass capacitor, as well as a number of resistors and contacts for transfer trip, required separate mounting.

The neutralizing reactor available from General Electric includes the gas tube and mounting, as well as the resistors and capacitors, with mounting plate, to provide the return path for the reactor magnetizing current. The mutual drainage reactor available from General Electric includes the gas tube with mounting plate.

These various components, which are shown in the photographs in Figure 18 and 19, can be combined to provide a number of schemes which differ in whether or not the sensitive ground connection is used, whether pilot monitoring is used alone, or with transferred trip, and whether two-terminal or three-terminal lines are involved. The schematic diagrams in Figures 1 and 5 describe the basic scheme, while the elementary diagrams in Figures 11 and 12 cover the monitoring and transferred tripping applications.

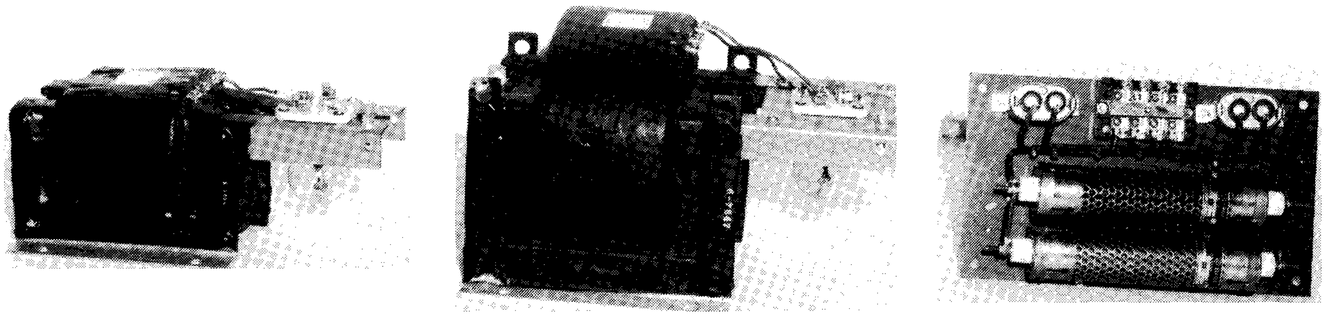
Table VI
Items Included in SPD Pilot Wire Scheme

ORDERED ITEM	INCLUDED	FUNCTION	REMARKS	REQUIRED OR OPTIONAL
SPDIIA	Test Switch Ammeter & Transformer	Pilot wire relay Check of AC connections in Pilot wire circuit.		Required
SPA11A or SPA11B		Pilot Monitor	Transmit End	Optional
		Pilot Monitor & Transfer Trip	Transmit End	Optional
SPA12A or SPA12B		Pilot Monitor	Receive End	Optional
		Pilot Monitor & Transfer Trip	Receive End	Optional
Neutralizing Reactor (0257A9787G3)	Capacitor & Resistor Assem. Ungrounded Gas Tube	Neutralizes ground potential rise or common mode induced voltage Provides exciting current path for neut. reactor		Required if calculations indicate insulation withstand capability will be exceeded.
Mutual Drainage Reactor (0257A9787G4)	Grounded Gas Tube	Limits common-mode induced voltage, pilot wires to ground		Optional



SPD Relay | Milliameter | Meter Range-Changing CT | Test Switch | SPA Relay (See Table II)

Figure 18



Mutual Drainage Reactor | Neutralizing Reactor | Excitation Assembly

Figure 19

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