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Predicting Solar Power Production:

Irradiance Forecasting Models, Applications and Future Prospects

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Front cover photo of control room has been provided courtesy of ISO New England.

GLOSSARY OF TERMS

Area Solar Forecast: A forecast of two or more solar energy plants.

DG Solar: Solar energy systems deployed within utility distribution networks.

Direct normal irradiance (DNI): The amount of solar radiation received per unit area by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky.

Diffuse Horizontal Radiation (DHI): The amount of radiation received per unit area by a surface (not subject to any shade or shadow) that does not arrive on a direct path from the sun, but has been scattered by molecules and particles in the atmosphere and comes equally from all directions.

Global Horizontal Irradiance (GHI): The sum of DNI and DHI.

Global NWP: Predictions of global weather patterns.

Insolation: Short for incident or incoming solar radiation, which is a measure of solar radiation energy received on a given surface area and recorded during a given time.

Mesoscale NWP: Predictions of regional weather patterns.

Nowcast: A detailed description of the current weather along with forecasts up to 30 minutes.

Numerical Weather Prediction (NWP): The use of mathematical models of the atmosphere and oceans to predict the weather based on current weather conditions.

Persistence Forecast: Forecasts based on extrapolating current conditions into the future.

Point Solar Forecast: A solar forecast for a single solar energy plant.

Variable Generation: Sources of power that vary based on weather conditions, including wind and solar.

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Executive Summary

Solar energy represents a vast, renewable resource that can be tapped to meet society's growing demand for electrical energy. Deployment of systems that convert solar irradiance into useful electrical energy has accelerated in the past decade in the U.S. and globally, particularly for photovoltaic (PV) systems—the direct conversion of irradiance to electricity. Utility companies play an integral part in managing this growth and integrating solar generating plants into the existing grid infrastructure and utility operations.

Grid integration studies of variable generation resources, including wind and solar, conclude that it is technically feasible for these resources to provide a significant portion of the nation's energy needs at manageable costs. These studies recommend operational strategies and market structure changes needed to address increased levels of uncertainty that high-penetration of renewable resources presents to utility companies and grid operators due to their intermittent nature. The use of advanced forecasting of variable generation is one of these essential strategies. Forecasts of future solar energy system output allows grid operators and utilities to proactively manage variable output, and thus integrating solar resources into the existing grid at lower costs to society.

This report provides a review of solar forecasting approaches and how they are being used by grid operators, utility companies, and other market

TABLE 1: SEPA RECOMMENDATIONS TO ADVANCE SOLAR FORECAST MARKET DEVELOPMENT

I. DEVELOPMENT OF FORECASTING STANDARDS/ GUIDELINES	The solar forecasting industry lacks a set of standards or industry guidelines, which acts as a barrier to greater use and understanding of the value of solar forecasting to utility planning and operations. Guidelines or standards with regard to defining forecast time horizons relevant to utility and market operations, measuring and reporting forecast error metrics, and data and communication requirements for modern solar forecasting systems are needed.
II. ECONOMIC ASSESSMENT OF SOLAR FORECASTING VALUE RELATIVE TO COSTS	There is a lack of information within the literature on the economic value that solar forecasts could provide to grid operators and utilities. While the value of solar forecasting qualitatively seems quite large relative to the costs associated with producing solar forecasts, there are currently no quantitative analyses to support this notion. Solar forecasts provide value to numerous stakeholders; an attempt should be made to quantify these values to provide the economic basis for expanded use. Furthermore, these analyses could help to identify the incremental value associated with improved forecast accuracy.
III. DISTRIBUTED SOLAR WORKING GROUP AND WORKSHOPS	While there are various groups working on different aspects of solar deployment and variable generation forecasting, there is a need for a focused effort on DG solar. A working group comprised of relevant stakeholders should be convened to identify the critical issues and begin a collaborative process to address the unique challenges of DG solar. Periodic workshops should be held to share research and current practices used to understand and manage the impacts of DG solar and the role of solar forecasting.
IV. EXPANDED ENGAGEMENT OF POLICYMAKERS AND REGULATORS	Policymakers and regulators need to gain a greater understanding of the value that solar forecasting can bring to meeting policy objectives, including renewable portfolio standards. As grid-connected solar deployment expands and forecasting needs increase, utilities, regulators and forecast service providers need to investigate the best mechanisms in terms of reporting system characteristics providing the needed data to produce accurate solar forecasts, standards in terms of allocating the costs incurred by grid operators and utilities associated with solar forecasting, and promoting market structures and scheduling timelines that leverage modern solar forecasting services.

participants for planning and operations. This report is based on a survey of the literature and interviews with experts from three broad stakeholder groups (ISO/RTO managers, utility managers, and research scientists). Seventeen companies globally were identified that potentially provide solar forecasting services and asked to complete an online questionnaire. Thirteen companies completed the questionnaire, all of whom work with utilities or related organizations. These companies use state of the art solar forecasting systems to provide customized forecasts to meet their clients' particular needs.

