BALANCE-OF-SYSTEM IMPROVEMENTS FOR PHOTOVOLTAIC APPLICATIONS RESULTING FROM THE PVMaT PHASE 4A1 PROGRAM

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ABSTRACT

The Photovoltaic Manufacturing Technology Program (PVMaT) began in 1990 as a cost-shared partnership among the photovoltaic industry and the United States National Photovoltaic Program. It has been conducted in several phases that were staggered to support technology evolution in the industry. Phase 4A goals broadened the scope of PVMaT resulting in a proposal solicitation that was divided into two parts: (1) Phase 4A1- Product-Driven System and Component Technology - with goals to improve system integration, improve component efficiency, and support manufacturing and system or component integration to bring together all elements for a PV product and (2) Phase 4A2- Product-Driven PV Module Manufacturing Technology - which addressed PV cell and module manufacturing to maximize the flexibility of applications and to reduce costs for PV products. Of the thirteen awards made in Phase 4A, eight were in 4A1. Developments through these subcontracts include advanced system integration, new and innovative inverter products for a broad range of PV applications, and product modifications intended to result in improved reliability and reduced manufacturing costs. This paper summarizes the research, development and progress under phase 4A1.

INTRODUCTION

The PVMaT program is a partnership involving the U.S. photovoltaic industry, the U.S. Department of Energy (DOE), the National Renewable Energy Laboratory (NREL) and Sandia National Laboratories (SNL). The overall PVMaT management that was established by the DOE tasked an Implementation Team with development and implementation of the project. The team consists of one representative each from DOE, NREL, SNL, and the Solar Energy Industries Association (SEIA). The subcontracts are subsequently monitored by Technical Monitoring Teams (TMT), each consisting of engineers and scientists from both NREL and SNL.

Solicitations for partnering between the U.S. Department of Energy and U.S. PV Industry have resulted in a total of 50 awards from five phased procurements: Phase 1A, Phase 2A, Phase 2B, Phase 3A, and Phase 4A1. A sixth procurement, Phase 5A, is currently underway with proposal evaluations scheduled to be completed in November 1997. Research is still in progress in Phase 2B and 4A2 and is being reported in another paper at this conference [2].

The objectives of the most recent Phase 4A1 projects were to stimulate broad interest in the production of PV balance-of-system (BOS) related products. They encouraged and supported high-risk development by the industry to explore new manufacturing options and ideas that also resulted in improvements in their PV products or components. These advances in BOS components and system integration, along with new developments in system design, were also to lead to an overall reduction in life-cycle costs of PV applications. The thrust has been to emphasize the importance of cost reduction, improved efficiency, perfected manufacturing, widened product flexibility and broader market applications for PV systems as a whole. NREL awarded eight, 2-year Phase 4A1 to the manufacturers listed in Table 1 below.

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<td>Ascension Technology</td>
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Table 1. PVMaT Phase 4A1 Subcontract Awards
The Product Driven System and Component Technology portion of the PVMaT Phase 4A1 asked for proposals for subsystems, components and system integration improvements directed toward improved and innovative manufacturing, low-cost, high-return, high-impact PV products. The subcontractors were selected through competitive evaluations of the submitted proposals.

OVERVIEW OF R&D AND PROGRESS

The progress and significant improvements achieved by these subcontractors are detailed below. For discussion purposes, they have been grouped by general categories. They are discussed alphabetically in each category.

BOS and PV Module Manufacturer Teams

Of the eight subcontracts awarded in Phase 4A1, four firms, Ascension Technology Inc. (ATI), Solar Design Associates (SDA), Solar Electric Specialties (SES), and Utility Power Group (UPG), are each working as a team with a PV module manufacturer to develop integrated units or systems.

Ascension Technology, Inc. (ATI), directed its research and development through a contract titled "Manufacture of an AC Photovoltaic Module [3]." ATI teamed with PV-module manufacturer, ASE Americas (ASE), to develop an AC Photovoltaic Module, called the SunSine300. ATI developed a new module scale inverter to be integrated with the ASE 260-300 W, large-area, PV module. The inverter is designed for enhanced performance, ease of application, high reliability, and compliance with applicable Underwriters Laboratories (UL) standards and Federal Communications Commission (FCC) electromagnetic interference (EMI) standards. The complete package has now been UL listed and has met applicable FCC standards for EMI.

