Case Study: Mobile Photovoltaic System at Bechler Meadows Ranger Station, Yellowstone National Park

Figure 1. Mobile 9 kW Photovoltaic System at Bechler Meadows Ranger Station, Yellowstone National Park. *Photo from DOE Federal Energy Management Program (FEMP)*

Introduction

This report describes the performance of a mobile photovoltaic (PV) system installed in 2011 to provide power to Bechler Ranger Station in Yellowstone National Park, Wyo. This small, remote outpost is not served by the electric utility grid and previously relied on a propane generator as the only source of power.

Mobile Photovoltaic Systems

Mobile solar systems consist of photovoltaic (PV) solar-energy panels, batteries, and other components that can be moved as a package from one location to another. Mobility is advantageous if the power supply must be moved or quickly deployed from one location to another, such as for event power or disaster relief. They offer an advantage in situations when fuel would be difficult or expensive to deliver, such as remote or crisis areas. Mobile solar systems can be pushed on carts, mounted as packs on horses or camels, mounted on trailers, or shipped in standard shipping containers. The systems operate autonomously without connection to any utility company. PV modules are not heavy, but they require a large surface area to intercept solar radiation – between 5 and 10 m^2 (50 to 100 ft^2) per each kW generated. A battery the size of two car batteries is required per each 1 kWh of energy stored, so, in order to store many kWhs, the batteries are big and heavy. Designers of mobile PV systems must overcome these two challenges.

Bechler Ranger Station, Yellowstone National Park

The Bechler Soldier Station was established by the Army in 1910 as an outpost to Fort Yellowstone. It provided a base for soldiers to stop illegal hunting in the remote southwest corner of the park. Today the National Park Service (NPS) operates the facility from late May until early November. It accommodates six to eight park rangers and functions as a contact station for visitors entering the backcountry, including hikers, backpackers, and fishermen.

Facilities consist of a historic duplex housing unit, workshop, visitor contact station, a modular building used as a dormitory, and a historic horse barn. There are also two RV sites for seasonal employees. Electrical loads include a large well pump for supplying water and for fire suppression. In 2002, the Federal Energy Management Program (FEMP) estimated the daily electric use to be approximately 35 kWh/day and overall consumption for the occupied period to be approximately 5,355 kWh/year. Previously, the site depended on a 20-kW propane generator, which operated 24 hours per day. The site also uses propane for thermal loads such as water heater, clothes dryer, and space heating.

Project Delivery Process

In 2002, FEMP provided a feasibility study which recommended a PV system and battery bank in a permanent installation. However, staff were concerned that PV would be vulnerable to damage in the severe winter conditions and also subject to theft and vandalism due to the isolation. Bechler Ranger Station is designated as a National Historic Landmark district,

Maximum Daily Solar Energy Delivery (on 6/26)	*34.7*	*kWh/day*
Minimum Daily Solar Energy Delivery (on 9/3)	*10.2*	*kWh/day*
Average Daily Solar Energy Delivery	*23.0*	*kWh/day*
Peak Instantaneous Solar Power (at noon 7/13)	*10.6*	*kW DC*
Total Solar Energy Delivery for the season (6/2 to 10/8)	*2909.9*	*kWh*

Table 1. Daily and total solar energy delivery for the 2012 season, June 2 to Oct. 8, 2012.

so a permanent solar system would also have a visual impact on the cultural resource. The only buildings available for roof mounting are historic and do not face south.

Deployment of a mobile PV system avoids these problems, and, in October 2010, NPS posted a solicitation for a trailer-mounted system. A concept offered by Strategic Services International was selected based on a design that they had developed for military applications.

Deployment

First deployed at Bechler Ranger Station in July 2011, the solar trailer is brought to the site each May once roads are passable and returned to Yellowstone's Mammoth Hot Springs in early October. The system is built on a gooseneck trailer that can be pulled behind a properly equipped truck. The trailer does not have to be placed precisely because the solar panels can be moved to the optimal position regardless of the position of the trailer. The solar modules are mounted on racks that rotate, extend, and unfold to expose the large solar array. One person can operate hydraulic controls from a position at the back of the trailer to deploy the system in approximately 45 minutes. First, feet are put down to stabilize the trailer. Then, hydraulic actuators fold the PV arrays out from the trailer on long cantilevered arms, and then another set of hydraulic actuators slide apart the two rows of solar panels on each arm. Orientation (the tilt and azimuth angle of the solar collectors) can be easily adjusted using the hydraulic controls. However, the system does not automatically track the sun across the sky. The tilt angle is periodically adjusted, typically twice in the summer season, to better intercept solar energy.

Figure 3. Hydraulic actuators rotate, unfold, and position the solar arrays. *Photo: Andy Walker*

Equipment Specifications

An enclosure at the front of the trailer houses boxes to combine wiring, DC/AC inverters, charge controllers, and a panel with breakers to each load. A 22 kW propane-fueled generator (Generac) is mounted on the deck of the trailer. The batteries are laid in down between the rails of the trailer frame. The system has the following components: 32 multi-silicon PV modules (Suntech STP 280-24Vd), each rated at 280 W for a total solar power rating of 8.96 kW DC; 2,500 amp hours of battery storage at 48 volts (UPG Corp. UB8D, 40 batteries total); 183-amp charge controller (Outback Solar); and three inverters totaling 18-kW capacity (Xantrex XW6048).

