CONCEPTS AND STRATEGIES FOR REMOTE HYBRID SYSTEM: A CASE STUDY OF GRAY WOLF LANDFILL

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INTRODUCTION

Photovoltaic-genset hybrid systems can be an economical alternative to generator only for powering remote commercial sites. Described in this case study is the development and installation of a hybrid system at Waste Management's Gray Wolf Landfill in central Arizona.

This case study will describe the project from its inception to the completion of construction. Examined are the following.

- Site description and current power sources
- Reasons for selecting a photovoltaic (PV) system as an option
- Design process including reasons for component selection
- System assembly and site installation
- Operation and maintenance?
- System performance?

PHOTOVOLTAIC GENSET HYBRID SYSTEM – BRIEF DESCRIPTION

Photovoltaic-genset hybrid systems are used to generate power for off-grid sites. These systems are composed of PV modules, a generator, battery storage, an inverter and other electrical hardware.

Photovoltaic modules are semiconductor based panels which produce DC electricity when exposed to solar radiation. Modules are the smallest building blocks used by designers to make photovoltaic systems. Modules typically range in size from 10 watts to 350 watts. They are combined into photovoltaic arrays up to several hundred kW in size.

These arrays are the primary generating source of photovoltaic–genset hybrid systems. Ideally, 80% to 90% of the power comes from PV. A gas or diesel generator supplies the remainder of the energy as well as some peaking capacity. Both of these sources are used to supply the customer's loads or charge batteries. Lastly, the inverter controls the conversion from DC to AC power, battery charging, and generator starting and stopping.

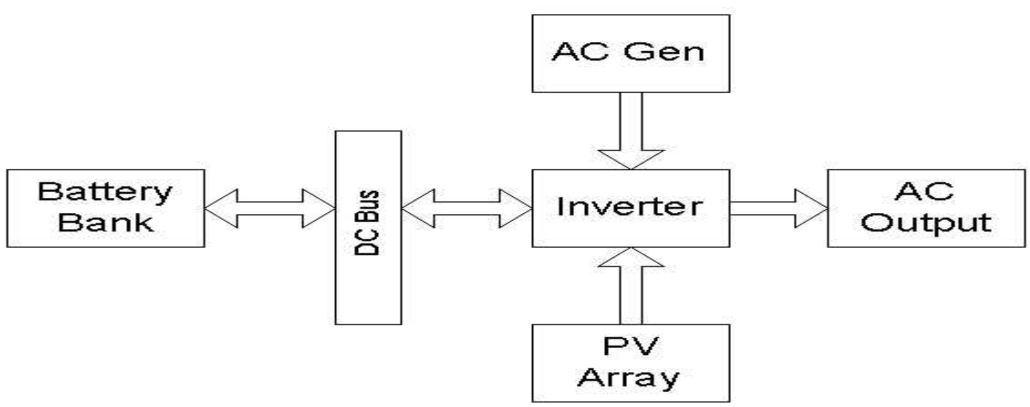

Figure 1 provides visual interpretation of the interaction of these components.

Photovoltaic-genset hybrid systems can be a cost-effective option compared to generator only option for remote power. The electricity from the PV greatly reduces fuel consumption and maintenance, which over time, are the most costly parts of most remotely powered sites. In addition to the cost savings, PV-hybrid systems offer improved reliability and reduced emissions.

In addition, hybrid systems have a redundant power source in the generator. Several inverters on the market are designed to default to the generator when there is a failure. A manual transfer switch can be installed to allow the customer to switch to generator only operation when more major malfunctions occur, giving service technicians time to repair, maintain and troubleshoot the system while still keeping the customer's lights on.

The combination of the photovoltaics and a genset also increases battery life. Through many years of experience leasing small residential and commercial systems, APS has seen that most systems without generators have greatly reduced battery life. Ideally batteries in systems without generators should last as long as systems with them. However, in practice, photovoltaic systems without generators require much more involvement and attention by the customer. This involvement is not always practical because of the lack of customer understanding or a mindset associated with leasing arrangement. As a result, systems with generators have charging that is more regular and complete than those without generators. These batteries lasted 50% to 300% longer.

