PV System Evaluation Plan

Commonwealth Biogas/PV Micro-Grid Renewable Resource Program

Project 3.2 –Building Integrated PV Testing and Evaluation

Prepared for
California Energy Commission
Public Interest Energy Research Renewables Program

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Table Of Contents

Table Of Contents

Endecon Engineering PV System Evaluation Project Plan

1. Introduction

A key aspect of energy system affordability is a realistic assessment of component and system performance and longevity. For years, the PV industry has relied on manufacturer literature to judge the performance and suitability of products for various applications. As a result, installing contractors are confronted with products that have no third-party evaluation and must use their clients as field-test guinea pigs. Equipment often has optimistic performance claims, and the customer is routinely disappointed with the actual performance of their system. This situation places the contractor in a difficult position of questioning whether the products they use will perform as advertised. Manufacturers that attempt to buck the trend and provide more realistic product information are likely to lose market share when consumers base their buying decisions on lowest cost and dollars per advertised watt.

Because the performance of PV components, especially PV modules, is strongly dependent on operating conditions, rating and evaluating these components is complex. Not only does characterization require accurate measurement of appropriate parameters, it requires a thorough understanding of the long-term operating issues and the ability to translate and interpret results. Few places in the US currently provide credible third-party performance information on PV modules, inverters, and other components relevant to the California market or make that information available to the public.

While component performance is certainly important, system performance is even more important and factors in the interaction of all the components. The goals of a properly designed system should be performance, safety, reliability, quality of components, ease of installation, code compliance, and low cost / high value. The compromises the system designer makes to meet an initial cost goal may have serious implications on the remaining aspects, adversely affecting life cycle cost –in other words, affordability.

The Florida Solar Energy Center has initiated a program for evaluating and certifying residential PV systems to be sold under that state's rebate program. Although similar to the California Energy Commission Renewable Buydown Program's approved component list, the Florida program takes the process a step further by reviewing and approving system designs. While the California program requires that PV modules and inverters be listed to UL safety specifications, the limited performance information is based on manufacturer-provided data, which is sometimes suspect, typically without third-party verification. There is also no information on or requirements for the systems in which these components will be used.

Although Florida review program is largely an engineering evaluation of documentation, it also requires that modules be tested by a third-party lab and are within 10% of rated values, and that the relevant components have passed their respective IEEE and UL tests. One limitation of the Florida program is that it only considers systems sold into their market and only involves an engineering evaluation of the available documentation for small grid-connected systems. PowerMark, Arizona State University PV Test Laboratory, and others are developing PV module and system certification programs, but adoption of these programs is slow, expensive for manufacturers, and provides only a piece of the puzzle.

System affordability must be based on realistic performance estimates. The expanding California renewables market needs a trustworthy source of quantitative and qualitative information for both components and systems. Ideally, what would be most useful is a Consumer Reports approach to PV evaluation. As part of the Commonwealth Biogas / PV Micro-Grid Renewable Research Program, Endecon Engineering will initiate a PV Evaluation Program. This program will encompass two primary evaluation tasks, along with technology transfer activities:

- Comprehensive PV System Comparison
- Tech Transfer – Workshops, Technical Papers, Conference Presentations

Through these tasks, we will establish definitive performance and quality information. The information will be used by the Commonwealth team for upcoming purchase decisions, it will be made available through the Energy Commission buydown program, and it will be used to supplement and field-verify any performance ratings established by others. Suppliers who tend to provide optimistic performance claims will be called into check, and those who would prefer to sell their systems based on realistic, achievable performance will be supported.

1.1. Mission Statement

"Empower the PV consumer"

1.2. Purpose

The Endecon Engineering PV System Evaluation Project will provide side-by-side evaluation of available PV system and component technologies, information that is not currently available from any one source. This evaluation will yield the following products:

- Real world performance data
- On-line performance comparisons
- Systems optimized for the California market; Results useful for all markets
- Develop Consumer Confidence Guidelines (Consumer's Report for PV)
- Provide purchase guidance to Commonwealth BIPV program

The objective of this project is to perform side-by-side evaluation of commercially available PV systems and component technologies, and to compile objective, consumer-friendly information on the costs and performance parameters of these systems. This type of information is not currently available from any one source, and is needed by the PV-buying public.

This effort directly supports the Commonwealth Biogas / PV Micro-Grid Renewable Research Program, and the California Energy Commission's Public Interest Energy Research (PIER) Program, by helping to better understand the affordability and diversity of renewable energy systems.

PV installations will be monitored for 12 months to provide "real-world" performance data relevant to building-integrated PV applications. Information on design features, flaws, weak points, etc. will be evaluated to develop suggested fixes. Factors affecting overall system value will be assessed, including ease of installation, component selection, component failures, and performance factors.

This information will be used to develop a rating system for use by consumers, and compiled into a Consumer Confidence Guidelines document. Manufacturers and system integrators should also find this information valuable in selecting, designing and installing PV systems. In addition, the project results will be used to provide purchase guidance to the Commonwealth Building Integrated PV Program (Project 3.3).

Real-time performance data will be available via a Web page accessible from the Commonwealth Program web site, as well as reports on performance comparisons between installed systems.

While the PV systems under evaluation will be optimized for the California market, effort will be made to make the results relevant and useful for all national markets. The procedures developed in this program will provide the basis for the development of standardized tests to be adopted nationwide. This project is linked with efforts to produce a national PV system testing procedure underway for the U.S. Department of Energy at Sandia National Laboratories. The results of this project will be used to help establish standards to be published by organizations like the Institute of Electrical and Electronic Engineers (IEEE) or the American Society for Testing and Materials (ASTM).

