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Study on Integration of Renewable Technologies into Power Systems

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Abstract

Renewable energy resources, which are becoming integrated into electric power systems around the world, connect to existing transmission grids at a range of voltage levels. The changes brought about by these new power sources are certain to have a significant impact on system performance and efficiency and to necessitate advances in the planning and operation of electric grids. 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.

Key words: Electric grids, power system planning, grid reliability, power electronics.

Introduction

The increasing penetration of renewable resources will have a significant impact on the performance and reliability of the electricity grid. This is largely because of the variability of renewable resources and the lack of large-scale economical storage capability. This impact will be discussed with respect to planning and operation, primary functions related to grid performance and reliability.

Traditional planning for a power system and for expanding transmission functions has been undertaken in response to the needs of the transmission system based mainly on past and projected loading levels, which have traditionally been estimates of future demand. In the deregulated market, and in the present case of using different renewables (i.e., different in source and in temporal characteristics, as well as in geographic location), transmission planners must respond to the needs of power generators. In other words, planning to expand transmission may now be driven by the location and type of generation, rather than by the needs of the transmission system. To compare, traditional transmission planning processes are driven by loads and have a “bottom up” structure, whereas current transmission planning is driven more by generation needs.

Objectives

Power System Planning and Risk Management: Maintaining the balance between generation supply and real-time customer demand becomes more difficult with variable generation re-sources, 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.

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 net-works that are interconnected to the electric grid for sensing, monitoring, and control. Increased penetration of renewable 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 al - low 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.

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) be-come 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.

Power system operation

Power systems operate in a range of time frames from nearly real time to "operational real time" (i.e., a few seconds). Economic dispatch, that is, determining the most economical distribution of the committed generation outputs to meet a given pattern of load demand while accounting for system losses (Wood and Wollenberg, 1996), is performed in operational real time. The incorporation of renewable resources would significantly alter the traditional approach to unit commitment. The variability of renewable resources would require measures to accommodate fast generation (e.g., a few seconds) changes. The inclusion of storage devices would also alter unit commitment. Both features of renewable resources (i.e., variability and storage) would also alter economic dispatch. No fuel costs would be associated with the renewable energy resources, but increased operational and maintenance costs would be incurred and must be accounted for.

However, the most critical element would be the variability of renewable resources and accounting for sufficient commitment and dispatch of reserve generation to guarantee the reliability of the system in the event that the renewable resource suddenly becomes unavailable. For example, the wind might suddenly stop blowing, or the weather might become cloudy.

Variability is also closely tied in with automatic generation control to maintain system frequency. In power systems, electricity has to be produced to match the load on the system, and load patterns are highly variable. For example, a customer may switch on the TV and air conditioner and blend a smoothie almost simultaneously. The sudden increase in demand, however small, must be met by a concomitant increase in generation. If it is not, the system frequency will change, which will have an adverse effect on expensive power system components, as well as on customer-owned appliances. Hence, the system frequency has to be carefully controlled within tight tolerances.

Frequency control is achieved by providing control mechanisms that adjust the generation output to match the load. With the high degree of variability of renewable resources, either sufficient conventional generation would have to be maintained on active spinning reserve (i.e., be readily available) or sufficient energy storage would have to be provided to guarantee that load and generation remain in balance. Overall, the increasing penetration of variable renewable resources will require a re-examination of the economic dispatch/automatic generation control formulation and could require reevaluation of the limits of frequency variation in the system.

Interface between the Grid and Renewable: 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 renewable 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 micro grid and energy management systems that transparently provide control and regulation.

Results and discussion

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 re-sources with their particular characteristics. These tools include:

1. optimal power flow studies with low to high penetration of renewable resources
2. power market analysis under environmental policy constraints including low to high pe-netration of renewable resources
3. contingency analysis, stochastic power flow studies, dynamic security assessment and se-curity analysis with stochastic models that capture the uncertainty of renewable re-sources.
4. resource scheduling algorithms that co-optimize the network topology along with re-source commitment.

New tools for planning are also needed for:

1. long-term infrastructure assessment including generation planning under uncertainty, again including short term uncertainty of renewable resources
2. distribution and transmission planning that includes locations of likely renewable re-source development
3. 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 require 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. This article has highlighted the potential impact of increased penetration of renewable resources on the planning and operation of the bulk power system. Increased penetration of renewable resources has the potential to introduce major technological challenges that would have to be met to satisfy existing planning and reliability standard.

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