AVAILABILITY OF DISPERSED PHOTOVOLTAIC RESOURCE DURING THE AUGUST 14th 2003 NORTHEAST POWER OUTAGE

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ABSTRACT

In this paper, we pose the following question: could distributed PV help prevent the type of power outage that occurred on August 14th, 2003 in the US and Canada? Although the direct cause of this outage was a combination of technical deficiencies and human error, we present evidence that, had local dispersed PV generation – amounting to a few percent of regional peak loads -- been available it would have made a critical difference. Such a dispersed PV resource base would have reduced large power transfers occurring in the region and provided enough load and voltage relief near load centers so that uncontrolled events would not have cascaded into the massive blackout.

1. THE BLACKOUT

The events of August 14th have been analyzed in detail and reported in a comprehensive report jointly prepared at the request of the US Secretary of Energy, and the Minister of Natural Resources Canada [1].

Precursor events: In the afternoon of August 14, 2003 loads and power transfers through the northeastern US were high, although not at record levels. Air conditioning demand was the main peak load driver. Although not at record levels, weather conditions were somewhat unusual because the entire North American continent experienced high temperatures, coast-to-coast, as far north as the Bay of Hudson (see Fig. 1)

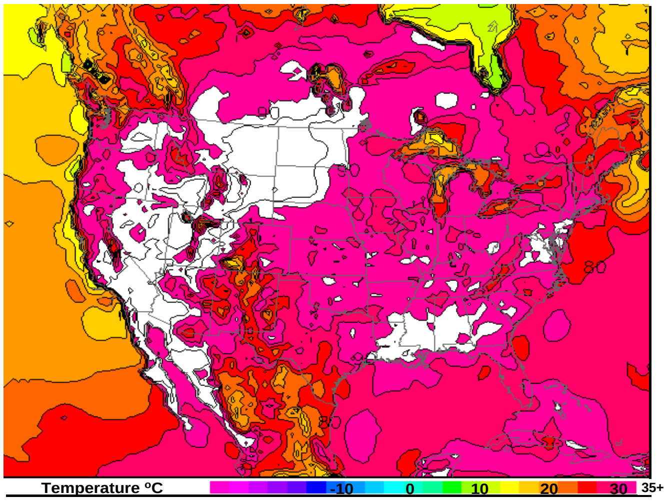

Fig. 1: Temperatures at 4 PM on 8/14/04 (source UCAR)

In the hours preceding the outage, the region was experiencing substantial power transfers (~ 5 GW) from south-central US to the north (Fig. 2-a). Much of that power transited through northern Ohio, southeastern Michigan and western Pennsylvania on its way to the major load Centers of Detroit, Cleveland and Toronto, where local energy production was insufficient. New York State as a whole was almost self sufficient, but, as usual on hot summer days, much power transited towards the power-starved New York metro area. A pattern of depressed voltage was persistent in northern Ohio caused by high demand for air conditioning.

The US/Canada report notes that such conditions did not represent highly unusual or emergency conditions and, as

