PROTECTION USING TELECOMMUNICATIONS[1]

LINE PROTECTION

Analog Comparison Schemes

Analog comparison protection is based on the transmission and comparison of electrical parameters such as primary currents (amplitude and/or phase) between the ends of a protected line. Each end sends its registered values to each other and compares them with the remote ones. When an internal fault occurs, the result of the comparison will be a differential value, so that, if it is higher than a threshold, the relay will initiate the trip.

These systems are called analogue comparison protection systems because they exchange analogue quantities such as amplitude and/or phase with the other ends. They are sometimes also referred to as "unit protection" or "closed" schemes. The term “unit” refers to the clear interdependence between the ends for operation and to the closed and absolutely selective characteristic of this protection.

Obviously, the comparison must be made between magnitudes at the same instant, which implies a transmission and comparison system as fast as possible. A delay must be provided for the local signal to compensate for the transmission time of the remote value.

Unlike the time-grade protection such as distance and time overcurrent relays, the trip of the analog comparison protection is instantaneous for every fault on the protected line.

It is applicable to any overhead line or cable at all voltage levels and for any type of system neutral arrangement. It is particularly suitable where:

- Step distance relays (without acceleration schemes) have limitations, for example:
  - Very short lines and cables due to their low impedance, which makes it difficult to find an adequate setting to get a instantaneous trip for faults on the main part of the line.
  - Multi-terminal lines, since the intermediate infeeds modify the impedance seen by the distance relays, which depends not only on the distance to the fault, but also on the infeed from the remote terminals, making impossible an accurate measure of the impedance.
- No potential transformers and only current transformers are installed at each end of the line.

We can distinguish two types analog comparison protection systems: longitudinal current differential protection and phase comparison protection. The current differential protection compares the power frequency signals proportional to the primary power system currents (amplitude and phase angle), while the phase comparison one is based on comparison of the phase angle (or sign) between currents of each end of the protected line.

Since both of them use only current information, in comparison with the distance or other system protections, analog comparison protections have the following advantages:

- Not responsive to system swings and out-of-step conditions
- Unaffected by inadvertent loss-of-potential (i.e., due to a blown potential fuse)
- No mutual coupling problems from parallel lines. This may cause the line-to-ground fault current reverses and flows into a weak source terminal, causing faulty directional discrimination if other protection systems are used.
- Not subject to transient problems associated with coupling capacitor potential devices.

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[1] Extract from CIGRE Publication
Protection Using Telecommunications
Joint Working Group 34/35.11
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- With segregated current differential there are no problems of phase selection for single pole auto-reclosing at simultaneous faults on different circuits and phases close to one line end, because it operates only for faults between current transformers in each phase.
- Some relaying problems in EHV transmission lines due to applying series capacitors are also overcome, e.g. voltage reversal, current inversion or phase imbalance.

When phase selection is required for single phase tripping, especially at simultaneous faults on different circuits and phases or in a faulty line when handling heavily loaded EHV lines, the phase-segregated technique is used. The analogue information is transmitted separately for each phase.

In cases where the complete information about the polyphase conditions is not essential and single-phase tripping is not needed, the non-segregated technique is used. It reduces the threephase system of currents to a single-phase one by means of a mixing device. The communication link needs therefore to only accommodate the transmission of this single phase information. Some mixing techniques are described in [1].

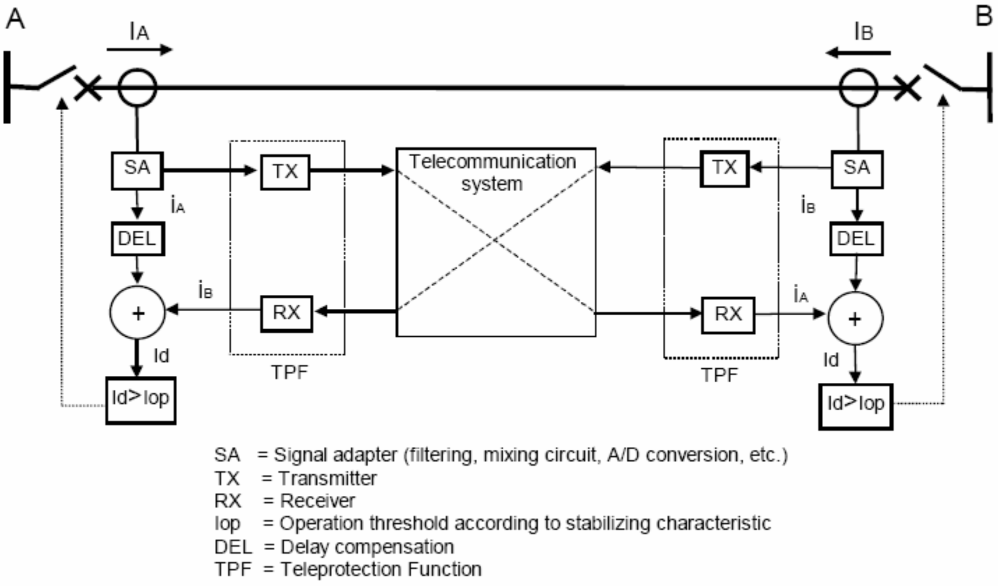
Current Differential Protection

Operating Principles

As mentioned above the current differential protection is an absolutely selective protection system for transmission lines, tripping instantaneously for faults in the protected zone defined by the current transformers of each end of the line.

It is based in the principle of current comparison. The Figure 3.1-1 shows a basic scheme of the differential protection. In each terminal, an evaluation circuit compares the sum of the local and remote current values, i.e. the differential current, with an operation threshold value I_{op}. In normal operation conditions or external faults, the current entering at one end is practically the same as one leaving at the other end, so the differential current value is practically zero and the protection will remain stable. For a fault on the protected power line the differential current value will exceed the operation value and the protection will trip.

When very large currents flow through the protected zone for a fault external to the zone a differential current appears due to the different ratio error and saturation characteristic of the current transformers, which could exceed the operation level. Such a maloperation of the protection is prevented by the stabilizing. The stabilizing characteristic uses a bias current, which is usually proportional to the sum of the absolute values of the currents at each terminal, i.e. $|I_A| + |I_B|$, in order to make the protection less sensitive for higher through currents. This technique is also called percentage restraint.



SA = Signal adapter (filtering, mixing circuit, A/D conversion, etc.)
TX = Transmitter
RX = Receiver
Iop = Operation threshold according to stabilizing characteristic
DEL = Delay compensation
TPF = Teleprotection Function

Figure 3.1-1: Principle of differential protection

Figure 3.1-2 shows an example of percentage restraint characteristic with two slopes: the lower slope ensures good sensitivity to resistive faults under heavy load conditions, while the higher slope is used to improve relay stability against saturation of the current transformers and other distortion effects under heavy through fault conditions.

The selection of the minimal operation current I_{s1} is based upon the magnitude of line capacitance current and switching transients expected on the protected line. The capacitance of the three conductors to earth and, except in single core cable, also between each other, makes that under undisturbed conditions the current at both ends differs in angle and magnitude. Particularly in cables, the capacitive charging current can attain significant values. Nevertheless, usually the necessary rise of the I_{s1} does not involve an important loss of sensitivity.

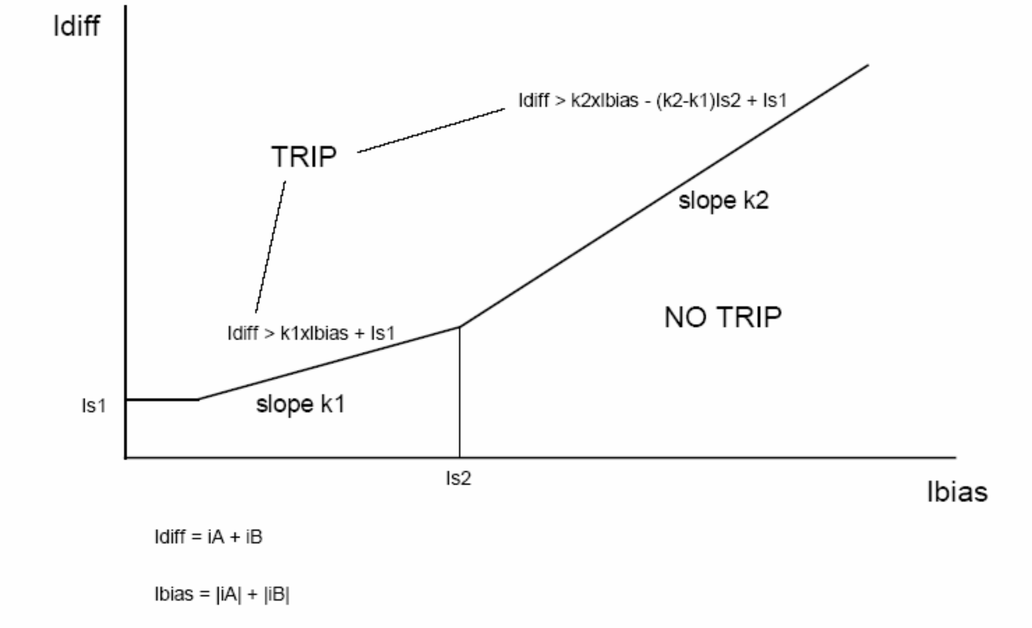


Figure 3.1-2: Differential protection: Example of percentage restraint characteristic

The differential principle may be applied to multi-terminal lines. The protection relies on the sum of the inflowing currents, which are added geometrically. For this purpose, the measuring circuits have to be so arranged that at each end of the line, the local current and the currents from each of the others ends of the line are available for comparison. Generally, the most recent designs allow up to three terminals applications.

