Grid-Connected Photovoltaic System Parity with PJM Generation

J. Roche, P.M. Jansson, S. Turner, J.L. Schmalzel, U.K.W.Schwabe

Center for Sustainable Design – South Jersey Technology Park

Rowan University

ABSTRACT

This research provides compelling economic and technical analysis of photovoltaic (PV) system performance in New Jersey and contrasts the generation availability marginal pricing on the world's largest regional transmission organization (PJM). This analysis indicates that PV generation concurrence with high PJM system locational marginal prices (LMP) reveals values approaching the commensurate life cycle costs of PV without local subsidies. The study provides analysis from three years 2008, 2009 and 2010 showing LMP market values for PV generation located at the South Jersey Technology Park ranging from 15-20 cents per kWh. It is LMP pricing that determines the value of all generation operating at that given hour on PJM. This data indicates that life cycle cost PV generation is of similar magnitudes during the summer periods and with recent reductions in module pricing and commensurate installed PV system cost, these values will reach parity on an annual basis in the near term.

Keywords: locational marginal pricing, LMP, PV life cycle cost

1 INTRODUCTION

How close are photovoltaic installations to achieving the goal of grid parity? As electrical rates continue to rise and installation costs for renewable energies decrease, grid parity for photovoltaic (PV) systems should be achieved in many areas of the U.S. in the near future. But for New Jersey, has grid parity already occurred?

An upward trend in the cost of electricity has been observed for New Jersey, occurring mainly over the last eight years (Figure 1) [1]. This rise in electrical rates has helped economic assessments of solar installations, by providing results that are more feasible than previous years. Additionally, an aggressive renewable portfolio standard (RPS) has been adopted by the state, which assures a strong growth in wind and solar energies. With the support of the RPS and a continued rise in electrical rates, the percentage of renewable energy will continue to grow in New Jersey, as PV systems approach grid parity.

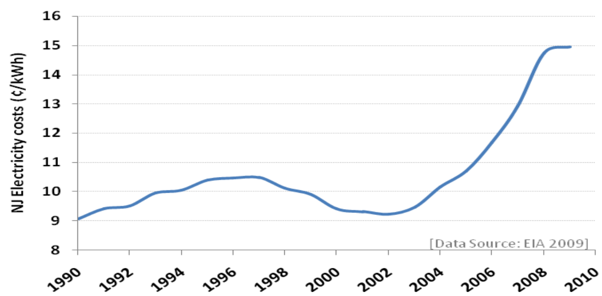

Figure 1 – Annual NJ Electricity Costs

Renewable energy (specifically PV) in New Jersey has been supported over the last decade by rebates, tax credits and the generation of Solar Renewable Energy Certificates (SRECs) [2]. These credits and SRECs can be included in the life cycle cost analysis of PV systems. Their inclusion ultimately allowed previous PV systems to compete with or even exceed local electrical rates.

Concurrently, PV systems have become less expensive, as residential systems that were installed at $7/W to $9/W a few years ago, have now begun to approach installed costs near $5/W. In this paper, we will examine the life cycle costs for a $5.50/W residential system, $4.40/W commercial-sized system (100 – 400 kW), and $3.90/W large-scale PV system, and compare these values to the prevailing utility rates (enhanced by LMP of generation) [3,4]. These life cycle costs are needed to truly compare the costs of PV systems to the electrical rate. Inconsistencies can arise when comparing this cost to utility’s rates, as many variables play into the determination of the life cycle cost of a PV system. Comparing this PV life cycle cost to the local delivered electricity price allows one to estimate when grid parity can be reached. This paper compares PV life cycle costs to the local delivered electricity rate (including LMP) on the PJM Interconnection (PJM) grid.

The research analyzes pricing for the local utilities, Atlantic City Electric Company (AECO) and Public Service Electric and Gas Company (PSE&G).

PV systems coincidentally generate the bulk of their electricity during times of high demand on the electric grid, which typically occurs during the high solar intensity of summer afternoons. Therefore, the PV system's generation value should be compared not to the average annual electrical rate, but rather the actual costs during PV generation times. To accomplish this, the LMP is analyzed for the time periods PV systems are generating electricity.

