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UNDERSTANDING THE BENEFITS OF DISPERSED GRID-CONNECTED PHOTOVOLTAICS: FROM AVOIDING THE NEXT MAJOR OUTAGE TO TAMING WHOLESALE POWER MARKETS

Abstract:
Over the past two decades the operation of the U.S. electric grid has become increasingly complex as it has been called upon to accommodate growth in total electricity consumption of 75%, accompanied by an increase in non-coincident peak demand in excess of 65%. At the same time, the electric industry is in the midst of an historic restructuring to promote non-discriminatory, open access to the nation's electricity super highway to facilitate greater competition in the provision of electrical energy. This article investigates the role that dispersed, grid-connected photovoltaic (PV) can play in helping to build an electric grid for the 21st Century. The article describes how a better characterization of the solar resource based upon satellite remote sensing has facilitated an improved understanding of the role that grid-connected PV installations could serve to enhance electric grid reliability. Evidence is presented that PV installed in dispersed applications could serve to prevent and/or hasten recovery from major power outages and serve to mitigate extreme price spikes in wholesale energy markets. Dispersed, grid-connected PV system's contribution to the electric industry should be understood in the context of both grid support and as a provider of electricity during the hours of peak demand.

I. Introduction

Electrical energy plays a central role in delivering a level of wealth and affluence that Americans have come to expect. A proliferation of electrical appliances over the past century has made life for millions of Americans more comfortable and convenient. Over the past two decades, the operation of the U.S. electric grid has become increasingly complex as it has been called upon to accommodate growth in total electricity consumption of 75%, accompanied by an increase in non-coincident peak demand in excess of 65%.[1]

Accompanying this growth in electricity consumption and peak demand has been an ongoing process of creating an industry structure to accommodate robust wholesale competition, beginning first with the 1978 Public Utility Regulatory Policies Act (PURPA). Since PURPA, the Federal Energy Regulatory Commission (FERC) has continued the march toward a competitive electric power sector through its historic Order 888, effectively requiring the unbundling of generation from transmission, and more recently with its Order 2000 to foster independent, non-discriminatory operation of the electric grid.

In recent years, several studies highlighted the concern that investment in the nation's electric grid has been inadequate to accommodate increasing energy flows, resulting from an increase in electricity use and greater wholesale market activity. The U.S. Department of Energy's 2002 National Transmission Grid Study called attention to these issues. The report concludes that:

> There is growing evidence that the U.S. transmission system is in urgent need of modernization. The system has become congested because growth in electricity demand and investment in new generation facilities has not been matched by investment in new transmission facilities. Transmission problems have been compounded by the incomplete transition to fair and efficient competitive wholesale electricity markets. Because the existing transmission system was not designed to meet present demand, daily transmission constraints "bottlenecks" increase electricity costs to consumers and increases the risks of blackouts.

It has also been argued that the competitive model, which has usurped the regulated franchise model of electricity production and delivery, creates a disconnect between economic and reliability interests.[2] One remedy being pursued, which appeared as one of the recommendations in the U.S.-Canada Power System Outage Task Force's final report on the August 2003 blackout, is to move toward mandatory reliability standards.[3] Section 215 of the Energy Policy Act of 2005 codified this recommendation into law and calls for a nationwide Electric Reliability Organization and a much greater role for the FERC in assuring reliable operation of the grid.[4] The FERC is now placed in the interesting position of both championing electric utility competition, and the associated economic efficiencies, and a more robust and enforceable reliability regime for the nation's electric grid.

While a variety of investments will be required to address the deficiencies of the nation's electric grid, greater use of dispersed solar photovoltaics (PV) systems should be included in the portfolio of solutions. This paper present empirical evidence that dispersed, grid-connected PV can serve a number of valuable functions when deployed at the distribution level. In fact, PV has unique characteristics that could address the two potentially competing goals now under the purview of the FERC—effective wholesale competition and a reliable electric grid. The article begins with a description of modern solar resource assessment techniques and how they can be used to better understand PV's contribution as a grid-connected resource.

