Digital Solutions for Optimizing Renewable Generation into the Energy Grid

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The long-standing paradigm of producing electricity by large-scale utility plants located near fuel sources, moving electricity to the location of the demand via wires, and distributing the electricity to individual consumers, has been the model of utility operation for over a century. This model has relied heavily on the availability of low-cost fossil fuels, especially coal, the most carbon-intensive fossil fuel, to generate electricity and heat.

Policy decisions (e.g., tax credits, feed-in tariffs, and renewable portfolio standards) and the rapidly falling production cost of wind and utility-scale solar have driven the shift from fossil fuel electricity generation to renewables. Growth in distributed energy resources (DERS) can further reshape or shift localized consumption patterns, complicating bulk energy and distribution services in some regions and system load dispatch decisions.[1]

The rising cost of natural gas is accelerating the growth of renewable generation. For example, in the first half of 2022, 24% of U.S. electricity generation came from renewable sources. Wind capacity is expected to increase by 12% in 2022 over the previous year, according to the U.S. Energy Information Administration (EIA). Utility-scale solar reached 65GW of capacity earlier this year, an increase of 31% over the past year. The growth in renewable energy resources, principally wind and solar, is forcing utilities to reimagine a grid with relatively few large power generation stations to one dominated by myriad smaller renewable generators.

Integrating large blocks of variable renewable generation into the grid is challenging for grid operators and market traders. In this paper, we examine how GE Digital has developed advanced algorithms that calculate wind farm and solar field power net generation, how those predictions are integrated within facility operations and maintenance to produce more accurate generation predictions, and how this information allows owners to optimize the economic value of the assets when engaged in electricity market trading.

See how Tampa Electric is swiftly evolving their renewable needs with GE Digital

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[1] DERs are physical and virtual assets deployed across the distribution (relatively low voltage) grid, typically close to load, usually behind the meter, which can be used individually or aggregated to provide value to the grid, individual customers, or both. DERS are typically small, flexible resources such as customer-sited batteries, electric vehicle charging, rooftop solar, and smart thermostats. DERs may also include energy storage devices such as batteries or flywheels. Of late, many industry leaders consider demand response and energy efficiency programs as falling within the definition of DERS.

Predicting Renewable Generation

The variable nature of renewables has created challenges for grid operators responsible for ensuring electricity supply always meets electricity demand (Figure 1). Not long ago, plants were designed for dedicated missions, such as base, intermediate, and peaking load applications, and plant dispatch order was predictable. The plant with the best efficiency and lowest operating costs was dispatched first, and so on. This level of predictability no longer exists in the modern power market.

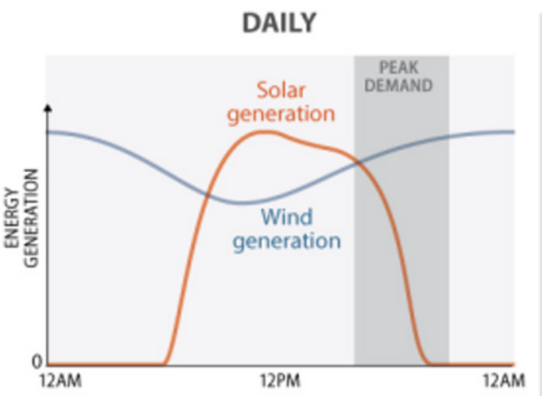

Figure 1. General patterns for U.S. wind and solar generation. Specific generation patterns vary by region, local weather, and other factors. Predicting these patterns is essential for resource planners. Source: *U.S. Energy Information Administration*

With the dramatic growth in renewable generation, predicting the amount of wind or solar generation in a day-ahead (DA) market, much less in real-time (RT) markets, is very challenging, as the wind doesn't blow and the sun doesn't shine on a defined schedule (Figure 2). Until bulk energy storage and smart grid technologies are widely commercialized, dispatchers will continue relying on flexible fossil-fueled plants as a "spinning reserve" to cycle plants to rebalance supply and demand quickly. Spinning reserve resources include "flexible" plants with advanced automatic generation controls that feature fast ramp rates and fast-start simple cycle combustion turbines.[2] Accurately predicting the available renewable generation is essential to select the most economical combination of utility assets available to the power market.

