Presented at RENEW 94 11-13 April 1994 Stamford, CT

MATCHING UTILITY PEAK LOADS WITH PHOTOVOLTAICS

Richard Perez
Robert Seals
Ronald Stewart

Atmospheric Sciences Research Center
100 Fuller Rd. Albany, New York 12205

Abstract

We evaluated the load matching capability of photovoltaic (PV) power generation for a large sample of US electric utilities and sub-utilities (feeders, large customers). Load matching is an important parameter because of its impact on the value (both financial and technical) of PV. Estimating load matching capability requires access to site/time specific PV output data. Here, that data was obtained via system simulation, based on satellite remote sensing. We show that (1) the overall magnitude of the local solar energy resource is not highly correlated with load matching and that (2) key characteristics of the considered load are strongly correlated with load matching -- indeed, some of the best load matching cases are found in regions not traditionally associated with solar energy development (e.g., the US heartland, the Eastern Seaboard) often bettering results obtained for "traditional" solar energy regions such as Florida and the Southwest.

1. Why load matching?

PV power generation is not dispatchable, hence it has traditionally been given little or no capacity credit. However, it has been shown that there may exist a substantial degree of correlation between load requirements and PV output. This correlation has been associated with loads driven by commercial activity and air conditioning requirements, both in the case of customer loads [e.g., Doty et al. 1992] and utility loads [e.g., Perez et al., 1993].

Quantifying this correlation or ***load matching*** capability as we term it here, is therefore important because it is directly linked to the ***capacity value*** that may be assigned to the PV resource. This value includes not only utility-wide generating capacity value, but also localized transmission and distribution (T&D) benefits, many of which are directly linked with the capability of PVs to be in phase with the highest load requirements (such as line upgrade deferment, transformer life extension, etc. [e.g., Hoff et al, 1992]).

2. Estimating load matching

2.1 Defining load matching parameters: Load matching itself is not an exactly measurable quantity, but several of its practical aspects may be quantified using appropriate parameters. Here, we focus our attention on two key parameters.

The first parameter, ***the generalized Garver's Effective Load Carrying Capability (ELCC)***, provides a statistical measure of load matching. It was originally defined by Garver [1966] as the increase in generating capacity available to a utility, resulting from the addition of the new resource, at constant loss of load probability (LOLP). We generalized the use of ELCC [Perez et al., 1993] so that it would characterize only the load-resource relationship, independently of the considered utility's generation mix and of its LOLP. Under this generic formulation, it is possible to extend the use of the ELCC parameter to any type of load (from a utility load, down to a substation or even a customer load).

The second parameter, the ***Minimum Buffer Energy Storage (MBES),*** provides an absolute "worse-case" measure of load matching. The MBES is defined as the minimum amount of stored energy required in association with the PV system, to guaranty, in the case of a demand side system, a firm peak load reduction at least equal to the size of the PV system, or in the case of a supply side system, the firm ability to meet a peak load increase equal to the size of the PV system. As an additional measure of load matching, MBES is compared to the ***Total Energy Storage (TES)*** that would be required to accomplish the same task without PV.

2.2 Estimating load matching parameters: Pending a better understanding of the feed-back between load requirements and solar-dependent load drivers, the only practical way of estimating load matching is to proceed experimentally, that is, to analyze actual load and coincident PV output data time series. Unfortunately, actual time/site specific PV output data are rarely available. PV output could be simulated rather precisely, but only as long as one could access satisfactory solar irradiance data, which are, as well, rarely available for arbitrary locations and times.

2.3 Using satellite remote sensing as a proxy measurement of insolation: Geostationary satellites monitor the earth's cloud cover, and provide an indirect way of estimating irradiance at any point in time and space: precisely the type of information one needs to carry out a national evaluation of PV load matching opportunities. Our first concern was to assess the ***physical accuracy*** of the satellite (i.e., the precision of satellite-derived irradiance, and, more importantly, to assess its ***end-use accuracy*** (i.e., the precision of satellite-derived load matching parameters). Results of this assessment, which proved to be satisfactory given our objective, were recently reported by Perez et al. [1993-1994a].

