# A Performance Evaluation Study of Photovoltaic Systems Installed through the Long Island Power Authority's Clean Energy Initiative Solar Pioneer Program

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## Abstract

Solar photovoltaics (PV) technology holds significant promise, including environmental benefits, modularity, ease of siting, and high coincidence with the electric utility's system peak, fueling a rapid growth rate in the industry. The Long Island Power Authority (LIPA) in New York has paid rebates totaling more than $25 million for over 1,000 grid-connected PV installations through their Clean Energy Initiative Solar Pioneer Program. Because of this level of commitment, it is important to verify that PV equipment is being designed and installed properly.

The performance of PV systems depends upon a number of factors, including: system design, or the appropriate matching of system components; quality of the installation, including proper wire sizing and connections; site conditions, such as solar access including shading; and the performance of major system components, such as PV panels and inverters. In order to verify equipment performance, LIPA decided to conduct a three-year study including both in-field site inspections and monitoring of system output. This paper summarizes the first six months of results from the study. As of June 30, thirty-five site inspections have been completed by Steven Winter Associates (SWA), the contractor selected for this study. Monitoring equipment is scheduled to be installed this fall, after the first year's site inspections are completed.

Because this study is ongoing, the results summarized in this paper are preliminary and are still being assessed. Further analyses will be presented at the conference in August.

## Introduction

The performance of photovoltaic (PV) systems depends upon a number of factors. These factors include: system design, or the appropriate matching of system components; quality of the installation, including proper wire sizing and connections; site conditions, such as solar access including shading; and performance of major system components such as PV panels and inverters. How does the expected output of PV systems compare with the actual output of rebated systems once they are installed? Does the performance persist over time? Are customer and planning expectations of performance consistent with in-field experience?

PV technology holds significant promise, including environmental benefits, modularity and ease of siting, and high coincidence with the electric utility's system peak. Establishing a strong track record and identifying problems early is important. The PV industry is relatively young, and experiencing a very rapid growth rate averaging 25% to 40% annual compound growth over the last decade. Because of this explosive growth, there are many new market entrants on both the manufacturing and installation sides of the industry. In-field performance evaluation is important to help gauge how well the industry and its training and certification programs (such as the North American Board of Certified Energy Practitioners, or NABCEP) are handling this growth.

The approach taken by LIPA in this study to address these issues is to review the system design and its appropriateness for that location, inspect the quality of the installation, and verify that the PV system performs as designed. With over 1,000 installations rebated to date, there are PV systems from sixteen different manufacturers installed by more than fifty contractors included in the study population. A stratified sampling strategy has been developed to study time series and cross-sectional variables, such as installation date, location, system size, installation contractor, and panel manufacturer. This study expands upon and contributes to the literature documenting monitored PV system output and performance. Previous studies, referenced during the development of the current research plan include Hester, 2001, Schuermann et al. 2003, and Thorne & Booth, 2001.

Site visits to a sample of the homes and businesses that have installed PV systems through the Long Island Power Authority's (LIPA's) Solar Pioneer Program on Long Island in New York were performed. The annual shading on the solar panels was calculated, the data acquisition system (if present) was also reviewed for a record of operation and faults, and the output of the PV system was measured at the time of the site visit. Long-term monitoring of the PV system output for a subset of visited installations will also be conducted as part of this study.

The effectiveness of solar PV programs depends upon verifying that installed equipment is performing as expected. In addition, favorable customer perception of this technology is essential to its widespread adoption in the marketplace. Program evaluators and managers will benefit from being able to modify the program's implementation to address any concerns that are identified in this study.

Steven Winter Associates, Inc. (SWA) was chosen through a competitive bid process to conduct this study on behalf of LIPA. Although this three-year study will address all of the above-mentioned issues and questions over time, this paper is focused on the first six months of the study and includes: background on the Solar Pioneer Program; a summary of the study's objectives; a discussion of the research methodology, including the sampling plan, site visit protocols, data analysis, & monitoring plan; results from ten site visits completed during the pilot phase of the study; and preliminary results of the first site visits completed after the pilot-phase. All or most of the additional sixty (60) site visits will be completed by the end of July, so results from these visits will be available for presentation at the conference in August.

## Background on the Solar Pioneer Program

Introduced in 1999 as part of LIPA's Clean Energy Initiative, the Solar Pioneer Program promotes the installation of solar photovoltaic (PV) systems as an environmentally clean and viable alternative to electricity generated from fossil fuels. LIPA has committed to transforming the market for PV on Long Island by: increasing consumer awareness and market demand for PV systems; accelerating the development of a vibrant, self-sustaining local infrastructure for the delivery and maintenance of quality PV systems; reducing institutional barriers to streamlined system installations; and developing mechanisms to overcome financial barriers to purchasing PV systems. Although the original focus of the Solar Pioneer Program was on the residential market, in 2001 rebates were also paid to commercial customers.