> **"Although the solar forecasting industry is in the early stages of market development and acceptance, several companies currently offer solar forecasting services"**

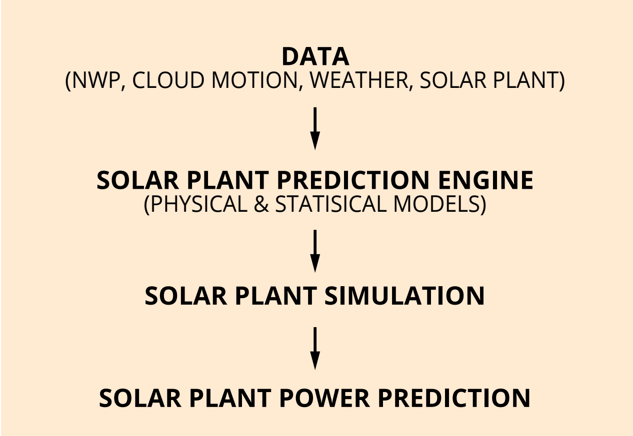
The research and interviews conducted for this report suggest several initiatives that should be undertaken to accelerate the adoption of solar forecasting in response to the anticipated growth in solar energy system deployment in the coming decade. These initiatives can be grouped into the following four broad categories presented in Table 1.

The report begins with a review of the variable nature of solar and is then followed by an examination of the various ground-level solar irradiance forecasting approaches and models used for each solar production forecast time horizon. Next the various ways in which utilities and grid operators can use forecasts of variable generation are explored, including specific uses of solar forecasts at the transmission and distribution levels. Given that California is leading the nation in the adoption of solar energy, extended coverage of the California Independent System Operator's (CAISO's) uses of a central solar forecast is provided. Extended coverage of the Hawaiian Electric Company (HECO) and Tucson Electric Power (TEP) is also provided to highlight efforts at the distribution level to integrate solar forecasting into energy management systems. HECO has the highest PV penetration levels of any utility company and is on the leading edge of exploring how to use solar forecasts to manage high penetration of distributed PV. TEP is a power company and balancing authority in the Southwest that has experienced significant growth in utility-scale and distributed PV deployment. Next the results of the solar forecast provider survey are presented and the report concludes with a section on future developments and recommendations.

Although the solar forecasting industry is in the early stages of market development and acceptance, several companies currently offer solar forecasting services to various end-users as part of other services they provide to the renewable energy industry and other weather-sensitive industries. Modern solar forecasting services use sophisticated physical numerical weather prediction models (NWP), cloud imagery analyses, and statistical manipulations to provide state of the art solar forecasting services covering a range of forecast time horizons (see Figure 1). A point solar forecast is prepared for a particular solar power facility, while an area forecast represents the predicted aggregate output of two or more solar power plants within a defined geographic region.

One study finds that solar irradiance forecast error measured in root mean square error, a measure of the standard deviation of the differences between predicted values and observed values, can range from 100 watts – 200 watts per square meter depending on the forecast method and time horizon. To place this in context, the solar resource is approximately 1,000 watts per square meter for a surface perpendicular to the sun's rays at sea level on a clear day. Irradiance forecast errors vary depending on the overall weather conditions; forecasts on clear sky days are more accurate than

FIGURE 1: MODERN SOLAR FORECASTING SYSTEM SCHEMATIC



forecasts on partly cloudy days. Furthermore, forecast errors are lower for area solar power forecasts relative to point forecasts due to the fact that aggregation of geographically disperse systems reduces the random impact clouds have on solar generation system output. There is no standardized approach, however, to calculating and reporting forecast error for solar system predictions thus making comparisons between alternative forecasts difficult.

