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INTEGRATING PHOTOVOLTAICS INTO UTILITY DISTRIBUTION SYSTEMS

H.W. Zaininger
Zaininger Engineering Company, Inc.
San Jose, CA

P.R. Barnes
Oak Ridge National Laboratory
Oak Ridge, TN

ABSTRACT

Electric utility distribution system impacts associated with the integration of distributed photovoltaic (PV) energy sources vary from site to site and utility to utility. The objective of this paper is to examine several utility- and site-specific conditions which may affect economic viability of distributed PV applications to utility systems. Assessment methodology compatible with technical and economic assessment techniques employed by utility engineers and planners is employed to determine PV benefits for seven different utility systems. The seven case studies are performed using utility system characteristics and assumptions obtained from appropriate utility personnel. The resulting site-specific distributed PV benefits increase nonsite-specific generation system benefits available to central station PV plants as much as 46%, for one utility located in the Southwest.

INTRODUCTION

PV is an environmentally beneficial electricity producing renewable energy technology which can be considered as an electric power generation resource when planning electric utility systems. If PV is employed in large central generation stations like conventional generation, nonsite-specific utility generation system economic benefits, such as energy and capacity displacement will be obtained. These nonsite-specific utility generation system economic benefits can be very large. However, delivering this central station PV power to electric utility customers requires increased transmission system costs to deliver the power to the utility load centers, and increased distribution system costs to deliver the power to the end user within the load centers.

Small, distributed PV installed in electric utility distribution systems can obtain local site-specific economic benefits which are not available to large central station PV, such as the deferral of new transmission and distribution (T&D) line and transformer additions, loss reduction, improved reliability and power quality. Electric utility distribution system impacts and resulting distributed economic benefits associated with the integration of distributed PV energy sources vary from site to site and utility to utility based on the local solar insolation characteristics, PV penetration level, whether battery or other energy storage systems are applied, distribution system characteristics, design standards, voltage levels, load density, reliability, and power quality.

Small, distributed PV energy sources installed on utility distribution systems at load centers will also produce nonsite-specific utility generation system economic benefits like large central station PV, such as energy and capacity displacement benefits, in addition to the local site-specific distribution system benefits. Although generation system benefits are not site-specific, they are utility-specific, and will vary significantly among utilities in different regions of the United States. In addition, transmission system benefits, environmental benefits and other benefits may apply.

This paper summarizes the results of a research project [1] [2], in which case studies for the following seven utilities are evaluated to examine a range of expected utility- and site-specific conditions throughout the United States that may effect the economic viability of distributed PV energy sources.

UTILITY	STATE
Southern California Edison	California
Public Service Co. of New Mexico	New Mexico
Green Mountain Power Co.	Vermont
Georgia Power Co.	Georgia
Florida Power & Light Co.	Florida
Lenoir City Utilities Board	Tennessee
Orcas Power & Light Co.	Washington

ASSESSMENT METHODOLOGY

One major objective of this research project was to develop an assessment methodology and produce results that are credible and acceptable to electric utility distribution engineers and system planners. Thus, the benefits are determined from a utility perspective, and the assessment methodology is compatible with the technical and economic assessment techniques employed by utility engineers and planners. The assessment methodology uses a bottom-up approach and provides flexibility for considering PV or other renewable resources at different levels of aggregation on a utility system. The resulting site-specific distributed utility benefits and nonsite-specific generation utility benefits are then combined, and the total benefits compared with the capital and operating costs of the PV system.

The primary economic assessment approach [3] [4] [5] used in this research project consists of performing a benefit-cost assessment using present worth of revenue requirements (PWRR) engineering economic analysis, providing for suitable economic and financial parameters corresponding to different investor-owned and public utility perspectives and assumptions. The PWRR approach, which is compatible with the system planning techniques generally employed by both private and public utilities worldwide, consists of calculating the relative annual revenue required to support the alternative utility system expansion plans with and without PV throughout the study period. The benefit-cost calculations for six of the seven utilities were performed using this PWRR economic approach. The calculations for the seventh, Lenoir City Utilities Board, used simplified payback economic methodology, which was compatible with the utility's economic assessment approach.

The best available data were collected from each of the seven utilities during a site visit. Appropriate distribution design standards and associated line and transformer per-unit material and labor cost estimates were obtained, along with representative circuit layouts. The members of the project team familiarized themselves with each utility's distribution planning and design philosophy, reliability and power quality criteria. Energy and capacity costs, and economic assessment procedures and assumptions also were obtained. Transmission costs and applicable environmental externalities were obtained from the utility when available.

A planning study was then performed on rural, suburban, and urban distribution primary and secondary system scenarios for each utility. The studies assumed installation within a typical 5-year distribution planning horizon; the study period was 30 years. First, a base-case distribution system expansion without PV was performed using the cost and distribution planning and design information collected from each utility. Then a similar expansion of the distribution system scenarios was performed, integrating PV applications for an appropriate range of penetration.

