ELECTRIC POWER RESEARCH INSTITUTE

TECHNOLOGY INSIGHTS

A Report from EPRI's Innovation Scouts

SOLAR POWER FORECASTING FOR GRID OPERATIONS: EVALUATION OF COMMERCIAL PROVIDERS

THE TECHNOLOGY

Solar power forecasting employs historical weather, irradiance, and energy production data—as well as real-time data and weather forecasts—to estimate future solar generation over various time horizons.

THE VALUE

For grid operators, accurate solar power forecasting promises to increase the efficiency of tasks such as unit commitment and dispatch, trading, and ancillary service provision while facilitating further integration of renewables.

EPRI'S FOCUS

Through experimental trials based on real-world data, EPRI has assessed the current state of the art in solar power forecasting to help grid operators understand forecast accuracy and evaluate service providers.

INTRODUCTION

The rapid and continued growth of solar power generation has led to an increased need for awareness of expected solar production among grid operators and balancing authorities. Most independent system operators (ISOs) in market regions and vertically integrated utilities in non-market regions now use wind power forecasts, and many have started to obtain, or are looking to obtain, solar power forecasts.

Accurate solar power forecasts—and knowledge of the uncertainty in these forecasts—can help grid operators accommodate output from photovoltaic (PV) projects effectively and efficiently by ensuring that sufficient flexibility is available in the form of operating reserves and quick-start generation. Energy production forecasts also are employed by solar power producers to enhance market participation.

To understand the general state of the art in solar forecasting and help member utilities identify a particular solar forecast that best fits their needs, EPRI has worked with CPS Energy and Southern Company to trial the performance of a number of commercial service providers. The CPS Energy trial was completed in 2014, while the Southern Company trial was completed in the second half of 2016. This *Technology Insights Brief* focuses on the results of the latter trial and provides overall lessons learned in how to set up such trials and to assess the forecasts obtained.

FORECAST TRIAL DESIGN

Experience in wind and solar power forecasting over the past decade demonstrates that setting up a transparent, fair, and efficient trial process is important both for forecast end users such as utilities, ISOs, and traders and for the forecasting companies that elect to participate. As many trials are done on a free basis, sound trial design is essential to entice developers of deployed forecasting services and of emerging solutions so that even if they don't win, they will feel some advantage by taking part.

TECHNOLOGY INNOVATION QUESTIONS

- What is the current state of the art in solar power forecasting to support power system operations?
- What is the best way to assess forecast accuracy and the performance of individual forecasters?

EPRI worked closely with CPS Energy, Southern Company, and participating forecasters over several months to set up 6-month experimental trials and create a best-in-class evaluation process. Some key features and observations relating to EPRI's forecast trial design include the following:

- **Anonymous forecast submission and evaluation, plus intellectual property protection:** The EPRI team developed a double-blind forecast submission process, where only submitting forecasters know their alias. This allows them to submit forecasts knowing they will only be identified with permission. The EPRI team is then able to determine the state of the art and make recommendations to utilities without concerns about making the performance of specific forecasters known, a key barrier for gaining greater participation in previous free trials. Forecasters sign multi-party non-disclosure agreements to participate in the trial and ensure data security.
- **Data exchange:** Over the two trials, EPRI improved the mechanisms for exchanging and storing data. This includes both historical and live data sent to forecasters about plant conditions (power output, irradiance, equipment availability, and weather conditions), as well as the forecasts submitted by participants. As data are uploaded on a frequent basis – at hourly forecast resolution up to 10 days out, once an hour, for the Southern Company trial – an efficient database storage system was created. EPRI also developed a standard data format, removing a significant complication in previous trials where utilities would need to accommodate each forecaster's own format.
- **Evaluation process:** EPRI worked with the utilities to develop a unique process for assessing and comparing the performance of individual solar energy forecasters, designed to provide a more thorough evaluation than typical trial processes where very few summary metrics are typically used. As discussed below, this includes a suite of forecast evaluation metrics, from typical mean error to more detailed metrics focused on specific time periods of interest.