1.3. Scope

The project is comprised of the following work tasks:

Building Integrated PV Testing and Evaluation Test Plan

This task will entail the development of a Test Plan that includes formation of a Project Advisory Committee to oversee the project, development of criteria for site selection and PV systems selection, system testing and monitoring plans, data acquisition protocols, and reporting procedures.

Building Integrated PV Testing and Evaluation Project

This work is divided into two categories of systems intended for building integration:

- Large Systems – three systems to be installed and evaluated, nominal 20 kW each, configured as one or multiple building blocks.
- Small Systems – three systems to be installed and evaluated, nominal 2 kW residential / small commercial rooftop systems.

To the extent reasonable and practical, systems will be selected and purchased so that they represent off-the-shelf, commercially available products, and not products specially selected by the vendor. They will be installed in accordance with the Test Plan, and monitored for a period of 12 months. Deliverables will include documentation of the selection, acquisition and installation process; initial characterization report; 6-month and 12-month exposure and operations reports, and consumer confidence guidelines.

Technology Transfer and Reporting

This will include the aforementioned Web page with real-time operational and comparative performance information, technical papers, presentations and workshops; a final report, and coordination with the Renewables Program Advisory Committee (RPAC).

2. Advisory Committees

2.1. Project Advisory Committee

A Project Advisory Committee (PAC) will be formed to provide technical guidance and feedback to this project plan and its implementation. The committee will comprise a relatively small group—fewer than 10 members—of recognized industry experts. Our intention is to use electronic communications extensively and hold as few meetings as possible to minimize the time and financial burden on the volunteer participants.

2.1.1 Function

The PAC will provide review and approve function in the following three specific areas.

Review and approve test plan

One of the first activities of the PAC will be to review and approve this document. In particular, the committee will be responsible for defining and approving the system selection criteria and the system evaluation approach.

Review and approve system selections

The PAC will review proposals for the various systems and select the most appropriate systems for installation.

Review and approve evaluations

The committee will review each evaluation report and approve it for final submission to the Energy Commission.

2.1.2 Membership

The project team will invite membership from known industry experts performing component and system level research in the PV industry. Organizations that we expect will provide experts include:

- California Energy Commission
- Sandia National Laboratories
- National Renewable Energy Laboratories
- Florida Solar Energy Center
- Southwest Technical Development Institute

The Commonwealth Project Team will have at least one member on the committee.

2.1.3 Structure

The PAC will elect a chairman who will

- convene and chair meetings
- call for and certify votes on issues and documents

In addition to having one seat on the committee, the Commonwealth Project team will support the committee in all of its activities.

2.1.4 Deliverables

The function of the Project Advisory Committee is indirectly related to most of the deliverables. It is intended to provide a substantive basis of expertise so that the project team members, the manufacturers of PV products, and the consumers of PV products have the assurance that results of the system evaluations have been thoroughly and appropriately reviewed. Several different experts form a consensus opinion in the review rather than just one or two experts presenting their isolated opinions.

2.2. Industry Advisory Committee

An Industry Advisory Committee (IAC) will be formed to provide industry feedback to the project plan and its implementation. The IAC will also be a relatively small group—less than 10 members—of recognized PV manufacturing industry experts. Again, our intention is to use electronic communications extensively and hold as few meetings as possible to minimize the time and financial burden on the volunteer participants.

2.2.1 Function

The IAC will provide review function for the evaluation procedures and methods for the system evaluation program. It is important that manufacturers provide feedback on the process so that they will embrace both the process and the results. Although manufacturer's participation is not mandatory for this project, it will definitely provide for a broader venue for the information if manufacturers recognize the benefit of third-party evaluation information. Compared to the PAC, the IAC's role will be much less integral to the project. Where as the PAC will be asked to make decisions on activities, approve deliverables, review bids, and evaluate potentially confidential information, the IAC will only be asked to comment on information that the PAC has already approved for public consumption.

2.2.2 Membership

The project team will invite membership from known manufacturing industry experts producing components and system packages in the PV industry. Companies that we expect will provide experts include the following:

AstroPower
BP Solar
Kyocera Solar
Shell Solar
USSC

Xantrex
Advanced Energy
Outback Power
SMA

2.2.3 Structure

A member of the Commonwealth Project team will convene the industry review committee meetings. In addition to having one seat on the committee, the Commonwealth Project team will support the committee in all of its activities.

2.2.4 Deliverables

The function of the IAC is indirectly related to many of the project deliverables. It is intended to provide a means for the industry to provide feedback to the process and to make the process more effective and meaningful. This committee will provide input that will be factored into the reports that are major deliverables under this program.

3. Comprehensive PV System Comparison

3.1. Comprehensive Large PV System Comparison

The Large system evaluation will cover the selection, installation, operation, monitoring, and evaluation of three independent 20 kW PV systems. These systems are intended to be indicative of the kinds of Building Integrated PV hardware that will be installed under Project 3.3 of the Commonwealth PIER program. While these sample systems may not all represent actual building integrated products (i.e. those designed to replace traditional building roofing, glazing, or cladding materials), they will be representative of currently available electrical technologies (PV cells / modules, structures, inverters, wiring, etc.) that are used or can be used to make BIPV products.

