PV AND GRID RELIABILITY:
AVAILABILITY OF PV POWER DURING CAPACITY SHORTFALLS

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ABSTRACT

In this paper, we take a systematic look at photovoltaic (PV) power availability during major summer 1999-2000 power outages in the United States.

We provide solid evidence that PV could be part of the solution to deliver firm, dependable power during extreme peak conditions leading to outage situations.

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1. INTRODUCTION

However, system operators still view effective capacity as probabilistic measure and may hesitate to rely on PV as a firm peaking capacity component. A critical test in support of PV capacity claims, and its potential to offer reliability benefits, is to look at PV availability during instances of major grid stress and supply shortfall events caused by high, localized demand and inability for the grid operators to deliver local power through burdened power lines and substations.

In this paper, we take a systematic look at PV availability during the major outage, or near outage, events of the summers 1999 and 2000 [1,2]. We also take a systematic look at the issue of firm PV delivery with the assistance of minimal load control during some of these events and show that PV+end-use load control could be 100% reliable with only a minimal end-use impact.

2. UPDATE ON PV EFFECTIVE CAPACITY

We use three complementary benchmarks to quantify PV's effective capacity from a stream of actual load and PV output data: (1) The effective load carrying capability (ELCC) is a direct probabilistic measure based on the concept of loss of load probability [3,4,5]; (2) the minimum buffer energy storage (MBES) is an indirect measure of capacity that represents the minimum amount of backup energy necessary to make up for any deficit of PV to meet all loads above a given load threshold; (3) the solar load controller's (SLC) minimum temperature adjustment [6], is an other indirect measure similar to the MBES but quantified in terms of end-use load shedding via air conditioning mitigation.

ELCC: An extensive study by the authors based on the analysis of over 200 load-years from 45 utilities and substations had led to the effective capacity map shown in Figure 1. This map is based on late 80s' and early 90s' loads and corresponds to a level of 2% PV grid penetration assuming two-axis tracking PV geometry. This map shows three regions of high PV capacity: the southwestern US the Great Plains and the Mid-Atlantic seaboard. In the Mid-Atlantic region 2-axis PV ELCC peaks at 70% in the New York metro area – fixed array PV ELCC peak at 60-65%.

As a spot check of current conditions, we analyzed recent load data (1997-99) for the New York City metro area and Long Island. Time/site specific PV output was simulated using high-resolution satellite cloud cover data [7]. The results are reported in Figure 2. Relative ELCC is plotted as a function of PV grid penetration from 1% to 15%. These results are well in line with the map in Figure 1: at low penetration, ELCC approaches respectively 60% and 70% for fixed and tracking PV. Effective capacities are slightly larger in New York City than in Long Island and exhibit a little less degradation with penetration – reflecting the fact that NYC's underlying load is primarily "9-to-5"

