Evaluation of the Impacts of Deep Penetration of Wind Resources on Transmission Utilization and System Stability

Contribution to the Panel: "A Comprehensive Cost Assessment and Analysis of Integrating Wind into the Grid as a Function of Penetration Level"

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***Abstract*—The quest for energy independence and the push towards sustainability coupled with the legislative initiatives and the recent advances in wind generation technology have made wind one of the fastest growing sources for electricity production. The effective integration of wind generation resources into the power grids requires the evaluation of the impacts of wind resources on the system performance. Of particular interest are the impacts on the utilization of the transmission assets and system stability. In this paper, we present techniques which provide a systematic quantification of the impacts of wind resource integration on the system. The evaluation of these impacts on the transmission usage is useful for planning purposes. Similarly, the stability analysis techniques have applications in the operations arena. We present some illustrative examples of the proposed techniques.**

***Index Terms*—wind generation, grid integration, transmission utilization, stability analysis, dynamic performance, operations and planning**

Summary for the Panel Presentation

THE rapid increases in the wind power installations over the past ten years have benefited tremendously from the technology advancements that have brought about significant reductions in the investment costs associated with wind generation. In addition, the quest for energy independence and the growing concerns over climate change issues have led several countries to adopt policies that encourage wider use of the renewable energy sources to bring about tangible reductions in the CO_2 emissions from electricity production. In fact, several jurisdictions around the world have specified ambitious targets for deepening the penetration of renewable generation resources in their electricity systems. Currently in the United States, there are 24 states plus the District of Columbia that have adopted renewables portfolio standards (*RPS*s) which mandate that a certain percentage of energy production must come from renewable energy sources [1]. In this way, regulatory and legislatives initiatives have sparked additional investments in wind. As a result, wind is today the fastest growing source of new capacity for electricity.

The integration of wind generation resources into the system presents major challenges in the operation and planning of the power system due to the nature and the characteristics of wind generation [2], [3]. To effectively overcome these challenges, system operators need practical tools to deal with the intermittent nature of wind generation, given the lack of controllability of wind resources. Indeed, these problems become more pronounced as the penetration of wind increases. The intermittency of wind generation in systems with deep levels of wind penetration impacts the system dynamic performance, i.e., small-signal and transient stability [4]. Furthermore, growing investments in wind projects entail upgrades to the existing transmission grid so as to be able to transport the generation from the wind farm locations to load centers. In this regard, it is widely acknowledged that as the penetration of wind in the power grid deepens, new tools are necessary to assess the impacts of wind on the system for operations and planning applications. In particular, there is acute need for system quantification of the impacts of wind generation on the transmission utilization and stability analysis. We review the existing methods in the literature and tools used by the Independent System Operators (*ISO*s) and Regional Transmission Operators (*RTO*s) to address this need. The review provides a thorough understanding of the key issues that need to be addressed and presents insights on the modeling and analysis required in the development of the appropriate evaluation tools. We use the insights to develop techniques for evaluating the impacts of wind resources on the system.

Wind generation affects the utilization of the transmission assets and the transmission planning activities

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and, in turn, is impacted by the availability of transmission. Indeed, transmission access is critical to ensuring the competitiveness of the wind generation. A salient characteristic of the wind projects is that they must be located at the sites where the wind is plentiful. Good wind sites are often located remotely from electricity load centers, which means that wind generation facilities are more dependent upon long-distance transmission and less able to avoid transmission problems than other technologies. American Wind Energy Association presents, in the white paper [5], specific target issues, including scheduling imbalance penalties, rate pancaking, nondiscriminatory interconnection, and the need for future transmission infrastructure planning; to ensure that wind projects get fair access to transmission.

The integration of new wind projects in the system often often entails grid reinforcement to maintain transmission adequacy and security. Consequently, there is need for appropriate tools which effectively represent the interplay between wind generation and transmission utilization and which may be applied to transmission scheduling operations studies and planning of upgrades/additions in transmission assets. References [6] and [7] outline the approaches used by Midwest ISO and ERCOT for transmission planning purposes. The restricted ability to accurately forecast wind speeds is restricted as the forecasting period increases [8]. Indeed, wind speed forecasting introduces an additional source of uncertainty that must be considered in planning studies. We show that wind integration increases the variance of the flows observed on the transmission lines because wind speed variability leads to intermittent wind generation which, in turn, impacts transmission flows. Thus, wind speed variability needs to appropriately represented when quantifying the impacts of wind on transmission utilization.

Wind interconnection studies also investigate the impacts of wind penetration on the system performance, including stability analysis and voltage regulation requirements. The objectives of the stability studies for systems with wind resources are two- fold. One, to study the impacts of large variations in the wind generation on the system stability. Two, to investigate the capabilities of the wind generators to "ride-through" faults. Stability studies require a representation, with appropriate level of detail, of the dynamic and steady-state behavior of the system. Reference [4] and [9] describe the specific models used for voltage and transient stability analysis. A detailed summary of the stability studies conducted on actual power systems with integrated wind resources is available in [10]. However, the wind forecast error is typically not considered in these studies. Reference [11] address the deviations in the system variables due to wind variability with special attention given to wind forecast error. We adopt such techniques to develop computationally tractable approaches for addressing the stability assessment needs.

The proposed techniques have a wide range of applications ranging from the analysis of investment in transmission assets and wind generation to the investigation of storage systems to facilitate wind integration, from the analysis of the impacts of new policies to the study of alternative operating procedures to provide fair transmission access to wind resources and from stability studies for operational analysis to quantifying environmental benefits of the smart grid implementation. We discuss a few illustrative examples in this presentation.

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