MAINTAINING

Reliability in Power Grids with High Levels of **Wind and Solar**

A BRIEF FROM ESIG

The power system is evolving quickly as increasing numbers of countries, states, and utilities set 100 percent renewable or 100 percent carbon-free goals. Responding to a number of technical considerations for operating a power grid with increasing levels of renewable generation, system planners, system operators, and utilities are developing innovative ways to increase the flexibility and maintain the reliability of a cleaner power system.

Two aspects of wind and solar generation that call for changes to power system operation are their variability and some aspects of their behavior. Their variability makes balancing supply with demand more challenging. In addition, since wind, solar photovoltaics, and battery storage are inverter-based resources—rather than traditional power plants with spinning masses—their behavior differs from that of traditional generators (coal, natural gas, or nuclear) in ways that change the grid's response to disturbances.

System operators, system planners, and utilities around the world are addressing the integration challenge using a variety of tools. Some are in real time—improved protection and control to maintain system stability during disturbances—and some relate to forecasting. Proven technical and economic solutions such as those discussed here have already enabled cases in which instantaneous levels of variable generation exceed 100 percent (including some export to neighboring regions) and annual levels reach 40 to 50 percent. Very high levels of variable generation will likely require system operators' and planners' use of all of these tools, as well as some innovations still in the pipeline.

Greater System Flexibility

Utilities and system operators and planners are developing new practices to meet demand when variable energy sources are low. On the island of Kauai, Hawaii, as solar capacity increased, Kauai Island Utility Cooperative (KIUC) increased its system's flexibility and helped maintain a stable and balanced system by building combination solar and storage plants. By early 2019, the utility cooperative was able to run at 100 percent renewable energy for short periods of time (see figure 1). A third solar/storage plant commissioned at the end of 2019 will extend the periods when the island can operate at 100 percent renewables. Kauai Island Utility Cooperative has also increased flexibility by converting a gas turbine to operate in synchronous condenser mode (serving as a grid-connected spinning mass but providing no electricity) and by reducing the minimum generation levels on its traditional generators (thus allowing greater quantities of renewables to be brought onto the grid). This additional flexibility allows greater integration of mid-day solar generation.

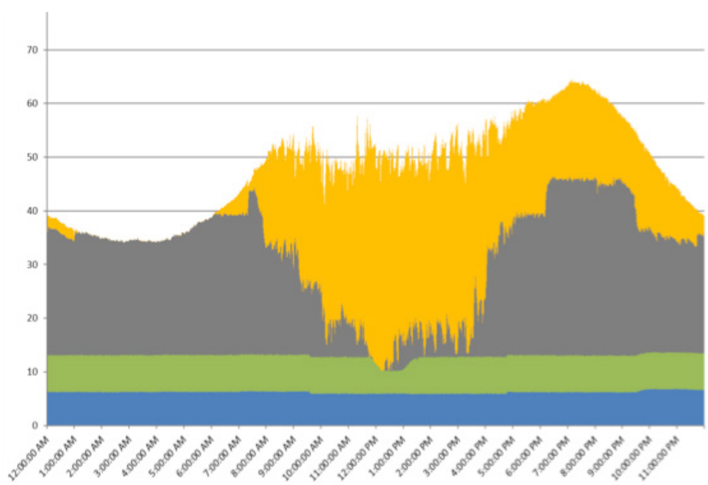

Figure 1. Dispatch of the KIUC system on February 24, 2019, showing 100% renewables operation. Yellow depicts PV and/or battery storage, gray is oil, green is biomass.

Denmark has increased system flexibility by using price variations in the market to incentivize flexibility from different generation sources and by using interconnections with neighboring countries. Denmark's next phase of innovations in system balancing will involve vertical integration to increase the flexibility provided by retail markets, as well as sector-coupling between electricity, heating, transportation, and gas systems (figure 2).