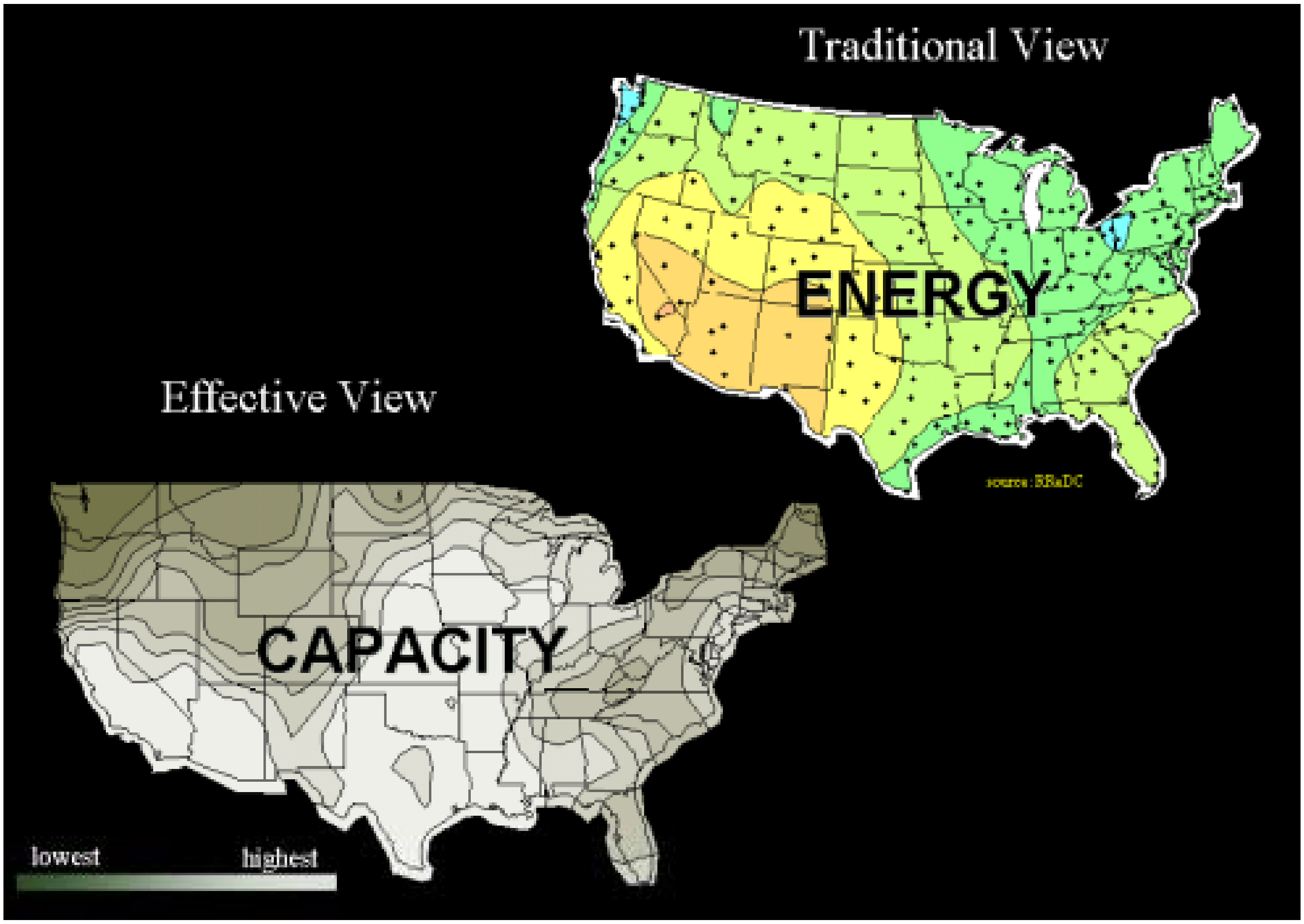


Fig. 1: Traditional (energy) vs. effective (capacity) distribution of photovoltaic solar resource in the US

commercial. Interestingly, there is less year-to-year variability in Long Island.

MBES: Our initial studies had shown that only a fraction of an hour's worth of PV output was necessary to make up for any critical PV output deficit and deliver 100% effective capacity [8]. This is fully confirmed by the current findings for New York City and Long Island shown in Figure 3.

We have plotted the amount of stored energy necessary to meet all loads above the PV penetration threshold. Units are in PV system-hours. For instance, at 5% PV penetration in New York City, it would take 0.7 system-hours worth of storage for fixed PV systems, to guarantee that all loads above 95% of the peak are met. It would take six times this amount of stored or backup energy to meet the same loads in the absence of PV. To put these numbers in perspective, a typical 2 kW residential PV system designed, as it should, with an emergency battery storage system, would have a 10-15 kWh reserve. 0.5 system-hours (i.e. 1 kWh for a 2kW array) would represent only a small fraction of the system's built-in reserve.

SLC: With this measure of capacity, any critical PV deficit is made up by a mitigation of air-conditioning requirements via end-use temperature increases. The degree offset vs. MW equivalence was derived empirically for each considered load via a fit of observed load-temperature relationships. In Figure 4, we report the maximum hourly, daily and seasonal temperature offset needed, in addition to PV to meet all loads within the PV penetration range. For instance, at 10% PV penetration in NYC (i.e., ~ 1000 MW installed PV capacity) it would have taken only 4.5 degree hours of user discomfort on the worse day, with a maximum one-hour offset of 1.5 ^{o}C, to have met all loads above 90% of the City's peak with non-tracking PV systems. Without PV the figures would have been respectively 19 degree-hours and 4 ^{o}C, respectively -- still remarkably small given the achieved peak load reduction but representing a considerably stronger end-use discomfort. For the entire

Fig. 2: ELCC (%) as a function of grid penetration in NYC and Long Island,
for tracking PV (top) and fixed southwest facing PV (bottom)