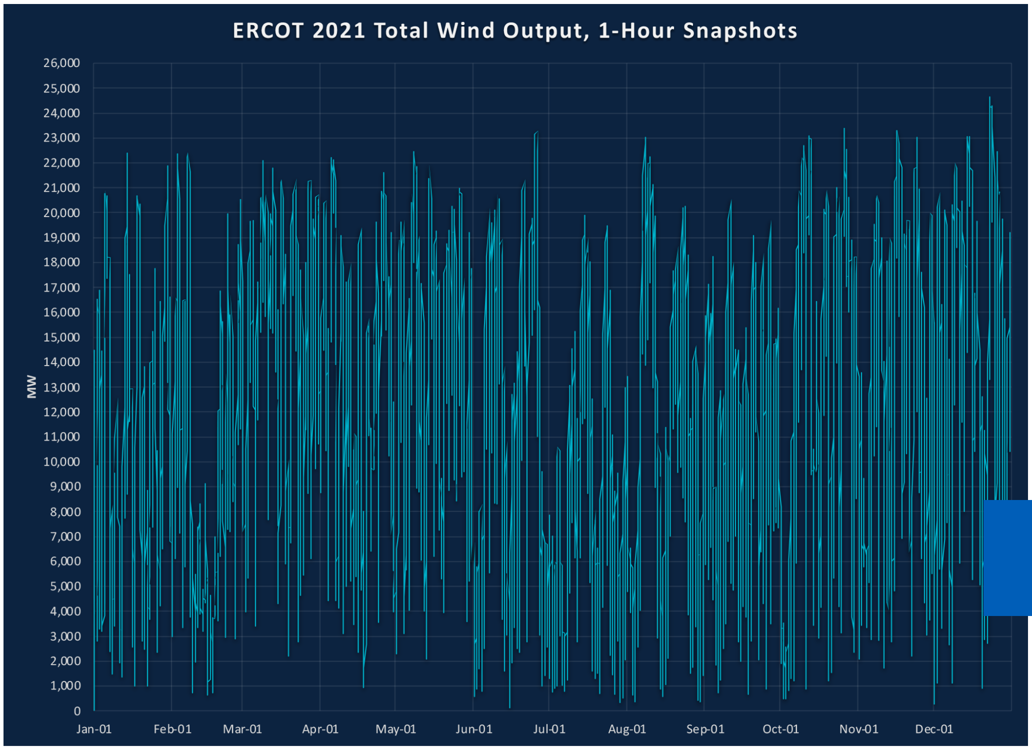

Figure 2. Source: *ERCOT*

[2] See *Digital Solutions for Optimizing Combined Cycle Plant Operations* for a more detailed discussion of flexible plant operations.

Figure 3. The GE Digital AI/ML model predicts wind turbine power generation during 15-minute intervals for the day-ahead market and displays the actual turbine farm combined output. The model also includes predicted "lost availability" based on equipment degradation. Source: *GE Digital*

Grid operators must have the tools to predict wind and solar better to optimize power production. Wind and solar are, by nature, uncertain, dependent on a variety of complex and challenging factors to predict atmospheric forces, and are often affected by unique site characteristics (e.g., terrain, wind farm configuration). Wind turbines, for example, may generate less electricity than expected because of the uncertainties in forecasting wind speed, direction, and the complex flows between wind turbines within a specific wind farm. With improved models that accurately predict available capacity, asset owners and operators can maximize the economic value of their sizable investments and more skillfully bid into the energy market.

