Transmission Line Principles

The Purpose of Transmission Lines

Transmission lines act like the arteries in the human circulatory system, moving electrical power from were it is produced by generators to where it is consumed at load centers. And like arteries in the human body, the loss or damage to transmission infrastructure can have disastrous effects on the overall power system and the customers it serves. and is measured in either kilowatts (kW) or horsepower (Hp).

Transmission Line Construction

Transmission lines are generally built in one of two methods: overhead, air-insulated lines, and underground cables. Other constructions, such as Gas Insulated Lines (GIL), are extremely rare.

Types of Transmission Lines

Overhead

The most common type of transmission circuit are overhead lines, where the energized conductors are suspended from structures using porcelain, glass or polymer insulators. The spacing between conductors is dependent on the voltage level the line is operated at, and typically the conductors are located dozens of meters above the ground for isolation and safety reasons.

Due to the weight of the suspended conductors and the distances needed, the structures to support overhead lines are very large and have a large geographic footprint (commonly referred to as Right-of-Way or ROW). One of the advantages of overhead construction, beyond the easier ability to maintain it, is the ability to use ambient air to cool the conductors and therefore dynamically change the rating of transmission circuits based on ambient air temperature and wind speed.

This method of construction is typically the most common, and usually meets the most public opposition when new construction or upgrading of transmission infrastructure is discussed.

Figure 1.
Overhead transmission lines

Underground Cables

As opposed to overhead lines, underground cables use a solid dielectric material to isolate the energized phase conductors and ground. Older cables made use of many layers of paper saturated in mineral oil to insulate the phase conductors, while newer cable technology make use of polymer dielectric materials such as crosslinked polyethylene (XLPE). Due to the high insulation value of polymer dielectric materials like XLPE, the conductors within an underground cable may be placed much closer together when compared to the air insulated overhead line. For lower voltages, all three phases may be built into a single cable; for higher voltages each phase conductor is in a separate cable.

While the geographic footprint of underground cables is generally less than that of overhead lines, the overall power capacity of underground cables tends to be significantly less than overhead construction. For underground cables where large power transfers are required, cables are often installed into conduits that are filled with mineral oil that is continuously circulated in order to provide additional cooling. This incurs additional capital and maintenance costs and presents additional risks for environmental incidents should the oil leak.

Underground cables tend to meet less public opposition for aesthetic reasons, however the costs associated for fixing underground cables is far greater. Repairing faults on underground cables require expensive excavation and therefore providing highly accurate fault location is critical.

Figure 2.
Underground cables

Power Transfer Across Transmission Lines

The ability to move power from generators to loads is determined by a number of factors, including the voltage level expected and produced at both ends of the system and the equivalent impedance of the transmission system as viewed from a generation source to a load. The voltages at each end of the transmission system are typically controlled either by a required voltage magnitude (for loads) or by the maximum safe operating voltage of the source (for generators). The impedance is determined by such factors as the individual impedances of the transmission lines – ultimately determined by the size and type of conductors used and the geometry of the transmission line.

The power transfer across a simple transmission system like the one shown in Figure 3 is determined by the formula:

$$P = \frac{V_s V_r}{X} \sin_d$$

, where Vs and Vr are the voltages at the sending and receiving ends, d is the angle difference between Vs and Vr, and X is the equivalent impedance (neglecting resistance) between sending and receiving terminals. Real-time knowledge of the various voltage magnitudes, angles and power flows from generation to load centers across the system are essential to the reliable operation of the bulk electric system, especially when determining steady-state and transient stability limits.

