Photovoltaics as a Distributed Energy Resource

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ABSTRACT

The use of distributed energy resources (DER) is increasingly being pursued as a supplement and an alternative to large conventional central power stations. Distributed energy resources offer a number of advantages including shorter lead times for construction due to smaller project sizes; increased flexibility to respond to changing prices, fuel supplies, and demand growth; improved power quality; reduced transmission losses by locating generation close to the need for power; improved reliability of electricity; and improved power grid security. Photovoltaic technology is fundamentally well suited to meeting needs for distributed energy systems and is significantly more "market ready" than some other evolving distributed energy resources. A variety of activities are ongoing at Sandia with the goal of making PV a preferred electrical energy supply option for distributed energy applications. This report describes those activities that are centered around laboratory testing.

1. Introduction

Barriers to widespread use of PV in DER applications are the same as those to use of PV in general; namely,

1. Specific technical problems related to balance-of-systems components (such as inverters) and systems engineering
2. Lack of standard approaches to interconnection to the grid
3. Lack of awareness and experience with the technology by potential users
4. Historical perceptions of the technology that are both negative and anecdotal
5. Lack of sound data regarding field performance and true life-cycle costs
6. Unmet need for quality assurance in installation and system management
7. Understanding of the motivations to install PV

The approach chosen at Sandia to address these barriers is to partner with industry and users of the technology to ensure customers are ready and able to make use of PV technology whenever the economics or other drivers dictate that they should. Partners may include entities such as the branches of the United States military, tribal authorities, state and federal governments, utilities, and coops. Cost share with the partners as appropriate is sought through CRADAs or Work for Others agreements. Activities include:

1) Characterize the system components and the overall system in the distributed energy technologies testing laboratory, feeding the results back to the equipment manufacturers so they can evolve their products accordingly.
2) Define customer requirements – learn where the users of the technology perceive a need, including working with electric utilities to understand their motivation to be involved with PV.
3) Work with users to develop reasonable system specifications.
4) Quantify system economics, including and emphasizing maintenance costs.
5) Work with users and industry to develop effective installation and procurement methods.

The remainder of this paper focuses on Sandia testing activities that relate directly to the first items in the two lists above.

2. Distributed Energy Technologies Laboratory (DETL)

Prior investment by the DOE PV program is being leveraged to address utility issues with PV in combination with other forms of distributed energy resources (DER). Extensive inverter test capability has been developed at Sandia to test power electronic inverters designed for photovoltaic applications. Because other types of DER (in addition to PV) utilize power electronic inverters, it was straightforward to extend this test capability to include other generation types. This was done using internal Sandia program development funding to create the Distributed Energy Technology Laboratory (DETL). The DETL is presently configured as shown in the one-line diagram (Figure 1). It is a fully instrumented, configurable, controlled, utility-interconnected test bed for study of a variety of issues that may be raised by utilities concerning the interactions of multiple distributed sources of various technologies.

3. Energy Security Focus of DETL Activities

The primary mission of DETL is to use DER to increase the security of electric energy delivery. DETL staff have been engaged in a broad range of related activities including:

- Source characterizations
- DER hands-on training
- DER configuration for Base Energy Security
- Multi-PV unit testing
- Multi-DER testing

- High penetration impacts on grid
- Lab-supported modeling
- Microgrid controls
- Power quality