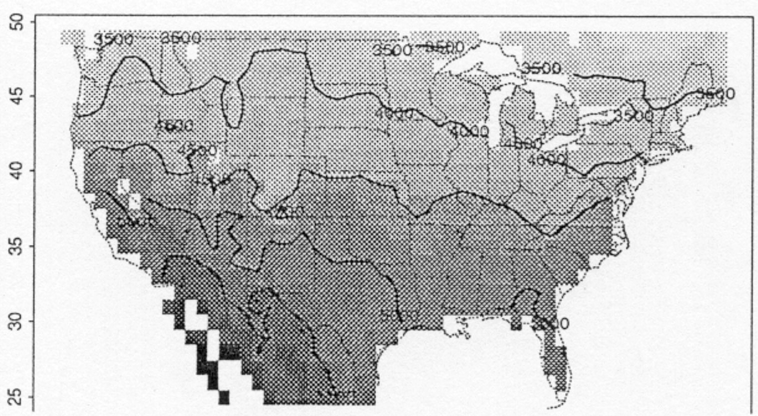

Fig. 1: Average satellite-derived 1987-88 daily global irradiance (Watt-hour/m^2/day)

2.4 Logistical limits for this study: Because of time and budget constraints, we used geostationary satellite data which had already been partially processed into irradiances at NOAA-NESDIS [Tarpley, 1991], using a simple model [Justus et al., 1986], on a 1°latitude-by-1°longitude grid over the US territory, for the years ***1987 and 1988***. For these two years, we were able to generate hourly global and direct irradiance (see Fig. 1), and simulate the hourly output of fixed and 2-axis tracking PV systems at any point on the 1°x1° grid [Perez et al. 1993b]. The climatological impact of selecting these two years was found to be minimal, at least for the type of load matching study considered here [Perez et al., 1993-1994b]. (*Note that it is likely that satellite's spatial resolution, time resolution, accuracy and geographical coverage could be substantially increased, given proper means, by combining and exploiting currently available resources).* Some of the loads analyzed here, especially substation and customer loads, were not available for the 1987-1988 time frame, hence our ability to study these load was limited to locations where ground-measured irradiance data could be found.

3. Load Matching Results

3.1 Initial Phase -- preliminary US utility sample: Twenty utilities provided us with hourly system load data for 1987 and 1988 (see Figure 2). With generating capacities spanning two orders of magnitude and totaling well over 100 GW, and with service territories ranging from the size of a city to that of a large state, these utilities already represented a diversified US sample.

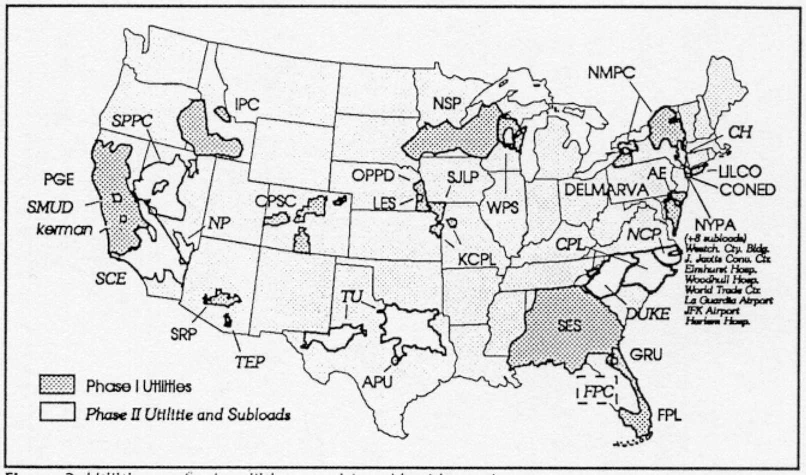

Figure 2: Utilities and sub-utilities considered in this study

For each utility, nominal service area-wide hourly PV output was computed and qualitatively compared to load requirements (Figure 3). Load and PV data were further processed to produce a quantitative estimate of selected load matching parameters as a function of the penetration of PV within the considered utility grid. Figure 4 presents an example of the variations of photovoltaic ELCC as a function of the resource's penetration on the grid of LILCO -- note that ELCC tends to decrease as more PV penetrates onto the grid.