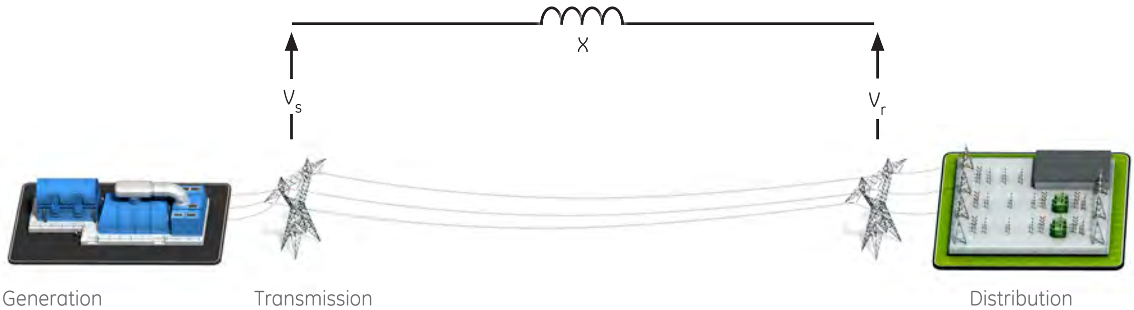


Figure 3.
Power transfer across a simple transmission system

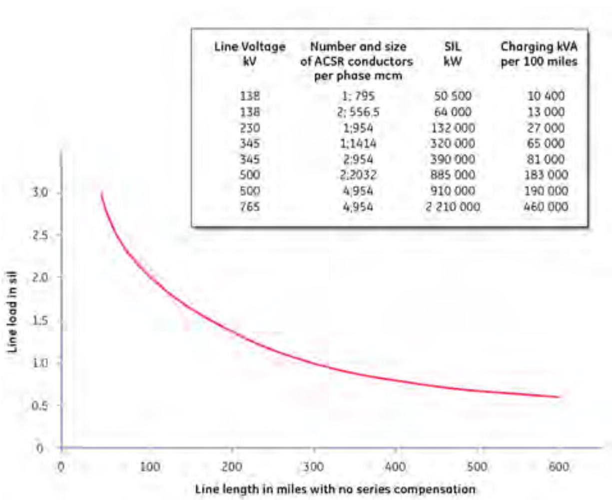
Loadability Limits & Thermal Effects

One of the limiting factors in the ability for a given transmission line is the heating effect caused by power lost due to I^2R losses in the resistance of the conductors themselves. The I^2R losses in the transmission line resistance heat the conductors and cause them to lengthen and sag. The additional sagging of the conductors reduces the distances between phase conductors and ground – if the sag becomes too great then the transmission line may flashover and cause a fault.

The heating effect is directly related to the resistance of the conductors that make up the transmission line and the cooling provided by the environment. For example, an overhead line will be able to carry more current on colder windier days than on hot days with no wind. For underground cables, circulating oil around the cables provides additional cooling.

Besides the steady-state thermal limits, there are also short term considerations that determine the amount of load that a given transmission line can carry for a limited period of time. Essentially a transmission line may be overloaded for a short period of time to allow the system to ride through disturbances. For example, one transmission line may be overloaded temporarily when a nearby transmission line is tripped and is waiting to be automatically reclosed.

The loadability limits and requirements on transmission lines can introduce additional constraints for protective relaying, as protection must be able to allow the transmission line to be temporarily overloaded while still retaining the ability to correctly detect and clear faults.



Line Voltage kV	Number and size of ACSR conductors per phase mcm	SIL kW	Charging kVA per 100 miles
138	1; 795	50 500	10 400
138	2; 556.5	64 000	13 000
230	1;954	132 000	27 000
345	1;1414	320 000	65 000
345	2;954	390 000	81 000
500	2;2032	885 000	183 000
500	4;954	910 000	190 000
765	4;954	2 210 000	460 000

Figure 4.

St Clair diagram showing transmission line capability in terms of surge impedance loading (SIL). The table shows loadability of various transmission solutions. (ACSR - aluminium conductor steel reinforced).

Abnormal Conditions

Faults

Transmission line faults are generally caused by a loss of insulation, either between the conductors of two or three of the phases or between one or more phase conductors and ground.

