COMBINING WIND & SOLAR RESOURCES IN NORTHERN ARIZONA: CORRELATION AND VARIABILITY ANALYSIS

Ana R. Dyreson — *Graduate Research Assistant*

Samuel H. Monger — *Graduate Research Assistant*

Eric R. Morgan — *Post-Doctoral Researcher*

T.L. Acker — *Professor, Mechanical Engineering*

NORTHERN ARIZONA UNIVERSITY

Institute for Sustainable Energy Solutions

1. Introduction

With increasing grid penetration of variable generation sources such as wind and solar, the variability of these generation sources has an impact on the electricity grid. This study seeks to investigate the manner in which solar and wind power can complement each other on the power grid. The co-location of wind and solar power plants could be advantageous to grid operators who seek to provide steady power with minimal fluctuations. This wind/solar variability study examined the potential output of a combined wind and solar power plant in northern Arizona. The study was completed by Northern Arizona University and WindLogics, Inc. (NextEra Energy Resources, LLC). The analysis considered four one-week periods having different solar irradiance variability. The results of this particular study are interesting examinations of the combined impacts of solar and wind resources in this climate, which is characterized by relatively high irradiance, a summertime monsoon season, and a windy spring. The methods are useful for similar combined wind/solar power plants in any location.

2. Methods

This study utilized 45 irradiance sensors installed on a square-mile grid 40 miles north of Flagstaff, Arizona as shown in Figure 3. 1-second irradiance data from these sensors along with 10-minute wind speed data from a single met tower were analyzed to characterize the variability of the resources. Solar irradiance was determined using the 45-sensor network and Sandia's Wavelet Variability Model [1]. This model is used to determine how much spatial smoothing occurs over the area of a PV power plant depending on the specific conditions of the day. The power timeseries was estimated by using a simple irradiance-to-power conversion that uses clear sky plane-of-array estimates and measured clear sky index values. Simple loss factors were included as well. A power conversion estimate was completed using a power curve for a single 1.7 MW turbine, and then the power of a 30 MW (and 15 MW) installation was estimated by simply multiplying the resulting power timeseries by the number of turbines required to reach the desired capacity. This estimate is expected to overestimate the variability of the wind plant. Although the analysis was completed on four one-week periods over the year, the focus is on the two summertime periods. The monsoon period (made up of 7 days from late June and late July 2012) highlights the results of high variability time periods associated with summertime storms. The peak summer period shows the resource availability during periods of peak air conditioning load. Figures 1 and 2 show the raw irradiance and wind speeds during these periods. The peak summer period has unusually high wind speeds.

