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Applications

Operation and Maintenance Field Experience for Off-grid Residential Photovoltaic Systems[‡]

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The field performance of photovoltaic systems has been studied extensively for many applications and a number of databases exist in the United States and internationally. However, these databases focus almost exclusively on the system elecrical performance. Published information on the operation and maintenance (O&M) experience and costs for photovoltaic systems is almost nonexistent. At a time when photovoltaics is being considered as a viable option for distributed energy generation, it is critical that maintenance experience be captured to identify lifecycle costs and/or levelized energy costs for these systems, as well as to identify areas for system and component improvements. This paper addresses the data collection, analysis and results of an off-grid residential customer service program offered by the Arizona Public Service (APS) Company over a six-year period from 1997 through 2002. Standardized, packaged photovoltaic systems were offered and operated by APS through a lease arrangement with customers throughout the state of Arizona. The operation and maintenance records for these systems were carefully tracked and analyzed. The O&M costs, database development, cost drivers, lifecycle cost implications, and lessons learned are presented and discussed. Published in 2004 by John Wiley & Sons, Ltd.

KEY WORDS: photovoltaic systems; operation and maintenance; off-grid residential; utility photovoltaics; database; field experience

INTRODUCTION

Reductions in the manufacturing costs of photovoltaic (PV) modules[1] coupled with improvements in the balance-of-system hardware[2] have made PV systems an increasingly viable alternate energy option for a variety of applications.[3] Electrical field performance of a number of installed systems has been examined extensively and performance databases[4–6] have been developed. However, as PV attempts to expand into potential markets, questions regarding PV system lifecycle cost (LCC) are bringing a renewed interest in the operation and maintenance (O&M) experience and cost from installed systems. A recent study[7] of grid-tied and stand-alone systems installed throughout the United States over the period 1995–2002 concludes that 50% of the systems were installed improperly, having deficiencies in safety, durability, and/or performance. The impact

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of these deficiencies on the long-term viability of PV systems is yet another compelling reason to gather and analyze O&M data. Unfortunately, published information on O&M field experience and cost is nearly nonexistent.

Why is this information so important? Compiling and analyzing field maintenance events (component and system reliability, scheduled and unscheduled maintenance) are invaluable both from a business and from an engineering standpoint. On the business side, it enables the determination of the LCC for PV systems. The O&M costs coupled with the initial system capital costs allow informed business decisions to be made as PV is compared with other competing distributed energy generation options. On the engineering side, O&M records help identify the key technical issues (component selection, system design, and O&M strategy) that underlie the performance and reliability of a PV system. This serves as invaluable feedback to guide system engineers and system developers. These are the reasons the Arizona Public Service (APS) Company and Sandia National Laboratories entered into a collaborative effort to track and analyze the field O&M experience associated with nearly 60 off-grid residential hybrid systems installed through a program offered by APS. This paper describes the program, O&M experience, database development, system LCC and the lessons learned.

OFF-GRID RESIDENTIAL (OGR) PROGRAM

Background

Headquartered in Phoenix, APS[8] is the largest electric utility in Arizona, serving 902 000 customers in 11 of the state's 15 counties. Responding to customer requests, APS established a program in 1997 to provide off-grid electric service to remote customers throughout its service territory. This program was initiated as a new business opportunity to gain familiarity and experience with PV energy options while meeting customer energy needs.

The program offered four standard packages of leased systems, corresponding to nominal daily outputs of 2·5, 5, 7·5 and 10 kW h. Emphasis was placed on quality components and installations, with each system configured and tested at the APS Solar Test and Research (STAR) facility in Phoenix prior to installation at the customer's site. Quarterly and emergency O&M was provided by an APS contractor, who was required to document each maintenance activity for each system in sufficient detail to identify dates of service, cause of outage, replacement components, service performed, and costs of travel and labor for the maintenance. A program option allowed customers to purchase systems, although the vast majority of the systems were provided through a lease arrangement.

