A Reliable Power-Line Carrier-based Relay System

Avoiding Mistakes That Cause PLC Systems to Misoperate or Fail to Operate

Miriam P Sanders, PE(Quanta Technology, LLC)

Abstract

Power-Line Carrier (PLC) communications has been used since the 1930's for protection functions. It was one of the first widely used communications for this purpose. Presently there are tens of thousands of terminals installed in the United States as well as over the world. The majority of the terminals in the United States are "dedicated" or narrowband type PLCs. While there are other and even newer technologies available such as broadband PLC, the dedicated PLC type is by far the most pervasive, particularly for protection functions. In order to have a reliable communication channel, the engineer must know the pros and cons of the channel, no matter what type of channel is used. PLC experience is diminishing in the industry as this "simple" communication scheme is overshadowed by the complexity of highly flexible micro-processor –based protective relays and more complex communication solutions. This paper will present topics that are helpful to understand power-line carrier problems in order to provide a reliable channel for protection functions. Topics will include such things as issues with design, installation and maintenance. Information will be presented to help the protection engineer avoid those mistakes that cause PLC systems to misoperate or fail to operate.

For tutorial type of information the reader is encouraged to see IEEE 643-2004, IEEE Guide for Power-Line Carrier Applications as well as several other references listed in the back of this paper.

What this paper does not cover are the PLC applications that are not dedicated to protective relay applications such as Broadband PLC, Single side band PLC, or Digital PLC. These technologies are multi-purpose – typically combining multiple applications into one channel or multiple channels. These are all technologies that are in use today, but for differing reasons may not be as applicable to protective relaying as the dedicated PLC.

Introduction

Power-Line Carrier is a communications channel used by the power utilities to provide simple communications on a two-terminal or three-terminal ended transmission line for protective relaying functions. PLC superimposes a high frequency, low voltage signal unto the power system's low frequency high voltage transmission line. A quick review of what makes up the channel will be helpful to the novice.

The intelligence of the communication channel comes from the transmitters and receivers. There may be only one or multiple sets of transmitters and receivers, based on the needed channels. Today's new installations will have processors that digitally synthesize the since wave transmitting the radio frequency (RF) signal and filtering the receive signal. Historically this may have been done with vacuum tubes, operational amplifiers and transistors, and other discreet components. Today the devices are more sophisticated from an interface perspective, while still transmitting and receiving a basic analog signal. The transmitter will convey a state of the protection system from one end of the transmission line to the other end's receiver as a go or no-go state. More details on what that state is will be covered in the section on relaying systems.

When more than one protection channel is required, these signals need to be combined over the single transmission line. This is typically done with RF hybrids. A hybrid is a device that can isolate one signal from another while combining the two onto a single output. Its main purpose is to prevent multiple high-power transmitted signals from causing intermodulation distortion. Intermodulation distortion is when two analog signals combine (multiply rather than add) to form spurious frequency signals not present in the original two signals. A hybrid is also used to isolate a high power transmitted signal (usually 10 watts or 22.4 Volts@50 ohms) from a low level received signal (usually milliwatt or millivolt levels).

The RF signal needs to be coupled and tuned to the transmission line. A line tuner in combination with the coupling capacitor voltage transformer will form a tuned resonant circuit to the transmission line. The line tuner will also act as an impedance matching transformer between the 50 ohm RF circuit of the transmitter and the transmission line impedance – typically 250 to 500 ohms for overhead lines.

To prevent the signal from flowing into the substation instead of to the remote end, a wave trap is used to direct the signal down the transmission line. It also serves to isolate switching transients and fault transients from adversely affecting the PLC signal. The basic dedicated PLC channel is illustrated in Figure 1. The other end of the transmission line will have a mirror image of this figure.

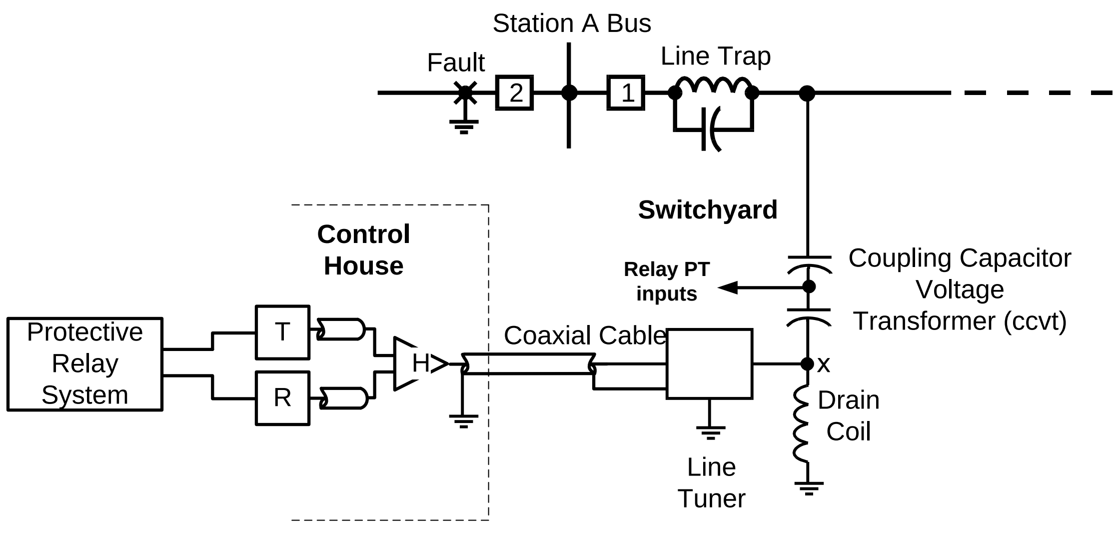

Figure 1. Typical Power-Line Carrier Channel Equipment

Relaying Systems Using PLC

Relaying systems requiring communication channels include protection of the transmission line and protection of major equipment such as for breaker failure or transformer protection. As protection engineers we are always concerned about reliability – how well the system works when called upon to issue a trip to isolate the fault and how well does it restrain from issuing the trip when it shouldn't trip. This is the double edge sword of dependability (trips when it should) and security (doesn't trip when it shouldn't). It is a balancing act as you cannot have 100% dependability and 100% security. The protection engineer decides many times which is the lesser of two evils – to overtrip for the sake of high speed fault clearing, or undertrip (or not trip) and risk additional systems tripping to clear the fault.

Transmission Line Protection

Since the channel is the protected transmission line, the relay system must be designed to mitigate loss of channel issues due to the possibility of the fault causing the loss of channel. Transmission line protection utilizing PLC tend towards the dependable balance of reliability. This means that they are designed to produce trip outputs in the absence of a signal, with some qualifications.

There are two basic systems used for transmission line protection. The simplest and probably most widespread is the directional comparison blocking (DCB) system. This system uses a blocking signal that is transmitted when the fault is outside of the transmission line protection zone, to prevent the remote end for tripping for fault beyond the local terminal. This signal is not transmitted (off) during normal conditions and is turned on for a fault in the reverse direction. This is the "blocking" characteristic of the system. This utilizes the on-off type or the amplitude modulation channel. Another system is the permissive system, which requires a signal from the remote end to give permission to trip for a fault. This system provides a continuous block or guard signal and shifts to a trip frequency to provide the permission. This is the frequency shift keyed (FSK) channel. If the fault is detected to be in the forward reach of the relay, it will key the channel to shift to the trip frequency so that the other end can trip should the relay at that end see the fault in the forward direction as well. Should the fault be outside the zone of protection, only one end will receive permission to trip without a relay arming to trip and the other end relay will arm to trip with no permission to trip. This is a system that shifts the balance to the security side. But what would happen if the channel was lost? Neither end would trip so therefore the fault will need to be cleared with backup systems, usually at a cost of time. To help mitigate this, when these permissive systems are used with Power-line carrier channels, an "unblock" window is added in the channel's receiver logic to provide a window of opportunity to trip on loss of channel. This window is closed after a pre-determined time, such as 150 or 300 ms. After this time, the channel must be restored to the guard or block state for a pre-determine time such as 120 ms. This unblock window provides some dependability into a relatively secure transmission line relay system. So you get both a dependable and a secure system. This is the directional comparison unblock (DCUB) system. It is the same as a permissive overreaching transfer trip (POTT) with addition of the unblock trip window.

