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**PROJECT TITLE: ASSESSMENT OF THE UNIVERSAL FEASIBILITY OF USING POWER SYSTEM HARMONICS AS LOSS OF MAINS DETECTION FOR DISTRIBUTED ENERGY RESOURCES**

**CONTRACT NUMBER: RD3-21** **MILESTONE NUMBER: 7** **REPORT DATE: SEPTEMBER 21, 2010**

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# MILESTONE REPORT


**EXECUTIVE SUMMARY**

The purpose of this project is to assess the universal applicability of harmonic signatures and/or synchrophasors as a means for detecting unintentional islanding of distributed generation equipment such as photovoltaics. This report covers the time period August 27, 2010 to September 21, 2010, and describes our progress on Milestone 7. Milestone 7 has been substantially completed. Accomplishments in this reporting period include:

- Began testing of synchrophasor models. Significant results obtained.
- Initiating work on harmonics-based methods.

This version of Milestone Report 7 is for public dissemination.


Project funding is provided by customers of Xcel Energy through a grant from the Renewable Development Fund.

**TECHNICAL PROGRESS**

Milestone #7 consisted of: initiation of modeling of the synchrophasor- and harmonics-based anti-islanding methods. Descriptions of the methods and results are given below.

*Description of the synchrophasor-based methods*

For our work, a "synchrophasor" is merely a time-synchronized phasor voltage measurement [1]. The difference between a synchrophasor and the phasor measurements available from today's SCADA systems is the time synchronization. SCADA systems poll a wide network of sensors, reading data from each and aggregating those data. Polling time, communications delays, and other factors lead to differences in the time stamps on the various sensors' data, which means that the snapshot of the system provided by the SCADA contains data points measured at slightly different times (typically spread over 5 sec or so [2]). Thus, this snapshot is "blurry" in the time sense. By contrast, synchrophasors use GPS timing signals to time-synchronize the measurements to microsecond-level resolution. In this way, synchrophasors can give a sharply focused, and thus much more accurate, snapshot of the system state.

Synchrophasors can be used to detect islanding if two synchrophasor measurements are available, one local to the distributed energy resource (DER) and one from upstream in the system and acting as a reference. These synchrophasor measurements can provide the DER with information about how its local state is related to the higher-level system state, enabling the DER to detect differences that can indicate the formation of an island. In this work, two synchrophasor-based islanding detection methods have been studied: the Wide Area Network (WAN) method, developed by Schweitzer Engineering Laboratories (SEL) [3]; and the Correlation Coefficient Based (CCB) method, developed by Northern Plains Power Technologies as part of this project, building on the work described in [4,5].

The WAN method detects islanding by monitoring the local and reference synchrophasors and continuously calculating the slip and the acceleration of the phase angle difference between them. When the values of these parameters fall outside certain thresholds, islanding is indicated and the system shuts down. SEL has successfully deployed the WAN method to prevent islanding of wind farms connected at the transmission level, but prior to this project it had not been investigated in distribution, where conditions are significantly different. In contrast, the CCB method detects islanding by monitoring the statistical correlation between the frequencies of the local and reference synchrophasors. When specific patterns are observed in the correlation, islanding is detected.

*Procedure*

The purpose of this project is to show that the anti-islanding methods under investigation work "everywhere, all the time"—that is, that they work at all points in the system and for all variants in system configuration and loading. To do this, the following test procedure has been adopted.

1. Both WAN and CCB methods have been tested first on one of the IEEE standard distribution feeders. The 34-bus feeder was used here; it is described more fully in Milestone Report #5.
2. Both methods are being tested on three different real-world Xcel feeders. This part of the procedure has been described in several previous Milestone Reports (particularly #5) and deals with testing the methods on "strong", "weak", and "average" feeders. Development and validation of the feeder models themselves was described in Milestone Report #6.
3. On all the feeders, both methods have been tested using four test cases: a) a multi-inverter case; b) a multi-inverter case with rotating machines; c) a system-level frequency event; and d) a local load switching event. The first two situations are ones in which islanding detection is difficult; the second two are cases in which ride-through is desired, but transients may exist that "fool" an island detection scheme into falsely tripping.
    a. Multi-inverter case. In this case, a large number of inverters is connected to the feeder at multiple points, so that there is interconnecting impedance between them. The number of three-phase inverters on each feeder is typically around 18. In cases in which there is significant load imbalance, single-phase inverters are added to the more heavily loaded feeders, partly to investigate their behavior and partly to assist in obtaining a generation-load balance when the island is formed.
    b. Multi-inverter + rotating machine case. This case is similar to case a except that an engine-driven synchronous generator is added to the island. This case is very difficult for islanding detection because the synchronous generator looks like the grid from the perspective of the other DERs.
    c. System-level frequency event. This case simulates what the DERs might see if there were a major loss of generation elsewhere on the network. In that case, the frequency will begin to decline, but it is highly desirable that the DERs stay on-line to support the system. The frequency profile used in this case drops below the IEEE 1547 low-frequency trip threshold.
    d. Local load switching event. When large loads local to the DER are switched, transients may result that could cause anti-islanding schemes to falsely trip the DER. For this work, the switched load was a large three-phase induction motor started across the line.