Electrical power is delivered through overcurrent circuit breakers in the electrical panel of the trailer to temporary electrical cabling. The voltage is 120/240 V AC and the maximum current is 150 amps, so the mobile solar power system provides an electric service almost identical to that of typical residential service. This cable feeds power to the electrical distribution panel in the old generator building that distributes power to each of the buildings. Inefficient appliances in each building were replaced with ENERGY STAR-qualified equipment.

Figure 2. Mobile PV system shown stowed on the trailer upon delivery to Yellowstone National Park. *Photo: Jim Evanoff*

Performance

Performance of the system was evaluated during the 2012 summer season (June 2 to Oct. 8). The mobile solar system reduces the run-time of the generator from 24 hours a day to one to two hours a day depending on

Figure 4. Components mounted in a NEMA 4X enclosure in the front of the trailer include (clockwise from top left) combiner boxes and charge controllers, breakers to loads, and inverters. *Photo: Alicen Kandt*

the weather, saving associated noise, emissions, and propane use.

Shading is a serious detriment in this forest location. Shading is minimized by careful positioning of the trailer and the array arms. Still, there is really only one place on the site to locate the trailer and the removal of trees would detract from the character of the site. Shading analysis estimates that, in the summer months, when the sun is almost directly overhead, losses due to shading are 11% in June, 9% in July, and 9% in August. But in fall, when the sun is lower in the sky, shading losses increase to 25% in September and 51% in October.

Daily solar energy delivery (kWh/day) is shown in Figure 5 for the summer of 2012. The system very consistently delivers about 23 kWh/day. This daily delivery depends not only on the amount of sunlight and the efficiency of the solar system, but also the state of charge of the batteries and whether there is load sufficient to use all the solar energy available in a day. Since the solar output often exceeds the load during the day, excess solar energy is put into the batteries for use at night. Each of three charge controllers reduces the amount of solar energy put into the batteries as they get charged up, and when the batteries reach their full state-of-charge, each charge controller disconnects the PV array attached to it. Figure 6 shows the details of one-day energy delivery through the three charge controllers. It is seen that during the middle of the day, when the available solar energy is maximum, charge controller 2 and 3 discontinue charging due to the battery becoming fully charged, and there is no useful purpose for the excess solar power. Based on the system size, efficiency, shading, and climate data, the PV system could deliver between 13 kWh/day in October and 32 kWh/day in July, so as much as 9 kWh/day of solar power are currently wasted. Park staff may look at ways to use this excess energy to heat water in the future rather than open-circuiting the PV array when the batteries are full.

Savings in propane consumption are estimated at 3,300 gallons per year. Much of this savings is attributable to the batteries allowing the generator to be kept turned off at night when the load is small, and the PV helps keep the generator turned off for days at a time.

Operation and Maintenance

The trailer requires three visits by park electrical staff from Mammoth Hot Springs each summer – one to deploy it at the beginning of the summer season, one to stow and haul it back to Mammoth at the end of the summer season, and one to change the angle of the panels mid-season. Frequent trips to maintain the permanent generators have been practically eliminated. There have been three system failures since the system was first deployed in July 2011 – twice the system was simply restarted and the third time a failed relay was found.

The dirt road and parking area are a source of considerable dust accumulation on the array, which staff removes with mild detergent and water. Trees around the array definitely reduce the output, and any removal of trees would need to be carefully designed to maintain the aesthetics of the site.

Batteries require maintenance, but the sealed batteries used in this portable system avoid complicated systems to measure density and add water required to maintain the electrolyte

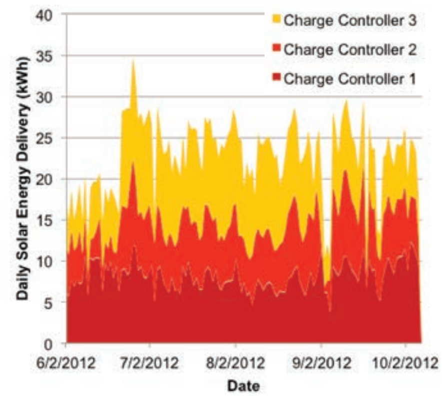

Figure 5. Daily Solar Energy Delivery (kWh/day) summed for the three solar charge controllers, adding up to an average of 23 kWh/day. *Figure by the author*

inside the batteries. However, this type of battery will need to be replaced about every eight years at a cost of $880 per battery or $35,000 for the set of 40. If the solar array is stowed, these batteries should be attached to a float charger to avoid damage due to discharge while in storage during the winter.