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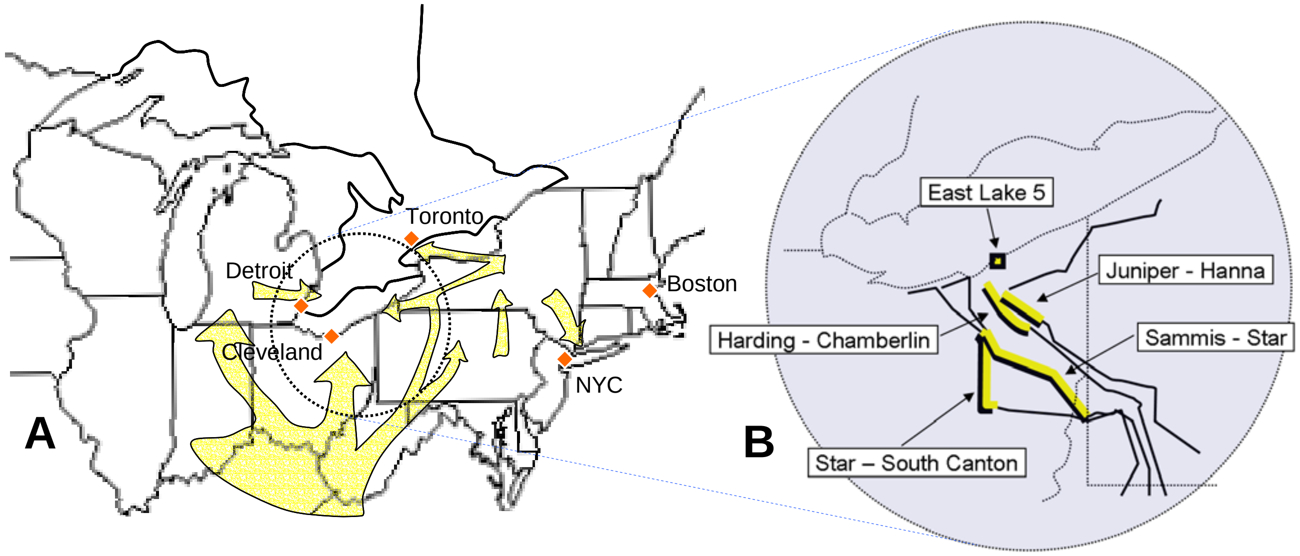
such, were not the cause of the blackout. However, these conditions did lower the grid's resilience to multiple contingencies. Unfortunately, multiple contingencies did occur, compounded by human/technology errors. Several significant unplanned outages and line trips occurred in the hours preceding the outage. These precursor events all took place near Cleveland, OH, where large (345 kV) power lines were carrying much of the north-to-south power flow (Fig 2-b)

- 1:31 PM -- The East Lake power plant located near Cleveland tripped off line, resulting in the loss of 600 MW generation in power hungry northern Ohio. The failure was attributed to the plant exceeding its reactive power generation limit. Reactive power was needed to support depressed voltages resulting from high air-conditioning demand.
- 3:05 PM -- The Harding Chamberlain 345kV power line which was wheeling some of the power lost from East Lake, failed. The cause of the failure was not overload (the line was carrying 45% of its allowable limit), but tree contact resulting from inadequately maintained right of ways. 500 MW transiting through this north-south conduit found their way on other neighboring lines.
- 3:32 The Hanna Juniper 345kV power line, which had absorbed part of the East Lake and Harding-Chamberlin losses failed, also due to tree contact. However this time the line was much closer to its emergency rating (80%). The 1200 MW it carried were rerouted to other paths.
- 3:41 PM The Star-South Canton 345 kV power line, which had picked up some of the above losses failed, resulting in the redirection of 1200 MW. This time the failure was overload (120% of line capacity).

Two aggravating factors in these events were: (1) the inadequate situational awareness of the local utility (First Energy) which was unaware of some line failures – due to inadequate monitoring and contingency analysis tools – and (2) the failure of the concerned reliability coordinator organizations (MISO and PJM) to provide effective problem diagnostic (resulting from the above lack of monitored data). The precursor events were thus left to evolve without effective interventions from the grid operators -- such as targeted rolling blackouts.

Cascading blackout: Much of the power carried by the Star-South Canton line found its way on secondary (138 kV) power lines and on the only remaining 345 kV line (Sammis-Star). The 138 kV lines failed line after line due to



