Green Technology for Disaster Relief and Remote Areas

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Abstract

Hurricanes, cyclones, tornadoes, earthquakes and flooding are natural disasters that can happen at any time anywhere. The electrical power is usually the first critically important service to be lost affecting homes, hospitals, schools, food stores and other vital services. In the aftermath of these disasters photovoltaic (solar electric) energy has the potential to help bring natural, reliable power to places devastated by these events. The earth surface receives an average of 120,000 Terawatt from the sun, (ignoring the energy being scattered by the atmosphere and clouds) which would be sufficient to satisfy the energy requirements of all human activities for more than one year in less than one hour. Photovoltaic (PV) power systems is an example of green technology which provide emission free electricity fueled by the sun which is reliable, secure, noise free and does not need refueling. It also helps to reduce consumption of fossil fuels in power plants, pollution and greenhouse gas emissions causing climate change.

One of the new trends in disaster relief is to mount PV systems on trailers, move the energy supply to wherever it is needed and redeploy as necessary. Mobile PV power systems are stand-alone systems which have been deployed to provide electricity to power radio stations, health clinics, shelters and homes at the disaster sites before utility electricity is restored. These systems can be assembled in a short time and can replace gasoline and diesel generators for temporary power in many small applications. Such systems can also be used for more than a billion people living at remote locations that have no access to electricity. New community partnerships are also emerging between citizens, utilities and governments to provide electricity at a reduced rate for small businesses, low-income utility customers, agricultural producers, and other people frustrated by shading, limited roof space, not owning their home, or the high initial cost of ownership. These community partnerships or solar gardens essentially allow such people to "own" a portion of the energy from a solar electric generating facility operated by an electric utility or other entity and have that energy credited toward their electricity bill similar to what would happen if they installed solar panels on their roof or property.

The purpose of our paper is to review the use of mobile photovoltaic system to provide electricity in the aftermath of disasters for emergency relief and to remote areas having no access to the grid. It will also discuss the advantages of community solar and solar microgrid for disaster resilience. The paper concludes by emphasizing the importance of these technologies in engineering education and integrating them in programs related to solar energy and disaster & emergency management.

Introduction

According to recent reports, [1, 2] the number of natural disasters worldwide has steadily increased since 1970s. It is also reported that the number of natural disasters is the highest in North America with tornadoes, hurricanes, severe heat, floods and even drought. When a disaster strikes, the whole infrastructure including electricity shuts down for days or longer years depending on the nature of the disaster. In the absence of electricity, all human activities and businesses are either damaged or ruined. According to a recent report by World Bank, [3] natural disasters have cost the world $3.8 Trillion since 1980. The World Bank analysts found by using data from Munich Re [4] that 74 % of the total cost is related to hurricanes and drought disasters and that the annual cost from damages has increased from $50 billion a year in 1980s to $200 billion a year today. When businesses fail to survive after a disaster, the overall economic health and social viability of a community is threatened requiring measures to return the community to normal after providing relief in the early stages of disaster. To provide electricity to each home after the disaster requires propagation, transmission, distribution and management of electricity which is expensive and takes time to implement. The use of diesel –powered engines to provide emergency power unfortunately can be dangerous in the hands of untrained users and is reported to have incidents of fire, fuel explosion, burns and problems of noise. Generating electricity from solar energy through the process of photovoltaic (PV) is safer, noise free, environmentally benign and is rugged. Mobile PV systems are a natural solution to providing electrical power to homes, businesses, street lights, radio stations, health clinics, and shelters at the disaster sites before utility electricity is restored.[5,6] After the immediate disaster relief, it is important to provide continuous power to the community in case grid systems takes longer to resume or are located at remote areas. Solar energy has the ability to enhance resilience in the communities by providing backup power even if the grid is not restored. This can be achieved by using solar microgrids and developing community solar which is a partnership between citizens, Government and businesses.