3.1.1 Large System Site Selection

The Large PV systems will be co-located (at a single site) for fair and impartial comparison of the selected technologies. The site should have adequate installation area for 60 kW of PV (5000 to 10000 ft^2) along with associated power conditioning and monitoring equipment. The installation area should have an unobstructed view to the east, south, and west so that no shading of the arrays is possible.

As the cost of these systems will be borne by a project participant, it appears most likely that the participant will want the system(s) in a location where they can take advantage of the energy generated and the public relations value. A flat-roof commercial or industrial building with limited protrusions (HVAC equipment, skylights, vents, etc.) will be most appropriate. The single site requirement will also accommodate the use of CPUC buy-down funds that are available for systems over 30kW.

3.1.2 Large System Selection

Systems will be bought from dealers, distributors, or otherwise in such a way as to ensure that the components are not specially selected by the supplier. Large systems will be procured via competitive bid, including installation. An RFP will be prepared based on available sample documents (PVUSA, SMUD, UPVG / SEPA, etc.). The systems will be 20 kW (ac, PTC rating). The RFP will note that we are interested in three systems total, including at least one single-inverter system and at least one string-inverter system (1-2kW inverters). Bid evaluation will include the following criteria:

- ☒ Price (actual and projected—ask for multiple or larger system bids for Project 3.3 as well?)
- ☒ Supplier experience
- ☒ Degree to which proposed system meets program objectives
- ☒ Degree to which proposed system adds variety to project
    - ☑ At least one single-inverter system

  - ☑ At least one string-inverter based system (may incorporate a variety of modules and inverters—i.e. high versus low voltage strings)
  - ☑ Variety of modules
  - ☑ Variety of inverters
  - ☑ Mounting technique
  - ☑ Other BOS or installation characteristics
- ☒ Degree to which proposed system is representative of potential BIPV products

3.1.3 Deliverables

The following lists the specified deliverables for this task:

- ☒ DAS Letter of Notification
- ☒ Initial Characterization Reports
  - ☑ System #1
  - ☑ System #2
  - ☑ System #3
- ☒ 6-month Exposure and Operation Report
- ☒ Interim Report on Large Systems Progress
- ☒ 12-month Exposure and Operation Report
- ☒ Consumer Confidence Guidelines for Large Systems

These deliverables comprise the documentation and results of the Large System testing program. Once the data acquisition equipment is specified, procured, and configured (though likely prior to installation), the DAS Letter of Notification will be submitted. Once each system is fully installed, commissioned, and operational, the Initial Characterization Report for that system will be submitted. This Initial Characterization Report will include the first draft of the PV System Test Procedure. This Test Procedure will be refined throughout the project and the final version will be submitted with the Consumer Confidence Guidelines deliverables for small and large systems as an Appendix to those documents. That Test Procedure will be presented to Sandia National Labs who will then begin the process of incorporating that procedure into a standardized national test to be published by organizations like the Institute of Electrical and Electronic Engineers (IEEE) or the American Society for Testing and Materials (ASTM). After 6-months and 12-months, Exposure and Operation Reports will be prepared to update the project team and the Commission on the results of the field performance evaluations. At an appropriate intermediate interval, an Interim Report on the progress of the Large Systems testing program will be submitted. Once the major lessons have been learned and documented in these series of reports, a Consumer Confidence Guideline will be developed that will help prospective systems owners better choose a system that will meet their company’s needs. This guideline will describe both the method of testing and evaluation used as well as the results from the systems under test.

3.2. Comprehensive Small System Comparison

The small system evaluation will cover the selection, installation, operation, monitoring, and evaluation of three independent 2kW PV systems. These systems are intended to be indicative of the kinds of PV hardware that an energy service provider would market to its residential and small commercial customers and should also be indicative of hardware installed under the California Emerging Renewables Buydown Program. Over 2,000 systems like these have been installed in California over the past several years, but as yet with little quantification of system quality or performance.

We intend to select mostly pre-engineered systems (i.e. EarthSafe, MYGEN, Sunline/SunUPS, etc.). At least two of the selected systems should fall into this category depending on the availability of systems that meet the selection criteria. If necessary and appropriate, the remaining systems will be designed by the project team subject to the criteria above. For example, a particular inverter may be selected if it is not represented in the other systems.

3.2.1 Small System Site Selection

The Small PV systems will be co-located (a single site) for fair and impartial comparison of the selected technologies. The site should have adequate installation area for at least three typical 2 kW residential roof-mounted PV systems (600 to 1200 ft^2) along with associated power conditioning and monitoring equipment. The installation area should have an unobstructed view to the east, south, and west.

Our prime candidate site for this activity is the EMT/SST area of the PVUSA site in Davis, CA. We are currently negotiating with Nuon Renewable Ventures to use the site and its facilities. The site is well characterized, has excellent solar resource, and has been designed and built to test PV systems and components. It also has the potential to host some or all of the workshops discussed in Section 4.3.3.

Other potential sites include property owned by team members that meets the criteria for testing, and the Sacramento Municipal Utility District's (SMUD's) Hedge facility. The Hedge facility is currently used by SMUD to test many different modules and systems. Since they are running a parallel PIER project, this would certainly increase the cross-pollination between the two projects.

