TJPD3.1 Atmospheric Input for Renewable Energy Microgrids (Educating 'Smart Grids')

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ABSTRACT: "Smart" mobile microgrids are evolving tools that could assist disaster relief efforts. A mobile microgrid is a semi-fixed, transportable power-generating resource that is able to connect to a larger power grid, yet is also able to function independently. Like the fixed microgrid, typical power out can range from 1 to 40 MW. Renewable energy power resources, such as solar and wind power, tend to be constructed as "microgrids". For microgrids to function effectively, their power integration needs to be transparent to the user. One of the significant challenges for a grid operator is to anticipate when to ramp up and down renewable energy resources. Smart grid technology has been addressing the automated balancing of power load requirements and resources. Not yet readily available to the mobile "smart grid" process is an automated atmospheric component. A long-term research goal is to "educate" mobile (and fixed) microgrids with current and future atmospheric conditions, so that an automated ramping of atmospheric-dependent renewable resources can be seamlessly executed. In this paper, the ongoing research being done to support the long term vision will be summarized.

1. BACKGROUND

Electrical power generated from renewable energy resources has the potential to become an invaluable tool of the human recovery processes from natural disasters. Some renewable energy resources have a heavy dependency on atmospheric conditions. Designing, developing, and integrating tailored weather forecast information into disaster relief and recovery renewable energy technology is a sagacious vision. Before the vision can be realized, however, at least 3 professional disciplines need to come together: Energy, Power (generation, storage, distribution), and the Atmospheric Sciences. Each field has its own language and priorities. Gaining a working knowledge of all 3 areas is an important foundation upon which the vision can be built. Consequently, this paper has been written as a "Part 1" ("understanding the problem") for a series of papers aimed at solving the problem of how to educate "smart" mobile microgrids. This paper is also the written portion of a panel discussion on *Adapting to Climate Variability and its Impacts on the Energy Sector Resilience*. The next section will briefly describe the panel context.

1.1. Climate Applications

One product of climate variability is an increase in "natural disasters" for human beings. An example of these natural disasters is an increase in, and/or stronger, severe weather events such as hurricanes and tornados. The *Adapting to Climate Variability and its impacts on the Energy Sector Resilience* Panel has suggested that by anticipating climate change requirements, we can prepare our reactions and generate a sensible recovery plan. (D'Agostino 2015). This author would extend that concept by proposing that 1) a recovery plan would be strengthened with the integration of renewable energy resources, and 2) that hybridized (nonrenewable and atmospheric-dependent renewable) energy resources could become more valuable to mobilized applications, by integrating real-time and forecasted atmospheric input into the power generation, storage, and distribution process. More succinctly, renewable energy applications can be strengthened by "educating" the mobile and fixed smart microgrids with current and future atmospheric conditions.

1.2. Energy

There are many forms of energy. For this research, the term "energy" refers to the generation of operational electrical energy, to be used in-field, for specific functions. We are not looking at powering an entire state or region ("utility" scale power), but rather a subset of that application.

1.3. Renewable Energy

For this research, the term "renewable energy" is defined as energy that replenishes itself within a short period, such as seconds to minutes, or a resource where the amount of material consumed is miniscule with respect to the amount available. Some renewable energy examples include the following:

- Earth: Geothermal energy comes from heat that is generated and stored by the earth. This perpetual thermal resource initiates from the planet's formation and an ongoing radioactive decay of internal materials. Power generated by geothermal energy extracts heat from a fuel source in the ground to heat a second fluid (such as water). The second fluid is then used to turn a generator turbine, which produces electricity. This second fluid is then cooled and returned to the heat source. Since the heat extracted is small, with respect to the total heat content of the earth, the process qualifies as a "renewable energy" (Geothermal Energy 2015).

- Water (hydropower): Water energy uses naturally cascading water to generate electricity. The process exploits the kinetic energy of falling water by using it to turn a turbine, which spins a generator and produces electricity. The stability of hydropower makes this resource competitive with fossil fuels; however, running water is not universal, so the resource has limitations. Solar and wind resources, however, are generally universally available, making them a more practical consideration for renewable energy resources (Hydroelectricity 2015).

