Evaluation of Energy Systems at Dry Tortugas National Park Addendum Report

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at
Dry Tortugas National Park

Addendum Report – September 2000

OVERVIEW

This report summarizes findings and recommendations regarding energy systems and opportunities for conservation and renewable energy systems at Dry Tortugas National Park. Currently, electrical energy use at Dry Tortugas National Park supplied from diesel generators, while a small amount of LP gas is used for cooking and clothes drying. Energy use at the park is primarily for park operations, of which approximately two-thirds is used in staff living quarters. Air-conditioning is the predominant load, accounting for two-thirds of the energy use and over one-half of the peak demand. Refrigeration, water production and water heating account for the majority of the balance.

Two separate islands within the park are maintained by the park service. Garden Key - home to Fort Jefferson - is the hub of park operations and is where the majority of park staff reside. Peak energy use on Garden Key is over 1200 kWh/day, with a peak demand of over 125 kW. Loggerhead Key is the largest island in the park and includes two residences, a number of smaller structures and an historic lighthouse. Energy use on Loggerhead Key is approximately 100 kWh/day, with a peak demand of less than 25 kW. Due to the size of the generating equipment and associated loads, energy costs range from approximately $0.33/kWh for Garden Key, to about $1.00/kWh on Loggerhead Key.

Numerous opportunities exist for reducing electrical loads at both of these sites, however significant changes would be required to the existing generating systems for these measures to impact overall costs. Due to the costs and concerns associated with fuel delivery, and the relatively small and manageable load, the situation on Loggerhead Key presents the best potential for viable renewable energy systems. A 15-20 kW photovoltaic hybrid system could satisfy the entire existing load on Loggerhead Key, at an installed cost of less than $500 K. Conservation measures could reduce the size of system required even further. While the economics for a similar approach on Garden Key are less favorable, a similar size or smaller system installed at this site would be highly visible to the park visitors.

1. INTRODUCTION

The most remote and inaccessible of the U.S. National Parks, the Dry Tortugas are located approximately 70 miles west of Key West, Florida in the southern Gulf of Mexico. The park encompasses over 64,000 acres (100 square miles) of marine sanctuary and seven small islands, of which only two (Garden and Loggerhead Keys) have man-made structures that are maintained by the park service.

The objectives of this report are to identify opportunities for increasing efficiency, reducing costs and improving environmental quality by implementing conservation measures and renewable energy systems in park operations. Information in this report was derived from a site survey conducted on April 4-6, 2000 by personnel from the National Park Service (NPS), U.S. Department of Energy (DOE), Sandia National Laboratories (SNL), Oak Ridge National Laboratory (ORNL) and Florida Solar Energy Center (FSEC). It builds on earlier site assessments and reports developed in 1989 and 1997 by FSEC under contract to DOE and SNL [1, 2]. These reports, images of park facilities, charts of selected data and other supporting materials are accessible from FSEC's web site at http://www.fsec.ucf.edu/pvt/drto/.

2. GARDEN KEY - FORT JEFFERSON

Garden Key is home to Fort Jefferson and base operations for the park. Approximately 12-15 persons, including NPS staff and family members, marine researchers and official visitors reside in living quarters built into the casements of the fort. Also located within the fort are offices, workshops, storage rooms and a museum. Public visitation at the park is approximately 50,000 persons per year and increasing.

2.1 Power Generation

Four diesel generators ranging in size from 100-120 kVA are used to supply electric power on Garden Key. In 1989, three 60-kVA generators and one 45-kVA were used to supply power for the park. Power is distributed as single-phase 120/240V service to the residences and other facilities via four main service panels and fourteen subsystem load panels. The generators are typically operated two at a time, with each unit being cycled out of service every couple of weeks for maintenance.

Since 1990, generators have been replaced approximately every 18 months, or about every six years per unit. New generators are purchased on GSA contract – the most recent purchase for a 120-kVA unit was approximately $37,000. Scheduled maintenance for the generators is estimated to cost $6,000 per year.