3.2.2 Small System Selection

Small systems will be selected by consensus of the Project Advisory Committee. The systems will be nominally 2.0 kW (ac, PTC rating). We are interested in three systems total, including at least one incorporating battery storage, and at least one without battery storage. System selection decisions will include the following criteria:

- ☒ Price (actual and projected—ask for multiple or larger system bids for Project 3.3 as well?)
- ☒ Supplier experience
- ☒ Degree to which proposed system meets program objectives
- ☒ Degree to which proposed system adds variety to project
  - ☑ At least one system incorporating battery storage
  - ☑ At least one system without batter storage
  - ☑ Variety of modules
  - ☑ Variety of inverters
  - ☑ Mounting technique
- ☑ Other BOS or installation characteristics
- ☒ Degree to which proposed system is representative of potential BIPV products

3.2.3 Deliverables

The following lists the specified deliverables for this task:

- ☒ DAS Letter of Notification
- ☒ Initial Characterization Reports
  - ☑ System #1
  - ☑ System #2
  - ☑ System #3
- ☒ 6-month Exposure and Operation Report
- ☒ Interim Report on Small Systems Progress
- ☒ 12-month Exposure and Operation Report
- ☒ Consumer Confidence Guidelines for Small Systems

These deliverables comprise the documentation and results of the Small System testing program. Once the data acquisition equipment is specified, procured, and configured (though likely prior to installation), the DAS Letter of Notification will be submitted. Once each system is fully installed, commissioned, and operational, the Initial Characterization Report for that system will be submitted. This Initial Characterization Report will include the first draft of the PV System Test Procedure. This Test Procedure will be refined throughout the project and the final version will be submitted with the Consumer Confidence Guidelines deliverables for small and large systems as an Appendix to those documents. That Test Procedure will be presented to Sandia National Labs who will then begin the process of incorporating that procedure into a standardized national test to be published by organizations like the Institute of Electrical and Electronic Engineers (IEEE) or the American Society for Testing and Materials (ASTM). After 6-months and 12-months, Exposure and Operation Reports will be prepared to update the project team and the Commission on the results of the field performance evaluations. At an appropriate intermediate interval, an Interim

Report on the progress of the Small Systems testing program will be submitted. Once the major lessons have been learned and documented in these series of reports, a Consumer Confidence Guideline will be developed that will help prospective systems owners better choose a system that will meet their company's needs. This guideline will describe both the method of testing and evaluation used as well as the results from the systems under test.

3.3. System Testing and Monitoring

3.3.1 Documentation and Design Review

A complete system documentation package is essential to reproducible success in system installations. The documentation should be complete; it should provide information supporting safe and code-compliant electrical designs; it should describe applicable methods for the safe, secure, and durable attachment of PV arrays to the building structure; and it should detail critical installation and testing processes.

PowerMark, with the Florida Solar Energy Center, has developed a detailed evaluation process for evaluating PV systems. The following process was initially developed by these with slight modifications to meet the needs of this project. In each of the following sections, reviews will be performed to determine the extent to which the documentation supplied by the manufacturer or system integrator provides the information specified. Functional areas break down the reviews and guidance is provided in each area.

3.3.1.1. Documentation Review

The availability of a complete system documentation package is a key feature leading to reproducible success in system installations. At a minimum, this documentation should include system specifications, parts lists, electrical and mechanical drawings, installation instructions, operation and maintenance instructions, and warranty information. At a minimum, this documentation should include the items listed below:

- ☒ System description and specifications
- ☒ Parts and source lists for equipment supplied and not supplied with package
- ☒ Electrical diagrams and schematics
- ☒ Mechanical drawings
- ☒ Installation and checkout procedures
- ☒ Operation, maintenance and troubleshooting instructions
- ☒ Owners manuals for individual major components
- ☒ Information on how system performance monitoring is accomplished
- ☒ Warranty information on components and complete system

The review will determine the extent to which the documentation fulfills the documentation criteria. If any of these items are not provided in the documentation, written justification must be submitted explaining the deficiency. The evaluation team will review the explanation to determine whether to wave the requirement or deny approval.

3.3.1.2. Electrical Design Review

A principal concern of this evaluation is establishing that the system electrical design is safe and compliant with the National Electrical Code. Sufficient detail must be supplied in the documentation to show the recommended method of complying with the electrical code. At a minimum, supplier's documentation and drawings should specify or identify the following:

- ☒ Appropriate types, sizes, and locations of DC conductors based on temperature, location, and length of wire run
- ☒ Appropriate types, sizes, and locations of AC conductors based on temperature, location, and length of wire run
- ☒ Types and ratings for conduit and wire ways to be used in the installation based on temperature, location, and conductor fill.
- ☒ DC voltage drop limitations and conductors required for a given length
- ☒ Ratings and locations for required DC overcurrent and disconnect devices
- ☒ Ratings and locations for required AC overcurrent and disconnect devices
- ☒ Types, ratings, and locations for junction boxes
- ☒ Ratings and locations for blocking diodes if field accessible, as applicable
- ☒ Requirements for equipment and system grounding
- ☒ Requirements for surge suppression equipment for AC and DC sides

3.3.1.3. Mechanical Design Review

Methods for the safe, secure and durable attachment of PV arrays to rooftops is an essential part of a complete design package. At a minimum, the System Manual documentation and drawings should include details for assembling module / panels, layouts for the entire array, making structural connections to rooftops, and weather sealing of roof penetrations. Independent laboratory test results or certification from a licensed engineer should be provided for mechanical loads on PV arrays and buildings.