Last, some inverters allow the generator and inverter to be operated in parallel. When operated in this mode, the generator can add additional capacity for infrequent, seasonal, motor starting or other operations where short-term or surge power is required. Normally, these surge loads do not justify a larger inverter.

There are drawbacks to photovoltaic-genset hybrids in comparison to photovoltaic only systems. (1) The addition of the generator adds a new component which can cause problems or fail. To overcome this, the generator must be reliable and function well with the inverter and remainder of the system. (2) Additional maintenance is required to keep the generator running and correctly interacting with the rest of the system. Most of this maintenance is in the form of quarterly planned visits to the site. For APS, these disadvantages are outweighed by the advantages above. This analysis appears to be atypical for most applications.

GRAY WOLF SITE DESCRIPTION

Gray Wolf is a regional, solid waste disposal facility operated by Waste Management, Inc. The fill incorporates a state-of-the-art engineered protection system to achieve the highest standards of environmental protection. It is Yavapai County's only permitted, fully lined municipal solid waste facility and serves many communities including Prescott, Prescott Valley, Cottonwood, Sedona and many other small communities with a total population of 150,000 to 200,000.

The facility has a sizable operation for off-grid application comprised of several buildings and a mechanics shop.

Included is a scale-house which contain offices and a meeting room. The building is approximately 1000 sq. feet. The major loads are a HVAC system, computers and lights. This office is open from 5 AM until 6 PM.

Next to the scale house is a two bay mechanics shop. This shop is used to repair the trash trucks and other site vehicles from 5 AM until midnight. Connected to the shop are offices, changing rooms and a restroom. The building is heated and cooled by an HVAC system. In addition, the shop has tools and equipment, including an air compressor, welder and various other shop tools.

Last, a mobile office is the truck dispatch office for the area's waste pickup fleet. Drivers begin their day at 3:30 AM and the last drivers leave at 3:00 PM. This office is also conditioned and operates radios, office equipment and lights.

The manager is planning to move and expand the mechanics shop and add a dumpster repair crew. Sites like these are always growing, so the hybrid system should be designed with expansion in mind.

Site Power

The site is located three miles from the nearest electric utility service; however, National Forest Land surrounds it. Because of the location, traditional power lines must be buried, making them costly. For this site, lines would cost upwards of one million dollars and take years to move through the permitting process. Instead of traditional lines, two diesel generators, (125 kW and 70 kW) powered the site. These generators operated 24-hours per day and every day of the year. After rental, fuel and maintenance, the cost of power was more than $10,000 per month. In addition, outages were common, and the maintenance was a distraction to the site's main reason for operation.

PROPOSED PHOTOVOLTAIC-GENSET HYBRID REPLACEMENT

At the end of 2001, APS began discussions with Waste Management about a landfill gas project in Phoenix, AZ. At these discussions, APS gave a presentation about our involvement with renewable energy and photovoltaic specifically. At these discussions, the Waste Management people asked for our assistance with the Gray Wolf site.

Initially, APS visited the site and performed an investigation to determine the overall loads and collect information to develop a system quote. These investigations began with placing a standard utility meter at the site for 6 months. A top-level energy audit was performed to determine the site's general electricity usage and peak demand.

Though performed briefly and with little detail for this project, the audit should be very thorough. This will be your primary sizing and design input. With a thorough understanding of the site usage, the system will be properly sized saving time and money making it well worth the effort.

From the data gathered, initial estimates of the system requirements and overall cost were made using experience from similar systems.

Once the estimates were calculated and approved, APS entered into an agreement with Waste Management. APS financed the system for a period of five years leasing. After the five-year period ends, Waste Management will own the system and can operate it or hire APS to do the maintenance. In addition to this payment, Gray Wolf is responsible for the diesel fuel consumed. Energy usage constraints are placed on the customer. If these are exceeded, APS will either upgrade the system at Waste Management's expense or help them find ways to reduce loads.