For a multi-terminal system, the master/slave or centralized configuration is also used. In this case, the current values are sent to a specific terminal for evaluation of the differential current. This terminal will henceforth be noted as a master, while the terminal sending information about currents will be denoted as a slave terminal. For a two-terminal system, the master/slave configuration can, of course, also be used, but a master/master or distributed configuration, where the current information is exchanged between both terminals and evaluated at both ends is normally preferred, since this gives a shorter operating time than that in a master/slave configuration. See Figure 3.1-4 and Figure 3.1-5 for more details about centralized and distributed configurations.

The saturation of the current transformers for heavy through currents normally requires the selection of a higher slope setting which involves a loss of sensitivity for internal faults. Recent protections include some techniques to detect the saturation, so in only such conditions is the protection desensitized increasing the restraint slope. To avoid the maloperation of the remote protections, the terminal that detects the saturation includes a code in the message transmitted to the other ends, so that all terminals increase the degree of stabilization.

Time Delay Compensation

As mentioned, the current values used in the differential protection must be taken at the same instant at all ends of the power line for comparison, so a delay circuit is needed to compensate the transmission time for the remote values. Classical designs incorporate an adjustable delay for aligning the current values. However, when digital communication systems with automatic route switch are used, the time delay can change and the protection must continuously adjust the time alignment. For this purpose, digital devices incorporate different techniques in which the messages of current values sent through the communication channel are tagged with the sampling time. The principles of some synchronization techniques are described in more detail in A4.1. An error in delay compensation results in a differential current that - according to Figure 3.1-2 - increases the risk of unwanted tripping. For more information see 6.1.2.2 and 6.3.1.1.

Additional Functions

Generally, differential protections use intertrip functions, i.e. the sending of trip commands to the remote ends. Intertrip commands are sent through the same communication channels used to transmit the current values (switching the channel frequency to a specific intertrip frequency when analogue links are used, or flagging the corresponding command bits in the out-going data messages in digital links).

The intertrip function is activated either when the relay reaches a trip decision, or by closing an external contact connected to an input of the relay.

The intertrip function can be used for:

- Breaker failure protection
- Stub protection: this is applied in switchyards with 1½ circuit breaker configuration. Operating an input by external contact when the line isolator opens allows to protect the line between the circuit breakers and the line isolator.

Telecommunication Systems Used For Differential Protection

Differential protection systems using pilot wires for 50/60Hz signals

Pilot wires connect both ends electrically and establish a differential circuit where the secondary quantities may be in the form of current signals or voltage signals, which are proportional to the primary current. Accordingly, there are two basic methods of creating a differential circuit, current balance or voltage balance. Figure 3.1-3 shows a basic scheme of a current balanced system using three pilot wires.

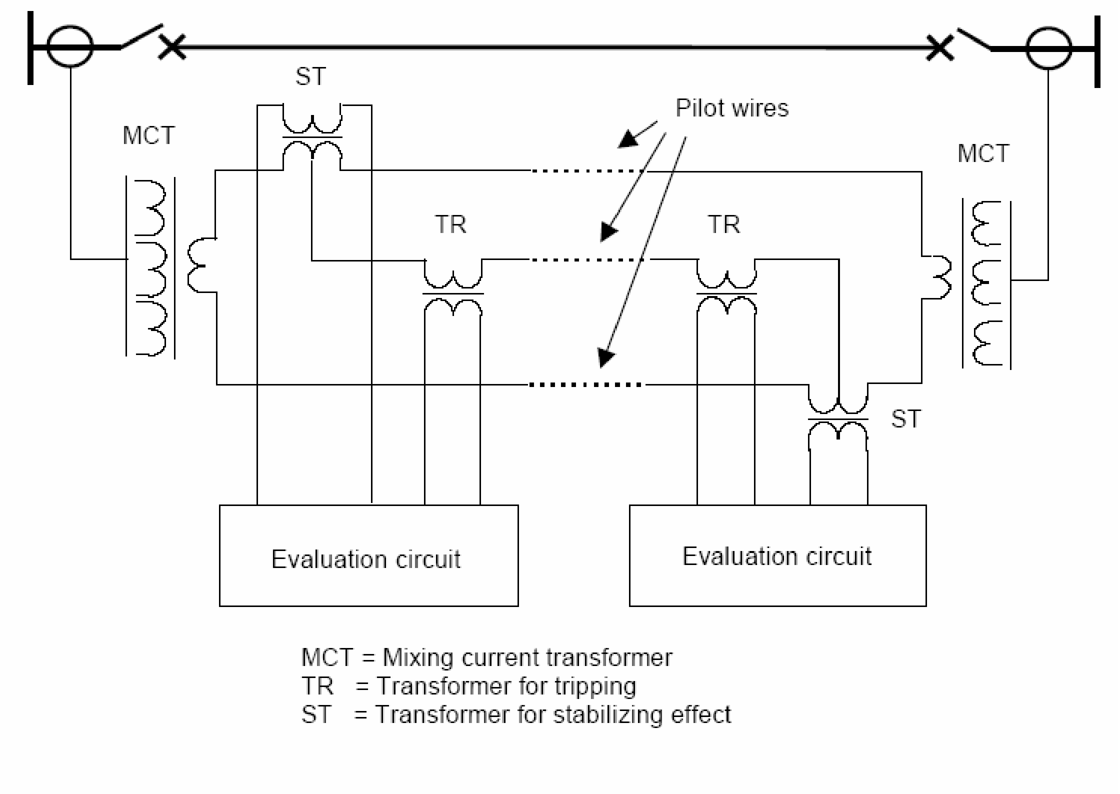


Figure 3.1-3: Basic scheme of a current balanced system using three pilot wires

In this case, the three-phase system is converted into a single AC current in the mixing transformer MCT (non-segregated).

One differential system for each power phase (segregated) of the protected circuit can also be provided. If high resistance faults are expected or faults on which the value of earth fault current is relatively low, a fourth measuring system for the zero sequence component can be introduced. This however, increases the number of pilot wires and therefore the communication cost of the comparison information.

In both methods, a replica of the vector difference is formed at each line end by means of a transformer ST for the stabilizing effect and a replica of the vector sum of the currents flowing at each end by means of a further transformer TR for the tripping effect. These values are evaluated separately at each line end in a measuring module and a tripping command is issued to the circuit-breaker when the fault current has exceeded a permanently adjusted threshold value.

Where the voltage induced into the pilot cables during earth faults may exceed the rated values, the protective relays should be isolated from the pilot wires by isolating transformers, which can also be used to subdivide the total length of the pilot wires into two or three sections. This prevents the equipment from being subjected to excessive longitudinal voltage due to interference. In any case, the grounding conditions should be considered.

The application of differential protection using pilot wires is restricted on lines up to 10-25 km depending upon the scheme used. So for longer lines, modulation techniques over other transmission media should be used. More details about differential protection using pilot wires and their limitations can be found in [1] and in chapter 4.3.1.

Differential protection systems using modulation or coding techniques

Modulation or coding techniques that are compatible with analog and digital telecommunication circuits are used to overcome some of the shortfalls experienced with direct pilot wire coupling[2]. Typical techniques that are used:

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[2] 1 Note on pilot-wire replacement:

- Frequency modulation (FM) for analog voice frequency (VF) channels. The instantaneous current values at each terminal are transmitted as analogue quantities to the other terminals in a voice frequency band (0.3 to 3.4 kHz) using frequency modulation. Whatever transmission media for analogue voice channels may be applied.
- Numerical coding for digital telecommunication systems The instantaneous current values at each end of the power line are sampled, converted to digital data and transmitted towards the other terminals through a digital telecommunication system. Sample rates ranging from 12 to 60 samples per cycle have been used. Normally, the telecommunication system is shared with other services like voice, telecontrol, etc. using Time Division Multiplexing techniques (see 4.4.1.2). The protection system is connected to the PCM) multiplexer through standard interfaces. The most commonly used electrical interfaces are those contained within the ITU-T or EIA recommendation and are described in 5.3.1 and in [2].
- Dedicated optical fibres. Direct optical fibre links between protection terminals are also used. A higher reliability is achieved because intermediate devices are eliminated. However, when using dedicated fibres over long distances, the cost can be prohibitive beyond 10-20 km. See 4.3.4 for more information on optical fibres.

