Advanced P&C Applications using Broadband Power Line Carrier (B-PLC)

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Abstract – Power line communications (PLC) has been employed by electric utilities for many decades. The primary application has been protective relaying, in which a PLC pilot channel is used to provide a tripping or blocking command. PLC is well suited to this application because it requires low bandwidth. A more recent and very desirable application, digital line current differential protection (LCDP), requires greater bandwidth and low latency; hence it is not suitable for conventional PLC.

The development described in this paper offers a next generation PLC system which supports wide band applications like LCDP, as well as SCADA, station video surveillance and other digital applications. Dubbed Broadband-Power Line Communications (B-PLC), this new technology builds on the advances in digital encoding and modulation technology that have taken place over the last decade.

The first commercial use of this technology is at AEP, where existing pilot wire protection systems employed on 5-10 mile long, 69 KV lines have reached the end of their useful life. Seeking a modern solution to this immediate problem, AEP has worked with B-PLC inventor Amperion to prove and refine its application to LCDP and other related functions.

I. BACKGROUND

Amperion is a private communications company located in Lawrence MA and is the inventor of Broadband -Power Line Carrier (B-PLC) technology. AEP is the 4th largest investor owned utility, with 5.1M customers in 11 states. AEP owns the nation's largest transmission system - a 39,000 mile network that includes more 765kV EHV lines than all other US transmission systems combined. Renz Consulting, LLC is a private consulting company that specializes in advanced power systems technology applications and has been a consultant to both AEP and Amperion since 2001.

AEP has employed pilot wire protection on short 69 KV lines for decades, with about 300 installations less than 10 miles long in service today. Pilot wire is a fairly simple to install and accurate scheme but it is now reaching the end of its useful life. Copper-based wire is aging and deteriorating and phone companies are phasing out the service.

Fiber is a very costly replacement alternative. Conventional PLC is another alternative, but it can't support LCDP, is expensive and is not well suited to short lines. Hence B-PLC was of great interest as a cost effective pilot wire replacement, with the added benefit of large potential for future new applications.

Figure 1 shows a conventional PLC system, while Figure 2 shows a broadband PLC system.

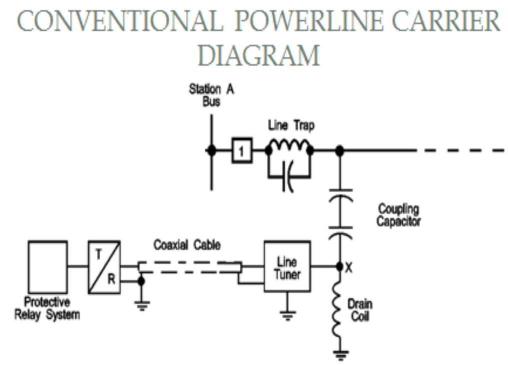

Figure 1

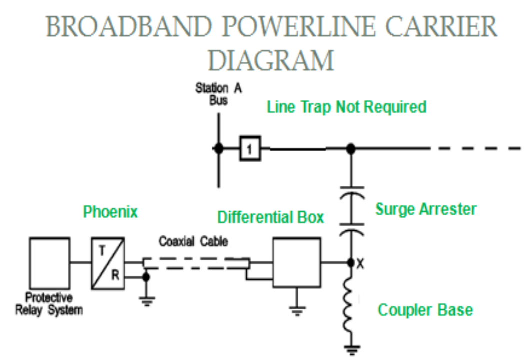

Figure 2

Note the similarities and the differences. Both employ a capacitive unit to couple the signal to the HV line, but the capacitor in Figure 2 is actually a standard lightning arrester (see Figure 3 for more detail), which has been selected to pass frequencies from 1 to 40 megahertz. In this design, the arrester not only couples the B-PLC signal, it also provides added lightning protection for the HV line.