Waste Management's motivation to enter this agreement was primarily economical. A reduction in operating cost allowed the site manager to gain the approval of his management to enter into the agreement. The energy cost for the site could be reduced by 10 to 30% depending on their usage habits. Though secondary, reliability was an important factor. Any reduction in downtimes due to power loss was welcome. In addition to the lost time from no power, the site personnel would not be distracted from their primary business for maintenance. Of less importance, Waste Management was motivated by environmental recognition. As the project continued to develop, the environmental and reliability benefits increased in importance as they began understanding the technology.

For APS, this project was an opportunity to continue building its name as a leading developer of remote photovoltaic projects throughout the western US. In addition, APS was willing to accept some additional risk from leasing the system in return for the customer's willingness to allow testing of new technologies. These technologies included dc generators for battery charging, a new photovoltaic tracker technology, an inverter, and battery charge controllers.

DESIGN

Once the contract was signed, the detailed design began. Information from the audit and metering was used to determine the systems overall output. This output includes the following:

- Peak kW
- Seasonal Average kWh consumption
- System AC voltage

From this analysis, it was determined that the generators were over-sized. The customer felt that this size was needed to gain some of the reliability they required.

At this point, load control options were also reviewed. In most cases, load control is less expensive than PV capacity. Several were identified, but none were pursued before assembly and installation. This information is passed on to the customer as part of the education, which would be included for most remote photovoltaic sites. Customers have to learn how to operate with a limited amount of electricity to be successful with PV. In addition, most customers eventually will expand their operations. These expansions will need to include energy efficient aspects to reduce the cost of increasing the output of hybrid system.

System Output Capacity

The Gray Wolf system was designed to meet the following system specifications.

Table 1 - System Specifications – Output

Continuous Output Capacity	40kVA
Surge Capacity	50kVA, 30 sec. 65kVA, 1 sec.
Output Voltage	480V single phase
PV Size rating, Nominal	28 kW
AC Generator Rating – Diesel	50 kVA
Battery Bank Ah rating @ 20 hour discharge	3000Ah at 120Volt

Once the system capacity had been determined component selection began. The inverter and the generator selection were dictated by the system's capacity and these decisions were relatively straightforward. In contrast, the battery and the PV systems have many more options and care was taken to find technologies which work with the site, customer usage and seasonal weather changes.

Inverter

The system design began with the inverter. The inverter must be selected based on the maximum continuous output, the surge capabilities for motor starting and output voltage, either single or three phase. For commercial sites supplying irregular loading, inverters should be sized or have expansion capabilities 50% above the calculated power needs.

The inverter voltage was set to supply single-phase 480V to ship the power almost a mile around the customer's site. At the load centers, the power is transformed to 240V. After the inverter selection, the battery bank voltage, the generator size and the PV system voltage was determined.

For this project, an Advanced Energy System inverter was selected. The inverter is a 40 kW unit, which has a surge capacity of 50kW and 65 kW for 30 seconds and one second, respectively. This inverter also handles 30 kW of photovoltaic and generator control for up to 50 kW of capacity.

Generator

From the inverter and system's capacity needs, the generator size was selected. The generator must be sized to handle all of the site's loads for charging modes. In this mode, the generator supplies the site loads and excess capacity is used to charge batteries. In addition, it is ideal to have the generator able to run all of the site's loads in case of inverter outages.
Using the inverter size as a starting point, the generator should be oversized to supply large loads without seeing frequency droops, which can cause inverter faults and possibly system shutdowns. To reduce the chance of this happening, the generator should be sized at least 20% to 50% above the inverter rating to handle surges and reactive power needs from motor loads. In addition to the size, the generator selected should be rated for more than a backup duty and an electronic governor needs to be included.

For this project, a 50kW Kohler generator was selected.

Photovoltaic Array

Ideally, the photovoltaic array would be sized to supply 80% to 90% of the systems yearly energy needs. Furthermore, seasonal changes in customer loads and photovoltaic resources were considered. The array size was determined using the battery voltage and expected system output. Many options exist for mounting structure. These include tracking and fixed array at various tilt angles.

