Comparison of Photovoltaic Modeling Analysis and Actual Performance Data of Lee County Justice Center Solar Power Installation Project

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This paper will discuss the installation of photovoltaic panels to Lee County's TK Davis Justice Center (LCJC) in Lee County, Alabama in the city of Opelika. This project consists of installing a 16.6 kW grid-connected solar-powered system that will be used to offset the energy costs of electricity used by the LCJC. The project monitors the performance of the system along with weather and environmental factors. Information gathered through the system's design, installation, and monitoring provides valuable information concerning photovoltaic alternative energy systems on public facilities. By using different mounting options and tilt angles the project is a learning tool and showcase for potential solar array installations at other facilities. This paper will take the data collected at the Lee County's T.K. Davis Justice Center 16.6 kW grid-connected solar-powered system and analyze it to find trends and anomalies. The analyses will include performance with insolation, especially early and late in the day, average overall operating efficiency and AC performance. Most importantly it compares the performance data to the results of photovoltaic modeling programs that were used before and during installation of the system. We wish to determine how accurate these modeling programs are and to determine the reasons behind variations between program results. We are also documenting the success story of Alabama's first State Government sponsored PV energy project. It serves as a model of how local governments can be a leading example of how to increase energy-efficiency, be environmentally friendly, and reduce operational costs over the long-term.

I. Introduction

IN the spring of 2009, Lee County's T.K. Davis Justice Center (LCJC) in Opelika, AL, installed a 16.6 kW grid-connected solar-powered system to help offset the energy costs of electricity used by the facility. This project seeks to establish the message that local governments need to take an active role in increasing energy-efficiency and being environmentally friendly while reducing operational costs for its citizens over the long-term. With this project's unique location, ease of replicability and expansion, this project has the potential to be the prototype for other similar undertakings across not only the state but also the country.

Auburn University's Space Research Institute (SRI) has monitored the performance of the system for the last year and makes the on-going results available to officials and the public. Information gathered through the system's design, installation, and performance monitoring provides valuable research information concerning practical photovoltaic alternative energy systems design and integration. The research value is enhanced by its additional asset as an excellent teaching and demonstration tool. The purpose of this program is to aid in photovoltaic system design by providing accurate and in-depth information on likely system power output and load consumption, necessary backup power during the operation of the system, and the financial impacts of installing the proposed system. This "first-step" 16.6 kW photovoltaic power system is vitally important to the overall scope of the

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alternative energy plan envisioned by the Lee County Commission. Furthermore, Auburn University's SRI will continue to support this expandable system located at the LCJC complex.

II. Component Selection

After careful consideration of all factors of the analysis: including shadowing analysis, module costs, fixed versus tracking arrays, angle of elevation, etc., the installation consists of a roof-mounted array using 64 SunPower 230W high efficiency modules in T-10 mounts angled at 13º for a total power of 14.7 kW (Fig. 1). The remainder of the array is pole-mounted and consists of 8 of the same modules (1.84 kW) mounted at a fixed, latitude angle (Fig. 2). The output of the roof array passes through a Solectria 13 kW grid-tied inverter delivering 480 VAC, 3-phase. This inverter has 94.5% overall efficiency. The pole mount array is connected to the building through a SunPower SPR3000m inverter (made by SMA) delivering 208 VAC with peak efficiency at 96% and a CEC weighted efficiency of 95%. Total power for the system is 16.6 kW. Inverter performance monitoring is through the use of an SMA Sunny WebBox and Solectria's SolrenView Web Monitor. The environmental monitoring utilizes SMA Sunny SensorBox with temperature sensors, irradiance monitoring cell, and an anemometer.

One of the interesting aspects of this installation is that it will deliver its power to a both a 480 VAC, 3 phase circuit and a 208 VAC circuit using two different inverters. The inverters selected have capability for easy integration into a web site that is being prepared for the system. This system has real-time reporting on electricity production and usage as well as other system and environmental reports. By using different mounting options and tilt angles, the project is both a learning tool and showcase for potential solar array installations at other facilities.