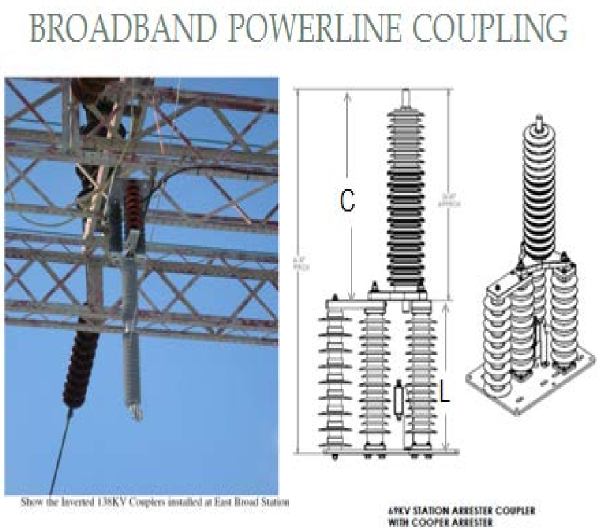

Figure 3

A second major difference of Figure 2 is the absence of line traps. And while the conventional PLC system typically operates at about 200 KHz and is a slow analog technology, the B-PLC system operates from 2 to 35 MHz and is a digital technology that can support megabit per second data rates with millisecond latency.

Figures 1 and 2 are one-line diagrams that do not indicate how many phases are employed. Conventional PLC will typically use just one phase, although multiple phase operation is available. B-PLC typically employs multiple phases. A properly designed single phase B-PLC system is expected to communicate during a fault on that phase since the fault path does not drain the entire signal and the fault- induced noise is usually short lived. None the less, the redundancy provided by using more than one phase provides additional confidence in communications during such faults. Also, by using a differential (multi-phase) signaling method, any common mode noise on the two communicating phases is cancelled and emissions from B-PLC signals are reduced. Future versions are under development that will employ all three phases and multiple frequency bands for even greater reliability.

II. B-PLC DEVELOPMENT TIMELINE

The first attempts to communicate at high speeds over a high voltage transmission line took place in 2006 on a half mile AEP 46 KV line in Charleston WV. This proof-of- concept testing attempted to demonstrate permissive overreach transfer trip (POTT) protection, combined with SCADA. While not 100% successful, it worked six of seven times and provided the basis for further exploration, as well as DOE funding. The following year, a 5.1mile three station 69 KV circuit in Ohio was equipped with B-PLC, as shown in Figure 4. The longest section of this circuit employed a repeater stage (pole 41), such that the longest B-PLC segment was about 2.5 miles long. A year later, this repeater stage was eliminated, thereby extending the longest unrepeated segment to more than 4 miles. In addition, a 138 KV B-PLC system was installed in Columbus OH that year.

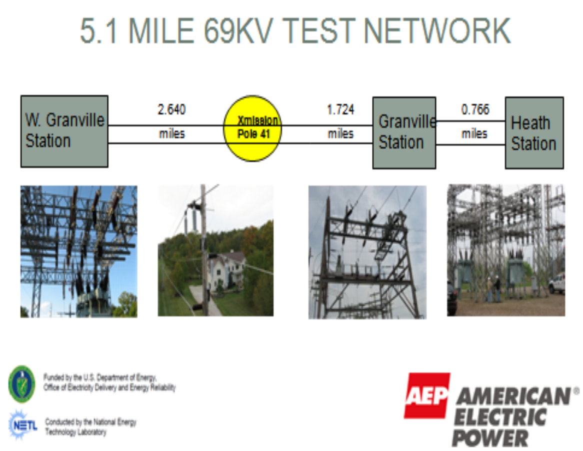

Figure 4

B-PLC uses different frequency bands in each repeated segment to prevent adjacent segment interference. Figure 5 shows the B-PLC signals measured using spectrum analyzers at the channel end points

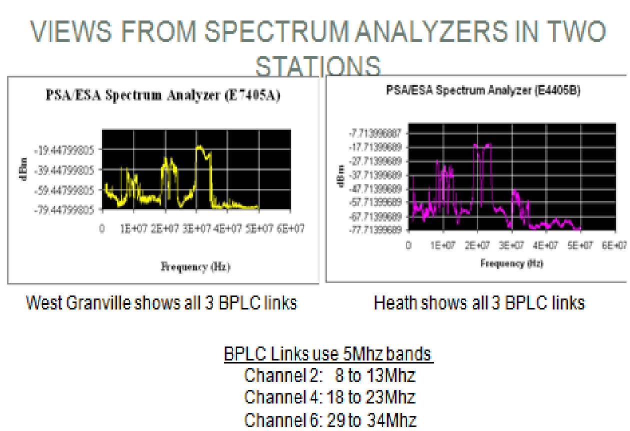

Figure 5

B-PLC operates in the frequency range from 1 to 35 MHz Since a power line also acts as an antenna, the B-PLC signal radiates and can be a source of interference to other users in this band. This was particularly a concern of amateur radio operators who feared B-PLC might impact their ability to communicate. This issue has been resolved by notching out those B-PLC frequencies used by “HAM “radio enthusiasts. This notching (highlighted in yellow) is clearly illustrated in Figure 6.

