NEW RESULTS FOR POWER LINE CARRIER-BASED ISLANDING DETECTION AND AN UPDATED STRENGTHS AND WEAKNESSES DISCUSSION

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ABSTRACT

As PV deployment levels increase, loss of mains detection, or islanding detection, has again arisen as a primary concern among the utility community. This is true especially in multi-inverter cases, cases with a mix of distributed resources, and on difficult feeders on which false tripping may be a disproportionately significant problem. Power line carrier communications can be effective in solving this problem for all types of distributed generation. This paper provides an update on laboratory and field testing of this technique; discusses some of its unique but lesser-known advantages; and examines some of its weaknesses.

INTRODUCTION

Distributed resources (DRs) in general, and photovoltaics (PV) in particular, are being increasingly widely deployed. Most DRs are being connected to the lower voltage portions of the electric power system (EPS), which historically were designed assuming unidirectional power flow. Now that this assumption is becoming less valid, changes are required in distribution feeder voltage regulation and protection schemes. In addition, DRs must participate in one key aspect of protection: avoidance of the formation of an unintentional island. In addition, it is becoming increasingly common to see a mixture of DRs involving inverters and rotating machines on the same feeder.

DRs actually can make a significant positive contribution to voltage regulation, and applicable standards that previously prohibited this are now being reconsidered to allow it. DRs can also provide transmission support—for example, by providing VArs to the local EPS to mitigate a fault-induced delayed voltage recovery or riding through momentary frequency sags caused by events on the area EPS. However, a fundamental conflict exists in the sense that today's anti-islanding techniques either monitor or cause abnormal voltages and frequencies, and there is overlap between abnormal conditions indicating an island, and abnormal conditions indicating a need for grid support. Using only local measurements, it is simply not possible to discern in all cases whether a particular abnormal condition requires a trip or a ride-through, for all possible combinations of DR and load.

To overcome this conflict in very high penetration scenarios and with mixtures of DRs, some form of situational awareness via communications with the utility will be required to enable the detection of an unintentional island. Several communications-based anti-islanding concepts have been proposed, including some using synchrophasors [1,2], and the use of power line carrier communications (PLCC) [3-11]. PLCC is a form of direct transfer trip (DTT) in which the power line itself is used as the communications medium. Recently, PLCC-based islanding detection has received greatly increased interest, as it has some obvious advantages in this application and is a mature technology.

This paper presents an updated discussion on PLCC as an islanding detection method. It will first review previous results, and then will discuss the unique strengths and challenges of the method, using new simulation results to underscore certain points. The focus will be on strengths and weaknesses that may not be intuitively obvious or that have not heretofore been a prominent part of the PLCC anti-islanding discussion.

PREVIOUS RESULTS

The use of PLCC for islanding prevention in distribution-connected PV is not a new one; references date back to the late 1990s [3], and the idea was discussed as early as the late 1980s. The reason is because of its obvious and intuitive advantages, which are discussed in the next section.

A number of investigators have reported on PLCC investigations. Two papers [5,6] reported on field and laboratory tests of low frequency PLCC systems. One [6] included field tests of a TWACS-type system and a purpose-designed analog receiver using a high-order active low pass filter to isolate the subharmonic signal. That study found that if an island were simulated by deactivation of the PLCC transmitter, the loss of carrier was always quickly detected by the receiver. However, the field data set was small, so no conclusions could be drawn regarding false tripping. The other study [5] was a follow-on to [6] and included actual island tests conducted in the Distributed Energy Technologies Laboratory (DETL) at Sandia National Labs. The signal used in this test was in the low-frequency band (not a subharmonic, but less than 1 kHz) and was designed to mimic one used by a commercially-available two-way automatic meter reading (AMR) system. This study had two primary noteworthy

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conclusions. First, it verified that the island was always reliably detected using PLCC, and no false trips were noted. Second, it showed that the cost of even fairly high-performance receivers for this purpose could be quite low. This study included the design of a digital receiver using a Texas Instruments DSP continuously running an FFT to pick out the low-frequency PLCC signal. This receiver cost less than $30 in single-unit quantities, with the primary cost being in the power supplies for the electronics (noting, of course, that the receiver had not been "productized"). Detection speed was limited primarily by an intentional delay that was inserted to help avoid false trips.