Similar philosophy is applied when phase comparison relay systems utilize PLC for the communication channel. These systems are not nearly as common as the directional comparison systems. However, the requirements for proper design of the PLC channel are the same.

Breaker Failure or transformer protection

PLC channels can be also used for Direct Transfer Tripping systems for breaker failure or transformer protection. These systems have requirements to be as secure as possible, since typically there is no monitoring relay at the receiver end of the system. These systems will have inputs from either a stuck or failed breaker system or a transformer differential relay to send a signal to the remote end to isolate the equipment from the rest of the system. Opening this upstream breaker erroneously could have a significant impact to the system operation so therefore security is the upmost concern.

Designing a PLC system for relaying

PLC systems can be a simple single on-off channel for DCB or a more complex system with multiple DCB, DCUB, and DTT channels. Of course the more channels, the more complex the system will be. There will be more hybrid combining, tuning and coupling options (or decisions) available to the protection engineer.

Questions that will need to be answered include the following:

- How many line protection channels are needed?
- What types of line protection channels are desired? This can be on-off, FSK or a combination of both.
- Is DTT required?
- If DTT is required, a single or a dual channel system?
- Is coupling redundancy required? This will be dictated by the criticality of the circuit usually.

The answers to these questions will help guide the design of the system along with typical practices of the utility.

Channel requirements

A single DCB system is the most basic of systems in that it does not require a hybrid since the transmitter and receiver are of the same frequency, and usually only is applied as a single phase to ground coupling scheme. These systems are typically applied where the reliability requirements are not high as this would indicate only a single line protection system without DTT or redundancy requirement. This system may also be a 3 or 4-level backup to more complex systems utilizing other communication channels. See Figure 2 below.

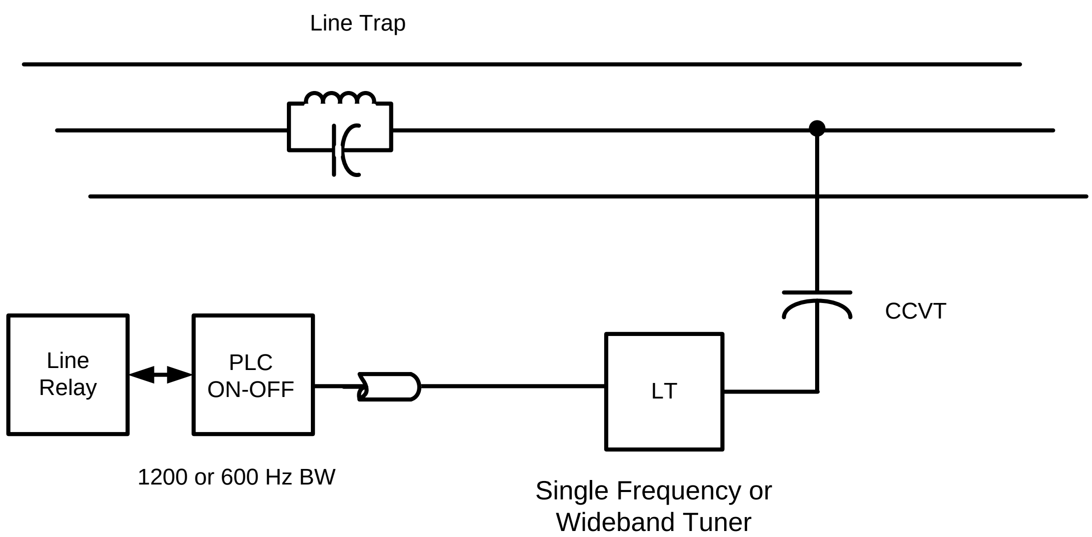

Figure 2. Single DCB System

The bandwidth requirement, either 1200 or 600 Hz typically, can be determined based on speed requirement of the channel, noise influence of the environment or available spectrum. If speed is important, then the wideband system will give about a 2 ms faster channel, whereas if noise is a concern, then the narrowband will give about a 3 dB improvement on noise. Or if frequency spectrum is a concern, the narrowband channel requires half the spacing as the wideband channel.

Center-phase-to-ground coupling is the most efficient coupling, as it incurs fewer losses than an outer-phase-to-ground coupling. For shorter lines (less than 20 miles or so), sometimes outer-phase-to-ground coupling is used due to ease of switchyard equipment placement.

As channels are added, this gets more complex. To add a DTT single channel system to the above scenario requires FSK transmitter and receiver, and necessary hybrids. Hybrids are used to isolate transmitters from other transmitters and transmitters from receivers, except for the ON-OFF transmitter from its receiver. Be careful with transmitters and receivers in a single chassis as they may not have an internal hybrid to isolate the signals. Figure 3 illustrates a typical DCB system and a single channel DTT system with center-phase-to-ground coupling. Here a resistive hybrid is used to isolate the DTT transmitter from the DTT receiver and then a reactive hybrid is used to isolate the ON-OFF transceiver from the DTT channel.

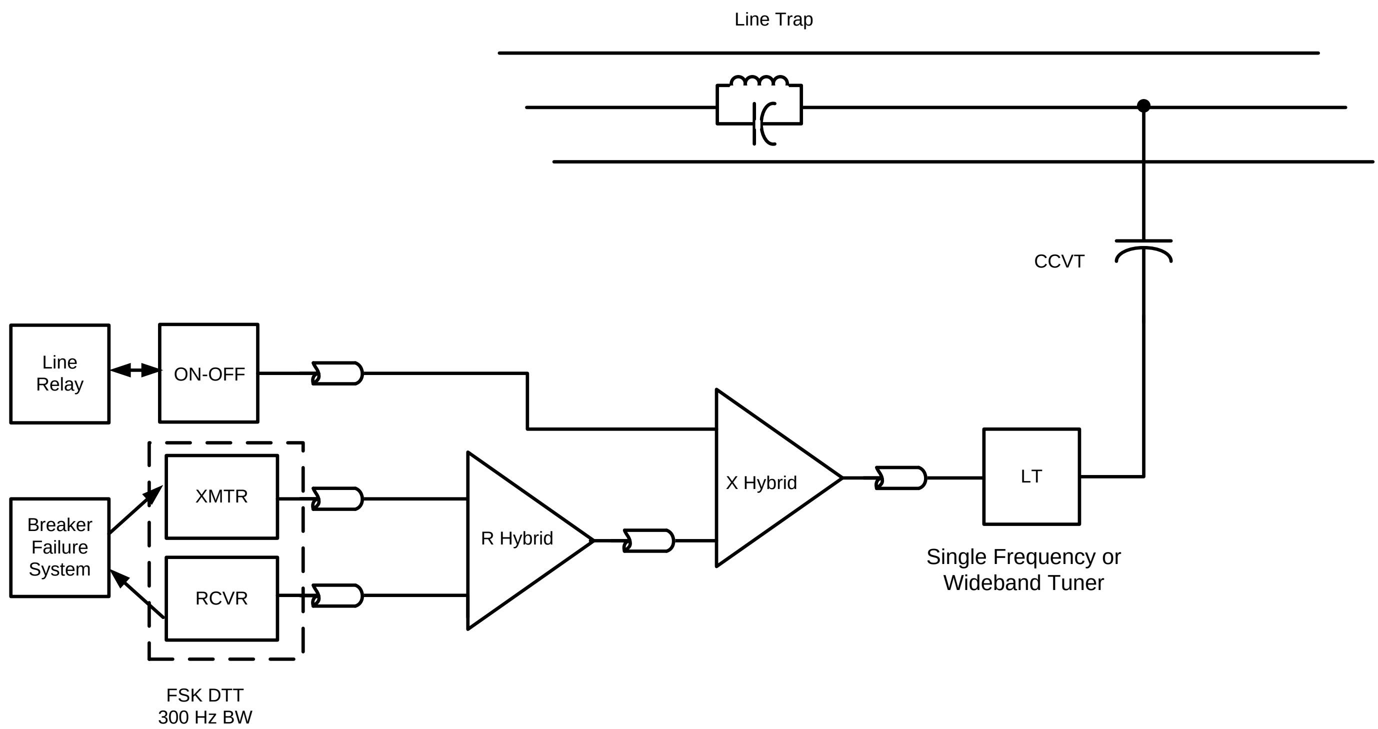

Figure 3. Typical DCB and single channel DTT system

This can also been done with a skewed hybrid at the end of the hybrid chain as shown in Figure 4. Here because the skewed hybrid has a receive port and a transmit port, the arrangement is a little different. Transmitters should not be placed on the receive port due to its high losses. Using the reactive hybrid as in Figure 3 results in lower overall channel losses but requires tuning of the hybrid. The skewed hybrid application in

Figure 4 results in more losses on the receive side of the channel, but can result in better signal to noise ratio and does not require tuning. Eliminating tuning will help improve installation time and accuracy.

