

ECONOMIC ANALYSIS OF PV HYBRID POWER SYSTEM: PINNACLES NATIONAL MONUMENT

Andrew Rosenthal • Steven Durand
Southwest Technology Development Institute, Las Cruces, NM

Michael Thomas • Harold Post
Sandia National Laboratories, Albuquerque, NM

ABSTRACT

PV hybrid electric power systems can offer an economically competitive alternative to engine generator (genset) systems in many off-grid applications. Besides the obvious 'green' advantages of producing less noise and emissions, the PV hybrid can, in some cases, offer a lower life-cycle cost (LCC) than the genset. This paper evaluates the LCC of the 9.6 kWp PV hybrid power system installed by the National Park Service (NPS) at Pinnacles National Monument, CA. NPS motivation for installation of this hybrid was not based on economics, but rather the need to replace two aging diesel gensets with an alternative that would be quieter, fuel efficient, and more in keeping with new NPS emphasis on sustainable design and operations. In fact, economic analysis shows a lower 20-year LCC for the installed PV hybrid than for simple replacement of the two gensets. The analysis projects a net savings by the PV hybrid system of \$83,561 and over 162,000 gallons of propane when compared with the genset-only system. This net savings is independent of the costs associated with environmental emissions. The effects of including emissions costs, according to NPS guidelines, is also discussed.

Key to the favorable economics of this PV hybrid system was an integrated program of load management and load segmentation. The net effect of this program was to reduce the original site loads by 50% and to divide them between two single-phase circuits, thus allowing the use of less-costly, off-the-shelf components. In this way, load segmentation kept initial costs down while load management ensured that, over time, the PV array would provide the large fraction of total site energy for which it was designed.

INTRODUCTION

Off-grid users of electricity have the option to select generation by either a fossil-fueled engine generator (genset) or by a system that produces some or all of its electric energy from renewable sources. Systems that use PV arrays and batteries (with inverters, when

required) supplemented by back-up generators are known as PV hybrid power systems. In general, PV hybrids present certain favorable characteristics when compared with gensets: 1. Produce less emissions; 2. Consume less fuel; 3. Produce less noise; 4. Reduce engine run-time.

These inherent advantages of PV hybrids are usually balanced by associated disadvantages: 1. Higher purchase price; 2. Increased complexity; 3. Added maintenance associated with batteries.

In some cases, the inherent advantages of PV hybrids are sufficient in themselves to justify their use. In these cases, the criteria are difficult to economically quantify, but the National Park Service emphasis on environmental benefits is noteworthy in this regard. Other users of PV hybrids base their purchase decision on a projected economy of operation that is expected to save money over the life of the system. Mountain-top telecommunications sites have been equipped with PV hybrids in order to reduce the number of difficult and expensive fuel deliveries otherwise required. These decisions are usually made based on a comparative life cycle cost analysis (LCCA).

Renewables and the National Park Service

The National Park Service (NPS) charted its policy direction into the next century with the 1991 document titled *National Parks for the 21st Century: The Vail Agenda*. This document placed an emphasis on sustainable design as a cornerstone for enabling the NPS to meet the needs of the present without compromising the ability of those who follow to meet their needs. Energy management, including the use of renewable energy sources, is a key focus of sustainable design.

In 1992, the U. S. Department of Energy and Sandia National Laboratories (SNL) partnered with the NPS to promote energy conservation and increase the use of renewable energy at NPS facilities. Surveys of existing PV use, the potential for future PV use, and barriers to

that use were obtained from 368 field units (parks). Phase II surveys were then sent to parks identified as potential users of larger PV systems. Ultimately, all survey data and analyses resulted in the formulation of the five-year program to expand the use of renewable energy known as *Renew the Parks* [4].

The highest priority was assigned to projects where existing diesel gensets could be replaced with renewable energy hybrid power systems that use propane generators as backup.

