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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: 1** **REPORT DATE: AUGUST 14, 2009**

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MILESTONE REPORT

EXECUTIVE SUMMARY

The purpose of this project is to assess the universal applicability of harmonic signatures as a means for detecting unintentional islanding of distributed generation equipment such as photovoltaics. This report covers the time period June 15, 2009 (project start date) to August 10, 2009, and describes our progress on Milestones 1 and 2. Milestone 1 has been completed, and substantial progress has been made on Milestone 2.

TECHNICAL PROGRESS

Four key project action items have been addressed during this period: a) hiring of our student intern; b) development of a strategy for making the determination regarding the universal applicability of harmonics and synchrophasors in islanding detection; c) development of a computer model of a photovoltaic system using the appropriate modeling tools; and d) setting up the first coordination meeting with subcontractor Enernex Corp. of Knoxville, TN.

Hiring of student intern (applies to multiple milestones)

This project's budget included funding for a student intern. That student, Mr. Dij Joshi, has been hired and is working out of NPPT's facilities in Brookings. Mr. Joshi is a candidate for the Masters in EE at South Dakota State University and will use his work on the RDF project to write his thesis.

First coordination meeting with Enernex (Milestone 1)

Our first coordination meeting with Enernex was held on Monday, August 10. The agenda for this meeting focused on four main tasks:

- Making all parties thoroughly familiar with the problem to be solved and proposed solution approach;
- Review and finalize the choice of software to be used for this work;
- An open technical discussion of both of the above; and
- Establishing a milestones and deliverables schedule, as well as a responsibility matrix, for the next six months (until the next coordination meeting).

All of these items were addressed. The technical approach is described more fully below. We have settled on the EMTP-RV software for this work because of its industrial acceptance, and its capability for this work. Our second coordination meeting is tentatively scheduled for February 15, 2010, in Knoxville. (The Enernex people were not too wild about the idea of holding our February meeting in South Dakota.) Enernex has signed off on the project Gantt chart and is internally assigning resources to tasks.

ADDITIONAL MILESTONES

Have all software acquired (Milestone 2)

We now have one copy of EMTP-RV in house, and will acquire another so that the PI and student intern can work independently.

Finalize selection of systems to be modeled (Milestone 2)

This work is ongoing. We have put considerable time and energy into deciding how best to make the determination of whether harmonic signatures and synchrophasors are "universally applicable"; that is, that they work at all times and in all locations on the grid. Of course, we cannot test all times and all places, so the key lies in choosing a subset of times and places (i.e., system configurations) that represents the boundaries of the range in which we expect the islanding detection methods to operate. To do this, one must first choose the smallest possible set of variables that includes all key variables that impact the effectiveness of the method in question, and then setting up a matrix that varies those variables over the range of expected values (this is referred to as "bounding the experiment space"). It is advisable to also choose one or two variable values lying inside the experiment space since the performance of the methods within the space may not vary linearly.

During this reporting period, we have identified for each method two primary variables that drive the determination of effectiveness. In the harmonic signature case, the key time- and space-dependent variables impacting the effectiveness of the method are believed to be system impedance, particularly the system harmonic impedance, and the system "stiffness", which is governed by the system's control dynamics—what might be thought of as system inertia. The system impedance is the impedance seen from the distributed generator looking back into the utility system (effectively, the Thevenin equivalent impedance one would obtain if representing the utility by its Thevenin equivalent). In the harmonic case, this impedance includes that of the local load, and must include frequency-varying components (components that respond to different harmonic components differently) and nonlinear components (those that generate their own harmonics). The system inertia describes how resistant the system is to changes in voltage and frequency under changes in load. The grid contains a large amount of rotating inertia in the main-line generators, and has reasonably fast-acting regulation mechanisms that make it very resistant to such changes—in other words, we say the grid is "stiff". Weaker grids, such as may be found on islands or in subsets of the larger grid, contain less inertia and will experience larger voltage deviations and different dynamics than the main grid.

Thus, to span the solution space, we intend to use the matrix of systems shown in Table 1.

