LOW-COST MODULAR DESIGNS FOR PHOTOVOLTAIC-ARRAY FIELDS†

H. N. POST
Sandia National Laboratories
Albuquerque, NM

D. C. CARMICHAEL
Battelle Laboratories
Columbus, OH

J. A. CASTLE
Hughes Aircraft Co.
Los Angeles, CA

Summary

This paper describes the design and development of optimized, modular array fields for photovoltaic (PV) systems. As a part of this activity, design criteria and performance requirements have been defined and evaluated for specific array subsystems. These subsystems include support structures, foundations, intermodule connection, field wiring, lightning protection, system grounding, site preparation, and monitoring and control. Fully integrated flat-panel array-field designs, optimized for lowest life-cycle costs, have been developed for systems ranging in size from 20 to 500 kW_p. These designs are applicable for near-term implementation (1982-1983) and reduce the array-field balance-of-system (BOS) costs to a fraction of previous costs. Key features, subsystem requirements, and projected costs are presented and discussed.

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

1. INTRODUCTION

Experience with application experiment systems and other PV field installations has demonstrated that array-field BOS and engineering costs must be substantially reduced before PV power systems can be cost-effective for grid-connected applications. Actual cost data for a representative application experiment (a 100-kW flat-panel, ground-mounted installation) gives the array-field BOS costs (site preparation, structural subsystem, electrical subsystem) as \$424/m²; engineering costs (system design, A&E fees, construction management) were \$560/m² of collector area (1). These costs are far too great to encourage widespread commercial interest, regardless of the cost of PV modules.

To reduce these costs significantly, Sandia National Laboratories, as manager of the U.S. Department of Energy PV Systems Definition Project, is engaged in a program to optimize and integrate array-field subsystems and to develop standardized, modular building blocks which can be used to construct PV array fields ranging from 20 to 500 kW_p. Two contractors, Battelle-Columbus Laboratories and Hughes Aircraft Company, were independently tasked with carrying out the objectives of this program for flat-panel systems.

2. DESIGN APPROACH

Actual reported costs and installation experience for operating systems were examined to identify areas in which costs could be reduced. In the area of array-field engineering, the development of standardized array-field designs and component hardware to minimize site-specific design work was identified as a key element for cost reduction. The use

†This work was supported by the U.S. Department of Energy, Division of Photovoltaic Technology.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

of low-cost foundations and integrated panel/structure hardware, coupled with simplified mechanical attachments, was emphasized for the structural subsystem. To avoid the very expensive site preparation associated with many of the array-field installations, sites entailing minimal clearing and excavation work were recommended. Also recommended was an integrated field wiring design to incorporate minimal subarray junction box installation and instrumentation. These cost-saving features were determined through detailed examination of the major costs for each subsystem. Each of these features has been incorporated in the designs developed by Hughes and Battelle.

The following design requirements for the array field were specified.

- Field operating voltage of approximately 400 Vdc
- Compliance with applicable codes and safety requirements
- Suitability for installation at favorable sites
- Module efficiency (for comparison purposes) of 10 percent at NOC conditions (80 mW/cm², AM 1.5, NOCT)
- Suitability for near-term (1982-1983) use.

Note that development work on power conditioning equipment was not included in the design activity; however, the requirements imposed by this equipment on the array-field design were considered.

3. ARRAY-FIELD DESIGNS

A summary of key features of each design is presented in Table I.

Table I. Characteristics of Modular Array Field Building Block Designs

	<u>Battelle Design</u>	<u>Hughes Design</u>
PV Module	- 0.6x1.2 m (2x4 ft) - 5-Vdc output	- 0.6x1.2 m (2x4 ft) - 5-Vdc output
Foundation	- Steel hat-section stakes - Treated wood beam - Support spacing at 1.2-m (4-ft) intervals	- Steel footing in front; concrete curb in back - Support spacing at 1.2-m (4-ft) intervals
Structure	- Lightweight steel - Two-module panel	- Lightweight steel angle - Four-module panel
Intermodule Wiring	- Crimp-spliced pigtails with insulating pad	- Folded daisy chain with quick-disconnect connector
Field Wiring	- Direct-burial cabling - Buried shield conductor	- Direct-burial cabling - Power collection center
Building Block	- 10-kW peak output at NOC - 400 Vdc - Two rows of structures - 50 m (165 ft) east-west by 5.5 m (18 ft) north-south with aisles	- 10-kW peak output at NOC - +200 Vdc bipolar - One row of structures - 53.9 m (177 ft) east-west by 2.4 m (8 ft) north-south

Both of the designs use commercially available PV module hardware of the same size and output voltage. Both of the designs can be adapted to 0.3 x 1.2 m (1 x 4 ft) module sizes with minor modifications. Similarly, both designs, although developed independently, incorporate many of the same design features.