PINNACLES NATIONAL MONUMENT

In January 1995, SNL and NPS staff assessed the Chaparral area at Pinnacles National Monument as a candidate for genset replacement with a renewable energy hybrid system. The area included a maintenance shop, two residence trailers, a ranger station, a campground with comfort station, and parking area. At the time, the site was served by two diesel gensets (Caterpillar 100kW, 3-phase diesel gensets derated to 57 kW for single-phase operation) that were in need of replacement. Gensets ran 24 hours per day. Review of 18 months of electrical meter readings showed an average site load of approximately 81 kWh per day.

SNL Recommendations

The SNL study provided a recommended implementation plan [3] for replacement of the existing diesel gensets with a PV hybrid power system. This plan addressed the desires of park personnel to reduce noise, emissions, and risk of fuel spill, as well as enhance the quality of visiting the park. Economics, though always important, were not the primary consideration.

Critical to the SNL plan was an integrated program of energy efficiency and load management designed to reduce site energy requirements by fifty percent. With the existing, oversized diesel gensets, it was necessary to leave several lights on continuously to provide a stabilizing load for the idling engines. Use of smaller gensets would eliminate the need for this stabilizing load. Installation of energy-efficient lamps would also ease the lighting load. Water pumping loads would be reduced through the installation of low-flow devices throughout the site. Replacement of an electric stove and water heater by propane-fueled units would further lessen the electric load. And electronic control of lift pump motors would stagger their starts so that inrush surges presented to the energy system would be minimized. Key to the plan was the use of load segmentation in the overall system design. All site electrical service would be divided into two, separate, single-phase lines. This would keep the maximum single-phase load below 16 kW and allow for the use of off-the-shelf inverters (see below).

PV Hybrid System Description

In late 1996, a PV hybrid power system was installed at the Chaparral area at Pinnacles by Applied Power Corporation, Lacey, WA. The system comprised: 9.6 kW PV array (160 Solarex MSX-60 modules); 4200 Amperehour battery (12 model 6-75RC33 Resource Commander batteries); battery charge controller (Ananda Power model APT-4444-48); 24 kW inverter bank (six 4-kW Trace SW4048 120/240 inverters, configured as 4 in parallel serving one line and 2 in parallel serving the other); 20 kW generator (Kohler 20RZ, 20 kW generator configured for propane). A dedicated data acquisition system (DAS) was installed on the PV hybrid to record the following parameters: PV, battery, load, and generator energy; battery string currents; battery voltage; battery, PV, and ambient temperatures; and irradiance. Data have been taken from January 1997 to the present.

1997 Load, Energy Generation, and Fuel Use

Figure 1 presents the monthly energy fraction (in percent) produced by the genset and the PV array along with the monthly electrical load in kWh at Pinnacles.

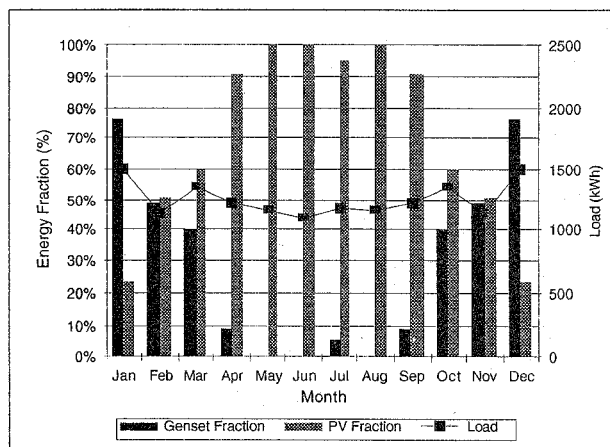


Figure 1. PV Hybrid System: Recorded Monthly Genset and PV Energy Fractions, and Load.

From May through September, the array provided virtually all of the energy needed by the site. Though site load is slightly higher in winter (due to increased lighting load and water pumping by comfort station pumps of winter rain runoff), it remains relatively constant throughout the year, varying from only 38 kWh/day in June to 47 kWh/day in January. Noteworthy in the figure is that the program to reduce the site loads has been markedly effective: site load average has dropped from its original 81 kWh/day in 1995 to 41 kWh/day in 1997.