Annual average energy production is approximately 1000 kWh/day, up from about 500 kWh/day in 1989. Peak production corresponds with highest ambient temperature and air-conditioning load during summer months at about 1250 kWh/day, while the minimum energy production in winter months is on the order of 700 kWh/day. Average peak loads on the generators are approximately 50 kW, ranging from a low of about 25 kW to a high of over 100 kW during heaviest load usage.

Diesel fuel is delivered to Garden Key from Key West via supply ship and transferred into primary storage tanks outside the fort. Delivered costs are approximately $2.40 per gallon. Diesel fuel is primarily used for the generators, although a minor amount is used for boats and other service vehicles. Pumps are used to transfer the fuel from the primary storage tanks to intermediate tanks in the generator room where the daily consumption is monitored. Average annual diesel consumption for the generators is approximately 3000 gallons per month, ranging from about 2000 gallons per day in winter to 4000 gallons per day in summer. Based on an average daily energy production of 1000 kWh/day and 100 gallons per day fuel consumption, the energy/fuel efficiency ratio is approximately 10 kWh/gallon. Figure 1 shows the average daily energy production (kWh/day) and the monthly diesel consumption (gal/month) for the diesel service.

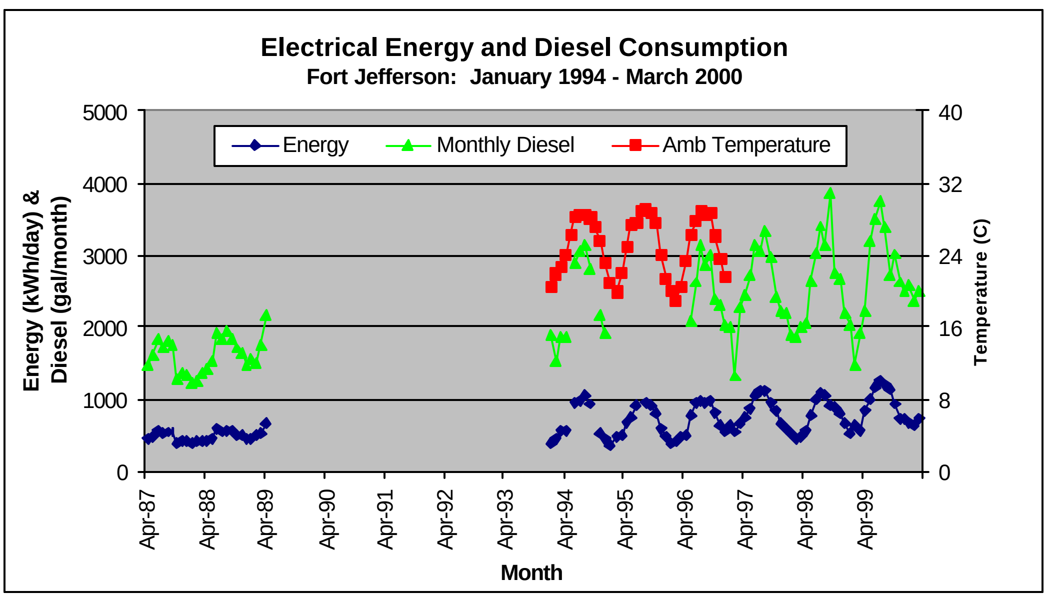

Figure 1. Fort Jefferson Energy and Diesel Consumption, 1987-2000.

The economic considerations for power generation at Fort Jefferson include the capital costs for equipment, fuel costs and delivery, and maintenance requirements. Based on the above data, annual costs for power systems operation, maintenance and replacement amounts to approximately $120,000. Based on an average daily energy production of 1000 kWh/day, energy costs are approximately $0.33 per kWh.

2.2 Electrical Loads and Other Energy Use

The primary form of energy use at the site is electrical power supplied by the diesel-fueled generators. Propane is used for cooking and clothes drying only, with an annual consumption of approximately seventy-five 100-lb cylinders per year.