A more recent study has detailed field tests of a low-frequency TWACS-based PLC scheme [10,11], with additional results from this same study appearing in [4]. In this work, a subharmonic PLC signal was used, generated by a custom-designed thyristor-based transmitter similar in concept to those used in other implementations of this type of signaling scheme. The field tests were run for several months, resulting in an extensive data set, and mostly examined whether a loss of carrier (simulating an island event—no actual DG was present on the feeder) was always properly detected, and that no nuisance trips resulted from momentary lapses of signal reception. The anti-islanding result was as expected; whenever the signal generator was deactivated, the receiver correctly detected the loss of carrier and indicated an island event. The authors did note some issues with false tripping, which seemed to result from two sources: the particular signal detection scheme used, which the authors believed was correctable, although they state that further work in this area is needed; and interference between the PLC permissive signal and an existing TWACS AMR system already installed on that feeder. The study delved further into the issue of interference with the existing AMR system, and concluded that further work was needed in this area.

UNIQUE STRENGTHS OF THE METHOD

The above-described previous work on PLCC-based islanding detection demonstrates that the method has a number of advantages, most of which are now widely accepted. These include that it should have no nondetection zone (NDZ), meaning that it should work equally well for all loads; it should work for any combination of distributed generators; it automatically includes all circuit interrupters on the feeder, whereas DTT requires separate instrumentation of each series device; and it automatically reaches all DR on the feeder (within propagation constraints [12]) without requiring a separate communications channel to each DR, which is particularly advantageous since rarely are all DRs on a feeder installed at the same time.

However, if properly implemented, PLCC could have certain additional unique strengths that are less well-known but that are becoming increasingly important. These include:

1. Ability to detect single-phase events. PLCC systems using different signals on each phase [9] may be uniquely well-positioned to detect single-phase opens upstream from the DG, and also to allow single-phase DR to identify the phase to which it is connected, provided that issues with cross-coupling can be avoided. The ability to identify which phase is which would have significant additional value beyond DG applications.
2. Ability to protect against temporary overvoltage (TOV) in the case of heavy PV switched into a light load—in particular, during breaker misoperation. If a breaker opens at a time in which a feeder has large DR inputs but very light loads, there can be a very large transient overvoltage. The case of breaker misoperation is particularly problematic, because of the very short time in which the PV system must cease to energize the line. A PLCC-based scheme of the type studied in [6] could provide very fast notification of the opening of the breaker, shortening the time to trip the DR and limiting the level of TOV. This is a particularly important advantage because few other anti-islanding methods are in a position to offer much benefit in this case.

WEAKNESSES OF THE METHOD

No anti-islanding method is perfect, and of course PLCC has drawbacks. Key challenges to the widespread use of PLCC anti-islanding include the following.

1. Cost. The key problem always mentioned with PLCC is cost, in particular in a case of a feeder that can be energized from multiple substations (which is the norm). Receiver costs can be very low, as noted earlier, but transmitter costs can be high, particularly for low-frequency transmitters whose power requirements can be very large because of the very low access impedance of distribution systems at low frequency [12]. Transmitter costs might prompt one to consider a high-frequency PLCC alternative.
2. Propagation. Propagation is a common concern with PLCC systems. Higher-frequency, higher-bandwidth systems have more propagation issues than lower-frequency systems. The most well-known and easily understood issue is the series inductances and shunt capacitances inherent in power systems, both of which lead to significant attenuation of PLCC signals, with the attenuation problem generally worsening as frequency increases [12]. Higher-frequency systems may also experience standing-wave or reflection-related problems, because the channel impedance is not well-controlled and contains many discontinuities [12]. System resonances must also be avoided. Propagation considerations would cause one to tend toward choosing a low-frequency PLCC system.
3. The fact that PLCC cannot protect against islands formed at the transmission level, unless multiple PLCCs and additional signaling to the DRs are

