



Frequency responsive services by wind generation resources in United States

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ABSTRACT

United States' Wind Vision report envisions wind energy to generate 20% and 35% of nation's electricity by 2030 and 2050 respectively. Taking in to account of the aforementioned vision, the electric power industry is promoting generation of wind power and integration into the US interconnection grids. Over the last decade, this fast growing grid connected wind power generation has raised several new technical, regulatory and economic concerns for grid operations and electricity markets. Therefore, it becomes essential to perform research study and determine possible solutions for the integration of high penetration levels of wind power with the power grid. This paper focuses on the grid integration issue associated with deteriorated frequency response of power system when significant levels of wind power generation is present in the total generation mix. A brief review of the recently introduced frequency response regulatory standards and requirements for wind power plants in United States is presented along with the turbine manufacturer's advanced grid technology upgrade options to maintain the power system reliability. This paper evaluates the provision of ancillary services such as Emulated Inertial Response (EIR) and Primary Frequency Response (PFR) by wind generation resources, and investigates the impact of different control architectures on frequency response metrics. Further, it discusses the costs, benefits and other economic impacts associated with the various frequency control techniques of wind power plants. Finally, guidelines and priorities for wind turbine manufacturers, generating entities, balancing authorities and regulators are provided to ensure the increased reliability without additional costs.

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1. Introduction

Wind power in the United States is one of the rapidly developing sources of electricity supply satisfying 4.5% of nation's electricity demand at the end of 2014. The two reports '20% wind energy by 2030' and 'Wind Vision' prepared by the U.S. Department of Energy envisioned that wind power generation could constitute up to 20% and 35% of the total US electricity by years 2030 and 2050 respectively [1], [2]. At the interconnection level, on an average in the year 2014, wind energy based generation provided 10.6% of the total electricity needs in Electric Reliability Council of Texas (ERCOT) interconnection [3]. At a particular instant on a windy day, the peak wind power generation could contribute to more than 30% of the total interconnection load. On February 19, 2015, the peak value of wind power generation supplied 34% of the total ERCOT load as shown in Fig. 1 [4]. Fig. 1 plots the hourly averages of actual ERCOT load, wind output, and total installed wind capacity. Such significant levels of participation by wind power in the total system generation mix has attracted the attention from several regional transmission organizations or independent system operators as they have encountered several technical and market issues. As a result, these reliability entities are proposing new regulatory standards, revising protocols and power system modeling procedures, and performing new interconnection studies to improve the grid reliability performance [5].

Frequency response (FR) which is dependent on active power balancing is one of the priority technological and market issues causing concern to the system planners and operators as it effects the system reliability. It measures the power system's ability to stabilize electrical frequency instantly after a sudden, loss of large generation or load as shown in Fig. 2 [6]. The slope 'AC' and point 'C' shown in Fig. 2 are dependent on total system inertia and governor response whereas point 'B' and 'D' are based on spinning and non-spinning reserves allocated during that hour. Failure to mitigate the rapid variations in frequency during such frequency measurable events¹ (ME) could cause under-frequency load shedding and cascading blackouts. According to [7], the decreasing trends in frequency response for all the three US interconnections could be experienced in the future with the increased wind power generation without frequency control capabilities. The high penetration levels of wind power generation could potentially impact the effectiveness of inertial and primary frequency control actions in limiting the quick frequency variations [8]. The frequency response could be improved by using the inertial and primary frequency control in a timely manner, by short term wind forecasting, and by reserve management strategies [9]. In simple words, as the wind power plants with no frequency control capabilities replace the conventional generation capable of reestablishing the overall system frequency, the robustness of the power

system in maintaining reliability may be reduced [11]. Therefore, it is necessary to enhance the control systems of power systems with variable renewable generation² by taking into account the evolution of grid reliability standards and the electricity markets.

The principal objective of this paper is to provide a detailed review on the various regulatory and economic aspects associated with provision of frequency response services by wind power plants. The rest of this paper is organized as follows: Section 2 reviews the current and future reliability standards and requirements associated with the frequency response services in United States. Section 3 explains the future frequency response services and its corresponding markets. A detailed explanation on the possibility of providing frequency response by wind power plants using different control architectures and its comparison with conventional power plants response is provided in Section 4. Impact of various frequency control schemes on both frequency response metrics and wind farm economics is compared in Section 5. Section 6 presents surveys of various original equipment manufacturer's (OEM) patents as well as grid integration technology upgrades of wind power plants associated with frequency and/or active power control. Section 7 provides specific recommendations for research directions for wind power plants to act as ancillary service providers (frequency response services). Finally, Section 8 concludes with discussion on further research.

2. Interconnection standards for wind power plants – frequency/active power control

Interconnection reliability standards also known as grid codes are technical and market requirements for the connection of generating entity to the power system, in order to maintain the reliable and economic operation of the bulk power system. Generally, these standards prepared by the Independent System Operator (ISO) or Regional Transmission Organization (RTO) through a consultative process with North American Electric Reliability Corporation (NERC). These standards are approved as mandatory and enforced by Federal Energy Regulatory Commission (FERC) in the United States and in the Canadian provinces such as Alberta, British Columbia, Nova Scotia and Quebec only and whereas NERC enforces standards in Canadian provinces such as Manitoba, New Brunswick, Ontario and Saskatchewan [12]. Recently, there has been a revision in the interconnection standards to overcome the technical and market issues arising out of large scale integration of renewable generation resources. The important reliability standards on the active power and frequency control (inertial and primary response) requirements on wind power plants are discussed below.

² The analysis in this paper is carried out only for type-3 and type-4 variable speed wind turbines as they represent the majority of current state-of-art technology.

¹ Frequency measurable event is defined in [10].

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