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SOLAR 2018: PROVIDING EMERGENCY POWER AND SURVIVING ON SOLAR Boulder, Colorado, USA

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ABSTRACT

Since Hurricane Hugo in 1989, solar has been used to provide electricity in disaster emergencies. Portable and consumer solar items powered lights, chargers, water pumps, radios and refrigerators.[1] What is notable is that historically, homes and businesses had utility interactive photovoltaic (PV) systems connected to the utility grid with battery storage. When buildings lost utility power, the PV/battery system provided power.

In 2000 that changed. Net metering practices were introduced and batteries were eliminated from many photovoltaic systems. In the aftermath of Hurricane Charlie in 2004, despite sunny skies many grid-tied PV homes were ‘dead in the water’, or shall we say, ‘dead in the sunshine’ without the ability to access their own PV systems’ power. Advance mitigation is the key to energy resilience. Some PV designs are once again including battery storage, protecting the systems from disaster power outages. Auxiliary distribution panels are often added to the design to assure emergency power to essential or critical items.

From 2010 through 2014, the Florida Solar Energy Center, a research institute of the University of Central Florida, through the SunSmart Schools Emergency Shelter program, installed 118 utility-interactive (solar+storage) PV systems with batteries on schools throughout Florida.[2] These schools benefited from the onsite production of clean, silent solar electricity during daylight hours. If there happened to be a utility power disruption, these schools that doubled as emergency shelters were able to tap into battery power to keep essential items powered.

The schools were real time tested during the 2016- 2017 hurricane seasons. After hurricanes Matthew and Irma, requests were made of the schools for information about the performance of their PV systems. Information was gathered from staff and administration from the SunSmart Schools. Only 3 school systems sustained damage and were still functional.

This data provided noteworthy support for the importance of solar + storage and valuable ‘lessons learned’ on school staff awareness and education. Some of the schools were used as shelters by local emergency management. However, a major problem was full utilization, as school staff and emergency management personnel overlooked the full potential of this resource. In designating shelters, some schools with solar were forgotten and in those that were used, staff turnover and time elapsed since system installation created a gap in understanding of how to use what was available. Just providing a PV-powered shelter is not enough; training and periodic hands on exercises are needed to fully utilize this resource.

1. INTRODUCTION

Since the early 1800s, hurricanes have impacted the modern development of the eastern Atlantic coast. The U.S. has been affected by an increasing frequency of disasters, manmade and natural, as the number of declared disasters in this country has grown by over 400 percent since the 1950s. In 2015, the Federal Emergency Management Agency (FEMA) declared over 100 disasters, including fires, tornados, hurricanes and floods [4]. Disasters damage or destroy nature, resources, utilities, property, homes and businesses and

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impact the local and regional economy. Many disasters damage thousands of residences and businesses, leaving them without functional water, sewage, communications, utilities, shelter and other life support services.

In 1960, Hurricane Donna damaged thousands of residences and businesses in Florida. This storm prompted a few home builders to offer hurricane- resistant houses as a marketing advantage over other builders. Houses were built with a lower rise angle on the roof, a secondary power panel for critical load items and an electrical outlet for safely connecting a gasoline generator. In 1989, a small group of solar companies provided portable solar electric (photovoltaic/PV) devices to survivors of Hurricane Hugo who were without power. At the time, the solar industry was producing consumer items and stand- alone photovoltaic (PV) systems with energy storage that met some of the basic needs for electricity.

Following Hurricane Andrew in 1992, building codes were strengthened to include hurricane tie-down straps and other structural practices [1]. Due to Andrew, the first organized effort was established to respond to hurricanes with solar equipment. The Florida Solar Energy Center, Florida Department of Transportation, U.S. Department of Energy, Sandia Laboratory, National Renewable Energy Laboratory and the solar industry provided various types of solar equipment for emergency power where the utility was out.

In 2004, Hurricanes Charley, Jeanne, Frances and Ivan, striking in succession, changed the way the United States prepares for disaster response and the way the Federal Emergency Management Agency (FEMA) responds to disasters. The solar industry and disaster organizations were learning how to coordinate with each other. Net metering had been established in 2000, prompting the elimination of storage/batteries from many PV systems as a cost saving measure. This proved to be a poor idea as many PV owners were left without power, thinking mistakenly their PV system would continue to operate after the utility went out.