- Wind: Wind energy is actually an indirect form of solar energy. When the sun heats the earth surface in the tropics, the warm air rises (as described by the Hadley cell) (Huschke 1970). Cooler, denser air from the polar regions advects toward the tropics, mixing in with the warm air, trying to establish an equilibrium. This endless cycle of heat transfer causes huge areas of air movement across the globe. Another contributor to the generation of wind energy is the spinning of the earth with the associated Coriolis force (Chelius and Frentz 1978).

- Fire: Solar energy can be generated via passive (i.e., greenhouse) and active designs. Active solar designs generally include an absorbent medium, such as a photovoltaic (PV) device. The PV or solar cell produces electricity whenever photons of sunlight are absorbed by the surface (Vaucher 2015).

1.4. Energy Grids

An "energy grid" in its basic format consists of power generation, storage and distribution. The electrical distribution then powers a device (load) or loads. For simplicity, these initial elements will be called "a system".

To help structure this research, the author has subdivided renewable energy grids into 3 categories: Utility scale, Microgrid and Personal scale. The Utility scale includes power resources greater than 10MW that are in a fixed location, attached to a large grid, and services communities. Hydropower plants, geothermal plants (e.g., The Geysers in California) (Types of Geothermal Power Plants 2015) and very large solar and wind farms would generally be associated with this scale.

Resources less than 1 MW that are easily transportable (generally hand-held), having a short-power requirement (duration) and specific device applications ("plug and play" design), are in the "Personal" scale group. A solar-powered calculator or solar-powered cell phone recharger would fit this category.

The microgrid category generally falls between the utility and personal scales, and will be discussed in the next section.

1.4.1 Microgrid

The distinguishing attributes between grids and microgrid is the ability of the system (generation, storage and distribution) to run independently as an "island", and/or, as an integrated part of a larger grid. The Department of Energy (DOE) defines a microgrid as the following:

> A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected and island-mode (DOE Microgrid Workshop Report 2011).

From a survey of microgrid types, several microgrid categories have been suggested. Two basic types include the following:

- Self-governed systems called “customer microgrids” or “true microgrids” (µgrids): µgrids are usually downstream of a single point of common coupling and their power system operation is generally given considerable independence (Types of Microgrids 2015).
- “Utility” or “community” microgrids (sometimes called, “milligrids” (mgrids)): mgrids involve a segment of a regulated grid and incorporate traditional utility infrastructure (that is, the mgrid complies with existing utility codes and standards) (Types of Microgrids 2015).

Other microgrid types include the “virtual” microgrids (vgrids) and “remote power system” grid (rgrids). The vgrids cover distributed energy resources at multiple sites, but are coordinated so that the grid recognizes them as a single controlled entity. The system must be able to operate as a controlled island or coordinated multiple islands. Very few vgrids exist, according to Berkeley Lab (Types of Microgrids 2015).

The rgrids are not grid-connected. These isolated power systems involve similar, closely-related technologies. From a research perspective, they are commonly described as microgrids. Rgrids come the closest to describing a mobile microgrid (Types of Microgrids 2015).

1.4.2 Mobile Microgrid

For this research and the disaster relief and recovery applications, mobile microgrids will be defined as self-contained power grids that can generate, store, and distribute electrical energy, and function as isolated units, yet also able to feed electricity to a larger power grid. They are semi-fixed, transportable, able to function for unknown durations (hours to months), and are generally a hybrid of renewable and nonrenewable electrical-generating resources.

Due to the current technical maturity of disaster relief and recovery equipment and applications, the mobile “personal scale” grid is included here, as well. This category is defined as being less than 1 MW, dynamic, flexible, generally used for short durations with limited alternative energy and of a plug and play nature—used for specific functions with a known load. The “personal scale” grid is also generally reliable and maintainable.

1.4.3 Smart Microgrid

For this research and application, a “smart” microgrid is defined as a microgrid that utilizes two-way communications for providing power, measuring variations in load demands, and automatically adjusting electrical distribution to accommodate load changes. The premise of this study is that by integrating “live” and future atmospheric conditions into a smart microgrid, this enhancement would enable “smart” microgrids to become strategically more efficient.