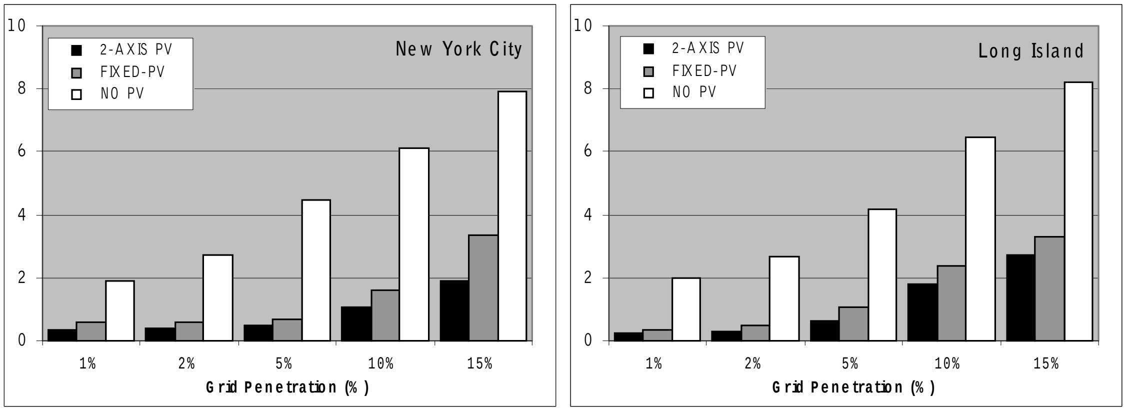


Fig.3: MBES (Installed capacity-hours) as a function of grid penetration for NYC and Long Island

season, the total degree-hour end-use off set would have only been 8 degree-hours to guarantee a 100% PV capacity at 10% penetration. Without PV the seasonal impact would have been 65 degree-hours.

3. POWER OUTAGES

The type of power outages considered in this paper are summer-peak, heat wave-driven events often characterized by rolling blackouts resulting from an inability to match supply and demand either locally or regionally. These outages represent the highest possible stress on the grid when electrical demand approaches available generating supply at a time when all supply sources are on line, but are either unable to supply regional demand or make power available locally through overburdened transmission and distribution (T&D) systems. These situations are often exacerbated by the fact that most power plant efficiencies drop with high temperature and extreme conditions increases the wear and tear, hence the probability of failure of plants and T&D components. There are other types of