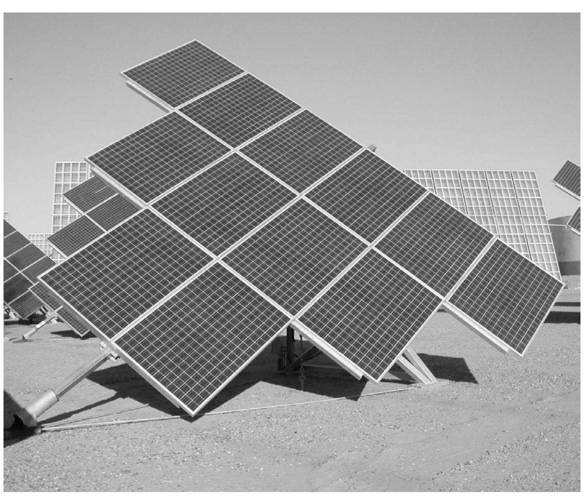

Figure 1 – Photo of APS Tilted Tracker

For this project, 28 kW of Sharp PV was mounted to eight APS tilted trackers. This tracker was designed to maximize the photovoltaic output on a yearly basis. Compared to a fixed array, the tilled tracker produces up to 35% more electricity. The tracker is driven by a simple hydraulic tracking system.

Comparison of Available Solar Resource for Fixed vs. Tracking Photovoltaic Arrays.

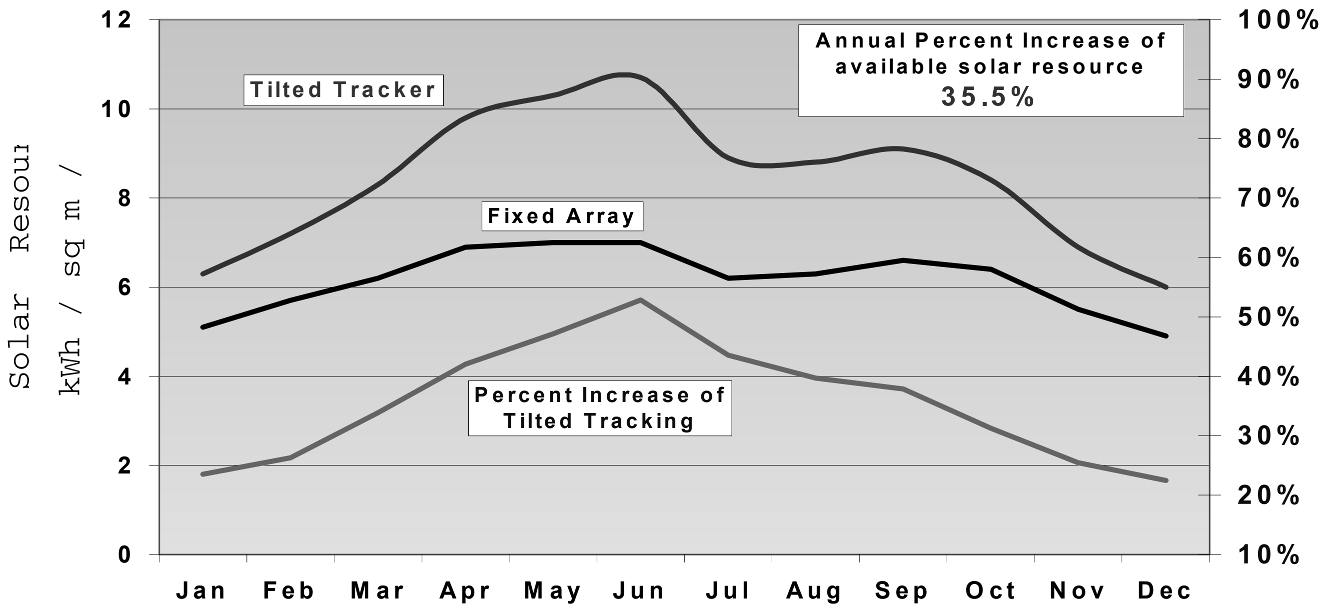

Figure 2 – Output comparison of tilted trackers to fixed arrays. Data take from the Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors published by the National Renewable Energy Laboratory.