For overhead lines, the insulation between phases is dependent on the dielectric value provided by the air surrounding the conductors according to the distance between each of the phases and ground. There are a number of ways in which the insulation level for overhead lines can be degraded to the point where a fault can occur:

- Loss of the dielectric value of air due to contaminants suspended in the air. A prime example of this is the presence of soot particles suspended in the air, coming from nearby fires or from the combustion exhaust from industrial facilities.
- Reduced spacing between conductors and/or grounded objects. This can be caused by high winds causing the conductors to sway, or conductor sagging from overheating or being loaded with ice.
- Contamination of suspension insulators. The isolation between the phase conductors and the grounded transmission towers is provided by insulators that if contaminated or "fouled" lose their insulating value and can lead to flashovers between a phase conductor and ground. Common causes of insulator fouling include salt residue near coastal areas, air pollution and ice in colder climates.
- The distance between the conductors is determined by the insulation requred for a given voltage level. If the voltage on the line increases beyond the normal operating value, the extra voltage may cause insulation breakdown and flashover.

For underground cables, faults occur due to the degradation of the dielectric material used as the insulator in the cable. This is often caused by thermal stress from repeated overloading of the line, electrical stress from steady-state and transient overvoltages but is most commonly caused by water penetration into the cable insulation itself. Water penetration is very common at junctions in the cable, where two separate pieces of cable are spliced together as the splice loses its watertight properties with age. Faults on underground cables can prevent an additional risk of public injury, as the cables are often run in populated areas and faults in underground cable vaults can result in explosions that may result in personal injury or property damage.

Transmission Line Protection

Introduction

Transmission lines are a vital part of the electrical distribution system, as they provide the path to transfer power between generation and load. Transmission lines operate at voltage levels from 69kV to 765kV, and are ideally tightly interconnected for reliable operation.

Factors like de-regulated market environment, economics, right-of-way clearance and environmental requirements have pushed utilities to operate transmission lines close to their operating limits. Any fault, if not detected and isolated quickly will cascade into a system wide disturbance causing widespread outages for a tightly interconnected system operating close to its limits.

Transmission protection systems are designed to identify the location of faults and isolate only the faulted section . The key challenge to the transmission line protection lies in reliably detecting and isolating faults compromising the security of the system.

Factors influencing line protection

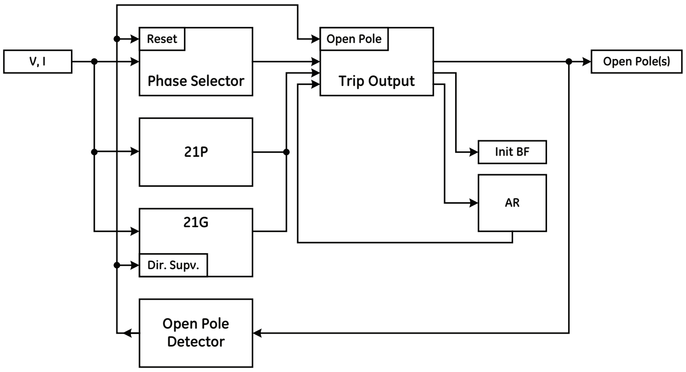
The high level factors influencing line protection include the criticality of the line (in terms of load transfer and system stability), fault clearing time requirements for system stability, line length, the system feeding the line, the configuration of the line (the number of terminals, the physical construction of the line, the presence of parallel lines), the line loading, the types of communications available, and failure modes of various protection equipment.

The more detailed factors for transmission line protection directly address dependability and security for a specific application. The protection system selected should provide redundancy to limit the impact of device failure, and backup protection to ensure dependability. Reclosing may be applied to keep the line in service for temporary faults, such as lightning strikes. The maximum load current level will impact the sensitivity of protection functions, and may require adjustment to protection functions settings during certain operating circumstances. Single-pole tripping applications impact the performance requirements of distance elements, differential elements, and communications schemes.

The physical construction of the transmission line is also a factor in protection system application. The type of conductor, the size of conductor, and spacing of conductors determines the impedance of the line, and the physical response to short circuit conditions, as well as line charging current. In addition, the number of line terminals determines load and fault current flow, which must be accounted for by the protection system. Parallel lines also impact relaying, as mutual coupling influences the ground current measured by protective relays. The presence of tapped transformers on a line, or reactive compensation devices such as series capacitor banks or shunt reactors, also influences the choice of protection system, and the actual protection device settings.