II. Understanding the Solar Resource

At some point, everyone has experienced the awesome potential of the solar resource, whether basking in the sun on a pristine sandy beach or opening the door of a vehicle that had been parked directly in the sun's path. Traditionally, the solar resource has been understood in diurnal patterns of average solar radiation striking the earth's surface. The U.S. Department of Energy's National Renewable Energy Laboratory maintains the National Solar Radiation Database, which contains hourly values of the three most common measurements of solar radiation (global horizontal, direct normal, and diffuse horizontal) over a period of time adequate to establish means and extremes (30-year period, 1961-1990), and at a sufficient number of locations to represent regional solar radiation climates.[5] While solar resource data in this form is extremely valuable for predicting the average annual output of a solar energy installation, it is less valuable when attempting to understand PV's contribution to meeting electrical demand or providing grid support services. In these cases, time and location specific resource data becomes critical to understanding PV's potential.

In the early 1990s new resource assessment techniques were developed using satellite-derived cloud cover data. Through well tested algorithms cloud cover data from geostationary weather satellites are utilized to estimate the ground-level solar resource at a particular location at any given time. The technique has been rigorously validated using actual ground-level measurements.[6] Furthermore, the availability of satellite-derived solar resource data frees researchers from the limitations of average solar resource data, and allows detailed analyses of PV's potential contribution as a grid-connected resource.

Prior to the mid-1990s, there was not much interest in PV for grid-connected applications, given that PV was viewed primarily as a power source for remote applications far from an electric grid. With the introduction of net metering rules in various states and the development of inverters for grid-tied applications, interest in grid-connected PV grew. Today, due to these changes and burgeoning government incentive programs, grid-connected solar is the fastest growing market for PV technology.[7] As a result, it has become increasingly important to gain a rigorous understanding of the contribution that grid-connected solar can provide to the nation's electric grid—satellite-derived solar resource data makes this possible.

III. The Capacity Value of Grid Connected PV

As anyone connected to the electric industry readily understands, peak demand for power occurs in regions with significant air-conditioning load during periods of hot, steamy weather. For example, the 2004 peak load of the New England Independent System Operator's network of just over 24,000 MW occurred on August 30th.[8] Similarly, the PJM Interconnection experienced their 2005 peak demand of 135,001 MW in the late afternoon of July 26th.[9] Coincidently, the solar resource tends to be quite good on days when peak demand for power is being driven by electrical demands for space cooling. Although the sun will likely be shining on days when peak demand occurs, how confident can grid operators be that a PV generator will be providing power when it is most desperately needed?

Electric power analysts have devised methods to quantify the capacity value that a generator can be expected to contribute to the overall network. While many approaches have been used, the Effective Load Carrying Capability (ELCC) is well-grounded in reliability theory and practice and can be applied to all generators.[10] While admittedly the ELCC approach require large datasets, it is viewed as the most rigorous approach that can readily distinguish capacity contributions among different generator types.[11] Prior to the development of satellite-derived solar resource assessment techniques, PV ELLC calculations were limited to those locations with multiple years worth of ground-level solar resource data.

Thus, one of the first applications of satellite-derived solar resource data was to calculate ELCCs for utility service territories across the country. Statistical derivations of ELCC for PV generators were derived using system load data for several utilities across the country. Energy output from hypothetical PV generators was simulated using time-coincident solar resource data for each of the utility service territories studied. Earlier ELCC results for PV were derived from late 1980 and early 1990 utility load profiles and simulated PV generator output.[12]

At low PV penetration rates—2% and less—PV's ELLC were calculated to be as high as 70% for regions along the eastern seaboard.[13] Figure 1 provides an ELCC contour map for the U.S. based on this early PV ELLC analysis. Recent updates to PV's ELCC using more current load data (2002 and 2003), high resolution satellite data, and a more accurate satellite model to simulate site- and time-specific PV output support the overall regional trends identified in the earlier work.[14] The updated PV ELCC study found a significant increase in PV's ELCC values in western and northern regions of the U.S., and a modest decrease in PV's ELLC values in the central and eastern portions of the U.S. In sum, the capacity value of PV has been well established. The logic underlying this empirical finding is quite simple—the principal cause of the demand peaks, solar gain, is also the direct source of PV generation.