LIPA has employed many efforts designed to raise public awareness of PV and the Solar Pioneer Program: two PV lotteries which installed 72 free systems on Long Island homes; Solar Pioneer Seminars with information on both PV and LIPA's programs, conducted at sites throughout Long Island; and media advertisements, bill stuffers, participation in the National Solar tour, and trade shows. LIPA also hosts an extensive web site (www.lipower.org/solar) which offers information on: building a PV system; available PV incentive dollars; monitoring a customer's PV system output; building department regulations, forms, and applications; a link to a list of PV contractors; frequently asked questions; and other links/resources. In addition, LIPA's Research & Development Department has supported the world's largest (1.01 MW) PV system on the Fala Direct Marketing buildings in Farmingdale, New York.

Solar Pioneer Program staff work closely with the Solar Energy Center at the State University of New York (SUNY) in Farmingdale, from training local contractors in the proper installation of PV systems to training of electrical inspectors, with LIPA co-funding many of these training sessions. LIPA maintains relationships with these installers, hosts a quarterly meeting for contractors and all interested parties, and has a link to a list of contractors on its web site. A total of twenty-four (24) PV Contractor Allies were listed as of June 2007. Contractor Allies are encouraged to network with homeowners and businesses at Solar Pioneer Seminars. Solar Pioneer Program staff also work with the Department of Energy (DOE) on their "Million Solar Roofs" initiative, work with local building departments, attend New York Solar Energy Industry Association (NYSEIA) meetings, and participate with Renewable Energy Long Island (RELI) - a local renewable energy advocacy group.

LIPA participates in a state-wide effort to standardize and continuously improve interconnection protocols. In fact, New York State has adopted IEEE 929 for use in ensuring safety and reliability in connecting PV systems to the electric grid. Recently, LIPA revised its requirements for isolation transformers, meaning that fewer systems will be required to have them installed.

LIPA offers its customers rebates to reduce the cost of installing a PV system. Solar Pioneer Program incentive levels have varied over time. Rebates were set at \$3.00/DC-watt in 1999 when the program began and were doubled to \$6.00/DC-watt for a six-month period in 2002. Then LIPA decided to begin a controlled, predictable reduction in rebate levels. After the \$6.00/watt promotion, rebate levels were set at \$5.00/DC-watt until a 1 MW allotment was filled. The rebate level was then reduced to \$4.50/DC-watt to fill the next allotment of 1 MW, \$4.00/DC-watt to fill the next 1 MW allotment, and is now at \$3.75 for a 3 MW allotment. Customers and contractors have the ability to check LIPA's web site to see if a rebate level is still available, and if so how close it is to being filled.

In addition to the rebate from LIPA, homeowners can take advantage of the following: excess electricity generated by PV systems receives credits through net metering; a Federal tax credit of up to 30%, capped at \$2,000; a New York State tax credit of 25%, up to a maximum of \$5000; and a New York State fifteen-year real property tax exemption. Commercial customers can claim a federal investment tax credit for solar energy property of up to 30% of the investment purchase and installation amount; and they can also take advantage of five years of accelerated tax depreciation on solar energy equipment. Not-for-profit, school, and government customers are not eligible for all of the tax incentives offered to residential and commercial customers, so LIPA offers these customers an additional \$1.00/DC watt, added onto the current rebate level in effect at the time of the installation pre-approval.

The number of PV systems installed on Long Island is summarized in Table 1. Incentives paid from program inception through June 30, 2007, total over \$25 million for the 1007 rebated systems installed.

**Table 1.** PV Systems Installed through the Solar Pioneer Program

| Year | Number of Systems | Total DC Watts |
|---|---|---|
| 2000 | 2 | 2,400 |
| 2001 | 13 | 33,240 |
| 2002 | 184 | 829,263 |
| 2003 | 142 | 751,562 |
| 2004 | 132 | 767,134 |
| 2005 | 128 | 826,752 |
| 2006 | 242 | 1,597,390 |
| 2007 (through June 30) | 164 | 1,028,846 |
| Subtotal for Rebated Systems | 1007 | 5,836,587 |
| 1999 Lottery | 31 | 19,142 |
| 2002 Lottery | 41 | 25,318 |
| Subtotal for Lottery Systems | 72 | 44,060 |
| **Total** | **1,079** | **5,880,647** |

## Study Objectives

The principal objectives of this equipment performance evaluation study are to:

1. Review the system design and its appropriateness for that home or location, inspect the quality of the system installation, and verify that the PV system performs as designed. This review includes items such as:
   - Estimating the annual shading on the solar panels
   - Reviewing data acquisition system, if installed, for record of operation and faults
   - Measuring the output of the PV system at the time of the site visit – i.e., spot check the output based on the installation and conditions present during the visit
   - Reviewing the orientation and tilt angle of the inspected installations
   - Developing a profile of the inverter types at the inspected sites, including parameters such as:
     - Number of inverters and the location of each inverter
     - Inverter manufacturer and model type (in DC watts)
     - Inverter nameplate data or cut sheet
     - Inverter warranties and age of the inverter
     - Power consumption: internal during operation/internal during standby
     - Efficiency of the inverter at the time of the site visit

   Seventy (70) site visits will be conducted in the first year of the study, and in years two and three, fifty (50) site visits will be conducted each year.
2. Define a performance index, or indices, that will be used to compare expected to actual system performance, based upon information from the site inspections, program database, PV estimation software, weather data, and output measurements as available.
3. Implement a methodology for benchmarking the inspection results by reviewing published literature on similar studies.
4. Develop a site visit checklist/protocol to be used in the future to perform routine quality control and performance monitoring inspections of PV systems.

5. Monitor the output of a sample of PV installations, considering issues such as how to balance the sample between older and more recent installations, which sample stratification variables to use, what the length of the monitoring period should be, and the type of equipment to use. Monitoring equipment will be installed at thirty-five (35) sites in the first year of the study, and in each of years two and three, monitoring equipment will be installed at twenty-five (25) sites.

## Research Methodology

### Sampling Plan

A preliminary sampling plan was developed in November of 2006, and ten pilot-phase site visits were completed from this list. The preliminary plan chose a sample based upon the distribution of sites in the population for the following parameters: PV module manufacturer, inverter manufacturer, geographic location, electric rate (to distinguish residential systems from non-residential), and installation date. At the time the preliminary plan was developed, installer information was not included in the data extract given to Steven Winter Associates (SWA) so was not part of the plan. After this information was received, SWA made sure that the sample selected did have good representation of installers. This sampling plan was used for the pilot-phase site visits, but it was decided to perform an additional analysis in the spring of 2007 to finalize the sampling plan for the summer. Installer information and installations rebated through the end of 2006 were then included in the new sampling plan.

The new sampling strategy focuses on the installation date as one of the main criteria, with site visits concentrated in later years to provide more useful feedback to the program moving forward. The distribution of the site visits by installation date is: five systems installed before 2002, five systems installed in 2002, five systems installed in 2003, fifteen systems installed in 2004, fifteen systems installed in 2005, and twenty-five systems installed in 2006. The reason for over-sampling recent installations is that these cases are expected to be more representative of current installations, and therefore should provide more useful information for improving the program. The ten pilot-phase inspections were mapped into the sampling plan, and an additional sixty sites, with alternates, were chosen.

In addition to the installation date, the following parameters were also used to select the sample: module manufacturer (Sharp, BP Solar, GE/Astropower, Kyocera, and Other), inverter manufacturer (SMA, Trace/Xantrex, Fronius, Sharp, and Other), and installer (each of four installers that have installed more than 5% of the systems on Long Island and Other). Minimum numbers were selected from each of the groups in each year. After an initial sample was selected following all of these criteria, the distribution of the locations of the selected sites across Long Island was reviewed to ensure good geographic distribution. The same was done for the residential/non-residential distribution.

The selected sample sites and alternates were first sent a letter explaining the study and asking for their cooperation. SWA followed up with phone calls to set up appointments for the site visits.

## Site Visit Protocol

During the inspection at each site, SWA documented the following:

- Equipment: make, model, and number of PV modules in each array; make, model, and number of inverters and which array(s) they serve; disconnect means and locations; and size of conductors and over-current protection,
- Installation: PV location and installation method; azimuth of array(s); sun-path diagram; and approximate length of DC and AC wire runs, and
- Results of short-term monitoring: DC current, DC voltage, DC power, total DC energy, AC power, total AC energy, insolation (W/m$^2$), radiant energy incident upon array, module temperatures, ambient air temperature, and sky & wind conditions during the test.