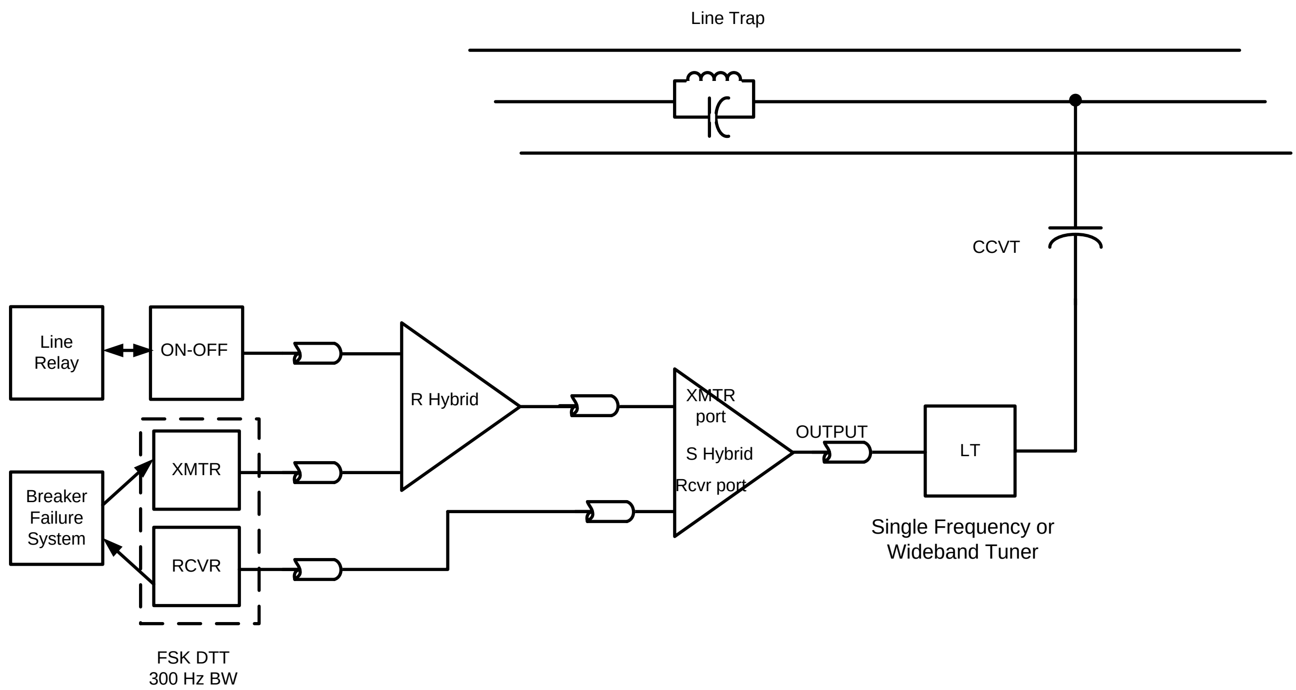

Figure 4. Typical DCB and single DTT with Skewed Hybrid

The more channels added, the hybrids and options become more complex. Figure 5 is an example of a DCUB relay system with a dual channel direct transfer trip system. Note that the DTT system utilizes a narrower channel than the DCUB. This is for two reasons. First the DTT channel requires higher security so to allow less noise into the channel, use as narrowest band channel as possible. This also results in a slower channel, but is acceptable for a DTT system. The line relaying system dictates higher speed therefore the wider channel, but the compromise in its security is mitigated since there are relays supervising confirmation of tripping. Time delay or pre-trip time is recommended to enhance security as well.

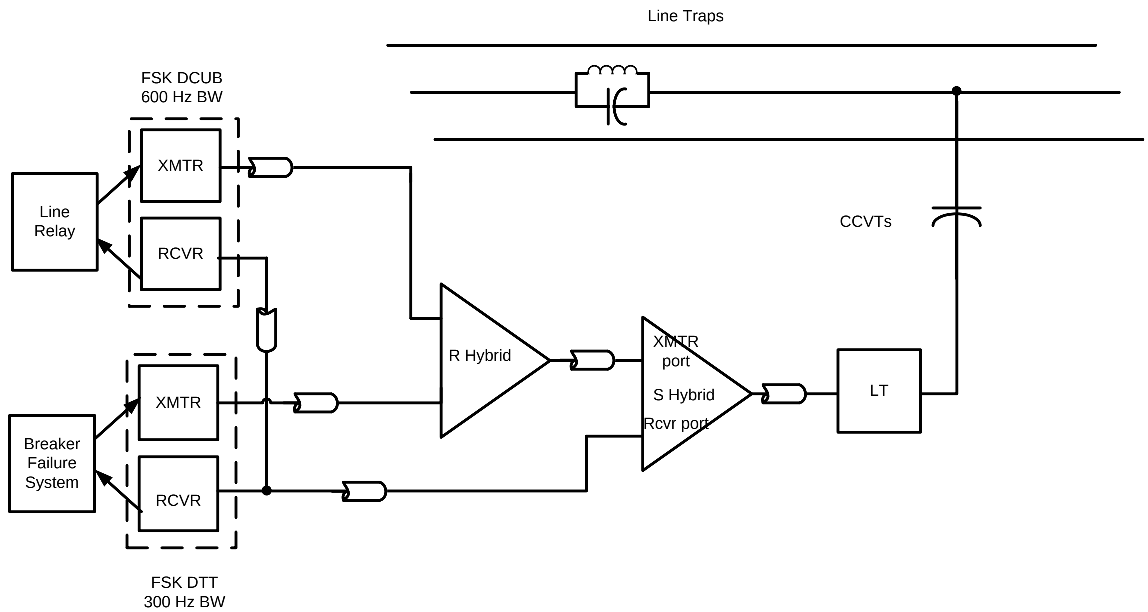

Figure 5. Typical DCUB and single DTT Channel

Adding another DTT channel would look something like Figure 6. In this example, another hybrid is required for isolation of the third transmitter but notice that the DTT transmitters are on the higher attenuation leg of the hybrid chain, as these channels can tolerate the additional 3.5 dB of loss due to their narrower bandwidth.