(Figure 1 about here.)

It is clear from recent trends that future PV deployment will likely continue in a distributed fashion. PV's modular, easily sited characteristics make it a perfect technology to deploy within the distribution network, preferably as close to loads as possible such as the millions of square feet available on buildings and other man-made structures. While the ELCC method to assess a generator's capacity value is typically applied to large-scale, central station generators like wind and fossil fuel-fired thermal plants, it is equally valuable in assessing the capacity value of PV even though it is deployed as a distributed technology. This attribute becomes particularly attractive in load pocket, capacity constrained areas, where it is not possible to easily increase local generation capacity or bring in additional power lines.

Given that PV will be connected primarily through existing meters, some may argue that it may be appropriate to evaluate its deployment in the demand-side management or demand response contexts.[15] To understand its potential in these contexts it is useful to look at a slightly different method of analysis from the ELCC approach, referred to as minimum buffer energy storage (MBES). MBES is a metric used to quantify the minimum amount of reserve energy (from storage and/or load control) necessary to guarantee a peak load reduction equal to value of the installed PV system's rated capacity. An analysis of Sacramento Municipal Utility District's load and solar resource profile suggests that a firm 2% peak load of the utility's 2,700 MW peak load requirement could be met with 54 MW of solar (southwest-facing at 30 degrees tilt) and 19 MWh of energy storage and/or load control.[16] This stands in contrast to 110 MWh of storage and/or load control to accomplish the same goal without PV.

Misconceptions that there is insufficient physical space to site PV arrays for solar to satisfy a significant portion of our energy requirements persist. However, based on existing solar PV technology, less then one half of one percent of the land area in the U.S. would be required to accommodate a sufficient amount of PV to produce all the electrical energy consumed in the U.S. This amounts to approximately 25,000 km^2 of PV panels to produce a total of 4 trillion kWh of electricity—roughly equivalent to the total electrical energy consumed each year in the U.S. Although the ELCC for PV declines as the amount installed increases, this does not preclude PV from providing a significant portion of our electrical energy needs. ELCC remains significant at load penetrations of up to 20-25% for large portions of the US . At higher penetration rates, energy storage and/or active load control would be required to maintain high ELCC values for PV as for other intermittent sources such as wind. Putting the intermittency issues aside, it is clear that there is sufficient physical space on building rooftops and other structures to accommodate amounts of PV that could provide a large portion of our total demand for electrical energy.[17]

IV. Can Solar Help Avoid the Next Major Outage?

Like a large thermal power plant, PV can deliver firm capacity to an interconnected power network. Beyond this, the distributed nature of PV provides additional grid support benefits that are becoming increasingly important for reliability purposes; reliability, after all, is fundamentally about keeping the lights on!

When the power grid fails significant disruptions are imposed on individuals and businesses alike, in addition to significantly increased risks to human safety as critical infrastructure becomes disabled. Experience has shown that most major power outages occur during times when the grid is under stress due to heat-wave driven peak load situations. Over the past several years, satellite-derived solar resource data has been utilized to retroactively demonstrate that dispersed PV systems injecting solar electricity on the grid may have avoided the major heat-wave driven power outages that have occurred.[18, 19] These studies have demonstrated that dispersed PV systems would have been operating near their peak output during the hours leading up to, and after, the outage.

The most severe outage in recent history, and the one foremost on the industry's mind, was the power outage that took place on August 14th 2003. This event serves to demonstrate how modest amounts of dispersed PV could serve to prevent, and/or hasten recover from, a major heat-wave driven outage.

(Figure 2 about here.)

On the afternoon of August 14, 2003 loads throughout the U.S. Northeast, though not at record levels were high, driven by air-conditioning demand. The region was experiencing large power transfers (of more than 5 gigawatts) from south central states to the north. Much of that power transited through Ohio on its way to the major load centers in Detroit, Cleveland, and Toronto. A series of precursor events took place near Cleveland eventually leading to a cascade of plant and transmission facility failures. The U.S.-Canada Power System Outage Task Force identified three main causes: (1) inadequate situational awareness from the local utility; (2) inadequate tree trimming; and (3) inadequate diagnostic support from reliability coordinators. The Task Force also concluded that the outage was preventable and that better, enforceable controls and regulations should avert future similar contingencies.

