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INTRODUCTION

There are substantial technological issues to be addressed in order to integrate high penetrations of utility-scale renewable resources into the wholesale power infrastructure.

While the North American electric energy resource portfolio continues to evolve, integrating large-scale renewable resources into the electric power infrastructure presents significant challenges. This is particularly true of variable renewable resources, such as wind and solar, which represent two of the most rapidly growing renewable resources being deployed. The root of this challenge lies in the inherent variability of wind and solar resources, which differentiates these from other renewable resources. Unlike conventional generation technologies, too, which are capacity resources, wind and solar power are energy sources that are susceptible to variability as the result of numerous factors.

TECHNOLOGY AREAS ENABLING BETTER INTEGRATION

The following identifies several areas where advances in technology R&D will pay great dividends in integrating renewable resources into the electric power infrastructure. However, identifying all such areas and exploring each area in detail is beyond the scope of this document. Rather, the following is intended to provoke thoughtful discussion on critical technology R&D areas, as well as others not yet identified, and provide a summary of research activities in these areas.

Areas in which R&D activities are already underway or being suggested include the following:

- Expanded and enhanced transmission technologies, practices, and tools.
- New operations and planning techniques and tools.
- Integration of technologies for increased system flexibility, including electric energy storage, demand response, and expanded control/balancing areas.
- Enhanced power market-based activities and/or rules to better accommodate variable renewable resources.

- Comprehensive economic assessments.
- Large-scale demonstrations of new technologies to advance commercial adoption.

Transmission Technologies, Practices, and Tools

This area encompasses both the need for transmission expansion and the optimization of existing transmission facilities. With regard to the former, some areas of North America, such as the upper Midwest and Great Plains regions, offer significant potential for wind energy output but offer little or no transmission capacity for such resources. Research into advanced new transmission infrastructure, such as 765-kV transmission and high-voltage direct-current (HVDC) transmission, is needed. Development of new transmission expansion planning techniques may be required in order for all the costs and benefits to be accurately considered on a regional basis to evaluate the transmission required for renewable resources.[1] Additionally, research is needed to optimize siting tools to maximize the reliability and minimize the environmental footprint of new transmission rights-of-way (ROW). With respect to land availability for siting large-scale wind and solar plants, alternatives to purchasing large tracts of land need to be considered. Some alternatives include leasing land from private owners or federal government agencies (i.e., the Bureau of Land Management) that would not preclude the use of adjacent lands for other purposes, such as farming or livestock grazing.

In the case of optimizing existing transmission capacity, R&D into methods of optimizing physically and contractually available transmission capacity need to be better understood. For instance, some researchers have suggested the development of new transmission products, such as "flexible firm" capacity, that can accommodate power transfers when lines are lightly loaded.[2] And, in fact, FERC has adopted a requirement for transmission service providers to offer conditional firm service via its Order 890, promulgated in February 2007.[3] Other opportunities for optimizing existing transmission may involve the use of power electronics devices to smooth power output variations at the interfaces between variable resources such as wind and solar and the grid. Many newer generation wind turbines already contain technologies to provide ride-through capabilities and produce VARs rather than consume them. Grid operators, such as the California ISO, recognize that deployment of new wind plants must be built to specific performance standards, and utilize some combination of advanced technologies to provide adequate dynamic reactive capabilities.[4] For example, reactive support and voltage regulation can also be provided through the deployment of additional devices, such as SVCs or STATCOMs, installed on location at wind farms.

As they occur, technology advances will feed into the development of new standards, such as the requirements of many North American Electric Reliability Council (NERC) regions concerning the ride-through capabilities of wind generators. In fact, NERC has formed the Integration of Variable Generation Task Force (IVGTF) to focus on these issues specifically.

Operations and Planning Tools

The area of operations and operational planning is perhaps the most vital for effective integration of variable resources such as wind and solar. Variable generation impacts operations on all time frames including: (1) seconds-to-minutes, which is also referred to as regulation; (2) minutes-to-

hours, which is referred to as load following; (3) the hour-ahead to day-ahead interval, which includes unit commitment; and (4) critical generation ramping times. Furthermore, generation ramping issues present specific challenges, particularly for wind, because typical wind patterns decline in the morning and increase in the evenings – counter to typical load patterns.