After the emergency response of securing lives and property, engineers of different disciplines are needed to assist in difficult task reconstruction efforts, analyzing risks, and evaluating damage. Engineers are responsible for designing building systems including heating, air conditioning, electrical, communications, fire protection, security, and developing technologies to help make building infrastructures stronger than before and after a disaster. Many educational institutions around the world are developing new programs and courses relating to the emerging field of disaster & emergency management to mange, mitigate and prepare for the disasters. The objective of these programs is not only to deal with disasters but also to implement strategies that could prevent or minimize the chances of reoccurring, and developing long term resilience to disasters. The educational approach to develop these multidisciplinary programs is to combine courses from different disciplines of engineering, management, natural sciences and social sciences. Federal Emergency Management Agency [7] (FEMA) has listed over 35 programs relating to disaster & emergency management in US universities and colleges. Many engineering institutions are also introducing courses and programs in solar (photovoltaic) energy at the undergraduate and graduate level in view of increased demand for renewable energy and concern for clean environment.

It is clear that engineering education has an important role to play in helping to educate professionals who can address the technological challenges of the 21st century and affect our future. As a result it is critical that information about new and emerging technologies is integrated into engineering education. This paper reviews some of the new trends and shows that the photovoltaic systems (mobile and standalone), community solar and solar microgrid are important technologies which should be incorporated in the new programs relating to disaster & emergency management and solar energy at the undergraduate or graduate level.

Mobile PV Systems for Disaster Relief

Mobile PV systems are autonomic systems which can be used as a source of power for supplying power to homes, businesses, hospitals, schools, in the aftermath of disasters. These systems are standalone system which are easily mounted on tow trailer and can be moved to the place where needed. Mobile PV systems consist of PV panels to produce electricity from the sun, charge controller to regulate the voltage and current from the PV panel and lead-acid batteries to store the electricity, inverters to change DC into AC and wiring to connect various components. Mobile PV systems use components similar to standalone systems but are configured for the harsh demands placed on portable systems.

Mobile PV systems were first [8] used in the disaster relief of Hurricane Hugo in 1988 to provide power for various usages. These systems on trailer have been used in many disasters including Northridge earthquake (1991), Hurricane Andrew (1992), Hurricane Bonnie (August 1988), Hurricane Georges (September 1988), Hurricane Charlie (2004) and Hurricane Katrina (2005) [9]. In 2010, SunBlazer [10] solar trailers were developed by a team of IEEE volunteers for disaster in Haiti as shown below.

Solar trailer used at Haiti

Features of Mobile PV systems for Disaster Relief

The features of mobile PV systems depend on the degree and scale of natural disasters. In Hurricane Hugo (1989), mobile PV generator systems were used to power a community center for six weeks after the storm. In Northridge earthquake (1994), PV systems were used to keep some communication links operating and to power homes of Southern California residents. In Hurricane Andrew (1992), PV systems were used at medical clinics and shelters and to power street lights & communication systems [11]. The PV systems for disaster in Haiti (2010) were used to provide low-cost, reliable electricity to a poor rural area for schools, community centers, small businesses and homes to power LED light bulbs, run a radio or power a small power tool and charge mobile phones. The PV panels in the trailer charge four large station batteries from which the smaller home packs are charged. [12] Trailer based PV systems can also be used in many other applications such as lighting systems, pumps, cabins, weather stations, concession stands and other needs compatible to trailer power production. The important design features to consider for trailer are size, load capability, stability and strength of the trailer, and should be based on the following features.[11,12]

- Compliance with Department of Transport standards for use on highways and trailer industry guideline and practices
- Provide safety and ease of PV panels' implementation
- Firm support of PV arrays
- Roof of the trailer should have vents to withstand the internal heat
- Folded solar array should be able to withstand 60.miles per hour winds and vibrations during transportation
- Height of the trailer should be enough for a person to stand inside the trailer
- Size of the trailer determine the weight which can accommodate the batteries and axle
- Easy to fold and unfold the solar panels

It is recommended that with the use of cargo/vehicle the height of the trailer should be at least 6 feet when enclosed. Plywood is a good material to use on the inside of the trailer and rib spacing which also makes it easy to attach equipment. Ventilation should be used to reduce heat buildup. Strong and reliable latches and doors such as ramp and single hung type should be used to overcome wind and vibrations on the highway.