Figure 1: Resources for Monsoon Week

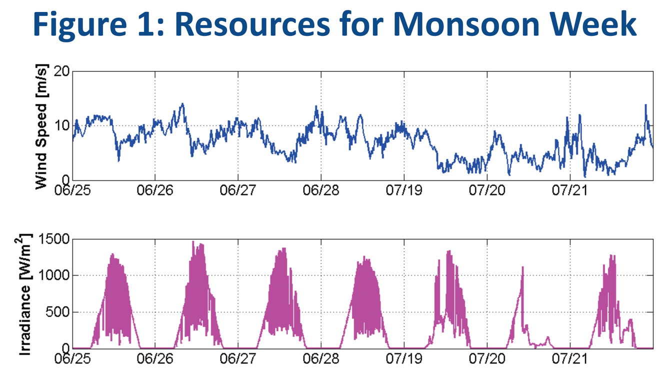


Figure 2: Resources for Peak Summer Week

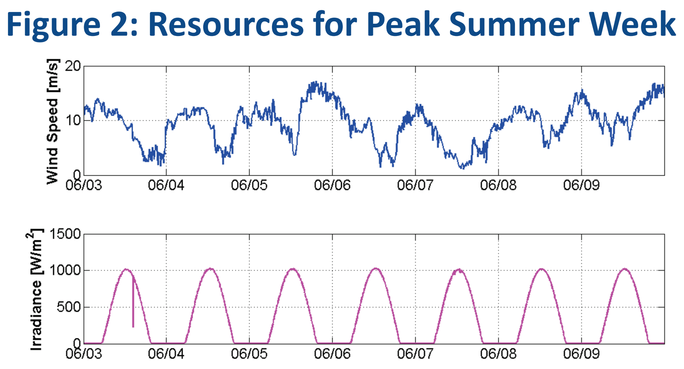
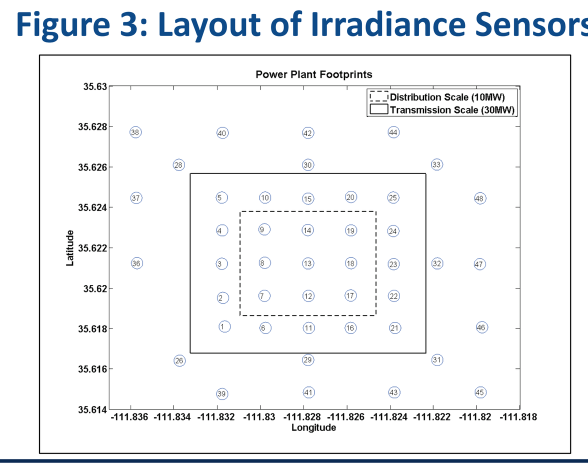


Figure 3: Layout of Irradiance Sensors



3. Results: Power Output

Three different power plants were simulated: 30 MW solar PV, 30 MW wind, and a combined power plant of 15 MW wind and 15 MW solar. Each of these was simulated over the selected one-week periods. These results compare the raw power timeseries as well as the "deltas" – or change in block averaged power over 10 minutes or 1 hour periods. Figures 4 and 5 show the simulated power output for the two summertime periods and three power plants. The combined power plant in each case (green) has a more consistent availability of power but reaches the 30 MW capacity less often than the wind or solar plants. In order to examine the power variability, the 1-Hr hour deltas are considered in Figure 6 and 7. The 10-Minute deltas are considered in Figure 8 and 9. Table 1 and Table 2 provide the standard deviation of the 1-hr and 10-minute power deltas, which provide a measure of variability. The results show that the combined power plant exhibits lower 1-hour variability for both periods than either the wind or solar plant. On a 10-minute scale, the combined power plant has a lower variability than either the wind or solar plants for the monsoon period. However, for the peak summer period, because the sky conditions were very clear, the solar power plant has the lowest 10-minute variability.