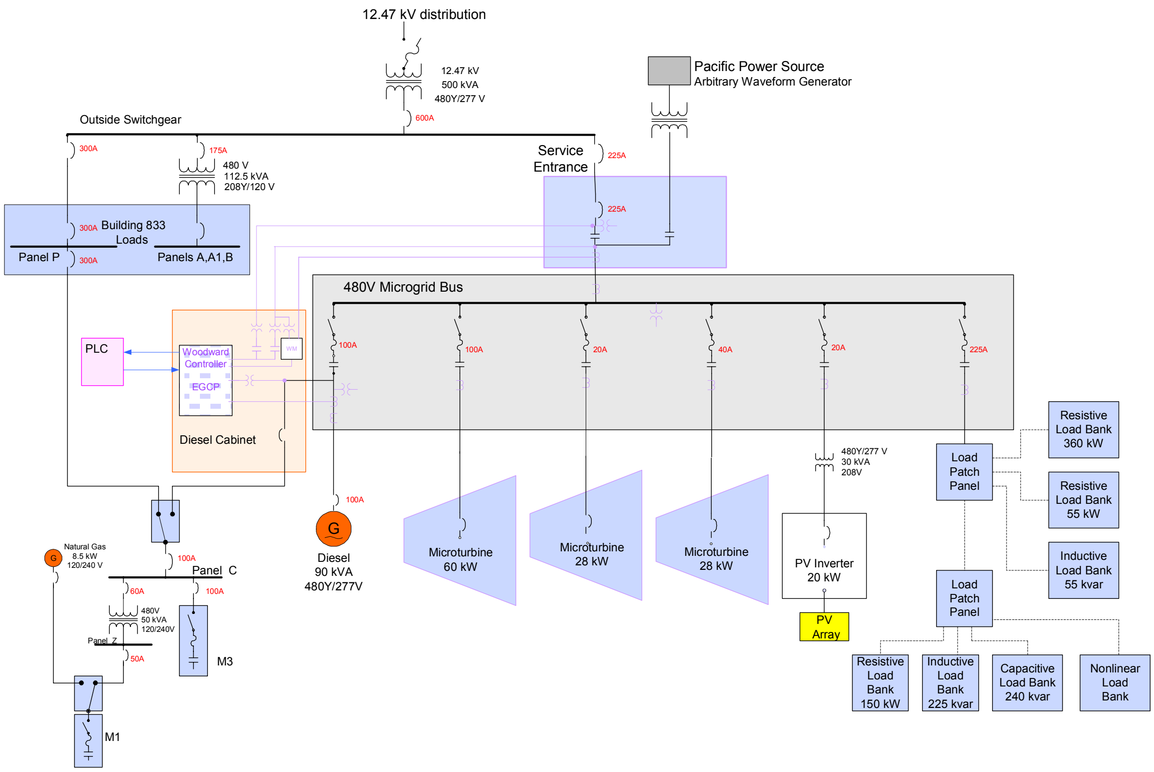

Figure 1. One-line diagram of DETL configuration as of March, 2002

4. Solar Program Leverages Other Funding Sources

DETL has worked with a variety of customers in addition to the DOE Solar Program. The following section lists some of the sources that have provided funding to DETL, along with brief summaries of the respective projects. Photographs of some of the associated hardware are shown in Figure 2.

- DOE Energy Storage Systems Department

Ultracapacitors in series stacks of a few hundred volts are being evaluated in a power quality improvement application. An inverter has been specially designed to use the energy from the ultracapacitors to stabilize the voltage of a microgrid.

A residential fuel cell is being evaluated per a test protocol developed at DETL, subject to the concurrence of the manufacturer. Following its grid-tied and standalone evaluations, it will be added to one phase of the DETL microgrid and operated in parallel with single-phase and three-phase PV inverters.

A patented alternate battery management configuration is being evaluated using an existing 200-kWh bank of valve-regulated lead-acid batteries and an existing 30 kW PV hybrid inverter at DETL.

- Federal Energy Management Program (FEMP)

A 70-kW microturbine leased with FEMP funding is the centerpiece of a series of DER hands-on training sessions for federal energy managers. In addition to classroom discussions, trainees also have the opportunity to operate various DER.

- Sandia Laboratory-Directed R & D (LDRD)

Support has been obtained to assist in the development of circuit and control models of DER inverters. A PV inverter was chosen as the first DER to be modeled. The manufacturer has provided detailed information for use in the model. The model is being validated by comparing simulations with physical measurements of the inverter characteristics at DETL.

- Salt River Project (SRP)

A CRADA was established to investigate the impact of DER on the SRP distribution system. As a first step, a 30-kW grid-tied microturbine was evaluated per a test protocol developed at DETL and mutually agreed upon with SRP. The test report is complete and will be posted on the Sandia DER website. The microturbine has been modified for due-mode operation, i.e., grid-tied and standalone, and will be evaluated further.

- Public Service Company of New Mexico (PNM)

A 60-kW and a 30-kW microturbine were evaluated per a test protocol developed at DETL and mutually agreed upon with PNM. The test reports are complete and will be posted on the Sandia DER website. The two microturbines have been installed at field sites in Santa Fe where their performance will be monitored for two years.

- DOE Distributed Energy Resources Program

Control system interactions of inverter-based DER will be evaluated in a cooperative project with the University of Wisconsin. Results will impact the control scheme for the microgrid concept developed for the California Energy Commission by the Consortium for Electric Reliability of Transmission Systems (CERTS).

- U.S. Army and U.S. Marine Corps

Guidelines will be developed for reconfiguring military base power systems to include DER in such a way as to enhance the energy security of the base and reduce its dependence on the grid for mission readiness. The Marine Corps base at 29 Palms will incorporate a 1 MW PV system into its base energy mix.

- Sandia Advanced Information and Control Systems Department

Selected data and control signals have been provided to the Secure SCADA laboratory. DETL is one node of the secure SCADA network, which is being used as a test bed to evaluate the security of various communication protocols and configurations. This activity will grow significantly this fiscal year when a national secure SCADA effort is initiated.