Approximately 1000 kWh of electrical energy is used at Fort Jefferson on a daily average, peaking at over 1250 kWh per day during the summer months due to the significant air-conditioning load. Predominant contributions to the total daily energy (kWh) consumption include air-conditioners (65%), refrigeration (11%) and hot water heating (8%). Peak facility loads may exceed 100 kW, but are more likely limited to around 80 kW depending on the time of use profiles for the various loads. The minimum load is estimated to be between 20 and 25 kW during late evening and early morning hours, primarily due to the air-conditioning and refrigeration loads. Figures 2 and 3 show the components of the daily peak and energy loads at Fort Jefferson, respectively.

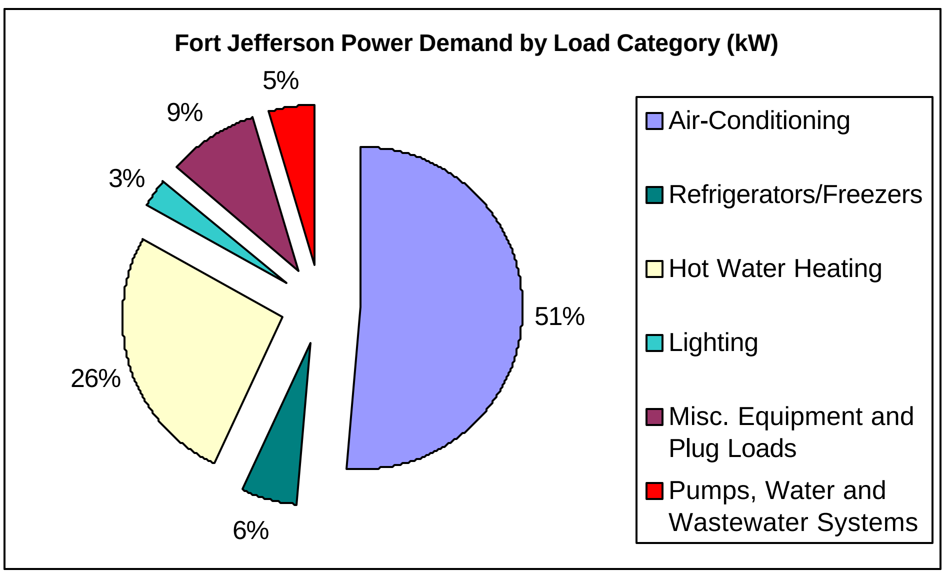

Figure 2. Fort Jefferson Peak Electrical Demand by Load Category.

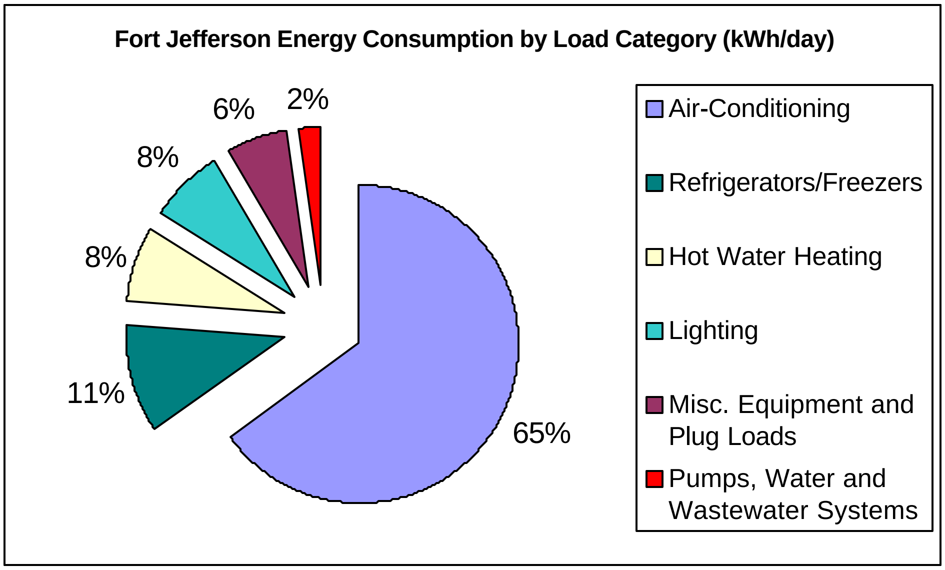

Figure 3. Fort Jefferson Electrical Energy Consumption by Load Category.