2 LOCATIONAL MARGINAL PRICING

LMP data for the PJM grid provides the hourly variation of electricity generation costs for a multitude of customers. Two variations of the LMP are available from PJM: day-ahead LMP and real-time LMP. Hourly data for both LMP conditions are available back to 1998 [5]. The real-time LMP data was used in this research.

The LMP is set by the most expensive generator required to meet demand during any hour. PJM organizes and dispatches generators to provide electricity, starting with the cheapest suppliers, to ensure demand is met. Throughout much of the year, the main electricity generating sources of nuclear, natural gas and coal supply the majority of the electricity needed to meet New Jersey's demand. Many of these generators are large in size and require long lead times to ramp up or ramp down their electricity generation. Therefore, these sources typically run near their optimum efficiency. When demand is at its peak, utilities may need to bring on all the generation they can supply. The generators available to meet this summer daily peak demand are typically agile but expensive generators, or low efficiency older plants. These sources can use expensive fuels, such as No. 2 fuel oil, causing them to be expensive to operate and therefore requiring a premium electrical generation price. Since the LMP is set by generation cost of the last generator needed to meet the required demand, the costs are typically highest during hot summer days.

3 GRID PARITY

Grid parity is the goal of modern PV systems. It is said to occur when the cost of PV generation becomes equal to the cost of retail electricity. In our case, grid parity is achieved when the adjusted LMP cost (LMP cost plus transmission, distribution, delivery and miscellaneous costs) equals the cost to generate PV electricity, during times of PV generation throughout the year.

When grid parity is met, the demand for PV systems will increase as consumers look towards forms of green energy, thereby reducing their carbon footprint. In fact, PV system's life cycle cost will eventually be lower than electrical grid prices. One factor driving down PV life cycle costs is continuous improvements in PV module manufacturing techniques. As further research and development continues to improve materials and methods of PV manufacturing, capital investment required for installations will decrease, making grid parity a reality for many areas of the U.S.

PV systems create all of their energy during daylight hours. Therefore, the value of solar energy should be the average cost of electricity during times of PV generation, not the cost for the entire day. With annual peak demands typically occurring during the afternoon hours in summer, the actual cost of electricity when solar energy is generated will be higher than the average cost for the entire 24-hour day. To determine this value of electricity during PV generation, a weighted average approach is taken (Equations 1 & 2) [3]. The PV generated energy used in these equations was acquired from a 1 kW thin-film amorphous PV system and a 12.96 kW monocrystalline PV system mounted on the roof of Rowan University's South Jersey Technology Park.

$$CE(i) = E_{PV}(i) \times LMP_{UTIL}(i) \tag{1}$$

where E_{PV} is the PV generated energy, LMP the marginal cost of the utility UTIL, i is the hour in question and CE is the value of the energy generated at that hour.

$$\overline{CPV_{UTIL}} = \frac{\sum_{i=1}^{8760}[CE(i)]}{\sum E_{PV}} \tag{2}$$

where $\overline{CPV}$ is the energy cost during PV operation.

4 ANALYSIS

LMP data was analyzed for the years of 2008, 2009 and 2010. Hourly data for AECO reveals a three-year average LMP cost of 6.95 ¢/kWh during the summer months of June, July and August (Table 1). Calculation of the CPV for the three-year period results in an average cost of 9.71 ¢/kWh for the summer months (Table 2), a premium of 2.77 ¢/kWh over the average daily LMP cost. The averages between years vary widely, likely due to annual variations in weather conditions and the recent economic slowdown. This is seen in the extreme variation of nearly 11 ¢/kWh between 2008's and 2009's summer CPV. The much higher costs for 2008 were due to a very high energy demand year, likely resulting from hot and dry weather conditions and the fact that the economic downturn had not fully engaged yet. The low costs for 2009 were caused by low demand, likely due to consistent cool and wet weather conditions and the economic downturn. The costs for 2010 were viewed as returning towards normal. Therefore, the average of this data is used for comparison purposes, as it will portray a realistic normal energy demand on an annual basis.