The inspection procedure included:

1. Introductions and interviews with customer
2. Collector documentation
3. Orientation and shading analysis
4. Balance of system documentation
5. Record system monitoring information, if any already exists at the site
6. Preliminary operation check
7. System reactivation
8. Short-term monitoring instrumentation installation
9. Record open circuit voltage
10. Collection of short-term data
11. Data checking
12. Identify problems
13. Remove instrumentation
14. Inspect for long-term monitoring feasibility
15. Provide customer with SWA and LIPA contact information
16. Take digital photographs of the site, system, and sky conditions as applicable

## Data Analysis

During short-term monitoring, inspectors installed the following instruments:

- Pyranometers to measure irradiance incident upon each array (Watts/m$^2$)
- Thermistors to measure module temperatures of each array (°C)
- A thermistor to measure ambient air temperature (°C)
- DC current transducers on up to four DC strings (Amperes)
- DC voltage transducers on up to four DC strings (Volts)
- AC energy transducers on up to four inverter outputs (Watt-hours)

At each site, readings from these sensors were recorded for a 20-30 minute period. With the data collected, inspectors calculated the following key values:

- Total solar energy incident upon the arrays (Watt-hours)
- Total DC energy generated (Watt-hours)

- "Ideal" DC energy adjusted for measured irradiance and module temperatures (Watt-hours)
- DC De-rate Factor (%)
- Total AC energy generated (Watt-hours)
- Inverter efficiency (%)
- Total De-rate Factor (%)
- Sun to AC efficiency (%)
- Fraction of ideal insolation (%)
- Predicted annual PV generation (kWh)
- Normalized annual PV generation ($kWh_{AC}/kW_{DC}$)

To calculate "Ideal" DC energy, the total rated DC power of an array at standard test conditions (1000 $W/m^2$ and module temperatures of 25°C) is adjusted for actual insolation and temperature. To adjust for insolation, rated PV power is multiplied by the measured insolation ($W/m^2$) divided by the reference of 1000 $W/m^2$. To adjust for module temperature, rated array power is reduced by 0.5% per degree Celsius above 25°C (or increased 0.5% per degree Celsius below 25°C).

Because of factors such as dirt on modules, wiring losses, module mismatch, etc., the measured DC energy is less than the adjusted "ideal" DC energy. The DC De-rate Factor, expressed as a percent, is the ratio of measured DC energy to adjusted "ideal" DC energy.

Inverter efficiency is simply calculated as the ratio of AC energy generated divided by DC energy generated during the monitoring period. The Total De-rate Factor is the product of the DC De-rate Factor and Inverter efficiency. The Total De-rate Factor is entered into PVWatts software to predict overall system performance. "Sun to AC efficiency" is calculated by dividing AC energy generated by total solar energy incident upon arrays.

Sun path diagram results are evaluated using Solar Pathfinder Assistant software to determine the fraction of ideal insolation incident upon collectors (ideal insolation is defined here as irradiance upon collectors facing due south, tilted at latitude, with no shading whatsoever). Using the shading results and Total De-rate Factor calculated from short-term monitoring tests, Solar Pathfinder Assistant software uses PVWatts algorithms to calculate annual PV system generation (kWh). The annual generation is normalized by dividing the value by the total installed DC rated capacity (kW) to allow for better comparisons of system performance.

## Monitoring Plan

Several strategic issues were considered in developing the monitoring plan:

- <u>What is the correct balance between more recent installations and earlier installations</u>? To assess the cumulative impacts of the program, it would be desirable to begin by characterizing the performance of the overall population of projects installed since the beginning of the program, and then move to an ongoing verification approach. However, there may be sampling economies in moving immediately toward a focus on recent installations. In addition, focusing on recent installations may yield more prospective improvements in installation practices and in predicting system performance. Finally, it is possible that newer PV systems may have features that make them easier and less expensive to monitor than those installed earlier in the program's life cycle.

- While there is an interest in assessing the cumulative impacts of the program, and while sites from all years will be visited, the study team decided that a focus on (or oversample of ) more recent installations would yield results more useful to the program moving forward. The experience level of the installers has increased since the beginning of the program, so that recent installations are more likely to inform us about the quality of installations in the near future. Also, focusing on more recent installations means that the PV modules and inverters inspected will be newer models that are more likely to be installed again in the near future.