ATI has also completed development of an entire system package for their AC Photovoltaic Module using a new version of its PV source circuit protector, an updated roof jack mounting system and a complete utility interconnection assembly. New anti-islanding circuitry has been designed and is being used to address utility-interconnect concerns.

Approximately twenty-two co-funding electric utilities are teaming with ATI to deploy nearly 100 of the pre-production AC Modules for on-site testing and evaluation. The AC modules are also undergoing tests at NREL and SNL. Extensive developmental tests are being conducted to evaluate the new anti-islanding circuitry.

Solar Design Associates, Inc. (SDA) directed research through a contract titled "The Development of Standardized, Low Cost AC PV Systems [4]." SDA teamed with Solarex and Advanced Energy Systems, Inc. to develop standard, certified modular units that combine digitally controlled inverters with the Solarex 240 W- to 300-W, large-area, polycrystalline, PV modules. These standardized, listed 'building blocks' are designed so that identical units can be combined to create pre-wired PV systems of virtually any power rating to suit any particular building installation. The team developed low-cost installation methods for ground-mound, roof-mount and building-integrated installations. The issues of finding enough unshadowed roof areas, array orientation, and inverter match due to size are virtually eliminated.

The micro-inverter has been submitted and received a UL listing. FCC testing has also been successfully completed. Early models of this design have already been incorporated as part of a building-integrated PV project at the new offices for the Center for Environmental Sciences and Technology Management at the State University of New York in Albany. The AC module prototypes are also undergoing developmental tests at NREL and SNL.

Solar Electric Specialties, Inc. (SES) directed its research through a contract titled "Design, Fabrication and Certification of Advanced Modular PV Power Systems [5]." Systems integrator, SES, is manufacturing two different fully engineered and pre-packaged integrated PV power systems. One is a modular, pole-mounted autonomous 200-W PV power system with battery backup called MAPPS. The second is a containerized 1-kW Photo-genset that includes a backup generator suitable for off-grid electricity applications and services. Both systems incorporate technical innovations and reduced-cost manufacturing methodologies. The MAPPS has received a UL listing and the Photo-genset will be submitted for listing when assembly is complete.

The MAPPS is a stand-alone PV system that is autonomous from any electric grid and uses no generator backup. It can also be assembled in sizes up to 500 watts. Additionally, the subassemblies that link the combiner box and battery/control enclosures, and the enclosures with the batteries are UL listed.

The 1-kW Photo-genset is a containerized PV system that includes a back-up generator suitable for off-grid electricity applications and services. It will be a 24-Vdc, 1-kW ac PV stand-alone power supply using twelve Siemens Solar Industries PV modules, flooded lead-acid batteries, a microprocessor-based charge/load controller, a 4-kW sinewave inverter, and a propane-fueled, 120-Vac generator. This manufactured unit will be trailer mounted for ease of transport.

Both products are the result of SES's concerted effort to establish fully-integrated, UL-listed, commercially available PV products. The advantages of these new products are shorter production lead times, higher overall quality, higher system reliability, lower overhead, reduced inventory costs, and lower material and labor costs.

Utility Power Group (UPG), directed its research through a contract titled "Development of a Low-cost
The subarrays are being deployed in grid-connected, customer-driven applications such as parking structures or ground-mounted systems. UPG has demonstrated a 40% reduction in area-related balance-of-system (BOS) costs and a 50% reduction in power-related BOS costs. Key cost reduction factors include the integration of seven discrete electrical enclosures into a single, multifunctional unit, elimination of extruded aluminum frames for each PV module, and nearly 50% reduction of field installation tasks through the substitution of factory labor for field labor. UPG reports a modular panel production capacity of 8 MW/year at its Sacramento facility. UPG is currently under contract from several electric utility companies to install over 50 such subarrays during 1997.

Inverter Design and Manufacturing Improvements

Another group of subcontracts in phase 4A1 was to improve inverter designs with a focus on modularity, manufacturability and performance for PV applications. Subcontractors include Advanced Energy Systems, Inc. (AESI), Omnion Power Engineering Corporation (Omnion), and Trace Engineering (Trace). These manufacturers have developed inverters that utilize standardized bridge designs, more digital controls and more efficient manufacturing methods.

Advanced Energy Systems, Inc. (AESI) conducted research through a contract titled "Next Generation Three-Phase Inverter [7]." AESI developed digital control, used advanced logic, and improved switching methodologies for its next generation inverters. The advanced inverters were designed for ease of manufacturing, economies of production, and also included communications for remote control and service.