The issue for plant operators is how to produce the best estimates of wind output on a more-or-less continuous basis. One approach is to develop statistical models based on the science of atmospheric physics. Researchers at Lawrence Livermore National Laboratory (LLNL), for example, have spent many years attempting to improve the fidelity of wind forecasting models through the use of complex numerical and high-resolution computer models to analyze intricate wind patterns to predict wind turbine output and the uncertainty (confidence level) associated with these predictions. Such complex models do not have practical application bidding into the DA electricity markets. There are also several general-purpose computational fluid dynamic models available that may be used to provide estimates of turbine farm output under prescribed conditions for initial wind farm design. These static performance models also have limited application in predicting wind farm performance under varying atmospheric conditions, do not accurately account for hourly capacity due to equipment degradation and maintenance practices, and will have weather forecast inaccuracies.

Figure 4. The GE Digital AI/ML model performance predictions for a solar field with real-time production superimposed. Source: *GE Digital*

GE Digital has taken a unique approach to renewable performance prediction. Based on historical site data, a site-specific model using artificial intelligence (AI) and machine learning (ML) tools with probability forecasting has been developed for solar and wind power generation. The empirical model is then customized with customer data enabling the model to accurately predict how each turbine in the field operates and how it interfaces with the grid. The model uses historical weather data and weather prediction data from suitable sources to account for the higher sensitivity of wind and solar to weather forecast inaccuracies. AI/ML is used to continuously update the model based on the latest performance to capture the wind turbine interactions within a given field.

Further, the decrease in turbine performance due to equipment degradation is determined and factored into the predicted performance of the wind farm. Figures 3 and 4 illustrate performance data displayed by the predictive models for a wind farm and a solar field, respectively, on a 15-minute interval. The data represents a macro view of the owner's wind and solar power generation fleet. Also, the predictions are presented in terms of statistical confidence intervals, such as "P10 Capacity" which represents the generation that 90% of the time will be achieved, as shown in the figures. The benefit is better visibility to risk, giving operators and marketers more certainty and buy in.

Real-world Performance

GE Digital's Asset Performance Management (APM) suite covers the full spectrum of APM services, from risk assessment and asset strategy development through condition-based maintenance, predictive maintenance, reliability center maintenance, root cause analysis, and inspection and compliance management. The APM is configured to assist equipment operators in optimizing asset performance to increase reliability and availability, minimize costs, reduce operational risks, and decrease unnecessary and unplanned maintenance expenses. APM may be deployed in the Cloud or other IT infrastructure.

The heart of the APM is software models that analyze and simulate real-world conditions to predict how renewable generation will behave in the future so that cost and risk may be managed more effectively. Further, when APM is integrated with GE Digital's Production Planning capacity forecasting, it integrates normally disparate workflows between maintenance and dispatch. In sum, GE Digital provides actionable information that will allow the owner to reduce fuel consumption, reduce emissions, and improve capacity while reducing operational risk.

The APM Solution consists of the following for renewables:

- **Health:** Provides unified view of assets' current state and health using an Asset Health Manager with customer-configurable dashboards and health indicators, and supported by operator rounds, calibration management and elog capabilities.
- **Reliability:** Leverages reliability analytics and predictive monitoring using "digital twins" that are supported by OEM expertise to reduce operating risk. Digital twins are analytic models of a customer's plant equipment, system design, and dispatch profile. Also included are collaboration and knowledge management tools to improve worker efficiency such as root cause analysis and production availability analysis. Furthermore, performance analytics can be deployed, providing visibility to performance data, trends, and insights, across the entire range of operating modes and loads for thermal assets.
- **Strategy:** Tools and techniques to help optimize asset strategies across availability, reliability, risk, and costs enabled by asset criticality assessment, reliability centered maintenance (RCM) and failure modes and effects analysis (FMEA).
- **Industrial Data Diagnostics:** Pinpoints opportunities to improve data quality and asset performance with data quality recommendations, benchmarking analytics, preventative maintenance diagnostics.

The APM solution configured for renewables integration can combine all or one of the above solutions with weather prediction, other pertinent factors and an AI/ML digital twin via Production Planning to provide an availability informed prediction of wind turbine and solar field electricity production (Figure 5). APM can integrate with the facility's computerized maintenance management system (CMMS) and provide SmartSignal predictive diagnostics to produce alerts for operator attention and resolution. Pending CMMS work orders, estimated equipment degradation, and other unique factors are used in algorithms that predict overall wind farm availability, which is used for production planning and capacity predictions. In other words, maintenance planning is directly linked with production planning so that availability and reliability metrics are integrated into performance predictions and, thus, optimize electric power market trading (Figure 6).