One critical area where R&D is needed is the integration of forecasting tools into control room operations for key operational timeframes. As control room operators acquire more and better information, they will require less of a "cushion" of reserves and will not be constrained to operate the system in an overly conservative way. Numerous research projects are underway to develop better tools for wind and solar forecasting. While traditional load forecasting scenarios might involve a single load shape for peak summer and peak winter days, accurate wind and solar forecasting might require hundreds or thousands of specific, hourly load shapes and vast numbers of simulations. Region- and even renewable plant-specific forecasting tools can provide more accurate data. For example, EPRI has worked closely with the California Energy Commission (CEC) and the California ISO (CAISO) to develop and test improved wind forecast algorithms for short-term (e.g., time steps of five minutes over three hours, updated every five minutes) and intermediate-term (e.g., twice-daily 48-hour forecasts) for each of five specific wind resource regions in the state.[5] The potential development of new scheduling tools that incorporate this probabilistic nature of a large portion of the generation portfolio requires study.

In addition to forecasting which provides operators more certainty, tools are needed to manage the variability on regulation and load following time frames. New AGC functionality and maintenance approaches need to be evaluated. Additionally, the role of wind power management, the ability of operators to curtail variable generation output or for variable generators to contribute to system reserves, needs further investigation. Finally operator decision-making tools that aid operators in making quick decisions in using these new tools may need to be developed.

The long-term planning timeframe also requires more robust tools. For instance, multi-year weather and load data is necessary for wind and solar integration impact studies as well as for supply and capacity planning. Another area of research involves identifying the best methods for capacity planning with high-wind scenarios. Various methodologies, such as stochastic, Monte Carlo, and risk-based techniques, can produce the greater number of simulations needed to capture and model the inherent variability of wind and solar resources.

Technologies and Initiatives for Increased System Flexibility

Increasing the flexibility of the electric power system can enhance the ability to effectively integrate variable renewable resources. This is analogous to increasing the physical flexibility of buildings and bridges to improve their ability to withstand the impact of an earthquake. Evolving technologies and tools that can contribute to this much-needed flexibility include the following:

- Electric energy storage technologies
- Demand response
- Expanding control/balancing areas to minimize the impact of variability

Electric Energy Storage

Large-scale electric energy storage technologies appear to offer great potential to "smooth" the energy output of variable renewable resources. These technologies, however, remain longer-term solutions and require R&D in the areas of assessment and demonstration. One key uncertainty is the timing of electric energy storage technologies penetration in relation to renewable resource penetration. Like utility-scale wind and solar installations, large-scale electric energy storage systems also pose high land use requirements.

Scarcity of suitable surface topology in the U.S. is likely to inhibit further significant development of electric utility pumped-hydro storage plants – at any price. The only other viable large-scale storage technology is compressed air energy storage (CAES). This technology uses electricity to drive compressors to charge an underground reservoir during off-peak hours. Then when needed, air is discharged from the reservoir into a fuel-fired expansion turbine connected to an electric generator. By using electricity for the compression cycle, the fuel normally used by a simple cycle combustion turbine plant is reduced by about 60 percent in a CAES plant.

Only two commercial CAES plants are currently in operation (and only one in the U.S.), using underground salt formations to store the compressed air. Broader use of CAES has been limited by the need for the following:

- Demonstrations to prove CAES commercial viability in porous rock/aquifers and in hard rock underground formations.
- Demonstration of the technical viability of the promising concept of above-ground pipelines to store compressed air for CAES applications. Such pipes, similar in size and pressure to those used to transport natural gas, could be sited within an existing transmission or distribution right-of-way.
- Demonstration of adiabatic CAES – a plant configuration in which no fuel is burned during the generation cycle.

Additional next steps needed include (1) exploration and optimization of below ground storage locations, including porous media and salt layers, and (2) a series of demonstration projects with well thought-out test procedures to apply and demonstrate a variety of CAES options.

One potential limitation of utilizing CAES to capture excess output from utility-scale wind or solar installations is the need to co-locate the two facilities, or at least locate them in close proximity to each other. This means that a suitable underground storage reservoir for the CAES plant must be at or near a location with high wind or solar levels (or above-ground CAES must be perfected). A new project, linking CAES with wind power generation, is underway in a project funded by the U.S. Department of Energy (DOE) and a group of municipal utilities in Iowa and adjacent states. These partners are collaborating to integrate a 75- to 150-megawatt wind farm with CAES. The Iowa Stored Energy Park (ISEP) will use wind energy that is not being sold on the grid as well as supplemental, low-cost, off-peak electricity to store air in an underground geologic structure of porous rock located 3,000 feet underground. When complete as planned in 2011, the ISEP will be the first plant in the world to combine wind energy production with energy storage.