2. RENEWABLE ENERGY DISASTER RELIEF and RECOVERY APPLICATIONS

Following a disaster, the traditional approach for providing energy needs, while the larger utility grid is being restored, is to deploy diesel or gasoline generators. These tools come with several challenges such as fuel costs, fuel availability, fuel safety issues, and noise complaints (especially when the recovery extends from hours to months). The Florida Solar Energy Center (FSEC) reported that small home generators were responsible for post-disaster burns, fires, fuel explosions, asphyxiation, and death (Young 2008). Solar renewable energy generators can provide quiet, emission free electricity, but are dependent on sunlit time periods. The creation of hybrid solar and conventional generators could provide the best of both tools.

Historically, the Department of Transportation started using PV power during the 1980s, when they needed stand-alone, reliable power systems (Young 2008). Table 1 lists some of the Renewable Energy Disaster Relief/Recovery uses between 1989 and 1996.

Table 1 Examples of Renewable Energy Disaster Relief/Recovery Applications from 1989-1996 (Young, 1996)

Year	Disaster	Location	Application	System
1996	Hurricane (H.) Iniki	Kauai, HI	Building Power	Fixed System
1996	H. Luis & Marilyn	Virgin Islands	Building Power	Fixed System
1996	H. Luis & Marilyn	Virgin Islands	Radio Communications	Tote
1996	H. Luis & Marilyn	Virgin Islands	Water Purification	Fixture
1995	H. Erin	Cocoa Bch., Fl	Building Power	Fixed System
1995	H. Erin	Titusville, FL	Security Lighting	Fixture
1992	H. Andrew	Miami, FL	Portable Lighting	Fixture
1992	H. Andrew	Miami, FL	Traffic Signs & Lights	Trailer
1992	H. Andrew	Miami, FL	Radio Communications	Trailer
1992	H. Andrew	Miami, FL	Security Lighting	Fixed Fixture
1992	H. Andrew	Miami, FL	AC Power	Fixed System
1992	H. Andrew	Miami, FL	Communications	Portable
1991	Earthquake	Northridge, CA	Lighting/Communications	Trailer
1991	H. Bob	Rhode Island	Home Power	Fixed System
1989	H. Hugo	S. Carolina	AC Power	Trailer
1989	H. Hugo	St. Croix	Lighting/Communications	Tote

Mobility of power was utilized in 1989 with Hurricane Hugo (St Croix, Virgin Islands). In 1992, Florida's Department of Transportation used numerous PV-powered traffic devices for road construction. When Hurricane Andrew struck Florida in that same year, it prompted the use of PV-powered highway advisory radio units to communicate road hazards, distribution areas, and route changes. By 1995, Hurricane Erin's recovery included the powering of a building with a fixed-site PV system.

In 1998, the Federal Emergency Management Agency (FEMA) and the DOE acquired 8 trailer-mounted PV systems for use in disaster response (Young 2008), as shown in Fig. 1 (a and b).

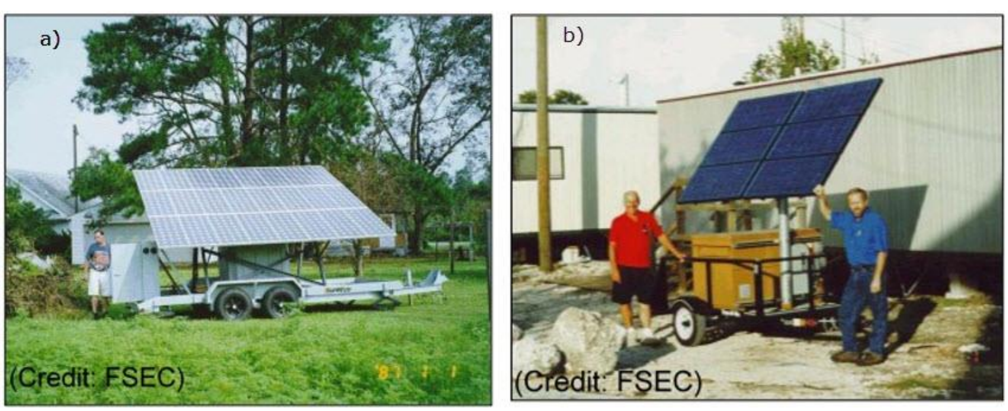

Fig. 1 Trailer mounted PV power: a) FEMA 1800 Wp trailer (left) and b) FEMA 500 Wp trailer (right) (Young 2008)