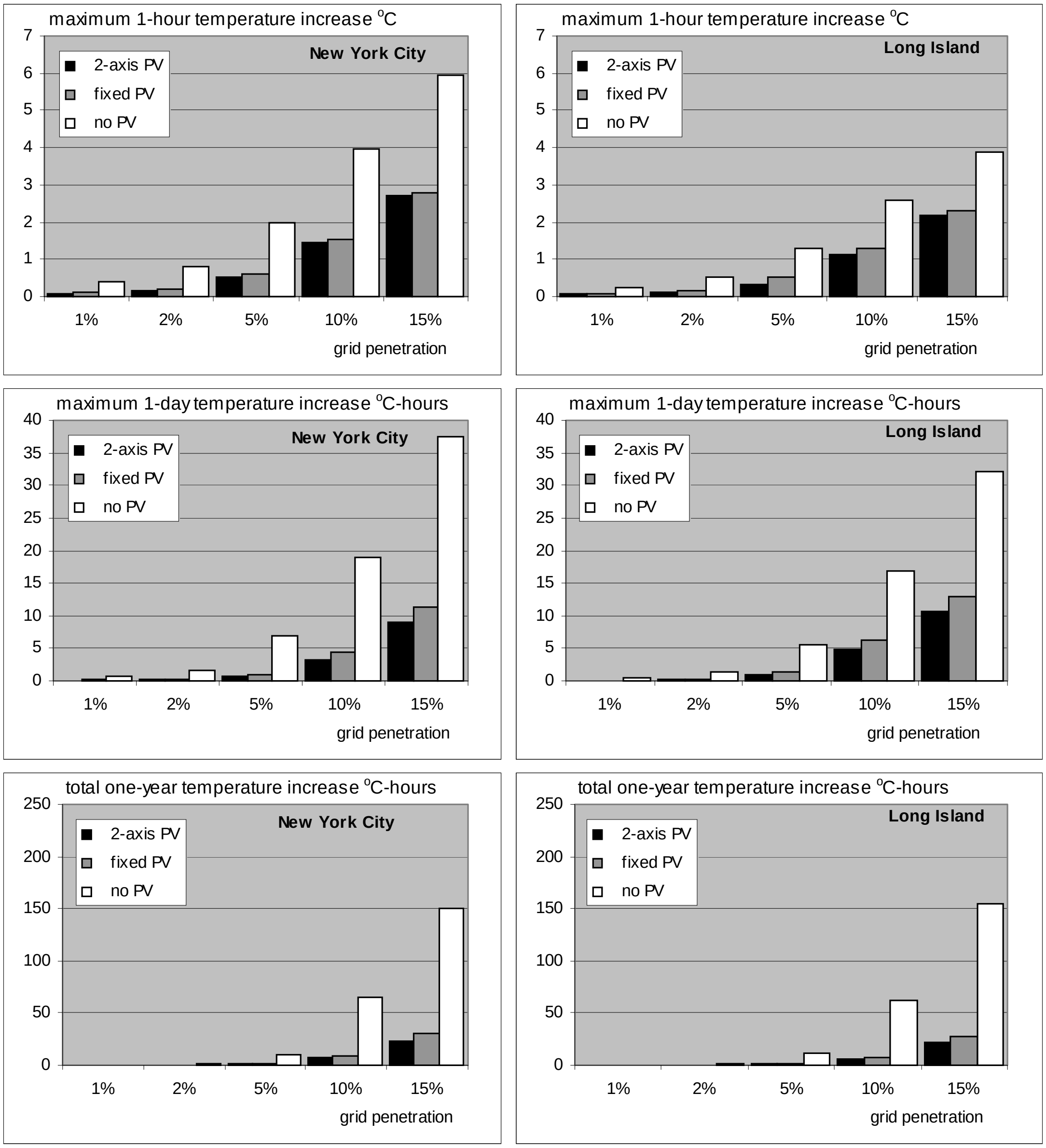
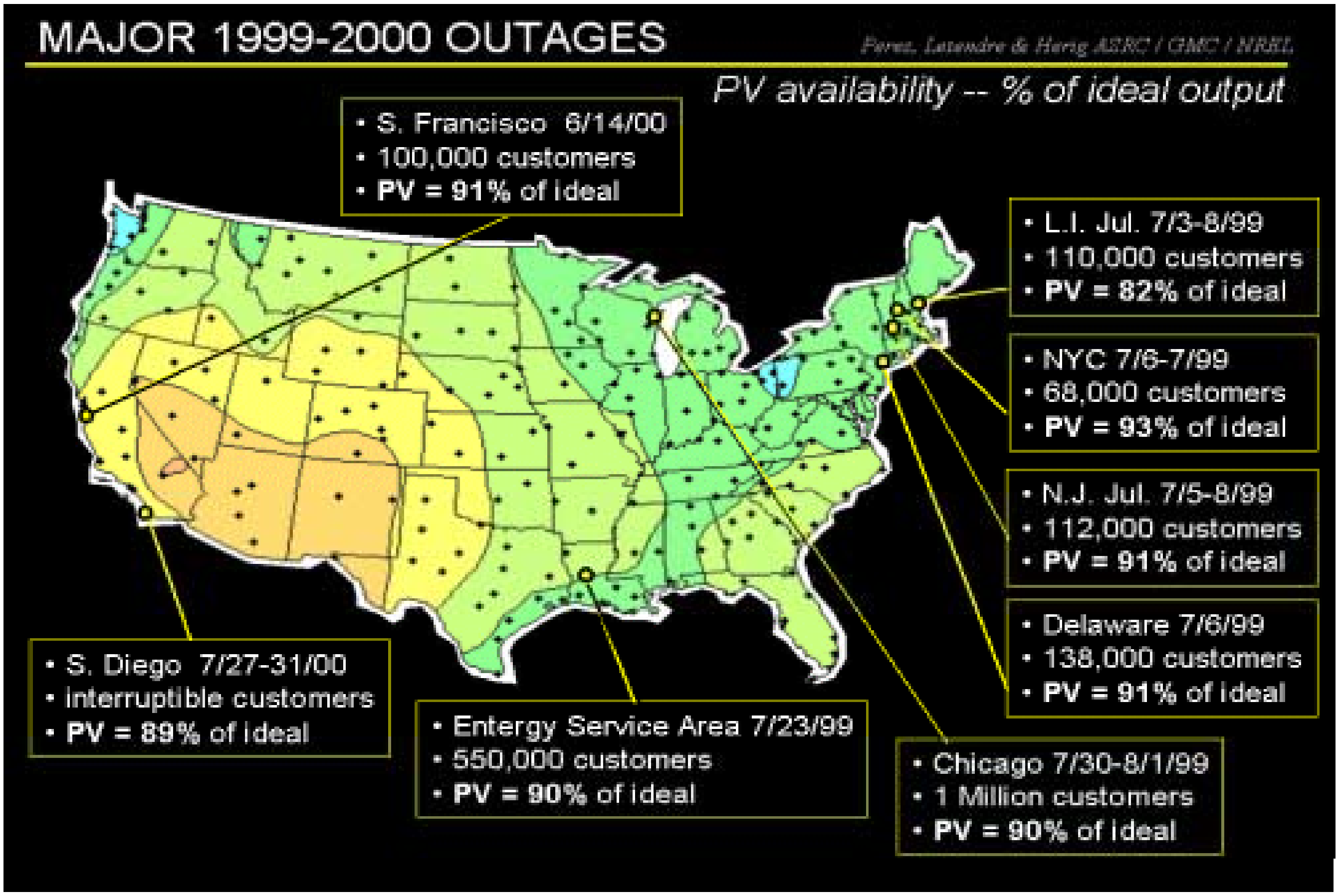


