

Pilot Protection - An Overview

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Abstract -- This paper presents the overview of pilot protection. It explains the principle of operation, the pilot communication channels, reason for chosen pilot protection technique and different zone of operation. Finally dealt with Permissive Overreaching Transfer Tripping (POTT) scheme.

Indexed Terms: distance protection, pilot wire, transfer tripping, zone of protection

I. INTRODUCTION

The term 'pilot' refers to a communication channel between two or more ends of a transmission line to provide instantaneous clearing over 100% of the line. Communication channels typically used include power line carrier, microwave, fibre optic, and communication cable.

Pilot protection for lines provides possibilities for high speed simultaneous detection of phase and ground faults protection for 100% of the line segment being protected from all terminals. It is a type of protection for which quantities at the terminals are compared by a communication channel rather than by a direct wire interconnection of the relay input devices. The increment in time delays when using distance relays becomes impractical, because of the distance between several terminals. Pilot protection offers increased certainty when a fault is present in a system. Implementation of pilot protection in transmission systems is widely used because of its adaptability.

Thus, pilot protection does not require any coordination with protection in the adjacent system unless additional backup is included.

Pilot protection conveys three fundamental concepts protective system design:

- a) Selectivity
- b) Reliability
- c) Security.

This is especially important in extra high voltage (EHV) circuits because of a considerable system

disturbance that occurs when a heavy load line is opened. For the protection system, the relaying system must be selective and precautions are taken to ensure no operations are initiated by the relay logic or other means that would cause tripping of important lines or other facilities when not absolutely necessary. Thus, pilot protection is an adaptation of differential relay principles that avoid the use of control cables between terminals.

Communications Channels use in pilot protection.

- a) Power Line Carrier (PLC): Operates on radio frequency signals over transmission lines in the 10 to 490 kHz band.
- b) Microwave: Operates at frequencies between 150 MHz and 20 GHz.
- c) Fibre-optic links

1.1 Fiber communication channel in pilot protection

The development of modern optical fiber communication technology has become increasingly popularized due to its long-distance, large-capacity, high-speed, and real-time synchronous data transmission. Fiber optic communication is applied in power protection because the appearance of digital communication technology makes information exchange reliable and fast. Hence, proposes the construction of an intercommunicated protection system. Pilot protection can improve relay reliability with communications between protections schemes. Fiber optic-based communications in pilot protection systems can detect faults more rapidly with a low time delay. With the implementation of fiber optics, information exchange is not limited to the digital state value. A variety of information exchange by the same communication channel provides sufficient information. Pilot protection can be implemented with distance relays, which distinguish internal and external fault by comparing fault direction of fault distance on both sides. The information exchange is logical instead

of analog quantities. Therefore, in a pilot protection system, protection Intelligent Electronic Device (IED) on each side of a transmission line collects information and calculates fault direction, fault distance, and other parameters based on local information and then sends the results to the IED on the opposite side.

The information exchange is voltage and currents values, protection start-up signal, fault direction, and distance information, fault phase selection information, and breaker status. Reference concludes that, besides providing better reliability and rapid communication, the digital communication channel also provides the possibility for various and large amounts of synchronous electrical information exchange. With the aid of an optical digital channel, multiple protection criteria can be executed to improve the operation performance of traditional pilot protection system which can complete various functions such as relaying protection, auto reclosing, measurement of transmission line parameters, and more functions within the unified pilot protection.

Pilot protections based on fiber communication technology have become one of the primary forms of transmission line. Consequently, many of these configurations rely on differential protection, but problems such as low sensitivity or poor reliability because of CT saturation and influence of large charging current because of line distributed capacitance for long transmission lines arise when implementing differential protection. These complications are seriously impairing and threatening to the speed and sensitivity of conventional current differential protection. To reduce CT saturation and line distributed capacitance, an Enhanced Transmission Line Pilot Impedance (ETLPI) scheme is adopted. ETLPI is defined as the ratio of voltage difference of fault-superimposed components at both terminals of the protected line, which can be calculated from real-time voltages and currents measurements synchronously transmitted from local terminal to remote terminal. When this model is implemented, the amplitude of ETLPI is greater than the amplitude of the positive sequence impedance of the protected segment of the line. ETLPI also effectively avoids distributed capacitances and CT saturation. Therefore, this scheme may suit larger transmission lines.

