



Challenges in Integrating Renewable Technologies into an Electric Power System

White Paper

Power Systems Engineering Research Center

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Power Systems Engineering Research Center

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The U.S. is not well positioned to handle high penetrations of renewable generation technologies due to the state of the current electric delivery grid along with its associated planning and operation criteria. This shortcoming also applies to the power engineering workforce which is only now beginning to see topics related to integration of renewable resources being introduced in the curriculum. Certainly there are challenges in developing renewable generation technologies, such as reducing the capital costs and improving energy efficiencies of the various types of renewable resources, such as wind, solar PV, solar thermal, and wave. Breakthroughs are also needed in large-scale energy storage technologies. To seamlessly integrate renewable resources in the grid, research and development must address challenges that high penetration levels will have in power system planning and operation, and in grid connection. Finally, the existing workforce and the students going into power and energy engineering careers need to be educated so that they can envision and develop the new approaches and technologies to maintain grid reliability and economy.

The challenges of integrating high penetrations of renewable energy technologies into the grid are less well recognized in part because they require interdisciplinary research in such areas as power systems analysis, communications, power electronics, economics, operations research, and industrial organization. The challenges result from needed changes to achieve national and state objectives for a low carbon energy system.

- (1) Power System Planning and Risk Management: Maintaining the balance between generation supply and real-time customer demand becomes more difficult with variable generation resources, but without large-scale, economical energy storage capacity and demand-responsive loads. Existing planning methods, tools, metrics and standards for resource adequacy need to be developed for an operating environment with variable generation, energy storage, demand-responsive loads, renewable energy standards, and GHG emission policies. Research is needed to understand and respond to the implications of emerging smart grid and customer-owned technologies on grid reliability. New planning and risk management tools must be developed to support decision-making in an electric system with much more uncertainty than experienced historically.
- (2) Distribution and Transmission Planning: The electric power grid is becoming an increasingly automated network and is expected to have increased functionality, higher efficiency, more programmability, and more flexibility. Specifications are needed for the communication networks that are interconnected to the electric grid for sensing, monitoring, and control. Increased penetration of renewables could result in low use of transmission lines unless large-scale storage is available. Distributed energy resources, storage, and demand-responsive load at the distribution level make line loading much more uncertain. Planners have to be able to determine (1) the network topology best suited for this new operating environment, and (2) the effects on system performance and reliability of having a large number of spatially distributed generation sources. New network topologies need to be designed to outperform traditional networks with lower transmission losses, and lower susceptibility to performance and

reliability problems under contingencies. The new topologies must enable vastly increased levels of renewable generation while considering legacy systems and incorporating emerging technologies in HVDC, FACTS, distributed electronic power-flow controllers, and power-conversion devices for interfacing renewable resources. Protection systems must be designed to accommodate the new operating conditions. Advances in computational methods will allow network topologies to be co-optimized as part of resource dispatch hence and network designs must not be designed as static assets and allow for dynamic reconfiguration driven by technical and economic objectives. Finally, new customer use and storage technologies such as PHEV's and EV's pose distribution planning challenges due to increased uncertainties about line and transformer loading.

- (3) Operations: Operations (day-ahead) planning have to account for variability of renewable resources and demand-responsive loads. Market designs must assure adequate business incentives for new generation while providing sufficient opportunities for compensation of embedded generation owners. Increased market price variability could become an important added risk for market participants, particularly under new environmental policies. Maintaining reliability and meeting NERC standards (e.g., for balancing and ancillary services) become difficult at high penetration levels. The standards themselves may need to be re-examined in light of new technologies and customer choices. Dynamic load control for balancing generation with load will require much higher levels of demand-responsive loads. Wide-scale use of PHEV's and EV's calls for even greater management on the load side. Applications are needed for using data from phasor measurement units (PMU's) in wide area monitoring systems. PMU's effectively monitor the dynamic state of the grid, including voltage and angular stability and thermal limits, and can provide early warnings to network operators of imminent failures, stress, or potential instability, thus enabling the operators to take preventive action. Operators of the control system of the future will have to have a new set of decision-making tools to assure power system reliability and stability under uncertainty.
- (4) Interface between the Grid and Renewables: Basic power quality requirements must be met for harmonics, voltage, frequency, etc. for interconnecting any equipment to the grid. Renewable energy generators with their associated power electronics generate harmonics and have electrical characteristics under voltage and frequency excursions that may make it difficult to meet those requirements. Large-scale wind farms and large-scale PV systems present a spectrum of technical challenges arising mostly from the expanding application of power electronic devices at high power ratings. The connection of renewables at the distribution levels also requires significant modification of the distribution design to accommodate bi-directional power flow. Facilitating the integration of distributed energy resources requires innovations in microgrid and energy management systems that transparently provide control and regulation.

New tools for operations and planning are needed to efficiently and effectively allow analysis under the greater uncertainty and the diverse technology options resulting from the new generation and smart grid technologies. New operation tools are needed to incorporate renewable resources with their particular characteristics. These tools include:

- optimal power flow studies with low to high penetration of renewable resources

- power market analysis under environmental policy constraints including low to high penetration of renewable resources
- contingency analysis, stochastic power flow studies, dynamic security assessment and security analysis with stochastic models that capture the uncertainty of renewable resources.
- resource scheduling algorithms that co-optimize the network topology along with resource commitment.

New tools for planning are also needed for:

- long-term infrastructure assessment including generation planning under uncertainty, again including short term uncertainty of renewable resources
- distribution and transmission planning that includes locations of likely renewable resource development
- system resource planning to accommodate all resources including generation and demand resources while considering the structure and flexibility of the transmission topology and higher levels of resource uncertainty.

Finally, the changes in electric energy system technologies, operation and planning methods, and analytical tools requires an empowered education system. New students need to be ready to make contributions when they enter jobs and existing engineers must have their skills upgraded. It is the workforce not just the technologies that will make high penetrations of renewable technologies possible.

Conclusion

Achieving high penetration of renewable technologies with their variable generation characteristics will require many fundamental changes in the ways that electric power systems are planned and operated to maintain reliable service and to do so economically. The National Science Foundation should be expanding its research program portfolio in the area of grid technologies. The Department of Energy should be allocating more of its research portfolio to a systematic study of electric power system operations and planning with high penetrations of renewable generation technologies. Industry should be calling for and supporting more research and education on grid integration challenges. We all need to be collaborating more to achieve the well-qualified power and energy engineering workforce needed for planning, building, operating and maintaining the next generation electric power system, and to manufacture the needed components of that system.

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