Auburn University's Solar Photovoltaic Array Tilt Angle and Tracking Performance Experiment

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Solar tracking mechanisms were developed to maximize the energy yield of solar cells. To compensate for the change of path by the sun throughout the year, software models were developed that predict the optimum angle to point the single axis tracker. These models predict which angle will result in maximum energy output for the entire year. We have used two modeling programs to predict the optimal angle and for this region they do not agree. Therefore, in the fall of 2009, Auburn University designed and built a test structure that will provide a test of each of these models. There are six test panels. Five panels are rotated in a single axis azimuthally at the tilt angles of 20º, 25º, 32º (latitude), 40º, and 50º. Another panel is a fixed control panel facing south at latitude tilt. The system is operational and data will be recorded for at least one year. This research will shed light on which of these models is correct, if either, and will make further recommendations about the best angle to set a single axis tracker for optimal performance. The research will also consist of in-depth study of both models to understand the differences.

I. Introduction

SOLAR tracking mechanisms and software were developed to maximize the energy yield of solar cells. In recent years, solar cells have become so inexpensive that it may not be economically sensible to use expensive multi-axis trackers. This has led to the use of single axis tracking systems. To compensate for the change of path by the sun throughout the year, various models can be used predict the optimum angle to point the single axis tracker to obtain the maximum energy output for the entire year. We have used two models to predict the optimal angle and, for this region they do not agree. (See Fig. 1) The first, PV Design Pro G, developed by Maui Solar Software, predicts the optimal angle to be 50°. 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°. A third model, PV SYST, which is used by major companies around the world, agrees more closely with PV Watts.

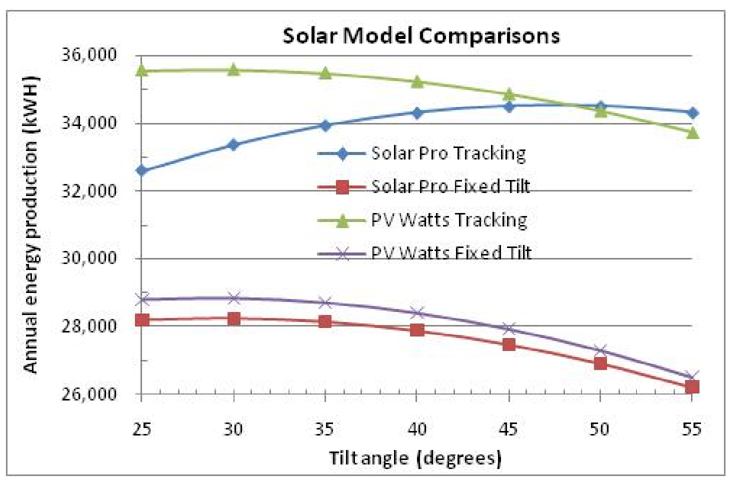

Figure 1: Solar Model Performance Comparisons

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II. Set-up

In the fall of 2009, Auburn University designed and built a test structure that is providing a test of each of these models. The test bed uses a 2-D Wattsun AZ-125 tracker with Sharp NT-175U1 panels. The tracker is used solely in the single axis, N-S azimuthally tracking mode. Sensors have been installed to measure the solar irradiance, wind speed, ambient temperature, and module temperature in addition to the primary power, voltage, and performance information. Each panel has its own Enphase inverter, each with an independent Maximum Power Point Tracker circuit, and which allows us to gather each individual panel's performance information for comparison. 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 (32.4º). The layout of the system is shown in Fig. 2 and the actual system is shown in Fig. 3. The system is operational and data will be recorded for at least one year.

