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**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) program began in 1990 as a cost-shared partnership among the US photovoltaic industry and the US Photovoltaic Program. Balance-of-systems (BOS) components and concepts were included under Phase 4A1 of the program. BOS contracts ranged from newly developed AC PV modules to 100kW inverters for photovoltaic applications. Utility-interactive, stand-alone and hybrid components were also improved, while better manufacturing processes were developed. Specific products developed through Phase 4A1 contracts included AC modules and module integrated inverters, an advanced polymer system to reduce BOS costs, low cost integrated tracking PV systems, improved inverters, new concept inverters, communications links for BOS, and advanced modular PV systems for remote applications. This paper summarizes the research and development work, presents product and applications improvements, and describes manufacturing improvements while analyzing performance and cost benefits.

Introduction

PVMaT began in 1990 as a partnership among the US photovoltaic industry, the US Department of Energy (DOE), the National Renewable Energy Laboratory (NREL) and Sandia National Laboratories (SNL). The program has continued and expanded to include balance-of-system components. The program was designed to assist the photovoltaic industry to keep its world competitiveness through cost-shared development of better manufacturing capabilities, equipment and processes for commercially available PV modules and systems. Solicitations for partnering between the U.S. Department of Energy and U.S. PV Industry have resulted in a total of 50 awards. Active subcontracts still exist from three of those solicitations.

The overall PVMaT management established by the DOE was an Implementation Team charged with development and implementation of the project. The team consists of one representative from DOE, NREL, the Solar Energy Industries Association (SEIA), and SNL. Procurement responsibility and day-to-day implementation takes place at NREL and technical progress is monitored by Technical Monitoring Teams (TMT) consisting of the contract manager and a technical representative from both NREL and SNL.

Advanced Energy Systems, Inc.	Next Generation Three Phase Inverter.
Ascension Technology	Manufacture of an AC Photovoltaic Module.
Evergreen Solar	Advanced Polymer PV System.
Omnion Power Engineering Corp.	Three-Phase Power Conversion System for Utility-Interconnected PV Applications
Solar Design Associates	The Development of Standardized, Low Cost AC PV Systems
Solar Electric Specialties	Advanced Modular PV Power Systems.
Trace Engineering	Modular DC to AC Power Inverter Module for PV Applications.
Utility Power Group	Low-cost Integrated 20-kW Solar-Tracking Sub-array for Grid-Connected PV Power System Applications.

Table 1. PVMaT Phase 4A1 Subcontract Awards

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Balance-of-systems (BOS) components and concepts were included under Phase 4A1 of the program and BOS contracts are among the most recently subcontracted phases of the PVMaT program. NREL awarded eight 2-year Phase 4A1 to the manufacturers listed in Table 1.

Overview of Research and Development and Improvements

The Product Driven System and Component Technology portion of the PVMaT Phase 4A1 asked for proposals for BOS manufacturing improvements directed toward innovative, low-cost, high-return, high-impact photovoltaic products. The topics of research chosen by the evaluation team for these subcontracts are outlined below.

Advanced Energy Systems, Inc. (AESI) and selected subcontractors conducted research to develop a "Next Generation Three-Phase Inverter." The goal was to reduce the manufacturing cost of inverters for medium-scale (50-100 kW) grid-interactive and stand-alone/hybrid PV applications.

Ascension Technology, Inc. (ATT), teaming with ASE Americas Corporation (ASE), directed research and development at the "Manufacture of an AC Photovoltaic Module." Ascension Technology refined and integrated ATT's module scale inverter with a large-area 300 W_p PV module manufactured by ASE Americas.

Evergreen Solar, Inc. directed its research at the development of an "Advanced Polymer PV System." Evergreen introduced improvements in PV module materials and assembly methods to reduce both factory and field BOS costs associated with interconnection, module framing, and mounting the PV array. To accomplish this Evergreen developed an Innovative Mounting System which incorporated quick-mount modules.

Omnion Power Engineering Corporation directed research at a "Three-Phase Power Conversion System (PCS) for Utility-Interconnected PV Applications." Omnion developed a resonant-link three-phase PCS and supporting manufacturing processes to achieve long term improvements in cost, reliability and performance.

Solar Design Associates, Inc. (SDA) teamed with Solarex Corporation and directed research at "The Development of Standardized, Low Cost AC PV Systems." SDA and Solarex created standard, listed modular 'building blocks' utilizing the new Solarex AC-PV MSX-240 module. These building blocks are designed so identical units can be combined to create PV systems of virtually any capacity to suit a particular application.

