Comparison of Relay Communication Technologies

Final Term Paper
EE 4800

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Introduction

Since the days when electricity was a luxury and not a necessity have long since past, the need for both reliable and selective protection systems is getting higher and higher. In the case of line protection, all terminals of a line must work correctly to quickly remove a fault on the line. In many cases, independent monitoring of the line at each terminal is not sufficient to reliably and selectively clear the fault. Communication systems between terminals must then be used to increase sensitivity to faults as well as guard against false trips from external faults. Various technology options have been used to implement the numerous schemes developed for this purpose. The choice for a given situation is often not cut and dry. Often more than one option is suitable for the task. Utility preference and the experience of the engineer often come into play. However, each of these options has its own strengths and weaknesses, which can be a deciding factor. We have chosen to explore a few of these options.

The first option explored is twisted pair pilot wire. This system uses twisted pair wires that are either owned by the utility or leased from another company. A low power signal that mimics the current on that line or a system of audio tones is sent down the twisted pair from terminal to terminal. The second of these is power line carrier in which a signal is sent from terminal to terminal via the conductors of the line itself. The signal is applied to the line by a CCVT and is contained to that particular line section via a filter at each terminal. Finally Fiber optic, which is similar to pilot wire, uses fiber optic cable to transmit an optic signal instead of an electric one, eliminating some problems associated with the electric signal.

Pilot Wire

Pilot Wires are a twisted pair of wires that either belong to the utility that is protecting their system or to the telephone company leasing them out. These wires are then connected between two or three terminals of the protected transmission line to allow the relays to communicate. The system that was analyzed sent an analog signal but a pilot wire can also support a digital signal as well.

How Pilot Wire Operates

As for the relays that will be communicating through the pilot wire would be SPD relays, which are static high speed pilot wire relays. These will provide both phase and ground fault protection for either transmission or distribution lines. Figure 1 shows the functional diagram of this relay system.
As for how the SPD relay functions to be hooked up to the pilot wire there are five different steps to create the relay. These steps include the phase sequence network, voltage limiting circuit, operating circuit, restraining circuit, and insulating transformer. The phase sequence network is connected to the three phase line via the CT’s as shown in figure 1 and turns the three phase current into a single phase voltage. This voltage is then limited in the voltage limiting circuit which consists of the zener diodes. The limited voltage then is a sine wave for small currents but when the current is high as when a fault occurs the sine wave starts to approach a square wave since it is being clipped. As for the operating and restraining circuits, they create the sensing circuit that is used to respond to a voltage proportional to the current flowing into the pilot wires as a restraining quantity. While the resulting voltage across the pilot wire pair as the operating quantity. Finally the insulating transformer works as an impedance matching devise between the relay circuit and the pilot wires the voltage will be going across.

For the SPD relay to trip the operating quantity and restraining quantity are compared using the static level detector as shown in the functional block diagram in figure 2. This is also found in the SPD relay despite not being seen in figure 1. As shown in figure 2, the restraint and operate are summed together using the summation amplifier. Then utilizing the level detector and timer, the relay decides whether the operate quantity exceeds the restraint quantity by more then the pickup bias setting for a time interval longer then the timer settings. If the operate quantity is exceeded then the SPD relay is tripped.
Disadvantages

- Limit on the distance
- Transfer trips differ for different lengths
- Limit for telephone lines

Since the pilot wires would be run from relay to relay the only restriction on how far the two stations can be apart depends on the loop resistance and the shunt capacitance. On a two terminal line the series resistance and the shunt capacitance of the pilot loop may not go above 2000 ohms and no less than 1.5 microfarads. Since these values increase and decrease with the distance of the line these values determine just how far one can reach with the pilot wires. If there are three stations they would have to be connected in a T connection, as shown in figure 3. Now the distance of the pilot wire can stretch would be decreased since the resistance in anyone leg of the T can not go above 500 ohms. This would allow at most only 1000 ohms between any two stations twice as small as when there are only two stations.