employed. This is not an immediate-term concern, but as DR deployment levels increase, it may become possible to island not only a distribution feeder, but perhaps an entire distribution substation, section of subtransmission, or some other higher-level section of the area EPS. PLCC may be able to address this issue, if:

a. The PLCC transmitter can be located on some far upstream portion of the area EPS; and
b. The PLCC signal reliably propagates from this upstream point to all endpoints on the system.

Criterion 3b can be realized using a subharmonic-based PLCC system, but this coupled with criterion 3a will significantly drive costs up.

SIMULATION RESULTS

To investigate the propagation of PLCC signals and the possibility of phase differentiation using different frequencies, electromagnetic transient simulation of the IEEE 34 and 37-bus radial distribution feeders [12] was conducted using the EMTP-RV software and frequency-dependent line modeling. Simulations were run for different distribution transformer and capacitor configurations. The frequency response of the IEEE 34-bus feeder (overhead, very long, lightly loaded) as seen from the substation, with no capacitors and all loads connected using delta-Y transformers, is shown in Figure 1. The top two plots in the blue box are the magnitude (left) and phase (right) responses for Phase A; the Phase B plots are in the green box, and Phase C plots in the red box. The well-known difficulty of the power line as a communications channel [12] is evident in the plots.

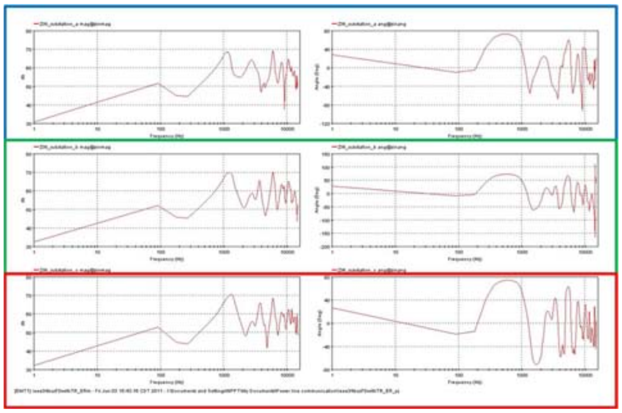

Figure 1. Frequency response of the IEEE 34-bus radial distribution feeder as seen from the substation.

Simulations were run with three different PLCC signal sets: 100, 200 and 300 Hz; 6, 6.1 and 6.2 kHz; and 10, 10.1 and 10.2 kHz. A representative FFT, from the 34-bus feeder with all delta-Y distribution transformers and no capacitors, is shown in Figures 2, 3 and 4. In these figures, the colored boxes separate plots from different locations on the feeder (the blue box is from 2850 feet from the substation; green is 36810 ft; red is 104350 ft; and purple is 135840 ft). Within each colored box are three FFT magnitude plots, for phases A (top), B (middle) and C (bottom).

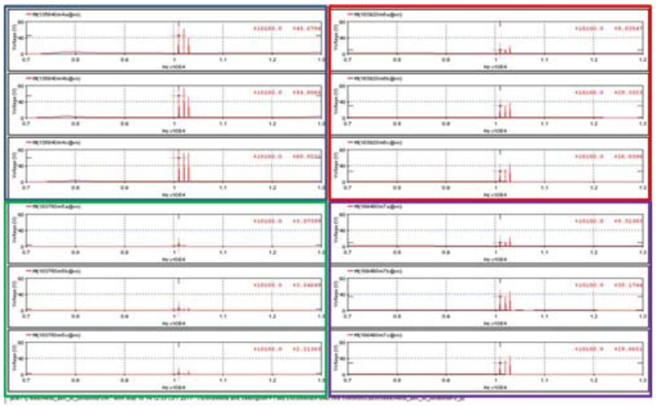

Figure 2. Magnitude FFT at four locations along the IEEE 34-bus feeder, with 10 kHz PLCC signals.