Figure 1: T-10 system on roof of LCJC

Figure 2: Pole mounted array at LCJC

III. System Modeling

To verify the power performance of the chosen arrays, an analysis was done using three modeling programs: PV Watts, PVSYST, and PV Design Pro-G. The power projections were consistent with that of the solar array installer

	Roof Array			Pole Array		
	PVSYST	**Design Pro G**	**PV Watts**	**PVSYST**	**Design Pro G**	**PV Watts**
Jan	1100	1203	1162	161	189	175
Feb	1156	1366	1288	163	201	182
Mar	1496	1805	1745	197	250	230
Apr	2132	2044	1982	265	263	243
May	2320	2160	1958	273	263	227
Jun	2264	2028	1887	261	240	213
Jul	2225	2063	1889	260	246	216
Aug	2245	2018	1797	273	252	216
Sep	1888	1817	1639	243	242	210
Oct	1803	1691	1615	252	245	224
Nov	1325	1290	1233	197	199	183
Dec	1220	1174	1082	188	190	165
Yearly Production	**21,174**	**20,659**	**19,277**	**2732**	**2777**	**2484**

Table 1: Modeled Performance Predictions for LCJC system using PVSYST, Design Pro G, and PV Watts

and are comparable to the experimental data gathered from the LCJC PV array. Each modeling program is different. Some use only the basic information such as location, tilt, and DC rating whereas others require detailed information such as daily load, specific module and inverter parameters, wiring specification, system costs, and shadowing effects. The estimated performance estimates from the models are shown in Table 1.

It is interesting to note that PV SYST predicts the highest power performance for the roof array whereas Design Pro G predicts the highest performance for the pole array. The discrepancy may be due to the way each program applies the angle tilt of the array thereby calculating solar irradiance to estimate the power production. In checking the reasons for these differences, we observed that the two programs used to determine the angle that results in maximum energy output for the entire year for a single axis tracking system do not agree (Fig. 3). The first, PV Design Pro G, developed by Maui Solar Software, predicts the optimal angle to be 50^o. This model uses algorithms developed by the Sandia National Laboratory. This model is used by many organizations. The second model, PV Watts, developed by DoE's National Renewable Energy Laboratory, predicts an optimal angle of 30^o. The third model, PV SYST, which is used by major companies around the world, agrees with PV Watts.

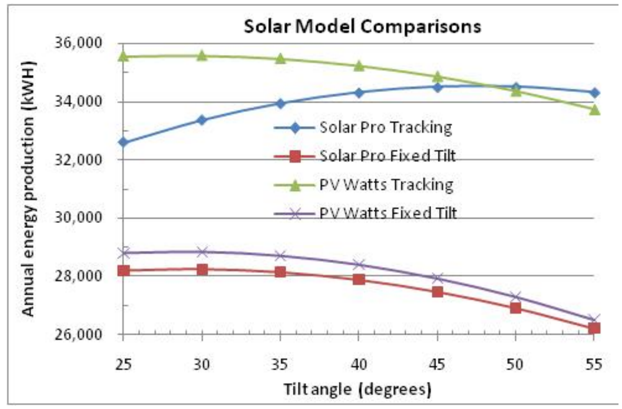

Figure 3: Solar Model Performance Comparisons

Therefore, in the spring of 2010, Auburn University designed and built a test structure that is providing a test of each of these models. We are using a 2-D Wattsun AZ-125 tracker with Sharp NT-175U1 panels. We use the tracker solely in the single axis, N-S tracking mode. Enphase Energy's single panel inverters are used to track panel performance. There are six test panels. Five panels are rotated in a single axis at the tilt angles of 20º, 25º, 32º (latitude), 40º, and 50º. Another panel is a control panel that is fixed facing south at latitude tilt. The system is operational and data is being recorded for at least one year. This research is shedding light on which of these models is correct, if either, and will be used to make further recommendations about the best angle to set a single axis tracker for optimal performance. The research also consists of in-depth study of both models to understand why these models differ. The first six months of data suggest that a panel with a 50 degree tilt is the optimal performer as suggested by PV Design Pro G. Please refer to the paper titled "Auburn University's Solar Photovoltaic Array Tilt Angle and Tracking Performance Experiment" for more detailed information.

IV. Data Collection and Analysis

Data analysis consists of efficiency with intensity, monthly and yearly performance comparisons of roof and pole arrays with PV modeling simulations, and the effect of weather, temperature, and different orientations on overall performance. In addition to providing the year-plus model-comparisons, we are looking at the impact of array temperature on output and are comparing it to a similar system in the high insolation area of the southwestern U.S.. Sensors have been installed to measure the solar irradiance, wind speed (for roof system), ambient temperature, and module temperature in addition to the primary power, voltage, and performance information. Data for the roof and pole system show that for one full year (from June 29, 2009 thru June 30, 2010) the total AC energy provided to the LCJC was 25,373 kWh. The offset CO_2 emissions are 18.2 metric tons or 40,163 lbs. That amount of CO_2 is equivalent to the amount produced by using 2,047 gallons of gasoline or 42.3 barrels of oil, the CO_2 emissions from 1.5 homes for a year, or the carbon sequestered by 467 seedlings grown for 10 years, or 3.9 acres of