*Results to date*

Initial results for both the WAN and CCB methods are summarized in Tables 1 and 2 below. As can be seen, these initial results are extremely promising; both methods appear to work well. The primary challenge for the WAN method is that it is difficult to select slip and acceleration thresholds such that the method always detects the engine-genset case but does not falsely trip in the local load switching case. The primary challenge for the CCB method appears to be speed of detection; it always arrived at the correct result, but in some cases it took longer than the IEEE 1547 limit of 2 sec to do so. Solutions to both of these problems have been identified and are under investigation.

**Table 1. Initial results for the WAN method. Results shown in green indicate success; results shown in red indicate that an undesirable result was obtained.**

| Feeder→ Test case ↓ | IEEE 34-bus standard feeder | Xcel "weak" feeder | Xcel "average" feeder | Xcel "strong" feeder |
|---|---|---|---|---|
| a | Detect | Detect | Not yet tested | Detect |
| b | No detection | Detect | Not yet tested | Detect |
| c | Ride-through | Ride through | Not yet tested | Ride through |
| d | Ride-through | Ride through | Not yet tested | Ride through |

**Table 2. Initial results for the CCB method. Results shown in green indicate success; results shown in red indicate that an undesirable result was obtained.**

| Feeder→ Test case ↓ | IEEE 34-bus standard feeder | Xcel "weak" feeder | Xcel "average" feeder | Xcel "strong" feeder |
|---|---|---|---|---|
| a | Detect | Not yet tested | Not yet tested | Detect |
| b | Detect | Not yet tested | Not yet tested | Detect |
| c | Ride-through | Not yet tested | Not yet tested | Ride through |
| d | Ride-through | Not yet tested | Not yet tested | Ride through |

*Description of harmonics-based methods*

The basic concept behind harmonics-based islanding detection is that when the grid is lost, the harmonic impedance of the system changes dramatically, and the grid is lost as a source of harmonic currents. Inverter-based DERs produce or draw low levels of harmonic currents; nonlinear loads will draw some level of harmonic currents; and any transformer left in the island with its primary side open-circuited will draw a significantly distorted magnetizing current. Thus, the loss of mains should theoretically lead to a detectable change in the voltage harmonic signature seen in the island. The primary difficulty in this passive method is in setting appropriate thresholds. There are many conditions under which the voltage waveform may be significantly distorted, at least temporarily, while the PV is grid tied; and there are also practical cases in which the distortion level within an island could be very low, if the inverter produces a very "clean" output waveform and there is only a limited amount of nonlinear load. This means that the "trip" and "no trip" parameter value spaces overlap, making it quite difficult to select conditions that reliably detect islanding without causing unallowable levels of nuisance trips.

The idea of islanding detection based on harmonics is not a new one. As early as the late 1980s, investigators were experimenting with the inclusion of deliberately-injected current harmonics for islanding detection [6], but utility objections coupled with reliability problems brought on by the site specificity of harmonic impedances prevented the widespread adoption of this method. In the early 1990s, Japanese researchers reported the use of total harmonic distortion thresholds for islanding detection, with some success [7]. However, widespread adoption of the method did not occur for the reason noted above, namely the difficulty in threshold selection. More recent work (some reported since the proposal for this project was written) has focused on harmonic signatures extracted using novel transforms or manipulations [8-10], or on combining total harmonic distortion with other metrics [11]. The authors often report that they have solved the problem of overlap between the harmonic content of grid-tied and islanded waveforms to enable reliable islanding detection without false trips. However, to use the wording of our original proposal, it has not yet been conclusively shown that this method is capable of working everywhere, all the time. The purpose of this portion of our work is to make a determination of whether harmonic-based anti-islanding, using any combination of frequency bands, is capable of meeting this need.

*Procedure*

For this work, an approach similar to that used in [11] is being followed; that is, the team is seeking combinations of parameters that, taken together, yield a passive anti-islanding system with a negligibly small NDZ and that can pass the

IEEE 1547 high-Q load test. The methods proposed in [6,8-10], although interesting, are not considered further because they all still rely on the inclusion of a deliberately-injected perturbation, which this work is specifically trying to eliminate in order to enable advanced utility support features.

*Results to date*

The team has selected a set of three parameters that will be used as our starting point in this investigation. The basis for the parameter selection is this: based on the investigators' past experience combined with work on this project, each of the three parameters taken alone results in an NDZ, but the NDZs are largely nonoverlapping [12,13]. We believe that via tuning using DERs in the feeder models reported in Report #6, it may be possible to use these three parameters in combination to create a method that meets the need. More details on the selected parameters, their NDZs, and results of the tests will be presented in a future Milestone Report.

## Project status

As we have been forecasting for quite some time, because we have been able to work ahead on future Milestones, we are finally making progress in bringing the project back onto schedule. This report is approximately three weeks late (note that our previous report was almost three months late), and we anticipate submitting milestone report #8 on time.

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