Table 1. Matrix of systems to use in harmonic signature case.

System impedance (Z)→ **System inertia (J)** ↓	**High Z**	**Medium Z**	**Low Z**
High J	HJ, HZ	HJ, MZ	HJ, LZ
Medium J	MJ, HZ	MJ, MZ	MJ, LZ
Low	LJ, HZ	LJ, MZ	LJ, LZ

We will check each case in the matrix, as well as examining the effectiveness of the method during transitions between elements of the matrix, to determine that no false trips occur during either steady-state or dynamic conditions. Then, for each system in the matrix, we will examine the harmonic spectrum as the system transitions from grid-tied to islanded mode and seek signatures that work in all cases, but do not produce false trips.

In the synchrophasor case, we believe there are two primary variables that impact the performance of the method and that represent the variations of time and place: system inertia, and system impedance. System inertia was described above. System impedance is the impedance seen from an endpoint looking back into the system, just as was the case for the harmonic method, although we believe that for synchrophasors the nonlinear portions of the impedance will have less of an effect. Thus, to establish universal feasibility of synchrophasors, we plan to use the matrix of systems shown in Table 2. Notice that Table 2 appears identical to Table 1, except that the elements of the system that are important in system inertia may be different between the two cases, so there is a subtle difference.

Table 2. Matrix of systems to use in synchrophasor case.

System impedance (Z) → **System inertia (J)** ↓	**High Z**	**Medium Z**	**Low Z**
High J	HJ, HZ	HJ, MZ	HJ, LZ
Medium J	MJ, HZ	MJ, MZ	MJ, LZ
Low	LJ, HZ	LJ, MZ	LJ, LZ

As before, we will check both the matrix elements, and the behavior of the system during transitions between matrix elements, to examine both steady-state and dynamic performance. We will then examine the synchrophasor relationships during a transition from grid-tied to islanded mode and develop a relationship that indicates islanding but does not result in false trips.

Development of a computer model of a photovoltaic system (Milestone 3)

During this period, the student intern undertook the process of developing a model of a photovoltaic (PV) system in an EMTP-based modeling tool. This was done partly to meet RDF project needs, and partly as a training tool to help the student begin digging deeply into the problem to be solved so that he can quickly gain a deep fundamental understanding of the problem and become a contributing member of the team. The PV model includes several traditional anti-islanding methods, to serve as baselines and also for inclusion in the study (because the methods being studied here will need to work in the presence of legacy anti-islanding methods as well), a realistic maximum power point tracker, a PV array model, and an averaged model of the power stage. These components have been tested and are working well. At this time, we have both single- and three-phase PV models that include all of the components needed to do the synchrophasor modeling. We will now add the needed components to perform the harmonic modeling.

A screen shot of the three-phase version of the model implemented in EMTP-RV is shown in Figure 1. For clarity, the conventional anti-islanding method blocks have been removed except for one, "SFSGen", which implements the Sandia Frequency Shift method (and also serves as our sine wave reference generator). The maximum power point tracker (MPPT) and PV array model blocks are both visible at the upper left. In the lower left corner are three current sources that model the outputs of the PV inverter to the grid. These connect to a three-phase bus that also includes a local load (shown as a P-Q load near the middle of the three-phase bus). At the lower right is a representation of a utility system using a thirteen-bus model available in EMTP-RV. This representation of the utility will make it possible to model all of the elements in Tables 1 and 2 while simultaneously maintaining a reasonable representation of the system's dynamics.