Multi-Terminal Configuration

Transmission line protection based on a current differential scheme detects zone faults by using each terminal current and transmits the detection results of the zone fault to the other terminals. There are two types of multi-terminal current differential protection configurations; *centralized* and *distributed* configurations. As these configurations are applied to a single zone protection, they may be also applied to multi-zone and wide-area protections.

Centralized configuration

Figure 3.1-4 shows an example of line protection for a five-terminal EHV line [7]. Each terminal has a terminal unit that detects the current and transmits the data to the main unit terminal via a communication channel. This configuration simplifies the unit of each terminal and communication channel. Since the main unit has current data of all terminals, the fault locator function can be easily implemented by using these data.

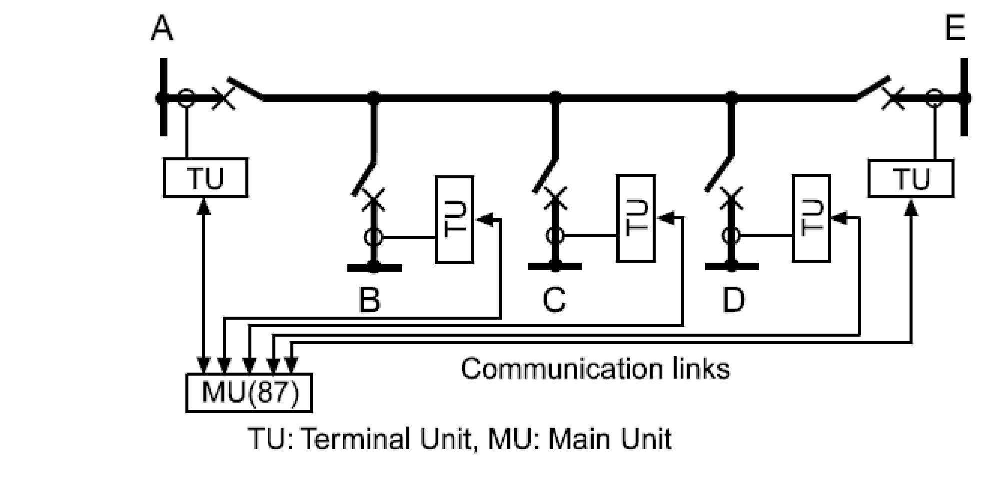


Figure 3.1-4: Centralized configuration

The corrosion problems of buried copper wires, with the trend of telcos to replace copper-pair cables with fibre communication links, have put pressure on utilities to consider alternate means of connecting their extensive infrastructure of pilot-wire relays; this has created a market for specialized interface units which emulate these copper wires.

The accuracy requirements of such interfaces depend on the accuracy requirements of the relay settings, the main parameters of concern are:

- The interfaces’ dynamic range. This should not limit on fault currents, whilst providing the required signal integrity during low line-current conditions.
- The end-to-end propagation delay. Since a 10% fault current error would be caused by the 5 degrees phase error accruing from 230∝s on a 60Hz grid (280∝s on a 50Hz grid), this delay is critical (this teleprotection application has the most stringent delay requirements of all teleprotection applications).
- In practice, up to 1ms may be manageable for the protection of 2-ended lines, but 500us or less may be required for 3-ended lines.

Distributed configuration

Figure 3.1-5 shows a distributed configuration of five-terminal current differential line protection system. Each terminal has the current differential protection function as well as the signal transmitting function that multiplexes current data at each terminal into one communication signal. Master station A sends its own current data to slave station B. Slave stations B, C, D and E multiplex their own current data over communication signal. Slave station E turns back this signal toward slave station D. Now current data of all terminals are on the communication bus and available for protection. In addition, this system contains sampling synchronization function which enables the simultaneous sampling of current data at each terminal with high accuracy. Many installations were conducted using a 1.544-Mbit/s fiber-optic communications channel for HV double-circuit multi-terminal (up to ten terminals) or tapped lines [8]. In this network configuration where current differential calculation is usually carried out at each terminal, a centralized scheme where only master station conducts the calculation and sends the transfer trip signal to all slave stations is also available.

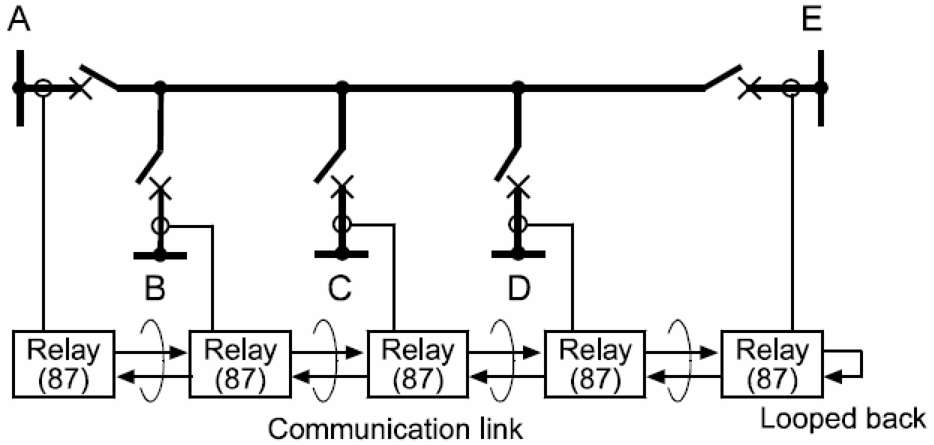


Figure 3.1-5: Distributed configuration

Phase Comparison Protection

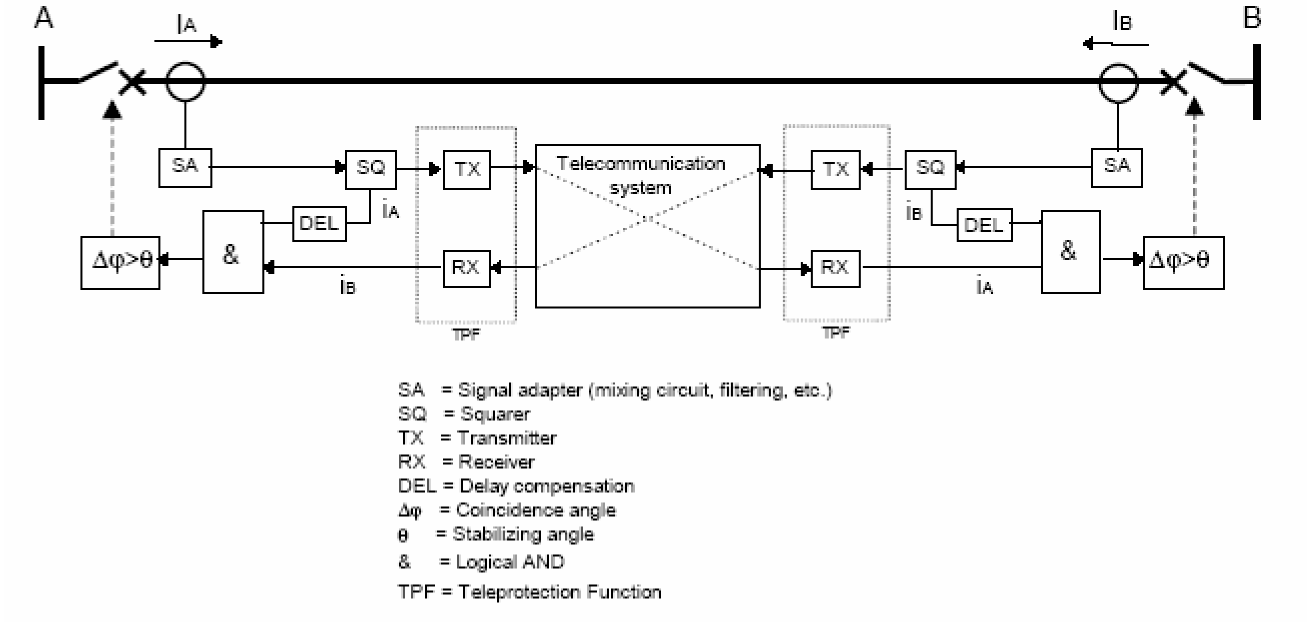
Operating Principles

Phase comparison protection is based on the comparison of the phase angle between currents of each end of the protected power line. Under normal load conditions or in case of an external fault, the angle measured between the local current and the current at the remote ends will be small. If the angle is large, it is due to an internal fault.

The basic principle of all phase comparison systems is to measure the angle as above mentioned. However, the method of doing so can differ from manufacturer to manufacturer. A phase comparison system can be characterised by the following features:

- Comparison is made for each phase separately. A zero sequence circuit may also be included => Segregated protection.
- The currents of the three phases are mixed into one quantity for comparison => Nonsegregated protection.
- The measurement is made twice every period => Full-wave phase comparison.
- The measurement is made once every period => Half-wave phase comparison.
- The phase angle signal is transmitted to the remote end only when a starter has picked up.
- Measuring is carried out continuously and the signals are permanently transmitted.
- A phase comparison scheme can be designed for a blocking mode or for an unblocking mode of operation, similar to a distance protection system using telecommunication.