Figure 4: Power for Monsoon Week

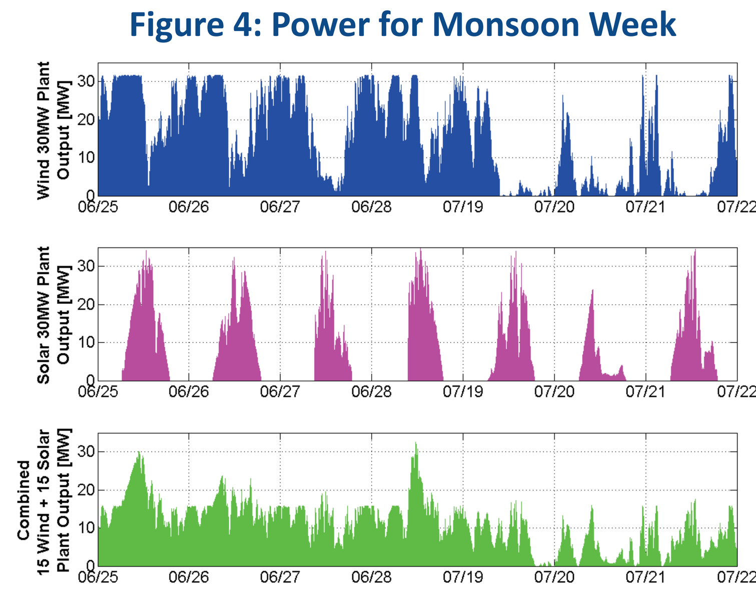


Figure 5: Power for Peak Summer Week

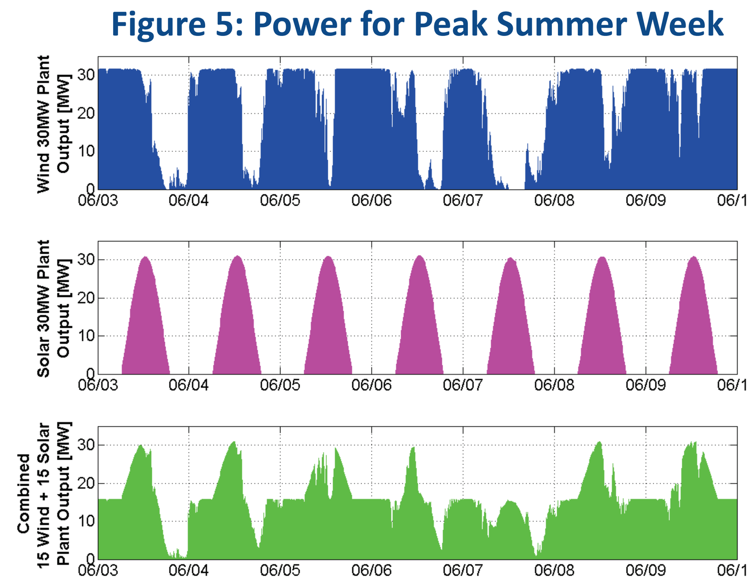


Figure 6: 1-Hr Power Deltas for Monsoon

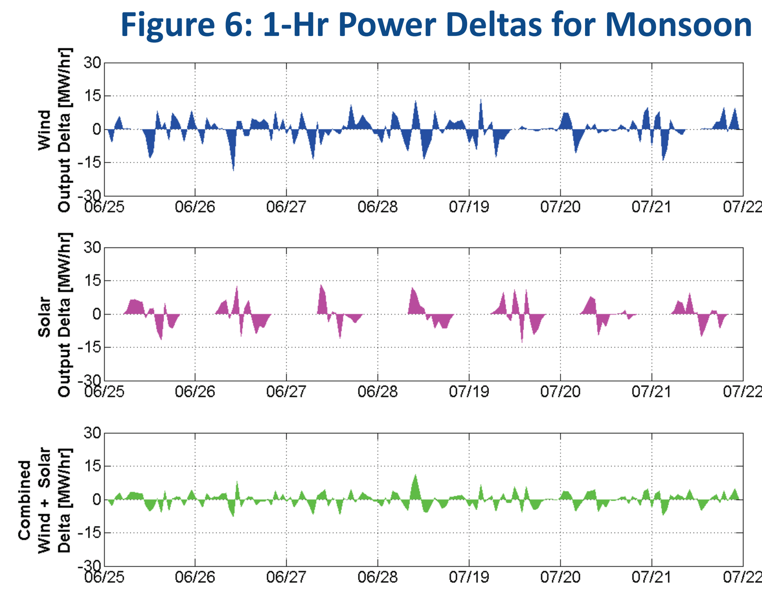


Figure 7: 1-Hr Power Deltas for Peak Summer

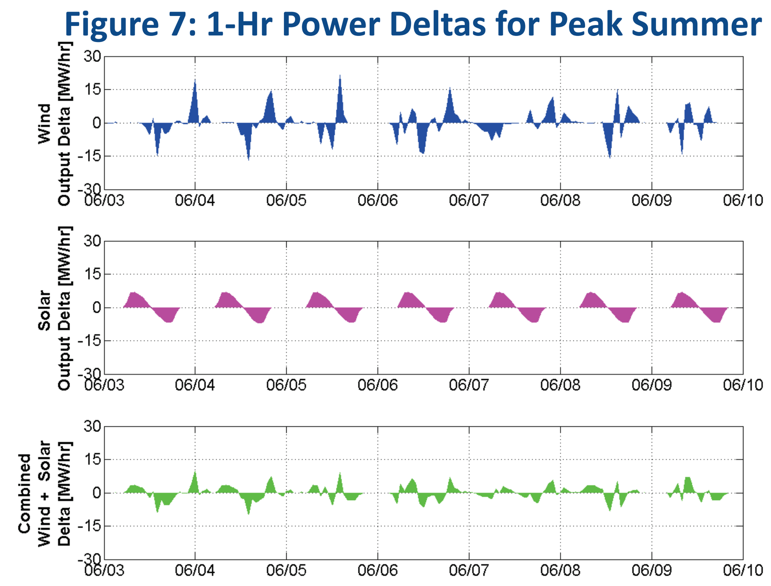