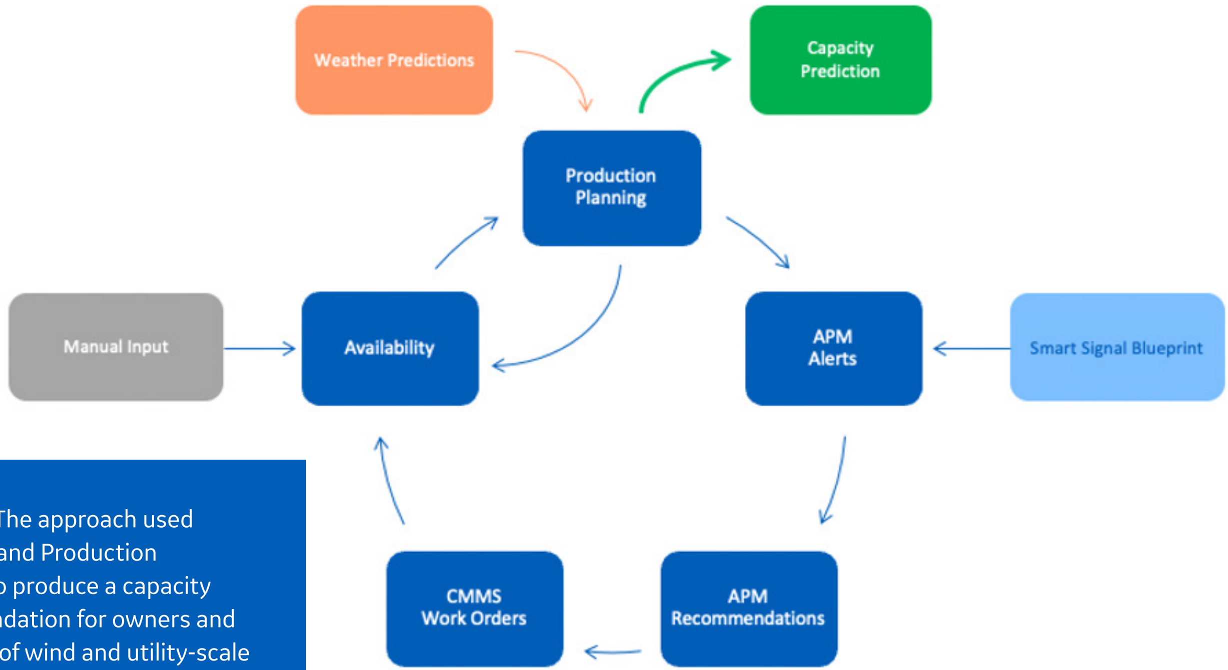

Figure 5. The approach used with APM and Production Planning to produce a capacity recommendation for owners and operators of wind and utility-scale solar plants engaged in electric power market trading and dispatch planning. Source: *GE Digital*