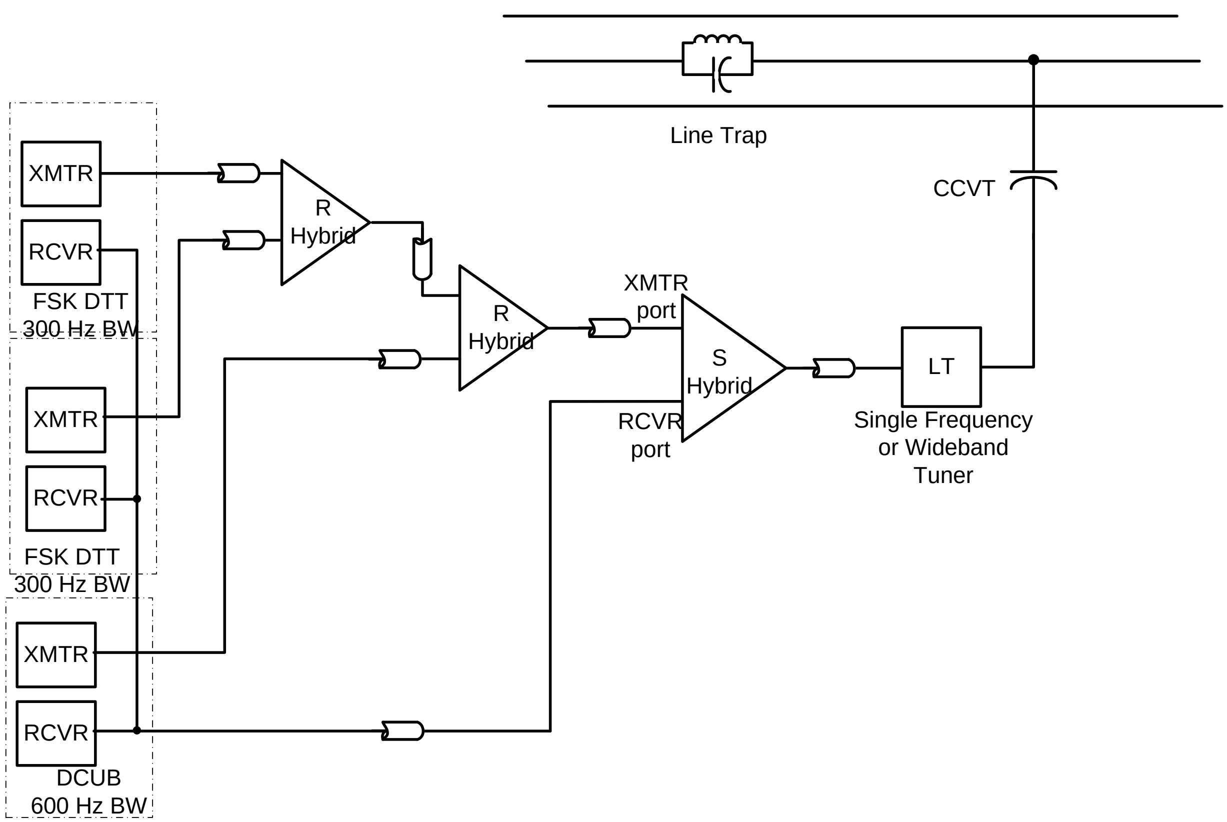

Figure 6. Typical DCUB and Dual DTT Channel

Frequency Spacings

When adding additional channels, recommended minimum frequency spacings should be followed per the manufacturer's literature. Also, when using a reactive hybrid, there is a maximum frequency spacing that is available to provide the necessary 30 to 40 dB isolation. Care should be taken to abide by that as well.

Coupling options

Whether to apply single-phase-to-ground coupling, phase-to-phase or three-phase coupling will be dictated not only by economics but by requirement for redundancy and reliability. While the PLC channel does not have a redundant or alternate path as some fiber-based systems have, the protection engineer can provide a level of redundancy in the PLC channel. Obviously having more than one component will provide some redundancy, so therefore two sets of tuners and wave traps will provide redundancy. But careful evaluation will show that careful combining of the channels with balancing transformers and tuners will result in a better system with higher redundancy than isolating it into two independent systems. Figure 7 illustrates the same system as in Figure 3 but with phase-to-phase coupling. This is better from a coupling efficiency stand point and provides required transmitter isolation.

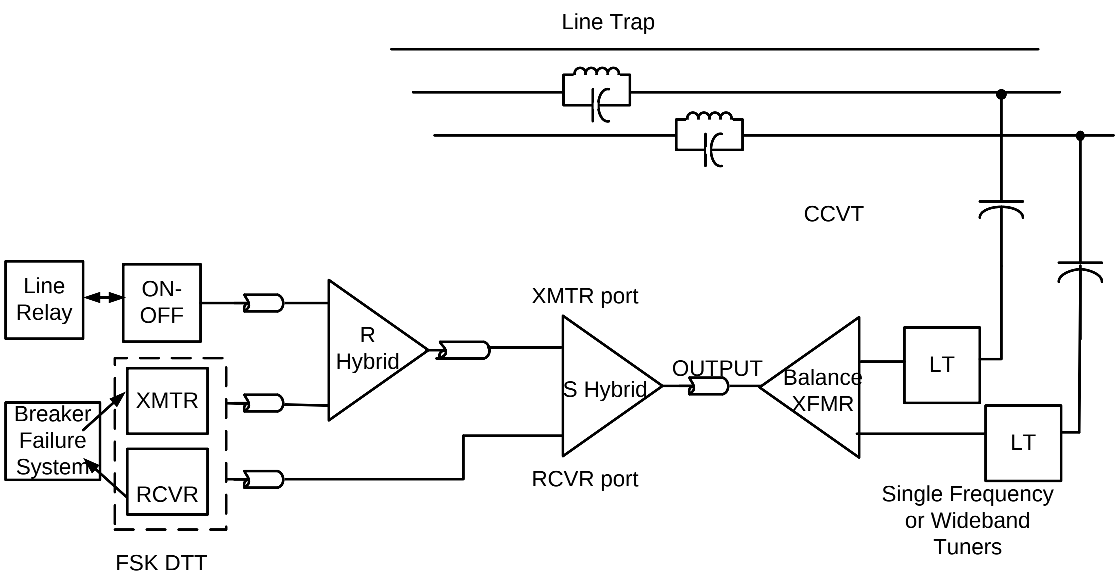

Figure 7. DCB and DTT with Phase to Phase Coupling

In comparison to independent channel coupling as in Figure 8, the transmitters in Figure 8 have only about 5 to 10 dB isolation from one system to the other, whereas the hybrids in Figure 7 provide 30 to 40 dB of isolation. An outer-phase-to-center-phase coupling has about a 4 to 6 dB improvement in coupling efficiency over an outer-phase-to-ground system. This coupled with the fact that losing one tuner or trap can result in failure of that a complete channel, whereas with Figure 7 type of coupling, failure of one tuner or trap will result in a reduction of signal, but not a complete failure of either system. Figure 7 couples both signals to both phases, thereby providing channel redundancy.

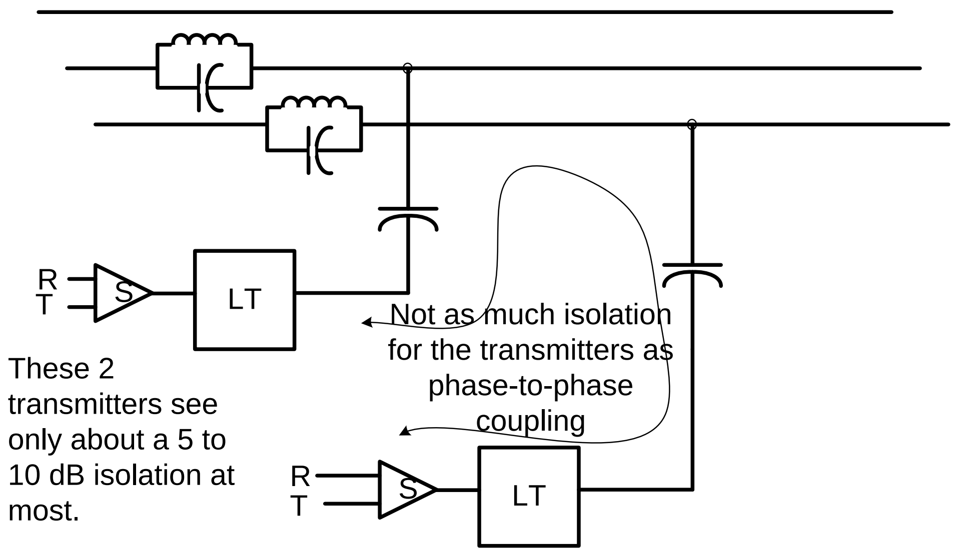

Figure 8. Independent PLC Systems

The coupling system in Figure 7 still has a single point of failure issue since all channels must go through one skewed hybrid and one balance transformer. For further redundancy, a coupling system such as Figure 9 eliminates the single point of failure of the one balancing transformer and one skewed hybrid by using a balancing combiner instead.