Figure 8: 10-Min Power Deltas for Monsoon

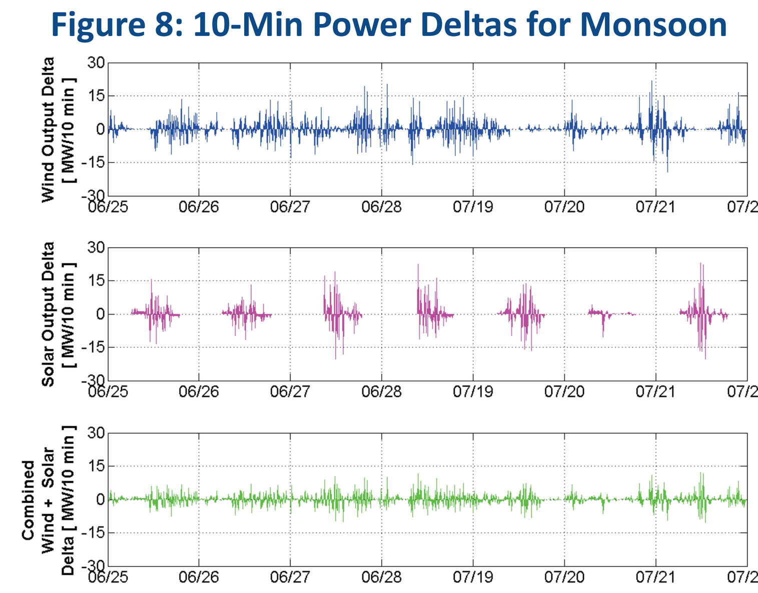


Figure 9: 10-Min Power Deltas for Peak Summer

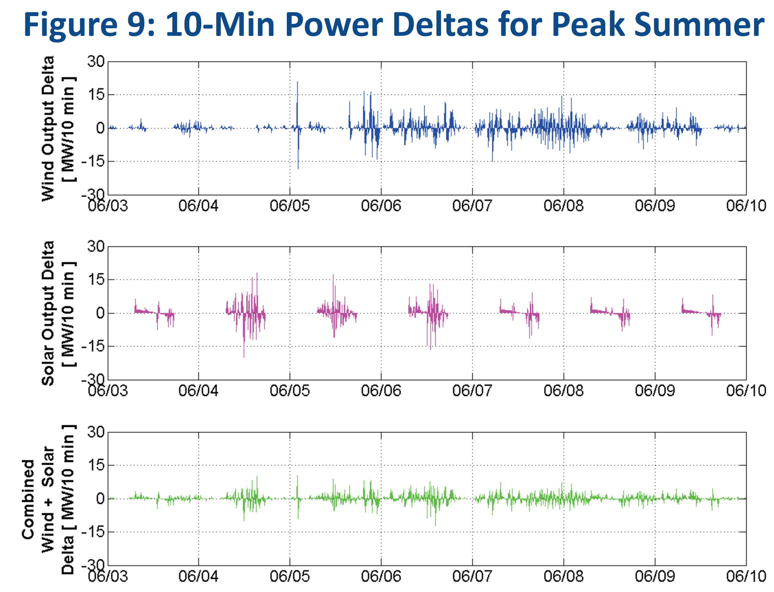


Table 1: Standard Deviations Monsoon

Standard Deviation of Delta [MW/time]	1-Hr	10-min
30 MW Wind	5.47	4.10
30 MW Solar	4.39	3.64
Combined 15MW Wind/15 MW Solar	3.33	2.78