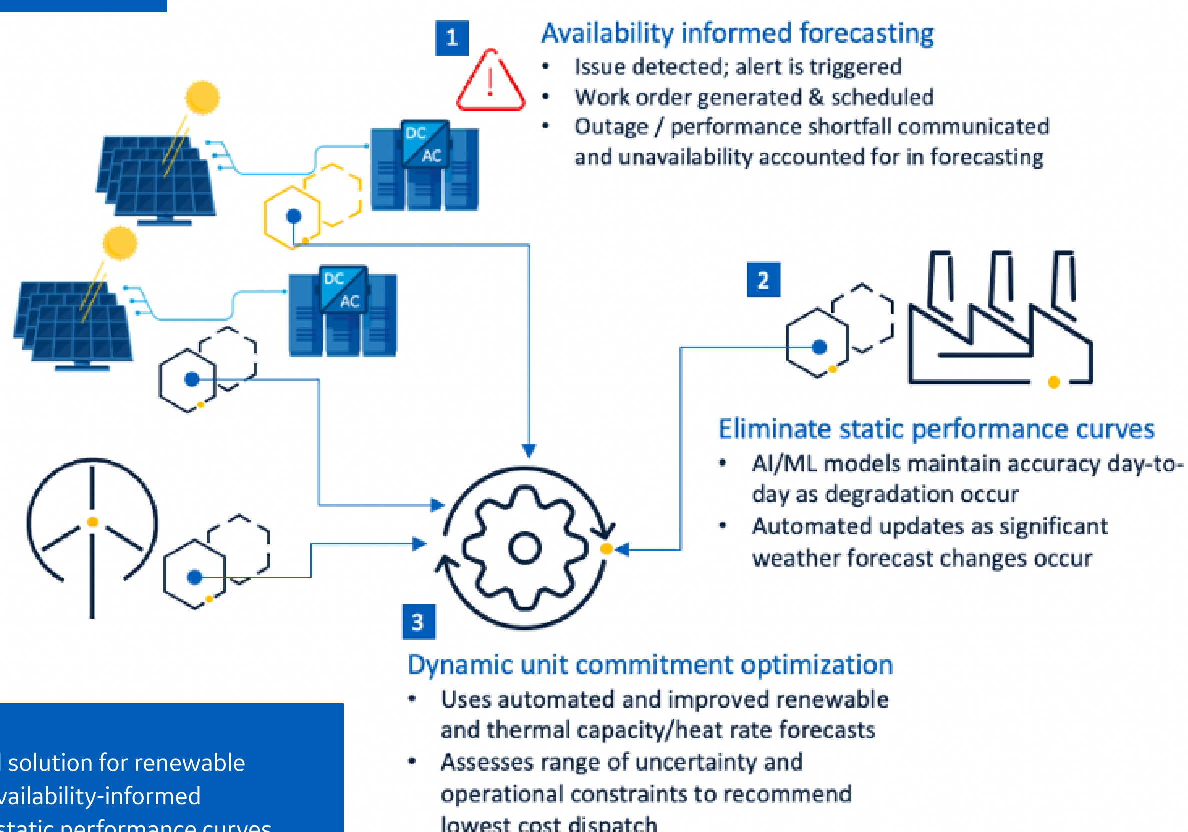

Figure 6. The GE Digital solution for renewable generation integrates availability-informed forecasting, eliminates static performance curves, and will dynamically[3] optimize commitment to identify the lowest cost dispatch. Source: *GE Digital*

[3] Currently part of GE Digital future roadmap plans

Capacity Predictions Drive Market Trading

Thus far, this paper has presented an overview of GE Digital's use of "Digital Twin" models of a customer's unique project characteristics combined with weather predictions based on AI/ML to determine renewable energy resource performance. Further, the plant performance is informed by the GE Digital APM based on equipment degradation and CMMS status to produce probability predictions of net electricity supply available to the power market. The challenge is to connect utility-scale forecasting with market analytics to improve market participation strategies. Traditional models allow participants to hedge risk because the fuel source is controlled easily. Not so with renewable generation.

Many electricity traders wrestle with an overabundance of data that must be consolidated quickly to actionable intelligence so that bids and offers into the power market maximize revenue while balanced with the desired level of risk. Capacity estimates may be too aggressive based on overly generous asset performance estimates, so shortfalls are filled by expensive fossil fuel generation. On the other hand, capacity estimates may be too conservative, leaving money on the table. Traders are often relegated to assuming too much risk without full knowledge of the material condition of the assets (e.g., operational status, pending maintenance, equipment degradation, and accurate weather forecasts). How does an energy trader find the "sweet spot" where risk-based capacity offers maximize the asset's economic potential?