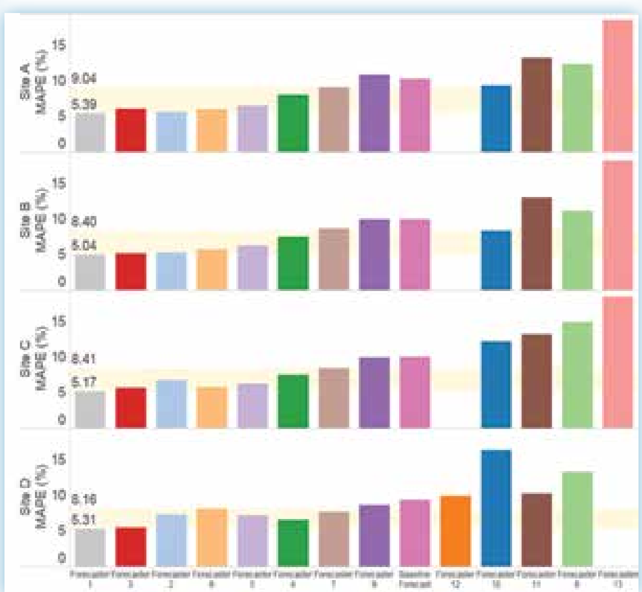

Figure 1 – Mean absolute percentage error (MAPE) for each forecaster by site for day-ahead horizon

Once forecasters enroll in the trial, they receive metadata characterizing the various solar site locations, as well as historical time series data required to train their models. After a suitable training and testing period, the 6-month trial begins. Ongoing discussion is maintained with all participants to ensure that the forecast trial proceeds as expected and to allow for issues to be raised and addressed.

MAIN RESULTS & OBSERVATIONS

The 2016 Southern Company trial was designed to identify the performance of solar forecasts over time intervals and for parameters that would influence operational tasks such as trading and fleet scheduling. The project team identified metrics and tests to characterize forecast accuracy for each of four solar PV plants—three fixed-tilt arrays and one with single-axis tracking—over each time horizon. For further comparison, the trial also included use of an advanced baseline forecast using publicly available data and models for transforming irradiance input data into PV power output.

On the day-ahead horizon, the trial included over 5000 competitions among participating forecasters, one for each daylight hour of the trial. Figure 1 shows the mean absolute percentage error (MAPE) for all forecasting methods—including the baseline—for all four sites, calculated by assessing the day-ahead forecast error as a percentage of installed AC capacity. The numbers on the left side of each chart show the lowest (bottom) and median (top) error values. Not all forecasters submitted forecasts for all four sites. Further, forecasts with higher MAPE may not be reflective of commercial offerings, as the anonymous nature of the trial allowed for individual forecasters to submit multiple entrants, with some potentially representing research-grade or experimental methods.

Figure 1 displays a range of performance among participants, along with a group demonstrating consistently higher accuracy