While much can be learned from the experiences gained using wind forecasts in the past decade for utility planning and operations, the distributed nature of solar deployment and the impact that clouds have on solar resource variability create unique and different challenges. By and large distributed (DG), behind the meter solar is invisible to balancing authorities and utility companies meaning they do not have real-time production data to provide situational awareness. The demand-side nature of DG solar shows up through shifting load patterns. While utilities have decades of experience with load forecasting, DG solar results in a new element of variability and uncertainty to system load not captured by existing load forecasting methods. This is a new paradigm for utilities and much work is needed to integrate solar forecasting into existing load forecasting practices. The consistent patterns of load seen over time are changing due to DG solar and thus load forecasting techniques will need to be modified in response, including greater emphasis on intra-day and intra-hour load forecasting.

Utilities and grid operators need to understand total system load, including the load being served by DG solar, to provide situational awareness. This is critical to proactively prepare for the net load impacts of DG solar variability resulting from changing weather patterns and emerging cloud formations. Systems and models are being developed today to make DG solar “visible” to grid operators and utilities. Clean Power Research is currently providing the California System Operator (CAISO) with forecasts of the 130,000+ DG solar energy systems in the State on an experimental basis. DG solar forecasts require data on DG solar systems, most of which is being collected through the net metering approval and interconnection processes, but might not yet be available for forecasting organizations to access.

SOLAR FORECASTING SERVICE PROVIDERS

- Clean Power Research (U.S.)
- 3 Tier (U.S.)
- AWS TruePower (U.S.)
- JHtech--Solar Data Warehouse (U.S.)
- Windlogic, Inc. (U.S.)
- Global Weather Corporation (U.S.)
- Green Power Labs (Canada)
- Iberdrola Renewables, LLC (Spain)
- irSOLaV (Spain)
- Meteologica SA (Spain)
- NNERGIX Energy Management, S.L. (Spain)
- Meteocontrol Energy and Weather Services (Germany)
- WEPROG (Germany)
- Reuniwatt (France)
- ENFOR A/S (Denmark)
- Datameteo (Italy)
- DNV-GL (Garrad Hassan, Inc.) (Norway)

In California the CAISO, utility companies and other market participants are using solar forecasting services for a variety of applications. Similar organizations in other regions including New Jersey, Hawaii, Arizona, and Colorado are beginning to experiment with using forecasts of solar plant production for operations and planning purposes. Grid operators and utilities in other regions are actively researching forecasting needs and potential solutions. Regional grid operators and balancing authorities can use forecasts of variable generation to determine the need for operating reserves and for scheduling utility-scale solar plant generation. An emerging use of variable generation forecasting is to predict significant ramping events caused by sudden changes in output from wind and solar generators. Utilities and energy traders can use forecasts of variable generation to develop bidding strategies for hour-ahead and day-ahead markets. Solar energy forecasts of distributed, behind the meter solar systems can be used to create more accurate load forecasts, as grid operators must prepare to meet system load net of DG solar. Distribution utilities can also use area forecasts of distributed solar to gain situational awareness to address potential reliability concerns within the distribution networks they manage. In addition, forecasts of variable generation, both central utility scale and distributed systems, can be used for planning purposes. In practice today, solar forecasting is used primarily at the system level to schedule energy production from large utility-scale solar plants. Developing tools that use forecasts of DG solar is still in the research and development stage in the U.S.

Based on questionnaire responses, some forecast providers report challenges in obtaining timely and reliable data from their utility clients to prepare a solar forecast and in some cases a lack of the necessary information technologies to efficiently integrate with their forecasting systems. In addition, communications between forecast providers and end users can be challenging in terms of clearly articulating forecasting needs and the value that solar forecasting can bring to utility planning and operations. All solar forecasting service providers responding to the online questionnaire indicated ongoing research and development efforts to enhance their solar forecasting services.

Predicting the output of solar energy plants for various forecast time horizons can be a valuable tool allowing grid operators and utilities to reduce the costs of integrating solar sources of generation into the existing grid. This report represents a snapshot in time, as we anticipate rapid developments in forecasting methods and uses in the coming years.

TYPES OF SOLAR FORECAST

TYPE	
Day-ahead, hour-ahead, & intra-hour	Forecasts based on time horizon.
Central utility-scale vs. DG solar	Large-scale vs. Small scale solar installations.
Probabilistic vs. Deterministic	A range of possible solar system output based on probability or a specific output value.
Point vs. Area forecasts	Forecasts for one solar plant versus a forecast for an aggregate of geographically dispersed solar energy systems.
Output vs. Rate of change	Forecast of power output versus expected change in output over the forecast time step.