Above and beyond the “official” causes identified by the Task Force, analysis of the events clearly suggests that, had regional power transfers to meet localized energy demand not been as high, the probability of each contingency—even unattended—leading to the next and finally into cascade would have been much lower. Conditions on August 14, 2003, although not extreme, represented a textbook example of high regional air-conditioning demand creating high power transfers and stress on the grid. Therefore, it was no coincidence that the solar resource was plentiful. The question becomes, how much PV-generated power would have been sufficient to prevent the blackout? There are two ways to answer this important question.

First, enough PV was needed to provide sufficient localized voltage support, power and reactive power to avoid precursor events. The first contingency involved the failure of a power plant near Cleveland due to exceeding its reactive-power-generation limit. High demand from air-conditioning compressors increases the need for reactive power or megavars—a service that power plants can deliver in addition to megawatts. It has been argued that the there should be increasing attention given to the issue of reactive power management, as the need for this service has increased over the past several decades.[20]

Thus, displacing even a small fraction of the cooling load that was creating the demand for reactive power would have been sufficient to keep the Cleveland power plant operational. This fact suggests that at most, a few tens of megawatts of PV deployed locally would have been enough. Further, the failure of transmission lines that occurred in the hours following the Cleveland power plant trip and before the cascading outage, may have been avoided by reducing power flows by at most a few tens of megawatts. It is reasonable to argue that, had these dominos not fallen, the cascade would not have occurred.

A second way to quantify the amount of dispersed PV needed to avoid the August 14th, 2003 outage is to look at the need to minimize regional power transfers via local generation. Prior to the precursor events, the north-south power flow was of the order of 5,000 MW. Had local dispersed generation been available near Detroit, Cleveland, and Toronto, it would have reduced these transfers, and inadvertent power line trips would have been inconsequential. A power-transfer reduction of as little as 10 percent (500 MW) likely would have kept the precursor events from feeding into each other.

Both approaches suggest that the availability of, at most, a few hundred megawatts of PV generation located in and around each major concerned metro area would have provided insurance against the contingencies of August 14th, 2003.

The accumulated evidence showing that the highest grid-stress conditions are directly caused by solar gain suggests that the deployment of a dispersed, grid-connected PV resource will contribute to strengthening the reliability of the U.S. power grid. Not only could a dispersed PV resource lower the probability of a massive grid failure by injecting power at peak demand times, but it could also provide insurance against outages should they nevertheless occur (e.g., for reasons other than stress induced by high demand, such as severe weather or terrorism). Properly designed, customer-sited PV installations that include emergency storage/backup at a modest additional cost could provide enough emergency power to keep critical loads at businesses and residences going almost indefinitely during an outage. The outage-preventive attributes of PV may even be enhanced when systems are designed with outage recovery in mind, by making part of the storage/backup reserve available to grid operators for emergency load management.[21]

V Solar and Peak Power Prices

In a number of regions throughout the U.S., wholesale power markets have been functioning for several years. The California energy debacle aside, it has been asserted that wholesale competition has delivered billions of dollars in savings to electricity consumers.[22] At the same time, however, power markets have exhibited considerable volatility in the form of dramatic price spikes during periods of peak demand. Most every wholesale power market has at one point experienced sharp spikes in the price of electricity. Many believe that price responsive load is a key strategy for keeping wholesale electricity prices in check.[23] As such, the subject of price responsive load (also referred to as demand response) has gained much attention in recent years.

While demand response requires an active engagement of loads in responding to high energy prices and/or emergency supply shortfalls, distributed PV offers a passive approach once the initial installation is completed. As established earlier in the discussion of PV's ELCC value, solar PV output is well correlated with peak power demands. By extension, given that price spikes tend to occur during supply shortages caused by high demand, PV output tends to correlate with peak power prices. Again using satellite-derived resource data, the empirical relationship between PV output and peak power prices has been well established.[25, 25]

Table 1 provides data on the number of days during the summer of 2002 when electricity prices in the PJM Interconnect and the New York ISO wholesale power markets spiked to 20¢/kWh and above. The table also presents the average daily PV availability statistic that corresponds with the peak price events. The PV availability (percent value) statistic represents the fraction of what a PV system would produce if the sky was ideally clear.