GE Multilin Application Advantages

Before considering using a GE Multilin relay for a specific transmission line protection application, it is important to understand how the relay meets some more general application requirements for simplicity, security, and dependability. GE Multilin relays provide simplicity and security for single pole tripping, dependability for protection communications between line terminals, security for dual-breaker line terminals, and simplicity and dependability of redundant protection schemes.



Single pole trip logic

Single -pole tripping

Single pole tripping using distance protection is a challenging application. A distance relay must correctly identify a single-phase fault, and trip only the circuit breaker pole for the faulted phase. The relay also must initiate the recloser and breaker failure elements correctly on the fault event. The distance elements protecting the unfaulted phases must maintain security during the open-pole condition and any reclosing attempts.

The D90^{Plus} Line Protection System and D60 Line Distance Relay use simple, dedicated control logic for single pole tripping applications. This control logic uses a Phase Selector, Trip Output and Open Pole Detector in conjunction with other elements as shown in the simplified block diagram.

The Trip Output is the central logic of single pole tripping. The Trip Output combines information from the Open Pole Detector, Phase Selector, and protection elements to issue a single pole or three pole trip, and also to initiate automatic reclosing and breaker failure. The Phase Selector is the key element for maintaining the security of single pole tripping applications, quickly and accurately identifying the faulted phase or phases based on measured currents and voltages, by looking at the phase angles between the positive sequence, negative-sequence, and zero-sequence components.

The Open Pole Detector ensures the relay operates correctly during a single pole trip, placing the relay in an open pole condition when a single pole trip command is issued, or one pole of the circuit breaker is open. The Open Pole Detector asserts on a single pole trip command, before the circuit breaker pole actually opens, to block protection elements that may misoperate under an open pole condition, such as negative sequence elements, undervoltage protection, and phase distance elements associated with the faulted phase (for example, AB and CA elements for an AG fault). The Open Pole Detector also resets and blocks the Phase Selector so the other distance elements may operate for evolving faults. The Open Pole Detector also accounts for line charging current and for weak infeed conditions.

Once the Open Pole Detector operates, a further trip will cause the Trip Output to declare a three pole fault, indicating either an evolving fault condition or a reclose onto a permanent phase-to-ground fault. This total logic simplifies the setting of the D60 for single pole tripping, and ensures dependable and secure operation when faced with single line-to-ground faults.

The L90 Line Differential Relay and the L60 Line Phase Comparison Relay are both phase-segregated, current only relays. Single pole tripping on these relays does not present any unusual challenges, as each phase of the protection element operates independently of the other unfaulted phases.

Communications

Often transmission lines are protected by using schemes that require communications with relays located at other line terminals. The reliability of the communications obviously impacts the reliability of the protection system. GE Multilin relays include features that maintain reliable operation of the protection communications during power line faults, communications channel delays, communications channel switching, and communications channel dropout.

Pilot protection: Pilot protection schemes, such as directional comparison blocking and permissive over-reaching transfer trip, use simple on/off communications between relays. There are many methods to send this signal. The most common method is to use contact closure to an external communication circuit, such as power line carrier, microwave, radio, or fiber optic communications. GE Multilin relays simplify fiber optic communications method by using internal fiber optic communications via Direct I/O, eliminating the need for external communications devices. Direct I/O is a reliable mechanism that is simple to configure, securely transmits digital status points such as tripping or blocking commands between relays via directly-connected or multiplexed fiber optic channels. Direct I/O operates within 2ms for high speed communications to the remote line end.

Direct I/O is available in any of the transmission line relays by adding an internal communications card. The output of the card can be IEEE C37.94, RS422 or G.703 communications to interface with fiber optic multiplexers, or may be a direct fiber connection to other relays. The communications card can be single-channel or dual-channel, to support point-to-point communications, dual point-to-point communications, or ring communications between up to 16 relays.

Line Current Differential: Communications is an integral piece of a line differential relay, as the currents from one line terminal must be sent to relays at other line terminals to perform the differential calculation. This requires the use of a digital communications channel, which is commonly a multiplexed channel where channel switching may occur. The analog information must be precisely time synchronized between the line ends for the differential calculation to be correct. Synchronization errors show up as phase angle offset, where identical currents produce phasors with different phase angles, and transient errors, where changes in current are seen at different times at different measurement points. For example, on a 60 Hz system, every 1ms of time shift between terminals introduces a 21.6° phase shift into the measured currents.