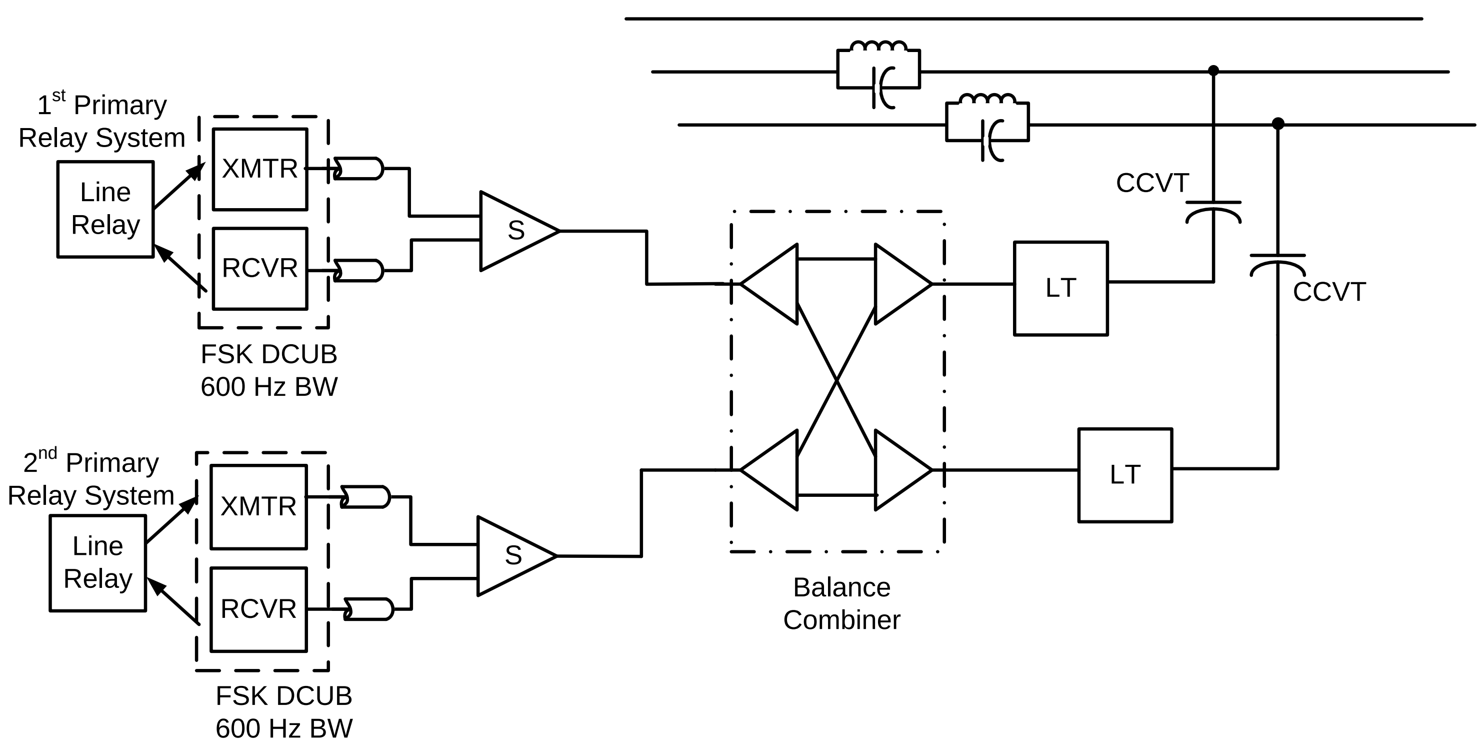

Figure 9. Redundancy with Balance Combiner

The possibilities are endless. There may be more than one correct way to couple the PLC channels, each with its own advantages and disadvantages. For more on hybrid and coupling applications, refer to the IEEE 643-2004 IEEE Guide for Power Line Carrier Applications [7] and "Redundancy in Coupling PLC to the Power Line" [9].

Increasing Security in DTT systems

As stated earlier, security is important in DTT systems as there is no supervision of relays at the receiver end of these systems. To increase security, narrowband channels are used since they are less susceptible to noise and are slower channels. These systems should have pre-trip delays set to the maximum the power system can tolerate to meet the critical clearing time. More time delay translates into higher security. Additionally, to increase the security of the DTT systems, adding a second channel, with the receiver outputs "anded" provides an order of magnitude difference in security. Noise is one the biggest culprits in erroneous trips signals but with two channels, the probability of both channels receiving an incorrect trip signal simultaneously, coupled with the pre-trip timer, is very small. To improve dependability on a dual channel DTT system, many utilities use logic to revert to single-channel DTT on failure of one channel. Thereby providing the field engineer time to repair the failed channel, while maintaining the DTT function.

Another word of caution is ensure that unblock logic is not part of the DTT systems. This will cause multitudes of misoperations. Throughout the years, as technology has become more user-friendly and flexible, this provides an opportunity as well to make errors in design. The protection engineer should be familiar with the PLC channel equipment and its capabilities. Older equipment prior to the late 1970's and early 1980's had much of the logic hardwired such that the ordering process dictated the function – either a DTT unit or a DCUB unit. As technology progressed to programmable logic and more flexible settings, these systems became "all-in-ones", with the design engineer responsible for determining the appropriate functions.

The DCUB Security and the Unblock Window

The DCUB system using the FSK PLC channel is a secure channel in that should it fail, no signal (trip or guard) is received at the remote end. General FSK logic (DTT or DCUB) is typically in place in the receiver to ensure that the channel is stable prior to issuing a trip signal; this is the "guard return logic", which will require guard to be present for a time period following a loss of channel before a trip is allowed. Additionally if guard is not present and trip is not received within a certain time period, then the channel is locked out. This is called "trip after guard" logic. These two logic function help insure a secure channel. See Figure 10 for the basic FSK logic. As in the DTT system, a pre-trip time delay will increase security. Normal recommendations are on the order of several (at least 4 to 8) milliseconds.

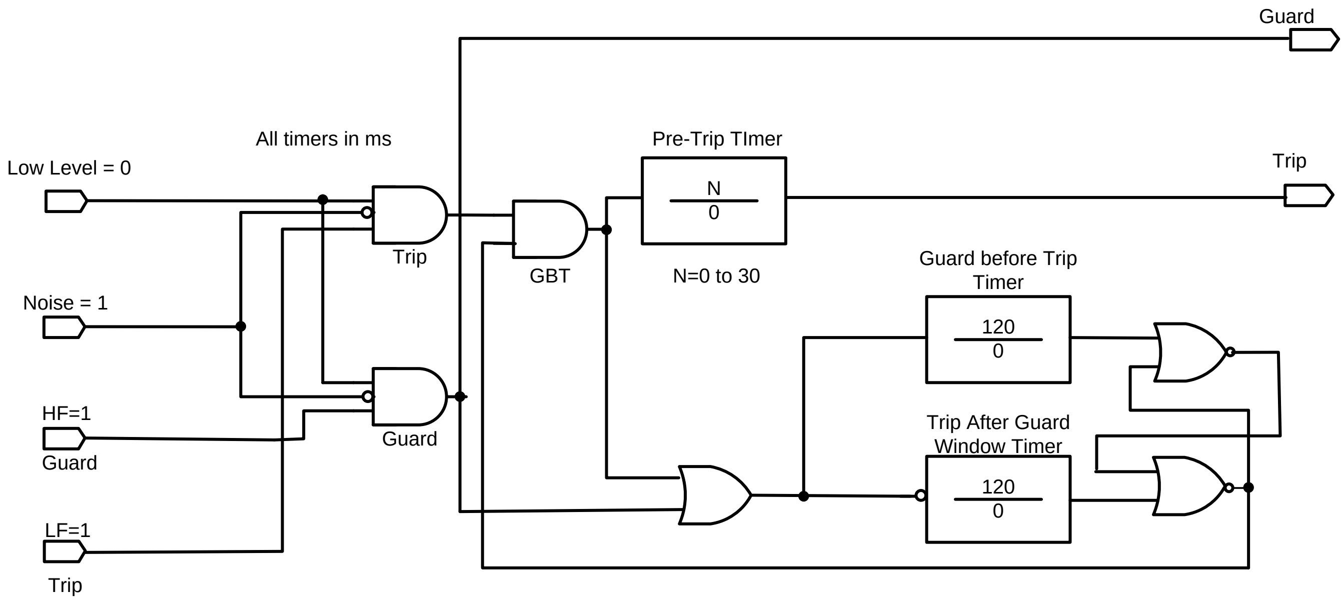

Figure 10. Basic FSK Logic

When applying an FSK PLC channel for line relaying, the issue of a possible loss of channel during an internal fault needs addressing. Not all internal faults will cause a loss of channel. Usually faults in the middle of the line or not involving all three phases, will result in some signal at the receive end due to the fact that the PLC signal will propagate on all three phases, not just the one(s) physically coupled. Modal analysis explains this. [7] For a loss of channel, the DCUB system will have logic that provides for limited trip output on loss of channel – the "unblock window" or unblock timer. With current technology, this timer is adjustable usually up to about 500 ms. After this time the logic is locked out from providing a trip output until the guard return logic has been satisfied. This is providing dependability in the otherwise secure system. A breaker trip is not executed unless the line relay also determines a forward fault exists. Experience has shown that this has been a successful application since the mid-1965s. Improvements to this logic has included a time-delay on the unblock trip window, to mitigate loss of channels for external faults causes by air gaps in tuners and coupling capacitive voltage transformers (ccvt) issues. This time delay on the unblock window adds an additional level of security on loss of channel. Keep in mind when designing the logic of the PLC channel that this will in turn delay tripping for an internal fault that causes the loss of channel.