As for the transfer trip times they can vary slightly with the amount of distance between the two stations from 4 to 5 cycles when between 0 to 2000 ohms. The pilot wire also needs the voltage to be limited to 60 volts and the current going through the wire can not exceed 100 millamps. The voltage and current levels are set so that telephone wires may be used.
Advantages
- Protection for phase or ground faults
- No ac potential source required
- Capable for two or three terminal lines
- Excellent sensitivity on short lines
- High speeds

As shown in figure 1 the line is protected from phase faults but with the addition of a ground sensor CT, as seen in figure 4, the relay will also be very sensitive to ground faults. By adjusting the ratio on the ground sensor CT one can provide the desired sensitivity wanted for the ground faults.

![simplified functional diagram of the SPD relay system with ground sensor CT](image)

Figure 4: The simplified functional diagram of the SPD relay system with ground sensor CT [3].

The direct connection between two stations is simple but as figure 3 shows by doing a center tap and creating a T connection one has the opportunity to create a three terminal connection.

As for the high speeds the SPD relay can react on heavy faults in 15 milliseconds and light to moderate faults in 25 milliseconds. Table 1 show the approximate operating times for the SPD. These times though vary from the condition on the primary system and abnormalities on the pilot wire. The operating times are also slowed from when the relay sees the fault to override voltage transients.

<table>
<thead>
<tr>
<th>Pilot Condition</th>
<th>Detection Time (s)</th>
<th>Restore Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open Circuit</td>
<td>.3</td>
<td>2</td>
</tr>
<tr>
<td>Short Circuit</td>
<td>.3</td>
<td>.7 - .2</td>
</tr>
<tr>
<td>Ground</td>
<td>.3 - .5</td>
<td>.4 - .8</td>
</tr>
</tbody>
</table>

Table 1: Approximate operating times for the SPD relay [3].
Needed Equipment for Connection
To connect this system one would only need the SPD relay, the CTs that were seen in figure 1 and the pilot wire to connect the entire system. The only version of the SPD relay that was found was the SPD11A which is shown in figure 5.

![Figure 5: SPD11A relay containing the circuitry shown in figure 1. [4]]

The SPD11A was primarily chosen because it was the only relay that was mentioned with the pilot wire. But modern relays would be able to work with the pilot wire as well especially since pilot wire sends either analog or digital signals.

Power Line Carrier
Power Line Carrier (PLC) has been around longer than you may think. For example, at the turn of the century, a 500 Hz signal on the power line was used to control the street lights in New York City. 100 years latter, the power industry still uses PLC. Although its use is expanding into the distribution area for load control and even into households for lighting and heat control. Still the major use is on transmission lines in protective relaying.

How Power Line Carrier Operates
The main problem with PLC is trying to place the carrier onto the high voltage line without damaging the carrier equipment. Then the signal is directed in the proper direction to have it received at the other terminal. To do this the diagram in figure 6 is created containing four main functions. These functions include transmitter & receivers, line tuners, coupling capacitor, and line traps.
The transmitter and receiver are connected to the relay system. The transmitter is then connected to the line tuner directly by coaxial cable unless there is more than one transmitter involved then a hybrid circuit would have to go in between the two. These hybrid circuits keep the signals from having intermodulation distortion from the signals of one transmitter affecting the output stages of the other transmitter.

The line tuner, coupling capacitor, and drain coil work together to provide a low impedance path for the carrier signal to the transmission line and a high impedance path for 50 and 60 Hz system frequencies. The line tuner and coupling capacitor makes a low impedance path for the power line by forming a series resonant circuit tuned to the carrier frequency. While the coupling capacitor and drain coil creates high impedance at the power system frequency since it is connected to ground. The drain coil acts as low impedance at the power system frequency and high impedance at the carrier frequency.