Figure 2 below shows a startup transient to demonstrate the operation of the maximum power point tracker (MPPT). The PV array starts from its open circuit voltage (zero power). Then, under the control of the perturb-and-observe MPPT, the PV power slowly increases until it reaches the maximum value, which in this case has been set to 10 kW. The MPPT then shows the characteristic small oscillation around the maximum power point. The startup transient in this case is a bit slow, indicating that further tuning of the MPPT parameters is indicated. The model will be used to perform this tuning. (It should be pointed out that because of the inherent nonlinearity of the MPPT, "back of the envelope" calculations to perform the tuning are not particularly effective; the normal process is iterative, using engineering

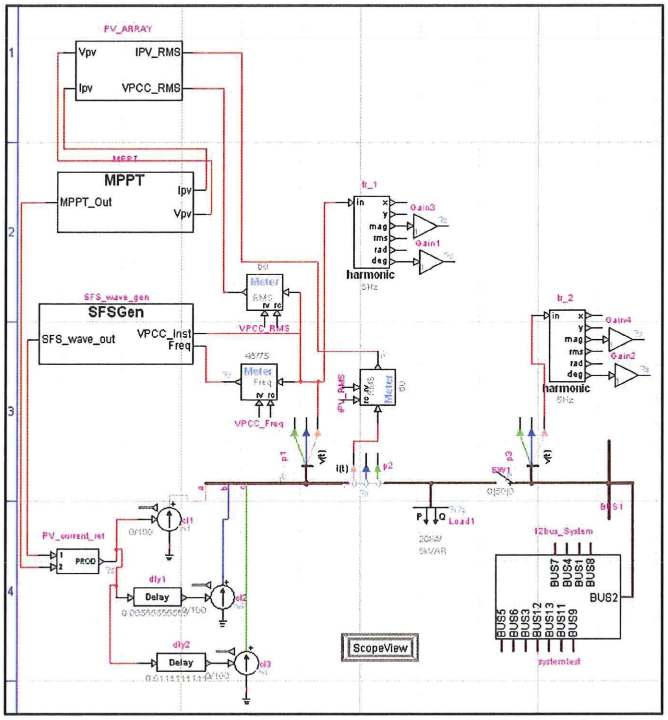

Figure 1. Screen shot of the three-phase PV model.

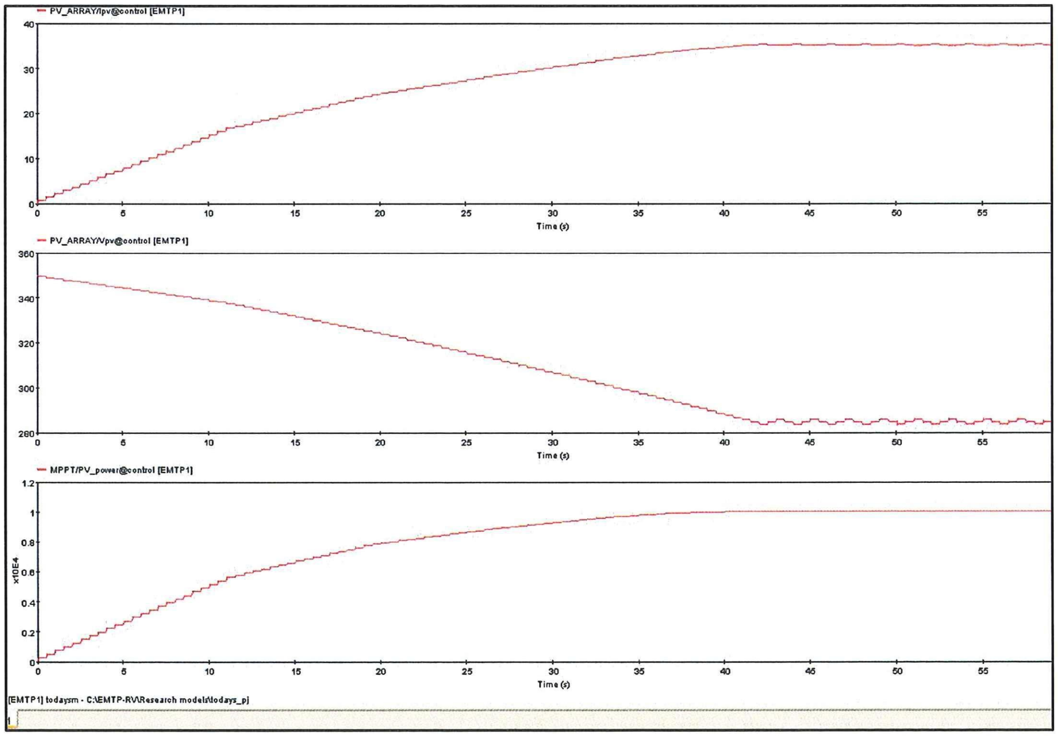

Figure 2. Startup transient showing PV output current (top trace), PV array voltage (middle trace), and PV output power (bottom trace) as functions of time.

intuition to guide a process of trying a value and checking MPPT performance to arrive at a set of parameters that has fast response but is stable.)