Table 2: Standard Deviations Peak Summer

Standard Deviation of Delta [MW/time]	1-Hr	10-min
30 MW Wind	5.39	3.09
30 MW Solar	3.77	0.66
Combined 15MW Wind/15 MW Solar	3.12	1.57

4. Results: Change Correlation

Scatter plots of the 1-hr and 10-minute changes for 30 MW wind plant vs 30 MW solar plant provide some insight into the correlation of the wind and solar changes. This analysis considers the springtime period as well as the fall period in addition to the two summer periods. It would be desirable to have anti-correlated resources for a combined wind and solar plant, in which case the changes would all appear in the second and fourth quadrants (i.e. the wind power would be increasing when the solar power was decreasing, and vise versa). The results in Figures 10 and 11 do not show a clear anti-correlation. However, the results in Figure 10 do show that the maximum 1-hour solar power deltas are less than the 1-hour wind power deltas. In addition Figure 11 shows that the maximum 10-minute solar power deltas of similar magnitude to the 10-minute wind power deltas (about 20 MW/10-min). On the 10-minute timescale, the solar power and wind power deltas are not maximized at the same time because no points appear around the (20,20) coordinate.

Figure 10: 1-Hr Wind and Solar Power Deltas

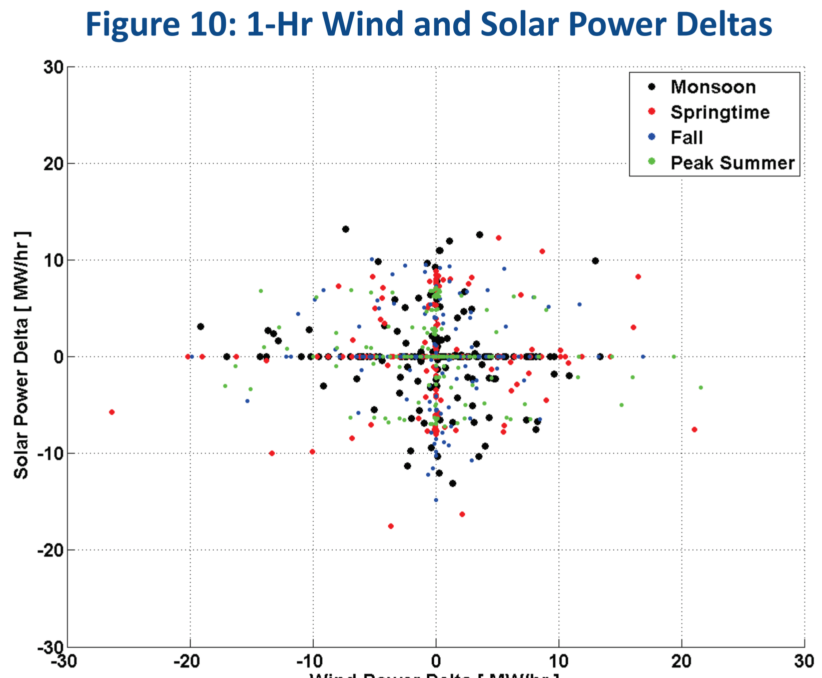
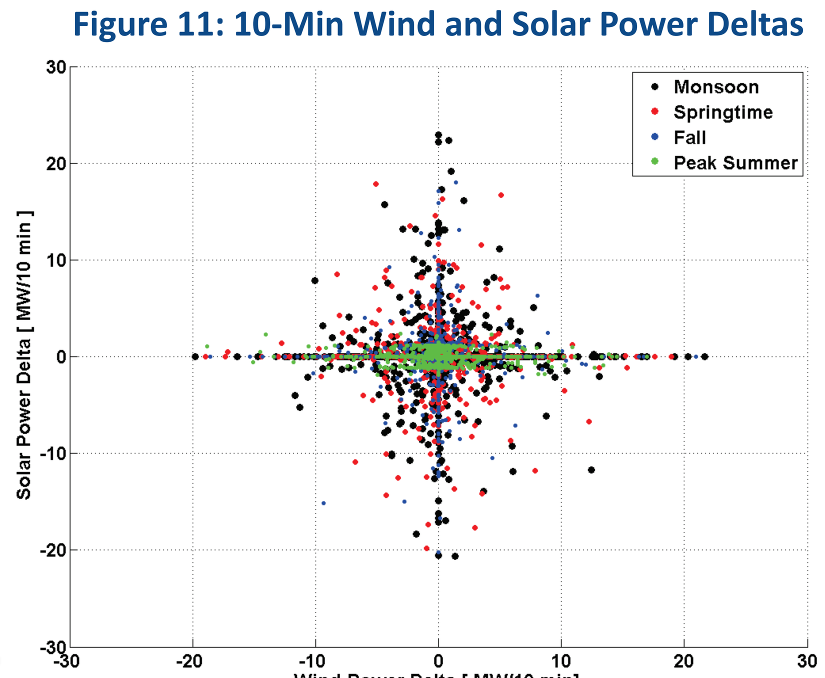