The line traps makes sure the carrier signal on the transmission line is directed toward the remote line terminal and not toward the station bus and therefore be isolated from bus impedance vibrations. This puts the carrier signal on the power line pointed in the right direction since it can not go towards the bus. The carrier signal will remain on the line until it reaches the other side of the transmission line where it hits the receiver and is decoupled about the same way it was put on.

Disadvantages
- Disabled if a communication line is faulted
- Line Attenuation
- Power Line Noise

The line attenuation reduces the amplitude of the frequency sent through the line which would affect the carrier frequency. This can occur by a host of problems but the most typical cause of the increase in attenuation would be skin effect that cuts the amount of conductor area resulting in a higher frequency current. The skin effect is a large problem because it is caused by whether issues especially heavy frost where frequency can change up to 5:1 depending on frequency size. Another skin effect is when containments are on the line it is much larger skin effect when the line is wet compared to dry as long as the
rain does not cause the contaminants to come off. Table 2 shows the correction factors needed to correct weather issues while figure 7 shows the typical transmission line losses due to attenuation.

<table>
<thead>
<tr>
<th>Line Voltage (kV)</th>
<th>Correction Factor (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>345</td>
<td>Add 50%</td>
</tr>
<tr>
<td>230</td>
<td>Add 25%</td>
</tr>
</tbody>
</table>

Table 2: Correction factors for foul-weather. [6]

![Typical Attenuation Curves for Power Lines at 34.5, 115, 345, and 765 kV.](image)

Figure 7: Typical transmission line losses. [6]

One of the factors that limits the distance of a PLC channel is the noise on the power line. This must be considered in the design of any PLC channel. The channel must be designed such that the received signal level is greater than the received noise level that is they must have a high signal to noise ratio (SNR). The level of the SNR will depend on the style of modulation and application of the channel. As far as realign is concerned, the effect of a poor SNR may either be a failure to trip or a false trip, both of which are undesirable responses.

There are two basic types of power line noise, Continuous noise and impulse noise. Continuous noise will be present at all times and its amplitude will vary slowly with respect to the frequency considered. Impulse noise will exist for a short time and have amplitude much greater than the average level of the continuous noise. Both types of noise consist of frequencies that cover the power line band.

Much of the noise on the power line is impulsive in nature because the noise is generated by the corona discharge which occurs every half cycle of the power frequency. The
impulses are, however, smoothed out by the input filter of the receiver and as a result can be considered as white noise. White noise is defined as noise having a level power density spectrum for all frequencies and an amplitude function which is considered to be random. It is important to note that very large impulses of noise, such as those created by disconnect switch operation, will shock excite the input filters and cause the filters to ring, and thus the receiver creates added in-band over and above the normal white noise.

Foul weather will have a great effect on line noise. Thunder storms produce discharges which can briefly increase line noise. Also a large increase in noise is due too the increase in corona noise during wet conditions. This noise level may be as high as 30 dB above fair weather conditions.

![Graph showing affect of Foul Weather Noise on Line noise](image)

**Figure 8:** The affect of foul weather on Line noise[6]

**Advantages**
- Completely covers the network
- In complete control of the utility
- No need to run separate lines for communication

**Equipment Needed for Connection**
For completion of this connection one would need the relay, transmitter & receiver, line tuner, coupling capacitors, and line trap. The transmitter and receiver was the only one of these parts that were found as one unit. In turn in order to create a power line carrier there would be the addition of five separate components needed.

**Fiber Optic Cable**

Fiber optic cables are of great importance in this day and age, since they form the basis for most of the communication systems in the world today. They are used in a wide range of places from telephone system operation, cable TV systems and the internet to medical imaging and mechanical engineering and more.
Digital information is carried through fiber optic lines, which are thin strands of glass that are optically pure. As these strands are as thin as human hair, they can be bundled up with ease into optical cables, capable of transmitting signals over long distances. Examining Figure 9, we can see that there are three basic parts to a fiber optic cable, going from the inside outwards, as follows:

1. Core – This is the part of the cable through which light travels, and is located at the center of the cable. This part is mainly composed of glass.
2. Cladding – This layer consists of an optical material on the layer outside the core, and reflects light back into the core.
3. Buffer coating – The main use of this outermost layer is to protect the cable inside from moisture and damage. Moisture is especially hazardous since it hinders the principle behind which the cable works.