The documentation should detail the following:

- ☒ Hardware for mechanical assembly of modules and panels
- ☒ Procedures required for assembling modules and panels
- ☒ Hardware for making structural attachments to rooftops
- ☒ Procedures for making structural attachments to rooftops
- ☒ Acceptable methods for locating and orienting arrays on rooftop
- ☒ Appropriate methods and materials for weather sealing roof penetrations
- ☒ How the design avoids use of environmentally incompatible materials, and contact of dissimilar metals

- ☒ Safety considerations for installing PV array on rooftops
- ☒ Methods to ensure unrestricted air flow around array
- ☒ Methods for accessibility and maintaining array
- ☒ Methods to improve the aesthetics and architectural integration of array
- ☒ Independent test results or certification for mechanical loads on array and rooftop

3.3.1.4. PV Modules and Arrays

Independent performance tests for modules are required for system approvals. How those tested modules are assembled into an array is also evaluated in this section. If not recently characterized, one or two modules from each system will be sent to Sandia for characterization. These characterizations will establish baseline performance of these critical components as well as system modeling parameters for the further evaluation. Initial module characterization will be done per the procedures established by Sandia [1, 2].

Requirements for PV Modules and Arrays:

- ☒ Complies with IEEE Standard 1262 or equivalent qualification test standards (A PowerMark certified module meets this requirement)
- ☒ Complies with UL Standard 1703 or equivalent product listing
- ☒ Provides STC ratings for modules (Isc, Voc, Imp, Vmp, Pmax)
- ☒ Provides temperature coefficients for voltage, current, and power
- ☒ Describes methods and materials for assembling and wiring modules, panels and arrays
- ☒ The specifications of the photovoltaic power source as identified by the National Electrical Code
- ☒ Describes the location and specifications of blocking diodes, if used
- ☒ Outlines safety issues for handling and installing modules and arrays

3.3.1.5. Power Conditioning Equipment

If not recently characterized, one inverter from each system will be sent to Sandia for characterization. These characterizations will establish baseline performance of these critical components as well as system modeling parameters for the further evaluation. Initial inverter characterizations are currently under development by Sandia and this project will be used as a basis for appropriate procedures.

At a minimum, this inverter and power processing hardware shall comply with the following requirements:

- ☒ Complies with UL Standard 1741 or equivalent product listing, including all provisions for “utility interactive” inverters, including anti-islanding.
- ☒ Provides user manual with operating and troubleshooting instructions
- ☒ Includes visual indicators of operating conditions and performance

- ☒ Provides appropriate ratings of array source circuit supplementary overcurrent devices
- ☒ Includes packaging that meets requirements for outdoor installations
- ☒ Provides acceptable voltage operating window for the specified array under operating extremes
- ☒ Provides means of locking accessible disconnects

3.3.1.6. Utility Interconnection

At a minimum, requirements for approval include compliance with accepted industry standards and identification of the equipment and methods used in interconnecting PV system to the utility grid.

- Compliance of inverter and overall system design with IEEE Standard 929-2000
- Provides guidelines for permitting, inspections, and interconnection agreements
- Describes options and means for point of utility interconnection
- Describes overcurrent and disconnect devices required at point of connection

3.3.2 Installation Evaluation and Commissioning Testing

Installation documentation needs to clearly describe the installation procedure. It should also explain how to evaluate the initial performance of the system to verify that the system is installed properly and operating to its fullest potential. To evaluate the effectiveness of installation and commissioning instructions, it is necessary to work with a qualified installer and document those aspects of the instructions that worked well and those that did not work well. This review will evaluate and document the installation process and compare competing products for their clarity of instructions and ease of correct installation. The evaluation criteria include the following:

- ☒ Clarity of instructions
- ☒ Reading level consistent with users
- ☒ Languages available (e.g. English, Spanish,…)
- ☒ Steps consistent with installation process
  - ☑ Site Analysis
  - ☑ Preparation
  - ☑ Array Structure and Roof penetrations
  - ☑ Array Mounting
  - ☑ Array Wiring
  - ☑ BOS Wiring
  - ☑ Commissioning
  - ☑ Troubleshooting
- ☒ Organization of installation steps well planned to minimize effort
- ☒ Key steps not overlooked
- ☒ Thoroughness of procedures
- ☒ Safety procedures properly stressed

- ☒ Commissioning tests outlined to account for site constraints
- ☒ Troubleshooting information available in case system does not meet commissioning criteria

3.3.3 Performance Monitoring and Evaluation

The function of a PV system is to generate electricity. The amount of energy it generates relative to the size and cost of the system is of great interest to any PV system owner. This evaluation will quantify the performance of the tested systems in such a way that prospective PV system owners will be able to make their own conclusions as to which product best suits their needs. The performance measures are here categorized by whether special tests or long-term testing is needed to obtain the necessary information. For cost comparisons, we will use the capital cost data provided by the manufacturer or as delineated in the bid. Where applicable, we will evaluate the observed installation labor to determine those costs.

3.3.3.1. Special Test Results

Special tests are those that are performed to provide input on specific components and their operation that are relevant in the system evaluation. These tests may be performed over a few hours or days, and may be performed on components of the system rather than on the system as a whole or with the system operating in a particular mode.

Special Short-term tests

These short-term tests are generally accomplished with apparatus that is setup for a short duration. Examples of some special testing that will be performed follow.

System Rating

The first concern of a new PV system owner is, "did I get what I paid for?" While energy delivered better defines "what I paid for", a key measure of system performance is the system rated output power. Regardless of how well the stated rating matches actual system performance, this is the value used in most economic calculations. In addition, the ability to estimate the expected hours of "peak" (i.e. at rated output) operation over a year provides a simple energy estimate for the system, one that is most accurate

Each system installed under the project will be rated according to the methods established by PVUSA. This rating will be compared to the value provided by the manufacturer and the rating established by the California Energy Commission Buydown program (www.consumerenergycenter.org/buydown). It will also be used in all calculations that require system power.

