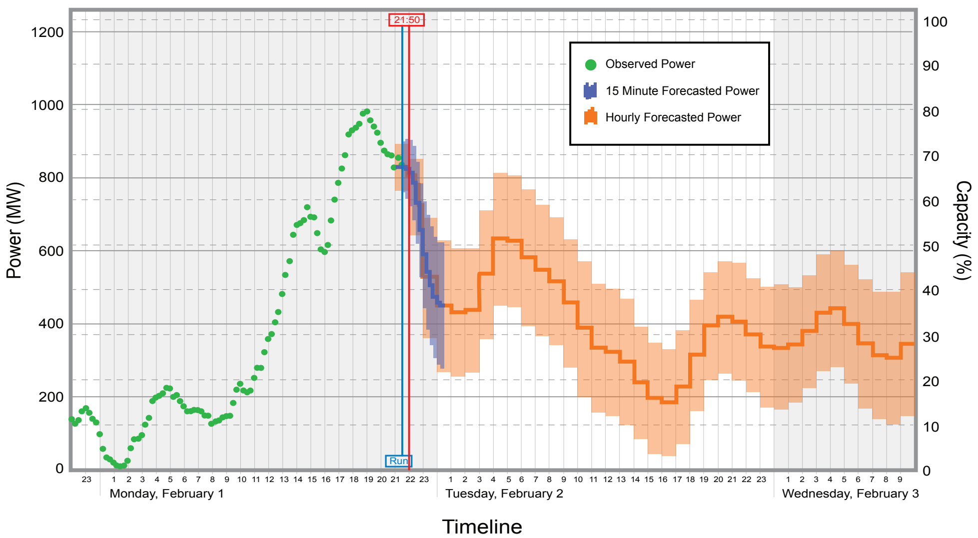
FORECASTING WIND AND SOLAR GENERATION: IMPROVING SYSTEM OPERATIONS



Many power systems with relatively high shares of wind power have integrated wind forecasting into system operations. This graphic, based on sample wind forecasting output for Xcel Energy (a utility in the United States), shows a wind power forecast over a 36-hour horizon, including actual power generation (green dots) up to the initial forecast point, the predicted wind power (solid line), and the typical forecast error from the preceding seven days (shaded area) [1].

FORECAST ACCURACY

Forecast error is the difference between forecasted output and actual generation. Errors are used to produce forecast accuracy metrics, which enable system operators to anticipate uncertainty in scheduling and compare various forecasting methods. Three widely used accuracy metrics are [3]:

- *Mean bias error* – indicates whether the model is systematically under- or over-forecasting
- *Mean absolute error* – measures the average accuracy of forecasts without considering error direction
- *Root mean square error* – measures the average accuracy of forecasts without considering error direction and gives a relatively high weight to large errors.

Factors that affect forecast performance include forecast time-horizon, local weather conditions (which influence variability in VRE resources), geographic scope, data availability (e.g., plant size, location, components), and data quality (e.g., consistency, accuracy, resolution). The accuracy of VRE forecasts generally increases at shorter time intervals. However, frequent forecasts are only useful when their time-steps match the time intervals in which system operators can make actionable decisions. Practitioners can minimize forecast errors by customizing their methodology to account for local conditions and system operator needs.

Forecasting is a crucial and cost-effective tool for integrating variable renewable energy (VRE) resources such as wind and solar into power systems.

VRE forecasting affects a range of system operations including scheduling, dispatch, real-time balancing, and reserve requirements. By integrating VRE forecasts into system operations, power system operators can anticipate up- and down-ramps in VRE generation in order to cost-effectively balance load and generation in intra-day and day-ahead scheduling. This leads to reduced fuel costs, improved system reliability, and minimized curtailment of renewable resources.

FORECASTING METHODS

In general, forecasting methods fall into two categories. *Physical methods* input weather data (e.g., temperature, pressure, surface roughness, and obstacles) into **numerical weather prediction** (NWP) models to create terrain- specific weather conditions, which can then be converted to energy production. *Statistical methods* use historic and real-time generation data to statistically correct results derived from NWP models. **Persistence forecasting** is a simple statistical method that assumes current generation levels will remain unchanged in the very near future. Persistence forecasts are often used as a benchmark or reference model to evaluate more advanced methods [2].