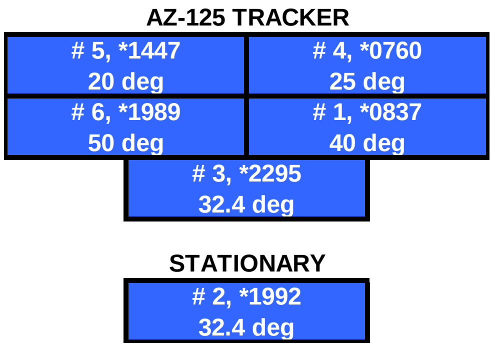

Figure 2: Layout of experimental system

Figure 3: AU Tracker Experiment

III. System Modeling

To estimate the power performance of our chosen panels at various tilt angles, an analysis was done using PV Watts and PV Design Pro-G software. Each modeling program is different. PV Watts is a more simplistic program and only uses basic information such as location, tilt, and DC rating to determine performance, whereas PV Design Pro G require detailed information such as daily load, specific module and inverter parameters, wiring specification, system costs, and the specific location's shadowing effects. The monthly performance estimates from PV Watts are shown in Fig. 4 and PV Design Pro G results in Fig. 5. It is interesting to note that PV Design Pro G predicts higher power performance for every panel. This could be the use of the default derate factor of 0.77 in the PV Watts simulation. PV Design Pro G may not take into account such a large overall factor. PV Watts predicts the module tilted at 20º to produce the most power from April through August and the 50º tilted panel to produce the most from October through February. PV Design Pro G agrees that the 50º tilted module will produce the most power in winter months but it also predicts that this same module will produce the most combined throughout the year. The 40º tilted module is expected to slightly exceed the 50º panel for power production in June and July. These programs are drastically different for the summer or high sun months of April through September. PV Watts favors low tilt angles whereas PV Design Pro G favors larger tilt angles. For the overall year PV Watts yields an optimal tilt angle of 32.3º or latitude whereas PV Design Pro G advises a high tilt angle of 50º. It is well known that the industry standard is to tilt fixed solar arrays at latitude for peak output.

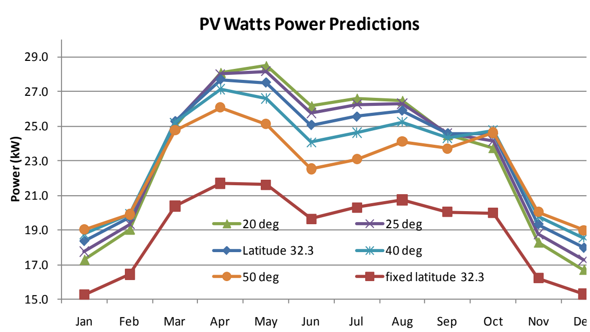

Figure 4: PV Watts Power Predictions

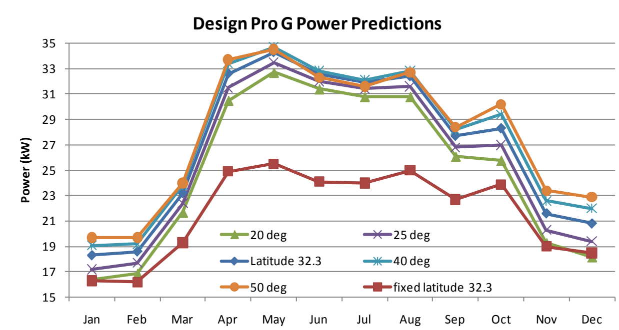

Figure 5: Design Pro G Modeling Predictions

IV. Data Collection

Information gathered through the system's design, installation, and performance monitoring are providing valuable research information concerning practical photovoltaic alternative energy systems design and integration. Its research value will be enhanced by its additional benefit as an excellent teaching and demonstration tool.

V. Data Analysis

Detailed analysis of the PV array performance is being executed. Data analysis consists of efficiency with intensity, monthly AC energy production, monthly and yearly comparison of various tilted panels and fixed control with PV modeling simulation, the effect of weather and different orientations, initially. An analysis was performed to determine the optimal elevation angle for both fixed and tracking arrays based on the location and time of year. These calculations are being compared to actual performance to determine their accuracy.