There are two methods to account for the phase shift between line terminals due to the communications channel delay. One method is to measure the round-trip channel delay, and shift the local current phase by an angle equal to ½ of the round-trip delay time. This method is simple to implement, but creates a transient error when the communications channel is switched. In addition, the differential element will be temporarily blocked when the communications channel switches, or noise in the communications channel causes communications packet loss.

The L90 Line Differential Relay employs a different method, using synchronous sampling by internally synchronizing the clocks on each L90. This method achieves high reliability, as the round-trip channel delay is not vitally important. The differential element successfully operates during channel switching or after packet loss, because the communications packets are precisely synchronized.

In the L90, synchronization is accomplished by synchronizing the clocks to each other rather than to a master clock. Each relay compares the phase of its clock to the phase of the other clocks and compares the frequency of its clock to the power system frequency and makes appropriate adjustments. The frequency and phase tracking algorithm keeps the measurements at all relays within a plus or minus 25 microsecond error during normal conditions for a 2 or 3 terminal system. In all cases, an estimate of phase error is computed and used to automatically adapt the restraint region of the differential element. The time synchronization algorithm can also use a GPS satellite clock to compensate for channel asymmetry. The use of a GPS clock is not normally required, except in applications such as a SONET ring where the communications channel delay may be asymmetric.

This method produces synchronization accurate to within 125 microseconds between the relays on each end of the protected line. By using internally synchronized sampling, the L90 can accommodate 4 consecutive cycles of communications channel loss before needing to block the differential element. If the communications channel is restored within 5 seconds of channel loss, the L90 differential element will restart on the first received packet, without any time synchronization delay, due to the inertia of the internal clocks of the relays.

Line Phase Comparison: As with line differential, communications is an integral part of phase comparison relaying. Simple binary communications, such as power line carrier or microwave, is used to send a pulse to the remote end when the phase angle of the measured current is positive. Coordination between the pulses from the remote end, and the phase angle measured at the local end, must be maintained.

The L60 Line Phase Comparison Relay directly solves two common challenges with the carrier signal. The first issue is channel delay. The channel delay is measured during commissioning and is entered as a setting in the phase comparison element. The remote phase angle measurements are buffered and delayed by this value to match the incoming pulses from the remote relays. The L60 has two communications channels, and two independent channel time delays, to support three-terminal lines.

The other common issue is pulse asymmetry of the carrier signal. Carrier sets may extend, either the mark (on) or space (off) signals at the receiving end compared with the originally sent signal. This difference is measured during commissioning by using oscillography data, and simply entered as a setting in the phase comparison element.

In addition, the L60 supports some other methods to improve the reliability of protection communications. For short lines with negligible charging current, the channel delay measurement can be automated by running a loop-back test during normal system conditions and measuring the difference between the sent and received pulses. The L60 also supports automated check-back of the carrier system. Under normal conditions, the relay can initiate transmission of and modulate the analog signal to exchange small amounts of information. This automatic loop-back can replace the carrier guard signal, and more importantly, verifies the entire communications path, including the relays on both ends.

Security for dual-breaker terminals

Dual-breaker terminal line terminals, such as breaker-and-a-half and ring bus terminals, are a common design for transmission lines. The standard practice is to sum the currents from each circuit breaker externally by paralleling the CTs, and using this external sum as the line current for protection relays. This practice works well during actual line faults. However, for some external fault events, poor CT performance may lead to improper operation of line protection relays.

When current flows through a dual-breaker line terminal, the line current measured by a relay using external summation matches the actual line current only if the two CTs are accurate. The most significant relaying problem is CT saturation in either CT. The current measured by the relay may contain a large error current, which can result in the relay operating due to an incorrect magnitude or direction decision. This incorrect operation may also occur if the linear error current of the CTs due to accuracy class is close to the through current level. These errors appear in the measured phase currents. As a result, relays that calculate the negative sequence and zero sequence currents from the measured phase currents may also see errors.