Shortly after the turn of the century, Public Law 109-58 framed the fiscal support for advancing renewable energy integration into the US economy (Energy Policy Act of 2005). With the DOE's Solar American Cities Program, PV backup-power supplies were established for critical traffic controls, emergency message boards, and radio repeaters along the Boston City Evacuation Route (Solar PV Emergency and Resilience Planning 2013). This DOE program also supported New York City's effort to better integrate the 672 solar arrays on the NYC rooftops that were undamaged, yet unusable after Hurricane Sandy (Solar PV Emergency and Resilience Planning 2013).

Midtown Community School in Bayonne, NJ, installed a commercial-scale, hybrid (solar/diesel) backup system (microgrid) in 2004. In October 2012, this microgrid allowed the school to function as one of the electrically powered, emergency evacuation centers for their town (Solar PV Emergency and Resilience Planning 2013).

Joint efforts between the FSEC and the National Renewable Energy Laboratory (NREL) have resulted in portable solar generators with battery storage that are safe for freeway travel. Figure 2 shows one such trailer, which is described as being able to be set up by one person in 10 minutes (Morley 2015).

Fig. 2 A portable solar generator with battery storage (Morley 2015; Crow 2015)

As more mobile renewable energy resources are being designed, it's also noteworthy that isolated PV-powered functions are also manifesting. Two examples from Florida include their 21 solar-powered community sirens (tornado warning) and their PV-powered meters to monitor river water levels for flooding (Solar PV Emergency and Resilience Planning 2013).

3. ATMOSPHERIC CONTRIBUTIONS TO SOLAR ARRAYS

Since this paper is intended to be a visionary summary, the content describing atmospheric contributions to solar arrays is restricted to briefly highlighting historical and current findings. Additional details are saved for future papers.

The 2 primary atmospheric variables of interest to operational solar microgrids are solar radiation and temperature. The ideal atmospheric scenario for solar power is clear skies, minimal aerosols along the sun-to-PV-panel path, and a panel temperature of 25 °C.

The reality is that panel-shadowing and aerosols filter "the ideal". Shadowing can be either hard or soft. An example of a hard shadow would be a tree branch fallen on the panel. Soft shadowing includes clouds, dust, growing plants, and so forth. While tree branches can be removed, over grown foliage pruned, and PV panels relocated to open ground, clouds can have an unnegotiable effect. Consequently, forecasting their presence and impact is an important concern.

3.1. Solar Radiation Forecasting

Two programs sponsored by DOE have been making good progress in this area. These include the SunCast Solar Power Forecasting System (led by the National Center for Atmospheric Research (NCAR)/National Oceanic and Atmospheric Administration (NOAA)), and the Watt Sun Program (led by International Business Machines Corp

(IBM)/NOAA). Note that the 2 equivalent programs for wind energy forecasting include, the Wind Forecast Improvement Project (WFIP1) led by AWS Truepower, Windlogics and NOAA; and WFIP2, led by Vaisala/NOAA (Haupt 2015).