Hurricane Sandy in 2012 was the deadliest and most destructive hurricane of the Atlantic hurricane season, and the second costliest hurricane in United States history with 285 fatalities and over 65 billion dollars in damages. Sandy was a category 3 hurricane with

winds over 115 mph, causing massive flooding and damage in 24 states and the Caribbean [4]. Over 9 million people lost electricity, generating massive consumer and business losses. Vastly increased electrical consumption and dependence in our high- tech world has changed the marketplace and put pressure on utilities to keep electricity flowing. Utilities are working to upgrade and modernize the grid through natural gas-fueled power plant conversions, deployment of distributed generation operations, using other energy sources, applying smart grid design and other efforts. Individual homeowners and businesses can apply new distributed energy concepts using renewables for resilient, sustainable power, limiting the effects of disasters and other power failure issues.

By 2014, 10 kWp PV arrays with storage had been installed on 118 schools in Florida designated as disaster shelters.[3] Identical designs were used to lower costs through volume purchase and to ensure ease of maintenance as shown in Fig. 1.

Figure 1. PV at Apollo Elementary.

Fortunately, solar is becoming more mainstream as an energy source and an effective emergency power option. In 2017, another fury of hurricanes (Harvey, Irma and Maria), classified as Category 4 storms, bore down on the Caribbean and the Atlantic coast. By this time, some home owners, businesses and utilities were equipped with solar installations. The solar industry and disaster organizations quickly responded with solar electric systems, replacing damaged utility equipment.

2. RESPONSE VERSUS MIGATATION

When a major disaster strikes, tens of thousands of disaster workers with thousands of tons of disaster

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relief supplies will respond, costing millions of dollars. The Federal Emergency Management Agency (FEMA) has determined that mitigating the effects of a disaster in advance is more cost effective and humane than staging thousands of disaster response workers and deploying thousands of pieces of equipment. FEMA's cost-effective recommendation is to mitigate the effects of a disaster through disaster-resistant building design, adding the component of sustainable renewable energy for power. Utility power is becoming more resilient and reliable as renewable energy sources are being implemented into distributive generation applications. The solar industry is learning about use of solar for disaster recovery and disaster recovery organizations have learned about the value of solar applications.

The first known response to a disaster with solar powered equipment was with a small group of solar companies providing portable solar powered devices to survivors of Hurricane Hugo in 1989. Both in the Caribbean Islands and North Carolina, thousands of people were without electrical power for lights, medical equipment, communications, water and sanitation. These companies provided several hundred lanterns, battery chargers, radios, portable power units and trailer-mounted generators that were powered by solar energy. The items were portable PV consumer devices carried to tent camps, damaged homes, businesses and shelters. None of the items were designed for disaster relief, but the camping equipment and stand-alone systems sent were amenable to disaster relief applications.

Hurricane Andrew provided a proving ground for the limited number of consumer and stand-alone solar products available at that time. The Florida Department of Transportation (FDOT), the Florida Solar Energy Center (FSEC) and Sandia National Laboratory (SNL) teamed to assemble and provide PV power systems for the first organized disaster response effort using solar equipment. In the years that followed, SNL and the National Renewable Energy Laboratory (NREL), working with FSEC, funded the development of solar-powered equipment designed specifically for disaster recovery applications. Formal research was begun to define needs, collect data, develop and test equipment for use in disasters. Workshops were organized to transfer information to the solar industry and disaster response organizations.

More companies entered the market, providing consumer items and portable photovoltaic devices designed specifically for disaster relief efforts. Solar systems designed to power building and micro-grids are being created for use during power outages and as emergency power backup systems during disasters.

Designing and building fortified disaster resistant, zero energy renewable powered buildings is resilience, sustainable and cost effective in mitigating the effects of a disaster.

Fundamental to mitigating the effects of a disaster in the most cost effective manner requires preparation and planning well in advance of the event. With resilience and sustainability as the goal, a key requirement is the design and construction of fortified disaster-resistant, zero energy, renewable-powered buildings.

3. MAIN POWER GENERATION

The 21st century brought the development of renewable energy sources, including solar, wind, bio- mass and water. A modern grid with interconnected power plants over vast areas forms a Distributed Generation (DG) network as shown in Fig 2. As utilities grew from city power to regional to nationwide coverage, the distributed generation concept evolved through the integration of multiple energy sources into one complete package.[5] Inter-connecting diverse sources keeps the grid up even if one or more energy sources fails. Modern monitoring and control of the grid forms a smart grid that provides greater resilience and reliability than ever before.

Modern technology has not solved all energy security problems, as the utility grid experiences power outages and brownouts. Many people are familiar with the causes of down time of conventional utility power and the distribution grid from time to time. The electrical failure is seldom the central plant electrical generator. Sometimes the failure is caused by a system overload that

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requires parts of the system to be shut down selectively to prevent generator overload. Many times, a tree falls and breaks a power line, pole or other utility electrical equipment. However, the main cause is extreme weather events, like ice storms, tornados, lightning, wind storms, hurricanes and floods [9].