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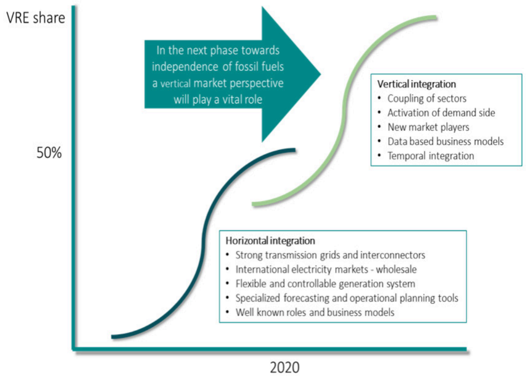

Figure 2. Denmark's transition from 0 to 50% variable renewable energy relied heavily on horizontal integration. The continued transition toward 100% renewable energy will require vertical integration.

Maintaining Stability Through Revamped System Services

With rising levels of variable generation, utilities, operators, and planners are also pursuing innovative system services. As Xcel Energy in Colorado continued building wind and solar capacity and the curtailment of these renewables also increased, the utility began using curtailed variable generation—in particular, wind—as a valuable resource for minimizing operating costs and improving system reliability. Wind generators increasingly contribute to real-time system balancing, which leads to reductions in curtailment of wind as well as to lower fossil fuel costs, since fossil-fueled units can be dispatched at lower generation levels. Xcel Energy (as well as Southwest Power Pool (SPP)) is also using fast-acting wind generation, when it is curtailed, to respond to sudden increases in demand.

The Electric Reliability Council of Texas (ERCOT) also uses solar and wind generation to provide many system services that were formerly provided only by traditional generators. For example, it now takes into account forecasted wind levels when scheduling grid services needed to maintain grid frequency and when calculating the necessary reserves.

The transmission system operator for Ireland and Northern Ireland, EirGrid, is addressing system reliability through revamped system services that incentivize technologies to provide frequency and voltage support when wind output is high. For example, traditional generators receive increased compensation when providing synchronous inertial response during periods of high wind generation. Wind plants and demand-side management units are providing system services such as fast frequency response and primary operating reserves. The revamped market is more than four times larger than the previous market and guarantees sufficient multi-year revenues for owners to recover capital investments.

System operators are also using variable generation to contribute to post-fault recovery. The Australian Electricity Market Operator's system sometimes transitions in 12 hours from one utilizing only traditional fossil-fuel generators to one in which solar and wind output surpasses regional demand. When these periods of high solar and wind output dominate the system, the responses of these variable energy resources also dominate the dynamic performance of the system as a whole. Since post-fault recovery of wind and solar generation in South Australia must be provided locally, the Australian Electricity Market Operator developed a new dynamic modeling tool to assess the post-fault stability and recovery of various combinations of traditional generation and wind, and to determine allowable levels of each type of generation under a range of conditions.

Improved Forecasting

Utilities and system operators are also developing innovative ways to achieve system balancing through improved forecasting methods. In the SPP region, which spans 14 states from Louisiana and Texas to North Dakota, actual wind output can deviate up to 40 percent from day-ahead forecasts. One technique used to manage forecast deviations is SPP's Uncertainty Response Team, which uses statistical analysis and historical data to identify days where wind forecast errors are more likely to be high, allowing SPP to mitigate the risk. SPP performs site-specific wind forecasting to understand the effects of local conditions on aggregate power production and is implementing more granular wind forecasting, new solar forecasts, and new icing forecasts. SPP is investigating new market products to address forecast uncertainty through both dispatch and pricing.

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Proven technical and economic solutions such as these have already enabled the use of energy from variable energy resources to approach 100 percent on an hourly basis and reach 40 to 50 percent on an annual basis. These practical, innovative approaches by system planners and operators demonstrate different paths toward increased system flexibility and reliability under high levels of variable, renewable generation.

Adapted from Debra Lew, Drake Bartlett, Andrew Groom, Peter Jorgensen, Jon O'Sullivan, Ryan Quint, Bruce Rew, Brad Rockwell, Sandip Sharma, and Derek Stenclik, "Secrets of Successful Integration: Operating Experience with High Levels of Variable, Inverter-based Generation," IEEE Power and Energy Magazine November-December 2019. guest editor, Charlie Smith, ESIG. DOI: 10.1109/MPE.2019.2930855.