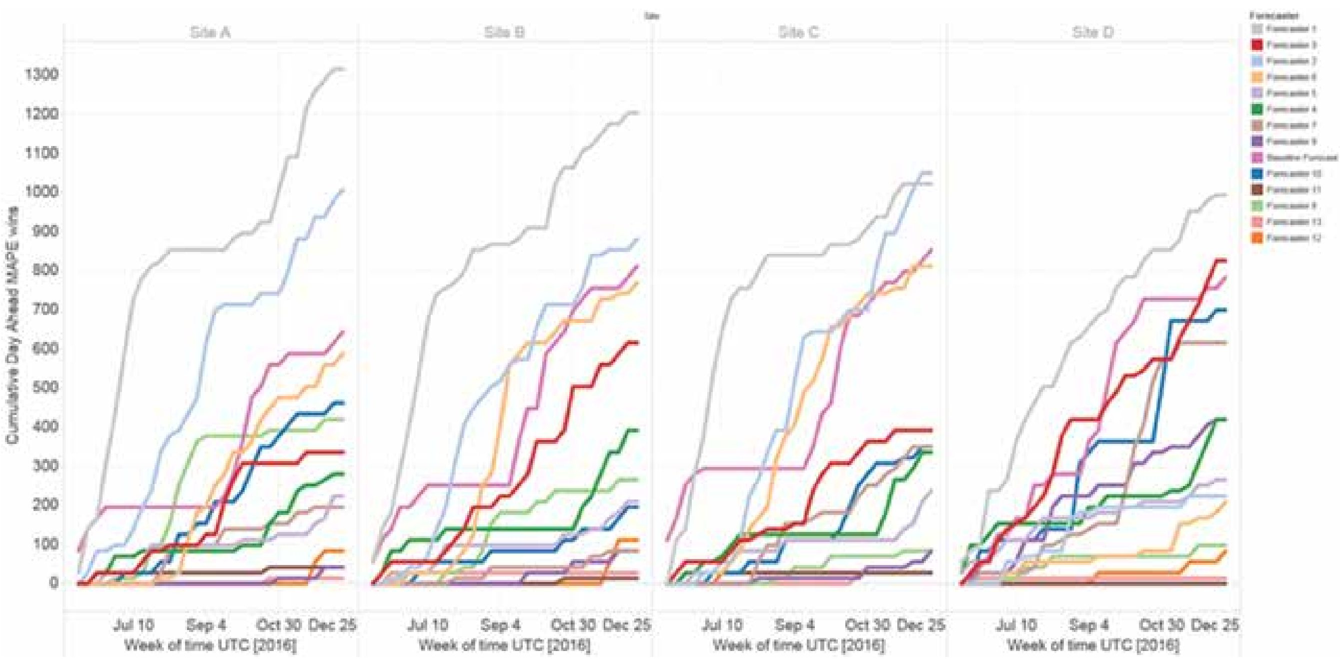

Figure 2 – Cumulative day-ahead MAPE wins for each forecaster by site across the trial period

(lower MAPE) across multiple sites. At least seven forecasters beat the baseline for each site assessed, showing the capability to improve upon simple use of publicly available data. The best forecasts have an error in the range of 5% to 5.4% of capacity. This compares favorably with the 2014 CPS Energy trial, where higher-performing forecasters achieved a day-ahead MAPE of 6% to 8%, depending on the solar plant assessed.

Another way to look at forecast accuracy is to consider "wins" for each forecaster, where each time period when forecasts are submitted is assessed separately against the metric of choice. The cumulative wins for MAPE in each day-ahead competition for each site across the trial period are shown in Figure 2. Here, the forecaster who had the best day-ahead forecast in each hour got a score of one. As shown, one of the forecasters, in grey, typically won more frequently than others for all sites. Among over 5000 competitions, that forecaster won between 1000 and 1300 depending on the site, while second place varied between the light blue and red forecasters.

These differences are not as apparent when looking at only average MAPE results as in Figure 1, where the same color indicators are used for each forecaster. On average, the grey forecaster appears marginally more accurate, but small differences across the year can have a large impact on a daily basis, on the time frames of relevance to grid operators. Figures 1 and 2 also show that even forecasters that perform poorly on average still are capable of providing the best forecast under certain conditions.

Additional metrics were used to analyze best-guess forecasting data from the Southern Company trial, including root mean square percentage error (RMSPE), which places a higher value on extremely large errors; a MAPE weighted by time of day, where afternoon was weighted higher; a MAPE calculated only during cloud-based ramping periods; and the average bias of the forecast, addressing whether a forecaster tends to over- or under-predict energy production, and by how much. In addition, irradiance forecasts and probabilistic forecasts were obtained and examined, providing further information about different providers.