The current which is used in the comparison is converted into a square wave signal, so that the positive portion corresponds to the positive half-cycle and the zero portion corresponds to the negative half cycle. The square wave from the remote terminal is compared with the local square wave as shown in Figure 3.1-6.



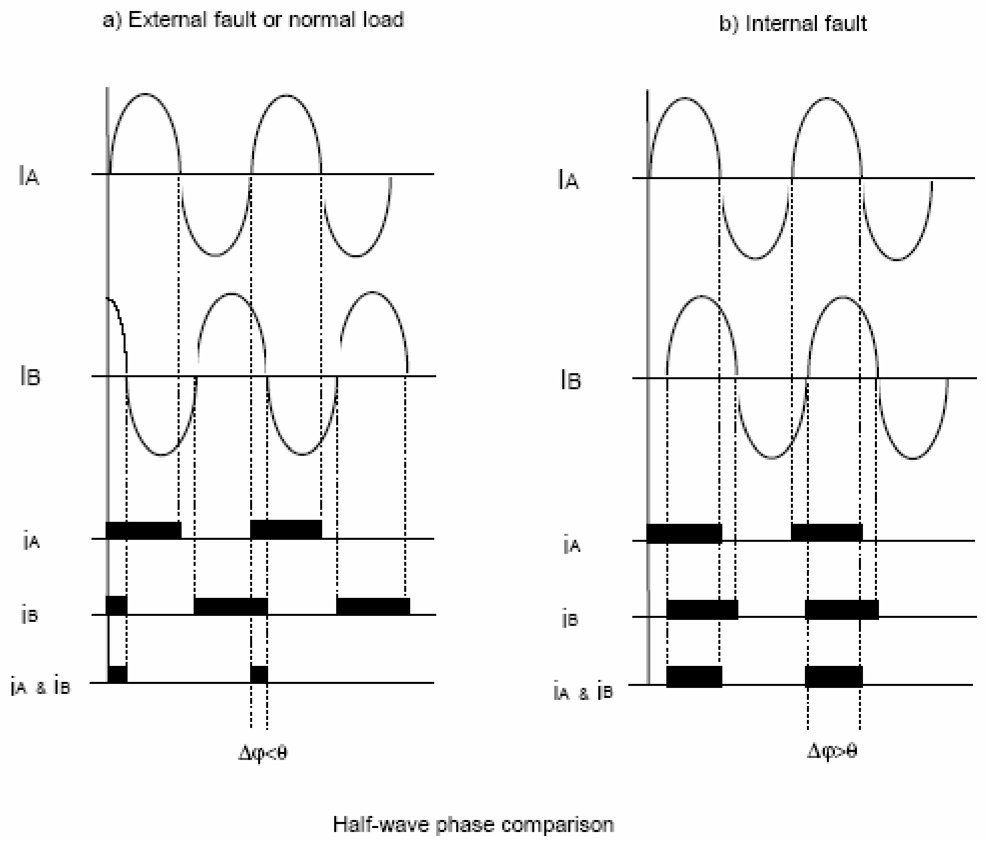


Figure 3.1-6: Phase comparison operating principles

In normal line conditions, there is a (small) phase current difference between line ends due to:

- The capacitance of the power line
- Errors due to the equipment, e.g. current transformers, sequencer, filters, squarer, etc.
- The time delay due to the signal propagation time between the terminals

To prevent false trips, a critical angle is defined, commonly called stabilizing angle, which limits the maximum phase difference between currents, which would correspond to a boundary between tripping and stabilizing.

In a non-segregated phase comparison protection, the three currents are mixed into one quantity by means of a composite sequence network. The half-wave system use starters, normally based on overcurrent detectors, to determine whether a fault has occurred, to initiate signal transmission to the remote end and to permit local tripping. In the full-wave system, the comparison is made for each semi-period and normally is therefore faster than the half-wave type. Phase comparison information is transmitted all the time to the remote equipment, and no starter is required.

The comparison in the segregated protection system is similar to the non-segregated protection but, the comparison is made separately for each phase. It is very suitable for single pole reclosing when handling heavily loaded EHV lines and parallel circuits on the same towers. Segregated protection is more sensitive for earth faults than non-segregated protection, but it is more costly and the requirements on communication are higher.

More details about non-segregated and segregated techniques can be found in [1].

Some recent designs use dynamic principles based on the variation of the instantaneous current values in for example two periods, i.e. −i = i(t) - i(t-2T), so that the signal to compare is the sign of this variation value −i. This principle, normally operating in combination with a conventional phase comparison with starter, gives a higher sensitivity for high resistance ground faults.

Time delay compensation

As described for differential protection system, time delay compensation must be also provided in phase comparison protection in order that phase current values can be compared at the same instant. Depending on the technology, the channel delay can be compensated either by dynamic measuring techniques, or by a fixed delay setting in the protection relay. This later case is only useful when there is no possibility for time delay variations.

Additional functions

A number of complementary functions may be included in the protection relay. Intertrip functions are used to trip the remote breakers by means of sending a command through the same communication channel used for comparison signals. An overcurrent criterion normally supervises the remote trip to prevent tripping under normal conditions. The same additional functions mentioned for current differential protection are also applicable for phase comparison protection.

Telecommunication systems used for phase comparison protection

Non-phase-segregated technique

In a half-wave comparison scheme it is very common to use power line carrier as communication medium, with the same carrier frequency used for both directions. The carrier is amplitude modulated i.e. switched “on” during positive half-cycles, and “off” during negative halfcycles, or vice-versa. This system operates as a blocking scheme. For an internal fault, if the blocking signal from the other end is not received, the output of the comparator circuit sends a trip command when the starters have picked up. This system might behave incorrectly in some situations due to the noise generated during a fault, i.e. blocking the operation for internal faults (=> delayed tripping) or deblocking for external faults (=> unwanted tripping).

In a full-wave comparison different frequencies for the two directions must be used. A FSK (frequency shift keying) signal is used, which can be transferred over pilot wires, power line, radio or fibre-optic link. The communication equipment continuously monitors itself and when a fault occurs, the local signal is compared with the remote for both positive and negative halfcycle in the protection relay.

Phase-segregated technique

In this case, the values of each phase are transmitted separately via independent channels. Most recent phase comparison systems usually operate in segregated mode and use digital communication systems. The square signals to compare are sampled and converted to digital data, which are transmitted serially to the opposite terminal by the telecommunication system. Data rates and electrical or optic interfaces are the same as those mentioned for differential protection.

When starters are used to initiate the comparison, a sequence of “guard” bits is transmitted in normal state of operation, in order to monitor the channel availability and performance by the receiver.

Some designs optionally include a modem to interconnect two terminals through a 4-wire audio channel. In this case, a data rate of 9'600 or 19'200 bit/s may be used.

Charge Comparison Protection

Charge comparison is based on the principle of conservation of charge at a node. The charge entering one line terminal must be approximately the same as the charge leaving the other line terminal(s) of a healthy transmission line. This is also the principle from which Kirchoff’s Current Law (the theoretical basis of current differential relaying) is derived.

To perform charge comparison, the waveform of each line terminal’s phase and residual current is sampled every ½ millisecond. The half-cycle area under each wave is measured by integrating current samples between zero-crossings. For each phase and ground, the resulting ampere-second area (i.e., coulombs of charge) is stored in local memory, along with polarity and start/finish time-tags. This storage operation occurs only if the magnitude exceeds 0.5 ampere r.m.s. equivalent and the half-cycle pulse width is equal to 6 ms or more.[3]

Every positive (negative 3Io) magnitude is also transmitted to the remote terminal, along with phase identification and some timing information related to pulse width and queuing time (if any) at the transmitting terminal. When the message is received at the remote terminal, it is immediately assigned a received time-tag. A time interval is then subtracted from the received time-tag. This interval represents the channel delay compensation (which does not have to be precisely equal to the actual channel delay time) and the timing information contained in the received message. The adjusted received time-tag (after subtraction) is then compared with the local start and finish time-tags, looking for a “nest”, per Figure 3.1-7 (shown for an external fault).

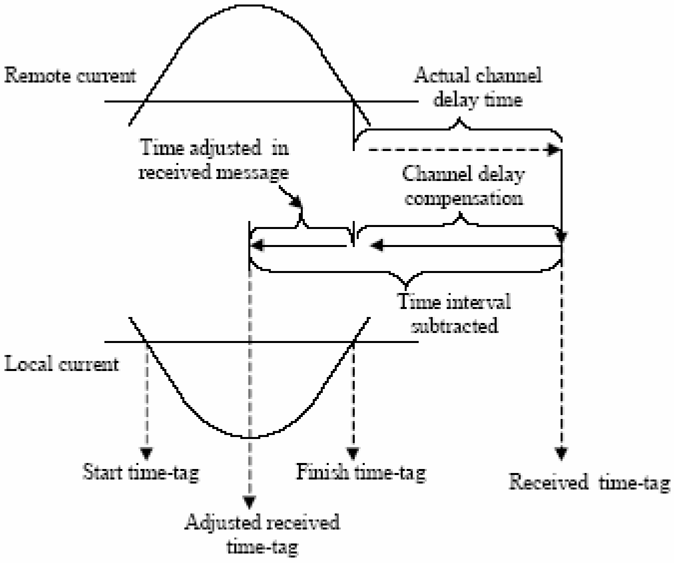


Figure 3.1-7: Operation of charge comparison, external fault

A nest is achieved when the adjusted received time-tag is greater than the local start time-tag and smaller than the local finish time-tag, for a given half-cycle stored in memory.