Air conditioning is the most significant electrical load at Fort Jefferson, estimated to account for two-thirds of the average daily energy use, and over one-half of the peak power demand. Twenty-four window units (mostly ½-ton and 1-ton systems) and two central systems with split condenser and evaporator units are used for the residences, offices, radio room, storage rooms and visitor's center. Despite the extensive use of air-conditioning, moisture control and infiltration are major problems in many of the living quarters and other conditioned spaces.

Refrigeration is the second largest load next to air-conditioning, accounting for an estimated 11% of the average daily energy use, and 6% of the peak demand. Fifteen refrigerators, ten freezers and two ice machines are in service at Fort Jefferson. Electric water heating accounts for an estimated 8 percent of the average daily energy use, and potentially 26 percent of the peak demand. A total of thirteen electric water heaters are used on site, including eleven 30-gallon units using 2-kW elements and one 55-gallon unit with 3.8 kW elements. Lighting is estimated to account for 8 percent of the average daily energy use and 3 percent of the peak load at Fort Jefferson. The majority of lighting fixtures use four-foot 34-watt T-12 fluorescent lamps, however there are significant numbers of incandescent lamps used as well.

2.3 Load Description by Facility

Over one dozen living quarters are used at Fort Jefferson for NPS staff and invited guests. These quarters include a variety of one and two bedroom units built into the casements of the fort, new energy-efficient quarters, as well as an historic building (formerly officers quarters) on the parade grounds divided into two units. Each living quarters contains one or more air-conditioners, an electric water heater, a separate refrigerator and freezer, lighting and miscellaneous plug loads. It is estimated that the living quarters account for approximately two-thirds of the energy use at Fort Jefferson.

Laundry and recreation facilities include two washers and two dryers for use by NPS staff, used for approximately 20 loads per week (Figure 17). Towels, sheets, and other linens are sent to Key West on the supply ship Activa once a week for laundering. The two washers have a 20-gallon capacity, with hot water supplied from a 30-gallon, 2-kW electric water heater in the laundry room. The two dryers utilize LP gas and consume about four 100-lb LP gas cylinders per month. A recreation room is provided for the residents, and includes a pool table, a weight machine, a TV, VCR and stereo. More prominent energy loads in the recreation room include one of the two ice machines on site, a window air-conditioning unit, a ceiling fan and a 6-kW sauna. It was stated that the sauna is used on an infrequent basis, if at all.

A boat dock is used for the Park Service vessels and complimentary 2-hour docking for private vessels. No overnight docking is allowed, however an anchorage is provided in the harbor next to the island. Lighting and shore power are provided on the dock for the benefit of campers and supply ships. Restroom facilities are available with seawater toilets and no sinks. Electric boat hoists for the patrol boats are also present, but used infrequently. An air-compressor for dive tanks is located in a sore room on the dock for park service use only.

The park office energy use consists of a window air-conditioning unit, lighting, and computer, copying and fax machines. An adjacent room, partly used for storage and as a mini-library has a ½-ton A/C unit and another computer. The visitor's center includes a museum and gift-shop and has two window air-conditioning units, fluorescent lighting, and a TV/VCR setup. A chilled water fountain is also located in the visitor's center.

2.4 Water and Wastewater Systems

Freshwater at Fort Jefferson is supplied by a combination of rainwater collection systems and a small reverse osmosis (RO) unit. The rainwater collection system uses several of the ducts from the original roof collection system, as well as runoff from the roofs of residences in the parade grounds. All water collection is channeled through PVC pipe to a sump, where it is then pumped into a 72,000-gallon cistern located in the parade grounds. The RO unit has a capacity of 2000 gallons per day, but is typically only operated for 8-12 hours daily. Product water from the RO unit is first directed to an emergency storage tank on the roof of the fort, and excess is diverted to the cistern. Pumps, pressure tanks and piping are used to distribute the cistern water to various end uses within the fort. Freshwater is available only for park staff and operations, and other than two drinking fountains, is not generally available to the visiting public. Low-flow showerheads are used and signs are posted at all sinks and baths to emphasize conservation.

Annual average daily freshwater use is approximately 600 gallons per day, varying seasonally between 400 and 900 gallons per day, with the greatest usage typically occurring during summer months and with additional visitation and crews on site. Due to the variability in rainfall and the threshold amounts needed to saturate the sand fill on the roof of the fort, the RO plant provides the bulk of the average daily water requirement. Figure 4 shows the average daily freshwater use at Fort Jefferson for the period April 1994 through March 2000.

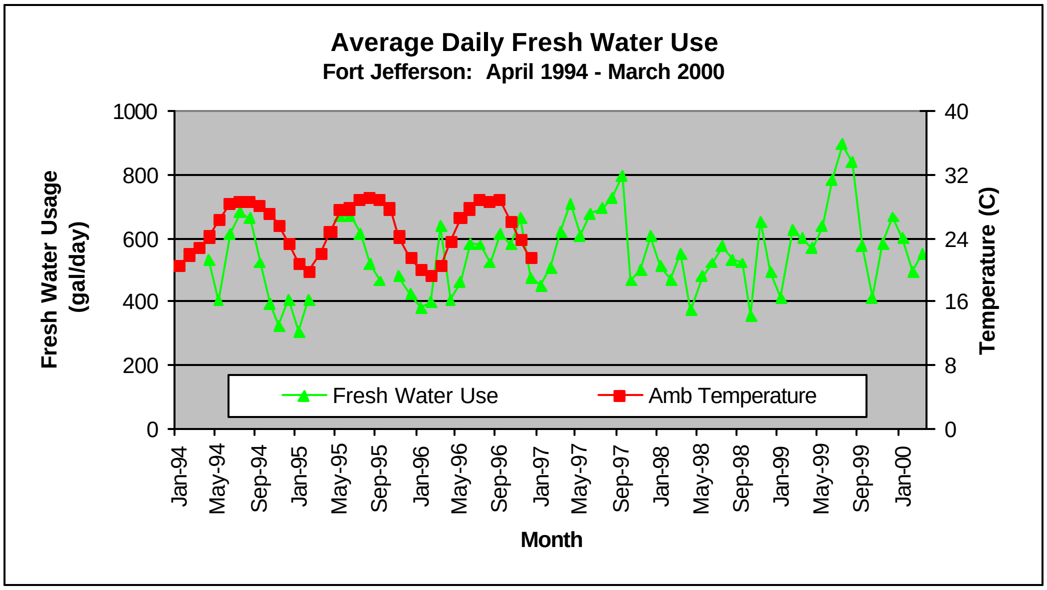

Figure 4. Fort Jefferson Freshwater Consumption, 1994-2000.

A dedicated seawater system, including pumps, pressure tanks and distribution system is used for all toilet facilities and feed water for the reverse osmosis system. Wastewater is handled by two sewage lift stations that transfer effluent to septic tanks located in the parade grounds and in the camping area.

There are several challenges in managing water and wastewater systems on Garden Key. With increasing visitation and usage, issues concerning the water quality and wastewater treatment have been raised, and are likely to require significant changes to these systems. Due to the large avian population in the area, extensive water testing has been required and may limit the use of rainwater collection. For this reason, it is likely that the RO system will be replaced with a larger capacity unit, and operated for longer periods each day. In recent years, cracks in the cistern have limited storage to less than full capacity of 70,000 gallons. Circulation pumps have also been added to the cistern to meet water quality standards. Another issue concerns the location of septic tanks and drain fields, and their relationship to sea level and tidal influences. This matter may require new, elevated septic systems.

3. LOGGERHEAD KEY

Located approximately 2 miles west of Garden Key, Loggerhead Key is the largest of the seven islands in the park. Formerly operated and maintained by the U.S. Coast Guard, management responsibilities have recently been transferred to the park service.

Facilities on Loggerhead Key include two houses, an historic 150-ft high lighthouse, and a number of other small buildings, workshops, and storage rooms. The electrical load is primarily air-conditioning, potable water production (reverse osmosis system), and refrigeration.

Three 50-kVA diesel-fueled generators are used on Loggerhead Key, each operated for a week at a time then alternated. Diesel fuel consumption averages 200 gallons per week, or about 800 gallons per month (two 5000 gallon deliveries were made in 1999). Load surveys conducted during the recent site visit suggest an average daily energy consumption of about 100 kWh/day, with peak loads typically less than 10 kW. Based on the existing loads, it is expected that the peak load could be as high as 25 kW if all loads are operating and the site is fully staffed. During most of the time however, these generators are oversized for the needs of the island.

Approximately 10,000 gallons of diesel fuel is delivered to Loggerhead Key annually. Aging fuel tanks need replacement, and past fuel spills have created serious environmental hazards. Approximate costs for energy production, including generator replacement, fuel and maintenance, are about $35,000 annually, or nearly $1.00 per kWh – three times the cost on Garden Key. Fuel utilization efficiency is very poor at less than 4 kWh/gallon. For these reasons, the park service is looking for alternatives to diesel generation on Loggerhead Key.

4. RECOMMENDATIONS

4.1 Garden Key – Fort Jefferson

There are numerous opportunities for improved efficiency of end-use loads at Fort Jefferson, with potential to reduce the energy and peak demand loads by as much as 50 percent. These measures are primarily related to the major loads including air conditioning, hot water heating and refrigeration.

However, there is an important point to make about the cost/benefit for any conservation measures considered. Because the fuel consumption/energy production efficiencies for the generators are highly non-linear, reducing the load will not significantly reduce fuel consumption or costs of operating and maintaining the generator systems – unless significant changes are made to the power generation equipment. In the case of major changes in the generating equipment (or implementation of renewable energy systems, e.g. PV or wind), these measures are absolutely critical to limiting and managing the loads.

The following section presents a discussion on each of these measures.

Conservation Measures for Fort Jefferson

Geothermal Air-Conditioning. This technology involves using ground water as the heat sink for the condenser portion of the standard vapor-compression refrigeration cycle. This is accomplished by using closed-loop ground wells – and the length and depth of the required condenser piping are determined by the overall capacity of the system and ground water temperatures. Ancillary advantages or this type of system are that a portion of the waste heat removed from the conditioned spaces can be used for water heating. Challenges to implementing this type of system include centralizing equipment, installing distribution piping and fan coils in widely separated conditioned spaces, and logistics associated with drilling wells into the coral and transporting drilling equipment to the site. If the hot water component is implemented, changes to the water heaters will also be required. Overall energy reductions for air-conditioning and hot water could be as high as 50 percent of existing use, with associated reductions in demand. The costs of implementing such as system are not known.

Weather Sealing. Most doors and windows were found to have significant infiltration (no weather-stripping or caulking), and even some areas (around a stove ventilation fan) had large openings to the outside. Sealing these areas is a low-cost measure, and would have immediate returns on reducing humidity levels and air-conditioning loads.

Air-Conditioning. In lieu of a geothermal system, there are still opportunities to reduce the load associated with the numerous window units. Select the highest EER rated air-conditioning units as possible when replacing existing units, preferably with a variable fan speed option. High efficiency air-conditioners are rated for their sensible performance and not on their ability to remove moisture. High fan speeds typically improve the overall cooling efficiency of the system, however lower fans speeds will result in better moisture removal. Where practical, lower efficiency window units could be replaced by more efficient split systems. These special requirements and the higher than normal energy costs at the site may dictate other than GSA contracted purchases for standard efficiency equipment. In addition, thermostat settings can be raised or other controls can be used in unoccupied areas.

Refrigeration. When replacing existing refrigerators and freezers, suggest using highest efficiency units available on the market. Reductions of over 50 percent peak demand and energy usage may be achievable for this load category.

Water Heating. Several options exist to minimize the water heating loads. The simplest measure would be to install timers on the existing electric water heaters to prevent concurrent operation – thus reducing the peak loads. Another simple measure would be to install additional insulation around the storage tanks where they are not already used. Using hot gas desuperheaters as part of a geothermal AC system would supply free hot water from the AC waste heat, but would need to be integrated to with the individual storage tanks. Alternative measures would be to install low-cost solar water heaters, either on a distributed basis (for each heater), or through a centralized system (would require common hot water plumbing).

Lighting. Although lighting is not a significant portion of the load, there are low-cost, easy to implement options to reduce this load. For one, any incandescent lamps can be replaced with compact fluorescent units, which provide comparable light output, use one-fourth the power, and have ten times the life as incandescent lamps. Secondly, T-12 fluorescent lamps and ballasts can be replaced with T-8 lamps and high-efficiency electronic ballasts. Motion detectors, timers or photo-control sensors can also be used for appropriate applications.

Renewable Energy Considerations for Fort Jefferson

This section presents opportunities and considerations for implementing renewable energy systems at Fort Jefferson, and includes a discussion on two options - photovoltaics (PV) and wind turbines. Because of the magnitude of the load, and the efficiency of the existing generation systems, the overall cost/benefit of implementing any renewable technology at this site can be questioned. Of course, the conservation measures identified earlier should receive top priority as part of any renewable energy project.

The following describes the opportunities and considerations for PV and wind energy systems at Fort Jefferson.

Photovoltaics

Photovoltaic generation can be integration into the electrical systems at Fort Jefferson in a variety of ways, depending on the desired objectives. The most viable approach would be a hybrid configuration as shown in Figure 5. A hybrid configuration uses PV as well as other sources (generator, wind, etc.) to meet the total energy load. Advantages of this approach are reduced dependence on diesel generation and downsizing of generation equipment. Other major components in a hybrid system include batteries, inverter and control systems.

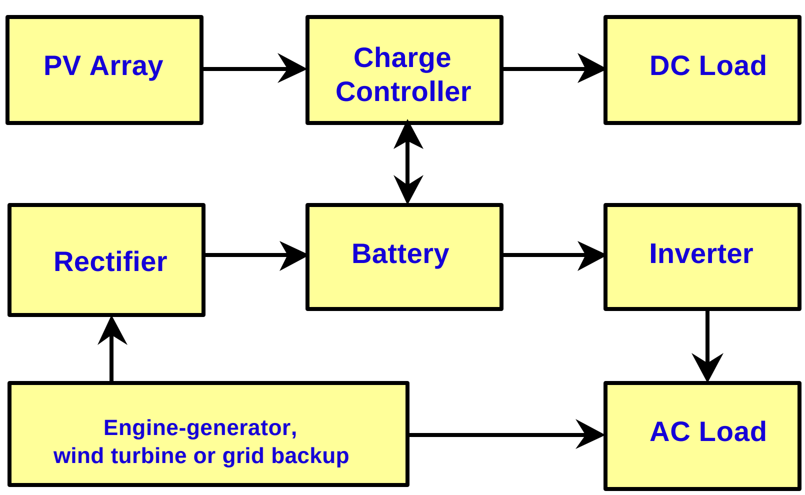

Figure 5. PV Hybrid Configuration

Based on the solar radiation data for Key West, FL, optimally oriented PV arrays would produce about 5 kWh DC energy per peak kW of installed PV capacity at Fort Jefferson. Factoring in power losses and conversion factors associated with inverters, batteries and distribution equipment, estimated AC energy performance would be on the order of 3.5 kWh per peak kW of installed PV capacity. Surface area requirements per kW peak of PV array are on the order of 100 square feet.

For example, to satisfy the existing energy use of 1200 kWh/day entirely with PV would require an array size of approximately 350 kWp. This would require on the order of 50,000 square feet (1 acre) of available area – not likely to be found on small Garden Key. Installed costs at $10/Wp would be on the order of $3.5 M. A more practical option would be size the PV to meet the base load of about 800 kWh/day and rely on generators to meet the balance. However, this would only reduce the size of the system by one-third. The implementation of conservation measures would also reduce the array size required.

Another advantage of having multiple generation sources in a hybrid system is that the battery storage size can be reduced to meet the load for only one or two days. In the case with the existing facility loads, a 1000-2000 kWh + battery bank would be required. Energy storage densities for commercial lead-acid batteries are on the order of 50 pounds per kWh, so the weight of the battery system required would be between 25 and 50 tons. At $100/kWh, the total costs for such a system would be on the order of $100 K to $200 K.

The inverter and battery charging equipment would need to be specified according to the peak loads, which are currently in excess of 100 kW. At a cost of $2/Wp, this equipment would amount to another $200 K. Diesel generators would be used exclusively for meeting loads beyond what the PV component could satisfy, depending on the sizing and load profiles on the system. The desirable situation in a hybrid configuration is to only operate the generators for short periods at high output levels – resulting in greatest efficiency with minimal maintenance.

In summary, the situation at Fort Jefferson doesn't lend itself well to PV generation, particularly without implementing extensive conservation measures and making wholesale changes to the generation systems. Some discussion centered around locating an array on the concrete pad near the south coaling docks. This 16,000 square foot area would accommodate up to a 120-kWp PV array, which could be interfaced with the electrical systems in a similar manner as described above. Although this system would present a highly visible demonstration of PV technology to park visitors, cost/benefit justifications would be extremely difficult.

Wind Energy

Based on the data presented in the earlier report [2] concerning wind speed frequency distribution, the estimated annual energy production for a nominal 10 kW turbine at Garden Key is approximately 17,000 kWh, or an average of about 47 kWh/day. A 10 kW machine would have a rotor diameter of approximately 23 feet, with initial hardware costs of about $25,000. However, the avian sanctuary on adjacent Bush Key raises serious issues about using wind turbines on Garden Key, and would likely be opposed by environmentalists.

4.2 Loggerhead Key

Significant opportunities exist for conservation measures and renewable energy systems on Loggerhead Key. In contrast with the situation on Garden Key, energy costs on Loggerhead Key are three times greater – and taking into consideration of the smaller load - makes this site extremely attractive for PV or wind systems. With upcoming renovations planned for the existing buildings and the need for fuel tank replacements, this is a perfect time to consider the options.

Conservation Measures for Loggerhead Key

In general, the conservation measures identified for Fort Jefferson apply equally to the facilities on Loggerhead Key. Again, these measures are critical in reducing the size and cost of any renewable energy system options considered. At present, the daily energy use is approximately 100 kWh/day with a peak demand of maybe 25 kW. Measures such as centralized AC units, gas or solar water heating, new refrigerators/freezers, and new insulation and windows for conditioned spaces could reduce this load by half.

Photovoltaics

Due to the relatively small and manageable electrical load on Loggerhead Key, high costs, and inefficient use of the existing generators, this site presents an excellent opportunity for a photovoltaic hybrid system. Based on the existing load information, the entire island could be powered with a nominally rated 20-kWp PV system, perhaps as small as 15 kWp if conservation measures are successfully implemented. Battery storage requirements would be on the order of 100 to 200 kWh, approximately one-tenth the size that would be required for Garden Key. An inverter and battery charger would also be required, and would need to be sized to meet the expected peak loads (~20 kW). A much smaller generator could be employed, to charge the batteries during periods of below average sunlight. Estimated costs for such a system on Loggerhead Key would be less than $500 K.

Wind Energy

Same analysis as discussed previously for Garden Key, although historic preservation and environmental concerns may be opposed.

5. REFERENCES

1. Energy Analysis for Ft. Jefferson National Monument, contract Report for Sandia National Laboratories, prepared by Florida Solar Energy Center, May 1989.

2. Evaluation of Resources and Energy Systems at Fort Jefferson, contract report prepared for Sandia National Laboratories, prepared by Florida Solar Energy Center, June 1997.