	Before 1:31 PM	1:31 PM	3:05 PM	3:32 PM	3:41 PM	4:05 PM	Cause
East Lake 5 Plant	100% (600MW)	Failed	Failed	Failed	Failed	Failed	Exceeding MVAR limit
Harding-Chamberlain	35% (400MW)	45% (500MW)	Failed	Failed	Failed	Failed	Tree Contact
Juniper-Hanna	55% (800MW)	70% (1 GW)	80% (1.2 GW)	Failed	Failed	Failed	Tree Contact
Star-South Canton	65% (650MW)	80% (800MW)	90% (900MW)	120% (1.2 GW)	Failed	Failed	Overaload
Star-Sammis	55% (650MW)	60% (700MW)	65% (800MW)	85% (1 GW)	120% (1.4 GW)	Failed	Overaload

Fig. 2: Regional power transfers in the afternoon of 8/14 (A). Much of this power flowed through 345kV lines in eastern Ohio (B). The loss of the East Lake generating facility and of the power lines compounded by the lack of situational awareness from the grid operators forced the power flows into alternate paths and precipitated the outage (source [1])

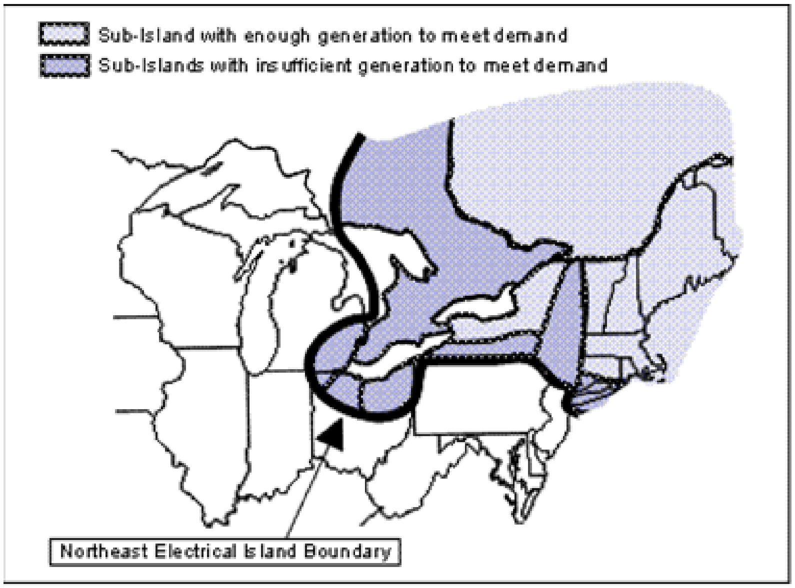


Fig. 3: Within 7 minutes of the Sammis-Star trip, all paths wheeling power from south to north were severed resulting in a large power deficient island (source [1]).

overload. Sammis-Star absorbed the losses, until it failed at 4:05 PM, marking the beginning of the massive outage.

The north-south power flow headed for Cleveland, Detroit and Ontario which had been traveling through northern Ohio got pushed on other paths via Western Michigan, Western Ontario, Pennsylvania and New York. Such a massive power flow rerouting resulted in line failure at an exponentially increasing rate as the flow was redistributed into fewer and fewer paths. The frequency and voltage disturbances accompanying these fluctuations were, as much as overload, responsible for many of the line trips. This was compounded by the shut-down of numerous power plants which had either reacted protectively to the power fluctuations or lost their energy output paths. Within a few minutes all the south-to-north paths had been severed (fig. 3). The northeastern corner of North America became an electrical island where demand exceeded generation. The resulting depressed voltages and frequencies caused the line trips and generation failure cascade to continue within the NE island, creating several sub-islands. The sub-islands where local generation was sufficient to meet demand (New England, Quebec[1], Upstate New York) stabilized and remained up. The other sub-islands which did not have enough local generating capacity, including the New York, Toronto, Detroit and Cleveland metropolitan areas, went into blackout (Fig. 3).