Justification of Pilot Protection on Transmission Lines

The protection zone for a transmission line is unique because the zone limits generally extend to geographically separate locations. In addition to their relay sources, elements entirely at one location can have instantaneous tripping configured. In order to affect high speed tripping for 100% of a transmission line, each terminal of the protected line must communicate with the other terminal(s) in some way.

When pilot protection is evaluated for implementation, its goal is to improve system stability by fault clearing in the shortest amount of time. From the perspective of electric utilities, clearing time reduction improves stability, reduces equipment damage, and improves power quality in addition to providing quality service.

Technical reasons to consider pilot protection:

Cascading Issues: Protective relay with protected zones are configured with distance elements, and stepped distance schemes are coordinated in a cascading manner. Therefore, this configuration risks triggering a chain of undesirable events, leading to widespread blackout.

1.2 **Limit fault damage due to high current:** Fault currents can cause thermal and mechanical damage to conductors and electrical equipment.

Need for high-speed reclosing: A system in equilibrium with no fault, mechanical power equals electrical power, ignoring losses. When a fault occurs, equilibrium is disturbed and the synchronous machine accelerates. The positive sequence voltage immediately after the fault can be used to estimate the requirement for high-speed tripping. The accelerating power is proportional to the difference between pre-fault and fault positive sequence voltages at the point of fault. Thus, the smaller the positive sequence voltage, the faster the system accelerates and the faster the system needs to isolate the fault. Therefore, high speed reclosing is required.

Protection performance requirements for the line dictate the number of pilots schemes required. The following are considerations to determine the number of required pilot systems:

Number of systems required: Where high speed clearing is desired for faults anywhere on the line, but time delayed tripping is acceptable under contingencies.

Different voltage levels: Protection system performance requirements can vary greatly and dictate at what voltage level pilot channels are used. From 230 kV to 345kV, at least one pilot scheme is typically present and, depending on system configuration, two schemes often exist, in addition to direct transfer tripping for the breaker. Above 345kV, at least two pilot schemes and a direct transfer trip for equipment failure are typically applied.

Regulatory/regional reliability council requirements: Reliability councils sometimes dictate protection system performance requirements, the number and type of pilot systems, and the channel required.

II. PROTECTION SCHEME

a) Permissive Overreaching Transfer Tripping Scheme

In the Permissive Overreaching Transfer Tripping (POTT) scheme, a distance element is set to reach beyond the remote end of the protected line to send a signal to a remote end. However, the received relay contact must be monitored by a directional relay contact to ensure that tripping does not occur unless the fault is within the protected section.

In Fig 2, the contacts of Zone 2 are arranged to the signal, and the received signal, supervised by Zone 2 operation, is used to energize the trip circuit. The scheme is known as a POTT. Since the signaling channel is keyed by overreaching Zone 2 elements, the scheme requires duplex communication channels.

To prevent the relay from operating under current reversal conditions in parallel feeder circuit, a current reversal guard timer must be used to restrain tripping of the forward Zone 2 elements. Otherwise, malfunction of the scheme may occur under current reversal conditions. It is necessary only when the Zone 2 reach is set greater than 150% of the protected line impedance.

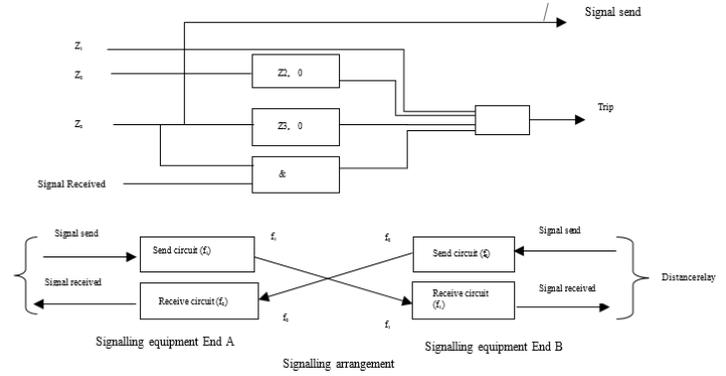


Figure 1: Permissive Overreaching Transfer Tripping (POTT) Scheme

a) Pilot schemes

The non-pilot protection schemes have usually an acceptable performance on short or medium lines. However, for long lines which are mostly operating in EHV or UHV levels and transmitting large electric power, the tripping time delays would cause severe network stability problems due to the system acceleration. Also the huge fault currents could cause dramatic damages for equipment's. In such cases, more complex transmission line protection schemes are required in order to perform a high speed tripping in both ends of the line.