AESI has been working with lower-tier subcontractors to reduce the manufacturing cost of its 60-kW inverters for both grid-interactive and PV-hybrid applications. AESI has evaluated digital control and is assessing options for new power-integrated-circuit components and soft switching. The final design will be highly manufacturable and will incorporate remote monitoring, control, and service communications capabilities.

A hybrid 60-kW prototype design has undergone preliminary characterization and developmental tests at the SNL Photovoltaic Systems Evaluation Laboratory (PSEL). The unit will be installed this October for long-term testing at the National Wind Energy Test Center at NREL after modifications to correct deficiencies found at SNL, and installation of new communications software.

The AESI utility-interactive inverter design, based upon many of the same manufacturing concepts, will be developed during the second phase of the subcontract. High-volume manufacturing plans will be developed, and pilot manufacturing will be initiated in the U.S.

Omnion Power Engineering Corp. has developed a standardized 100-kW, three-phase power conversion system (PCS) incorporating soft-switching technology. Omnion directed its research through a contract titled "Three-Phase Power Conversion System (PCS) for Utility-Interconnected PV Applications [8]." Omnion teamed with Soft Switching Technologies to develop a resonant-link three-phase PCS bridge and the supporting manufacturing processes to achieve long-term improvements in cost, reliability and performance. The PCS has been designed for high reliability (40,000 hours mean time between failure) and an improved converter efficiency of 96-97%, while reducing audible noise and meeting the Federal Communication Commission standards for EMI. The prototype design has been completed, and test procedures are being defined. Manufacturing costs are reduced in this design by using a standardized inverter bridge, better controlling the flow of assembly line materials, using fixtures for handling, and through semi-automated product testing.

Trace Engineering has developed a modular 2-kW dc to ac inverter under a subcontract titled "Modular DC to AC Power Inverter for PV Applications [9]." Trace used its previous experience to develop a next-generation inverter that is modular and designed to meet a wide range of performance requirements. The new design is reported to be more easily manufactured than current products and can be manufactured with lower costs. The inverter has higher efficiency than previous sinewave models, reduced tare loss for periods of light loads, and reported to have much-improved serviceability.

Trace adopted the 'universal' design to reduce its manufacturing costs while maintaining sufficient versatility and compatibility with current inverter models. Both parallel or series capabilities for the inverters are being developed. The inverters will also have the capability of being easily expanded through paralleling as load demand increases. Development testing of the prototype has begun at the SNL PSEL facility.

PV Module Improvements to Reduce BOS Costs

Evergreen Solar, Inc. directed its research and development through a contract titled "Advanced Polymer PV System [10]." Evergreen introduced innovative improvements in PV module materials and assembly methods to reduce both factory and fielded BOS costs that are associated with interconnection, module framing, and mounting the PV array. Evergreen initiated research to examine alternative materials for a modified approach to module fabrication. The use of alternative polymer materials was developed and shown to eliminate PV

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panel framing and to improve interconnection and mounting systems. These materials have been designed to meet UL requirements and additional environmental testing is in progress. Evergreen is also evaluating an alternative, continuous module manufacturing processes to reduce total module assembly costs and to reduce module installation cost.

ADDITIONAL PVMaT PROGRAM BENEFITS TO PV MANUFACTURERS

The cost-shared PVMaT program has provided for more than just technical advancements. It has worked in partnership with the manufacturers to take major steps toward improving PV and BOS related products. The subcontractors who developed components, subsystems and integrated systems can now utilize improved manufacturing processes, have demonstrated improved product performance and reliability, and have reduced manufacturing costs of their products. The PVMaT subcontractors have commented that the partnership has supported the necessary manufacturing and system integration R&D they would not otherwise have had the flexibility, time or resources to pursue.

SUMMARY

The manufacturers have reported significant hardware improvements in BOS, system integration and alternative manufacturing methods. Their approaches have improved hardware and PV system performance with improved inverters, better system compatibility and new system capabilities. New products such as listed AC PV modules, modular inverters, and advanced inverter designs that use readily available and standard components have resulted from the PVMaT 4A1 program. Standardized systems have also emerged.

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REFERENCES

The PVMaT reports referenced below may be requested directly from NREL Document Services, 1617 Cole Blvd., Golden, CO 80401.