The Florida Solar Energy Center (FSEC) [13] designed and created its own PV disaster trailer for many applications including operation of lights, refrigeration and operating a radio or TV for home owners after the disaster. The trailer consist of 440 Wp, PV array emergency power trailer-mounted system, 2000 DC/AC inverter and battery pack providing 2,600 Watt hours of energy storage. This system meets the smallest emergency critical load of a typical home owner while larger systems may be designed for medical clinics, schools, businesses, gasoline stations and other critical needs.

Standalone Systems for Remote Areas

Standalone systems are used for remote areas where electricity from the power grid is not available. These systems are not connected to the grid but can provide DC or AC by the use of PV panels in the presence of sun. According to a recent statistic,[14] approximately one out of every four people (about 1.6 Billion) worldwide, many of whom live in isolated areas, still do not have access to electricity or clean water, primary health care, education and other basic services, all of which are largely dependent on access to electricity. In India, Pakistan and Bangladesh, 50% (700 million) of the overall population and 90% of the rural population are not connected to the grid. In such remote areas, a standalone solar-powered solution would be an ideal solution which can help to improve the economic and social development of the people. The application of standalone PV system was first installed at Chile in 1960. In the early 1970s the UN combined solar, wind and biomass resources, under a new program and distributed electricity via a regular grid system in Sri Lankan villages. In recent years until 2012, several million solar home systems (SHS) have been installed in remote areas of Bangladesh. This was achieved with the help of Infrastructure Development Company (Government supported corporation) and by the financial support of World Bank, and global donor platform for rural development. [15]

The main components of a standalone PV system are similar to mobile PV system and can include PV panel, PV controller, charge controller, inverter, battery pack, mounting system, wiring, and DC and/or AC power disconnect. Some devices like water pumps, LED bulbs, cell phone charger and cooling fan only require DC without an inverter. The specific components of PV system will vary depending on the application of the PV system and will range from a few watts to several hundred watts capacity. PV systems can be designed to provide DC power, AC power or both, with or without battery storage and are modular based. Additional panels can be added to the system over time by appropriately sizing(inverter and wiring) the system to manage the additional panels. The cost of generating electricity from these systems is more than grid tied systems but is cost effective when used for remote areas and disasters.

Applications of Standalone Systems for Remote Areas

The following applications of stand -alone systems in the remote areas may include stationary and portable systems. These applications are also available for rapid deployment or temporary loads such as disaster, emergency, rescue, road repair and onetime event. [16]

Residential: Power provision for houses and cabins, lighting, refrigerators, fans, TVs, radio, cell phone battery charging, automatic gate opener, (significant applications in developing countries).
Industry: Power tools, motors, battery charging, protection of gas, oil pipelines and other types of piping; provision of power for limited electric charges in the order of a few kW.
Telecommunications: Radio/television relay stations, telephone devices, stations for data surveying and transmission (meteorological, seismic, indicating the presence of fire and level of watercourses).
Public Services: Security lighting of streets, gardens and public transportation stops, street signaling, water purification and desalination.
Agriculture: Water-pumping installations, microdrip irrigation systems of automatic irrigation, livestock watering and management, electric fencing, automatic feeders.
Health: Refrigeration, very useful in developing countries for the conservation of vaccines and blood, emergency power for clinics.

Examples of Practical Standalone Systems

Given below are two examples of standalone systems which are cost effective to build and can be easily acquired from charitable organizations on donations. The first standalone system is a solar generator cart which can be assembled easily as a DIY project. The second system is a solar suitcase, manufactured for humanitarian and disaster area for medical applications. Both systems cost less than $1500 and provide easy access to electrify at remote areas.