Table 1 – AECO Average LMP Costs

AECO LMP (¢/kWh)	June	July	August	Summer Average LMP	Annual Average LMP
2008	11.98	12.54	8.10	10.87	8.07
2009	3.35	3.45	3.87	3.56	4.07
2010	5.48	7.91	5.83	6.41	5.07
3-year Average				6.95	5.73

Table 2 – AECO Average CPV Costs

AECO CPV (¢/kWh)	June	July	August	Summer Average CPV	Annual Average CPV
2008	17.83	18.33	10.40	15.52	11.02
2009	4.16	4.23	5.21	4.53	4.43
2010	7.28	11.80	8.17	9.08	6.20
3-year Average				9.71	7.22

These LMP and CPV averages were determined from the monthly average electricity LMP prices on the AECO grid. To allow a comparison to PV life cycle costs, the transmission, distribution, delivery and miscellaneous (tdd&m) costs need to be added to these costs. The LMP or CPV costs with the added tdd&m costs will be referred to as the adjusted LMP or CPV price. Reviewing residential electrical bills from AECO, the costs for all line items other than the basic generation service (BGS) is approximately 6 ¢/kWh. This value will be the residential tdd&m costs. During 2010, the actual electrical rate was 16.5 ¢/kWh during the winter season, and 20 ¢/kWh during the summer months of June, July, August and September. Upon adding the tdd&m costs to the AECO summer average LMP, the average cost of electricity is approximately 13 ¢/kWh. This cost is only 65% of the actual AECO billed rate. Due to this adjusted LMP cost being 7 ¢/kWh lower than the actual retail cost, this method was not considered valid.

To acquire a realistic total residential electricity cost using the LMP data, the BGS rate was compared to the average LMP for AECO for all months of 2010. The average LMP was subtracted from the known BGS rate, based on winter and summer seasons. This result was then added to the CPV average value for each season, and next the tdd&m costs were added. This resulted in a winter season adjusted CPV of 16.6 ¢/kWh and a summer adjusted CPV of 22.4 ¢/kWh, giving an annual average CPV of 18.5 ¢/kWh. These results will be compared to life cycle costs for residential PV systems, to verify if grid parity has been achieved.

To acquire electrical rates for an industrial facility, data from Rowan University's Heating Plant was used. The same method to calculate the adjusted CPV as in the residential example was employed, but with limited data. Only data from the months of November and December of 2010 were available. The adjusted CPV for the winter months was calculated to be 16.1 ¢/kWh, which will be used as the estimated annual adjusted CPV cost for large-scale PV installation comparison purposes.

The adjusted CPV for commercial electrical rates was determined in the same manner, but used the average LMP for the PJM grid for the months of January to May 2009. The tdd&m costs for this utility were assumed to be the average of the tdd&m costs for residential and industrial. The adjusted CPV for winter months was determined to be 15.9 ¢/kWh. This number is slightly lower than the industrial rate, which is likely due to this data being from 2009. This will be used as the annual adjusted CPV cost for commercial installations and should be a conservative estimate, as recent rises in electrical rates have not been included in the commercial data.

5 GRID PARITY ESTIMATES

The costs of PV systems in New Jersey have been consistently dropping over the last few years. The average installed cost of a residential PV system is currently in the range of $5.50/W, a commercial-sized PV system is approximately $4.40/W, and a large-scale PV system is near $3.90/W. To compare these installed costs to the electricity rate, a life cycle study on the PV systems was performed.

Using the software program PVWatts [6], the total generation of a 1 kW PV system in Atlantic City, NJ was determined. Using a tilt angle 10° below latitude and an azimuth of 180°, the total power generated by this system annually would be 1,385 kWh. This power would be generated over the entire life of the PV system, which is assumed to be 25 years (per the standard manufacturer's warranty) [8]. The output of this PV array will not remain at 100% throughout its entire life, as the modules will exhibit some output degradation. This degradation rate is accounted for in the manufacturer's warranty, as modules are typically guaranteed to output > 90% of their rated output over the first 10 years, and then > 80% of their rated output for years 11 through 25 [8]. Using a PERT analysis of the predicted output with degradation versus a module exhibiting 100% output over its entire life, the lifetime total output of the module was determined to be 32,651 kWh. This total output is used in the calculation of a module's life cycle cost.