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Commented [SS1]: I think I understand what you are trying to say but not sure it sounds exactly right.

I don’t know that my attempt sounds right either.

Figure 2. Modern U.S. Utility Grid, (FSEC)

PV power systems for buildings are much larger than portable and consumer items. Alternating Current (AC) electricity generated by an inverter at 60 cycles sine utility waveform is commonly known as 'home power'. A system on a building consists of a PV array, PV controller and inverter, as well as conventional electrical power equipment items such as fuses, circuit breakers, batteries, combiner boxes and power panels as shown in Fig 3.

Figure 3. Photovoltaic power system (FSEC).

Stand-alone designs with storage (not connected to the utility grid) for remote locations were the precursors to modern PV systems [7]. Utility interactive inverter systems with storage were later developed, allowing PV to be a source of building power. Also, utility scale PV systems were deployed with arrays in the several megawatt range. For buildings, grid-tied inverter PV systems without storage came along after 2000 to save on the cost of batteries and problems related to batteries using the utility as the battery benefiting from net metering savings. In 2004, hurricane season came with four hurricanes crossing Florida, and thousands of people with grid-tied PV systems learned their system did not work without the grid interconnection, showing

Step-Up Transformer

Distribution Substation

Gas Turbine

Receiving Station

Distribution Substation

Distribution Substation

Recip

Commercial

Engine

Cogeneration

Residential

Industrial Commercial Central Generating Station

Recip Engine

Micro- turbine

Fuel Photo voltaics cell Batteries

Flywheel

the importance of site storage systems during utility power outages.

Photovoltaic and balance of system component technologies have advanced in efficiency, performance and reliability to rival anything that utilities can do, and in a more environmentally sound and cost- effective manner. Just last year (2017), an inverter manufacturer developed a grid-tied inverter that has a portion of its power provided without the grid.

Photovoltaic systems are subject to similar failure issues as utility power plants, such as extreme weather, fallen trees and loose or corroded connections. PV systems are subject to battery failure, controller failure and module failure. Like any other equipment, a preventive maintenance program can keep these failures at a minimum. The benefits are that properly installed and maintained solar is reliable. Its fuel (sunlight) is free, renewable and produces no noise or pollution. Unlike a gasoline or diesel generator, a solar system poses no threat of carbon monoxide poisoning.

4. MITIGATING A DISASTER

Local, state and federal emergency management entities have a plan for response and recovery and work to restore the community to a point where it can rebuild itself. The most critical time is the first 72 hours after a disaster, when survivors are fending for themselves until help arrives. This is why people should already have a disaster plan and own a disaster kit, as help cannot get to survivors until first responders evaluate needs and can move into place. Emergency management encourages people to assemble a disaster kit that includes water, food and first aid items. Typically, it takes about 3 days to 3 weeks to respond to a disaster and at least 3 years for people to recover, rebuild and resume their lives. [5]

Another way to reduce disaster-related damage and financial loss is by creating buildings that are truly disaster-resistant, energy efficient as possible and powered with renewable energy; then, truly sustainable homes and businesses can be realized. The Institute for Business and Home Safety (IBHS) has a Fortified Building Program with standards beyond normal building safety codes with 3 levels of design for creating stronger, safer buildings. DOE has a Zero

Energy Home Program, where the building produces as much energy as it consumes for a very energy-efficient building design. The ultimate goal is to combine the two programs for structurally sound buildings that provide sustainable operational use before and after a disaster. Renewable energy sources, such as solar thermal, photovoltaic, wind and biomass are sustainable, where fossil fuels are not and will one day be exhausted.

Homeowners and business leaders should evaluate their energy needs and operational activities. This involves identifying critical energy needs and incorporating the concept of critical operations power supply design into a home or commercial building. During a power outage, a homeowner may want to have electricity for a lamp, a refrigerator and a radio. A business may need a few lights for customer safety and a cash register to complete sales transactions. Most people would consider these items critical to maintaining home or business operations and personal lifestyle until utility power is restored. [7]

Essential needs can be powered through a backup power source and can be connected through a subpanel to the renewable energy source and the main utility power panel. When the utility power is operational, essential items are powered as usual; during a power outage, the backup energy source powers items through an essential/critical subpanel. This configuration can be designed and operated like an uninterruptable power supply (UPS) to ensure essential/critical items are always powered. This scenario works for bi-modal inverter designs, but not grid-tied only configurations. During normal times, utility interactive PV power can provide excess energy to decrease electricity bills.[7] Of course, stand-alone PV systems not connected to the utility grid are already properly configured for effective disaster operation, as the load and supply are matched. Therefore, multiple PV system configurations can be used in a distributed generation configuration. One system powers the critical load, one is grid-tied for HVAC and one with storage for other important load uses in a demand-side management operation based on the importance of maintaining operational functionality of the energy need. Some inverter systems are smart enough to do load shedding and perform priority loading to maximize energy use. Many of these applications have dual use, adding to their financial benefit.

