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IMPACT OF BALANCE OF SYSTEM (BOS) COSTS ON PHOTOVOLTAIC POWER SYSTEMS

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ABSTRACT

The Department of Energy has developed a program to effect a large reduction in the price of photovoltaic modules, with significant progress already achieved toward the 1986 goal of 50¢/watt (1975 dollars). Remaining elements of a P/V power system (structure, battery storage, regulation, control, and wiring) are also significant cost items. The costs of these remaining elements are commonly referred to as Balance-of-System (BOS) costs. The BOS costs are less well defined and documented than module costs.

The Lewis Research Center (LeRC) investigated the BOS costs associated with twelve photovoltaic experiments conducted by LeRC in 1976/77 and with two village power experiments that will be installed in 1978. The costs were divided into five categories and analyzed. A regression analysis was performed to determine correlations of BOS costs per peak watt, with power size for these photovoltaic systems. The statistical relationship may be used for flat-plate, DC systems ranging from 100 to 4000 peak watts. A survey of suppliers was conducted for comparison with the predicted BOS cost relationship.

INTRODUCTION

A major objective of the Photovoltaic Tests and Applications Project, managed by the NASA Lewis Research Center (LeRC) for the DOE, is to identify and cooperatively test with selected users, applications judged to be cost-effective in the near-term (prior to 1986). These near-term application experiments are structured to engage active participation and interest of the privat- sector. It is expected that these experiments will provide a flow of application-related information to the technical community, and to the DOE Photovoltaic Program participants and contractors. System costs are an important part of this application information.

Price goals per watt were established by DOE in 1975 (1). At that time, the module price for Block I DOE purchases averaged about $21 per watt. The future goal was for $.50 per watt by 1986. The average price per watt for DOE purchases in 1976 was $15.50 and in 1977 $10.96 (Blocks II and III respectively).

In the past, the cost of the modules dominated total costs for photovoltaic systems. However, as module cost goals are realized in the future, the cost of the other system components will become dominant unless these components also experience large cost reductions. The costs of these other system components (balance of system or BOS costs) must be examined to determine what cost reductions, if any, can be achieved. In many cases, cost reductions will be difficult to achieve due to the relative maturity of the component technologies involved.

This report documents the BOS costs for twelve LeRC photovoltaic application experiments (Table 1) with various federal and state government agencies during 1976 and 1977. In addition, BOS cost estimates are given for two village power systems that will be installed in 1978. BOS costs obtained from a survey of manufacturers are compared with LeRC BOS costs. The LeRC data were used to perform a regression analysis. The results of this analysis are presented.

COST DATA COLLECTION

The procedure for cost data collection consisted of defining BOS cost categories for a photovoltaic system and then determining the labor and material cost for each category.

The BOS cost categories include the following elements (2):

- Array, Structure, and Site Preparation
  - Module mounting frames
  - Frame supports and foundations
  - Security and safety equipment
- Electrical
  - Wiring, interconnects
  - Control circuits/instruments
  - Load management circuits
  - Voltage regulation, power conditioning
  - Enclosure or building
- Storage
  - Batteries
  - Racks and venting equipment
  - Enclosure or building
- Installation and Checkout

o Other

Module test and inspection
System sizing and design
Packaging and freight preparation
Maintenance equipment

Material costs were determined from purchase orders for all parts and materials on the design drawings. Time cards and interagency agreements were used to estimate direct labor hours supplied by LeRC and user agencies. Labor costs were determined by using an average labor-hour cost of $20/hour for engineers and $15/hour for technicians. Travel and shipment costs incurred for each installation were omitted because these costs would bias the cost of the experiment in proportion to the distance of the test site from LeRC. Other costs excluded were profit on government labor, indirect or overhead cost markups, warranties, insurance, taxes, site acquisition costs, spares, marketing and finished drawings for the customer. Although legitimate for commercial systems, these costs were not incurred by the government.

DISCUSSION

The photovoltaic application experiments conducted by LeRC are experiments intended to verify that photovoltaic power systems will meet the electrical energy requirements of a range of applications in a cost-effective manner. The experiment hardware included some elements not normally purchased for commercial systems, but these costs have been excluded here. The BOS cost summaries in Table 2 were developed from the categories mentioned previously.

In addition to the BOS costs for the 12 experiments, preliminary BOS estimates for two village power systems that will be installed during 1978 were also obtained and are shown in Table 2. These two systems are:

A. Village Power System for Schuchuli, Arizona. This DOE sponsored project is being managed by LeRC in cooperation with the Public Health Service and the Papago Tribe of Arizona. The system will consist of a 3570 watt D.C. photovoltaic power system and the electricity will be used to provide lighting, water pumping, refrigeration, laundry and sewing facilities for the residents of Schuchuli. Details of this system are being reported at this conference in a paper by W. Bifano of LeRC. The BOS cost in 1975 dollars is $13.08 per watt ($15.58 in 1978 dollars) for this system.