Fig. 4: Required hourly maximum, daily maximum and total seasonal load A/C temperature increase to guarantee 100% PV peak shaving capacity

outages that are not addressed here but where PVs have also proven to be part of the solution: (1) severe weather outages where the power grid as a whole remains sound, but power branches become damaged by weather events (e.g., see [9]); (2) "surprise" outages typically happen in the mid-peak or off-peak season, when demand remains well within a region's installed capacity, but when several power plants are off-line for scheduled maintenance (this was the case of widely reported California December 2000 power crunch [e.g., 10]) .

A few years ago, we provided a detailed analysis of a major summer power outage that crippled the Western System Coordinating Council (WSCC), that comprises all utilities west of the Rocky Mountains [11]. Recent outage events were more localized. There were several major summer outages or near outage events in the eastern part of the US during the summer 1999. In 2000, major heat waves spared the eastern US but affected the western US and led to power shortage conditions, resulting in rolling blackouts and/or major price spikes passed onto consumers.



MAJOR 1999-2000 OUTAGES

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PV availability -- % of ideal output

- S. Francisco 6/14/00
- 100,000 customers
- **PV = 91% of ideal**

- L.I. Jul. 7/3-8/99
- 110,000 customers
- **PV = 82% of ideal**

- NYC 7/6-7/99
- 68,000 customers
- **PV = 93% of ideal**

- N.J. Jul. 7/5-8/99
- 112,000 customers
- **PV = 91% of ideal**

- Delaware 7/6/99
- 138,000 customers
- **PV = 91% of ideal**

- S. Diego 7/27-31/00
- interruptible customers
- **PV = 89% of ideal**

- Entergy Service Area 7/23/99
- 550,000 customers
- **PV = 90% of ideal**

- Chicago 7/30-8/1/99
- 1 Million customers
- **PV = 90% of ideal**

Fig. 5: PV Availability during major summer 1999-2000 outages. Availability is quantified in terms of percent ideal daily output. Ideal daily output is defined as the output of a PV system on an clear day when plane of array irradiance peaks at

Figure 5 shows a summary of the availability of PV output during the major rolling blackout or near-blackout events of the summers 1999 and 2000. It is remarkable to note that in all cases, PV output on the day of the outage would have been within 80% of its maximum given ideally clear sky conditions and similar temperatures. In all but one case, PV output would have been within 90% of ideal.

In Figure 6, we take a detailed look at the NYC July 6 1999 peak day that was characterized by the failure of overstressed distribution systems in Manhattan. The City's load reached 10473 MW that day. PV output in Manhattan was within 90% of ideal given the extreme temperature conditions (38^{o}C ambient) penalizing the assumed crystalline silicon technology. The two bottom plots show the respectively the stored/backup energy and, alternatively, the end-use temperature increase that would have been needed to guarantee that with 5% installed PV capacity (i.e., 523 MW) all 5% top loads would have been met by PV+storage or by PV+control. Both the amount of backup energy and end-user temperature impact appear small in light of the fact that the City's peak would have been shaved down to 9950 MW by a clean, dispersed, and localized resource. At that level, the situations that led to outage conditions would have been alleviated.