Figures 6 and 7 show the power produced on a typical full sun day in March and in June for all the modules that are placed at varying angles. It is notable that several of the modules have a loss of power in the mid-morning and mid-afternoon due to shadowing for the March date. Due to the set-up of the system and the site available, this shadowing is not consistent from one panel to the next. The study could focus on the hours of the day that all panels receive full sun which is typically from 10:30 am to 2:30 pm but that may not fairly represent the higher tilted panels which produce more power during the rising and setting hours of the sun. The effect of this shadowing will be examined in closer detail at a later date. Thankfully as the sun's path gets higher in the sky shadowing will not affect the AU tracker system. The only panel affected by shadowing in the summer months is the fixed panel that is situated below the tracker. Unfortunately, the bottom two panels on the tracker shadow part of the fixed panel for some time before and after high noon which can be seen in the power drop-off for that panel in Figure 7. From Figures 6 and 7 it is seen that at the beginning of the day and at dusk the most power producing array is the one tilted at 40º. The 50º tilted array is next followed by 32.4º (latitude), 25º, 20º, and finally the fixed array. The sun's path across the sky changes throughout the year affecting each module's power performance. For the summer months with a higher sun angle, the lower tilted arrays become the top power performers for the hours of 10 am to 2 pm as seen in Figure 7. However, it is the overall power performance throughout the entire day that we are focusing on to determine the optimal angle.

Figure 8 and Table 1 show the power production of each panel from January 15, 2010 through June 2010. The 50º tilted panel has produced the most overall. The 40º tilted panel falls close behind. These data are highlighted in Table 1 and seems to verify the PV Design Pro G modeling. As mentioned before, shadowing has not been fully taken into account but it mostly affects the 40º and 50º tilted panels. This could mean in actuality, that their power production would be greater than shown. For this year, the AU tracker shows that April was the peak power month whereas both modeling programs predict May to be the peak month. This is reflected again in Figure 9 which shows the actual insolation measured on the tracker and the insolation used to predict the power performance for the two modeling programs. A more in-depth analysis is being performed but initial findings back up the modeling of PV Design Pro G which suggests that for this Southeastern region of the US, a higher tilted panel will produce more power throughout the year.