Figure 2 shows the monthly propane used by the PV hybrid system and compares this with the projected propane consumption that would be required to meet the site loads with genset-only operation. Estimated fuel consumption is determined based on measured site load and the genset manufacturer's published fuel consumption/load curve data.

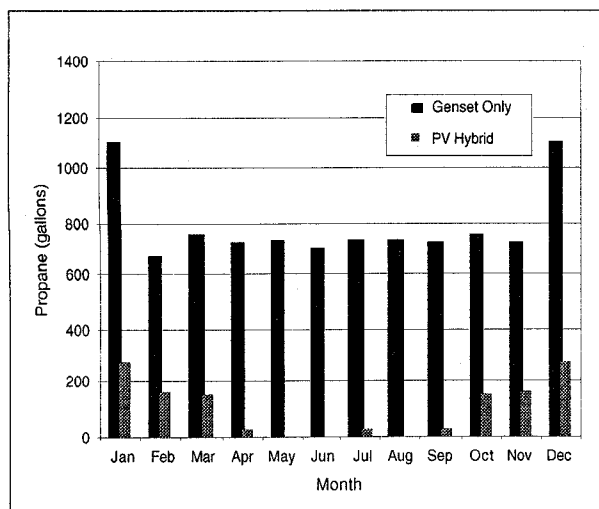


Figure 2. Fuel Use Comparison: Genset-Only System vs. PV Hybrid Alternative.

Over the year, the PV hybrid genset runs only 793 hours and burns 1265 gallons of propane, compared with 8760 hours or run-time and 9411 gallons of propane for the genset-only system.

ECONOMIC ANALYSIS

Conventionally, the old diesel gensets would be replaced through the purchase of two new gensets. Therefore, for this economic analysis, the base case determines the costs associated with replacement of the two diesel gensets by two new 20-kW propane gensets. The alternative case assesses the 20-year LCC of the PV hybrid system actually installed.

Summary of the LCC associated with the base case and the PV hybrid alternative is presented in Table 1. This analysis uses the DOE/FEMP 1996 recommended discount rate for Federal energy conservation projects of 4.1%. The LCC estimate projects a net savings associated with the PV hybrid of \$83,561 over the 20-year service life. This equates to a simple payback period of 7 years and a discounted payback period of about 11 years. In addition, the PV hybrid will save over 8,000 gallons of propane fuel each year, or over 162,000 gallons during a 20-year service life.

The strength of this analysis is its use of actual load, PV production, and generator run-time data recorded by the

on-site DAS. O&M and replacement schedules were also developed for all major components. For the gensets, O&M comprises: oil change (\$125, every 250 hours); valve adjustment (\$250, every 2000 hours); replacement (\$24,000, every 30,000 hours). In the base case, gensets are replaced every 7 years, while the reduced genset run-time for the PV hybrid system will allow it to serve for the full 20 years without replacement. For the PV hybrid, battery costs include watering (\$250 per year); replacement (\$22,000 every 8 years).

Table 1
Pinnacles National Monument Power System
20 Year Life Cycle Cost Analysis
Comparison of Two Present-Value Alternatives

	Base Case	PV Hybrid Case
Initial Investment		
Capital Requirements as of Service Date	\$24,000	\$135,000
Future Costs		
Annual and Non-Annual Recurring Costs	\$74,089	\$10,399
Energy-Related Costs	\$164,888	\$22,230
Capital Replacements	\$31,790	\$43,577
Total Present Value	\$294,767	\$211,207

Including Emissions Costs

The LCC analysis presented above was determined independent of any costs associated with the release of carbon dioxide, sulfur dioxide, and nitrous oxide gases, the main contributors to global warming. In 1994, the NPS Denver Service Center issued a guideline for use in planning and design of park facilities that assigned dollar amounts to the production of emissions that are a byproduct of electric power generation [4]. That guideline is summarized in Table 2.