When the nesting operation is successful, the local and remote current magnitudes (actually charges converted to equivalent currents) are then added to create the scalar sum (sum of absolute magnitudes). The scalar sum becomes the effective restraint quantity and the arithmetic sum becomes the effective operate quantity, per the bias characteristic shown in Figure 3.1-8.

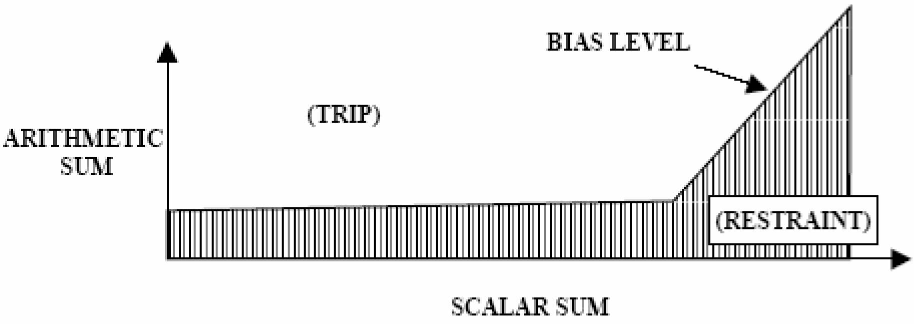


Figure 3.1-8: Bias characteristic of charge comparison

The bias level is an operate threshold which provides security in the presence of spurious operate current due to line charging current, current transformer mismatch, analog-to-digital conversion

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[3] Magnitude is actually measured in terms of ampere-seconds (i.e., coulombs). However, all values are converted to amperes rms equivalent, based on a perfect 60 Hz (or 50 Hz) sine wave, without offset.

quantizing errors, etc. As shown in Figure 3.1-8, the bias level rises sharply after the scalar sum reaches a high value. This provides security for unequal CT saturation during high current external faults. At lower currents, the bias level has a slight upward slope. This takes care of the relatively minor non-communications-related errors that increase with current level, such as CT ratio errors.

The operating characteristic of charge comparison, when plotted on a polar diagram, is the “ideal” rainbow-shape of Figure 3.1-9. Referring to Figure 3.1-7, if the adjusted received timetag nests with a local negative half-cycle, this is equivalent to the upper half of Figure 3.1-9. If the adjusted received time-tag nests with a local positive half-cycle, then the arithmetic sum and scalar sum are equal to each other, which describes a 45 degree line on the bias characteristic (well above the bias threshold for all except very small values of current). This is equivalent to the lower half of Figure 3.1-9.

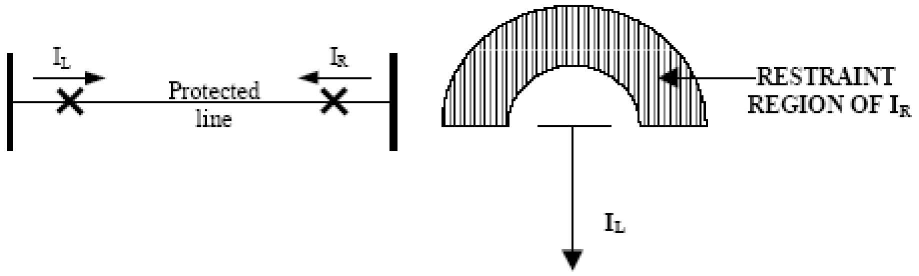


Figure 3.1-9: Ideal polar diagram characteristic

The bias level of charge comparison is significantly more sensitive than that of conventional current differential relays for line protection. The conventional relay requires a gradually increasing bias to take care of increasing spurious operate current for a given assumed error in channel delay compensation (the biggest single source of spurious operate current). In contrast, charge comparison introduces no additional communications-related error as the currents get bigger, for a given error in channel delay compensation. Furthermore, for a given magnitude of through current, no operate error current is introduced, at all, for increasing channel delay compensation error (up to + 4 ms, at which point a total relay misoperation occurs – typical of a digital system). The + 4 ms misoperation threshold for charge comparison is almost three times the + 1.5 ms (approximately + 30 degrees on 60 Hz systems) misoperation threshold which is typical of conventional current differential schemes with circular polar diagram characteristics. Lit: [38]

State Comparison Schemes

State comparison protection schemes use communication channels to share logical status information between protective relay schemes located at each end of a transmission line. This shared information permits high speed tripping for faults occurring on 100 percent of the protected line. The logical status information shared between the relay terminals typically relates to the direction of the fault, so the information content is very basic and requires very little communication bandwidth. Additional information may also be sent to provide additional control, such as transfer tripping and reclose blocking.

For instance, breaker failure protection in ring bus and breaker and one-half bus configurations must transfer trip the remote terminal breaker(s) to isolate the failed breaker. Refer to chapter 3.2.2.2 for Bus Bar Protection/Breaker Failure Protection for more information on this subject.

Overall, the communication requirements for state comparison protection schemes are considerably less stringent than for analog comparison protection schemes. Communication speed, or minimum delay, is always of utmost importance because the purpose for using communication is to improve the tripping speed of the scheme. Also, variations in communication speed are better tolerated in state comparison schemes than in the analog comparison protection schemes discussed in an earlier section. Communication channel security is essential to avoid false signals that could cause incorrect tripping, and communication channel dependability is important to ensure that the proper signals are communicated during power system faults, the most critical time during which the protection schemes must perform their tasks flawlessly.

Comparing the direction to the fault at one terminal with the direction to the fault at the other terminal permits each relay scheme to determine if the fault is within the protected line section, requiring the scheme to trip, or external to the protected line section, requiring the scheme to block tripping. Directional distance and/or directional overcurrent relays are typically used at each line terminal to determine the fault direction. The relays used at each line terminal operate independent of the relays at other line terminals; some may even be set to provide time delayed tripping for faults outside the protected line section, hence the term “non-unit” protection, or “open system” protection is sometimes given to these types of schemes.

If it were possible to set relays to see all faults on their protected line section, and to ignore faults outside of their protected line section, then there would be no need for communication schemes to assist the relays. However, distance and directional overcurrent relays cannot be set to “see” faults within a precise electrical distance from their line terminal. They are imprecise because of many factors, including voltage and current transformer errors, relay operating tolerance, line impedance measurement errors and calculation tolerance, and source impedance variations. The primary relay elements used to detect line faults are therefore set to see or reach either short of the remote line terminal (this is called under reaching), or to see or reach past the remote line terminal (this is called over reaching).

Communication between line terminals at different electric power substations could be accomplished by simply extending a number of wires between the substations. Connecting a relay contact output from a relay scheme at one terminal to a relay scheme control input at the other line terminal with a pair of copper wires provides the communication necessary for one relay scheme to tell the other relay scheme that it has, or has not, seen a fault. Unfortunately, connecting communication wires directly between substations is not that simple and can even be hazardous. Voltage drop, induced voltages, and ground potential rise between substations during a fault make direct metallic wire connection between relay schemes unreliable, insecure, and hazardous.

Communication for state comparison protection schemes must therefore be designed to provide safe, reliable, secure, and fast information transfer from one relay scheme to another. The communication scheme must also be able to transmit information in both directions at the same time. The amount of information required to transfer between relay schemes depends on the relay scheme logic. The basic and most common state comparison protection schemes are described in the following subsections. Their communication requirements are discussed within these subsections. The order in which they are presented does not imply their priority, relative importance, or usage. Other schemes and combinations of schemes may be designed to meet specific protection needs, however, they are typically all based on the basic schemes described in this document.