As an example, Figure 3 (SunCast) captures the essence of a solar power forecasting tool. Concentrating on clouds and aerosols, the system divides the forecast along a time scale. For zero to approximately 4 h forecasts, 4 approaches (Statistical Predictions, Satellite Cloud Advection, Total Sky Imaging and WRF-Based Nowcasting) are combined with observations through a Nowcast Integrator. The longer-term predictions (out to 48 h) call on the Numerical Weather Prediction models (such as WRF-Solar). The Dynamic Integrator (DiCast) integrates these results with the observations. The short and long term forecast results are blended together and converted to power. An Analog Ensemble process facilitates a look back into the historical experiences, before producing a probabilistic solar power forecast for the utility company(ies) (Haupt and Drobot 2014)

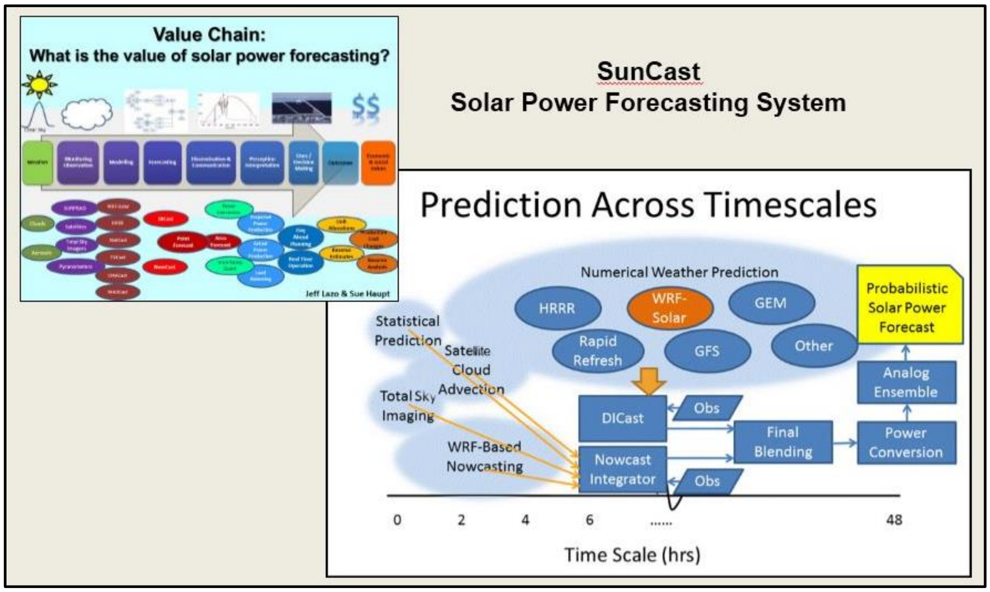

Fig. 3 SunCast Solar Power Forecasting System (Haupt and Drobot 2014)

3.2. Temperature

A less recognized, though still significant atmospheric effect on the solar PV power production, is temperature. Ambient temperature impacts PV panel performance. According to Boxwell (2013), the PV panels are rated (calibrated) for a “peak power” (Wp) measured at 25 °C. The PV peak power is scaled as 1 kW/m^2/day. For every 1 °C increase above 25 °C, the efficiency of power production drops 0.5%. When a PV panel is mounted on a roof, the panel temperature is 1.4 times the ambient temperature. When mounted on a pole, this ratio drops to 1.2. As an example: For a roof-mounted PV array, if the ambient temperature is 38 °C (about 100 °F), the panel temperature is about 53.2 °C, or 28.2 °C higher than the PV standard (25 °C), which means that the solar array power production efficiency will drop about 14%.

When the panel temperature decreases below the standard 25 °C, the power production efficiency increases by 0.5% for every 1 °C. A roof-mounted panel at 1 °C, has a panel temperature of 1.4 °C. This temperature is 23.6 °C less than the standard, which would result in a power efficiency improvement of about 11.8%.

When coupled with other system efficiency corrections, the impact of temperature on a remote or mobile microgrid could become significant. Consequently, planners sending solar panels to the field need to be aware of what ambient (/panel) temperatures they can expect. Smart microgrids need to assimilate the consequences in this decision making process.

4. FUTURE VISION

Providing uninterrupted electrical power to disaster relief and recovery areas can be accomplished with a mobile "smart" microgrid of hybrid generators (renewable and nonrenewable). To better integrate the hybrid technology, real-time and forecasted atmospheric conditions are critical information bits for the decision making software of the "hybrid microgrid". When flawlessly integrated, the ramping up and down of renewable and nonrenewable resources can be successfully completed. The margin for error and the ability to accommodate sudden power demand spikes in a microgrid, however, is projected to be tighter than those of a utility grid requirement. This contrast is primarily due to the limited microgrid "backup" resource options. Such options might be a battery bank with limited capacity, switching to an alternate "spinning" generator, and/or nothing at all.