Utilizing the logic provided in the PLC equipment should be the design engineer's first approach. The channel equipment is the source for the information and can provide more accurate results than programming external devices to perform these functions. Unblock logic in the channel equipment is far more reliable than external logic as the channel has more timely and accurate information to process and that processing time will be faster since it does not have the sampling rate of the external logic to further burden the process. It also provides a demarcation between the channel and the protective relay for analysis of operations.

Increasing Security in the Dependable DCB System

As stated before, the DCB utilizing the ON-OFF PLC channel is a dependable system. The signal is not required for tripping on an internal fault. But what happens when the signal is required to provide the blocking input for an external fault into the line relay and it is not there? It will allow a trip on an external fault. Since the signal is not normally "ON" the question is will it turn on when required? The answer is not known. Increasing the channel availability can mitigate this issue. Automatic checkback systems and routine maintenance will provide higher reliability. Modern PLC equipment has integral automatic checkback systems to help facilitate this testing. However this testing has some limitations. Does it test the interface between the relay and the PLC channel? Does it test the channel during a fault condition? For more on this subject, please refer to the section on Maintenance.

To mitigate issues with carrier holes, there has been custom logic added the protection systems to prevent these carrier holes from causing misoperations. While this increases the security of the system, it reduces the dependability and care must be used to insure that it does not create unexpected results. Be sure to review other logic that uses these signals to assist with such options as current reversals, and tripping for cross over faults, when an external fault becomes and internal fault.

Should a more secure system be required, the DCUB system might be a better selection.

Utilizing a normally closed contact for the start function as in Figure 11(a) reduces issues with contact bounce causing carrier holes, as well as providing a continuous monitoring of the integrity of the start circuit. When a normally open contact is desired, then the transmitter keying logic becomes as shown in Figure 11(b). Whichever logic is used, care must be taken to insure that the STOP input has priority, so as to allow tripping for an internal fault, no matter what else is occurring on the relay system, including automatic or manual testing.

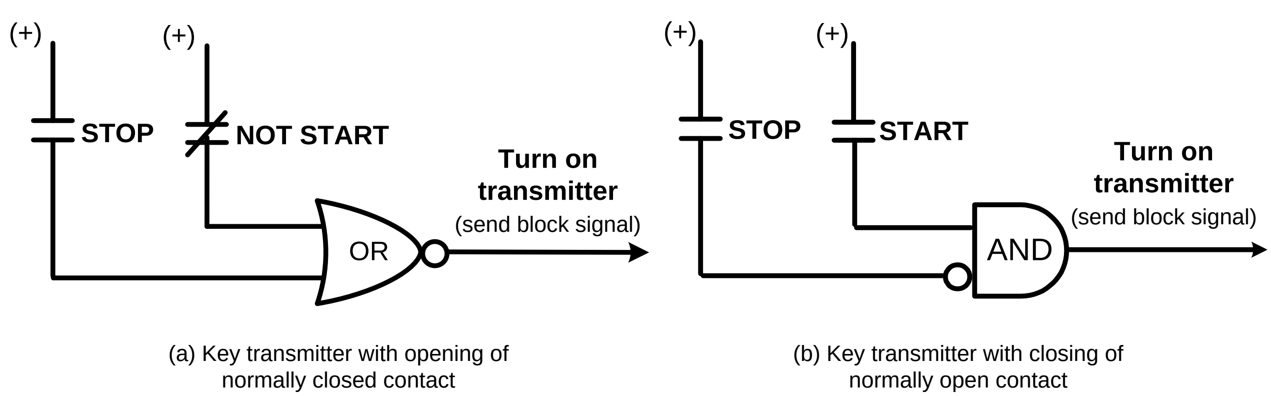

Figure 11. Transmitter Keying Logics

Installation/Commissioning

Proper tuning of the whole channel is necessary to insure correct operations during adverse conditions. Understanding each component's necessary tuning requirements will help improve the resulting installation and performance of the system.

Transmitters are designed on a 50 ohm impedance base and should be individually calibrated into a 50 ohm non-inductive load to provide the required power output at the desired frequency. Calibrating into a different load will produce a different power level than expected. Calibrating the transmitter with the turner and other devices connected results in a load that is not pure 50 ohms.

Reactive hybrids should be tuned, with a single frequency, terminated into a 50 ohm, non-inducted load. If more than one channel is being applied, It is best to use the geometric mean frequency (GMF) of the multiple frequencies. The GMF is the square root of the multiplication of the lowest and highest frequency passing through the hybrid. If that is not possible, then the frequency closest to that number is second best. After the line tuner(s) are tuned and the reactive hybrid is connected to the tuner then the hybrid adjustment should be tweaked for maximum trans-hybrid loss.

Tuners should be calibrated for maximum transfer of the power to the transmission line, which means minimum reflected power. This should be done at the GMF of the transmitter frequencies as well. For most applications reflected power below 10% is desirable. The local utility should have guidelines as to what is acceptable. The lowest reflected power is usually obtained on long lines, since the attenuation of the line isolates the remote end influencing tuning. That being said, shorter lines will tend to have higher reflected power and be more difficult to tune due the remote end influences. If the line is short, then several trips to each end may be required as one is tuned, the other may become mistuned and it will take a compromise to provide a viable system.

Receivers are calibrated after the local and remote end's transmitters, hybrids and tuners have been tuned. The receiver is connected to the tuner and hybrids during the calibration and all transmitters should be turned on, and if FSK, keyed to guard. The receiver is typically calibrated for a 15 dB margin. This means that it is set for the receive level as of the time of calibration and will continue to produce an output until the signal level drops 15 dB. This is to allow for bad weather and other signal degradations to occur up to 15 dB and still have an operational channel. Why not just have it set to the receiver's minimum sensitivity so that it can function all the way down to 5 mV? This would allow random noise to produce outputs as well as other extraneous signal to cause false outputs. Usually for an FSK system, when keyed to the trip frequency, it is also boosted by 10 dB to overcome noise during the fault.

What does a 15 dB margin mean in terms of signal degradation? Well if 3 dB is half power, then that means the signal has degraded by half its original level. The 15 dB margin divided by the 3 dB results in 5 times the half-powers. Doing the math, results in the original signal divided by 32. That's quite a decrease in signal strength. That's the threshold at where the channel stops functioning properly. Bad weather will typically cause 5 to 10 dB of signal degradation, unless it is icing on the lines. Then no signal will get through since RF tends to propagate on the outer edge of the conductor, which would be ice under this condition.

Proper ground of the equipment is often one area missed during installation. Each chassis of the PLC transmitters and receivers should be grounded with either a braided wire or a heavy conductor. Daisy-chaining of the ground leads is not a good practice.

The coax cable shield must be grounded at the first place it lands in the control house. This is to provide a direct path to ground for the transients from the switchyard before they damage electronic equipment. The use of a RF grounding switch is a convenient place to land the coax shield and ground it. This RF grounding switch may also be helpful during maintenance to ensure all RF signals are shorted. Notice in Figure 1 that the ground of the coax cable shield is shown on the control house side. The ground shown on the line tuner is on the high voltage side of the impedance matching transformer as shown in Figure 13. Grounding the low-voltage side of the coax cable shield at the tuner will not prevent switchyard transients from entering the control house since the cable will continue to pick up transients on it path to the control house. Grounding both ends will result in a ground loop and damage to the shield. Multiple grounds within the control house are typically not a problem as the control house should be well grounded itself.