PV system descriptions

A summary of the four standard packaged configurations (Figure 1) is shown in Table I. Each system included ASE Americas (now RWE Schott Solar) modules, a Trojan battery bank, Trace (Xantrex) inverter and battery charge controller and a propane generator. System pricing was established by APS to include the complete package plus installation and set-up.

DATABASE DEVELOPMENT AND DATA COLLECTION

Since early 1999, Sandia has been working to develop a comprehensive database model to track costs of PV systems. This database, which continues to undergo improvements, was utilized to capture, document, and track maintenance service, repairs, replacements, and labor and travel costs associated with maintenance activities on the OGR program. Based on Microsoft Access, the database architecture is modular to support future additions, allows associations at the component level, allows multiple components to be tracked with a system, and provides for multiple failures to be documented as a result of a maintenance visit. Failure modes (what and why), activity dates (failure and repair), and costs (labor, parts, and travel) were captured and analyzed for each individual OGR system from maintenance activity logs covering the period 1997–2002. From these data, analyses of failure modes, repair costs, and projected LCC for these systems were made.

Figure 1. Standard OGR system

Table I. Summary of packaged system configurations

OGR System (daily kW h)	2·5	5	7·5	10
PV(W)	570	1140	1710	2280
System voltage (Vdc)	12	24	48	48
Battery storage capacity (kW h)	10·8	22·6	33·4	43·2
Inverter size (W continuous)	Trace 2500	Trace 4000	Trace 4000	Trace 4000
Inverter output (V)	120/240	120/240	120/240	120/240
Battery charger (A/V)	40/12 V	40/24 V	40/48 V	40/48 V
Battery charge controller	Trace C40	Trace C40	Trace C40	Trace C40
Cost of basic system without generator (USD)	10 900	17 200	24 800	28 000
Cost of basic system with 7 kW generator (USD)	17 300	23 600	31 200	34 400

In addition to the OGR systems, Sandia is utilizing the database to examine O&M costs for other PV applications, including water pumping[9], residential grid-tied, and utility-scale grid-tied systems in conjunction with system owner partnerships. The database model is available for other systems/partnerships by contacting the corresponding author.

RESULTS

As noted earlier, each system received quarterly maintenance visits as well as unscheduled maintenance visits to handle emergency outages. The quarterly maintenance included generator service (oil change, filter, adjustment and inspection), battery inspection and service, inverter inspection, as well as an overall system inspection. When problems were noted during the quarterly visit, repairs/replacements were made. Figure 2 shows the total O&M costs for both the scheduled and unscheduled service as a percentage of the initial system capital costs. Figure 3 shows the total O&M average running cost per quarter as a function of the total installed units. Although the total number of OGR systems installed over the period 1997–2002 was 62, the maximum number of operational systems in the program at any given time was 50. As systems were sold to customers, they were removed from program operational status.

As noted, the total O&M costs stabilized about two years into the program, reflecting a statistically larger number of installed systems as well as an increasing learning curve on maintenance experience. In addition, the

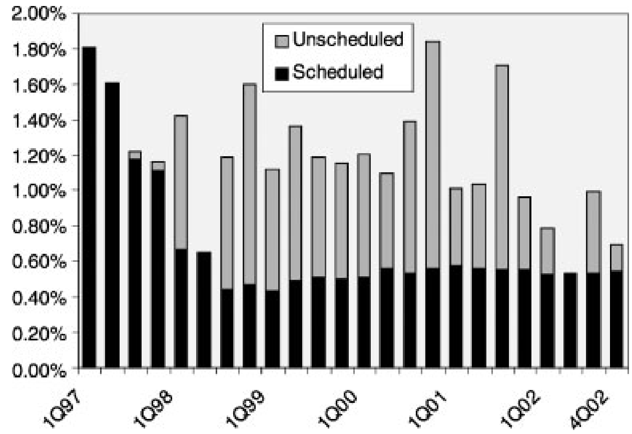

Figure 2. Total quarterly O&M costs as a percentage of the system initial capital cost

O&M costs decreased during the last year of the program period shown, reflecting the improvements to the systems from previous maintenance activities. The average annual O&M cost for the systems over the last four years of the period shown is 5–6% of the initial capital cost. These costs do not include battery bank replacements, only battery service. The first systems were reaching their battery end of life at the end of 2002, approximately six years after installation. The 25-year LCC analyses for these systems did include projected battery replacements at 6-year intervals.