An alternative protective scheme which has been in use for protection of EHV/UHV transmission lines, utilizes local information, as well as remote information for a relaying decision. In this category known as "pilot protection schemes" the relays installed at terminals, as shown in Figure 2, are able to make a common decision about tripping the line in case of fault inception inside the protection zone.

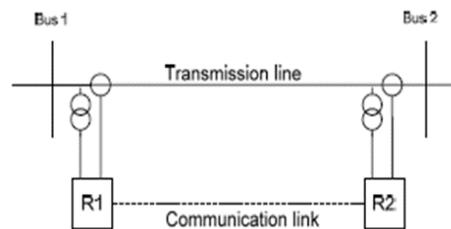


Figure 2: single line diagram of pilot protection scheme for transmission line

The integrated communication system in pilot protection schemes usually uses analog or digital signals transmitting in DC or AC power frequencies or in higher frequency bands such as:

Audio frequencies of approximately from 20 to 20000 Hz,

Power line carrier frequency in the range from 30 to 600 kHz,

Radio frequencies with practical limits of roughly 10kHz to 100,000MHz,

Microwave frequency bands loosely applied to radio waves from 1000 MHz,

Visible light frequencies with nominal wavelength range of about 0.3 μ m - 30 μ m.

Moreover, the communication link between the relays is usually chosen among the pilot wires, power transmission conductors, microwave-radio channels or fiber-optic strands.

In pilot protection schemes depending on quantities which are communicated and used in relay decision making, as illustrated in Figure 2, the schemes belonging to this group can be classified in two following major subgroups:

Unit pilot protection schemes are sometimes also referred to as "analog comparison protection" or "closed" schemes. In these schemes analog quantities such as amplitude and/or phase information of power system in one end is compared with the other end.

Two important unit pilot protection schemes are identified as longitudinal differential and phase comparison schemes. In such schemes the main communicated information between the ends of the protected line are either amplitude and/or phase data of the transmission line components.

In case of an internal fault the result of the compared data will be a differential value and for specific threshold values the relays in both terminals perform a relaying operation. Since there is an instantaneous comparison between the analog values, the information acquired from both relays needs to be time synchronized to guarantee the comparison of measured data at same time instants from both ends.

1) Longitudinal Differential Scheme

The operation principle of the relay is expressed by Kirchhoff's first law that says: "the sum of the currents

flowing to a node must be equal with the sum of the currents leaving the same node".

In external faults the same current is entering to protected zone and leaving it from the second end. But in case of internal fault the current entering the protected zone is not equal to the current which is leaving the same zone. Therefore, this principal could be utilized in directional protection schemes for protection of transmission lines.

2) Phase Comparison Scheme

In a phase comparison scheme the relay is able to distinguish an internal inception of the fault on protected transmission line by comparing the current phase angle at one end with current phase angle at the second end. Where in case of the internal faults there will be a notable phase difference. However, incorrect operation of the relay can happen by changing the system configuration which may affect the polarity of the quantities used for directional comparison.

Non-unit pilot protection schemes are sometimes also referred to as "state comparison protection schemes" or "open system" schemes. In these schemes direct comparison of measurements is not performed between two ends and only logical status related to fault information is exchanged between protective relays located at each end of transmission line.

Two important non-unit pilot protection schemes are identified as distance and directional comparison schemes. In such schemes the logical information typically related to direction of the fault are sent over the communication link for a common relaying decision. Therefore, there will be less dependency on data synchronization comparing to unit protection schemes.