Accurately estimating emissions from variably loaded engines is technically difficult. A very conservative approach is taken by the National Institute of Standards and Technology's BLCC Program [5] based on the type of fuel used and industry-wide averaging. Using this program, the yearly emissions and costs for each generation alternative are estimated and presented in Table 3.

Table 2
National Park Service
Environmental Emissions Costs Guidelines

Emission	Environmental Emission Cost
CO2	\$8/Ton
SO2	\$0.75/Pound
NOx	\$3.40/Pound

Table 3
Pinnacles National Monument
Annual Environmental Emissions Costs Estimates

Emission	Base Case	PV Hybrid Case
CO2	59.3 Tons	8.0 Tons
SO2	0.7 Pounds	0.1 Pounds
NOx	179.7 Pounds	24.2 Pounds
Annual Cost	\$1085	\$146

Converting the projected emissions to their equivalent dollar amounts results in a present value of \$309,396 for the base case and \$213,173 for the PV hybrid. Thus, because it releases less emissions, the present value of the PV hybrid saves an additional \$12,662 (total savings: \$96,223 over 20 years).

The favorable emissions figures and costs of the Pinnacles PV hybrid are even more striking when compared with those for the site's original diesel gensets. In 1995, SNL estimated [4] that the site's diesel system annually produced 143 tons of CO2, 6900 lbs. of NOx, and 343 lbs. of SO2. This high level of emissions had a proportionately high equivalent annual cost, \$24,861.

DISCUSSION

Of all PV hybrid systems evaluated through the DOE Photovoltaics Program, the system in operation at Pinnacles National Monument is the first that meets all expectations of environmental improvement, high reliability, and cost-effectiveness. Several factors combine to make this true.

Segmentation of the loads keeps them within the rating of commercial, off-the-shelf components. And, active management of the load keeps the peaks from exceeding these ratings. For example, the lift pump motor starts are electronically controlled so that only one motor starts at a time, limiting total inrush current.

Proper sizing of the array and battery are critical to controlling genset run-time and its associated recurring costs of fuel and maintenance. Further examination of

effective component sizing guidelines will be presented in a future study.

CONCLUSIONS

The PV hybrid system installed at Pinnacles National Monument has been in operation for 10 months with excellent availability and reliability. Though 5 times more expensive to purchase than a genset-only system, the 20-year life cycle cost (LCC) for the PV hybrid is actually less, with a discounted payback of about 11 years.

In addition, over its 20-year life, the PV hybrid will consume 162,000 fewer gallons of propane and avoid the emissions of over 1,000 tons of CO2 and 1.5 tons of NOx compared with the genset-only system. Thus, using National Park Service emissions costs guidelines, the PV hybrid also saves an additional \$939 per year when compared with operation of a genset-only system.

The cost effectiveness of this PV hybrid system is due to the combined effects of active load management, load segmentation, and effective system design.

ACKNOWLEDGMENTS

This work was supported by the U. S. Department of Energy under Contract DE-AC04-94AL85000. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the U. S. Department of Energy.

REFERENCES

- [1] S. Fuller, S. Petersen, *Life Cycle Costing Manual for the Federal Energy Management Program*, NIST Handbook 135, February 1996.
- [2] S. Petersen, *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis 1997*, Annual Supplement to NIST Handbook 135, July 1996.
- [3] H. Post, M. Thomas, *An Engineering Assessment of the Potential for Renewable Energy Power Systems at Pinnacles National Monument*, Sandia National Laboratories, January, 1995.
- [4] *Renew the Parks: Renewable Energy in the National Park Service*, United States Department of the Interior, National Park Service, February, 1995.
- [5] *NIST LCC Support Software, BLCC4*, United States [Department of Commerce, Technology Administration, National Institute of Standards, April 1997.