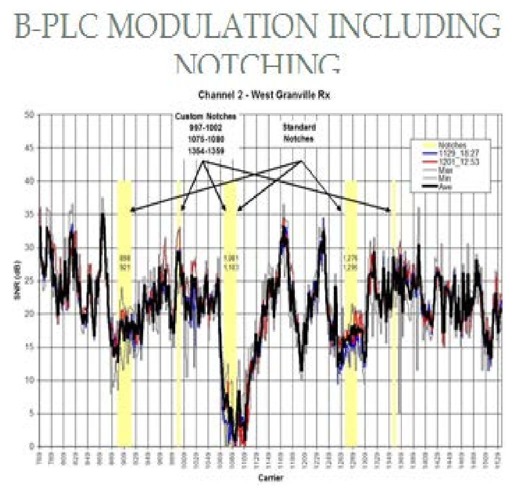

Figure 6

In 2010, line current differential relaying was successfully demonstrated over the three station path shown in Figure 4.

Based on these results, commercial deployment of LCDP over B-PLC began at AEP, as a replacement for aging pilot wire protection schemes.

III. B-PLC FOR LINE CURRENT DIFFERENTIAL PROTECTION

The addition of optical communications (fiber) on modern electric transmission lines has enabled high speed communications between connecting stations. One particularly attractive application for this communications link is LCDP. Important new transmission lines are often equipped with optical ground wires (OPGW) that support this relaying application. But older existing lines do not have such communications channels and adding them is expensive and time consuming. Yet their existing pilot wire protection may be wearing out. These factors led AEP to partner with Amperion in developing LCDP over B-PLC. AEP knew that successful development would lead to superior protection of existing lines, while avoiding the costs of fiber communications channels.

LCDP is a specialized application with some demanding requirements that B-PLC had to meet. In particular, maximum allowable loop latency of 66 milliseconds and link asymmetry of less than1.5 milliseconds represented a challenge. Add to this, tight limits on jitter and it became clear that a specially designed B-PLC package was required. Figure 7 shows the configuration that was implemented to meet these requirements. Using GE L 90 LCDP relays and specially designed TDM converters having jitter buffering, the B-PLC system shown was tested in the AEP lab, with results shown in Figure 8, which also shows related tests using SEL 421 POTT relays.

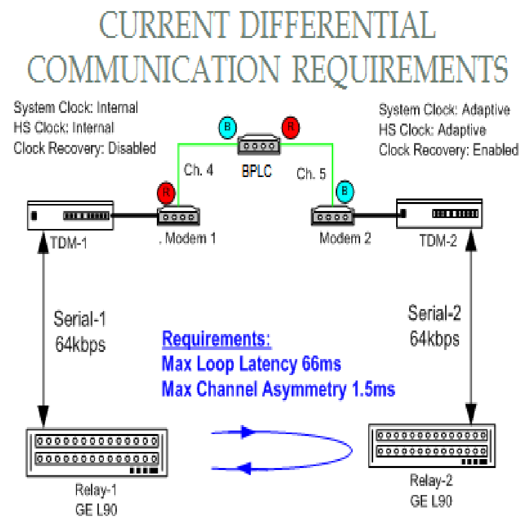

Figure 7

AEP LAB TEST RESULTS

L-90 to L-90	L90 + TDM Converter	Over BPLC One hop min	Over BPLC One hop max	Over BPLC Two hops min	Over BPLC Two hops max
20.68	24.91	31.25	38.39	40.08	46.19
421 to 421	**421 + MB Converter**	**Over BPLC One hop min**	**Over BPLC One hop max**	**Over BPLC Two hops min**	**Over BPLC Two hops max**
27.98	32.79	40.80	44.88	48.06	53.28

- All results are fault trip times in milliseconds
- GE L90 using 64Kbps Current Differential scheme
- SEL421 using Mirrored Bits protocol and POTT scheme

- **Test results provided basis to proceed with field testing**

Figure 8

Maximum trip times for any LCDP configuration were less than three cycles. POTT protection was slightly slower.