Solar Generator Cart

A solar generator on wheels is an example of a standalone system which can be easily assembled by personnel with a basic knowledge of electricity. It was implanted [17] by placing solar panels on a cart which can be moved or repositioned as needed. It consisted of 2 solar panels of 80 watt each, a deep cycle battery and an inverter. The battery and the controller were enclosed inside the cart and were rated to produce 10 Watt DC and AC. Deep marine battery was chosen to store current capacity of 210 Amperes hour. The inverter produced steady AC power of 1.100 k Watt and peak power of 2.2 k Watt. The cart was assembled using a 2×3 lumber for framing and T-1 siding for the enclosure. It was built by using a wooden frame around each panel. Next two L-shaped pieces for each panel were built to hold the panels at a 45 degree angle. The L-frames were cross braced to provide a solid base for each panel. The two panels were then attached together by screwing the frames together. T-1 siding was then added to enclose the cart, and a piece of plywood to form the cart floor. The doors were then added on the back to allow access to the battery and components inside the cart. Finally, the cart was painted and caulked to prevent leaks, and wheels added to make it mobile. The size of the finished cart is approximately 4 feet wide 4 feet long and 4.5 feet tall. The DC/AC output from the cart can power microwave oven, refrigerator, and LED lights in a house, campground, a desert or a forest. This system is capable of providing approximately 460 amps of power each week to charge a 12 volt battery and can be used to power a number of appliances, such as a small microwave, TV, laptop, or even some power tools and is available wherever the cart is located. The system cost less than US $1500 to build.

Solar generator cart on wheels

Solar suitcase

Solar Suitcase

Solar suitcase (We care solar) [18] is a potable solar electric system that provides power to critical medical lighting, laptop computers, medical devices and mobile communication devices in remote areas with no access to electricity. It was first built in 2009 by Aronson and Stachel in response to lowering maternal mortality in Nigerian state hospitals. It is currently deployed for medical and humanitarian use in nearly 200 clinics in 17 countries including Mexico, Nicaragua, South Sudan, and recent disasters in Haiti, Bali, Indonesia and Philippine.

Solar suitcase, an award winning system consists of 40 or 80 solar panels, sealed lead –acid battery, inverter, high efficiency LED medical task lighting, a universal cell phone charger, and a battery charger for AA or AAA batteries. The maternity kit comes with a fetal Doppler. An expansion kit with larger batteries is also available. Its application can range from providing lighting to emergency obstetric care to charging and operating cell phones, lap top computers and medical devices in a remote or disaster ridden area. The $1,500 suitcases are often funded by charitable organizations.

Community Solar for Disaster Resilience

Community solar[19] is a partnership between citizens, Government and businesses. The “Resilient Community” Partnership is a cooperative framework that is essential to fostering community disaster resilience. It is essentially a solar-electric system that through a voluntary program provides financial benefit and is owned by multiple community members. The goal of this partnership is to maintain the economic and social viability of the community following a disaster. The benefits of community solar are given below. [20]

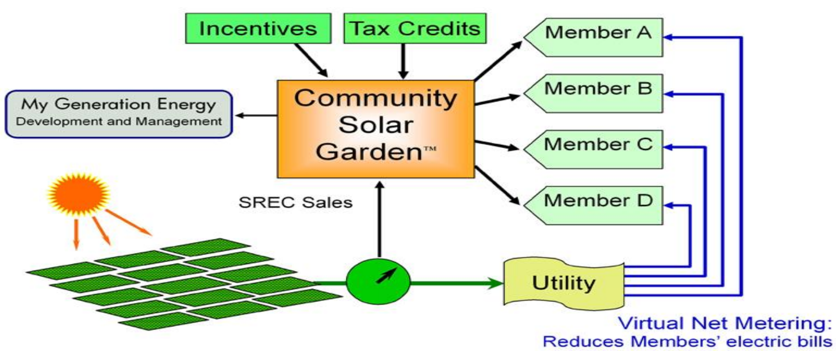
- No upfront investment. There are no upfront costs to install solar panels as it is a collective community project
- No maintenance or repair costs. There are no repair costs or panel maintenance in a community solar project
- Reduced greenhouse –gas emissions. It is environmentally friendly as it uses renewable sources of energy to produce power
- Suitable for renters, condo owners and homes not suitable for a rooftop system. Anyone can buy power whether you live in a condo, rent, or have a home that's not suitable for rooftop solar
- Cancel at anytime. It is easy to cancel any time after the contract period limit
- Fixed price for certain number of years
- Increased solar production. Community Solar panels usually track the sun throughout the day to produce higher energy than a stationary rooftop system
- Moves with you. Some community solar program unlike solar rooftop panels can easily move with you to another residence