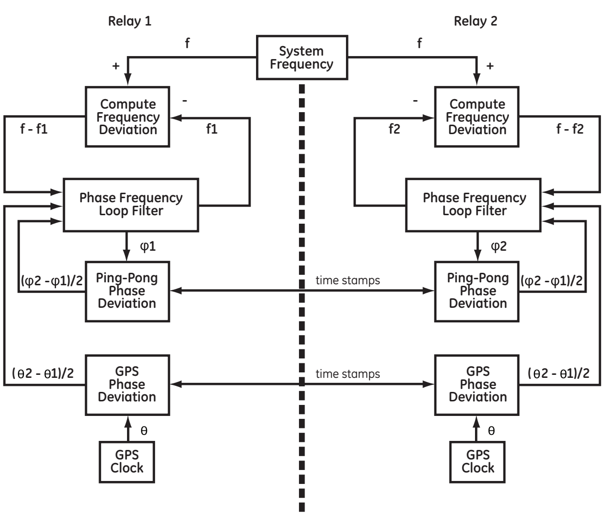
Distance: Distance relays applied at dual-breaker line terminals are vulnerable to mis-operation on external faults. During a close-in reverse external fault, the voltage is depressed to a very low level, and the security of the relay is maintained by directional supervision. If one of the line CTs saturates, the current measured by the relay may increase in magnitude, and be in the opposite direction of the actual fault current, leading to an incorrect operation of the forward distance element for an external fault.

The D90[Plus] Line Protection System and the D60 Line Distance Relay handles the challenge of dual-breaker line terminals by supporting two three-phase current inputs to support breaker failure, overcurrent protection, and metering for each circuit breaker. The relays then mathematically add these currents together to form the total line current used for distance and directional overcurrent relaying.

Directly measuring the currents from both circuit breakers allows the use of supervisory logic to prevent the distance element and directional overcurrent elements from operating incorrectly for reverse faults due to CT error. This supervisory logic does not impact the speed or sensitivity of the protection elements, operates during all load conditions, and correctly allows tripping during an evolving external-to-internal fault condition.

The dual-breaker line terminal supervisory logic essentially determines if the current flow through each breaker is either forward or reverse. Both currents should be forward for an internal fault, and one current should be forward and one reverse for an external line fault. The supervisory logic uses, on a per-phase basis, a high-set fault detector (FDH), typically set at 2-3 times the nominal rating of the CT, and a directional element for each CT input to declare a forward fault, for each breaker. The logic also uses, on a per-phase basis, a low-set fault detector (FDL), typically set at 1.5-2 times the nominal rating of the CT, and a directional element to declare a reverse fault, for each breaker.

Tripping is permitted during all forward faults, even with weak infeed at the dual-breaker terminal. Tripping is blocked for all reverse faults when one breaker sees forward current and one breaker sees reverse current. During an evolving external-to-internal fault, tripping is initially blocked, but when the second fault appears in the forward direction, the block is lifted to permit tripping.



Clock synchronization block diagram for a two terminal system using L90 current differential system

Line Differential: Line differential protection is prone to tripping due to poor CT performance on dual-breaker terminals, as the error current from the CTs is directly translated into a differential current. The only possible solution for traditional line differential relays is to decrease the sensitivity of the differential element, which limits the ability of the differential element to detect low magnitude faults, such as highly resistive faults.

The L90 Line Differential Relay supports up to four three-phase current inputs for breaker failure, overcurrent protection, and metering for each circuit breaker. The relay then uses these individual currents to form the differential and restraint currents for the differential protection element.

The L90 differential element design explicitly accounts for the performance of the CTs for dual-breaker line terminals. Each L90 protecting a transmission line calculates differential and restraint quantities based on local information directly measured by the relay, and information received from relays located at the remote line ends. Tripping decisions are made locally be each relay.