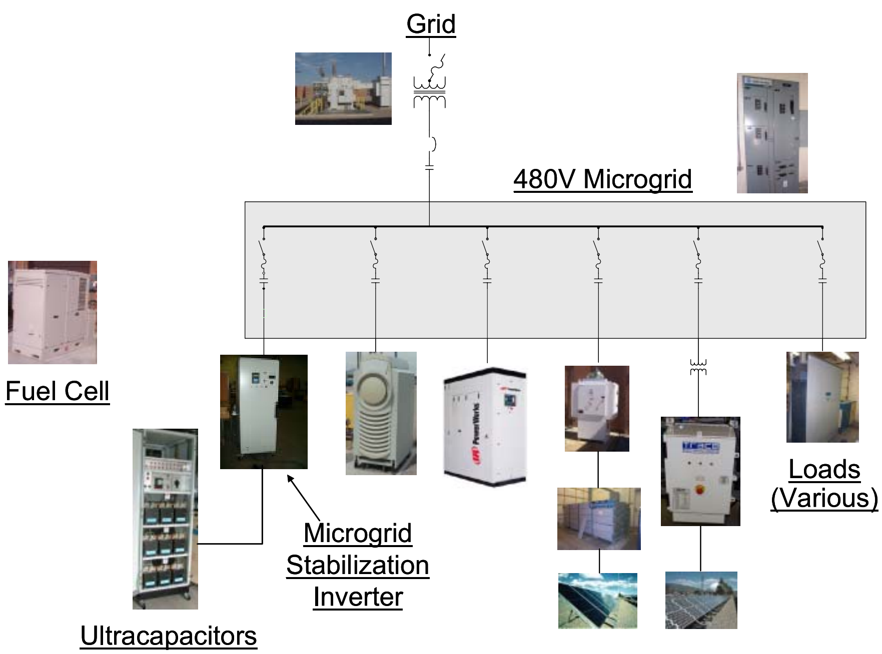

Figure 2. Hardware for various DETL customers as of March, 2003

5. Multiple DER Islanding Test Example

A test performed early in the development of DETL illustrates the capability of testing combined sources of different technologies. The parallel combination of a 10-kW PV inverter and a 75-kW microturbine was connected to the grid and subjected to the matched, 60-Hz resonant RLC islanding test developed at DETL in support of IEEE 929-2000. Figure 3 shows the test configuration.

Figure 4 is waveforms of the phase A current from each source. The active anti-islanding controls of the PV inverter quickly recognized the loss of grid and turned off the inverter. The microturbine continued to generate because its passive protection and controls did not detect the loss of grid under this special load condition.

Utility distribution engineers continue to request that anti-islanding behavior be thoroughly analyzed and tested for various sources and combinations of sources. It is desirable to develop computer simulation models of the anti-islanding controls of different DER. In cooperation with Xantrex, such a model has been developed at DETL for a Xantrex 20 kW grid-tied PV inverter. Testing is underway to experimentally validate this model. Such models will help to understand anti-islanding behavior and to reveal potential interactions among different sources and the local grid.

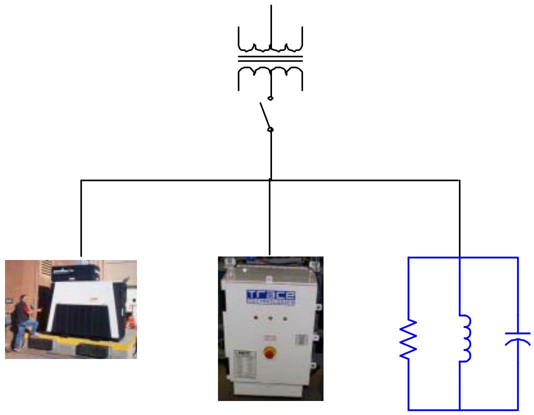

Figure 3. PV inverter/microturbine islanding test

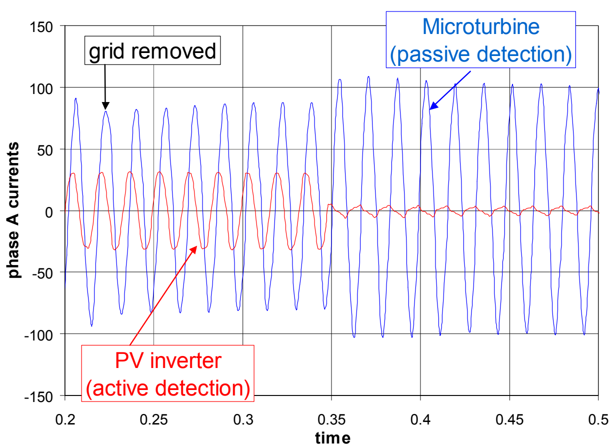

Figure 4. Islanding test current waveforms

6. Summary

A variety of activities are underway at Sandia to accelerate the implementation of distributed energy resources. By virtue of its experience with power electronics requirements in general and utility interconnection requirements in particular, photovoltaic technology is more mature than other DER such as microturbines and fuel cells. Testing is an important element of this program and provides valuable information for utility engineers, manufacturers, and end-users on performance and control system interactions. The ability to use common power electronic platforms for multiple DER applications has the potential to lead to larger production volumes, which can, in turn, lead to products having higher reliability. Widespread interest in DER has enabled significant leveraging of resources outside the DOE Solar Program.

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