5. SOLAR FOR SCHOOLS

The DOE had an established Solar for Schools Program and the Florida Solar Energy Center joined in 2003. The Florida program began with funding from the Florida Energy Office (FEO) to install photovoltaic systems on selected schools. The program was initially designed as a way to raise awareness and to provide experience and understanding of photovoltaic technology to students, teachers and the general public. Some of the math and science requirements of the Florida Sunshine State Standards were also met by this educational effort.

The educational component of the program included professional development (PD) for teachers, free solar curriculum and a kit of materials not typically found in the classroom. The curriculum activities and kit provided opportunities for hands-on, minds on learning through the theme of solar technology, which also tied together science, technology, engineering and mathematics (STEM). The PD workshops immersed the teachers into the activities using the kit of materials, which they would then use at their school with their students.

Initially, 47 schools received grid-tied PV systems designed with a 1 to 6 kW array operating as an educational demonstration application.[2] By 2005, the program was renamed SunSmart Schools and the hurricane season of 2004 lead to the expansion of the program to include larger PV systems with storage to be installed on schools designated as emergency shelters. In 2008, Middleton High School in Tampa was the first school to receive a bi-modal 10 kW system with battery storage. The system was installed on the shelter part of the school as a viable application for use during power outages and disasters. This was an example of a real-life application that generated power during normal times as well as during and following emergencies when utility power was unavailable.

In 2010, FSEC received a federal grant with matching state and utility funds which provided bi-modal PV systems to 118 schools

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designated as emergency shelters and was renamed SunSmart Schools Emergency Shelter (SSES) program. Of the 67 counties in Florida, 47 counties participated in the

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program, covering most of the state area and coast line, as shown in Fig. 4.

Figure 4. Florida Map school locations.

Each school participated in a selection process involving several steps: application, external review, site inspection, identification of critical loads and signing of a School Agreement. Schools that applied had to meet minimum criteria that included their status as a shelter, local demographics, the school's energy education plan and level of commitment to the project. Because the PV systems became the property of the schools once the installations were completed, each school was required to sign a "School Agreement" specifying ongoing expectations. The final location of the PV system was determined based on physical site issues. The first consideration was whether there was an area large enough for a ground-mounted array of this size. The school had to agree to install an IT port for the data monitoring system, send two teachers to attend a professional development workshop where they would become familiar with their PV system, participate in solar lessons, and receive a kit and solar curriculum to use in their classroom, and allow at least one facilities manager to participate in system maintenance training. It was also expected that each school would incorporate solar energy education into their school curriculum.

6. PV EMERGENCY SHELTER

These new emergency shelter systems were designed as uninterruptable power supplies (UPS) to power critical loads in the Enhanced Hurricane Protected Area (EHPA) shelter part of the school. The PV systems for this program were designed with 10 kWp

photovoltaic array and battery in a bi-model inverter configuration as an emergency power systems [4].

During normal time the new PV system reduces the school's electric utility bill as the initial SunSmart program did. This new program also provides a PV system designed for powering the shelter part of the school as an emergency backup system to energize essential items such as room lights, outlets for medical equipment, communication and operational computers used in a shelter in an emergency, as shown in Fig 5. The load was minimized to be able to be powered by the 10kW PV array/battery system. Each school that is a shelter has a different part of the facility dedicated to the shelter operation, such as a gymnasium, cafeteria, or a set of classrooms. The essential-critical loads of the designated area were wired to a separate critical load panel installed and wired to the general buildings load panel. During normal times the PV and utility power feeds all of the loads of the building as a utility interactive operation with net metering, but during utility outage the PV-battery supplies the power to the essential-critical loads through the added critical load panel.

Figure 5. Essential school loads and supply. (FSEC)

7. DISASTER IMPACTED SCHOOLS

The SunSmart Emergency Shelter program provides a viable, real-life PV emergency power design for any disaster application. As mentioned above, 47 counties participated in the program, covering most of the state of Florida. A hurricane crossing the state could impact any one of these schools.