![Figure 9: Typical composition of a fiber optic cable](image)

The three components listed above are intertwined, and are arranged in bundles to form what is called a jacket. This is what we commonly see in buildings and houses.

Optical fibers come in two modes – single-mode and multi-mode fibers, depending on the diameters of the cores. While single-mode fibers are 9 microns in diameter and are used to transmit infrared laser light, multi-mode fibers have larger cores of 62.5 microns diameter and transmit infrared light from LEDs. Apart from this, there are also optical fibers composed of plastic that are much thicker and transmit red light from LEDs.

**How Fiber Optic Cables Operates**

Fiber optic cables use the principle of total internal reflection to function. A signal is projected into the cable, and due to the fact that the cladding does not absorb most of the signal, and reflects most of it, it is used as a mirror. The signal “reflects” off one wall, and bounces to the other, and is in turn reflected. However, due to impurities present in
the cables, the signal becomes weaker, and there is loss or attenuation, and this is on the range of 60 % to 75 % for a long enough stretch of cable. This factor becomes extremely important while trying to communicate information about the status of a system.

![Diagram of light signals](image)

Figure 10: The principle of total internal reflection which governs how a fiber optic cable works [5]

A fiber optic relay system primarily works on the same principle that Morse code transmission works. Morse code is sent from one station (the transmitter) and is obtained by another system some distance away (the receiver). We can now understand what the four main components of a fiber optic relay system are:

1. **Transmitter** – This is the portion of the system that sends the signals out, and is close to the core of the optical fiber. There is a lens present in the transmitter to focus the signal into the fiber. The most common wavelengths used for signal vary between 850 and 1500 nm.
2. **Optical Fiber** – This has been examined previously.
3. **Optical Regenerator** – As afore-mentioned, signals become weaker and weaker as they make their way down the optical cable. The function of the optical generator is to prevent this loss, and to boost the weakened signals. This is done through the splicing of doped sections of optical fibers with a special coating into the optical cables. These doped sections are driven by the laser. As the initial signal travels down the line, it becomes attenuated, but when the signal comes into contact with the doped sections, the doped molecules of these sections become lasers and then retransmit a stronger signal. This prevents signal loss, since it is almost as though the signal is being transmitted anew from this point on.
4. **Optical Receiver** – This is the equivalent of the transmitter, except that it is on the receiving end of the signal, and receives, decodes and transmits the signal to other sections on its side of the system. To detect the signal, photocells and photodiodes are used.

**Advantages**
There are a number of advantages to using fiber optic cables and these are examined as follows:
1. Less expensive – Long lengths and stretches of optical cable can be manufactured at a much cheaper rate than the closest equivalent of copper wire. 
2. High carrying capacity – Since fibers are so thin, they can be bundled together to allow for a stronger signal to be transmitted, in addition to allowing more information to be sent across the cables. 
3. Thinner diameters – A lot of space can be conserved since the optical fibers are much thinner than smaller than copper wire. 
4. Less signal degradation – Compared to copper wire, a lower ratio of the signal is lost in the optical fiber. 
5. Lower power usage – Quite a lot of money is saved since lower power transmitters are used to transmit signals, due to the fact that the signals are attenuated less. 
6. Use of light and digital signals – There is little to no interference between different signals in the same cable, as compared to electrical signals in copper wires. Also, digital signals allow for information to be transmitted to be communicated very easily and quickly over computer networks. 
7. Lightweight and flexible – Optical cables weigh less than copper wires and cables and can bend much more easily, and can thus be transported and moved much more efficiently.