As shown in Figure 4, the total costs of unscheduled O&M (48·3%) and scheduled O&M (51·7%) are very close over the six-year period. However these data also identify a major cost driver associated with the operation of the program, that of travel costs associated with unscheduled maintenance. These costs (travel time and mileage) account for 42% of the unscheduled maintenance. The program was set up to provide contracted maintenance service from a central location in Arizona. However, the widespread, geographically dispersed systems, covering most of Arizona, clearly added a significant component of cost to the program.

Figure 5 shows a breakdown of the unscheduled O&M costs by component. The PV modules account for a very small percentage of the total O&M, mostly associated with the replacement of broken modules. Maintenance cost drivers include the generator at 27·8% and the inverter at 16·5%. In many cases, the actual problem was associated with the interface of these two components. The largest contributor is system setup, modification, and removal, all associated with the operation component of O&M.

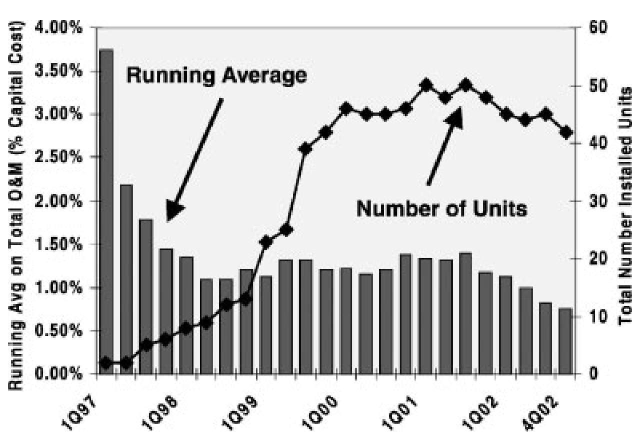

Figure 3. Running average of total quarterly O&M costs for OGR systems as a function of total number of installed systems

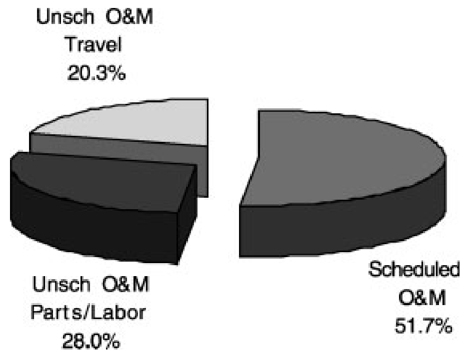

Figure 4. Total O&M cost breakdown for OGR program

Implications for customer service energy options

APS was prompted to initiate the OGR program to meet a need for customer service, to gather field experience with a new technology, and to examine whether this could be a profitable business opportunity. Figure 6 presents the total projected 25-year LCC for the OGR systems by system size. In each case, the O&M component of LCC is nearly equal to or greater than the initial cost. Clearly, the O&M portion of LCC is a substantial cost component that must be accounted for when looking at a positive cash flow for leased PV service. Figure 7 presents a comparison of 25-year LCC for two sizes of OGR systems with LCC for line extension. In the case of the utility line extension, the first mile construction cost is $19 K and each additional mile costs $35 K. Annual line maintenance costs $300 per mile. In both cases, OGR and line extension, the discount rate was assumed to be 3·4% and the interest rate on borrowed money is 5%.

As noted in Figure 7, the breakeven cost of the 2·5 kW h/day OGR system is at 1·25 mile and the breakeven cost of the 10 kW h/day OGR system is just shy of 2 miles. For line extensions greater than these breakeven points, the PV option is less expensive. In fact, from the customer's perspective, the avoidance of electricity cost associated with the line extension option would shorten the breakeven distance, making PV even more attractive. It should be noted that these conclusions for breakeven costs are based specifically on the assumptions made in the analyses. The actual cost of service varies significantly among various utilities and the assumptions made here are not appropriate to all utilities. Decisions should be made on a case-by-case basis and should address other service issues not included here. However, the impact of LCC comparisons clearly establishes that off-grid PV systems are a viable option to gridline extension.