In addition to the increased output, the tilted tracker is simple to install with minimal site preparation or disturbance to the surrounding vegetation.

Though this tracker was a good fit for this application, fixed arrays are often favored. The fixed arrays have no moving parts. For systems without involved customers or maintenance personnel on site, a fixed array is generally the preferred option.

Battery Bank

Last and most debated in the photovoltaic industry is the battery selection. The system battery is generally a significant portion of the total expense and can be costly to replace. It is common for the battery to cost 15% to 35% of the system's total cost.

The batteries used in most of the APS hybrid systems are flooded, lead-acid batteries. These have been selected for several reasons determined from more than five years of experience with remote photovoltaic system in the Arizona desert and high country. The following points are the major reasons. (1) The flooded batteries are durable in cycling operations where customers use systems with little regard for battery health. (2) They are forgiving of variable climates. This is necessary because air conditioning with photovoltaic power is cost prohibitive. (3) Lead-acid batteries have relatively long lives when maintained. In addition, regular maintenance is not a cost issue for photovoltaic hybrid system because generator maintenance is already necessary. (4) Last, these batteries are inexpensive and readily available. Batteries should be purchased from a company, which has experience with their product operating in a stationary, cycling operation. These companies will be better able to supply charging and discharging data for the application.

The Gray Wolf system was designed with the same battery type and sized for 3 to 4 days of storage. The battery is composed of two strings with a capacity of 3000 Ah at a 20-hour rate of discharge. The battery was programmed to discharge to a 60% state of charge, estimated from battery voltage with temperature compensation. The maintenance program called for servicing the batteries once every quarter.

Enclosures and Layout

Once all of the major components were determined, equipment enclosures were selected. For this project, a 20-foot shipping container encloses the power electronics. The battery was housed in a 24-foot insulated container. These containers are weather tight, cost effective and easily transported.

Last, a site layout was determined. The layout should minimize any shading between trackers and other obstructions.