In 2016, Hurricane Matthew caused no damage to any of the schools. Hurricane Irma in 2017 did present issues to some schools. Of the 118 shelter schools, 77 closed due to the threat of the hurricane. Of the 41 open, 13 did not lose power. The longest period a shelter was open was 56 hours. Several schools had fossil fuel generators that mechanically failed and others ran out of fuel. Three PV arrays were damaged by debris hitting the array.

None of the damage stopped PV arrays from working, as single modules were damaged. For example, at the Apollo Elementary shelter, damage was to the top glass cover and broken cells as shown in Fig 6. The array was wired in 14 strings of 3 modules, so when a module was broken only one string was out, causing only a loss of less than 10 percent of array production. People entered the shelters the day before the storm arrived and stayed the day after until the 'all clear' to go home. A significant storm's heaviest wind and rain usually lasts 2 days, so designing for 2 to 3 days of autonomy is enough, considering the utility power should be there for half that time before going out. The design goal was to power single phase loads, such as lights, wall outlets and electronic communication equipment. A 3-phase inverter design with loads across each phase limits power losses across the loads.

Figure 6. Damaged module, Apollo Elementary

Several shelters had amateur radio operators providing emergency communication. Knowing the news through AM-FM portable radios and television was a big help to everyone. Charging phones and flashlights was appreciated by all, but not as much as having hot coffee! Special needs people with medical life support equipment were able to use a nebulizer, an oxygen concentrator and a G-tube feeding machine. One shelter was used for special needs people and one for

pets. All together there were about 1700 people staying in the shelters and about 500 pets.

PV systems as small as 10 kWp can benefit the utility, the school shelter, home and business customers during a disaster. PV with storage with utility interactive with storage larger than 20 kWp PV would provide more stability and cost benefits to all to school shelters and business.

8. SSES PROGRAM NEXT STEPS

From educational and operational perspectives, the SunSmart Emergency Shelter program needs to address lessons learned more broadly. In hindsight, some new school staff had heard there was a solar installation at their school, but did not know how it worked and what it could do. Maintenance issues with the operation of the PV systems should have been addressed so systems would be fully functional. School staff changes over time should be tracked. Initial training and refresher training for school staff and partner disaster organization personnel could be conducted annually. SunSmart Emergency Shelter Schools with STEM, Technology, Environmental or other such clubs could integrate awareness and understanding of their PV system as part of their club's mission. May is Hurricane Awareness Month and the SSES should be an active part of that.

A program enhancement to check, update and educate people and equipment periodically needs to be implemented to better serve the educational goal of the program and better provide emergency power support.

9. CONCLUSION

Disasters, man-made or natural, can be very destructive, leaving thousands of people without shelter, power, water, sanitation and communications. Advance mitigation is the key to energy resilience. Why deploy thousands of disaster workers and tons of disaster relief supplies when disaster-resistant, renewable energy-powered buildings can mitigate the effects of a disaster, saving energy costs during normal times?

Utilities have made advances in becoming more resilient and sustainable. Distributed generation has played an important part by providing more sources of energy to the grid. Integrating all available sources together with smart grid technology greatly enhances the resilience of the modern grid. Renewable energy applications, such as roof-top solar, micro-grids and community solar using photovoltaic and wind have done their part to make the grid more resilient and sustainable. New storage technologies being developed will increase the benefit of distributed generation applications. Individual homeowners and business owners using renewables benefit from applying distributed generation concepts to their own buildings' energy supplies. Why not take advantage of the sun's benefit as an endless source of free energy, every day and during disasters, wherever the need?

Modern codes and construction practices have changed evolved to provide for more resilient buildings. Integrating multiple photovoltaic system designs can maximize the resilience of a home or business power system. Dedicating a particular PV design to an energy need functionally will provide greater energy resilience and lower overall operating costs. If utilities' hardware and systems are designed with fault tolerance in mind using palatable energy sources, disaster resistance through renewable resources will be achieved. Proper design withstands disaster forces.[8]

The SunSmart Emergency Shelter program has shown the viability of PV utility-interactive with batteries (solar+storage) effectively integrated into design and operation of a building will lower costs and operate effectively as emergency power in a disaster. Schools and FSEC need to maintain contact; education of school personnel will be critical to maintaining functionality of PV emergency power systems.

The lower cost of utility-interactive photovoltaics combined with the reliability of the 24-hour operation of photovoltaic battery systems will soon become mainstream. School shelter emergency power should be a fault tolerance PV design. Photovoltaic systems provide a free source of energy from the sun and an economic benefit to everyone during normal times as well as during power outages and following unexpected disasters.

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