B. Village Power System for Tangaye, Upper Volta (West Africa). This USAID sponsored project is being managed by LeRC in cooperation with the USAID mission in Upper Volta. The system will consist of an 1800 watt D.C. photovoltaic power system and the electricity will be used to provide water pumping and grain grinding for the village. The BOS cost in 1975 dollars is $13.61 per watt ($16.21 in 1978 dollars).

An analysis of the Table 2 data was performed to determine the degree of correlation for a power function of the form

$$y = ax^b \quad x \geq 0$$

where y equals direct labor and material BOS cost per watt and x equals the number of watts in the installation.

The regression equation developed from the data is:

$$\text{BOS \$/watt} = 296 \times (\text{Peak Watts})^{-0.4119}$$

$$R = -0.82 \text{ (Linear Correlation Coefficient)}$$

The BOS cost per watt, for D.C. flat-plate photovoltaic systems up to four kilowatts, is now larger than the cost per watt of the photovoltaic modules. Since A.C. systems are more complicated, the BOS cost for A.C. systems similar in size (viz., up to say 10 kilowatts) will also be greater than the cost of the modules.

The BOS costs for the two multikilowatt village power systems are nearly equal ($13.61 per watt for the Upper Volta system and $13.08 per watt for the Arizona System) despite the fact that one is nearly twice the peak power of the other. There can be little doubt that the magnitude of the BOS costs for multikilowatt systems is significant.

SURVEY OF BOS COSTS FROM THREE MANUFACTURERS

To provide a basis for comparison of LeRC BOS costs with commercially purchased systems, a survey was conducted of prices from three photovoltaic suppliers for typical BOS components. The pricing of these components included material costs and some labor for the assembly of voltage regulators, for the wiring and assembly of modules into arrays, and for other such labor items that could be accomplished in the vendor's plant. Labor for field assembly, installation, testing and checkout was not obtained during this survey.

In order to make a direct comparison of LeRC costs and manufacturers' BOS prices, a baseline system was selected. This baseline was a two kilowatt, D.C. system with battery storage for a region such as Arizona. The estimated average BOS cost per watt for this baseline system using the LeRC regression equation was $13. The range of BOS component prices obtained from manufacturers was $5.75 to $9.25 per watt. The manufacturers' prices were then adjusted to add installation related costs, which resulted in the range of $8.63 to $13.88 per watt. These BOS cost comparisons, summarized in Table 3, indicate that the BOS costs of LeRC experiments are in close agreement with manufacturers' prices. Thus, BOS costs for present multikilowatt photovoltaic systems are probably in the range from 9 to 14 dollars per watt (1975 dollars).

FRACTIONAL ALLOCATION OF BOS COSTS

An analysis was made of the LeRC BOS costs to determine the average fraction of total BOS cost for each category. These fractions are shown in Table 4. No single category of BOS cost seems to dominate.

FUTURE COSTS FOR BOS

Future BOS costs will be affected by a variety of factors; this makes it difficult to estimate possible cost reductions. For example, if module cost goals of $.50/watt are achieved, the battery size can be traded (if still required) against the lower module cost. This tradeoff, however, will increase the array requirements and costs although the net cost for storage may be somewhat cheaper. This is important considering the increasing costs of lead-acid type batteries. There will probably be some improvement in the cost of regulators as photovoltaic manufacturers begin to achieve economies of scale. Wiring requirements will probably not see an appreciable reduction since most of the wiring is from the array to the controls and loads.

Without a reduction in the amount of materials, there is not much chance of a reduction in cost. Frame and support materials will probably be reduced significantly as packing factors and cell efficiencies are increased. Moreover, it is possible to use lighter weight materials than are presently used and fastening methods can be improved significantly.

Experience and reductions of material requirements will lower the BOS material costs of future systems. It is not possible to predict accurately at this time what that reduction will be. BOS labor costs are open to considerable speculation. The labor costs of future commercial systems will most probably be less than the LeRC experiment costs for labor. The manufacturer's survey included items shipped as assembled subsystems (e.g., regulators, frames, supports) which reduce the amount of field labor required. Further economies may be possible by increasing the amount of in-factory assembly of systems.

Thus, it would appear that future costs for BOS components and labor will most likely be less than present costs (in constant dollars), but many of the BOS elements are obtained from mature industries. Wiring, fasteners, batteries, structural materials and other BOS components are obtained from industries that have achieved most of the possible economies of scale possible through reaching the limits of mass production economics. These items will not experience large cost reductions in the future.

SUMMARY AND CONCLUSIONS

The 12 application experiments conducted by the LeRC for the DOE and the 2 planned village power experiments were used to estimate the BOS costs (excluding modules) for photovoltaic systems up to 4 kilowatts in size. A survey of three manufacturers was conducted to obtain BOS cost estimates for a 2 kilowatt flatplate D.C. photovoltaic power system. Average BOS costs now exceed Block III module prices.