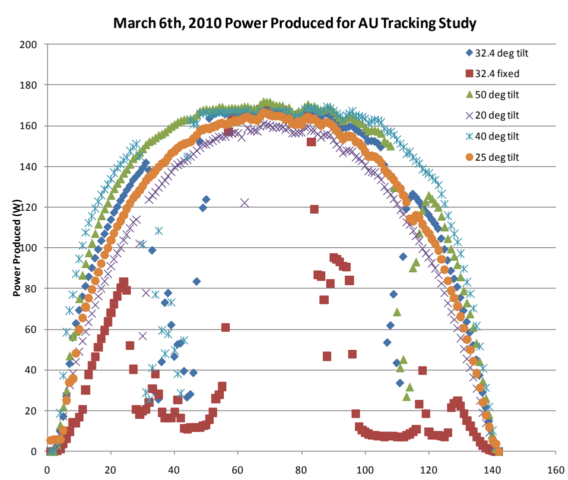

Figure 6: Comparison of tilted panels 03/06/10

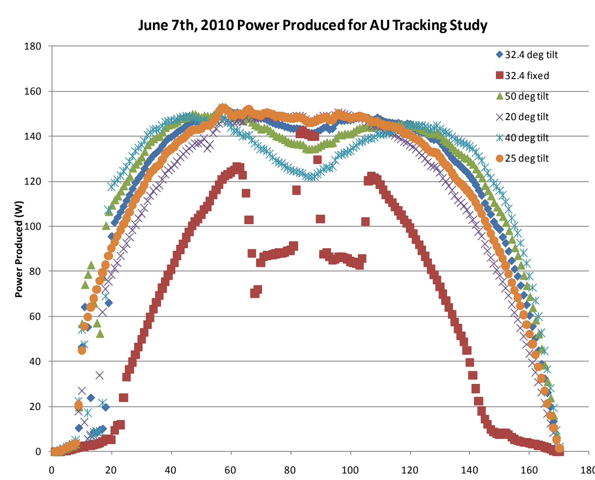

Figure 7: Comparison of tilted panels 06/07/10

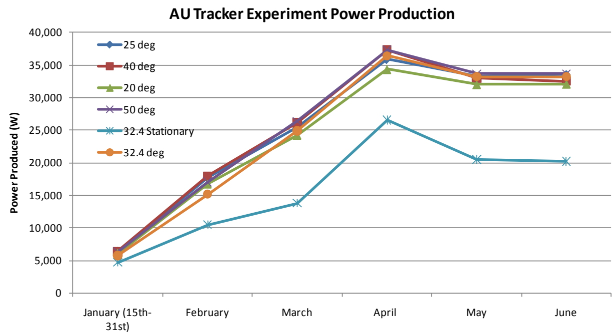

Figure 8: AU Tracker Power Production

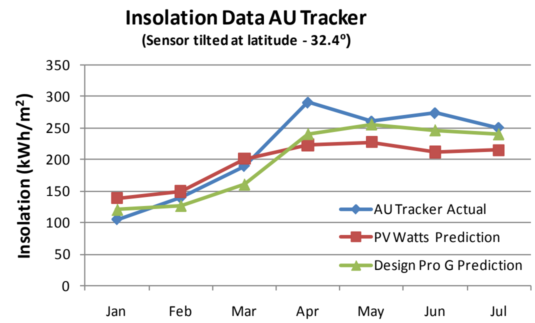

Figure 9: Insolation data for AU tracker

	Module 1 (0760)	Module 2 (0837)	Module 3 (1447)	Module 4 (1989)	Module 5 (1992)	Module 6 (2295)
	25 deg	**40 deg**	**20 deg**	**50 deg**	**32.4 Stationary**	**32.4 deg**
January (15th-31st)	6,358	**6,400**	6,083	6,326	4,697	5,763
February	17,689	**17,982**	16,728	17,048	10,484	15,156
March	25,459	26,152	24,235	**26,367**	13,789	24,908
April	35,872	**37,342**	34,341	37,288	26,557	36,402
May	33,292	32,971	32,020	**33,662**	20,475	33,195
June	33,537	32,495	32,095	**33,675**	20,206	33,202
Yearly Total	**152,208**	**153,341**	**145,501**	**154,366**	**96,207**	**148,626**

Table 1: Power performance of the AU Tracker system

Figure 10 compares the actual power performance of the AU tracker to the modeled performance. Only the 32.4º (latitude) and 50º panel data is shown since they were the two panels that were modeled as the peak performers by the two modeling programs. The PV Design Pro G performance prediction of the 50º tilted panel is quite close to the actual performance of that panel but the latitude tilted panel prediction is quite a bit off from the actual. Both predictions by PV Watts are lower than the actual performance. This could be due to using too high (0.77) a derate factor and thus under predicting the performance. The variation in PV Design Pro G will be examined more closely.

In addition to providing the year-plus model-comparisons, we are looking at the negative-temperature coefficient effect of PV. We aim to emphasize that while insolation is better in the southwest by ~20%, if you add the negative temperature effects on the PV modules that eliminates some of the advantage that the southwest has vs. the southeast part of the U.S. We wish to determine if part of the reason power production peaked in April and not May in this test could be due to the fact temperatures were much higher than normal in May this year thus lowering the efficiency of the solar cells. Initial observations are shown in Fig. 11. This figure takes a full sun day from different months that show a large