1) Distance Scheme

Communication link between relays in pilot distance schemes can eliminate the time delays for relay decision makings in case of occurrence of faults in second or even third zones for distance protection schemes. Thus, the local relays can communicate with the remote relay in order to make sure that the detected fault is located on protected zone. This provides fast directional fault detection as well as opportunity of implementing the step distance relays in protection of long transmission lines.

2) Directional Comparison Scheme

The relays in directional comparison pilot schemes, such as directional over current relays, detect the

direction to the fault at their local position and share the information with the remote terminal relay. Consequently, the overall functionality of the scheme can be accomplished by a common decision from both ends. Furthermore, the new generation of transmission line protection schemes called Ultra-High-Speed relaying (UHS) schemes.

Protection schemes based on fundamental frequency components usually are referred as ‘conventional’ or ‘classical’ transmission protection schemes. In these schemes both high and low frequency components in current and voltage quantities introduced by any disturbances in the power system are considered as noise to main signals and are used to be filtered out in order to perform the analysis.

POTT Scheme Settings and Parameters.

This section presents the parameters, settings, and zones of the POTT scheme of various protection zones. Figure 3 shows one line diagram simplified and its different zones of protection. In this case, three zones of protection are evident, two of which are forward looking and the remaining one is backward looking. This scheme is also used as a reference for design of the.

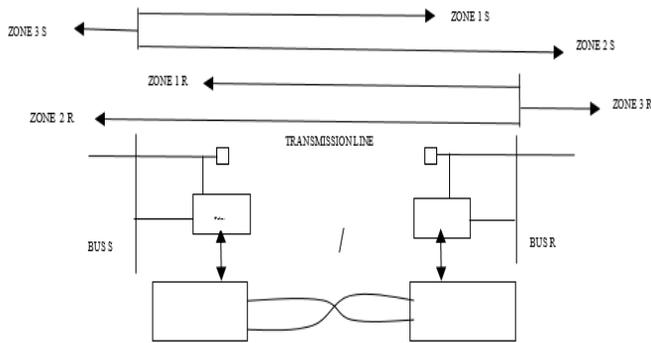


Figure 3; three zone POTT scheme

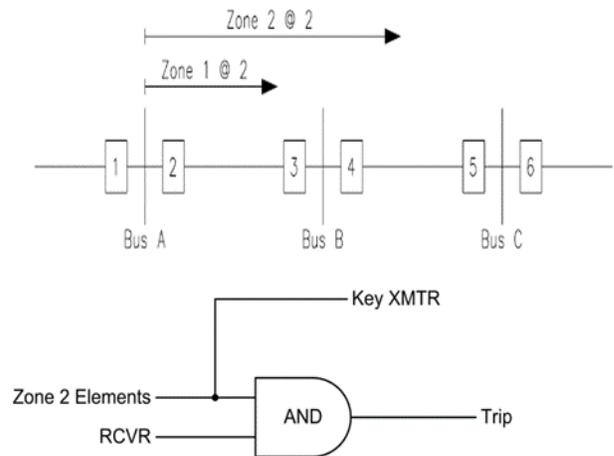
In the three protection zones, the first zone is instantaneous protection and is set at 90% percent of the total length of the transmission line. The second zone is set at 120% percent of the total length of the transmission line, overreaching the bus, and the third zone is set to protect 20% of the transmission line backward looking. Table 1 outlines protection zones for the POTT scheme.

Table 1: Protection zone

Zone 1	Forward Looking	90% of the Line Instantaneous Protection
Zone 2	Forward Looking	120% of the Line comm. assisted with Time Delay
Zone 3	Backward Looking	20% of the Line With Time Delay

III. COMMUNICATION-BASED PROTECTION SCHEME TYPES

a) Permissive Overreaching Transfer Trip (POTT)



$$\text{Trip} = z_2 \text{ element} \cdot \text{RCVR}$$

Permissive Overreaching TT

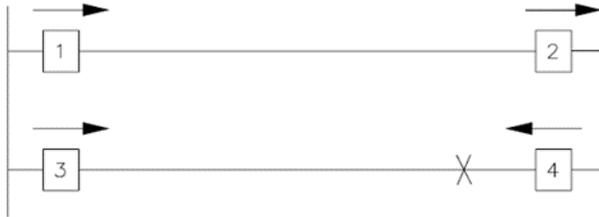
- Permissive signal must be detected from the remote end for the communication-aided trip
- Absence of communication channel disables the accelerated tripping