Inverter Efficiency

The efficiency with which dc power is converted to ac power can vary due to several effects. Among these effects are output power level, input and output voltage, and the operating temperature of the power electronics (which depends on power level and ambient temperature). During its initial characterization, each inverter model will be evaluated for efficiency over a range of conditions. The testing specifics are under development at Sandia National Laboratories.

Annual inverter efficiency is a concept that is gaining support since it takes into account the effects of system design and low irradiance performance on the overall conversion of PV energy into usable AC energy. Since this is a system-level evaluation, the annual or daily inverter efficiency is much more valuable information than peak efficiency. We will be able to compare the efficiency values from the initial characterization with those from long term testing to establish what conditions determine the average efficiency for the unit.

Inverter Maximum Power Point Tracking

Most inverters attempt to operate the PV array at the knee of the IV curve using a function called Maximum Power Point Tracking (MPPT). Using any one of a variety of methods, these inverters attempt to determine the particular combination of voltage and current that yields the highest array output. The maximum power point varies throughout the day with changes in irradiance, temperature, and other factors. Traditionally, this impact has been neglected or characterized imprecisely. Some recent MPPT implementations have demonstrated a tendency to get "confused" and may operate the array off of its maximum power point for significant periods of time. Accurate evaluation of MPPT can be difficult, requiring specialized equipment. For the purposes of this evaluation, it will be primarily a function of the initial characterization. There may be opportunities to do in-field evaluation by comparing measured operating voltage and current with nearly coincident array IV curves.

In addition, once the array is characterized, the optimal operating voltage can also be modeled for any combination of irradiance and operating temperature. This array performance prediction can then be compared with actual operating data to see how closely the two values coincide.

Array Efficiency

The efficiency with which solar irradiance is converted to dc power will depend on the cell technology, the prevailing ambient weather conditions, and on how the inverter controls the dc operating point of the array. Sorting out the effects attributable to the module construction from those of inverter operation requires additional measures, such as I-V curve results (operation independent of the inverter) or an accurate evaluation of the inverter's MPPT, as described above. Once the system array efficiency has been characterized and the nominal allocation of loss mechanisms has been determined, other measures may be used to track long-term performance changes, and special tests may be repeated at intervals if desired.

Field Wet Resistance Test

The Field Wet Resistance test (FWRT) provides a measure of confidence that the system has been manufactured, shipped, and assembled in a safe manner. This test, developed at PVUSA and described in [3] uncovers any breaches in the environmental seal protecting all components in the PV array, including module laminate materials, wiring, connectors, and junction boxes. These breaches are obviously a concern from a safety point of view, but there are also serious reliability issues that arise from these problems.

In this test, a megaohm meter is connected between the open-circuited or shorted array leads and ground. A mild surfactant (detergent) solution is sprayed on the array, the sheeting action of which tends to penetrate any voids or breaches in the environmental seal. If the surfactant solution is able to contact any of the current carrying conductors of the array, the megaohm meter will indicate low impedance. The presence of these conductive paths may later be activated during rainy weather leading to corrosion (reduced reliability) or shock hazard (reduced safety).

Special Long-term tests

Other special tests use long-term data acquisition equipment that is put in place to make measurements over months or years. Examples of some special testing that will be performed follow.

Performance Index

Performance Index (PI) was developed by PVUSA [4] as a simple means for determining system health. The simplest definition for PI is the actual system output divided by the “expected” system output. Output may be defined as instantaneous power or accumulated energy over an arbitrary period. The strength of this measure is that it is a direct indication of system function with environmental conditions factored out. Its weakness is that the “expected” output model is valid only under fairly moderate environmental conditions. Extremes of irradiance or temperature can produce inaccurate results.

Power-based PI has proven to be very useful as a real-time performance meter though, for the reasons describe above, it tends to yield inaccurate results in the morning and evening. An alternative is to present power based PI only during the middle four hours of the day or when the irradiance is above a nominal level. Daily energy-based PI will be presented so that the overall performance can be quickly viewed on a daily basis. This daily number is essentially what is used on the UPVG PV data site.

Extreme irradiance and temperature conditions correspond to relatively low fractions of the total long-term energy, so calculations based on long-term energy values tend to be most accurate.

If the system experiences significant downtime, sorting out the downtime for testing (which shouldn't count against the system's performance) from the downtime under "normal operation" can introduce errors as well.

Energy Capture

This value measures how much of the available radiant energy the system was prepared to accept. This value is weighted based on the type of day that the inverter is not operating. It is expected that the unit be off during night hours, but it is expected to be on during daylight hours. Should the system start later in the morning than another system, the impact on performance may be small compared to an outage at noon. This is distinct from how much it actually transferred to the grid or battery storage, and can be used to distinguish excessive downtime from excessive losses while operating. The weakness of this measure is that it depends on the existence of an "inverter operating" status signal that is rarely present on commercial inverters. This signal is sometimes synthesized by using a small, positive, nonzero threshold ac output power value to indicate "on" status. This can help determine how much of the time the system was available and producing power.

3.3.3.2. Energy Performance Testing Results

Energy is a common basis for evaluating long-term system performance. A weakness of this measure is that it is specific to the attributes (size, components, etc), location, and prevailing weather conditions of the system tested. Energy output normalized by array size for co-located systems can provide a much more relevant comparison.