Planned maintenance is conducted according to accumulated run-time as measured by a counter, including changing the oil and oil filter every 100 hours, replacing the air filter, fuel

	PV Production (kWh/year)	Generator Production (kWh/year)	Renewable Fraction	Propane Use per Year	Generator Run-Time (hrs)	Generator Life (years)
BaseCase		5,355	0%	734 gal (2,800 l)	3,672	4
PV/Hybrid	3,519	2,540	53%	244 gal (946 l)	115	40

Table 2. Annual energy and fuel consumption of the generator-only basecase and the PV/generator hybrid case.

filter, and spark plugs, and flushing and filling coolant as needed. This results in a cost of approximately $2 per hour of run-time. Eventually the generator engine will have to be replaced after approximately 15,000 hours of accumulated run-time at a cost of $32,500, or approximately $2.14/hour of run-time. Fortunately, since the PV reduces the generator run-time to only one or two hours a day, the generator should not need to be replaced within the analysis period. In contrast, running the generator 24 hours a day without solar would require that it be replaced every 4 years.

Economic Analysis

The initial cost of the mobile PV system was $169,995, delivered to the site ($40,500 PV, $32,500 generator, $39,200 batteries, $9,500 inverter, and $48,000 trailer).

Propane costs an average of $1.98/gallon in recent deliveries (2011 and 2012), so savings in fuel costs are approximately $6,500/year. Annual maintenance costs described above are reduced from $14,400/year for maintenance of the generator to almost $4,000/year for the PV case, more than half of which is battery replacement.

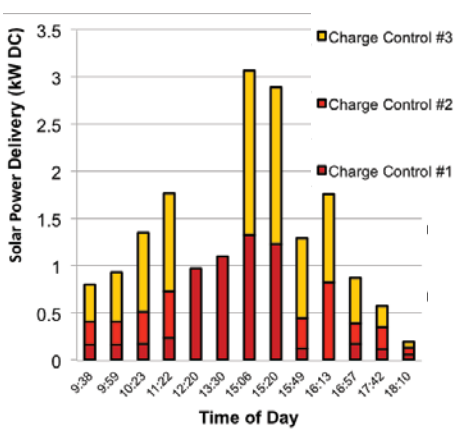

Figure 6. Solar power delivery (kW DC) through the three charge controllers over the day of Oct. 8, 2012.

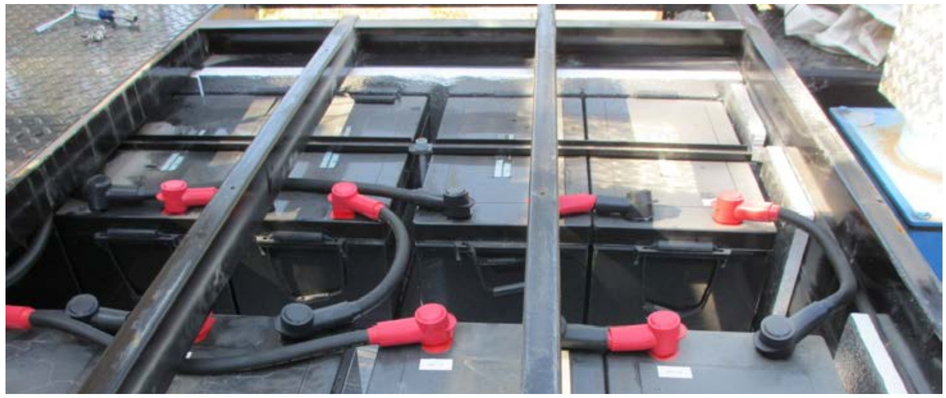

Figure 7. The batteries are protected in an enclosure built into the frame of the trailer.
Photo from DOE Federal Energy Management Program (FEMP)

Federal regulations specify the analysis period of 40 years (EISA) and the discount rate and fuel escalation rate to use in the analysis (10CFR436). These assumptions result in a present worth factor of 24 years, meaning that saving $1/year for 40 years is counted as $24 in net present value. Under this set of assumptions, the life-cycle cost (total of all costs over 40 years, discounted to present value) of the hybrid PV/generator system is $295,000, versus $400,000 life-cycle cost for the generator alone without PV. Dividing this life-cycle cost by 5,355 kWh/year and 24 years (to account for the discount rate) gives a Levelized Cost of Energy delivered estimated at $2.29/kWh, versus $3.11/kWh for the generator alone without PV.

With a $169,000 initial cost, $6,500 in fuel savings, and $10,400 in maintenance and replacement savings, the mobile PV system has a simple payback period of approximately 10 years compared to the case of the generator alone.

Conclusion

The mobile PV/generator hybrid system deployed at Bechler Meadows provides a number of advantages:

- Batteries allow the generator to operate only at its optimal rated load, reducing inefficiency at part-load
- Energy provided by the solar array reduces fuel consumption, run-time, air pollution, and maintenance of the generator
- The generator is off for most hours, providing peace and quiet at the site
- Maintenance trips from Mammoth Hot Springs to the remote site are reduced
- The frequency of intrusive fuel deliveries to the pristine site is reduced
- And the system gives rangers a chance to interpret Green Park values to the visiting public.

The PV system provides all these benefits at a lower cost than the base case of using only a propane-fueled generator, reducing life-cycle cost by about 26%, from $400,000 to $295,000.

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