Community Solar Garden for Disaster Resilience

One way of making community solar is through solar garden[21] which are solar systems that are community-owned and shared. Instead of installing solar panels on individual’s roofs, large numbers of solar panels are installed in a central location within a town or city limit to expand the availability of solar energy. The goal is to allow renters, or anyone who doesn’t or can’t put solar on their rooftops, to still benefit from localized solar electricity generation. In some countries it is encouraged by Federal and State governments through rebate and tax incentive programs. Electricity from the solar panels can be stored in the batteries for supplying to hospitals, schools, military bases and other needs in the aftermath of disasters. It can also be sent to the grid where it is sold to the local utility, which then credits the sale to the owners or subscribers of the solar garden.

There are over 20 community solar projects in USA and continue to increase in numbers. According to Solar Garden Institute [22] (SGI) the idea of community solar in USA was first conceived in 2003 by the City of Ellensburg, Washington State University Energy Extension, and the Bonneville Environmental Foundation. In USA Community Solar Garden” thought to be first used in 2009 by Luke Hinkle of My Generation Energy Inc., who constructed and maintained the Brewster Community Solar Garden® Project. [23] The first community-owned solar garden in Colorado started in August 2010 at El Jebel. The 340-panel solar garden is built on unusable land in the Roaring Fork Valley and was developed by clean energy collective. It is a 78 kilowatt solar array purchased by 20 members of local community. The system was connected to the grid with partnership by Holy Cross Energy local electric cooperative which collects the power produced by the solar garden and then directly credits owners' utility bill each month. [24]

The subscribers may purchase a portion of the power produced by the solar panels and receive a credit on their electric bill as if the panels were on their own roof using virtual net metering. The customers within the solar garden's service area, including businesses, residents, non-profits, local governments, and faith-based organizations, can all subscribe to the solar garden. A solar garden is a distributed generation project and provides benefits to communities by affordable energy, creating local and avoids destroying delicate habitats. It also bypasses the need for inefficient transmission lines, which lose power during transmission and can take many years to put in place. The solar garden helps the community save money by pooling resources and buying panels as a group, and give subscribers a lower cost than doing it alone. A schematic of a solar garden is given below:



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Community Solar Garden

The solar gardens can be located on a large roof, parking lot unused field or commercial area usually within a town or city limit. The size of a solar garden depends upon a country, state or the area in which it is located. Each country or state allows its residents to make solar gardens based on the need and newly passed bills in their laws. The size of solar gardens in the state of Colorado, USA, ranges between a large roof to 16 acres, accommodating 10 KW to 2 Megawatt. In the state of California the size of solar garden could be 160 acres accommodating 20 megawatt.

Despite many benefits of solar community gardens, it has many challenges and hindrances to implement. The first challenge is that every state or country doesn't have policies in place that allow such communal ownership and credit-sharing of a solar system. The next challenge is the price of land and its availability. The land in a big city may be very expensive or unavailable to implement a suitable system. Other issues include the minimum size of a piece of solar system that a resident must pay for or subscribe to and whether the subscriber can take their ownership to another state or town which may not be a solar garden from the same corporation.