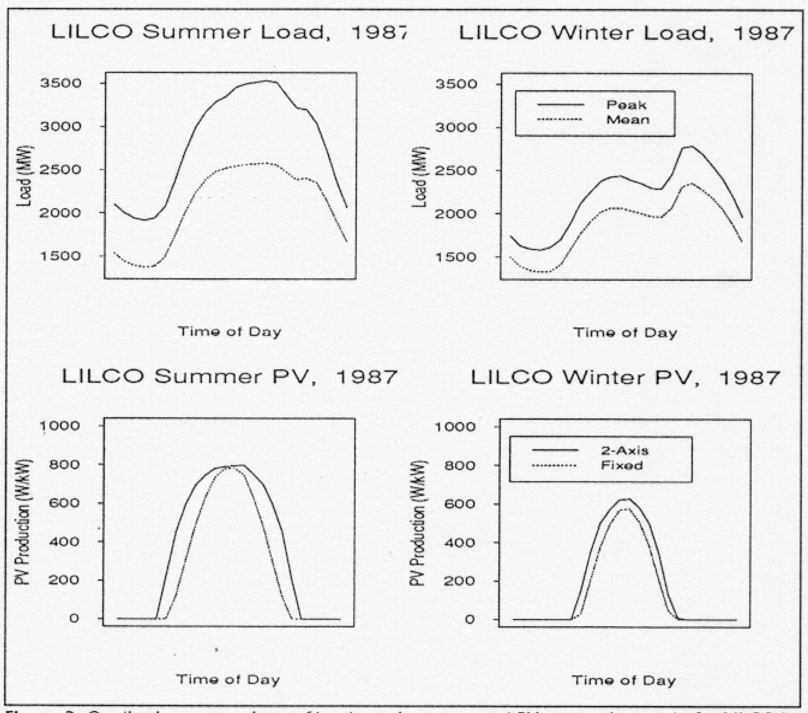

Figure 3: Qualitative comparison of load requirements and PV output (example for LILCO in 1987)

The major findings of this initial phase of work were:

(1) load matching was found to be only weakly dependent on the utility's overall solar resource.
(2) load matching was found to be strongly related to specific characteristics of the load, namely, the ratio between a utility's summer and winter peak load.
(3) As a consequence, the best load matching opportunities were not found in "traditional" high solar resource locations (e.g., southwestern deserts, Florida), but in areas with high day-time summer peak loads and low winter loads (i.e., likely driven by commercial air conditioning, and with low electric

heat usage), often corresponding to large metropolitan areas in the central/eastern US, and the California coast.

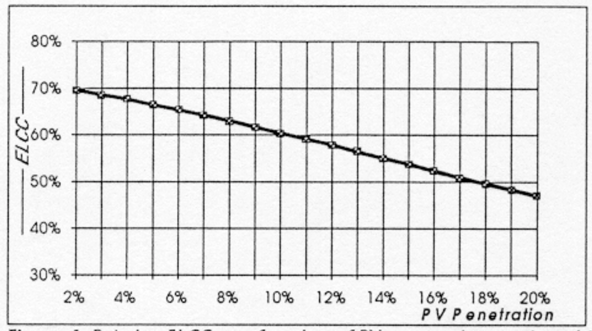

Figure 4: Relative ELCC as a function of PV penetration on the grid of LILCO

3.2 Second phase, additional utilities and sub-utilities: The original intent of this load matching study was to inform utilities, many of which were either unaware of, or had dismissed their PV application potential because they were not located in a "traditional" solar energy regions. A second phase was initiated, not only to continue this informative service, but also and, more importantly, to verify the findings of phase I. In particular, we were interested in (1) confirming the relationship observed between load characteristics and load matching with more data points and (2) investigating whether this relationship, already spanning a diverse group of utilities, could be extrapolated to "sub-utilities" (i.e., substations, feeders, or even large customers). The existence of such a relationship would provide a low cost investigative tool for utilities to do a "first-cut" assessment of load matching opportunities at the T&D level without having recourse to a comprehensive monitoring program -- more precise investigations, including solar monitoring, would then be targeted toward the most promising cases.

For this second phase, we secured twenty additional loads (see Figure 2), including nine sub-utility loads (the Kerman substation in Pacific Gas and Electric's territory, and eight large customer loads in the New York City area, including major office complexes, hospitals and airports). The loads at hand now span four orders of magnitude from less than 1 MW-peak to a few 10s-GWs.