Generally, leading forecasters under the average MAPE metrics did best according to other metrics, except at one PV plant site in the US southwest, where the top-performing forecasters were reordered, relative to results displayed in Figure 2. General consistency in metrics for forecasters and sites also was observed during the CPS Energy trial, with one exception: Forecast accuracy was lower for plants where tracking systems are employed to keep modules in alignment with the sun's path across the sky. This poorer performance was not observed for the Southern Company plant with tracking.

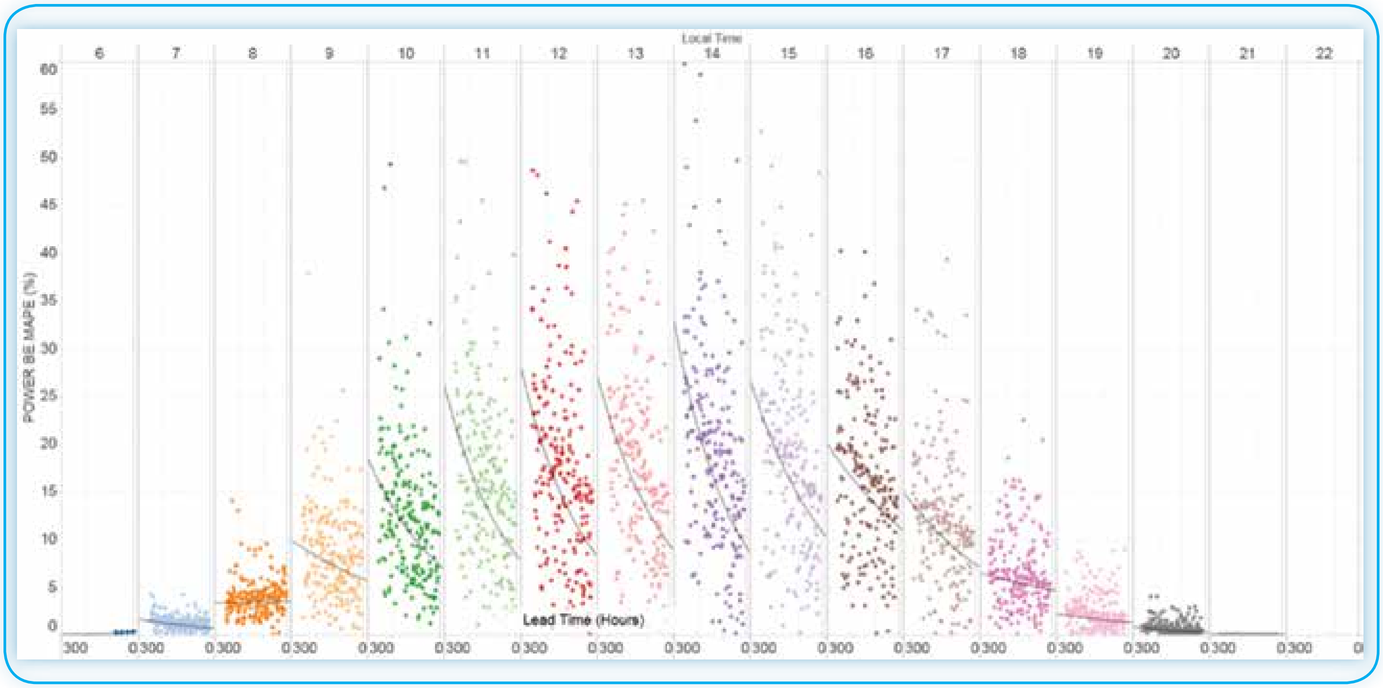

Figure 3 – Average MAPE of best-estimate forecast from top six forecasters by hour of day and lead time

The EPRI team mined the Southern Company trial data to examine additional broad issues related to solar forecasting, including accuracy over different lead times. In Figure 3, each dot represents the accuracy of an individual forecast from one of the top six forecasters. Dots are distributed into time-of-day blocks, and then for each time of day are arranged by look-ahead time, from approximately 240 hours (10 days) on the left side of each hour to 1 hour on the right of each hour. As expected, the error is reduced as one gets closer to real time within each time-of-day block. The middle of the day, with highest solar production, sees the greatest error. Even on very short time horizons, there are occasionally "big misses" that have operational implications.