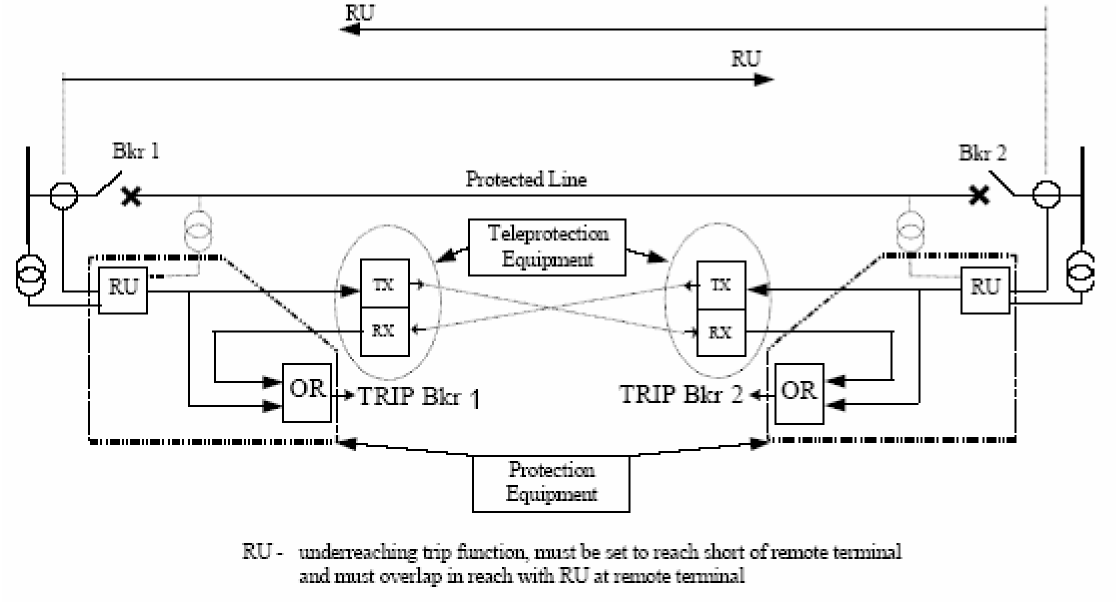
The terminology used to describe these state comparison protection schemes may differ from utility to utility and country to country. State comparison schemes are basically defined according to the impedance zone which sends the protection signal to the remote end of the line. The following Table 3.1-1 shows the preferred CIGRE scheme names and alternate scheme names used elsewhere. CIGRE scheme names will be used throughout this document.

CIGRE State Comparison Protection Scheme Name	***Alternate State Comparison Protection Scheme Name***
Intertripping underreach distance protection	Direct underreach transfer tripping
Permissive underreach distance protection	Permissive underreach transfer tripping
Permissive overreach distance protection	Permissive overreach transfer tripping
Accelerated underreach distance protection	Zone acceleration
Deblocking overreach distance protection	Directional comparison unblocking
Blocking overreach distance protection	Directional comparison blocking

Table 3.1-1: State Comparison Protection Schemes

Intertripping Underreach Distance Protection

The basic logic for a Intertripping Underreach Distance Protection scheme is shown in Figure 3.1-10. This scheme requires underreaching functions (RU) only, which are usually provided by phase and ground distance relay elements. The scheme is usually applied with an active channel that transmits a GUARD signal during quiescent, or unfaulted, conditions. The transmitter is keyed to a TRIP signal when the associated underreaching relay element detects a fault within its reach. The underreaching functions (RU) must overlap in reach to prevent a gap between the protection zones where faults would not be detected.



RU - underreaching trip function, must be set to reach short of remote terminal and must overlap in reach with RU at remote terminal

Figure 3.1-10: Intertripping Underreach Distance Protection Scheme Logic

For internal faults within the overlap zone, the underreaching functions at each end of the line operate and trip their associated line breaker directly. At the same time, the RU function keys its respective transmitter to send a direct transfer trip signal to the relay scheme at the remote line terminal. Receipt of the trip signal from the remote line terminal also initiates line breaker tripping.

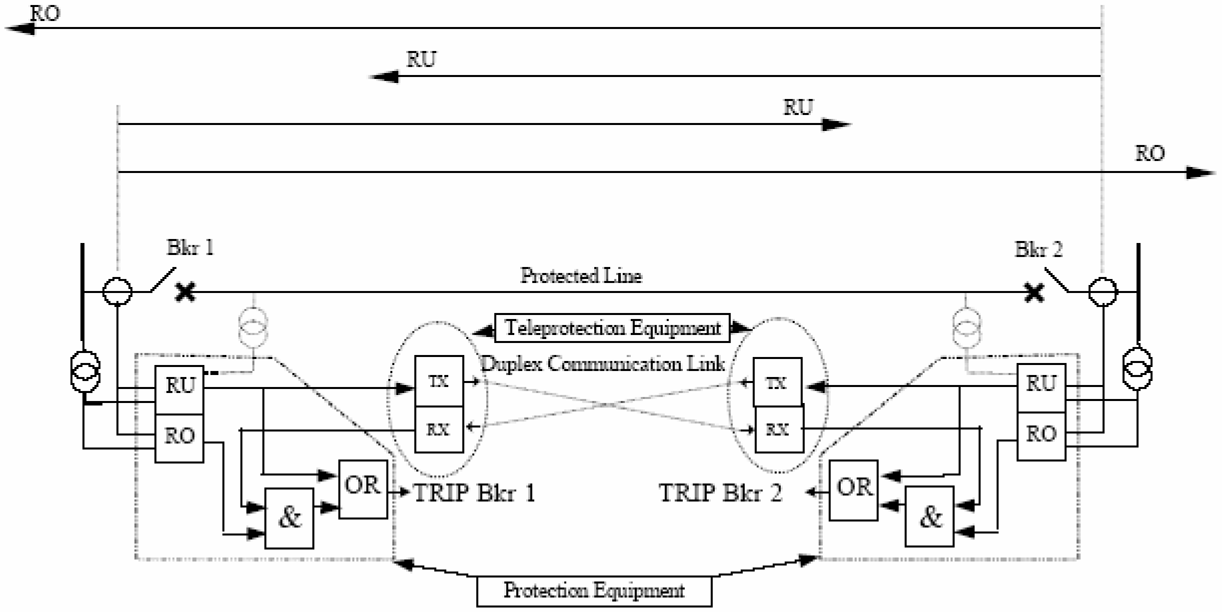
This scheme provides high speed tripping at both line terminals for all faults within the protected line section under most conditions. However, it will not provide tripping for faults beyond the reach of one of the RU functions if the remote breaker is open or if the remote channel is inoperative. If only one communications channel is used at each terminal, security may be jeopardized because any erroneous output from the channel initiates an instantaneous breaker trip. For this reason, this scheme is often applied with dual channels where both outputs must provide a TRIP signal to initiate a breaker trip. Or a slight delay may be added to a single channel output to ensure that the remote trip signal is valid before tripping the breaker.

Time-delayed overreaching back-up tripping functions that do not interface with the communication scheme are usually added to trip the associated line breaker for faults beyond the reach of the RU functions when the remote breaker is open, or when the communication channel is inoperative.

This scheme may use virtually any communication media that is not adversely affected by electrical interference from fault generated noise or by electrical phenomena, such as lightning, that cause faults. Communication media that use a metallic path are particularly subject to this type of interference, and must, therefore, be properly shielded, or otherwise designed to provide an adequate communication signal during power system faults.

Permissive Underreach Distance Protection

The Permissive Underreach Distance Protection scheme requires both overreaching (RO) and underreaching (RU) relay functions at both line terminals. This scheme is similar to the Intertripping Underreach Distance Protection scheme except that all communication assisted tripping is supervised by overreaching relay elements having what is often called a zone 2 reach. The scheme is usually applied with an active channel that transmits a GUARD signal during quiescent, or unfaulted, conditions. The transmitter is keyed to a TRIP signal when the associated underreaching relay element detects a fault within its reach. The underreaching functions (RU) must overlap in reach to prevent a gap between the protection zones where faults would not be detected. Basic logic for the Permissive Underreach Distance Protection scheme is shown in Figure 3.1-11. The relay functions and logic are easily performed with modern multi-zone phase and ground protective relays. Distance type relay elements are most often used for the underreaching functions (RU), and distance relay elements or directional overcurrent relay elements are used for the overreaching functions (RO).



RU - underreaching trip function, must be set to reach short of remote terminal and must overlap in reach with RU at remote terminal

RO - overreaching trip function, must be set to reach beyond remote end of line

Figure 3.1-11: Permissive Underreach Distance Protection Scheme Logic

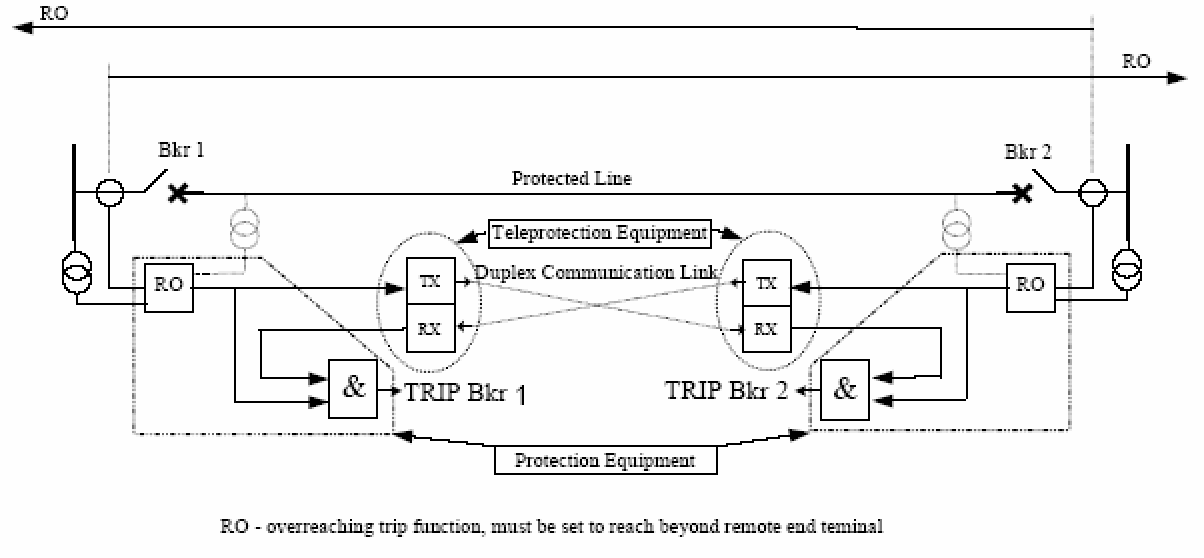
When the underreaching relay elements detect a fault, they trip the local breaker directly and key a TRIP signal to the remote line terminal. Unlike the Intertripping Underreach Distance Protection Scheme, the Permissive Underreach Distance Protection Scheme supervises the received trip signal with an overreaching relay element. Communication assisted tripping occurs only if the overreaching relay element detects a fault during the time that a trip signal is received from the remote line terminal via the communication channel.

