Applying Digital Line Current Differential Relays Over Pilot Wires

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1. Abstract

Digital current differential protection has the advantages of application simplicity, operation speed, and high sensitivity. Traditionally, current differential protection communication channels are either direct fiber optic cable or multiplexed channels using short copper links from a relay to a multiplexer.

Pilot wire analog differential relays are commonly used for protection of short lines. Many utilities still have copper twistedpair, links with pilot wire relays in service. However, these relays do not meet modern requirements and are can-didates to be replaced. Utilities, however, are reluctant to invest in new communication links to replace existing pilot wires.

This paper presents both problems and practical solutions (for example, modern HDSL communications modems) for applying digital line current differential protection over copper wires.

2. Introduction

Pilot wires are continuous copper connections between substations; however, the pilot wire relays communication pilot wires are not connected directly to existing pilot wires. For protection against GRP, they are connected through insulating transformers or repeaters.

By principle, pilot wire relays are very close to digital current differential relays using the same biased differential principle, same unit protection, and the same need for the pilot channel. The major difference between them is that pilot wire use analog signals while current differential relays digitize analog values into digital quantities transmitted at 64/56 kbps channels.

Both results of extensive testing and successful field ap-plications are presented. As a result, it becomes a very attractive alternative to retrofit existing analog relays with modern microprocessor-based current differential relays utilizing existing pilot wires.

Leased telephone lines are another low-cost alterna-tive. Several problems have to be overcome while applying current differential, using a 64 kbps communications channel over copper wire. Two major problems are noise and ground rise potential protection in the form of isolation transformers.

3. Basics of Pilot Wire Circuitry

The phase sequence network is connected to current trans-formers 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.

There are two basic types of pilot wire relays: “circulating current” or “opposed voltage”. “Circulating current” means that current circulates normally between line CTs through pilot wires and “opposed voltage” indicates that current does not normally circulate through pilot wires. Pilot wire relays only use two wires; therefore, it is necessary to derive a representative single-phase quantity. The insulating transformer, mounted inside the pilot wire relay case, acts as an impedance matching device between the relay circuit and 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 Figure 1. The turns ratio is one to four from the relay side of the transformer to the pilot wire side.

The pilot is a twisted pair of wires connected between two (or three) terminals of the protected transmission line. 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. 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.

Pilot loop resistance can be based on information supplied by the communication utility if the pilot is leased, or it can be calculated given the wire size and length of the pilot run, using dc resistance data published in wire tables. Pilot loop resistance

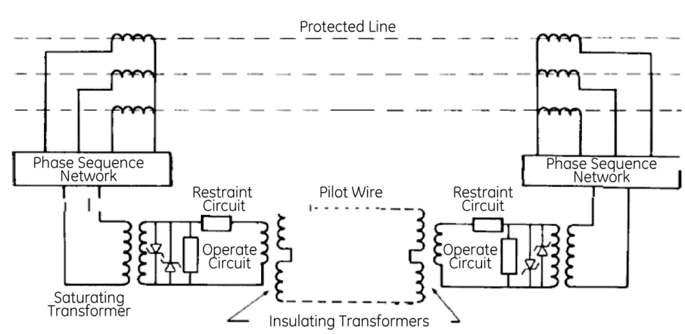

Fig 1.
Pilot wire simplified arrangement

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.

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 that can interfere with the proper operation of the scheme or cause damage to the pilot circuit and associated equipment. The most common hazards are:

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

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 pilot wires and other conductors in the same cable.

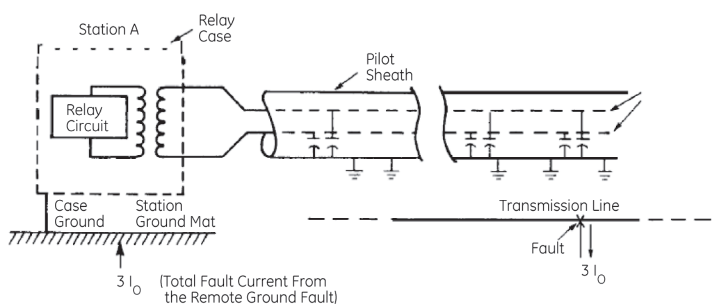

Fig 2.
Station mat.ground potential rise

As illustrated in Figure 2, 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 depends 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 impedance between the mat and the remote ground is determinedby calculation or test.