- What sample stratification (other than installation date) should be used? Some types of installations may have features that make them easier to monitor than others. Targeting these types of installations could improve the cost effectiveness of this project, but at the expense of decreasing how well the sample represents the population.
  - The monitoring plan will follow the sampling plan developed for the site inspections as closely as possible, given that thirty-five (35) of the seventy (70) sites inspected will be monitored. The PV system owner may or may not agree to allow their system to be monitored, and the system itself may or may not be a good candidate for monitoring. Therefore, there may be little choice in which systems are actually monitored. In spite of that, the study team expects the thirty-five sites to represent the overall population reasonably well, although not as well as the seventy inspected sites. Having monitored data for thirty-five sites will still be very useful.
- Length of monitoring period: What affect does the length of time over which monitoring is performed have on the reliability with which system performance can be estimated? How are monitoring costs affected by the length of the monitoring period?
  - In general, the longer a system is monitored, the greater the reliability of the results in predicting its performance in the future. On the other hand, short-term monitoring for a six-week period can provide a good indication of any obvious problems in system performance. All of the systems installed as part of this study will be monitored for five years because the cost of doing so was included in the proposal for this study, at a total project cost similar to other proposals received.
- Specialized versus generalized monitoring equipment: Are any economies possible due to the recent development of hardware and software intended specifically for the purpose of assessing the performance of PV systems?
  - Fat Spaniel Technologies' PV2Web system will be used to monitor the output of the thirty-five selected PV systems and provide the study team and the system owner with easy access to the data.

During each site visit, SWA will inspect the site for feasibility as a long-term monitoring candidate, checking for items such as: availability of "always on" high speed Internet access, an Ethernet hub with room for an additional connection, the work that would be required to run network cable to the monitoring equipment, space in the main panel for clamp-on current transformers, space to install voltage-sensing breakers, and space near the main panel for mounting the monitoring equipment. Because of these items, a separate sample will not be selected ahead of time for monitoring – the site visit results will instead be used to select the sites that will be monitored. If more than thirty-five of the seventy sites are good candidates for monitoring, then the thirty-five that best match the distribution of the seventy will be selected.

## Pilot-Phase Results

Ten pilot-phase site inspections were completed in 2007 for this project – seven in January and three in March. A number of useful observations were made during these visits:

- Larger systems with more than two inverters couldn't always be tested with the equipment used for the January visits, so additional equipment was ordered and tested during the March visits. The new equipment configuration worked well.
- It was difficult to inspect more than one site per day in January and March due to the short daylight hours.
- Significant shading of some systems in the late afternoon compromised test results.
- It was often difficult to measure DC power. There were multiple reasons for this, including lack of a DC disconnect to accessible wiring, space constraints for DC current sensors in inverters or disconnects, the need for more than two DC current measurement channels, and current outside of sensor ranges. All except the first of these factors have been corrected for the rest of the inspections through the purchase of additional equipment. Lack of a DC disconnect switch will continue to prove problematic as SWA will not work with live wires nor disconnect PV wiring while under load for safety reasons.
- Differences between the system information contained in the rebate processing database and the system information collected during the site inspection were found for several systems. The discrepancies covered a range of items, such as different module manufacturer, different module size, different inverter, different orientation, different tilt angle, and others. LIPA will assess these differences and follow up with the installing contractors to find out why these changes were made.

## Preliminary Results

Including the ten pilot-phase visits, thirty-four site visits have been completed as of June 30, 2007. There continue to be discrepancies between the information contained in the rebate processing database and the system information collected during the site visit. LIPA will study this issue in more detail, assess how these differences affect the expected system output, and follow up with installing contractors. While the results do require further analysis, some of the differences are:

- Six of the thirty-four sites have an installed capacity less than that listed in the program tracking database. Only one site has a difference greater than 5%, and even with this site included, the overall difference averages less than 2%. This finding is especially important because the rebate is paid based upon installed capacity.
- Eight of the thirty-four sites have an installed orientation that is different than that listed in the database – for three sites this difference would result in greater annual energy than estimated, and for five this difference would result in less annual energy.
- Seven of the thirty-four sites have a measured tilt angle different by greater than 10 degrees to the tilt angle listed in the program database.
- Only two of the thirty-four systems show a different module manufacturer than expected.
- Five of the thirty-four systems have a different inverter manufacturer than expected.

In a few cases, the site had panels installed on different roofs, potentially at different orientations and tilt angles, while the database only had the ability to include one orientation and tilt angle. Because the energy and demand that are entered into the program tracking database are calculated off-line using the Clean Power Estimator, it remains to be seen whether or not this database limitation affected the estimated annual energy and demand calculations.

## Conclusions

Utilities, regulatory agencies, and public power authorities are required to use rate payer and/or tax payer funds prudently. As such, verification of proper design, installation, and operation of PV systems is essential to continued funding for solar PV programs. Verification is also important for industry development, it is needed to design the most effective programs, and it can be used to inform the current debate about whether to use performance-based incentives ($/kWh produced) rather than capacity-based incentives ($/kW installed).

LIPA will be able to use the results of this ongoing study to directly inform program design and program policy, to work with the program's Contractor Allies to implement improvements, to more accurately track program savings, and to deliver an improved program to its customers.

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