Other CAES projects are being explored in West Texas, where TXU Corporation and Shell Wind Energy hope to connect 3000 MW of wind plants to a CAES system that will pump air into underground salt domes, and in New Mexico and the Gulf Coast.[6] Smaller storage devices at strategic locations, such as batteries at substations, could also help alleviate integration challenges.

Demand Response

While a detailed discussion of demand response (DR) is beyond the scope of this paper, effective demand response programs can provide essential flexibility over relatively short timeframes when unpredictable changes in variable renewable resource production occurs. ERCOT's response in calling on 1200 MW of curtailable load to restore system frequency during the incident in Texas in February 2008 demonstrates the effectiveness of using DR to enhance system flexibility.

DR basically involves short-term modifications to end-use electric loads in response to dynamic price and system condition information. By shifting electric load from on-peak periods to off-peak periods, energy providers can use variable renewable generation assets more flexibly. This contributes to grid reliability as well. Providing energy users with alternative pricing structures based on real-time costs enables customers to choose the combination of energy availability and cost that best fits their needs; this also contributes to price stability since demand can be leveled out to match supply. DR programs also help minimize the economic impacts of potential brownouts or blackouts, because commercial/industrial users can avoid unplanned production downtime by voluntarily shifting electricity use. In contrast to the manual and semi-automatic DR programs used today, the most efficient DR systems are fully automated, requiring no human intervention. Rather, preprogrammed DR strategies are executed upon receipt of an external communication signal into the facility's control system. Research into the potential for use of automated DR programs to help reduce the impact of variable renewable resources would be beneficial.

Consolidating Control/Balancing Areas

Finally, the current size of control/balancing areas can actually exacerbate the impact of variable resources. For example, researchers agree that because smaller balancing areas contain smaller resource bases, the exaggerated effect of system granularity can make managing variable resources more difficult. One solution is to consolidate balancing areas, aggregating more wind and solar plants over larger geographic areas and reducing the overall impact of variability on system operations. An alternative solution is to improve the access of one balancing area to markets in nearby balancing areas. Extending this concept, another option is to effectively broaden the resource base upon which each balancing area can draw using dynamic scheduling or some form of sharing of area control error (ACE) between balancing areas.[7]

Power Market-Based Activities

Adjustment of power market-based approaches can address some of the integration challenges that variable renewable resources present. For instance, the development of efficiently-functioning hour-ahead and day-ahead markets can provide an effective environment in which to manage variability, as shown by the experience in New York. A 2005 report on the impact of wind power on the New York State Energy Research and Development Agency (NYSERDA) system concluded that the existing day-ahead and hour-ahead energy markets in New York demonstrated enough flexibility to accommodate wind generation without any significant changes. The study noted that centralizing forecasting would ensure consistency of methodologies and rapidly identify changing weather patterns. With those minor changes in place, the NYSERDA report concluded that wind generation could be held accountable to similar standards as conventional generation in terms of meeting day-ahead forecasts.[8]

Another approach is to adjust market rules to better suit weather-driven resources such as wind and solar. Some of the transmission system tariffs that the Federal Energy Regulatory Commission (FERC) established during the deregulation era provided for penalties for noncompliance with prescribed activities. The imbalance tariff, for instance, included a provision for a penalty charge if generators produced outside the prescribed bandwidth. While the intent was to prevent gaming of the power markets, the regulation effectively discourages adoption of variable generation sources. As the NYSERDA study notes, "If a wind generator forecasted 100 MW for a particular hour but can only produce 80 MW due to a lack of wind then no amount of penalties can get them to produce the remaining 20 MW."[9] Some researchers argue that a cost-based tariff would provide incentives for wind operators to improve forecasting.[10] And, in fact, FERC has introduced a Notice of Proposed Rulemaking (NOPR) to widen the bandwidth for renewable generators that would impose cost-based payments for imbalances on most wind generators.[11] According to FERC, this NOPR (number 890, which reforms its 1996 open access rules), adopted on February 15, 2007, will "facilitate the use of and access to clean energy resources, such as wind power."[12]