Solar resource data was obtained for each day and location during these peak price events to determine a PV availability factor.

Two different PV availability measures have been calculated. The daily PV availability represents how a PV system would have performed throughout the entire day when the peak price event occurred. A daily PV availability rating of 0.70 indicates that a south facing appropriately angled PV array would be produce 70 percent of its ideal output, or rated output, during the day when power prices spiked upward. The second measure, peak time PV availability, measures a PV system's performance during the exact time of day that the peak power price event occurred. In this case, a 0.70 peak time PV availability measure would indicate that the PV system was performing at 70% of its ideal output during the hour(s) when power prices spiked. Both measures of PV availability were calculated based on the summer 2002 peak price events in the NYISO and PJM wholesale power markets.

Table 1
PV & Peak Price Events Summer 2002
(Number of Days with Peak Price Events / Average Daily PV Availability)

	May	**June**	**July**	**Aug.**	**Sept.**
PJM	9 / 0.74	2 / 0.79	6 / 0.88	10 / 0.83	4 / 0.78
NY-ISO	3 / 0.86	3 / 0.81	9 / 0.81	12 / 0.78	5 / 0.71

In New York, the average daily PV availability statistic for all peak price days in the summer of 2002 was 0.79. Thus, on average, in the NYISO control area, distributed PV systems would be operating at roughly 80 percent of their ideal output during the days when power prices spike in the wholesale market. The average peak time PV availability statistic was 0.55 for New York. Turning to the PJM Interconnect, the average daily PV availabilities for all peak power days during the summer of 2002 was 0.81, and 0.72 for the average peak time PV availability. These empirical results suggest that distributed PV output would be high during days when peak price events occur. By extension, PV could play a role in addressing price volatility in wholesale energy markets.

How much PV would be needed to have a positive downward effect on power prices in wholesale energy markets? There is no exact method to determine this. However, it seems reasonable that as little as 1 – 3 percent of peak load coming from PV could serve to restrain most of the peak price events. Again, this would result in several 100 MW connected throughout New York given its summer peak load of slightly over 30,000 MW.

VI. Creating a Solar-Friendly Policy Environment

Many predict that the next several decades will challenge society on several fronts, one of those being in the provision of environmentally sensitive, reliable, low-cost electrical energy. Advocates for addressing global climate change call for a rapid shift away from carbon based primary fuels. Although PV may not be the least costly resource to displace fossil fuel use for power production, it is clearly a climate friendly technology. This coupled with the other contributions solar could provide to the electric grid discussed in this article suggests that promoting greater investment in solar PV is a wise policy objective.

The contributions that PV can make to a more robust reliable electric network are shared broadly and not easily captured, in a financial sense, by any one single actor. Thus, like many states have initiated, general provisions that encourage private investment in solar PV should be aggressively pursued. This paper provides strong evidence that a significant public good is derived from greater use of dispersed solar PV.

Clearly, the state of California through its California Solar Initiative has identified solar as a key resource for the State. The goal of the $2.9 billion 10-year program is to increase the installed capacity of PV to 3,000 MW by the year 2017.[26] Similar, aggressive initiatives should be adopted by other states and perhaps supplemented by stronger initiatives at the federal level to stimulate greater investment in solar PV. As stated earlier, outage mitigation should be kept in mind to promote deployment of solar PV in such a way that it would have the greatest impact on system reliability. The FERC could commission a study, in the context of its new role ensuring a reliable electric grid, which provides technical guidelines for future PV deployment that take into account outage mitigation. These guidelines could be tied to more favorable federal tax credits or other mechanisms to encourage greater investment in solar PV.

Solar technology is a mature technology, and is poised to make a significant contribution to a more robust and reliable electric grid. From avoiding the next major power outage to taming wholesale power markets—the sun is rising on a new era for the solar electric industry!