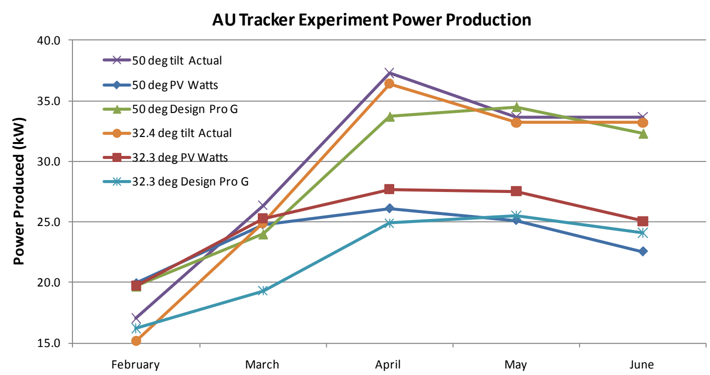

Figure 10: Actual Power Performance vs. Predictions

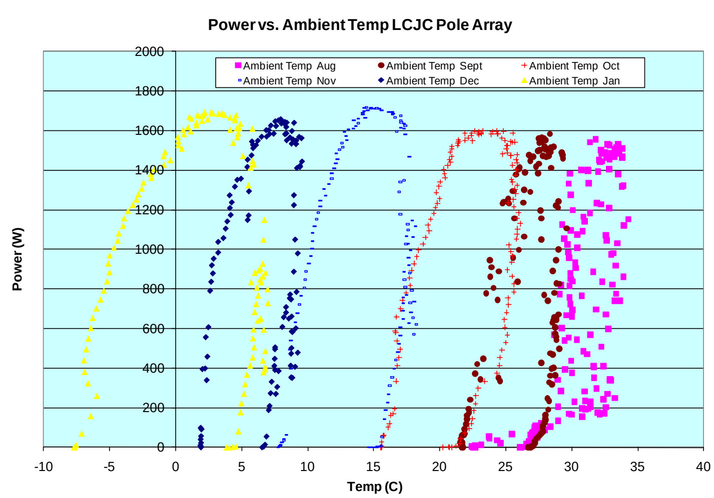

Figure 11: Power vs. Ambient Temperature on six full sun days

temperature differential. It is obvious that the power produced in colder temperatures is greater than in hotter temperatures. This analysis 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.

VI. Conclusion

In review, this paper has taken the data collected at Auburn University's Space Research Institute's solar experiment grid-connected solar-powered system and analyzed it to find trends and anomalies. Some of these included performance with insolation, especially early and late in the day, average overall operating efficiency and AC performance. Most important is the comparison of the performance data to the results obtained from photovoltaic modeling programs that were used before and during installation of the system. For the first six months this system has been in operation, the performance has closely resembled the modeling done by PV Design Pro G software. A more in-depth analysis is being performed but initial findings back up the modeling of PV Design Pro G which suggests a higher tilted panel (50º) will produce more power throughout the year compared to modeling from PV Watts that suggests a 32º tilt. Also when considering the negative temperature coefficient, the effect of reduced total solar radiation in the Southeast U.S. may in part be offset by the lower temperatures reducing somewhat the apparent advantage of the Southwest locations.

The Space Research Institute is interested in helping to explain how alternative energy, especially solar, can be economical for Alabama and the Southeast U.S. in general. We want to overcome the mindset that solar energy is not practical for the Southeast U.S. We hope to serve as a model of how and why PV should be used for commercial, government, and individual energy use. We hope to provide an excelled teaching and demonstration tool for all sectors and allow wide access to agencies, businesses, and individuals to inspire them to incorporate solar energy. The Enphase Energy web portal for this system is accessible via their "Enlighten" web site and is a public link allowing visitors to view general system performance graphs and specs. Please visit this site at http://enlighten.enphaseenergy.com/public/systems/5UZd1968 or the Auburn University's Space Research Institute website at .auburn.edu where we go into more detail on all our solar projects and installations.

VIII. Acknowledgments

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