Economic Assessments

In addition to the technology R&D work needed, economic assessments are necessary. While some states, such as New York and Minnesota, have already conducted comprehensive studies, utilities in states with mandatory RPSs will also need to conduct studies to identify paths to compliance with these mandates. Methodologies will be needed for assessing wind power vis-à-vis central station solar plants, including cost impacts of additional transmission capacity, power purchases, direct load control (DLC) incentive costs, and peak power costs. In addition, work is needed to identify ways to optimize direct load control incentive levels to ensure adequate availability of DLC when needed to offset renewable resource variability.

Demonstrations to Speed Commercial Adoption of New Technologies

A vital aspect of any R&D program is the use of large-scale projects to demonstrate the feasibility of the technology as a means of fostering commercial adoption of new technologies. In the area of variable renewable resources, numerous projects are underway to demonstrate

various aspects of large-scale wind and solar plants and their integration to the electric power grid.

In the area of wind power, for instance, the California ISO is considering a project to connect wind generators located in the Tehachapi region with the 1200-MW Helms pumped storage facility that Pacific Gas & Electric owns and operates. The largest storage facility on the California ISO system, the Helms facility could provide regulation services when it is in the generating mode but not in the pumping mode. This plant could be used in combination with Tehachapi wind generation, but would require an upgrade to transmission facilities in the region to facilitate the transmission of the Tehachapi energy to the Helms Pump Storage plant. Such a project would also enable the use of the third pump at the plant to store more energy from renewable resources for more hours annually.[13]

In the area of large-scale solar power plants, EPRI is spearheading a multi-partner concentrating solar power (CSP) initiative. In 2008, early studies to assess the feasibility of a large-scale facility in New Mexico were completed. The overall approach was to design a project that was as comprehensive as possible, assessing all available solar technologies, and using a very broad site characterization study to screen and evaluate potential plant sites. Two plant sites met siting requirements and were selected for further consideration. The study identified parabolic trough technology as the most mature technology and also the most economical. In addition, consideration of integrating thermal storage or hybridization into the plant designs was found to increase the reliability and dispatchability of the plant while also slightly lowering the cost of energy.[14] The methodologies and findings of this project will be instructive to other utilities considering a central solar plant project.

Conclusion

As energy providers continue to deploy variable renewable resources, particularly wind and solar power generators, the challenges of integrating these resources into the existing power system infrastructure increase in importance. Recent system reliability incidents in North America during which renewable resource variability either caused or contributed to the problems illustrate the challenges involved. Extremely low wind production on the California system during the 2006 summer heat wave raised supply adequacy concerns, and the sudden loss of wind generation in Texas in February 2008 prompted emergency curtailment actions by system operators. At a time when utility-scale renewable resources are increasingly viewed as a crucial part of the near-term future generation mix, these incidents focus on the need to explicitly address these challenges via a well-crafted, collaborative R&D program. High-priority R&D needs include the following:

- Transmission technologies, practices, and tools: R&D needs include designing and deploying optimal new transmission infrastructures, as well as methods of optimizing existing transmission facilities, to maximize transmission of energy from utility-scale renewable power facilities to load centers.
- New operations and planning techniques and tools: Key R&D needs center on the integration of wind and solar forecasting tools into control room operations for key

operational timeframes, as well as development of more robust tools for integrating utility-scale wind and solar resources into long-term planning.

- Technologies for increased system flexibility: R&D should also focus on increasing power system flexibility to accommodate variability by exploiting electric energy storage technologies (e.g., CAES), integrating demand response programs with variable resource production, and adjusting control operations over larger geographic areas to minimize resource variability impacts.

- Enhanced market-based activities and/or rules to better accommodate variable renewable resources: Key R&D needs include optimizing power market-based activities that encourage penetration and make most efficient use of variable renewable resources.

- Economic assessment: R&D is needed to develop effective and economical methodologies utilities can use to conduct comprehensive impact and cost/benefit studies and develop strategies to comply with mandatory RPS requirements.

- Facilitate large-scale demonstrations of new technologies to advance commercial adoption: Continued efforts are needed to conduct utility-scale demonstrations and projects that will expand industry experience and increase confidence in variable resource technologies.

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