The resulting site-specific distribution system benefits were then combined with other utility benefits including energy displacement value, generation capacity value, bulk transmission capacity and loss benefits, and various environmental and other applicable benefits.

PV PERFORMANCE

This paper considers utility interconnected PV applications. Thus energy storage, which increases PV capital investment, is not a requirement for PV systems, and was considered only when the increased cost can be justified by larger utility system benefits.

PV costs and performance strongly depend on the amount of energy generated by the PV plant. The major factor in determining the amount of energy that can be generated by a PV plant is the solar insolation available at the site in question. Typical meteorological year (TMY) hourly insolation based on SOLMET and ERSATZ data [6] [7] were used with Sandia's PVFORM program [8] to determine PV performance for the individual utility case studies.

PV performance varied significantly for the different utilities. For example, per-kW PV performance assumptions for the(Southern California Edison) SCE case study were based on SOLMET data for Daggett, which is located in Southern California. This site is representative of expected solar insolation in SCE's inland valley service areas. Expected annual capacity factor for a 10-m^2 PV system rated at 1 kW, assuming fixed orientation at the site latitude of 34.9^0 is about 25%. The fixed-orientation PV system capacity factor is about 25%, and the capacity factor of the two-axis tracking PV system is about 33.8%. Monthly performance for the two PV system configurations is presented in Fig. 1.

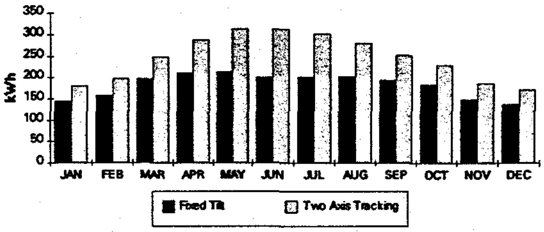

Fig. 1. SCE PV system monthly performance per kW.

Figure 2 shows the hourly performance for the fixed-orientation 1-kW PV system for the peak solar insolation day and average solar insolation day in April and in June. On April peak days when the solar insolation is high, the PV system can attain 1 kW output; on the average day, the PV system can attain over 0.9 kW output. In June, which represents the SCE summer peak period, the PV system does not attain full output.

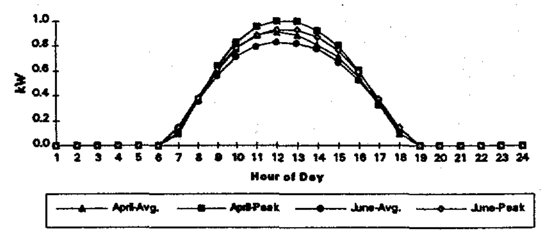

Fig. 2. SCE fixed-orientation PV daily output per kW

Figure 3 shows the corresponding hourly performance for the two-axis tracking 1 kW PV system for June and April. Two-axis tracking provides significantly better PV performance, but at a higher PV capital investment.

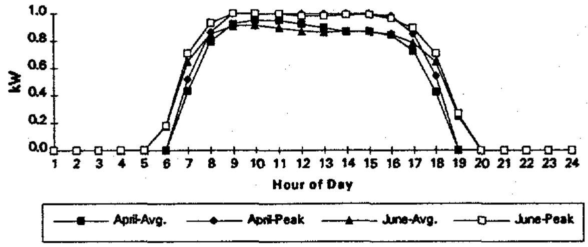

Fig. 3. SCE two-axis tracking PV daily output per kW.

To illustrate a less attractive example, per-kW PV performance assumptions for the Florida Power & Light (FP&L) case study were based on SOLMET data for Miami. This site is representative of expected solar insolation in the FP&L service area. In this case the fixed-orientation PV system capacity factor is about 18.8%, and the capacity factor of the two-axis tracking PV system is about 23.9%.

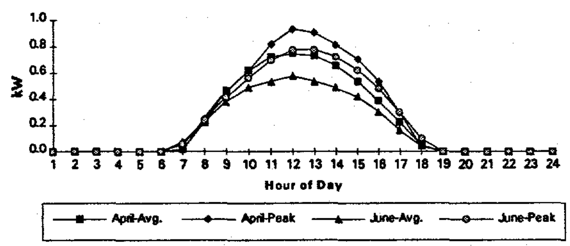

Fig. 4. FP&L fixed-orientation PV daily output per kW.