The cost to install a PV system should include taxes and interest. Many solar installations in New Jersey are tax exempt, so they will not be included. A home equity loan with an interest rate of 4.74% and a term of 5 years was standard at the time of this paper [8]. Dividing the interest adjusted installed costs by the total kWh generated, the PV system life cycle cost per kWh was determined (Table 3).

To entice consumers to install these expensive solar systems, tax credits and SRECs are available to help offset the large upfront costs. The inclusion of these credits and SRECs can be used to reduce the life cycle costs of a PV system. The current Federal tax credit for solar installations is 30%. A conservative SREC value of $500 will be used, with a length of SRECs limited to five years. The PV system life cycle costs with these incentives are shown (Table 3). To determine if grid parity has been reached, the PV life cycle costs are compared to the adjusted CPV (Table 4).

Table 3 – PV System Life Cycle Costs

PV System Size	Installed Cost	PV System Life Cycle Cost	Life Cycle cost with Tax Credit	Life Cycle Cost with SRECs and Tax Credit
Residential	$5.50/W	21.2 ¢/kWh	16.5 ¢/kWh	1.3 ¢/kWh
Commercial	$4.40/W	17.0 ¢/kWh	13.2 ¢/kWh	-1.3 ¢/kWh
Large	$3.90/W	15.1 ¢/kWh	11.7 ¢/kWh	-2.5 ¢/kWh

Table 4 – Grid Parity Analysis

PV System Size	PV System Life Cycle Cost	Summer Adjusted CPV Cost	Annual Adjusted CPV Cost
Residential	21.2 ¢/kWh	22.4 ¢/kWh	18.5 ¢/kWh
Commercial	17.0 ¢/kWh		15.9 ¢/kWh
Large	15.1 ¢/kWh		16.1 ¢/kWh

Examination of the data reveals that grid parity has been achieved for large-scaled system in New Jersey. Parity has not yet been achieved for residential or commercial installation types, but great strides have been made. When the Federal tax credits or SRECs are included in the analysis, grid parity has been achieved for all three installations. Large-scale PV installations are nearing grid parity in New Jersey without the inclusion of Federal tax credits or SRECs, as the life cycle cost is a mere 0.2 ¢/kWh away. For residential systems, grid parity during the summer months has been achieved. As the bulk of the electricity generated from a PV system occurs during the summer months, the summer CPV needs to be the basis for comparison and not the actual billed rate. As electricity prices continue to rise and manufacturing costs of PV modules decrease, grid parity will be achieved in New Jersey without the need of incentives.

ACKNOWLEDGEMENTS

The main authors would like to acknowledge the work of K. Whitten-Bellomo, P. Kostetsky and E. Smith for their many hours of data mining.

REFERENCES

[1] Energy Information Administration, "Annual Energy Outlook 2009, with Projection to 2030", http://www.eia.doe.gov/, March 2009

[2] P.M. Jansson and U. Schwabe, *"Photodiode sensor array design for photovoltaic system inter-row spacing optimization-calculating module performance during in-situ testing / simulated shading,"* IEEE Sensors Applications Symposium, Waikoloa, Hawaii, 1-4 November 2010

[3] U. Schwabe and P.M. Jansson, *"Utility-Interconnected Photovoltaic Systems Reaching Grid Parity in New Jersey,"* IEEE Power and Energy Society General Meeting, Minneapolis, Minnesota, 25-29 July 2010

[4] Ray Angelini, Inc., http://www.raiservices.com/

[5] PJM Interconnection, http://www.pjm.com/

[6] PV Watts, http://rredc.nrel.gov/solar/calculators/PVWATTS/version1/

[7] Sharp Electronics, http://www.sharpusa.com/SolarElectricity.aspx

[8] PNC Bank, https://www.pnc.com/