The diagram in Figure 3 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 becomes too great, there is danger to personnel and the possibility of damage to the

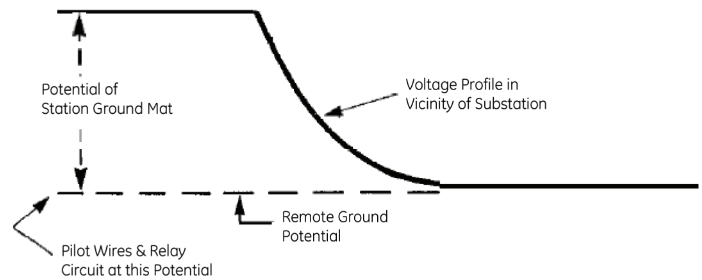

Fig 3.
Typical Ground Potential Profile During SLG Fault

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 the connected relays, terminal boards, panels and standard telephone cables.

4. Premises for Current Differential

Consider a communication link between two substa-tions that is twisted-pair wire and with all CTs and control wiring on the panels. This requires the ability to pass digital data over pilot wire without hazard and susceptibility to noise that could lead to possible misoperations. The following was successfully employed for current differential applications.

4.1 P31042 56kbs/HDSL Data Isolation Interface

This device is produced by SNC Manufacturing. This standalone transformer provides an isolated interface for two-wire data circuits. It is a passive, magnetic-coupled device. Primary to secondary isolation is rated at 65 kV BIL. Types of data circuits protected include Synchronet services and digital data services operating at 72k bits per second (bps) and subrates (including 72, 64, 56, 25.6, 19.2, 12.8, 9.6, 6.4, 4.8, 3.2 and 2.4 kbps), basic rate ISDN, HDSL, analog signals for data modems, SCADA, tone relay control, analog carrier, and tone signaling up to 100 kHz. The HDSL modem operates at 1024 to 2048 kHz signal. At this rate signal loss is less than 0.1 dBm, which is al-most negligible as a signal attenuation for the modem.

4.2 HDSL modem

There are a variety HDSL modems available on the market. However, not all meet industrial applications requirements. Modems must meet applicable environmental and communications standards to be safely applied for such applications. In general, HDSL modems support different interfaces. For this type of application, an RS422 interface was chosen; however, other galvanic interfaces like X.21 or G.703 can also be successfully applied. For the RS422 interface, one modem was set to generate a communications clock (Master) while other (Slave) was set to recover the clock from received data from the peer modem.

Set the modem interface as per manufacturer instructions. GE Multilin employed modems made by Schmid Telecommunications (Watson 2 or 3 HDSL modems) and Route 66 Communications, Inc (Crocus HDSL modems, not industrial hardened).

There is a limitation in length of the DSL cable depending on the modem driver and pilot wire gauge. Typical transmit power is 13.5 dBm at 135 Ω line impedance. Note that pilot wire characteristic impedance is 600 Ω at the voice band frequency. At DSL operating frequencies, it is about 120 Ω, which matches HDSL modem input impedance. AWG18 allows for 12 km pilot length and AWG22 allows for 8 km pilot wire length.

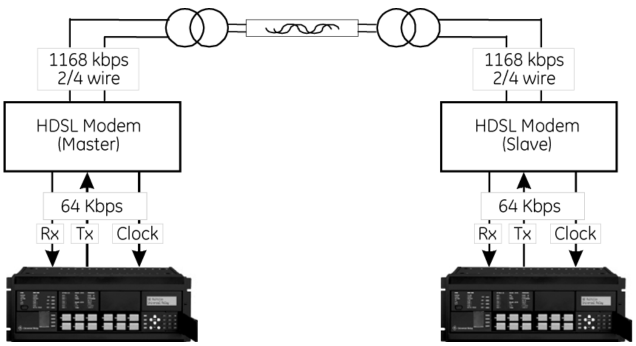

Fig 4.
Configuration of communication link over pilot wire

The HDSL modems are packaged with software for configuration as per specific application. On the DSL side, CRC checks are performed per DSL frame for each channel and direction. The software to count the block-errors of the respective DSL channel and to evaluate its error performance according to ITU-T G.826 standard uses CRC errors. It usually supports two-channel capability, which fits well into redundant channel concept for current differential relaying. This increases reliability of the protection system significantly. For example, for some applications customers used two independent modems via two separate pilot wires routes to increase security and availability of the protection system.