Energy per area per year

This value describes the value of the system on the basis of array area. In many cases, limited space is available for system installation and this will be a useful measure for constrained space locations. This measure is also useful for describing and comparing array packing density. A system using highly efficient modules mounted on a structure with poor packing density may not perform as well as system with a moderate efficiency modules and a very space-efficient mounting scheme.

Energy per rated power

Energy as a function of array / system size is useful for comparing the operational characteristics of co-located systems. This value will be computed using daily, monthly, and annual energy and the AC PTC output rating established for the system. This measure is sensitive to the value chosen as the system rating (comparisons may be done with manufacturer’s advertised rating, array STC rating, etc.), and takes into account the effects of all actual power loss and downtime mechanisms. As long as the tested system is representative of an optimal system (e.g. is properly oriented, unshaded, clean, and works properly), energy per rated power can also be normalized by measured insolation so that the performance of a system in Davis can be compared with a system in Chino.

4. Data Collection, Reporting, and Technology Transfer

Data collection encompasses the sampling and manipulation of the information needed to evaluate the PV systems per the goals of this project. Data reporting includes steps that transform the raw data into understandable information. Key planned features of these processes will include:

- Accessibility of data through internet access (both public and password protected)
- Graphical presentation of data on web
- Archiving data for project record and later detailed analysis
- Paper reports including initial characterization and interim and final reports

4.1. Data Acquisition Plan

4.1.1 Data Collection Procedures

Data collection will be conducted using a combination of automated and manual methods. Data collected for use in the initial characterization reports will include component-level evaluations using laboratory test equipment. Exposure and operation reports will depend primarily on the datalogger-based hardware described in the previous sections, supplemented with periodic field tests to check component function if measured system performance is unexpectedly low.

Automated data collection procedures will include sampling at 5 second intervals or faster, and statistical aggregation of samples over 10 minute intervals for recording. Data will be automatically transferred to a central data collection computer that is accessible by Endecon personnel at an interval of no less than once per day (once per hour, if the connection is local). As often as this data becomes available, it will automatically be processed to remove obviously erroneous data and both raw and summary data will be transferred to an internet web server using https POST to a server-side CGI application for storage in a server-side SQL database. Data will also be loaded into Microsoft Access databases to support ad-hoc data evaluation by an analyst to support generation of exposure and operation reports.

4.1.2 Function

The data acquisition system should include the following characteristics:

- Recording of parameters at appropriate accuracy
    - Ac real power at inverter-grid connection point
    - Ac voltage

  - Dc voltage and current
  - Ambient and array temperature
  - Irradiance: plane-of-array and global horizontal
  - Wind speed
- Statistical data volume reduction (average, maximum, minimum)
- Computation of nonlinear equations (power, modeled power) before averaging
- Buffering of data to minimize impact of any communications disruptions

4.1.3 Hardware

The reference data acquisition platform will be a Campbell Scientific 21X or CR23X datalogger, which has a variety of analog and pulse input capabilities that are appropriate for this application. The datalogger will be augmented with Watt/VAR and true RMS voltage[1] transducers for monitoring ac power production, and voltage transducers and current shunts/isolators for PV array monitoring. Weather will be monitored with silicon pyranometers and a thermistor for air temperature. Type T thermocouples will be used for monitoring the array temperatures. Data will be sampled every 5 seconds and aggregated over 10 minute intervals to reduce buffer storage requirements.

The reference DAS will be a costly solution for monitoring string inverters, so we plan to monitor one set of dc and ac measurements for each of the three systems and rely on monitoring by direct communication with the string inverters to complete the suite of measurements. By comparing the results from the string inverters that are instrumented with the reference DAS, we will quantify the accuracy of the string inverters' internal monitoring capabilities. We anticipate that inverter-based monitoring accuracies will be on the order of 2%, which will be sufficient for most troubleshooting purposes but may not be appropriate for use in computing inverter or array efficiency estimates.

As an example, assuming the string inverters are manufactured by SMA, the Sunny Boy Control (SBC) and associated software will be used. The SBC uses power line carrier communications to poll the local inverters. A computer running Windows will be installed within 100 ft of the string inverters to record inverter operating data through RS232 communications. We are currently assuming that this computer can be located in an environmentally controlled space. This computer will run the inverter communication software, be connected to the Sunny Boy Control interface device, and will also collect data from the reference DAS. The string inverters will be monitored using the SMA Sunny Boy Control software, and configured to record data every 5

[1] RMS voltage can adversely affect inverter efficiency, and out-of-spec voltage can trigger inverter disconnects. The inclusion of RMS voltage measurement is intended to support troubleshooting of possible intermittent variations in inverter operation.

seconds. Since this software does not include any data aggregation capability, this data will be post-processed to generate “average” data on the PC.

Availability of an Ethernet connection to the internet will simplify data collection from the remote site. Lacking this option, a telephone line connection will be required for such data transfers, and to support remote access to the computer for maintenance.

4.1.4 Software

The reference DAS will be monitored and data will be downloaded to CSV files using the PC208W software written by Campbell Scientific. The data will be loaded into a relational database management system and post-processing of “average” data will be performed. Periodically a screened subset of data will be transferred to a public (web) data server.

Remote access to the data collection computer will be implemented via PCAnywhere or GoToMyPC, depending on the configuration of the available networking capabilities. PCAnywhere is a lower-cost solution with a number of connection methods available, but, if used through the internet, requires that the data collection computer offer “server” capability that is often blocked by network firewalls. GoToMyPC is an option that uses a secure outbound web connection to allow encrypted, password-controlled access through the internet for a monthly fee.