2. DISPERSED PV SOLUTION

The three "official" causes of the blackout as stated in the US/Canada report are: (1) Inadequate situational awareness (the concerned utility was not fully aware of developing problems); (2) Inadequate tree trimming (the first line failure was not caused by very high load but by poorly maintained right of way); (3) Inadequate Diagnostic Support from Reliability Coordinators (lack of situational data for grid contingency simulations, miscommunications)

However, above and beyond these three direct cause, the analysis of events clearly suggests that, had regional power transfers to meet localized demands not been as high, the probability of each contingency – even unattended – leading to the next, and into the cascade would have been much lower – the analogy of a car blowing a couple of tires at high speed vs. low speed comes to mind.

In this article we pose the question: could dispersed photovoltaic generation have made a difference in preventing the outage?

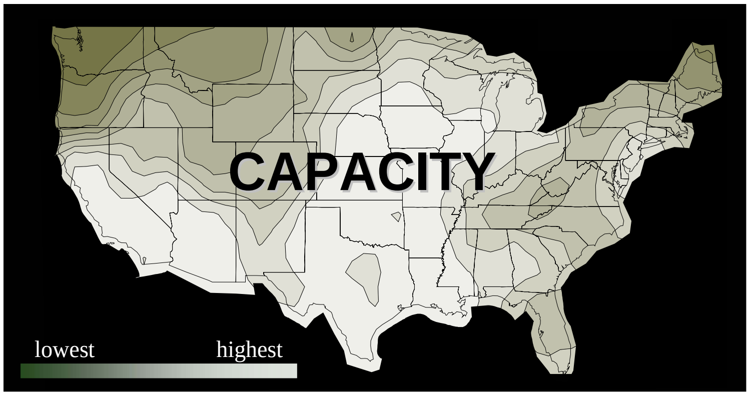


Fig. 4: Distribution of PV's effective capacity in the US (see [3])

Effective Load Carrying Capability: One of the well documented characteristics of PV generation is its high

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[1] Quebec, which had abundant local power generation online was further protected by its DC power ties to the rest of the eastern American grid -- the frequency disturbances do not propagate through DC interties.

Effective Load Carrying Capability (ELCC) when loads are driven by air-conditioning demand. PV ELCC is significant in the concerned geographical area, where summer peak loads are driven by commercial A/C -- see map in Fig. 4 [2, 3]. For most utilities servicing metropolitan areas in the northeast, the effective capacity of stationary PV installations is of the order of 65%[2], and remains higher than 50% for grid penetrations of up to 15% (see [3,4]).

PV availability on 8/14: The high effective capacity of PV may be explained by the fact that the indirect cause of the peak (solar gain) is also the source of PV generation. As expected on this hot summer day, the solar resource was near ideal throughout the region on the afternoon of 8/14 – see Fig. 5 and 6.

How much PV? While it is clear that considerable solar resource was available region-wide prior to and during the outage event, a key question is to establish how large a PV base would have been sufficient to prevent it. Two approaches to this question may be considered:

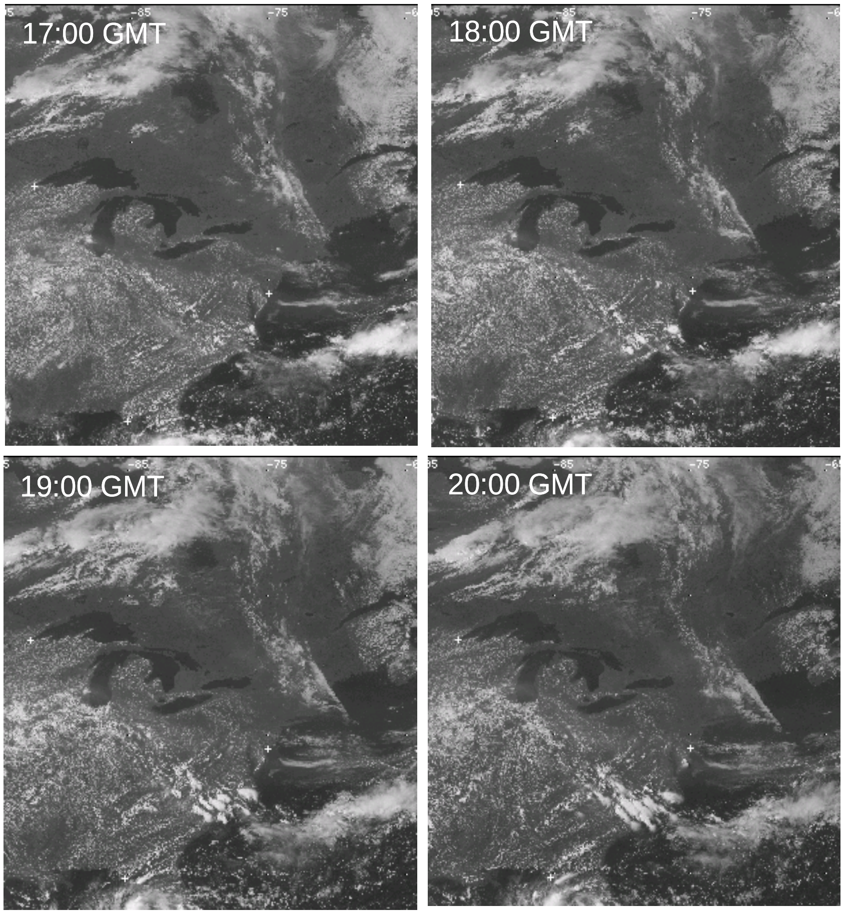

Fig. 5: Cloud cover distribution in eastern North America on 8/14/04 -- note that the area affected by the outage is almost cloud-free.

1. Providing enough localized resource through dispersed PV generation -- including voltage support and reactive power [5] – so that precursor events would have been avoided. When the East Lake Unit failed it was trying to produce about 400MVar. This level of reactive power production was about 40MVar above the units rated limit of 360 MVar [1, Figure 3.5] Thus displacing even a relatively small fraction of the cooling load-induced reactive power requirements that the East Lake Unit was attempting to meet when it failed would have been sufficient to keep the plant on-line. This suggests that at most a few tens of MW deployed locally would have been enough. Further, the Hanna Juniper line failure could have been avoided by reducing its power flow also by a few tens of MW (this line touched trees at 3:32 PM when ambient temperatures (hence power demands) were near the very end of their peak and natural day-cycle cooling relief was almost in sight – Fig. 7). It is reasonable to argue that, had this domino – adding a 1200 MW burden to the local grid -- not fallen, the cascade would not have occurred, notwithstanding other more direct outage causes: inadequate situational awareness and erroneous power flow diagnostics.

2. Minimizing regional power transfers via local generation: Prior to the precursor events power flow from the south into Northern Ohio, Southern Michigan and Western Pennsylvania were of the order of 5000 MW, a substantial portion of this was transiting to Ontario. Had local dispersed generation been available in/near Detroit, Cleveland and Toronto, these transfers would have been reduced and inadvertent power line trips would have been inconsequential. A 10% power transfer reduction could have been achieved with a total PV resource of 0.5 GW dispersed throughout northern Ohio, Michigan, Pennsylvania, New York and Ontario.

Both approaches suggest that the availability of at most a few 100s PV MW in and around each major concerned metro area would have provided an insurance against the unfortunate contingencies of 8/14 compounded by the

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[2] 65% ELCC may be interpreted as saying that for the concerned utility, 100 MW of PV generation, is equivalent to installing 65 MW of ideal peaking resource

"blindfolds" of the concerned utilities and grid reliability coordinators.