Wire ties should not be used to neatly bundle coax or triax cables together. While these are insulated cables, there still can be signals induced from one coax to another, creating interference and possible intermodulations of the transmitted and receive signals.

Maintenance

Utilities are striving to minimize maintenance as much as practical. If an element can be monitored and adequately alarmed, then that element will require less human intervention. The protection engineer should review the standard practice to see where more monitoring can be added to eliminate unnecessary human intervention.

ON-OFF Channels

Several issues can arise that prevent the blocking signal from being received. Failure of the channel equipment is easily detected by the PLC's automatic checkbacks, producing an alarm should the block signal not be received. This is easily detected prior to requiring the blocking signal and appropriate response and resolution should help insure proper operations. Issues that occur due to faults are more difficult to test.

As mentioned before, the PLC channel signal is not required for tripping for an internal fault, but is required to block tripping for an external or out of zone fault. Therefore, the integrity of the PLC channel is important to prevent misoperation. Since the signal is not normally transmitted, it is advantageous to have some sort of automatic periodic testing of the channel. This is normally done with either a checkback system in the channel equipment itself, through the line relay exercising the protection function output, or with an external stand-alone device. The time interval is usually determined by the experience of the local utility and current practices, but may typically be done daily or weekly. This periodic testing checks the ability of the system to key the transmitter on and the ability to transmit the signal, the receiver to receive and detect the signal during the normal (non-faulted) state of the transmission line. What this testing does not check is the ability of the system to properly perform during a transmission line fault, either internal or external.

Faults produce transients on the transmission line that are orders of magnitude greater than the normal voltages and currents. Transients can also be produced during switching operations and breaker opening operations. The transients typically are short in duration, high in frequency and high in noise. These qualities may or may not affect the PLC channel. Sometimes faults will totally short out the PLC signal if the fault is close in to either terminal but normally there will be some signal received at the remote end, even during an internal fault. Protection systems are designed to tolerate loss of the PLC signal during internal faults– as the blocking signal is not required to trip for an internal fault – erring on the side of dependability. But if the signal is not able to be transmitted or received for an external fault there could be an overtrip condition which is most undesirable. This can occur due to what is commonly called “carrier holes”.

What is a carrier hole? It is when the signal disappears during a fault on the transmission system due to something in the PLC channel system shorting out to ground. There are several culprits of carrier holes on the PLC transmission path. The signal is propagated from the transmitter through a coax or triax cable to the line tuner, through the coupling capacitor to the transmission line itself. Flash-overs of the signal to ground can occur at several of these places in the channel. It is the “weakest link” that causes the issue. As coax ages, the insulation begins to degrade, allowing a path from the center conductor to the grounded shield, allowing a flash-over. This will result in a loss of signal or carrier hole for the time the flash-over is present. A sample of a carrier hole is shown in Figure 12. [8]. This shows the blocking signal present with gaps aligning with the peaks and valleys of 3I0.

In the ccvt and in the line tuner, there are protective units, made up of protective air gaps (spaced electrodes), gas tube or other limitation devices, and an RF grounding switch. In the ccvt, the protective unit is across the drain coil. The line tuner may also have a secondary drain coil, in which the protective unit is across that as well, but otherwise, the protective unit is still there, along with an RF grounding switch. Figure 13 shows the protective gaps.

The protective gaps serve to provide a low impedance path to ground for surges due to transients, thereby preventing high level surges from getting into the electronics of the PLC channel as well as protecting the drain coil in the ccvt. The goal of the protective gap is to arc over quickly and “seal-off” or extinguish the arc expediently. The gap should arc and seal-off within 1 to 2 milliseconds, so fast that the transmission line protection relay has not had time to process the fault data and take action for the fault.

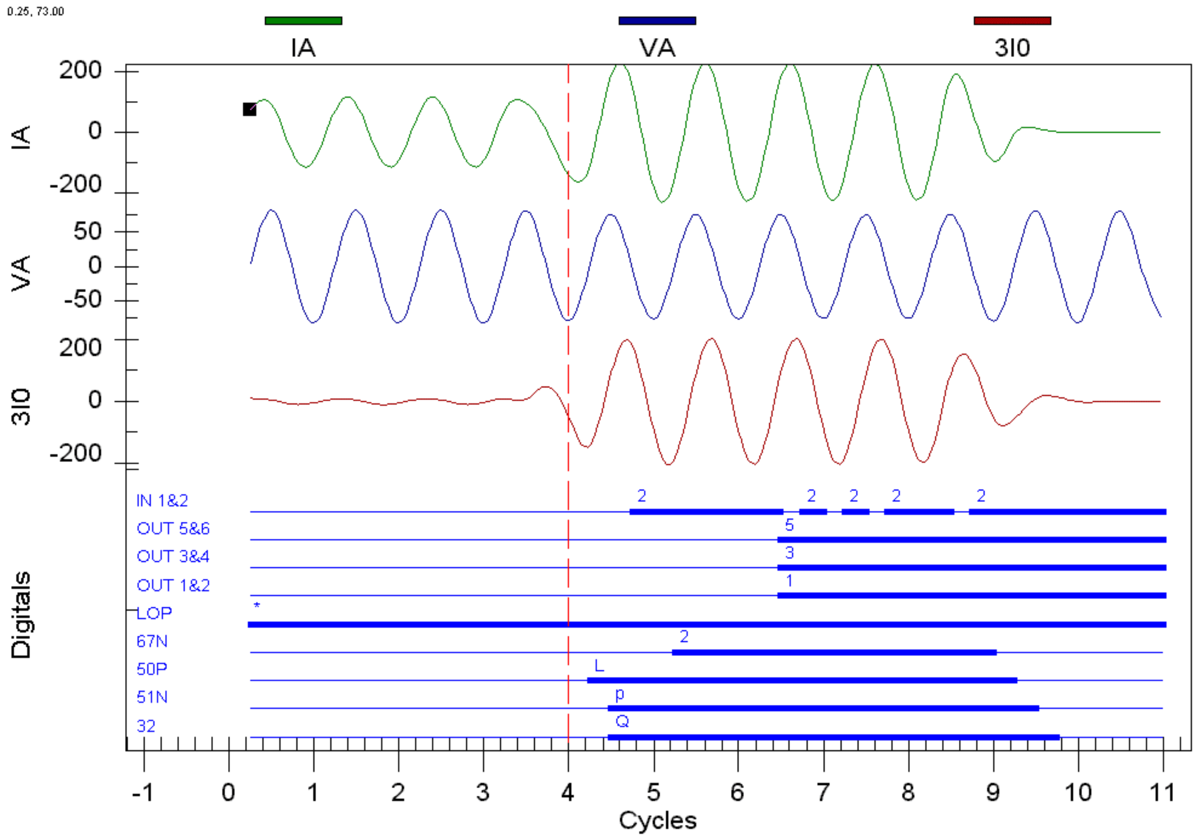

Figure 12. Sample of carrier hole (IN 1&2)

These surges are also limited by the substation lightning arresters. The flashover point is defined in the ANSI C93 standards to be above 2.5 kV RMS at power frequency voltage and below 85% of the BIL rating of the device (10 kV for Line Tuners, ccvt's).