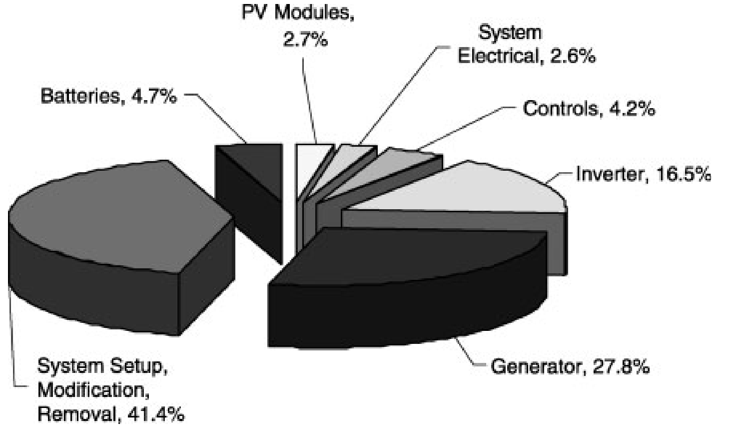

Figure 5. Unscheduled O&M cost by component

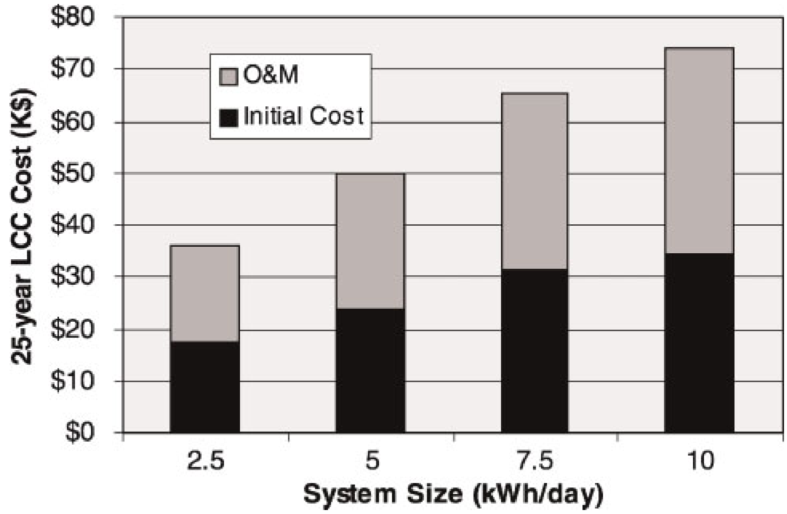

Figure 6. LCC for OGR systems

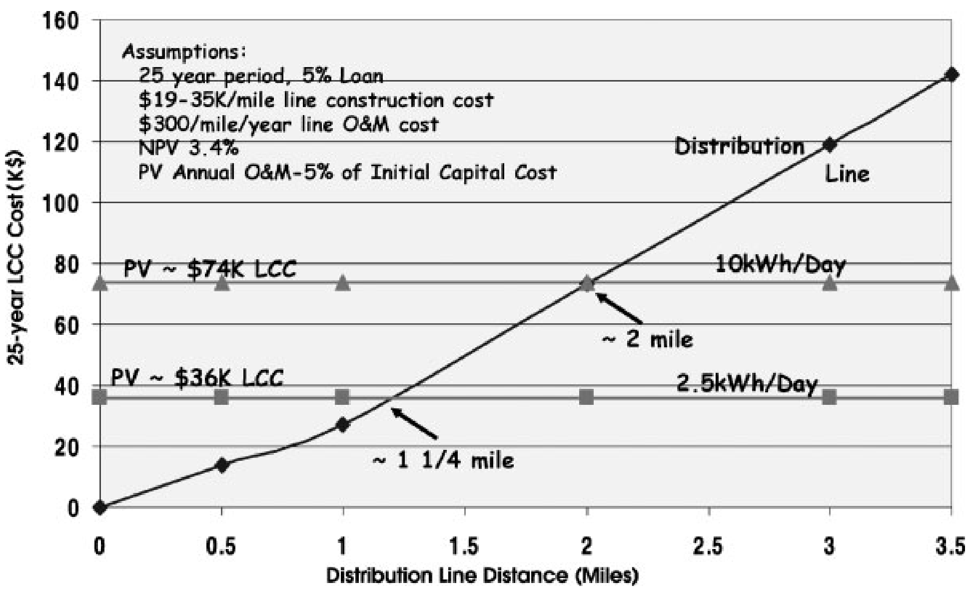

Figure 7. OGR LCC versus line extension LCC

LESSONS LEARNED

A number of lessons were learned regarding the program features, O&M service, and component hardware through the OGR program. Others interested in developing an off-grid PV service business would be well advised to consider the following findings.

Design simply and pay special attention to the generator and inverter:

- conduct a site review and energy audit of the customer's power usage and load characteristics to make sure the system is appropriately matched;
- follow a conservative system design to reduce long-term O&M costs;
- limit packaged systems using same hardware to standardized sizes of 5 and 10 kW h/day to reduce inventory needs, to reduce/eliminate modifications, and to simplify O&M;

- performance match and extensively test the generator, inverter, and interface before installation to reduce unscheduled service calls.

Unscheduled maintenance and a geographically dispersed territory are extremely costly:

- increase preventative actions during scheduled O&M service to reduce emergency calls;
- reduce the size of the service area to avoid the high travel costs of unscheduled maintenance.

Assure best use of systems by the customer:

- ensure that the program includes a customer education component to assure the customer's needs are compatible with the limited energy output of the PV service option and to inform the customer of expected O&M;
- meter the systems so that energy output and use may be conveniently monitored by the owner;
- help the customer implement load efficiency improvements and load control strategies to reduce cost of service.

Implement program controls to reduce overall cost:

- require a minimum one-year lease arrangement with a significant deposit to reduce the high cost of system set-up, modification and removal;
- implement a tiered lease pricing structure to charge appropriately for energy use to avoid excessive generator runtime and service calls created by over-consumption;
- consider a deductible service fee to reduce nuisance calls and improper operation of the system by the customer.