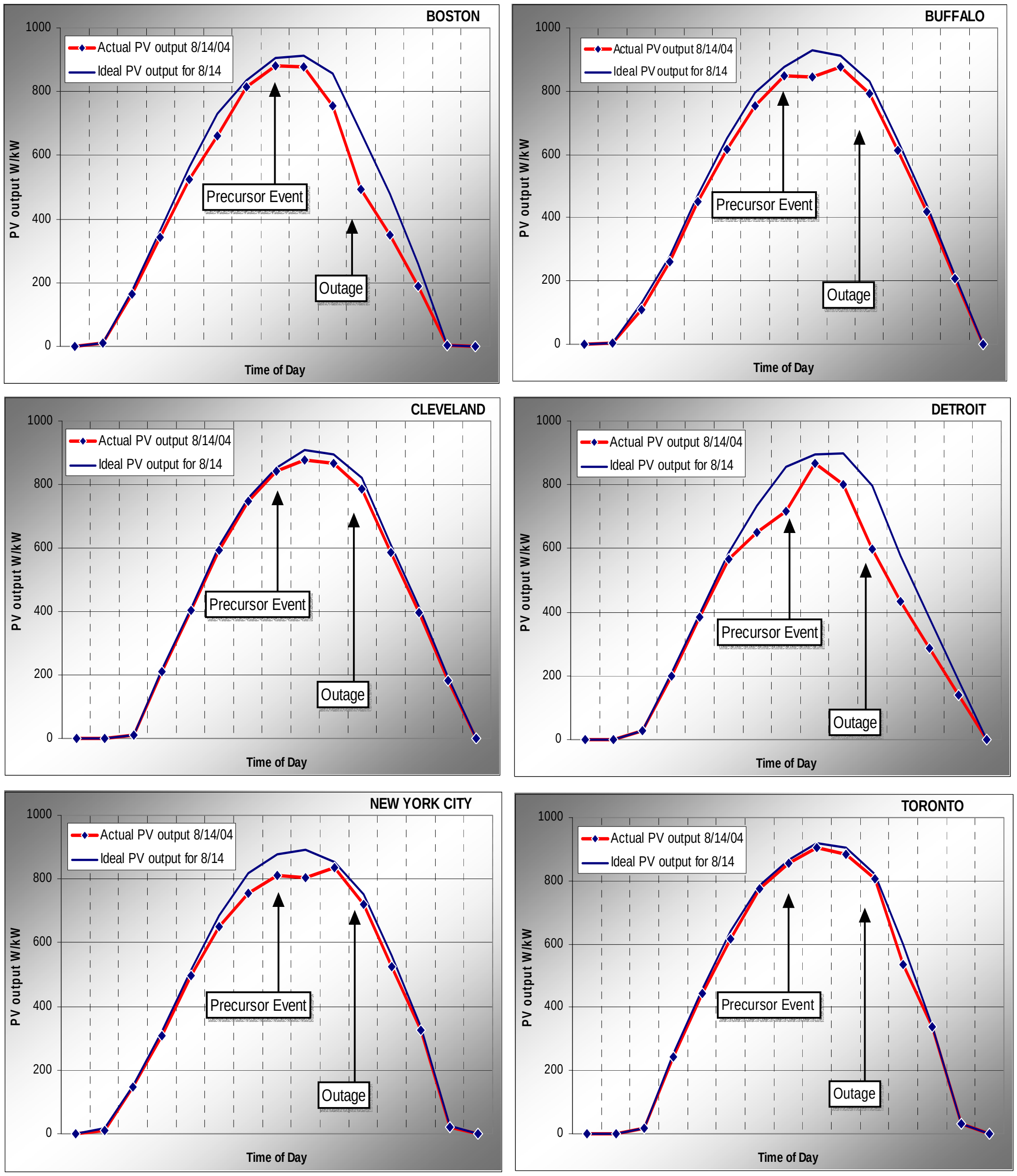

Fig. 6: Actual vs. Ideal simulated output of fixed-optimized PV arrays on 8/14/04 in major eastern American cities.