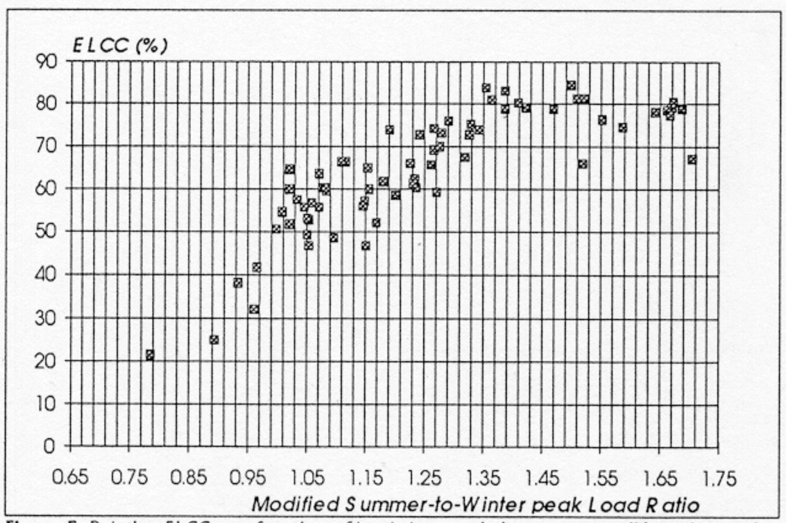

Figure 5: Relative ELCC as a function of load characteristic parameter. *(Note that each point represent one load-year)*

In Figure 5, we plotted PV ELCC (Y-axis), for each utility, sub-utility and each year studied (a total of 70 load-years), as a function of a composite parameter (X-axis) characterizing each load. The points in Figure 5 correspond to a 2% load penetration. The load characteristic parameter is based on the simple summer-to-winter peak load ratio previously introduced by the authors [Perez et al., 1993], but also includes information on off-season peak loads, time of summer peak, extent of evening shoulder, size of excursion between summer peaks and valleys as well as load size/diversification. Note that the load characteristic parameter, which is still under development stage at the time of this writing, depends only on load-related information. The original summer-to-winter peak load ratio formulation was modified in an attempt to account for observed departures from the trend, traceable to specific load characteristics. Departures were strongest at the sub-utility level, typically showing lower ELCCs for a given summer to winter load ratio.

Figure 5 shows a solid relationship between the load characteristic parameter and load matching as quantified by the ELCC parameter, thus confirming preliminary results of Phase 1 over a large sample of loads.

By contrast, there is no apparent relationship between observed ELCC and the local solar resource as shown in Fig. 6, where ELCC was plotted against mean yearly global irradiance.

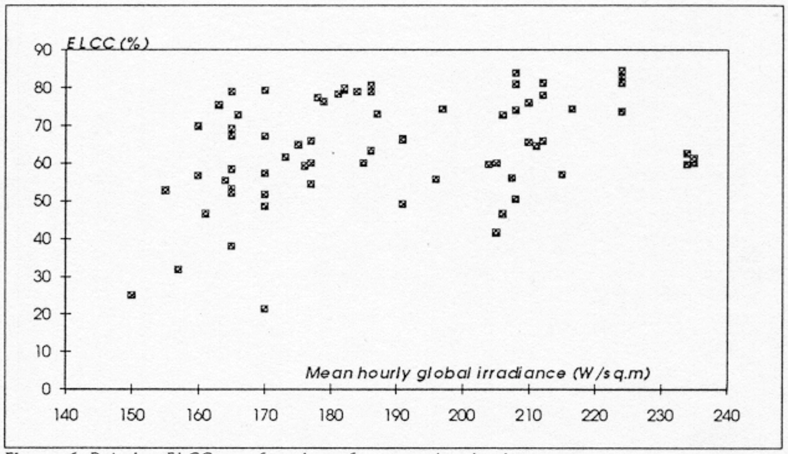

Figure 6: Relative ELCC as a function of average local solar resource

Results for the second load matching parameter considered here are shown in Fig. 7 for a PV penetration of 10%. The MBES for the 70 considered load years is compared to each TES. Load-years are ranked in terms of increasing ELCCs. The unit for MBES and TES is system hours (i.e., 5 hours corresponding to a 10% penetration with a peak load equal to 100 MW would amount to 50 MWh). It is interesting to remark that a TES of the order of six system hours is generally required with little dependence on the load characteristic ranking. MBES is considerably more dependent on the load parameter. In the most favorable cases, minimum storage requirements of the order of an hour are sufficient when used as a buffer to a PV system. It is also interesting to note that MBES remains substantially lower than TES even for low ELCC cases, (that include winter and evening peaking loads).