Solar Electric Specialties, Inc. (SES) directed research at the "Design, Fabrication and Certification of Advanced Modular PV Power Systems." Two different packaged integrated systems were developed. First is the "Modular Autonomous Photovoltaic Power Supply" or MAPPS. This is a modular, pole-mounted stand-alone PV system that is autonomous from any electric grid and uses no generator backup. The second was a 1-kW Photogenset. It is a containerized PV system including a back-up generator suitable for off-grid electricity applications and services.

Trace Engineering has developed a "Modular DC to AC Power Inverter for PV Applications." Trace used their previous experience to develop a next generation inverter that is a modular design to meet a wide range of performance requirements, is easily manufactured, and is manufactured with lower cost, with higher efficiency and improved serviceability in the field.

Utility Power Group (UPG), teaming with Siemens Solar Industries, directed research at the "Development of a Low-cost Integrated 16-kW AC Solar-Tracking Sub-array for Grid-Connected PV Power System Applications." UPG focused on the design and fabrication of a Modular Panel and an Integrated Power Processing Unit. They are combined with an advanced, listed Siemens PV module laminate to create a fully-integrated and modular 16-kWac PV solar-tracking sub-array designed to be deployed in grid-connected customer-driven applications.

Manufacturing Specific Improvements

Most contract goals have been met. It is estimated that approximately 80% of the expectations have been met on an overall scale. Some contractors have exceeded their expectations, some found roadblocks and were forced to

modify plans to reach their goals or to change the goals slightly. The improvements are summarized below but will be better quantified in the presentation and paper.

Advanced Energy Systems, Inc. developed digital control and used soft switching techniques for their next generation inverter line. They were designed for ease of manufacturing and economies of production, and also included communications for remote control and service. AESI produced a prototype 50-kW utility-interactive and a 50 kW stand-alone/hybrid inverter. The new line of inverters meet most of the requirements of utility-interconnected, hybrid and stand-alone applications.

Ascension Technology, Inc. redesigned the overall layout for an enhanced performance, lower weight, high reliability module scale inverter with compliance with applicable Underwriters Laboratory (UL) standards. ATI also completed development of a complete system package for the AC PV Module using a new version of their PV source circuit protector, an updated roof jack mounting system and a utility interconnection assembly.

Evergreen Solar, Inc. developed a new back skin material that accommodates the Innovative Mounting System concept, eliminated the module frame and integrated the junction box. They also developed an alternative lamination method for the new back skin; and used a new encapsulant suitable for alternative lamination methods.

Omnion Power Engineering Corporation's new resonant-link PCS was designed for higher reliability, (40,000 hours mean time between failure) and improved efficiency (96-97%), while meeting FCC standards for electromagnetic interference, and reducing audible noise. Manufacturing costs are reduced by better controlling the flow of assembly line materials, using fixtures for handling, and through semi-automated product testing.

Solar Design Associates, Inc. delivered kits incorporating low cost mounting systems, enhanced modular inverters and pre-manufactured wiring systems. The units were first developed for US applications, then modified for export to foreign markets. Units are deployed at utility team member locations in the U.S., Europe, and Japan.

Solar Electric Specialties, Inc. incorporated design innovations, low-cost manufacturing, and a listing or certification for the system. The advantages are: shorter production lead times, higher overall quality and system reliability, decreased engineering time, lower overhead and inventory costs, and lower material and labor costs.

Trace Engineering developed a 2.5-kW DC to AC modular power inverter that utilized, and was compatible with much of Trace's existing, tested technology. The new design allowed for cost reductions through the increased manufacturing volume of a single unit design, but retained versatility for expandable applications.

Utility Power Group demonstrated a 40% reduction in area-related balance-of-system (BOS) costs and a 50% reduction in power-related BOS losses. The measured (16 kW inverter) efficiency topped 98% with no perceptible audible noise and very low harmonic distortion in the output current.

Additional PVMaT Program Benefits to PV Manufacturers

The BOS hardware produced today utilizes improved manufacturing processes, demonstrates improved performance and reliability, costs less and is more versatile. The cost-shared PVMaT program has, in addition to providing for technical advance, provided incentive for manufacturers to take major steps toward improving their products. Without the PVMaT boost, management of these relatively small companies would have been forced to concentrate on short term, profit making endeavors, instead of allowing any long term R&D.

Summary

The manufacturers have demonstrated significant hardware improvements in manufacturability of BOS hardware and have at the same time 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, inverters that use readily available and standard components, standardized systems, and have resulted from the PVMaT 4A1 program.

PHOTOVOLTAIC'S BALANCE-OF-SYSTEM IMPROVEMENTS RESULTING FROM THE PVMaT PHASE 4A1 PROGRAM*

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