PV deployment: There is more than ample space to deploy such amounts of PV (customer-sited or not) in each concerned metro area – including e.g., low rise commercial roofs, residences, exclusion zones and parking lots. PV geometries optimized for mid afternoon production would be best. On-site emergency storage/backup would also be very effective, because: (1) it has been shown that a small amount of storage (i.e., a Minimum Buffer Energy Storage or MBES) can greatly increase the ELCC and the value of PV, particularly if this occurs in parallel with low-impact solar load control [6,7], while adding little to the overall cost of PV installations; (2) user-sited storage and load control could be managed -- in part -- by local utilities, adding instantaneous dispatching capability to meet contingencies [8]; (3) on site storage of course provides security benefits should outages nevertheless occur – allowing adequately-sized emergency loads (e.g., refrigerators, security equipment and emergency lights, minimum computer and communication services) to remain on indefinitely.

Cost/value: For all of these scenarios, we are not suggesting that one install PV systems for the sole purpose of preventing a potential outage. There are certainly cheaper ways to accomplish this goal. Rather, we are suggesting that, if PV had been installed, it would have been beneficial to the utilities and their customers by reducing multiple stresses on the system. Utilities (and their customers) should recognize that PV has value to them whether or not they own the technology. As a result, a portion of the resources devoted to remedying these sorts of situations should be directed towards encouraging the installation of PV systems, particularly in stressed areas of the grid. The issue of how much this should be will be discussed in a subsequent paper.

3. CONCLUSIONS

In this article, we investigated whether the presence of strategically located distributed PV generation could have prevented the August 14th, 2003 blackout. The joint US-Canada report [1] attributes the causes of the outage to both human and technological failures. However, there is much evidence that, had a local dispersed PV generation base amounting to at most a few hundred MW been on line, power transfers would have been reduced, point of use generation and voltage support would have been enhanced and uncontrolled events would not have evolved into the massive blackout.

The results of this study are fully consistent with previous observations that, in time of maximum grid stress for summer peaking utilities (high power transfers, existence load pockets depressing voltages) the probability of PV output being near ideal is very high [e.g., 9,10].

Another important point noted in this study is that in addition to its “outage preventive” benefits, a distributed PV base could also provide “outage recovery” security insurance, if the PV systems are optimally designed with emergency storage/backup to handle minimal critical loads. We will address the economic aspects of these deployment options in a forthcoming article.

4. AKNOWLEDGEMENTS

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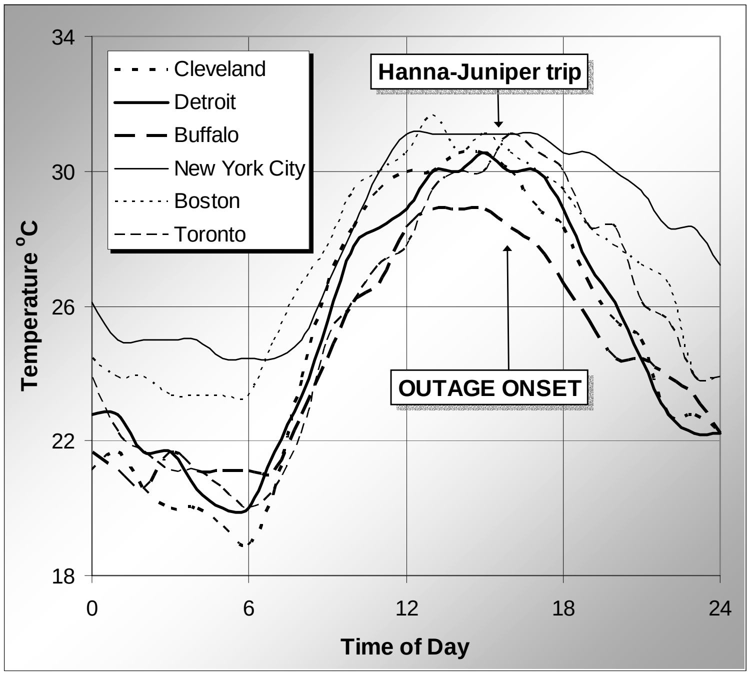

Figure 7: Ambient temperatures in major northeastern cities on 8/14