These results served as justification to take the application to the field for further evaluation. Figure 9 shows the trial installation and Figure 10 shows a typical result of testing; using GPS synchronized relay test sets at each end of the line. In Figure 10, the trip command is issued less than 2.5 cycles from when the fault occurs.

Multiple tests were done for faults both within the zone of protection and outside of it. All tests were successful.

Figures 11 and 12 show commercial applications AEP will be deploying in 2012.

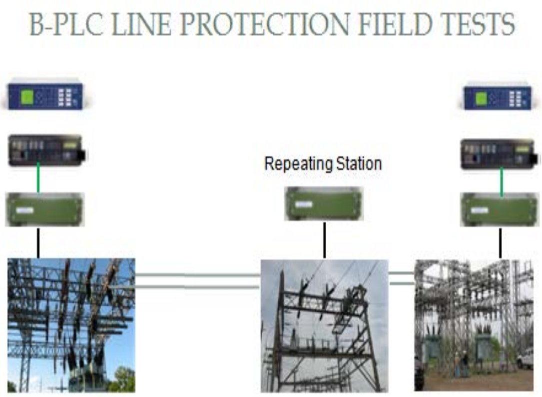

Figure 9

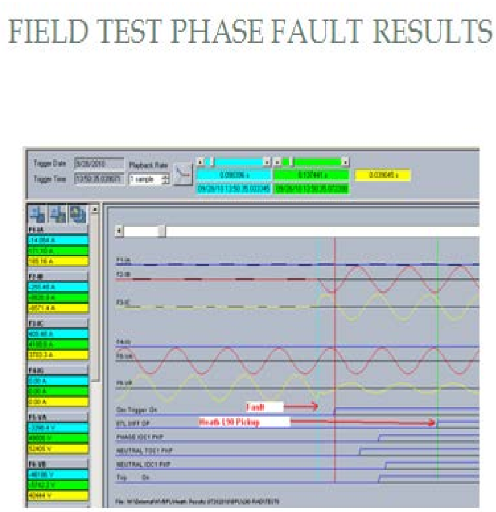

Figure 10

Figure 11

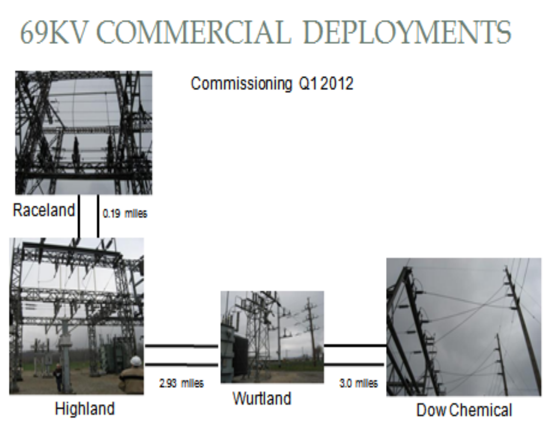

Figure 12

IV. CONCLUSIONS

- B-PLC is a disruptive new technology that takes advantage of the latest communications techniques to provide a range of electric power system benefits:B-PLC can be used to connect substations over transmission, sub-transmission and distribution lines

- B-PLC supports POTT, DCB and current differential protection - the most accurate and reliable protection scheme.

- Fiber is often too costly for lower voltage substations and not always available. B-PLC provides a ready-to-deploy, cost effective digital alternative. A typical B-PLC station installation takes only one day, including a short line outage.

- Broadband connectivity between stations supports multiple future smart grid applications, in addition to protective relaying and SCADA. Highly secure IP communications will be a key enabler of the smart grid.

- B-PLC may have value in distribution applications as well. At the Distribution level, protection and control coordination will be much more difficult with more distributed generation and multiple terminal points.

In summary, B-PLC is a new tool for the 21st century power system; a tool that can make that system more reliable and smarter at a fraction of the cost of available alternatives.

V.REFERENCES

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