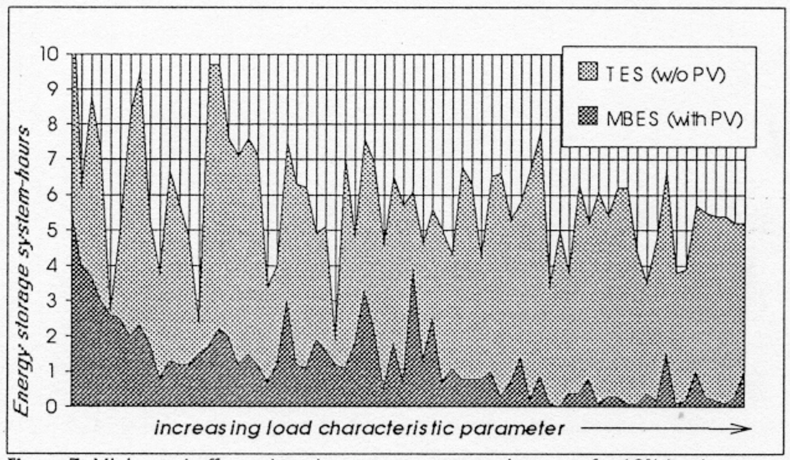

Figure 7: Minimum buffer and total energy storage requirements for 10% load reduction, ranked as a function of each load's characteristic parameter

4. Conclusions

Load matching is found to be high in many locations outside traditional high solar resource areas. Indeed, the majority of the 50% highest ELCC cases correspond to utilities and loads on the eastern seaboard and the north-central US. Many of the southeastern and mainland southwestern cases are found in the lower 50%. The additional loads studied since we first reported this observation tend to confirm this assertion.

The trend observed in Phase I between specific characteristics of the load and the effective capacity of PV is confirmed. However, the simple summer-to-winter peak load ratio parameter had to be refined to account for other relevant load characteristics. Using this refined parameter, the trend was found to remain valid for smaller non-utility loads.

The observed load matching trend should be quite helpful because it could be used to do a "first cut" estimate of load matching opportunities in the absence of PV system or irradiance data. Beyond a first cut assessment, however, access to quality solar data will be necessary. In this respect, this study has also indicated that satellite could be very useful and affordable way to provide large scale (US and abroad) insolation coverage, particularly used in combination with strategically located ground stations.

Acknowledgment

This project was supported by NREL under contract XR-1-11168-1 with Roger Taylor and William Wallace as NREL project managers -- many thanks for their help.

Mike Bergman and the UPVG staff played a key role in helping us contacting interested utilities.

Thanks to all the participating utilities and their staff, and thanks to Mark Kapner and Dan Shugar for providing us with custom load and irradiance data, and to J. Dan Tarpley for providing the satellite data.

Reference

B. Bailey, J. Doty, R. Perez and R. Stewart, (1993): *Evaluation of a Demand Side Management Photovoltaic System*, IEEE Transactions on Energy Conversion (Winter 93 Meeting),

R. Perez, R. Seals and R. Stewart, (1993): *Assessing the Load Matching Capability of PVs for US Utilities Based upon Satellite-Derived Insolation Data*. Transaction IEEE 23d PV Specialists Conference pp. 1146-1151, Louisville, KY.

T. Hoff, D. Shugar, A. Suchard, H. Wenger, K. Lau, G. Ball and J. Mead, (1992): T*he Photovoltaic Grid Support Project at Kerman Substation -- Project Plan*. PG&E Advanced Energy Systems Report 007.5-92.5 , Pacific Gas and Electric Company San Ramon, California

L. Garver, (1966): *Effective Load Carrying Capability of Generating Units*. IEEE Transactions, Power Apparatus and Systems, Vol. Pas-85, no. 8

R. Perez, R. Seals, R. Stewart, A. Zelenka and V. Estrada-Cajigal (1993-1994): *Using Satellite-Derived Insolation Data for the Site/Time Specific Simulation of Solar Energy Systems*, Proc. ISES World, Congress, Budapest, Hungary and Solar Energy (in press -- accepted 12/93)

J. D. Tarpley (1991): *Personal Communication*. NOAA-NESDIS, Washington, DC

C. G. Justus, M. V. Paris and J. D. Tarpley, (1992): *Satellite-Measured Insolation Data in the US and Mexico*, Remote Sensing Env. 20 pp. 57-83

R. Perez, R. Seals and R. Stewart (1993b): *Solar Resource -- Utility Load Matching Assessment* Phase 1. NREL Contractor's Report (contract # XR-1-11168-1). NREL, Golden, Colorado

R. Perez, R. Stewart, M. Rymes and D. Renne (1993-1994b): *Assessment of Photovoltaic-Utility Load Matching Potential -- Impact of Long Term Insolation Variations*. NREL Contractor' s Intermediate Report (contract # XR-1-11168-1). NREL, Golden, Colorado and upcoming Proc. ASES Annual meeting, San Jose, California.