Figures 4 and 5 show the hourly performance for the fixed-orientation and two-axis tracking 1-kW PV system for the peak solar insolation day and average solar insolation day in April and June for FP&L. In April and June, during high solar insolation periods, the PV can provide fairly high levels of kW output. However, the average monthly output in both June and April is relatively low compared with SCE. Again two-axis tracking provides somewhat better PV performance. However, the average monthly performance of the two-axis tracking PV system is still low compared with SCE. It seems clear from this information that for many days, PV output will not correlate with system daily peak loads during the summer peak season. At FP&L even with two-axis tracking, it is likely that on many days PV MW output will not correlate with daily peak loads during the summer peak season.

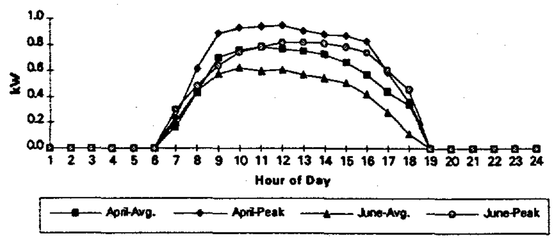

Fig. 5. FP&L two-axis tracking PV daily output per kW.

SUMMARY OF RESULTS

Representative benefits for selected fixed-orientation applications in the seven case studies are shown in Fig. 6. Tracking PV cases resulted in additional benefits. However, the additional investment required for tracking PV appeared to exceed the additional benefits in the applications assessed in the case studies [2].

The value of the distributed T&D utility benefits was found to be utility- and site-specific for the seven utilities evaluated in this study. For PV applications, the distributed utility benefits increased the total benefits $23/kW–$823/kW (4-46%) above the corresponding nonsite-specific benefits applicable to large central station PV applications. The largest increases were in the southwestern U.S., where daily peak loads correlate well with PV electric generation. For regions where the correlation between PV output and peak load is poor, the distributed utility benefits were much smaller. Note that battery or other storage may significantly increase the T&D benefits, at additional cost.

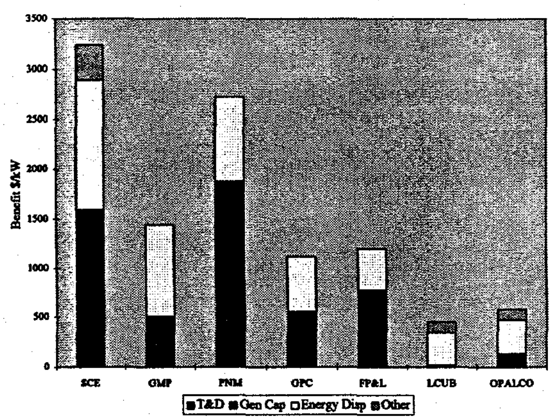

Fig. 6. Representative benefits for seven utilities

Deferred distribution facilities are more likely to be realized with PV systems located in the Southwest. Commercial loads, particularly office buildings, were found to correlate well with PV output. PV applications could utilize the large roof areas associated with these commercial loads for PV electric generation. Large T&D benefits also were obtained from mixed residential-commercial distribution system applications. In these mixed distribution systems, PV could be installed on residential roofs and still obtain large T&D benefits.

The value of voltage and var control power quality benefits were generally small because of the low-cost conventional methods that were currently used by the utilities. In fact, a small penalty occurs when line-commutated inverters are employed. Enhanced reliability of a distribution circuit may be a benefit in some very special cases. In our case studies, utilities did not give credit for a reliability enhancement benefit.

Additional capacity credit due to dispersing the PV throughout the distribution system varied significantly among the utilities. The highest values occurred for PV applications in the southwest U.S. (SCE and PNM).

The energy displacement value was a direct function of the solar insolation. Both capacity value and energy displacement value can be enhanced by the appropriate application of battery storage.

Other benefits include environmental externalities and Federal incentives resulting from the 1992 Energy Policy Act (EPACT) [9]. The consideration of externalities and set-asides in the economic assessment of new generation is mandated in some states by the PUCs. Environmental benefits were included in the economic analysis only when they were part of the utility's economic evaluation criteria for resource planning. EPACT PV production incentives benefits were applied to public utilities only, as the tax credits do not directly apply to private utilities.

CONCLUSIONS AND OBSERVATIONS

Some conclusions and observations resulting from these case studies are as follows;

- Site-specific T&D benefits can significantly increase the economic benefits of small, distributed PV connected to electric utility distribution systems, compared to large central station PV applications.
- PV output has excellent time-of-day correlation with SCE & PNM summer peak day commercial load shapes. Battery storage is not expected to be needed to obtain large T&D benefits.
- PV output has poor correlation with GPC and FP&L summer peak day load shapes, as peak days are likely to occur on cloudy days as well as sunny days. Battery storage is sure to be needed to back up the PV to attain large T&D benefits.
- PV output has poor correlation with GMP, LCUB, and OPALCO winter peak day load shapes. Battery storage is sure to be needed to back up the PV to attain large T&D benefits.

ACKNOWLEDGMENTS

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