CONCLUSIONS

The management of O&M cost is critical for the economic viability of a successful business offering PV systems for off-grid residential electrical service. The APS OGR program found that the O&M component of LCC is nearly equal to the initial first cost of the systems. Additionally, the average annual O&M cost is 5–6% of the initial capital cost and is a significant consideration in pricing service. A number of cost drivers for the OGR program were identified, including the high cost of travel for unscheduled service calls; the high program operating cost of system set-up, modification, and removal; and the high incidence of service calls associated with generators, inverters, and their interface. On the basis of these assumptions , the OGR PV service option will reduce utility costs for remote customers requiring 300 kW h/month when line extensions exceed 2 miles. A number of lessons learned from a six-year operating period for the OGR program have been identified to help control costs and help establish success in a new business opportunity. Finally, the need to capture, understand, and quantify the O&M field experience of installed systems is mandatory for expanding PV applications into new markets.

POSTSCRIPT

In 2003 APS discontinued the OGR program for new customers. The systems that remain in the existing program will continue to be serviced and maintained by the utility until sold or the lease expires. However, APS will continue to offer an Environmental Portfolio Standard (EPS) customer green credit purchase on off-grid PV systems of $2 per watt. In the first two years (2002–2003) of the EPS rebate program, nearly 200 remote APS customers have claimed the rebate on new system purchases. The Arizona Corporation Commission EPS goal encourages APS to generate 1·1% of its energy through renewable resources, with 60% of that amount from solar. To accommodate this goal, APS will increase the EPS credit purchase on grid-tied PV systems to half the system cost, with a limit of $4 per watt. In addition, APS is installing several large utility-scale solar plants in Arizona. These programs will provide new opportunities to gather field O&M experience with installed systems in the APS service territory.

Acknowledgement

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