Figure 3 shows an example oscilloscope-type output available from EMTP-RV. Again, this is during the PV startup transient, which is clearly visible in the top trace of three-phase PV output current. The middle trace is the voltage at the PV terminals, which changes insignificantly during the startup, indicating that this is a low-impedance grid. The bottom trace is the three-phase utility voltage and serves as a reference point. Of course, as needed, one can zoom in on these graphs to examine details close-up, so these types of plots provide the power engineer with the same insights as a high-quality oscilloscope or power monitor would in a fielded system. EMTP-RV allows the user to examine almost any variable in the system in a similar way.

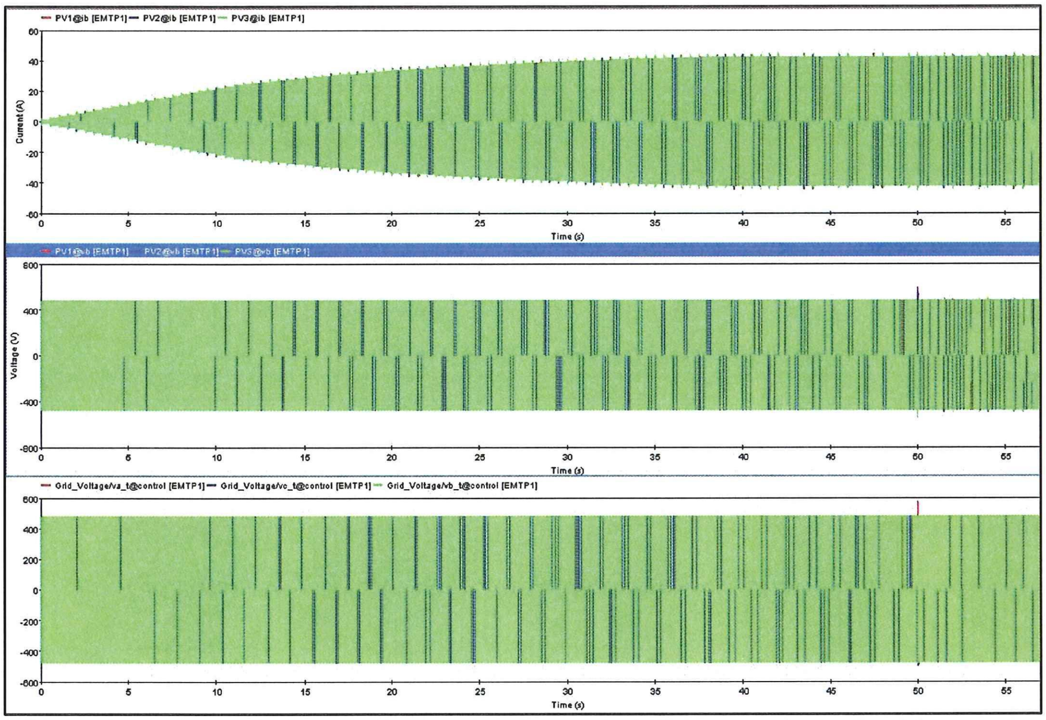

Figure 3. Plot of the three-phase waveforms of PV current (top trace), voltage at the PV (middle trace), and voltage at a point in the utility system (bottom trace).

PROJECT STATUS

We are approximately one month behind schedule on completing Milestone 1 due to the logistical difficulty in bringing the parties together for the first coordination meeting. However, we are far along on completing Milestone 2, so we hope to bring the project back onto schedule by the next report. Monetary spending has so far progressed as planned in the Budget.

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