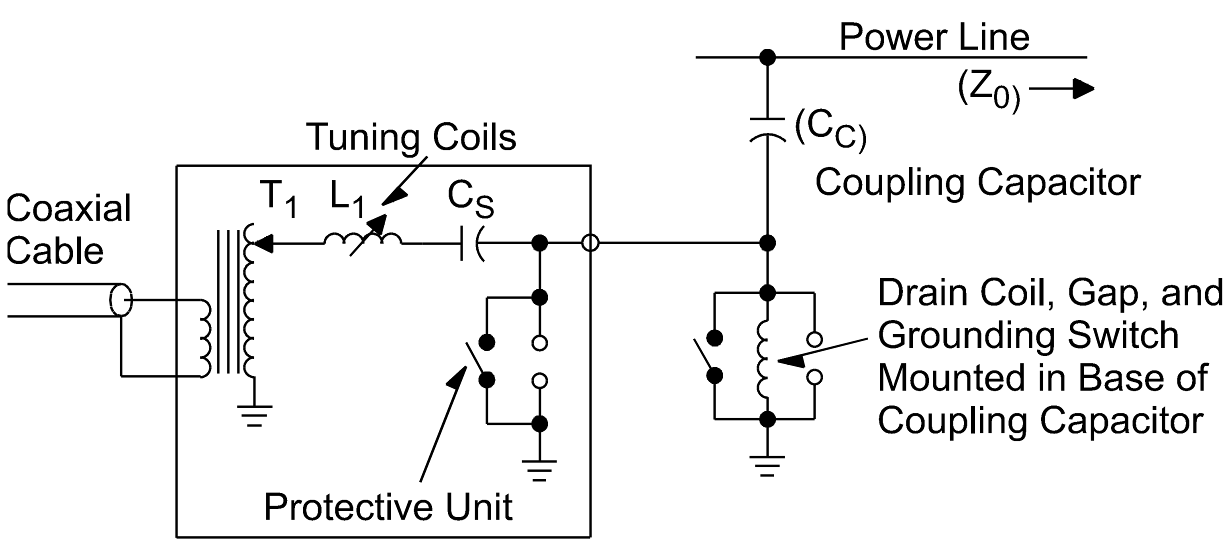

Figure 13. Protective Gaps in Line Tuner and CCVT

Other areas of concern may be what occur during a ground potential rise caused by the fault, what about Transient Voltage Recovery capacitors, what about series of shunt capacitors and their interaction with the ccvt's capacitance? There may be other areas to consider.

Maintenance is the key for preventing carrier holes. The protective gaps need to be routinely cleaned and re-adjusted for proper flash-over voltage and coax cables should be periodically tested and replaced if necessary. Every time there is a transient on the transmission line, the protective gap will more than likely flash-over, which in turns builds up carbon, thereby decreasing the flash-over voltage of the gap. So that next time, it may flash-over sooner than expected and not seal-off in time, thereby creating a carrier hole. ***Maintenance of the gaps will greatly improve the overall reliability of the channel and the protection system.*** Be aware of the type of gaps used in the tuners and ccvts. Gaps which are two electrodes (air gaps) are maintainable, whereas the sealed gas tube types require replacing. Air gaps can be inspected and periodically cleaned and adjusted. Checkback systems do not detect issues with carrier holes since they are executed during non-fault conditions.

Coordination of the gaps in the tuners and ccvt can also be helpful. Since the ccvt requires a line outage to maintain, setting the gap in the tuner (which typically does not require a line outage) to a lower flash-over voltage than the one in the ccvt will allow more frequent maintenance intervals. This is explained in Special Considerations in Applying Power Line Carrier for Protective Relaying [8].

It would appear that there is an increase in the occurrence of "carrier holes"; is it due to the increase of information that is now available with the micro-processor-based devices and the ability to obtain sequence of events out of these devices or lack of maintenance? No matter the reason, better maintenance will improve the PLC channel.

Adding logic to DCB systems eliminate carrier holes from causing misoperations on the relay system provides for more security in the system. This serves well for the initial carrier-hole issue or maybe several more, but in the long run, careful monitoring of the logic - when and how often does it operate - could help predict catastrophic failure of channel equipment. Be careful that this logic is not masking an otherwise serious condition that needs attention.

FSK Channels

FSK channels are continuously monitored due to the fact a guard signal is present normally. But the question remains as to if the system will shift the transmitter to the trip frequency and if the receiver will properly receive it to produce the desired tripping function. Therefore the FSK channel is not maintenance free either. Periodic testing is still recommended for these systems and close monitoring of the performance may also be desired. Protective gaps are still a problem in FSK channels as they could cause a DTT system not to trip or a DCUB system to fail to trip.

Margin Alarms and Reflected Power Alarms

Under the installation section, discussion on the margin setting suggested a 15 dB margin. If the receivers have the ability to set a margin alarm for a level 5 dB or so less than the margin setting, the an alarm can be monitored to provide feedback of impending bad channels. This function is more useful on channels that are normally on, such as the FSK systems, but with custom logic, may prove beneficial on ON-OFF systems as well. Logic that determined if both the receiver output and the margin output are true simultaneously would indicate a good channel, or if only the receiver output is true, then that would indicate degradation of the channel.

Reflected power alarms at the receiver point may not be as effective in alarming because the receiver can be several devices downstream from the tuner point where reflected power is measured. The reflected power determined by the local receiver may be significantly less than the actual reflected power. Use of this indication as a fine scale alarm is cautioned.

After Final Checkouts

There are several areas that if not monitored, can be left in a maintenance type of condition. Be sure to check all knife switches for proper positions as well as any selector switches (85CO or carrier cut-off, etc.). Knife switches have several locations – relay cabinets in the control house, the line tuner cabinet and the ccvt.

Summary

Power-line carrier has been used for protective relaying applications successfully for almost 75 years. While new technologies introduce new pilot channel options, the simple PLC channel is still an economically viable channel for one or several protective relay functions. Understanding the pros and cons of the channel provides a better understanding when design, installing, commissioning and maintaining the system. Recent technology advances in the hardware of the electronics have added to the ease of application of the PLC channels and the flexibility but with that comes complexity. Therefore it is important to understand the characteristics of the PLC channel and its role in the protective relay systems.

References

[1] Meinardi, J and Sanders, M.; "Investigation and Analysis into the Mis-Operation due to Carrier Holes". Presented at 2008 Georgia Tech Protective Relaying Conference

[2] ANSI C93.1 ANS Requirements for Power-Line Carrier Coupling Capacitors and Coupling Capacitive Voltage Transformers (CCVT)

[3] ANSI C93.3 ANS Requirements for Power Line Carrier Line Traps

[4] ANSI C93.4. ANS for Power Systems, Power Line Carrier Line Tuning Equipment.

[5] ANSI C93.5 Requirements for Single Function Power Line Carrier Transmitter/Receiver Equipment.

[6] IEEE C37.2 IEEE Standard Electrical Power System Device Function Numbers, Acronyms, and Contact Designations

[7] IEEE 643-2004 IEEE Guide for Power Line Carrier Applications

[8] “Special Considerations in Applying Power Line Carrier for Protective Relaying”. Working Group (H8) to the IEEE/PES/Power System Relaying Committee. (http://www.pes-psrc.org/Reports/SpecialConsiderationsPLC.zip)

[9] “Redundancy in Coupling PLC to the Power Line”. Working Group (H15) to the IEEE/PES/Power System Relaying Committee. (http://www.pes-psrc.org/Reports/Redundancy%20in%20Coupling%20PLC%20to%20the%20Power%20Line%20-%20H15%20WG%20Report.pdf).

[10] CF44-VER06, TCF-10B System Manual from Ametek, Corp.

[11] Ray, R. E. and Sanders, M. P. “Power Line Carrier Channel & Application Considerations For Transmission Line Relaying”. Presented at 1996 Western Protective Relay Conference.

Biography

Miriam P. Sanders, PE

With over 30 years’ experience in the relay industry, Miriam has worked with protection channels, transmission pilot relays and distribution relays. She is a Principal Advisor with Quanta Technology. Previous employers include Ametek Power Instruments, Pulsar Technologies, Inc, ABB Power T&D, Booth & Associates and Westinghouse Electric. At Ametek and Pulsar, Miriam was Product Manager for the PLC products. Miriam has published several papers on the application of Power-Line Carrier for use in protection systems. Miriam is a senior member of the IEEE, past Chairman of the Power and Energy Society’s Power System Relaying Committee, and has held many positions in the organization including, Committee Vice Chairman, Committee Secretary, and Assistant Secretary, the Standards Coordinator, Chairman of the Transformer Protection Guide, member of the Power Line Carrier Practice Working Group and Transmission Line Protection Guide. She is also active in the PES’s Power Systems Communications Committee and its Power Line Carrier Subcommittee. She is a registered Professional Engineer in the states of North Carolina and Florida.