The information sent by one L90 to the other L90s on the line is the local differential and restraint currents. The local differential current is the sum of all the local currents on a per-phase basis. One L90 can accept up to 4 current measurements, but only 2 currents are used for a dual-breaker application.

$$I_{LOC} = I_1 + I_2 + I_3 + I_4$$

The local restraint current is defined by the following equation for each phase.

$$I_{LOC\_RESTRAINT} = \sqrt{(I_{LOC\_REST\_TRAD})^2 + MULT \bullet (I_{LOC\_ADA})^2}$$

The starting point for the restraint is the locally measured current with the largest magnitude. This ensures the restraint is based on one of the measured currents for all fault events, and increases the level of restraint as the fault magnitude increases. ILOC_REST_TRAD is this maximum current magnitude applied against the actual differential characteristic settings. ILOC_ADA is the sum of the squares estimate of the measurement error in the current, and is used to increase the restraint as the uncertainty of actual measurement increases, such as during high magnitude fault events and CT saturation. MULT is an additional factor that increases the error adjustment of the restraint current based on the severity of the fault event and the likelihood the fault is an external fault, when CT saturation is most likely to cause an incorrect operation.

The values of I_{LOC} and $I_{LOC\_RESTRAINT}$ are transmitted to the L90 relays located at the other line ends. The differential and restraint values used in the actual tripping decision combine both the local differential and restraint current, and the differential and restraint currents from the remote line ends. These calculations are performed individually on each phase.

$$I_{DIFF} = I_{LOC} + I_{REMOTE\,1} + I_{REMOTE\,2}$$

$$(I_{REST})^2 = (I_{LOC\_RESTRAINT})^2 + (I_{REM\,1\_RESTRAINT})^2 + (I_{REM\,2\_RESTRAINT})^2$$

Considering the worst case external fault with CT saturation, the differential current IDIFF will increase due to the CT error that appears in ILOC. However, the restraint current IREST will increase more significantly, as the ILOC_RESTRAINT uses the maximum of the local currents, that is increased based on the estimation of CT errors and presence of CT saturation. The end result is a correct restraining of the differential element.

Phase Comparison: The L60 Line Phase Comparison Relay supports two three-phase current inputs for breaker failure, overcurrent protection, and metering for each circuit breaker. The relay then uses these individual currents to form the local phase angle information for use in the phase comparison scheme.

A phase comparison relay operates by comparing the relative phase angles of the current from each end of the transmission line. When the measured current exceeds the level of a fault detector, and the phase angles from each end of the line are in phase, the phase comparison relay operates. For a dual-breaker application using an external sum, the saturation of one CT may cause the relay current to increase high enough to operate the fault detector. Because the current from the unsaturated CT predominates in this waveform, the phase angle of the relay current may change. If the phase angle of the relay current is in phase with the relay current at the remote end of the line, the relay will trip.

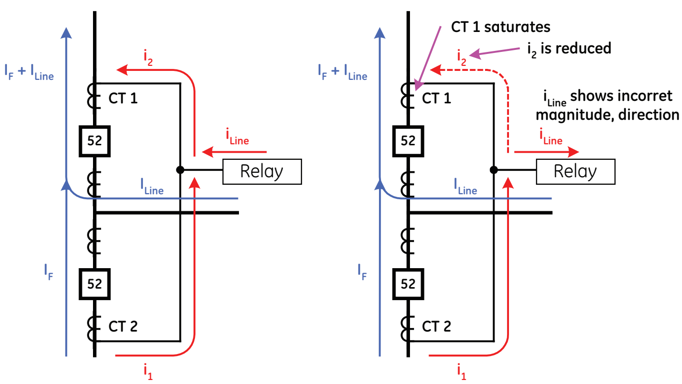
The L60 in dual-breaker applications selects the appropriate phase angle, based on the information measured from the current flow through both circuit breakers. The relay uses fault detectors on each current input, and develops the phase angle for each current input, and then special dual breaker logic consolidates the fault detector flags and the phase angle pulses for the line terminal.

The fault detector flag is set for a line terminal if either fault detector from the two breakers is picked up. The type of phase comparison protection scheme, tripping or blocking, controls the pulse combination logic. For a tripping scheme, a positive polarity is declared for the terminal if one breaker displays positive polarity with its respective fault detector picked up, while the other breaker either does not show negative polarity or its fault detector is not picked up.