The modular array-field building block developed by Battelle is a 400-Vdc monopolar unit with a nominal output power rating of 10 kW. As shown in Fig. 1, the building block corresponds to a branch circuit of two modules wired in parallel and 82 pairs wired in series and includes one junction box per building block. The high degree of paralleling in the circuit design minimizes the effect of cell failures and allows for 20-year operation with a maximum estimated power degradation of 15 percent, assuming normal cell failure rates and no module replacement. The design incorporates an innovative support structure using galvanized steel stakes and panel support members. Treated wood beams permit simple fastening of the structural members using lag screws and provide flexibility in alignment during installation. All field wiring is direct-burial cabling, and the continuous metal support structure is attached to a bare copper wire counterpoise network to provide a uniform site ground. Details of the design are described in an engineering drawing package and construction specifications document which includes example layouts for 20-, 100- and 500-kW array fields (2). As an illustration, the 100-kW array field shown in Fig. 1 consists of ten building blocks which occupy an overall fenced area of approximately 56 x 59 m (185 x 195 ft).

Fig. 1. 100 kW Array Field Layout Using Battelle's Building Block Design

The modular building block developed by Hughes is a +200-Vdc bipolar unit with a nominal output power rating of 10 kW. The building block, which is a branch circuit, consists of two 200-Vdc monopolar subarrays positioned in an east-west-oriented row. Each subarray structure accommodates two parallel circuits of 40 series-connected 5-Vdc PV modules. As shown in Fig. 2, this design uses a galvanized steel support structure which incorporates a hybrid foundation. The front foundation is a buried metal foot which is an integral part of the grounding network; the rear foundation is a concrete curb. This design also incorporates a high level of parallelism in the module circuitry to enhance reliability and reduce lifetime power loss. A daisy chain module-to-module wiring scheme is used: the circuits run in horizontal rows, fold back on themselves, and all input-output leads terminate in a common junction box at one end of the subarray structure. The modules are connected by a quick-disconnect cable assembly manufactured by AMP, Inc. Power from each building block is routed from a subarray junction box to a power collection center (PCC) via direct-burial cable. The PCC contains a standard circuit breaker switch and bus panel, fault detection sensing, and a power control module (PCM) for every two building blocks. The PCM contains transient protection devices (MOVs), blocking diodes, and snubbers. Thus, the control of the array field is sectionalized in 20-kW increments. Design details are included in an engineering drawing package and construction specifications document (3). As an illustration, the 100-kW array field shown in Fig. 2 consists of ten building blocks which occupy a fenced area of approximately 66 x 74 m (217 x 242 ft).

Fig. 2. 100 kW Array Field Layout Using Hughes' Building Block Design

4. COST PROJECTIONS

Table II presents a cost comparison of a typical (as-built) application experiment system with the modular array-field designs. The cost projections for the Hughes and Battelle designs are estimated prices derived primarily through cost quotations from several general and electrical contractors and component suppliers. The estimates assume a field size of 100 kW and a business volume of 1 MW/yr and 10 MW/yr, respectively, for the Battelle and Hughes designs.

Table II. Comparison of Array-Field BOS Costs for a Typical Application Experiment System and Price Estimates for the 100-kW Modular Array Field Designs

	1980 \$/m ²		
	<u>Application Experiment System</u>	<u>Battelle Design</u>	<u>Hughes Design</u>
Site Preparation	137	8.07	9.46
Structural Subsystem	114	27.82	34.70
Electrical Subsystem	<u>173</u>	<u>16.04</u>	<u>18.76</u>
TOTAL	424	51.93	62.92

5. CONCLUSIONS

Modular array-field designs, optimized for lowest life-cycle energy cost, have been developed for PV systems ranging in size from 20 to 500 kW_p. These designs are applicable for near-term (1982-1983) implementation and reduce the array-field BOS costs to a fraction of previous costs. The designs are also more reliable than comparable existing installations and minimize maintenance requirements and costs. From estimated array-field BOS costs (1980\$), the Battelle and Hughes designs are projected at \$51.93/m² and \$62.92/m², respectively, for low-production quantities and favorable installation sites. Similarly, the standardized designs and components should significantly reduce project engineering costs. Complete engineering drawing packages, including detailed construction specifications, are available for each design.

6. REFERENCES

- (1) E. L. Burgess, K. L. Biringer, and D. G. Schueler, "Update of Photovoltaic Cost Experience for Intermediate Sized Applications," Proceedings of the 15th IEEE Photovoltaic Specialists Conference, Orlando, FL, June 1981.
- (2) D. C. Carmichael, et al, Development of a Standard Modular Design for Low Cost Flat-Panel Photovoltaic Array Fields, SAND81-7183 (Albuquerque: Sandia National Laboratories, to be published). Work performed by Battelle-Columbus Laboratories.
- (3) J. A. Castle, et al, Photovoltaic Array Field Optimization and Modularity Study, SAND81-7193 (Albuquerque: Sandia National Laboratories, to be published). Work performed by Hughes Aircraft Company.