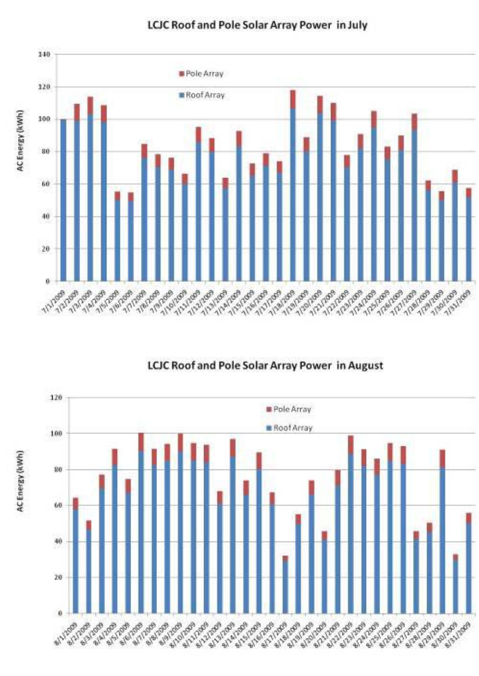

Figure 4: AC Energy produced by day in kWh for July and August

pine or fir forests. The AC energy produced by day in kWh for July and August are shown in Fig. 4. The week of July12-18th was studied in detail. It demonstrates all different types of weather patterns as shown in Fig. 5. Power profiles vary due to cloud cover and storm fronts.

The first year of power production surpasses model predictions: PVSYST – 104.8%, PV Watts – 115.1%, and PV Design Pro-G – 106.9%. The power produced vs. predictions can be seen in Fig. 6. The monthly comparisons can be seen in Fig. 7. The programs were quite accurate considering they use thirty years worth of weather data. The most detail oriented programs seem to map the performance better than the generic programs. The larger difference shown by PV Watts may be due to the choice of a 77% derate factor for the system.

Figure 8 shows the relationship of the power and solar irradiance for the roof and pole array. It is a linear relationship as expected. Roof scatter is due to the difference in how the data is acquired and averaged corrected for temperature. From this information the overall system efficiency of the panels including the inverters and wiring ohmic losses is ~18%.

Actual insolation data obtained by our sensors on the roof and pole arrays have been compared to the modeled insolation for both PV Watts and Design Pro G. Figure 9 shows the results for the pole system and figure 10 shows the results for the roof system. The two modeling programs use different insolation