Permissive Overreaching TT Complications and Concerns

- Desensitization due to infeed
- Dependability issue –failure to trip high speed
- Current reversal
- Occurs in parallel lines with sequential tripping

- Security issue –coupled with long channel reset times may cause trip of the healthy parallel line

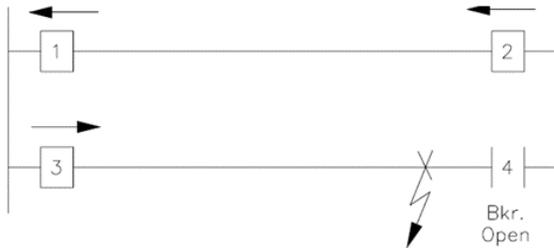
Current Reversal. All Sources In



Z2 at Breaker 1 picks up and sends permissive signal to Breaker 2

- Z2 at Breakers 3 and 4 send permissive signals to each other
- Z1 at Breaker 4 trips instantaneously

Current Reversal System, after Breaker 4 Opens



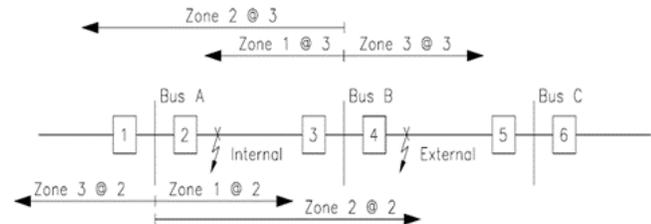
- Current reverses through the healthy line
- Z2 at Breaker 2 picks up
- If the permissive signal has not reset, Breaker 2 trips on POTT

Current Reversal, Possible Solution

- Timer with instantaneous pickup and time delayed dropout, initiated on reverse Z3
 - Delay trip with POTT until the timer drops out
- b) Permissive Under reaching Transfer Trip (PUTT)

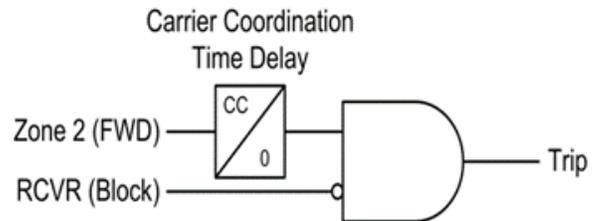
- Similar to POTT but permissive signal sent by under reaching Z1 elements
- At the receiving end, Z2 elements qualify the permissive signal
- No problems with current reversal since Z1 doesn't overreach

Directional Comparison Blocking Protective Zones



- Zone 2 elements cover the entire line
- Reverse Zone 3 elements must reach further than the opposite Zone 2 overreach

Zone 3 (RVS) ————— Key XMTR (Block)



Directional Comparison Blocking, Basic Logic

- In-section faults will not key transmitter and both ends trip high-speed
- Out-of-section fault will key the transmitter at the nearest end to block the trip at the opposite end

Directional Comparison Blocking complications and Concerns

- Coordinating time at fault inception
- Z3 faster than Z2, but channel delay time reduces the margin
- Z must be slowed down
- External fault clearing

- Z3 and Z2 race to drop out, if Z3 drops out first Z2 over trips
- Z3 operates faster and drops slower
- Channel reset time helps
- Slower transmitter key dropout time helps.

REFERENCES

- [1] W.A Pullman, 'Transmission Protection Overview', Schweitzer Engineering Laboratories, 2014, pp 19-30
- [2] A.A. Chavez, J.L. Guardado, D. Sebastian and E. Melgoza, 'Distance protection coordination using search methods' IEEE Latin America Transactions, March, 2008 Vol.6, No.1.
- [3] S. H. Horowitz, A. G. Phadke and B. A. Renz, "The Future of Power Transmission" IEEE Power & Energy Magazine, March/April 2010
- [4] J. D Glover, M.S. Sarma and T.J.Overbye 'Power System Analysis and Design' 5th Edition, 2011