4.2. Data Evaluation and Reporting

Exposure data will be evaluated by reviewing graphical and tabular summaries. The graphical summaries will consist primarily of time-series plots of weather and measured system variables such as voltage and output power. Tabular summaries will primarily consist of aggregate energy, energy per unit area, energy per unit rating, performance index, energy delivered, system efficiency, energy capture, and insolation.

These exposure data will be presented in reports and presentations along with the results of the component characterization tests, documentation / design reviews, and installation and commissioning results, to allow interested parties to evaluate the relative strengths and weaknesses of the systems. Any individual system evaluation will be presented in terms of significant strengths and weaknesses of a particular design, as the intended use of a particular system may warrant tolerance of poor evaluation results in some areas in exchange for specific features, and such decisions must be made in a case-by-case basis.

4.2.1 Automated

SQL will be used to compute statistical quantities and derived measures described in the sections describing the Large and Small Systems Test Plans. The SQL language supports the use of "null" (unknown) values, allowing intermediate calculations to filter "known-bad" data and compute results based only on the remaining data. In order to obtain "sensible" results in the presence of null data, these computations require careful construction to avoid confounded results. For example, invalid / missing weather data will cause a shortfall in the expected energy portion of the performance index, causing a misleading increase in performance index. We will apply the techniques used in the PVUSA performance database to minimize the effects of such data anomalies.

4.2.2 Ad Hoc

The need for ad hoc data evaluation arises when standard data summaries do not directly show the nature of some phenomenon of the system operation. For example, an inverter that self-limits power conversion at high temperatures may show "erratic" daily performance index values. When plotted against temperature instead of time, this relationship will become clear. The activity of ad-hoc data evaluation consists of this interactive extraction and plotting of data in response to theories of operation. Since the exact nature of the unusual behavior is not known beforehand, the availability of a flexible data extraction and review system is a valuable resource for characterizing PV systems.

The standard tools used by Endecon for this analysis include Microsoft Access for formulating and executing data selection queries and Excel for plotting and applying hypothesized models to data. Data may be extracted using Access from either Access MDB files or from more heavy-duty SQL databases using ODBC drivers.

4.3. Technology Transfer

4.3.1 Web Presentation

A PV System Evaluation web page will be developed to present the status and results from the project. Though the data and underlying html will reside on a separate server, this page will be coordinated with and accessible from the Commonwealth program web site www.pierminigrid.org. The web site will include pages that provide the following information:

- Project description – include text on the goals of the project, the scope and purpose, participants, and how the project fits in both the Commonwealth Biogas / PV Renewable Mini-grid Program and the California Energy Commission PIER program
- Static System Information – This section will provide a detailed description of each system under test. Information will include description of components and key features, manufacturer's rating and installed system rating.

- Performance Data – will include both historic and “Real time” (frequency of update to be determined) information. Limited real-time data will be made available to the general public. Appropriate passwords will be necessary to access more detailed data
- Tech Transfer – This section will include references to workshops, papers, presentations, and reports, as available.
- Restricted Access pages – As necessary, password-protected areas will be set up for transferring proprietary information between project participants (Commonwealth Team, Energy Commission, Project Advisory Committee, etc.)

Guests to the website will be able to sign up for event notifications, such as system installations, significant changes to the website, publication of papers or reports, etc.

4.3.2 Technical Papers

We plan on writing and presenting two technical papers at relevant conferences. The first will likely be after most or all systems have been installed and initial evaluations performed, the second after more substantive results are obtained.

4.3.3 Workshops

A series of workshops will be developed to provide consumers and installers with test results from the evaluation testing. In-depth workshops that go into detail on the actual evaluation tests that are on-going at the test facility will primarily be given at PVUSA to allow Commonwealth installers, interested consumers, and maintenance personnel hands-on experience with the systems under test. These workshops will typically cover a two-day period and attendees will be charged approximately $100 per day. Another series of workshops will be developed for outreach across the state. These workshops will cover up to one day of training and focus on the results of the evaluation tests, how to interpret the results, and how to continue to track the results from the test facility (web resources). Various project partners and interest companies could host these workshops across the state to reach the constituents in the appropriate geographical areas in the state.

4.3.4 Deliverables for Technology Transfer

The following are the specified deliverables for this task:

- Initial Web page design
- Web page updates for all Systems with Links
- Technical Papers and Presentations
- Workshops

The Initial Web page design will be based in large part on the information defined in this document. Web page updates will be made for all the systems as begin operation. Technical papers and the presentations of that material will be submitted as a result of findings in the reports and on-going system monitoring. Workshops will be scheduled and presented as significant findings are published and made available.

5. References

[1] King, D.L., J.A. Kratochvil, and W.E. Boyson, "Temperature Coefficients for PV Modules and Arrays: Measurement Methods, Difficulties, and Results," Proceedings of the 26th IEEE Photovoltaic Specialists Conference, October 1997 Anaheim, CA.

[2] Whitaker, C. et al, "Application And Validation Of A New PV Performance Characterization Method", Proceedings of the 26th IEEE Photovoltaic Specialists Conference, October 1997, Anaheim, CA.

[3] ASTM Std E 2047 *Test Method for Wet Insulation Integrity Testing of PV Arrays.*

[4] Townsend, T., C. Whitaker, B. Farmer, and H. Wenger, "A New Performance Index for PV System Analysis." Proceedings of the First World Conference on Photovoltaic Energy Conversion (24th IEEE Photovoltaic Specialists Conference), December 1994, Waikoloa, HI.