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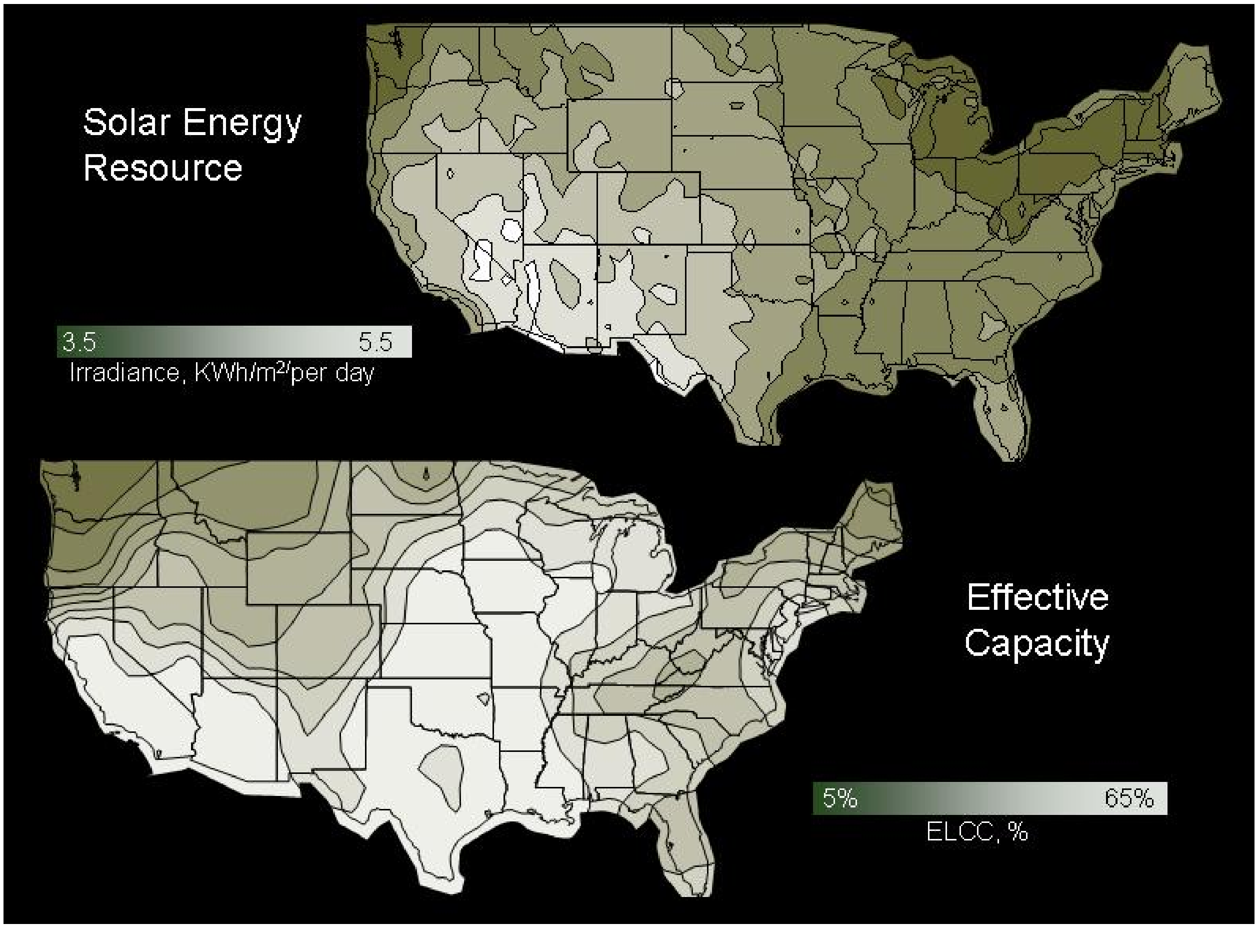

Figure 1: Solar Irradiance and Effective Capacity
Possible caption: Locations with relatively low average irradiance values may still have high PV capacity values.