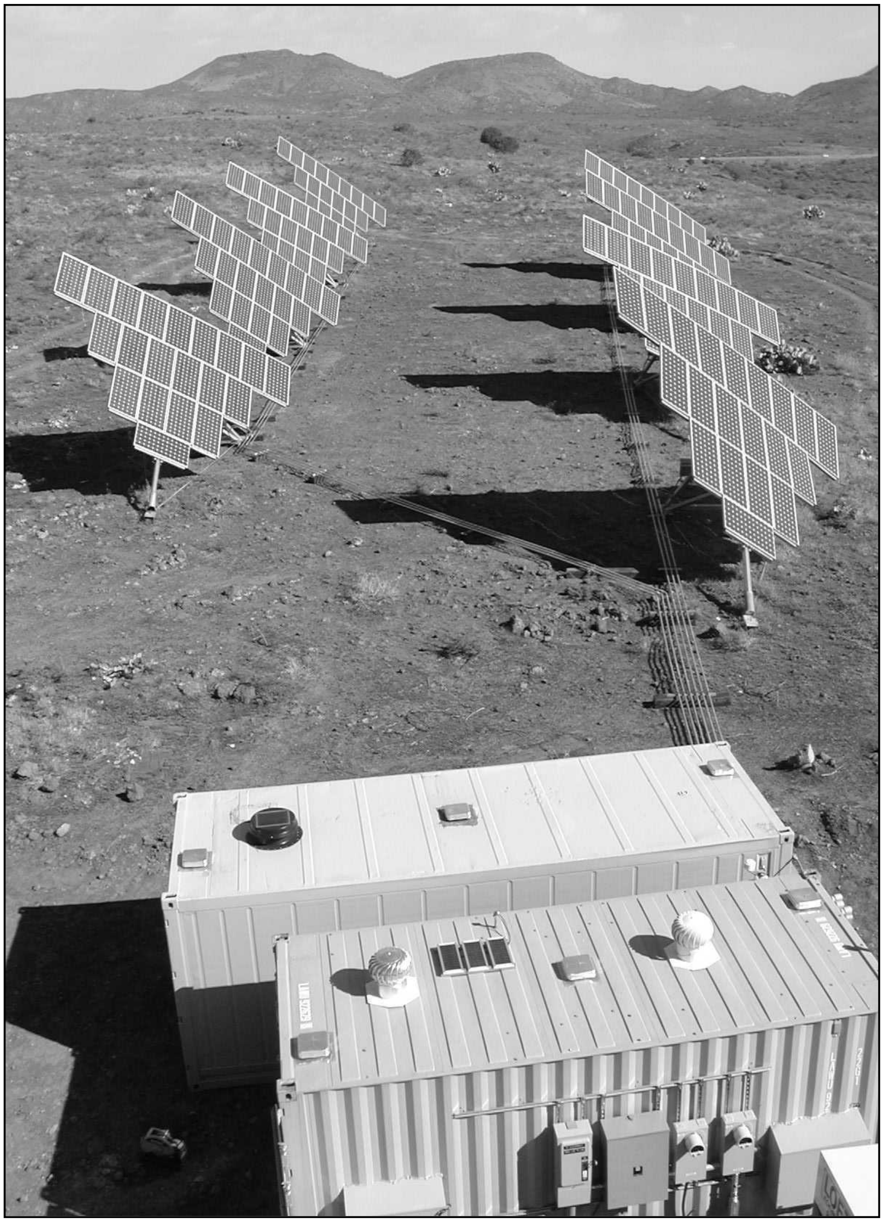

Figure 3 – Photo of final Gray Wolf Landfill installation.

ASSEMBLY AND INSTALLATION

All but the photovoltaic trackers were assembled at the APS Solar Test And Research (STAR) center for evaluation. This approach reduced the labor and time needed to have a system installed, because of the savings in travel time and availability of tools and materials. In addition, technical support from local experts was cheaper. The STAR assembly work took three technicians 2.5 to 3 weeks.

Once assembled, the function and interaction of components require effort to work through technical issues. Therefore, APS had learned that testing at STAR saves money and frustration. This project was no different. The power electronics had a manufacturing and minor programming error, which were easily addressed in Phoenix.

Once the system was tested at STAR, the enclosures were shipped to the site. The photovoltaic trackers were installed. And, all of the components were connected. This step took approximately five weeks for four labors.

The system was further tested during off times at the landfill. After working through a couple of problem loads and installing some load sharing controls, the site was permanently placed on the system.

EXPECTED MAINTENANCE

As with most power systems, it is important to have an effective regular maintenance program to ensure reliable and economical operation. A service technician will visit Gray Wolf quarterly to perform preventative maintenance. At this visit,

the following list will be addressed.

- Water the Batteries.
- Change fluid and filters in the generator.
- Change filters in the inverter.
- Inspect the pumps and hydraulic fluid on the trackers.
- Perform a general inspection of the site.

This process takes two technicians 12 hours to complete including the travel time from Phoenix, 130 miles.

In addition to the preventative maintenance, emergency service calls are required. Some minor inverter faults can be handled through modem communications with the inverter. More serious calls require visits, which can be expensive. The manual transfer switch allows the generator to power the site. This backup is valuable because it gives the technicians time to plan and organize their visit. This greatly reduces the cost of the repair.

CONCLUSIONS

Photovoltaic-genset hybrid power systems can be an economical alternative to generators. In addition to the economical motivation, these systems can improve reliability and reduce the environmental impact of off-grid power. To make these projects successful, proper energy audits, design and installation by qualified professionals are necessary.

Furthermore, the incorporation of some of the lessons learned throughout this project will make future projects more economical and ultimately more successful. These lessons learned include:

- Perform a thorough energy audit before defining the system requirements.
- Purchase batteries from a source that can provide technical support for their product in a solar application.
- Anticipate system expansion and design to accommodate future needs.
- Oversize inverters and generators to accommodate surge loads.
- Provide energy management education for the client.