GE Digital addresses the problems of optimizing plant operations under uncertain conditions while minimizing generation risk with Production Planning, that provides two distinct offerings for regulated and deregulated markets, discussed later in this paper. Production Planning leverages the Digital Twin models that are continuously updated based on actual performance for each facility in your fleet, as described earlier, such as forecasted wind speed, ambient temperature, site humidity, as well as predicted and risk-based capacity, as discussed earlier. With Production Planning for deregulated markets, AI/ML models for all relevant market prices that affect your fleet operating economics are also developed, such as predicting day-ahead and real-time locational marginal pricing (LMP).[4]

[4] Locational marginal pricing is a way for wholesale electric energy prices to reflect the value of electric energy at different locations, accounting for the patterns of load, generation, and the physical limits of a transmission system. In New England, for example, wholesale electricity prices are identified at over 1,000 pricing nodes (i.e., locations) on the bulk power grid. The LMP establishes the price for electricity purchases and sales at specific locations on the operator's grid. The ISO typically calculates day-ahead (DA) and real-time (RT) LMPs based on adopted market rules. DA LMPs are calculated based on the energy offers and bids scheduled in the DA energy market from all market participants for all applicable locations. RT LMPs are based on each participants energy offer for each generating resource, purchases from external resources, and a dispatchable asset-related demand resource based on economic dispatch of the resources, while observing resource and transmission constraints. ISO New England, for example, calculates the RT LMP every five minutes. Each ISO has different market rules.

Utility Renewable Assets

Production Planning answers the crucial questions asked by energy traders, offtakers, fuel buyers and asset managers when participating in the DA and intra-day electricity markets:

- How much energy can my asset generate tomorrow?
- How much will that energy be worth?
- What is the right bid strategy to match by bid profile?

Production Planning addresses these and other questions for utility and financial clients who hold merchant price risk through a renewable energy offtake agreement, with its Offtake Risk Advisor:

- Hedge Risk: Minimize exposure to intra-day price variance by confidently participating in Day Ahead markets
- Create Process Efficiency: Automation of data capture and analysis assures accurate, reliable MW and price forecasting
- Increase Productivity: Save time while improving accuracy by switching from manual, Excel-based modeling to an automated solution
- Delivers Value: +$2/MWh, equivalent to $1.3M+/yr of additional revenue for a 250MW 30% CF wind farm, by providing a risk-adjusted recommendation for DA market participation

Offtake Risk Advisor Case Study

A 250MW wind farm in Oklahoma, U.S., has a virtual Power Purchase Agreement (vPPA) for 100% of its output and participates in the Southwest Power Pool (SPP) ISO. The vPPA settles at the generation node, so there is no basis risk. Despite the vPPA strike price being above the time-average Real-Time Locational Marginal Price (RTLMP), the offtaker has experienced significant drawdowns.

To assess the ability to provide a hedge to the offtaker through a DA trading strategy, GE Digital began an evaluation in November 2021 using Production Planning. Using its advanced algorithms, the software made daily recommendations of how much energy to offer into the DA market for each hour.

The team calculated daily shadow revenue and costs based on Production Planning recommendations relative to actual prices and generation, then compared that performance to the baseline RT only approach.

With its Offtake Risk Advisor, Production Planning would have produced $2.3 million in additional revenue over RT only.

Merchant Renewable Assets

While most renewable assets are financed under a PPA, there are some with a merchant portion and others that are rolling off their PPA and operating as fully merchant facilities. Most merchant renewable facilities are price takers in the RT market and shut down when RT prices fall below their O&M cost. This makes economic sense, but it reduces the annual operating hours and capacity factor of those facilities. Since DA prices generally clear above RT prices, there is an opportunity to extend profitable operation through DA market participation, but it entails managing price and cost risk. To address these issues, GE Digital developed its Production Planning.