Because the received communication signal is supervised by the output from an overreaching relay element, there is less concern about a false signal causing an incorrect trip. This scheme is therefore typically applied with a single duplex communication channel. This scheme may use virtually any communication media that is not adversely affected by electrical interference from fault generated noise or by electrical phenomena, such as lightning, that cause faults. Communication media that use a metallic path are particularly subject to this type of interference, and must, therefore, be properly shielded, or otherwise designed to provide an adequate communication signal during power system faults.

The overreaching (RO) relay elements often start a zone 2 timer to provide time delayed tripping for faults outside the reach of the underreaching (RU) relays elements if the communication channel is inoperative.

Permissive Overreach Distance Protection

The Permissive Overreach Distance Protection scheme requires only overreaching relay functions. Phase distance functions are used almost exclusively for detection of multi-phase faults, whereas ground distance functions or directional ground overcurrent functions can be used for the detection of ground faults. The scheme is usually applied with an active duplex communication channel that transmits a GUARD signal during quiescent, or unfaulted, conditions. The transmitter is keyed to a TRIP signal when the associated overreaching relay element detects a fault within its reach. Basic logic for the Permissive Overreach Distance Protection scheme is shown in Figure 3.1-12.



RO - overreaching trip function, must be set to reach beyond remote end terminal

Figure 3.1-12: Permissive Overreach Distance Protection Scheme Logic

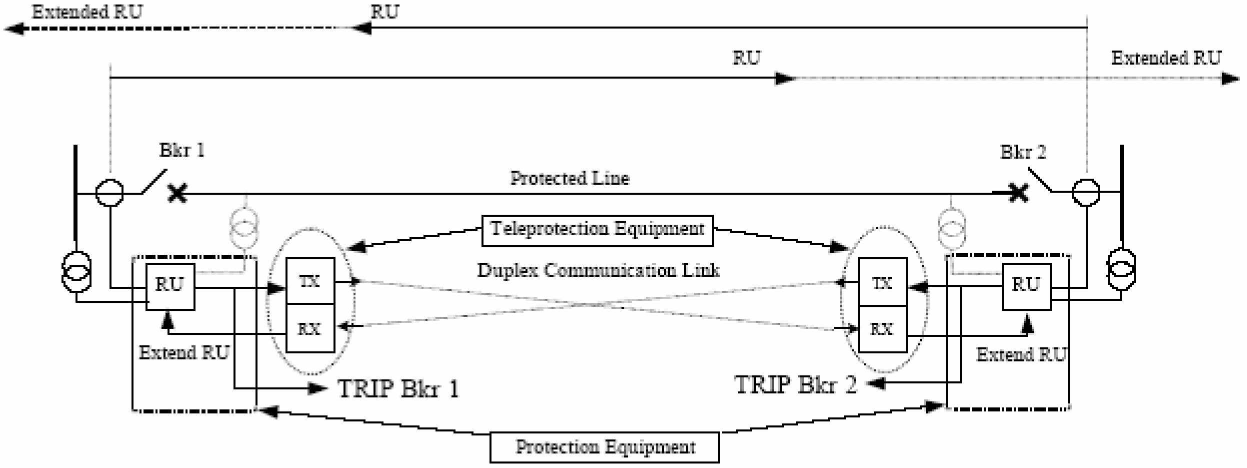
For a fault anywhere on the protected line, both of the RO functions operate and assert one of the inputs to the logic AND (&) gate. At the same time, RO also keys the transmitter TRIP signal. Receipt of the TRIP signal at each terminal, and an output from the RO function, satisfies the logic AND (&) gate to produce a TRIP output to the breaker. For external faults, the RO functions at only one end of the line will operate, so communication assisted breaker tripping is not initiated at either terminal.

The scheme is very secure in that it does not trip for any external fault if the channel is inoperative. Conversely, the scheme is lacking in dependability because it will not trip for any internal faults if the channel is inoperative. The scheme also will not trip for any fault if the fault is not detected at all terminals of the line. The scheme may not trip at high speed for close-in faults at the strong terminals because the fastest tripping time that can be expected is dependent on the slowest function to operate for an internal fault. Some means must be used to key the transmitter at an open breaker if tripping is to be initiated for faults seen at the other terminals. Breaker auxiliary contact switch keying with echo logic is commonly used to provide this requirement. Time-delayed back-up tripping can be provided because the scheme uses overreaching functions. Because the GUARD signal is transmitted continuously, the channel can be monitored on a continuous basis.

This scheme may use virtually any communication media that is not adversely affected by electrical interference from fault generated noise or by electrical phenomena, such as lightning, that cause faults. Communication media that use a metallic path are particularly subject to this type of interference, and must, therefore, be properly shielded, or otherwise designed to provide an adequate communication signal during power system faults.

Accelerated Underreach Distance Protection

Basic logic for the Accelerated Underreach Distance Protection scheme is shown in Figure 3.1-13. This scheme requires the use of underreaching relay element functions (RU) that can be extended in reach by the receipt of a TRIP signal from the relay scheme at the remote line terminal. The RU functions must be set to overlap in reach to avoid a gap in their fault detection. This generally requires the use of ground distance functions for the detection of ground faults, whereas phase distance functions are used for the detection of multi-phase faults. The scheme is often applied with an active communication channel that transmits a GUARD signal during quiescent, unfaulted conditions, and is keyed to a TRIP signal when the associated RU function detects a fault within its reach.



RU - underreaching trip function, must be set to reach short of remote terminal and must overlap in reach with RU at remote terminal. It must be capable of being switched in reach.

Figure 3.1-13: Accelerated Underreach Distance Protection Scheme Logic

For an internal fault within the overlap zone of the RU functions, breaker tripping is initiated directly at both line terminals and each communication channel is keyed to the TRIP signal. Receipt of the TRIP signal extends (accelerates) the reach of the RU functions to beyond the remote line terminal. This reach extension has no further affect because breaker tripping has already occurred at each line terminal. For an internal fault near one terminal, the RU function at that terminal operates, tripping the breaker and keying its transmitter to the TRIP signal. Receipt of the TRIP signal at the other terminal extends the reach of that terminal’s RU function, which then detects the fault to initiate tripping. For external faults, none of the RU functions operate, therefore tripping does not occur at either line terminal.

The scheme is more secure than the Direct Underreach Distance Protection scheme because it does not trip directly on receipt of a trip signal. Conversely, it is slower than the Permissive

Underreach and Overreach Distance Protection schemes because it must wait for the extended RU function to detect the fault before tripping. As mentioned before, it also requires a special relay with zone extension capability.

This scheme may use virtually any communication media that is not adversely affected by electrical interference from fault generated noise or by electrical phenomena, such as lightning, that cause faults. Communication media that use a metallic path are particularly subject to this type of interference, and must, therefore, be properly shielded, or otherwise designed to provide an adequate communication signal during power system faults.