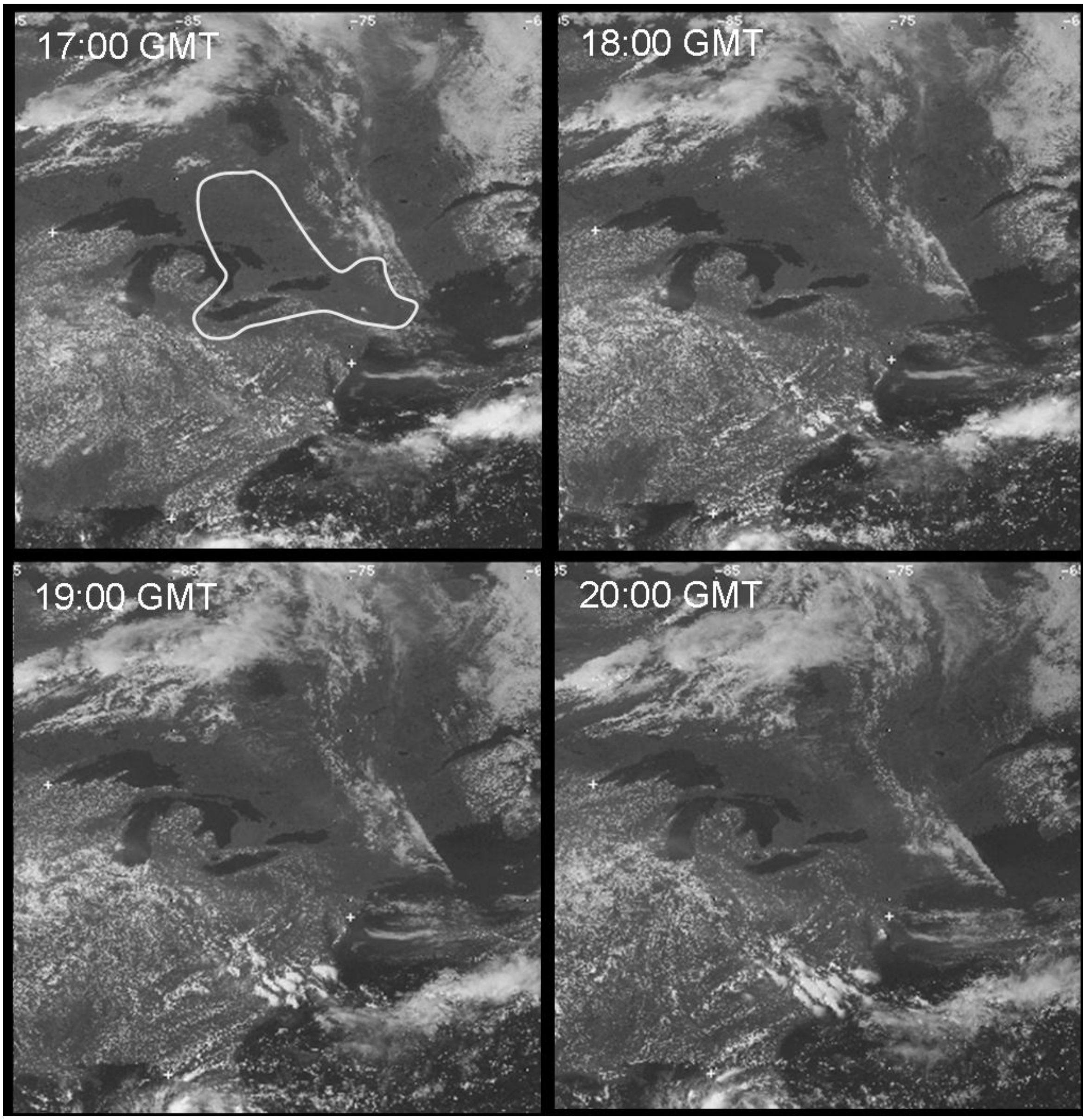

Figure 2: Satellite Photograph of Area Affected by the Summer 2003 Power Outage
Possible caption: These satellite images demonstrate that the area affected by the August 2003 power outage had clear skies, thus dispersed PV would have been performing near its peak rated output, thus possibly preventing the outage.