**Equipment Needed for Connection**
Obtaining a suitable fiber optic relay to analyze proved to be an extremely challenging task since there were not many prototypes available online for analysis. However, after stumbling across the *EIA-232 Port-Powered Transceiver*, it was understood that this was merely a device connecting the relay and a remote Input/Output module. The transceiver and the module are shown in Figure 11, while an analysis of the relay titled the *SEL–2100 Protection Logic Processor* is presented afterwards.

![Figure 11: The transceiver, on the left, and the I/O module on the right. [7]](image)

As mentioned previously, the relay is in fact a protection logic processor, and its function is to obtain the status of the system and monitor system information. This is performed through the use of *Mirrored Bits* communications, and *SELlogic®* is used to put protection and control into effect. The relay itself can be seen in Figure 12.
The system is designed to perform the following:

1. Assist in protection of the system through the coordination of complex decisions like trip and close to clear faults.
2. Integrate and link to other systems through "resident protocols".
3. According to the specification sheets, the relay performs reporting through the "Sequential Events Recorder (SER)" since it "stores status of up to 144 user-selected elements in over 36,000 nonvolatile records."
4. Powerful and secure bus protection is performed very cheaply and efficiently through the use of Mirrored Bits communications and SELOGIC control equations. Breaker failure protection as well as tripping and blocking protection are also performed.
5. Scheme security is increased through the monitoring of data channel integrity.
6. Communications-assisted protection schemes are created which are in turn compatible with fiber optic transceivers and modems, as well as the I/O module.

This relay allows a transmission line to be tapped, and thus helps to maintain line availability, while improving service to customers, and easing up on circuit breaker costs. Figure 5 shows how a trip signal from the relay is transmitted to the line relays, and thus allows for protection signals to be routed through the use of the mentioned Mirrored Bits communications over direct fibers. In addition to this, the relay also allows for three terminal transmission line protection, shown in Figure 14. Permissive tripping between all the terminals of a multi-terminal line is coordinated by this relay and processor. For example, relays are coordinated such that if permissive trips are received from two relays, then a permissive trip is transmitted to another relay. In addition to this, direct transfer tripping is also provided. All communication channels can be monitored, and a trip signal is sent to the other relays if any of relay fails.

In addition to all of the above, a record of sequential substation events is kept, and recluses are controlled through the local substation topology and remote breaker status from the connected relays. Redundant pilot communications paths are used since the possibility of two paths failing at the same time is remote, as separate ports communicate to other paths using separate paths.
Finally, Figure 15 shows a schematic of the logic processor.

Figure 13: Protection of a Tapped Transmission Line[7]

Figure 14: Diagram showing Three Terminal Line Configuration[7]
Figure 15: Schematic showing a Functional Overview of the SEL-2100 Protection Logic Processor. [7]

Conclusion

When comparing the three types of relays that we analyzed, it was surprising that the information that was gathered said that the most reliable and most economical form of communication between the relays was that of PLC. The information found considered it the most reliable and economical because of the fact that it utilizes the power line to send information between terminals. Despite the cost savings from no pilot wires or fiber optic cable, it seems like the additional hardware used for the PLC would cause major effect on the systems reliability and economic cost in comparison. We would have felt that the pilot wire should have been the cheapest and the most reliable since it only had the cost of the pilot wire, and the relay and reliability since it only has two components to breakdown while the PLC had many more. Even the fiber optic cable, which there were prices found for all the components, came to only $2000 which would far less then buying all the PLC components separately. Though again all information found on power line carrier suggested that it was the best choice, be it economic or reliability wise with none of the other forms of relay communication systems making the same claim. As far as comparing individual engineering stats on the three types of relay communication systems there was not enough information found to be similar between the
communication systems. Most information was general for that type of system and did not make sense comparing with the other.
References

Books:

2. Relaying Communication Channels Application Guide Malvern, PA

Websites:


