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PROFESSIONAL PAPER

Deploying Mobile PV Emergency Power System In A Disaster

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1. Introduction

Disasters can be as destructive as Hurricane Katrina, leaving several hundred-thousand people homeless, or as minor as an afternoon thunderstorm that brings down local power lines to your home. After a disaster, utility services may be damaged or destroyed, leaving people without water, sanitation, communication and electricity. In response to a disaster, first responders are deployed with life supporting resources, such as water, food, and medical supplies. Energy resources are often lacking, making recovery efforts difficult in our high-tech world of cell phones, television, computers, refrigerators and many other electronic devices.

After a disaster, the long time tradition used to meet energy needs is to deploy conventional gasoline and diesel emergency generators. But in recent years, another energy source has become available and the demand for its use is increasing. Photovoltaic (solar electric) power systems that provide quiet, reliable, emission-free electricity have been used in response to a disaster since 1988. Portable photovoltaic (PV) battery chargers, lights, radios and other devices have been employed, including trailer mounted photovoltaic power systems. [1]

For example, PV power systems from 100 to 3,000 watts are mounted on trailers and used as mobile emergency generators. These mobile systems are deployed to disaster sites to power clinics, shelters, radio stations, homes and other buildings. These mobile solar generators are typically stand-alone PV systems connected to a load by a cable to an electrical power panel or to a device through extension cords. When the emergency is over, the system is disconnected and redeployed.

2. Conventional Generators

Typically, conventional gasoline or diesel generators are used to restore electrical power during an outage, whatever the need. Conventional generators use internal combustion engines that burn fuel to produce the needed electricity. Lawnmower or vehicle engines are used to rotate a generator to produce 500 to 500,000 watts of alternating current electricity in voltages from 120 to 480. Gasoline, diesel/biodiesel, propane or natural gas fuel is used by the engine from fuel stored in tanks ranging in size from 1 to 5,000 gallons.

Generators can be connected directly to a device such as a pump or light, or they can interface with a building's utility power. Many are small enough to be hand carried for residential or construction site use and are in the 500 to 15,000 watt range. Commercial units range from 15,000 to 1,000,000 watts and are often secured for backup power as a permanent installation. Some are configured as mobile units. Many local governments have support contracts with generator suppliers to provide generators on demand during a disaster. They can be transported to the location where needed and connected to or placed permanently on site ready for use at any time. Unfortunately, their portability feature also makes them a target for theft.

Conventional generator power is not provided without a price. High fuel costs, availability of fuel and safety problems are issues to consider. Small home generators are responsible for incidents of post-disaster burns, fires, fuel explosions and even asphyxiation and death. In addition, many new users do not select the best generators for their need, which leads to cost overruns, high fuel consumption, power shortages and poor power quality. Medical and communication workers also complain that the noise from generators is annoying, adds to victims' trauma and reduces environmental quality. Those drawbacks acknowledged, conventional generators do have the advantage of physical size to power output ratio, portability and very large power outputs that make them a valued resource in a disaster. Benefits and limitations need to be understood for safe and proper deployment.

3. Solar Generators

Use of the sun's power to generate electricity through photovoltaic technology is gaining acceptance. Light energy is converted to electrical energy by photovoltaic cells which are wired into series and parallel circuits to construct modules of various sizes. There are three types of photovoltaic cells commercially available with average conversion rates of 8 percent for thin film, 11 for multi-crystal and 14 for single-crystal at standard test conditions of 1000 watts/square meter. Photovoltaic modules produce direct current (DC) electricity in voltages from 3 to 48 volts at wattages from 1 to 300.

Modules can be used in specific stand-alone DC systems that may include a charge controller, batteries, and electrical safety devices, power distribution network to power a specific load. DC systems can be incorporated into PV generator power systems. PV generator power systems provide alternating current (AC) in voltages from 120 to 480 that match utility grid power and include an inverter to convert the DC into AC. PV power systems generate AC electricity to replicate the utility grid's 60 cycle waveform or what may be called 'house power'. Sine wave inverters match very closely the waveform of the utility to the extent the grid-tied sine wave inverters use the utility's waveform to stay in phase and control power factor. Square wave and quasi-square wave inverters also operate at 60 cycles, but with a square-looking waveform that operations at less efficiency and suffers from more harmonics.

A commonly used PV power system uses a utility interactive grid-tied inverter without storage. Utility grid-connected PV systems operate only in conjunction with the electric utility mains, synchronizing the output phase, frequency and voltage with the utility and direct connected to the PV array. When utility power fails, so does the PV power system, therefore does not operate as backup or emergency power.

Like specific DC PV systems, PV power systems can operate without utility grid power in a stand-alone operation using a stand-alone inverter. Stand-alone PV systems work in remote locations where there is no utility power or in emergency/backup power configuration when the utility goes out. Stand-alone PV power systems have battery storage and replicate utility power. A Bi-modal inverter can operate either in grid-connected or stand-alone mode, but not simultaneously. This type of PV system offers the advantage interacting with the utility and providing emergency power during outages.

Beyond the electrical capability of photovoltaic power systems, they provide quiet, emission free electricity. The Coast Guard and the Department of Transportation started using PV during the 1980's, because they needed stand-alone, reliable power systems. The sun supplies an inexhaustible supply of fuel every day. To meet the needs of a mobile or trailer mount generator for remote or emergency power in a disaster, a PV power system with a bi-modal inverter can operate as a conventional emergency generator. Conventional generators do provide more energy density in watts per pound weight than PV generators, but must be fueled.

4. History of Mobile PV Systems

Portable PV systems have been carried into disasters since Hurricane Hugo in 1988. Hugo first struck St. Croix, in the Virgin Islands, and later arrived on the coast of South Carolina. In response to a request for help, the Arizona Solar Energy Office deployed their Solar Emergency Response Vehicle build by Photocomm. The unit powered a law enforcement traffic facility and an orphanage 24 hours a day for several weeks until utility power was restored. The trailer-mounted PV system supplied 12 VDC and 115 and 220 VAC of electrical power from a 200 peak watt PV array. Several days after its arrival at the transportation facility, power was restored and the unit was moved to the orphanage. The unit operated more successfully at the orphanage, where demands for power were not as large or as critical.

In the summer of 1991, an Emergency Mobile Communications and Lighting Unit was built by Barrett Manufacturing for use during the earthquake recovery efforts at Northridge in Los Angeles, California. The trailer-mounted PV system contained 4 Siemens 48 watt PV modules. The system provided reliable stand-alone electrical power at both 12 VDC and 120 VAC for site communications and lighting. If a fossil-fueled generator had been used, two people would have had to spend 6 hours a day filling it with gasoline.

In 1992, the Florida Department of Transportation was already equipped with numerous PV-powered traffic devices used for road construction. When Hurricane Andrew struck Dade County, a PV-powered highway advisory radio unit, built by Digital Recorders, was operating along I-75 in the Everglades, transmitting messages about rest stops and construction. After the storm hit, the unit's AM radio transmitted road hazards, distribution areas and route changes in the disaster area offering the capability of dual use.

Other PV-powered traffic devices were transported to the disaster area to assist in the relief effort. Traffic control was increased by use of changeable highway message signs, flashing arrow boards, and warning signals and signs. Changeable highway message signs were invaluable to relief workers arriving from outside the area, directing them to staging areas and shelters. Many pieces of equipment owned by DOT have been converted to photovoltaic power.

Two PV-powered traffic signals were developed, constructed and shipped to the Dade County Transportation Department under the direction of the Florida Solar Energy Center, in partnership with the Florida Energy Office for FDOT, to implement PV into their operations. Three months after Hurricane Andrew, they were deployed and tested at an intersection where the power for the traffic lights was not yet restored. After testing, the systems were not used again, as they did not meet all DOT standards. Due to the load of the incandescence bulbs used at the time, the units were capable of powering only one signal head.

Figure 1: FEMA 500 Wp trailer

In 1998, the Federal Emergency Management Agency (FEMA) and the U.S. Department of Energy (DOE) purchased eight trailer-mounted PV systems for use in disaster response.[2] Two sizes of PV systems were obtained: a 500 watt PV Applied Power Corporation system and a 1,800 watt PV SunWize Technologies Corporation system.

The first organization to use two of the FEMA 1,800 watt PV trailers in a disaster was North Carolina Solar Center after Hurricane Bonnie in August of 1998 on Knotts Island. (Figure 2) The trailers were used for several days to power two homes of people with special needs so they could stay in their homes.

In September of that same year Hurricane Georges arrived, providing the second opportunity for two of the FEMA PV trailers to be deployed by the Florida Solar Energy Center. The 1,800 watt PV trailer was used at a Catholic Charities disaster relief distribution center in Miami, Florida. The 500 watt PV trailer was used by Habitat for Humanity on Big Pine Key. (Figure 1)

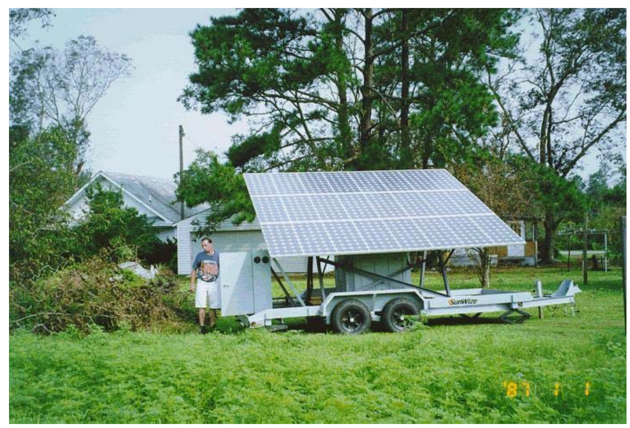

Figure 2. FEMA 1,800 Wp Trailer

The SunWize 1,800 watt trailers and the Applied Power 500 Watt trailers have been used by many organizations for many types of applications. The Miner Institute in Chazy, New York, used the SunWize trailer at their environmental research facilities to monitor the effects of environmental changes on atmospheric carbon releases for the temperate forest.

In 2000, FSEC designed and built a PV Disaster Trailer and that has been used many time since them for disaster like the one in 2004, after Hurricane Charlie. The FSEC trailer was use to provide electricity to the operating tent for a Florida Disaster Medical Assistance Team (DMAT) in Port Charlotte. In 2005, after Hurricane Frances, the FSEC trailer power amateur radio communications in Central Florida. On February 12, 2007, when tornadoes destroyed hundreds of homes in Lake County, Florida, the FSEC trailer provided electricity to a special needs person for three days to power their nebulizer and lights.[3]

Figure 3: FSEC trailer powering radio station

During Hurricane Katrina recovery efforts, National Renewable Energy Center and Florida Solar Energy Center provided mobile PV power systems to Kilm, Mississippi. The NREL unit powered the oxygen generator, fan and lights for a special needs person living in a tent after his mobile home was destroyed. The FSEC unit was used to power a commercial AM radio station that transmitted emergency communications every hour after a gasoline generator failed. [4] (Figure 3)

For another Hurricane Katrina application, Worldwater and Power Company donated the use of one of their mobile solar- powered water pumping and filtration systems for use in Waveland, Miss. The system provided 15,000 gallons of drinking water per day to victims. The water pumping and filtration systems are designed for both stationary and mobile applications. Thermal Conversion Technology constructed a solar thermal (hot water) disaster response trailer for use at tent camps and clinics which has a PV system to power the pumps. Another trailer-mounted system was donated by Stellar Sun, to a shelter at St. Bernard Port in New Orleans, LA.. The unit was built many years before to provide power for construction sites and has an array that can be unfolded to increase the array size once it is set up on-site.

PV power trailers have also been used during other disasters, such as the one built by Live Oak Solar and used to power communications and lights for forest fire fighters in California. The trailer is enclosed and has 1000 watts of PV mounted on the top and sides, which extend to form the array after placement at a site. These trailers have been used at several fires since being placed in service in 1999.

Trailer-mounted PV systems have been used for monitoring and instrumentation, such as Reynolds Aluminum's application for air quality measurements around a bauxite tailings (aluminum processing waste from bauxite ores) covering several hundred acres near Corpus Christi, Texas. Poor air quality in the area could create negative health effects. Air samples are taken 24 hours a day for 7 days a week by this trailer built by Direct Power and Water.

5. Trailer Designs

Trailers are made in three types, conventional travel trailers, fifth-wheelers and cargo/vehicle trailers. While PV can be used on all three types, this report addresses cargo/vehicle trailers for utility use that have an open or enclosed bed. There are many trailer design features to consider, such as size, strength, stability and load capability.[5] The biggest difference in trailers is load carrying capability, ranging from 100 to 10,000 pounds. When designing a mobile PV system, Department of Transportation standards for use on highways should be followed along with trailer industry guidelines and practices. It is recommended that a trailer be chosen which offers options for safety and ease of PV implementation. If enclosed, the trailer should be at least 6 feet in height so that a person can stand up inside. The type of siding material, spacing and placement of ribs will make the trailer sturdy enough to support the PV array. Plywood mounted on the inside and rib spacing makes attaching equipment easy. Heat builds up inside trailers, so installation and vents many be needed. Strong and reliable latches and doors should be chosen for highway speed and mounted to withstand wind and vibration. Various types and combinations of doors are available, including ramp and single hung.

If many batteries are required, this will increase the cargo load and require two axles. The chaise may need to be strengthened, and the size of the wheels, tires and wheel bearings should be considered. Electronic or hydraulic brakes are important if the trailer is large and heavy. An aerodynamically designed trailer would add stability, and is particularly important to offset the addition of PV. Sway and spring bars add to the control of the trailer when driving. The size and type of tow vehicle is important, as cars and small trucks have limits of about 1,500 pounds. Medium sized trucks will tow up to 3,500 pounds and larger trailer loads will require even larger trucks.

6. PV System Considerations

The same criteria and practices for designing a typical PV system are used whether mounted on a trailer or not. Most photovoltaic manufacturers or installers customize their PV systems for each customer and application. This makes each PV system unique, and therefore making them cost more requiring specialized? maintenance. Though there are many different PV system designs, there are only a few PV system configurations. Therefore, there is little difference between one system design and another of a given configuration, except mounting and some application-specific components. Of these differences, the biggest is in the individual component designs between one manufacturer and another. This difference does not present a negative issue because components are designed for interchangeability. Modularity of components, such as the PV and batteries, makes increasing production easy. A few manufacturers make a packaged PV system that can be mounted on the ground, a building or a trailer; therefore, the mounting attachment is the only difference between stationary and mobile units. Presently, most trailer- mounted PV power systems are unique, as they are custom designed for a specific mobile application.

In recent years, the Florida Solar Energy Center has promoted packaged "kit" PV systems, where a tested specific design is defined with a set of standardized parts. Each kit of the same model performs in the same way and a manufacturer can make several different kits, reducing the costs of parts, manufacturing time and maintenance. Kits may be essentially the same except for the number of PV modules and batteries installed to handle various loads. Most user applications break down into typical sizes with respect to load, physical dimensions and energy production.

Typical PV system components are used on trailers with some exceptions when considering vibration of a moving trailer and wind speeds while traveling. Some inverters have units designed for mobile application, while other inverters will need special mounting deigned for vibration.[6] All braces and mounts need to be designed for this tough environment. The PV trailer needs to be designed for hurricane winds of 140 miles per hour in case it is placed in a location that will experience such winds. Traveling on expressways at a legal speed is your first level 1 hurricane test. Tie downs and secure connections are needed not just for wind conditions, but also to keep the trailer from being stolen.

In designing a mobile PV unit, the weight of the PV system may be within the ranges of 400 to 1,000 pounds for small load units, 1,000 to 2,500 pounds for median load units and 2,500 to 6000 pounds for large units. The size of the battery bank needed to provide storage affects the size of the system as well as trailer weight limits. In designing a unit that does not exceed a trailer's weight limit, there is a balancing act involved between meeting the load, providing required energy and the array size. [7] The balance of system components, including charge controller, disconnects, wire, circuit breakers, inverter and other hardware must be considered in the weight equation. The physical size and weight of PV systems affect mobility, as units over 8,000 pounds require a tractor trailer to transport.

Most PV arrays are a fixed size whether mounted on a tracker or a rack on the trailer. Some racks are connected to the trailer with hinges for ease in transporting and are locked in place at the site. Secure mount with multiple tie downs help keep components from coming apart from vibration and wind loads. Solar trackers may be trailer-mounted and tied down during transport. A few systems have extendable arrays stowed under another array which extend once set up. Rack-mounted arrays usually have an adjustable tilt angle for array deployment as well as energy production. A deciding factor on the size of the array is mounting to provide a greater physical area for energy production without going over trailer weight limits. PV trailers have been made with arrays sizes from 100 to 3,000 watts, with the maximum based on the physical limits of the trailer's size. Typically, there are three sizes - 100 to 500 watts, 500 to 1,200 watts and 1,200 and up.