In both the CPS Energy and Southern Company forecast trials, EPRI worked with participating utilities to create an overall "Forecast Skill Index" (FSI), with a maximum value of 1 representing an always-perfect forecaster winning every competition. FSI allows for summary comparison across forecasters, integrating several metrics, including MAPE, RMSPE, and weighted MAPE, as well as the relative ranks of forecasters during all periods and during periods of high ramping. FSI trends were similar to those registered by MAPE analysis, with the same forecasters doing well.

NEXT STEPS & COLLABORATIVE OPPORTUNITIES

In the immediate future, Southern Company and CPS Energy are looking to further integrate solar forecasts into their operational functions. Findings and metrics from these trials provide guidance on the capabilities of commercial forecast providers, on the potential implications of forecast uncertainties, and on factors to account for in selecting a forecast vendor. EPRI plans a number of follow-on activities:

- **Continue research and demonstration of the use of forecasting in system operations and market participation for solar, wind, and other new resources.** This includes understanding how system operators are integrating such forecasts and how to account for the error observed. Recently, EPRI's Bulk System Integration of Variable Generation Program (P173) has performed a significant amount of work in the use of probabilistic forecasting to inform system operations under its "Operator tools for managing uncertainty" project (173.005). Distribution system applications for forecasting also are being evaluated. Knowledge gaps, such as current forecast accuracy for tracking systems, remain to be filled.
- **Work with forecasters, national labs, and others to design and implement new or improved forecasting methods.** Notable EPRI activities here include a recently awarded California Energy Commission (CEC) grant on improved solar forecasting using advanced sensors, as well as a similar project under development for a state in the US northeast.
- **Conduct additional evaluations of forecasting capabilities.** As needed, EPRI can work with utilities, system operators, and power producers to help design and implement forecasting trials and assess the accuracy of solar and wind power forecasts using

the metrics and methods described herein. In addition, EPRI's standardized data format and its data storage and exchange mechanisms are available to potential users of forecasts, so as to facilitate technology integration within operating systems.

- **Ensure that the lessons learned in the design and implementation of forecast trials are shared across industry.** Best practices developed around data sharing, forecast assessment, and trial design are needed to raise the overall bar for forecasting applications by grid operators. EPRI participates in the International Energy Agency Wind Implementation Task on Wind Forecasting (Task 36) and is contributing to a report on this topic.

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RESOURCES

1. Lannoye, E. *et al.*, "Solar Power Forecasting Trials and Trial Design: Experience from Texas," 5th Solar Integration Workshop, Brussels, Belgium, October 2015.
2. Lannoye, E. *et al.*, "Anonymous Solar Forecasting Trial Outcomes Lessons Learned and Trial Recomendations," 7th Solar Integration Workshop, Berlin, Germany, October 2017.

KEY ACTIVITIES & INSIGHTS

- Over two separate 6-month trials in 2014 and 2016, EPRI evaluated the performance of solar power forecasting providers at multiple PV plant sites, gaining valuable information about the current state of the art.
- The EPRI-designed trial mechanism allows for anonymous provision of solar power and solar irradiance forecasts by multiple providers and their assessment in best-guess forecast competitions relative to utility operational functions such as 1-hour and day-ahead scheduling and ramp rate control.
- A range of forecasting accuracy was seen, with the best performers in the 2016 trial showing an average error in the range of 5%-6% of PV capacity during daylight hours, significantly improving on forecasts based on public data.
- While the forecasts were provided for different locations and with different site conditions and available data, solar forecasting capabilities appear to have improved in 2016 compared to the similar trial in 2014.
- During mid-day periods with maximum solar generation, the best-performing forecasters periodically generate "big miss" errors, highlighting the need to account not only for average error but also forecast uncertainty.

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