Redundancy Considerations to Enhance Reliability

The reliability of transmission system protection is dependent on the reliability of the protection scheme used and the individual components of the protection scheme. Transmission protection systems typically use redundancy to increase the dependability of the system. There are two general methods of implementing redundancy. One method is to use multiple sets of protection using the same protection scheme. The other method is to use multiple sets of protection using different protection principles. Depending on the voltage class, either method of redundancy may involve using 2 or 3 sets of protection. In both cases, the goal is to increase dependability, by ensuring the protection operates for a fault event. Security may be improved through the use of so-called voting schemes (e.g. 2-out-of-3), potentially at the expense of dependability.

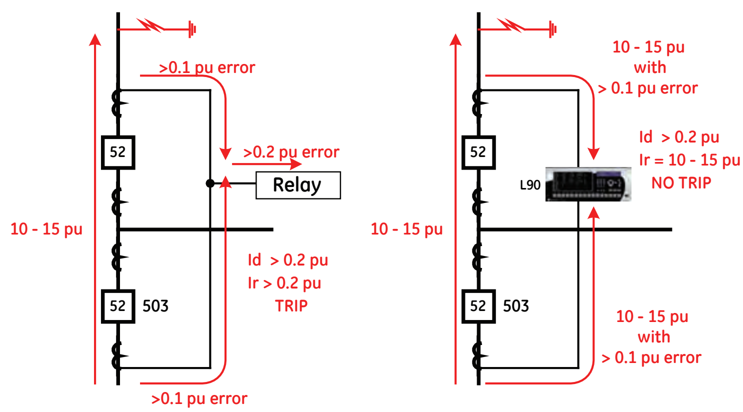
Multiple sets of protection using the same protection scheme involves using multiple relays and communications channels. This is a method to overcome individual element failure. The simplest method is to use two protection relays of the same type, using the same scheme and communications channel. This only protects against the failure of one relay. In some instances, relays of different manufacturers are



Impact of CT saturation on two-breaker line applications.

(a) Accurate CTs preserve the reverse line current direction under weak remote feed.

(b) Saturation of the CT carries the reverse current may invert the line current as measured from the externally summated CTs



Sensitivity of Line Differential system for Dual-Breaker applications

Redundancy Requirements - Alternate Main Protection Possibilities from GE Multilin used, to protect against common mode failures. It is also common to use redundant communications channels, in case of failure on one communications channel. Often, the communications channels use different methods, such as power line carrier and fiber optic. This is especially true due to the concerns of power line carrier operation during internal fault events.

An alternative way to increase reliability through redundancy is to use multiple protection methods on the same line such as phase comparison and permissive over-reaching transfer trip, using different communications channels. This method protects against individual element failure of both relays and communications channels. More importantly, it protects against the failure of one of the protection methods. For example, a VT circuit fuse failure blocks a distance relay from operating, while a line differential system or phase comparison system will continue to operate. For this reason, often at least one current-only scheme, such as phase comparison or line differential, and then one pilot protection scheme based on distance relays are employed.

A second advantage of using multiple protection methods to protect one line is the ability to increase the security of the line. It is possible to implement a "voting" scheme, where at least 2 protection methods must operate before the line can be actually tripped. Such a voting scheme may be applied permanently on lines where security is an issue, such as major inter-tie lines. A voting scheme may also be applied only when the system is at risk, such as during wide-area disturbances, either automatically based on system conditions, or by command from system operators.

GE Multilin simplifies solutions when multiple protection schemes are used by providing both protective relays that only use current and protective relays that use both current and voltage. The L60 Line Phase Comparison Relay and the L90 Line Differential Relay are both current-only protection relays with different operating principles. The D90^{Plus}, D60 and D30 Line distance protection systems are full-featured distance relays. These relays are on a common hardware and software platform, simplifying engineering, design, installation, and operations issues. All of these relays support multiple communications options, including power line carrier, microwave, and fiber optic communications. The relays are also designed to communicate with each other, to implement voting schemes, reclosing control, and other applications.