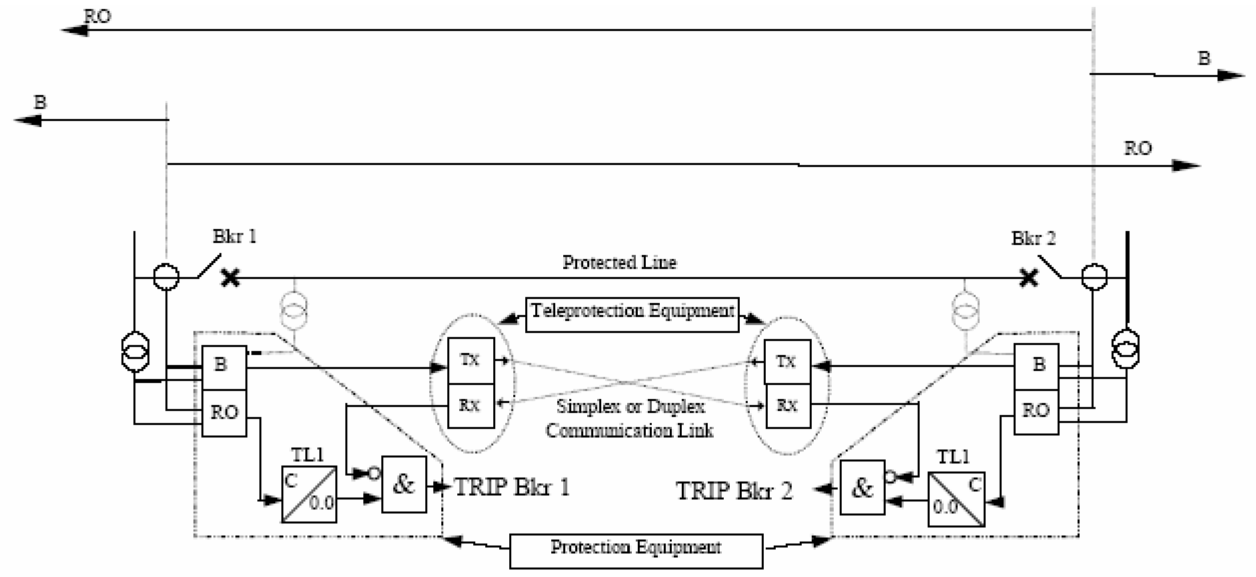
Blocking Overreach Distance Protection

Basic logic for a Blocking Overreach Distance Protection scheme is shown in Figure 3.1-14. The scheme requires overreaching tripping functions (RO) and blocking functions (B) as shown. Distance functions are used almost exclusively for multi-phase fault protection, but either ground distance functions or ground directional overcurrent functions are used for ground fault detection. A quiescent, or OFF/ON, communications channel is typically used with this type of scheme. The power line itself is often used as the communications medium because the communication channel is not required when the fault is on the protected line. The communication channel is only used to transmit a block trip signal when the fault is external to the protected line. Audio tone over leased phone lines, microwave radio, and fibre-optic media are also used. The transmitter is normally in the OFF state for quiescent conditions and is keyed to the ON state by operation of any one of the blocking functions. Receipt of a signal from the remote terminal applies the NOT or inverted input to BLOCK the trip output.

The overreaching tripping functions (RO) must be set to reach beyond the remote terminal of the transmission line with margin so they will be able to detect a fault anywhere on the transmission line. The blocking functions (B) are used to detect any fault not on the protected line that the remote tripping functions are capable of detecting; so they must be set to reach further behind the terminal than the tripping function at the remote terminal.

For a fault external to the protected line, one or more of the blocking functions operate to key its respective transmitter to send a blocking signal to the remote terminal. Receipt of the blocking signal blocks tripping in the event one of the tripping functions has operated for the remote fault. The coordinating timer, TL1, is required to allow time for a blocking signal to be received from the remote terminal. It is set to compensate for channel time, signal propagation time and for any difference in operating time that might result if the remote blocking function is slower than the local tripping function.

For a fault anywhere on the transmission line, one or more of the tripping functions (RO) at each terminal will operate and apply an input to its respective AND gate (&). The blocking functions will not operate for an internal fault, therefore neither transmitter is keyed, so that there is no output from either receiver. The logic at each terminal produces an output that starts the TL1 timer. When the TL1 timer expires, the scheme produces an output to trip the breaker.



RO - overreaching trip function, must be set to reach beyond remote end of line
B - blocking function, must be set to reach beyond overreaching trip function at remote end of line
C - Coordinating time, required to allow time for blocking signal to be received
(set equal to channel time plus propogation time plus margin)

Figure 3.1-14: Blocking Overreach Distance Scheme Logic

The scheme is very dependable because it will operate for faults anywhere on the protected line even if the communication channel is out of service. Conversely, it is less secure than permissive schemes because it will trip for external faults within reach of the tripping functions (RO) if the channel is out of service. This scheme does not require breaker auxiliary contact or echo logic keying when the remote breaker is open to permit tripping for faults anywhere on the line. It provides relatively fast tripping (dependent on coordinating time delay) for most source and line conditions. However, it may not trip weak terminals of the transmission line, if fault levels are below the sensitivity of the tripping relays.

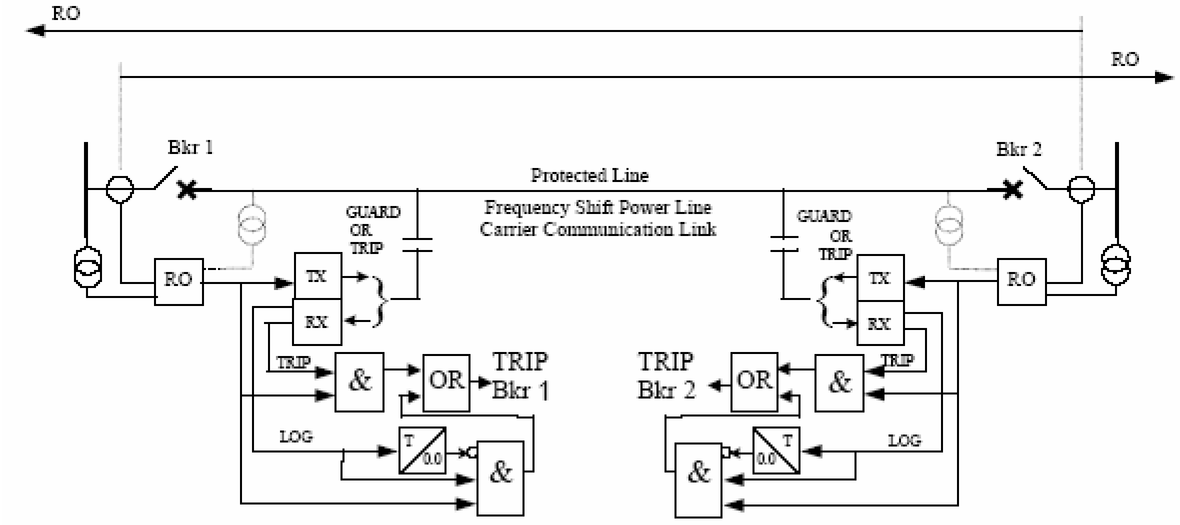
If quiescent (OFF/ON) communication channels are used there is no way to monitor the channel continuously because the channel is only keyed on during external faults. A communication channel check-back scheme is often used to periodically key a momentary block signal to check the channel status. Some check-back schemes echo a signal back to verify that the channel is operational in both directions. Other schemes must receive a signal within a preset time period to declare the channel in service.

The overreaching functions can be used to drive timers so that time-delayed back-up tripping can be provided for faults within reach of the overreaching functions.

Deblocking Overreach Distance Protection

As mentioned in some previous sections, metallic communication paths adversely affected by fault generated noise may not be suitable for some teleprotection schemes that rely on a signal transmitted during a protected line fault. With power line carrier, for example, the communication signal may be attenuated by the fault, especially when the fault is close to a line terminal, thereby disabling the communication channel. Multi-phase power line carrier coupling schemes can be used to minimize this problem.

The Deblocking Overreach Distance Protection scheme includes logic specifically designed to accommodate a loss of communication signal during the protected line fault. The Deblocking Overreach Distance Protection scheme, like the Permissive Overreach Distance Protection scheme, uses overreaching phase distance functions almost exclusively for multi-phase fault detection, and ground distance or directional ground overcurrent functions for ground fault detection. The logic requires the use of an active communication channel that transmits a GUARD signal during quiescent, or unfaulted, conditions, and is keyed to a TRIP signal when the associated overreaching relay element detects a fault within its reach. To overcome the loss of signal caused by the internal line fault, deblocking logic permits a TRIP output if the loss of signal occurs at nearly the same time the overreaching relay function(s) detect a fault. A tripping period is controlled by a timer that is typically set between 150 and 300 milliseconds. Basic logic for the Deblocking Overreach Distance Protection scheme is shown in Figure 3.1-15.



RO - overreaching trip function, must be set to reach beyond remote end teminal
LOG - Loss of GUARD detection from receiver, RX
T - deblocking time delay, typically set for 150 to 300 milliseconds.

Figure 3.1-15: Deblocking Overreach Distance Protection Scheme Logic

If the signal loss is due to a fault on the protected line, at least one of the overreaching trip functions (RO) will be picked up. Thus, tripping will be initiated when the deblocking output is produced. If none of the permissive trip functions are picked up, the channel will lock itself out 150 - 300 milliseconds after the signal is lost and will stay locked out until the GUARD signal returns for a pre-set amount of time. It is important to understand that this logic requires that the loss of signal associated with the operation of an overreaching relay element must only be caused by a fault on the protected line. Loss of signal due to external line faults will cause false trips. Therefore, the Deblocking Overreach Distance Protection Scheme Logic is used almost exclusively with power line carrier communication.

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