Although it is not possible to predict BOS costs accurately for 1986, it is known that the BOS materials are obtained from relatively mature industries. If 1986 photovoltaic technology consists of incremental improvements in present silicon technology, it is not likely that BOS costs could be decreased by more than 50 percent, if that much. With a 50 percent reduction, the BOS costs will be between $4 and $7/watt in 1986.

Significant efforts will be needed to reduce BOS costs of future photovoltaic systems. Otherwise, the achievement of the 1986 goal of $.50/watt for modules will be accompanied by a BOS cost that may be an order of magnitude greater than the module cost.

No major conclusions can be made from the data in this report for large photovoltaic power systems. However, larger systems will require scaled but similar BOS components.

Without the benefit of knowing the nature of 1986 photovoltaic technology, it would be gratuitous to expect that BOS costs will be similar in magnitude to the $.50/watt cost of the modules.

TABLE 1

Experiment	Location	User
Papago Refrigerator	Sil Nakya, AZ	Public Health Service
Lone Pine Water Cooler	Lone Pine, CA	Owens Valley Interagency Committee
Forest Towers	Antelope Peak, Lassen National Forest CA.; Pilot Peak, Plumas National Forest, CA.	U.S. Forest Service
Insect Survey Trap (charged grid)	College Station, TX	U.S. Department of Agriculture
Insect Survey Trap (black light)	College Station, TX	U.S. Department of Agriculture
Arizona Dust Storm Warning Sign	Interstate 10 between Phoenix & Tucson, AZ	Arizona Department of Transportation
Remote Meterological Station (RAMOS)	Stratford Shoals, NY	National Weather Service

Experiment	Location	User
Remote Meterological Station (RAMOS)	Clines Corners, NM	National Weather Service
"	Southpoint, HI	"
"	Loggerhead Key, FL	"
"	Point Retreat, AK	"
"	Halfway Rock, ME	"

TABLE 2

BOS COSTS FOR LeRC EXPERIMENTS

Experiment	Array Power (watts)	BOS Material & Labor Cost ($)	BOS $/watt
Papago Refrigerator	330.0	4123	12.49
Lone Pine Water Cooler	446.0	13894	31.15
Forest Towers	294.0	13369	45.47
Insect Survey Trap (charged grid)	23.2	3186	137.33
Insect Survey Trap (black-light)	162.4	3767	23.20
Arizona Dust Storm Warning Sign	116.0	5689	49.04
RAMOS (NY)	110.4	3177	28.78
RAMOS (NM)	73.6	3151	42.81
RAMOS (HI)	73.6	3151	42.81
RAMOS (FL)	73.6	3151	42.81
RAMOS (AK)	147.2	6209	42.18
RAMOS (ME)	110.4	3177	28.78
Arizona Village Power	3570.0	46696	13.08
Upper Volta Village Power	1800	24498	13.61

TABLE 3

COMPARISON OF LeRC BOS COSTS WITH MANUFACTURERS' PRICES

Item	BOS $/watt
Manufacturers' Suggested Prices for BOS Components	5.75 to 9.25
Manufacturer's Prices Plus Labor for Assembly and Installation at LeRC Labor Rates	8.63 to 13.88
Estimate from LeRC Regression Equation	$13.00

TABLE 4

ALLOCATION OF LERC BOS COSTS

Category	Average Fraction of Total BOS Cost
Array, Structure and Site Preparation	.18
Electrical	.33
Storage	.20
Installation and Check-out	.20
Other	.09
Total	1.00

REFERENCES

1. Throughout this report, "watt" is used to mean "peak watt", and costs are in 1975 dollars unless noted.

2. Shipping is not included, nor are loads that would be powered by the systems.

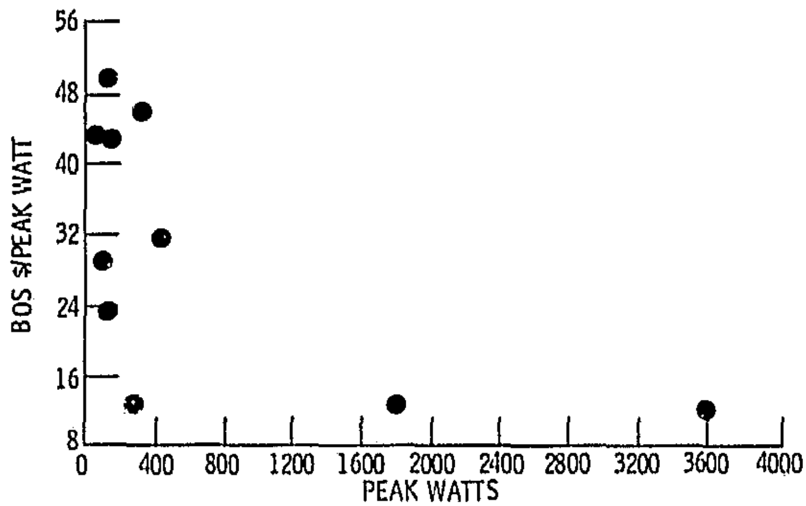

Figure 1. - Peak watts vs $/peak watt (excluding photovoltaic modules) 1975 dollars.

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