4. CONCLUSION

We have provided evidence that Photovoltaics are part of the solution to provide dependable peak power to utilities stressed by growing summer-time demand and faced with the risks of rolling blackouts and extreme prices.

The evidence presented includes:

1. An update on PV's effective capacity in the New York Metropolitan area, indicating that earlier findings are still valid
2. A systematic observation of high PV availability during 1999-2000 major summer outages throughout the US.

(3) An indication that it would take very little in terms of back-up storage or end-use load management associated with PV to provide the equivalent of firm PV capacity up to significant load penetration levels.

To date, grid-connected PV expansion is occurring largely due to the superior environmental characteristics of the resource, which is being developed to satisfy "green" power markets. Policy and institutional changes are needed to fully recognize the additional benefits that distributed PV systems offer to society, especially in the realm of enhanced grid reliability. Each major power outage costs society millions of dollars in lost productivity and customer inconvenience. Increased investment in PV manufacturing and deployment could prove to be a very wise investment to enhance the reliability of the nation's grid.

5. ACKNOWLEDGEMENT

This study was undertaken as a byproduct of NREL contract No. XAD 81767101 and NYSERDA contract No. 4694ERTERER98. Many thanks to Chuck Kowalski for providing us with load data.

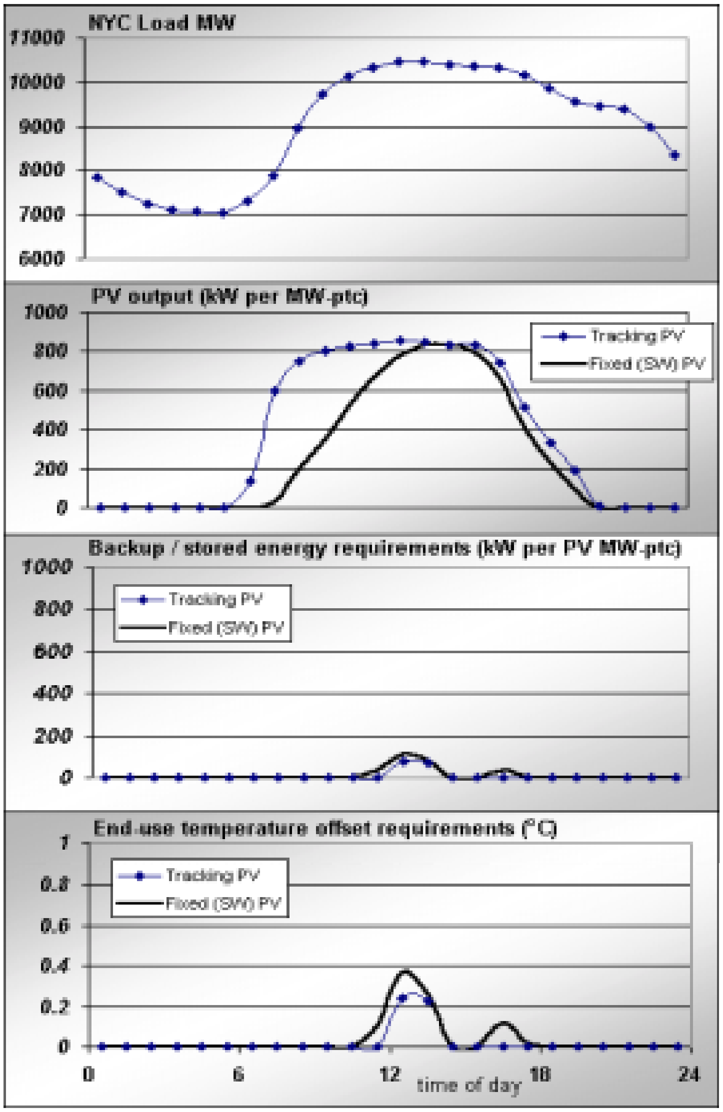

Fig. 6: Load, PV output, MBES requirements, and, alternatively, SLC temperature increase requirements to insure 100% peak shaving at 5% PV penetration in New York City, July 6, 1999

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