Where only a renewable energy (solar) microgrid is available, integrating current and future atmospheric variability into the "smart" element of the microgrid will enable onsite decision makers to better prioritize the supported loads.

The applications of mobile "smart" solar (or wind) power resources are not limited to disaster response and recovery. National Guard missions to remote locations, the weekend hiker/camper, remotely located scientific investigations can all profit from an educated "smart" power resource.

5. SUMMARY

Climate variability can produce "natural disasters" for humans. By anticipating climate-induced requirements, we can better prepare and react to the environmental conditions. When the climate changes involve disaster relief and recovery, using a blend of nonrenewable and renewable energy resources can help stabilize the return path back to "normalcy". One area being investigated is the integration of real and future atmospheric conditions into atmospheric-dependent renewable energy resources, such as solar and wind. The integration requires a working knowledge of multiple disciplines.

In this article, we began by clarifying "energy" as operational, in-field electrical energy. Renewable energy was narrowed to primarily solar. The microgrid was defined as an electrical system (electrical generation, storage and distribution) with the ability to run independently as an "island", and/or, as an integrated part of a larger grid. Mobile microgrids were defined as self-contained power grids that can generate, store, and distribute electrical energy, functioning as an isolated unit, yet also able to feed electricity to a larger power grid. The units are semi-fixed, transportable, able to function for unknown durations (hours to months), and are generally a hybrid of renewable and nonrenewable electrical-generating resources.

Due to the current technical maturity of disaster relief and recovery equipment and applications, the mobile "personal scale" grid was included. This category was defined as being less than 1 MW, dynamic, flexible, generally used for short durations with limited alternative energy, and of a plug and play nature—used for specific functions with a known load. The "personal scale" was also considered generally reliable and maintainable. The "smart" microgrid was defined as a microgrid that utilizes 2-way communications for providing power, measuring variations in load demands, and automatically adjusting electrical distribution to accommodate load changes.

Examples of renewable energy disaster relief and recovery applications from 1989 to 1996 were presented in Table 1. More recent examples included: 1) the City Evacuation Route in Boston, which uses PV backup-power supplies for critical traffic controls, emergency message boards, and radio repeaters; 2) New York City's efforts to better integrate their 672 solar arrays into a disaster relief plan; 3) Midtown Community School in Bayonne, NJ, which functioned as a solar-powered emergency evacuation center during the October 2012 Hurricane Sandy; and 4) the FSEC and NREL work in designing and building PV Disaster trailers.

For solar energy, 2 key atmospheric contributors include solar radiation and ambient temperature. Hard and soft shadowing inhibit the solar radiation. While hard shadowing can be addressed with onsite adjustments, soft shadowing involves cloud and aerosol forecasting. Several DOE programs have been addressing these issues. Using SunCast as an example, a sketch of the short (Nowcasting) and longer term (NWP) forecasting tools were described in Section 3.

The long term research goal is to integrate the solar power forecasting tools into “smart” mobile microgrids. This goal would strengthen the effectiveness of the mobile renewable energy microgrid, by reducing the dependency on nonrenewable resources, which may be difficult to locate and employ while in disaster recovery situations. The renewable energy resource would also give responders, and long-term recovery users, the option for a quieter environment. In short, a tool that successfully “educates” a smart grid with atmospheric conditions could enable disaster relief responders to focus less time on the critical recovery technology and more time on their human recovery efforts.

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7. ACKNOWLEDGMENTS

The authors would like to acknowledge the Florida Solar Energy Center for their helpful publication resources, Dr Sue Ellen Haupt for her iterative renewable energy atmospheric forecasting communications, and the US Army Research Laboratory colleagues Dr Jeffrey Smith and Sean D’Arcy, for their engineering expertise.