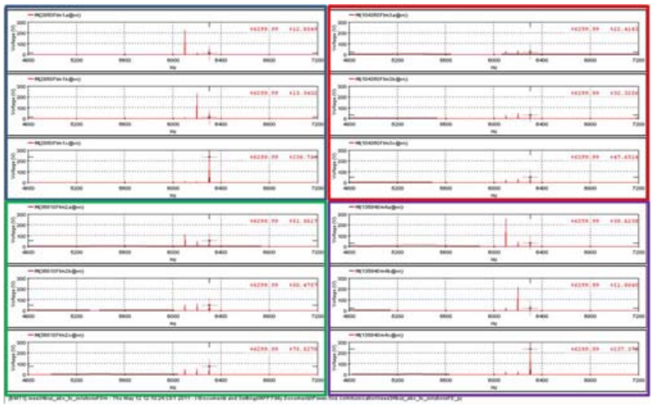

Figure 3. Magnitude FFT at four locations along the IEEE 34-bus feeder, with 6 kHz PLCC signals.

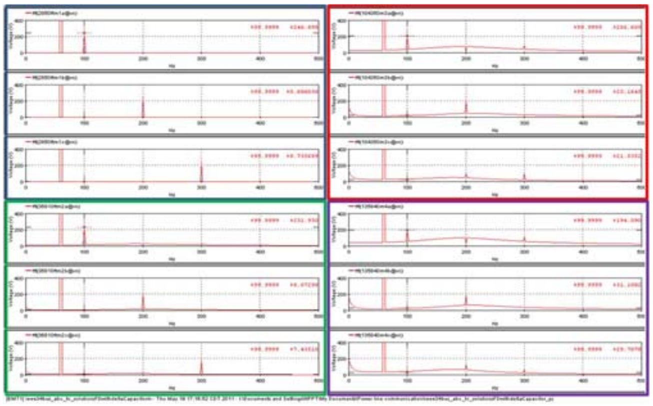

Figure 4. Magnitude FFT at four locations along the IEEE 34-bus feeder, with 100 Hz PLCC signals.

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From these FFT plots, one may deduce the following. First, all three signals are detectable all the way to the distal end of the feeder, although they become strongly attenuated—even the 100 Hz signal set is greatly reduced in amplitude by the time it reaches the end of this very long feeder. This validates the somewhat intuitive view that a lower-frequency signal would be better for this application, although none of the signals simulated here is likely to be effective in protecting higher levels of the system (i.e. weakness #3). Second, cross coupling for the 10 kHz signal set is such that even at the first location from the substation, the FFT of each phase is essentially the same. The 6 kHz signal does not cross-couple nearly as strongly, although there are still localized problems; at 104350 ft (red box), the three phase signals are nearly indistinguishable. The 100, 200 and 300 Hz signals remain distinguishable all the way to the end of the feeder. They leave very little margin of error at the distal end, but part of this is believed to be an FFT resolution issue in this specific simulation. There was some speculation that perhaps delta-connected distribution transformer windings might cause cross-coupling of the low frequency signal, but this does not appear to have happened. These results support that a lower-frequency signal is preferable and can result in phase differentiation.

CONCLUSIONS

Power line carrier communications-based islanding prevention has great promise. It can reliably detect islanding without false trips, and can do so quickly in the presence of any combination of distributed generators and loads. PLCC also has two additional and unique advantages: it should not lose effectiveness if rotating DG are present, and it should provide at least some mitigation of the temporary overvoltage situation that could result if a breaker were manually switched or were to misoperate at a time of high reverse power flow. Simulations suggest that low-frequency PLCC signals are most preferable; they propagate best, and cross-couple least, so that phase differentiation remains possible.

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