WIND VERSUS SOLAR FORECASTING

Wind energy forecasting is widely implemented among power systems with modest to high levels of wind power generation (e.g., Denmark, Ireland, Texas). Solar power forecasting is relatively new and not as widely used, though methodologies and best-practices are rapidly evolving.

Both wind and solar forecasts utilize NWP models to predict variables such as temperature, humidity, precipitation, and wind. Solar forecasts also employ sky imagers (digital cameras that produce high-quality sky images) and satellite imaging (data from networks of geostationary satellites) to track and predict cloud formations at different timescales [3].

Forecasts for distributed solar photovoltaic (PV) generation are more difficult to produce and are most accurate when near real-time meter data and detailed static data (e.g., location, hardware information, panel orientation, etc.) are available for all interconnected systems. **Up-scaling** is a less detailed method that uses a subset of representative PV systems to forecast regional generation [3].

CENTRALIZED AND DECENTRALIZED FORECASTING

Centralized VRE forecasting is widely considered a best-practice approach for economic dispatch. Administered by the balancing authority or system operator, centralized forecasts provide system-wide forecasts for all VRE generators within a balancing area. **Decentralized VRE forecasting**, administered by individual plant operators, provides plant-level information to help inform system operators of potential transmission congestion due to a single plant's output.

Compared to decentralized forecasts, centralized forecasts provide [4]:

- Greater consistency in results due to the application of a single methodology
- Lower uncertainty due to the system operator's ability to aggregate uncertainty across all generators
- Reduced financial burden for VRE plants to produce and submit individual forecasts.

Reliance on a single forecasting methodology for centralized forecasts can increase the risk of systematic bias. A common way to improve centralized forecasts is through **ensemble forecasting**, whereby practitioners combine and aggregate the results from different forecasts produced by multiple forecast providers or methods [5].

INTEGRATING VARIABLE RENEWABLE ENERGY FORECASTING INTO SYSTEM OPERATIONS

Integrating VRE forecasts into energy and market management systems improves efficiency of system operations at various timescales. **Day-ahead forecasts** provide hourly power values for three to six days ahead. They are used in the scheduling process to help avoid costs and inefficiencies due to unnecessary starts and stops of thermal generators. **Intra-day forecasts** typically provide power values with frequent time steps (i.e., every ten minutes) up to six hours ahead [4]. They are used in real-time dispatch and market-clearing decisions. **Ramp forecasting**, useful for increasing grid reliability, identifies the risk and potential for rapid and sustained change in power output within a specific time interval [5].

Forecasts for distributed PV can be integrated with load forecasting to obtain net load forecasts, increasing the visibility of demand-side variability [5].

OBTAINING FORECASTS AND TRAINING SYSTEM OPERATORS

System operators can procure forecasts from third-party vendors or meteorological research institutions, or they can develop in-house forecasts.

Integrating VRE forecasts with real-time system operations requires advanced information technology, standardized data requirements, and certification for forecast-relevant data. Control center staff may require additional training on VRE plant models and new decision support tools for integrating VRE forecasts in dispatch decisions.

	Type of Forecast	Time Horizon	Key Applications	Methods
Generation	Intra-hour	5-60 min	Regulation, real-time dispatch, market clearing	Statistical, persistence
Generation	Short term	1-6 hours ahead	Scheduling, load-following, congestion management	Blend of statistical and NWP models
Generation	Medium term	Day(s) ahead	Scheduling, reserve requirement, market trading, congestion management	NWP with corrections for systematic biases
Generation	Long term	Week(s), Seasonal, 1 year or more ahead	Resource planning, contingency analysis, maintenance planning, operation management	Climatological forecasts, NWP
Decision Support	Ramp forecasting	Continuous	Situational awareness, curtailment	NWP and statistical
Decision Support	Load forecasting	Day ahead, hour-ahead, intra-hour	Scheduling, economic dispatch, congestion management, demand side management	Statistical

Various types of VRE forecasting have different time horizons, methods, and applications in system operations [2].

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Greening the Grid provides technical assistance to energy system planners, regulators, and grid operators to overcome challenges associated with integrating variable renewable energy into the grid.

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