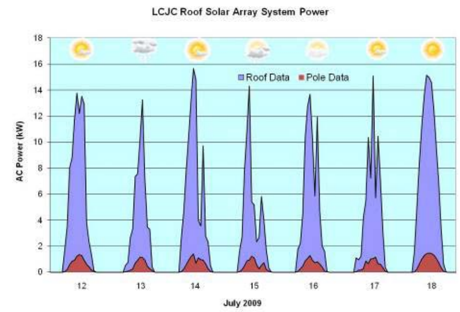

Figure 5: AC power produced compared to weather data from the same week

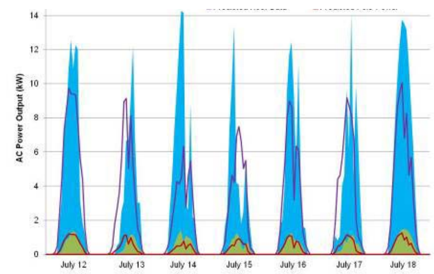

Figure 6: Power produced vs. power predicted

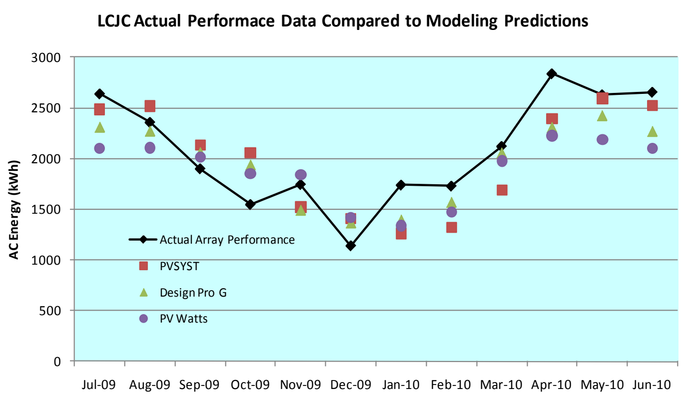

Figure 7: Performance Data Compared to Modeling Programs

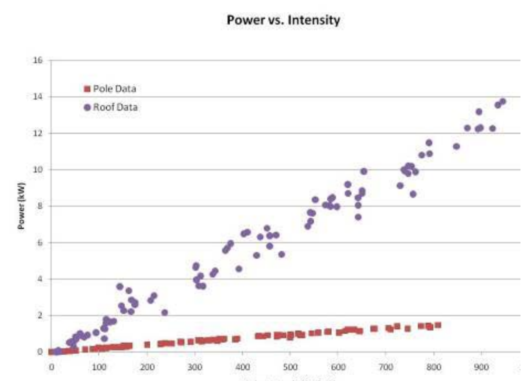

Figure 8: Solar array power vs. insolation

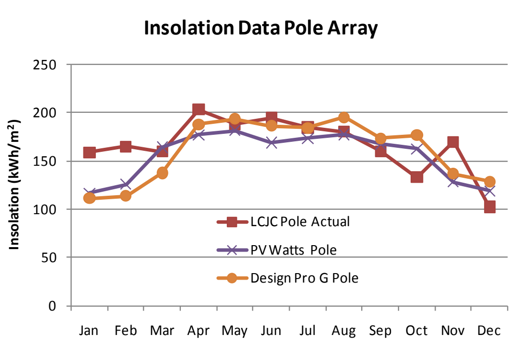

Figure 9: Insolation Data Pole Array

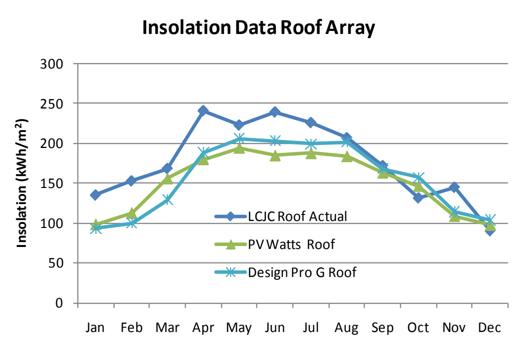

Figure 10: Insolation Data Roof Array

estimations. Also it is important to note the roof insolation is greater than expected. We are seeking to understand the cause of these differences. One possible reason could be that the roof array is tilted differently than expected. These graphs are just part of a first order analysis of the solar system. Data collection and analysis will be continued over the rest of this year.

As noted befor, although insolation is better in the southwest by approximately 20%, if you account for the array temperature differences between the southwestern and southeastern U.S. this advantage is diminished. Initial observations are shown in Fig. 11. This figure takes a full sun day from different months that have a large temperature differential. It is easy to see the power produced in colder temperatures is greater than in hotter temperatures as expected. The detailed analysis of these data and comparison to modeled results for the soutnwestern U.S. is still underway and is working to incorporate the solar irradiation factor that varies day to day and determine actual power performance over the whole year.

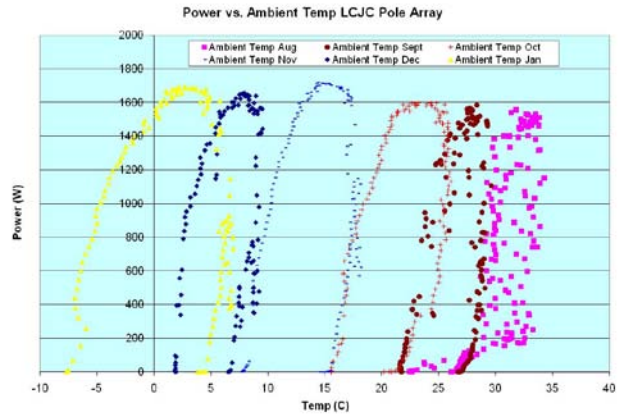

Figure 11: Power vs. Ambient Temperature for LCJC

The accompanying presentation to this paper will go in further depth. Additional information is also available on our website: ://sri.auburn.edu/leecounty.htm. This solar project is also featured at Lee County's official website: www.leeco.us/solar_project/index.html.

V. Conclusion

In review, this paper has used the data collected at the Lee County's T.K. Davis Justice Center 16.6 kW grid-connected solar-powered system and analyzed it to find trends and anomalies. Most importantly it compared the performance data to the results of photovoltaic modeling programs that were used before and during installation of the system and showed that the accuracy is quite good. Currently the system is producing about 5-7% more power for two detailed modeling programs and 15% more than the more basic modeling program. Variations between program results appear to be based on how detailed the program is and how many variables used to better represent the system.

The LCJC is Alabama's first State Government sponsored PV energy project and it has been very successful. The Lee County Commission is hoping to expand upon the system. This installation is serving as a model of how local governments can demonstrate leadership as well as increasing energy-efficiency, being more environmentally friendly, and reducing operational costs over the long-term. With this project's unique location, its ease of replication and expansion, this project has the potential to be a prototype for other similar undertakings across not only the state but also the country. It allows wide access to agencies, businesses, and individuals to inspire them as well as providing an excellent teaching and demonstration tool for all sectors. This initial system is the backbone of an expandable system at this complex and currently the facility is installing a solar water heating system to further their mission to become more energy efficient.

VIII. Acknowledgments

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