Figure 11: 10-Min Wind and Solar Power Deltas



5. Results: Capacity Value

The Capacity Value (CV) for variable generation resources represents the fraction of time the resource can reliably contribute to the summer peak hours. Considering the lack of data in this immature study (less than 3 years), the CV is calculated for each of the one-week long periods during the summer using the following formula:

$$CV = \frac{\sum peak\ hourly\ output}{\sum net\ maximum\ capacity}$$

A simplified method of estimating CV was used, roughly following the guidelines in the PJM operating manual [2]. The afternoon hours of 3, 4, 5 and 6:00 PM are considered the peak hours for the summer. The Net Maximum Capacity in this study is defined as the manufacturer's power output rating less any amount of energy consumed on site at the variable generation source. Because of the theoretical power conversion performed, the Net Maximum Capacity was taken as the total power output: 30MW. Table 3 shows the weekly CV results. During the periods examined, the CV of wind, solar, or combined power plants are similar. The CV for the peak summer period is very high (0.45) because this one-week period included some unusually high wind speeds as well as clear sky conditions.

Table 3: Weekly Capacity Value Results

Weekly CV	Monsoon	Peak Summer	Avg.
30 MW Wind	.27	.45	.36
30 MW Solar	.30	.44	.37
Combined 15MW Wind/15 MW Solar	.28	.44	.36

6. Conclusions

We have shown that in Northern Arizona during four week-long periods, the wind power and solar power can complement each other and be beneficial to the grid. During the peak summer and monsoon seasons, the standard deviation of the 1-hr power output changes is reduced with a 30 MW combined wind and solar power plant compared to a 30 MW wind plant or a 30 MW solar plant. During the highly variable monsoon period, the combined power plant also has a lower standard deviation of 10-minute deltas. Thus, co-locating wind and solar power plants in Northern Arizona could make financial sense and could alleviate some of the grid integration issues that wind power and solar power have individually. In order to validate these results, similar analysis could be completed over a longer term period using at least one year's irradiance and wind resource data.

References :

[1] M. Lave, J. Kleissl, and J. S. Stein, "A Wavelet-based Variability Model (WVM) for Solar PV Power Plants," *Sustainable Energy, IEEE Transactions on*, vol. 4, no.2, pp 501-509, April 2013.

[2] System Planning Department, "Manual 21: Rules and Procedures for Determination of Generating Capability. Appendix B: Calculating Capacity Values for Intermittent Capacity Resources ," PJM, 2013.

Acknowledgments:

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