5. Applications Considerations

There are few application considerations have to be taken into account;

a. Channel availability;
Which in its turn is affected by noise presence on the channel. ITU-T G.821 recommends that when a 64 kbit/s channel is available, severely errored seconds should be limited to less than 0.002% of the time, and errored seconds should be limited to less than 0.08% of the time. An errored second is a one second time interval in which there are one or more bit errors, which comes out to be an equivalent Bit Error Ratio (BER) of about 1.5E-5 at 64 kbit/s.

A severely errored second is a one second time interval during which the BER is greater than 1E-3. For example, the 87L function is unavailable when its BER rises above 1E-4 or when the channel is down altogether. We recommend, if not more than 0.06% of overall “in service time” is “unavailable time” to be a reasonable margin to consider Channel as adequate for single-channel application.

For two-channel, two-terminal configuration, both channels must be unavailable for 87L to be unavailable. Assuming independent communications channel operation, the probability that 87L will not be available drops to 0.006%*0.006% percent of the time, or 0.000036%. 87L function has to detect in timely manner that protection is not available to switch to the backup strategy.

b. Noise immunity;
As route of the pilot wire is completely unprotected from electromagnetic interference with other sources. Usually, HDSL modems themselves have CRC-4 or CRC-6 protection against noise, which is not adequate for line current differential protection security. Therefore, 87L has to rely on its own noise detection mechanism and supervising functions.

Good example of protecting communication packet against communications noise is utilizing CRC-32 in the differential relay. The most severe situation as far as false operation is concerned is a high bit error rate, because a 32-bit CRC detects all one, two, and three bit errors in a message, so the necessary condition is an error of four or more bits. In the this worst case scenario of a collection of random bits, the probability of a corrupted message sneaking by the 32-bit CRC check is ½**32, or approximately 2.33E-8%.

According to above indicated recommendation of channel unavailability, this worst-case scenario occurs no more than 0.06% of the time during errored seconds. At 60 Hz, the differential relay, which sends 2 packets per cycle in a two terminal single channel configuration, transmits 9.5E8 packets per year in each direction. The probability of a false operation in a year is equal to the product of the probability of the 32-bit CRC failing to detect a severely errored packet times the fraction of severely errored packets, times the number of packets transmitted in a year. Multiplying 2.33E-10, 0.0006, and 9.5E8 together, we arrive at an upper bound for the prob-ability of a false operation of 0.0133%, or less than one false operation in 7,500 years.

c. Channel monitoring;
This includes; channel delay measurement and compensation, lost packets count and CRC errors count are essential differential relay means to determine

quality of the channel during commissioning and maintenance.

d) Redundancy;

Channel Failures have to be considered as imminent. Most reliable approach would be having 2 separate pair of pilot wire via two separate pairs of HDSL modems. However, in the case if both channels fail, fallback strategy has to be considered. Modern current differential relays have enough backup elements, like distance, overcurrent, directional etc, to provide essential backup protection for such case.

e) Security;

security is a measure of how well the relay avoids responding to conditions that do not warrant true internal fault presence. For the relay, which heavily depends on communication channel integrity that means receiving erroneous data not detected by relay's security means and leading to false operation. Even CRC-32 has finite capability in detecting packet's corruption as indicated above. Therefore, to eliminate even this remote possibility of misoperation, simple current disturbance detectors would be beneficial to use as supervising 87L trip elements. Usually, burst of noise occur during fault due to electromagnetic interference and this is exactly the situation when relays have to operate correctly.

f) Dependability;

Dependability is a measure of how well the relay detects the fault and issues the appropriate command (such as breaker opening). In the context of current differential protectoin, this means either burst of noise will take relay out-of-service for time enough to miss true a fault presence. Atypical scenario is an internal fault with corona leading to a burst of noise, which is gradually decreasing during the fault, and in question is relay response to such conditions.

6. Summary

Current differential relaying can be easily applied over pilot wires. Modern technologies like HDSL modem fa-cilitate such applications. GE relays have been in-service over pilot wire application for several years trouble free. This allows replacing out of date pilot wire relay with modern current differential relay with a minimum invest-ment and labor.

7. References

[1] C. Russell Mason, "The Art & Science of Protective Relaying", GE Publication GER-3738, 1967.

[2] "Application Guide AC Pilot Wire Relaying System SPD and SPA Relays", GE publication GET-6462A

[3] SNC Manufacturing Company HDSL/56kbps Data isolation Interface Part #31042 specification.

[4] GE Publication GEK-112994A, 2005, L90 Line Differential Relay, Instruction Manual.