Solar garden institute, [21] USA, has outlined the following steps to organize a solar community garden. The organizer need to work concurrently in 3 different areas namely policy, community organizing, and project development.

- Work on policy to promote community power for support of solar gardens. This can be achieved by working with your local utility, legislators and county planning commission to develop solar gardens programs and zoning rules. Be prepared to support and work toward nationwide policy dealing with solar gardens.
- Organize communities by arranging meetings, partnering with local nonprofit and recruiting early adopters. Work with neighborhood associations to find out about parking lots, religious places and unused lands for asset mapping in the community. This will also help you to find host sites on large roofs and suitable properties near utility distribution lines or substations.
- Arrange the bidding process for the construction of solar garden by identifying local solar companies involved in solar panel hosting**.**
- Locate and recruit subscribers from businesses, city governments, nonprofits power users in addition to regular subscribers who can use a significant amount of the power.

Solar Microgrid for Disaster Resilience

Micro-grid is an autonomous scaled down version of the traditional power grid that is able to balance generation and consumption within itself on a much smaller scale. It could be as small as a small disaster ridden town, an offshore oil rig, or as large as a military base. It might use storage to buffer distributed renewable energy resource like solar PV, or it might simply fire up a fuel-burning generator. The components necessary to provide power include batteries for energy storage, a power electronic converter, software and hardware. Microgrids can operate independently or in parallel with the traditional power grid. [25,26]

Because of much lower line losses in the transportation of electricity, off grid institutions like prisons, campuses, military operations, and large commercial and industrial markets in remote setting are building and maintaining their own microgrid. In places like Africa, Brazil, Haiti and India that have never had access to reliable grid power, microgrids are replacing expensive and polluting fuels like diesel and kerosene. Others place where grid power is available, microgrids are being built to justify the high cost or risk of an outage and be self-reliant. Microgrids have served as disaster recovery apparatus in the aftermath of natural disasters. [26, 27] One of the first solar microgrid projects is recently completed by solar Grid storage at Konterra, Maryland which is a grid-interactive energy storage system co-located with a 1368 panel array (402kW clean electric power). It provides backup emergency power and allows critical circuits energized at Konterra to remain energized in the event of a grid power outage [28.] A D.C., based nonprofit company (Earth Spark) has recently been awarded funding from the US Agency for international development to boost power and food in Les Anglais, Haiti by using solar microgrids. This will be achieved by connecting homes and businesses to solar mivcrogrid in order to supply power to process local crops that would otherwise not before arriving at markets. [29]

The advantages of solar grid are that they are less vulnerable to cyber attacks because of its ability to shut off from the main grid, more efficient and reliable because of size and able to respond to demand quickly, easier to expand because of its modular nature and easier to plan because of local control and smaller size. However, the challenges of implementations include the lack of regulation in certain areas, lack of safety and operation standards, lack of technical experience and communication protocols and increased cost because of the possibility of market monopoly against pricing abuse in the absence of suitable infrastructure.

Conclusion

The review of the use of green technology for disaster relief and remote areas shows that PV systems are the natural solution to providing electrical power to homes, businesses, street lights, radio stations, health clinics, shelters and homes at the disaster sites before utility electricity is restored. PV systems can also be used for more than a billion people living in remote locations that have no access to electricity. The examples of solar generation cart and solar suitcase showed that relatively inexpensive stand alone system on wheels can be assembled off the shelf to use it for various applications in disaster relief and daily living. The portable solar suitcase can also be manufactured locally at a reduced cost or bought by donation for medical and humanitarian applications. New trends such as community solar and solar microgrid are emerging to provide electricity for disaster resilience in case grid system takes longer to resume or is located at remote areas. These trends have the ability to enhance resilience in the communities by providing backup power even if the grid is not restored. It is also concluded that the photovoltaic technology in conjunction with community solar and solar microgrid should be incorporated in the new programs relating to disaster & emergency management and solar energy at the undergraduate and graduate level.

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