Merchant Renewable Operator Advisor, designed to:

- Increase merchant revenue: Confidently enter DA markets with renewable capacity
- Manage risk: Minimize exposure to generation shortfall and RT price variance with world-class accuracy of energy and price predictions
- Create process efficiency: Automation of data capture and analysis with Production Planning assures accurate, reliable MW and price forecasting
- Increase productivity: Saves time while improving accuracy by switching from manual, Excel-based modeling to an automated solution
- Delivers value: +5pts of capacity factor, equivalent to $2M/yr additional revenue for a 250MW 22% CF wind farm, by providing a risk-adjusted recommendation for DA market participation

Merchant Renewable Operator Advisor Case Study

A 150MW wind farm in Texas, U.S. no longer receives Production Tax Credits, does not have a PPA and participates in the Electrical Reliability Council of Texas (ERCOT) energy market. Since the facility is fully exposed to Real-Time Locational Marginal Price (RTLMP), the plant voluntarily curtails when the RTLMP falls below its O&M cost and restarts when RTLMP passes above the same threshold.

This dispatch approach has been more profitable than operating with no regard to RTLMP. But, there is an opportunity to increase plant revenues by participating in the DA markets. Doing so with renewable assets carries an inherent generation risk where any shortfall between energy committed and energy delivered must be purchased at the RTLMP. Therefore, an accurate prediction of generation and price a day in advance is imperative to managing this risk.

An evaluation was started in November 2021 to quantify Production Planning's ability to provide improved revenue while managing operational risk. Daily recommendations were made of the energy offered into the DA market for each hour. Daily shadow revenue and costs based on Production Planning recommendations relative to actual prices and generation were calculated. The shadow system performance was compared to the baseline RT only approach and a passive DA strategy.

Over nine months, the Merchant Renewable Operator Advisor increased revenue by $3 million over RT only and $2.6 million over passive DA participation.

The preceding discussion generally addressed deregulated utilities and merchant fleets. For regulated utilities and balancing authorities, specifically fleets with renewable assets, the same operational uncertainty remains. Most dispatch and unit commitment optimizers are configured, assuming thermal plant operations are deterministic. Thus, fleets with renewables may risk unnecessary financial exposure caused by excessive expenditures for fossil fuels, purchased power and increasing carbon emissions. When incorporating renewables, probabilistic optimizers are needed to avoid overbuilding/procuring reserve capacity or facing system reliability issues.

As such, GE Digital is actively piloting multi-staged optimization for regulated fleets with renewable assets. It provides day-ahead, day-of, hour-ahead, and 15-minute-ahead plans for how the fleet can reliably meet demand by determining which asset to dispatch to maximize economic value to the owner. Production Planning achieves this goal using AI/ML algorithms, considering the distribution of possibilities in combination with a probabilistic understanding of demand. The inputs include variable generation resources, capacity, transmission constraints, as well as power purchase and interconnection agreements.

Conclusion

The essence of market trading of generation resources is risk management. Missing for many traders is consolidated information on the availability and reliability of resources necessary to make informed decisions when bidding into electricity markets. Wind and solar generation pose unique challenges because the "fuel" is not controlled by dispatchers like fossil fuel-fired plants. Further, the intermittency of electricity production is challenging to predict due to the chaotic weather patterns that typically don't lend themselves to hedging in the RT or DA markets.

GE Digital's Production Planning provides energy predictions for utility-scale renewables with probability-informed forecasting to present the owner/operator with accurate capacity recommendations. Further, when integrated with GE's APM the recommendations are moderated with plant maintenance planning systems and advanced analytics to determine asset degradation and reliability to produce actionable capacity planning predictions.

Production Planning for deregulated markets integrates capacity predictions with market analytics (e.g., the price of power updated hourly with the weather and asset availability) to produce improved bid and offer strategies for energy market traders. The result is a much improved economic dispatch of available generation resources to anticipate market movement in time to capture value while minimizing market risk enabled by accurate asset performance and market predictions. In sum, Production Planning optimizes renewable asset performance under the uncertainty of environmental conditions and minimizes generation risk by preparing capacity, reliability, and availability predictions so that you may derive the maximum economic value of your renewable generation portfolio. Production Planning for regulated markets provides similar economic value and reliability improvement for utilities and fleets in regulated markets.

Learn more about GE Digital APM and improving the performance of your critical assets for renewables generation

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