Once the trailer is on site, the array should be oriented to collect energy from the sun needed for that application. Fixed arrays on the ground or on buildings have a fixed orientation to the sun for energy production. Trailer-mounted systems can be reoriented to the sun as needed, requiring the user to be properly trained to prevent misalignment with the sun. Small units can use solar trackers, which makes their placement easier. The Department of Transportation avoids possible misplacement and incorrect orientation of their equipment by mounting the PV array flat on the surface of the trailer.

7. The PV Disaster Trailer

If the power goes out, you may want to keep the refrigerator running, lights on and be able to operate a radio or small television for the latest news. To meet this need, FSEC created its own 440 Wp PV array emergency power trailer-mounted system. The unit uses a 2,000 DC/AC Trace inverter made for mobile use. The battery pack provides 2,600 Whrs of energy storage. The system design meets the latest standards and code requirements.

The FSEC PV Disaster Trailer was designed to provide critical power for a typical home owner following a disaster and typically represents the smallest emergency critical load.[8] Larger systems may be designed for clinics, gasoline stations, business or other applications based on their critical power requirements. Another benefit of the trailer, is that it will power any application, such as pumps, lighting systems, cabins, construction sites, weather stations, outdoor events, concession stands, or any energy need matching the trailers energy production. Comparing operation of a mobile PV system to that of equipment powered by a stand-alone PV system, is that the user needs to be trained not to consume more power than the mobile PV unit produces. What mobile PV systems cannot do is supply loads requiring 800 watts or more of continuous power.

The FSEC unit makes a great training device for workshops. The PV system is more than a solar demonstration unit as it actually powers any small application. Design information is available for the do-it-yourself person, with a caution to follow the latest standards and regulations.

It is mounted on a trailer to allow it to be moved to a critical need area after a disaster and used by relief organizations. Relief workers gain experience with PV and FSEC personnel gain real-life experience operating in a disaster situation. The unit has been used following such Hurricanes as Charlie, Frances and Katrina. The unit provided clean, noiseless, stand-alone power that was easy to use and deploy for temporary operation of critical items. Since the sun provides the fuel to generate the electricity, availability of fuel and the fuels transportation is not an issue. Like most PV systems with batteries, storage for long periods of time is a challenge. The FSEC trailer can be deployed upon request to disaster organizations.

FEMA currently owns 8 systems which are used mainly for training. The PV industry provides designs, but usually does not offer off-the-shelf availability. The typical cost of a mobile system ranges from $1,000 to $3000 more than a ground or building-mounted system which typically costs from $11,000 to $40,000. At these prices, few mobile PV systems are stored in inventory by an industry waiting for sales. Manufacturers and distributors of PV power trailers include SunWize Technologies, CHI Mobile Systems, Schott Applied Power, Direct Global Power, Solar Technologies, Eneract, Worldwater and Solar Technologies, Adventruetrailers, Sunshineworks, CTSOLAR, Powerup Corporation, Mobile Solar Power, Trident Security Devices and NEST Energy Systems.

8. Conclusion

Inevitably, disasters such as hurricanes, tornadoes and floods will bring down power lines to homes, businesses, schools and medical facilities leaving many without electricity. When the utility grid goes down, gasoline and diesel generators will still be the main stay for emergency power for some time, due to widespread acceptance and the large market share they maintain. Times are changing as interest in solar increases and the solar industry grows. PV systems are being installed on increasing numbers of schools, business and homes. The best solution is for buildings to have photovoltaic systems with at least one stand-alone or Bi-mode inverter that will continue to provide electricity during power outage, as compared to only grid-tied inverters. Not only can PV be integrated into buildings as a source of power, but also as a critical power supply in the event of a power outage.

A growing trend is to mount solar systems on trailers, move the energy supply to the need and redeploy as necessary. Photovoltaics (PV) provide quiet, reliable, emission free electricity that does not need refueling. PV trailers have been made with PV array sizes from 100 to 3,000 watts with maximum size being based on the physical limit of the trailer's dimensions. Designs are becoming standardized into three ranges from of 100 to 500 watts, 500 to 1,200 watts and 1,200 and up. The PV system trailer designed to power applications such as camp sites, social events, concession stands, construction sites, cabins or anywhere electricity is needed. Mobile emergency backup PV power systems are a viable designed for clinics, shelters, gasoline stations and businesses, based on critical power needs after a disaster. What mobile PV systems cannot do is supply loads requiring 800 watts or more of continuous power. As history has shown, mobile PV emergency power systems can replace gasoline and diesel generators for emergency power in many small, but important applications.

9. Acknowledgments

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