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Provision of enhanced ancillary services from wind power plants – Examples and challenges

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ABSTRACT

Emphasis in this article is on the power system impact of wind power plants capability to provide enhanced ancillary services, i.e. temporary frequency response (TFR) and power oscillation damping (POD). The main objective of the article is to analyze and justify the challenges in the use of TFR and POD from wind power plants (WPPs). The study is conducted with an aggregated wind power plant model which is integrated into a generic power system model, specifically designed to assess the targeted ancillary services in a relatively simple, but still relevant environment. Various case studies with different wind power penetration levels are considered.

The study shows that WPPs can provide additional control features such as TFR and POD to enhance the stability of power systems with large share of wind power. Nevertheless, the results illustrate that the power system stability can be potentially degraded without careful coordination between WPPs, simultaneously providing TFR or POD in power systems with large displacement of conventional power plants by WPPs. The article provides to TSO new insights into the need for service coordination between WPPs into future power systems.

1. Introduction

Across the globe, power systems are continuously changing and expanding through new interconnections and an increased number of wind power installations. As a result, power systems are getting increasingly complex, but also more vulnerable and dependent on wind power production. Moreover, conventional power plants may be replaced by wind power in the future. This aspect raises concerns about the operational security and stability of the systems. One way of ensuring that WPPs are not detrimental to the power system stability and security is to require control functionalities (e.g. reactive power, voltage control, fault ride-through, up-/downregulation of active power, primary reserve, power system stabilization) from WPPs which resemble those traditionally offered by conventional power plants, namely ancillary services (AS).

During the past decade, this concern has led to an intensified research interest from both academia and industry for developing AS for WPPs, i.e. Refs. [1–38], to name but a few. Initially focus was on investigating the capabilities of individual wind turbines (WTs) to provide a given service e.g. Refs. [2–6,8–10], while in the recent years more research is analyzing provision at plant level [7,11,15,19,20,27,30–36], including also operation in isolated power systems [24–26,34]. The frequency stability support in terms of inertia and primary frequency control [4–6,8,13,15,21–23] and the small-signal stability support as the damping of power oscillations [21,32–36] have been investigated thoroughly. Some research is focuses only on particular WT topologies e.g. doubly-fed induction generator or full scale power converter based WTs e.g. Refs. [2–4,8–10,16,17,29] while other address generic variable speed topologies e.g. Refs. [6,8,22,27,31,49]. Little research is dedicated to provision of AS from multiple assets e.g. wind and solar generation combined with energy storage [23]. The coordination of services is barely treated in recent years [12,24,34,38] and without a thorough insight on the need for service coordination between WPPs to avoid instability in the power system. This paper shows how the power system stability can be potentially degraded without careful coordination between WPPs, simultaneously providing services in power systems with large displacement of conventional power plants by WPPs.

As revealed in the European synthesis project *ReServices* [44], most of the research today confirms the technical and operational

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capabilities of WPPs to provide services such as frequency support, voltage support and fault ride-through. These capabilities, available from WPPs and reported in the literature [1–43] for years, have made their way into different technical connection requirements from transmission system operators (TSOs).

As mentioned previously, in the past years several research studies have started focus on development of new control features, such as Temporary Frequency Response (TFR) e.g. Refs. [15,19,24] and Power System Stabilizer like functionality, i.e. Power Oscillation Damping (POD) [20,32–36] at plant level to enhance even more WPP's capabilities to support the power system. TFR and POD delivered by WPPs might become attractive in the context of large displacement of conventional power plants by WPPs in the future. According to [12,20], the consideration of TFR and POD as AS should proceed cautiously and with emphasis on functional systematic needs, as WPPs' contribution is temporarily dependent on wind conditions, mechanical/electrical limitations, control strategies and availability of WPPs. So far, TFR and POD have only been prioritized by few research groups including partners from WT industry [21,39,40]. This is due to the fact that these services normally need temporary power reserve, i.e. prior curtailment of the WPPs with a resulting loss of energy. Meanwhile, discussions on enhanced AS have also been started in several working groups where TSOs are involved. For instance, Hydro-Quebec and Electricity Reliability Council of Texas (ERCOT) have analyzed the possibility to request emulated inertia/synthetic inertial response to be incorporated into future WPPs [13,14,18,19], while the TSO in Great Britain (NGET) has investigated the possibility to include the fast frequency control into their grid code requirement [20]. Power oscillation damping is also required by NGET [20] and recommended by ENTSOE [45]. However, in this respect, the present grid codes (GC) do not formulate clear requirements that enable WT manufactures to translate and implement them into their commercial products, yet [46].

Emphasis in this article is on the power system impact of WPPs capability to provide TFR and POD. The TFR of WPPs refers to the short-term additional active power contribution that can temporarily be released by using the stored kinetic energy in the rotating mass of variable speed WTs. However, as indicated e.g. in Refs. [12,13] unlike the inherent response of synchronous generators (SGs), the capability of WPPs of injecting short-term additional active power into the grid is strongly dependent on wind speed conditions, mechanical/electrical limitation and proprietary control strategy of the turbines.

The POD provision from WPPs refers to the damping of electromechanical oscillations which are typically undesirable in the power system as they limit power transfers on transmission lines, in some cases may even induce stress in the mechanical shaft of SGs [20], and ultimately may lead to system collapse in extreme situations. The POD provision from WPPs has found room for investigations on control strategy design in several recent publications [32–36]. As indicated in Refs. [33,34], the location of WPPs may be a physical limitation in respect to their capability to damp the power system oscillations.

The capability of WPPs to provide TFR and POD have thus been studied in details so far. Nevertheless, the detailed review of the previous research work in the area of AS provision from WPPs [1–45] shows knowledge gaps and needs for further research. The results underline the potential need for further research for better understanding of the main factors influencing the impact of large scale wind power integration on power system stability. Furthermore, to the author's knowledge, the impact of simultaneous provision of ancillary services like TFR and POD from WPPs without any coordination have not been investigated so far for power systems with various wind power penetration scenarios.

According to the synthesis European report [44] further investigations strengthening system reliability are necessary regarding the need for coordination of WPPs in providing AS. Many aspects, such as real limitations imposed by WPPs, the role of the power system characterizations on the implementation of POD, impact of TFR and POD, location of WPPs and the variability of WPPs' output on the power system performance could still be enriched.

The goal of this article is primarily to demonstrate that WPPs can support the power system with TFR and POD. Consequently, an adequate simple power system model should be relatively weak in order to be able to stress and push the system close to its stability limit. In this respect, a generic island power system model instead of a large interconnected power system has been therefore used to generate relevant case studies. Furthermore, an assessment of the entire European grid through simulation studies may be a tremendous task due to the necessary level of information which is not typically available for academia. By studying a small but representative power system that has characteristics and properties similar to continental European is therefore more feasible as long as the proposed solutions are scalable and replicable. Moreover, this small generic power system model is developed with various wind power penetration scenarios [24,34], and therefore the conclusions of this work on the impact of the provision of TFR and POD services from WPPs on a power system with large displacement of conventional power plants by wind power can be approached in a future ENTSO-E network with large wind power penetration. Furthermore, a perfect knowledge of instantaneous available wind power has been assumed. The impacts of available power uncertainty and communication delays on providing AS are out of the scope of this work, as they are considered in details in a new research project [48]. The article does not focus on the design of TFR and POD controllers and parameter tuning, as this has been addressed in many publications over the past years [8–35]. By expanding previous work started in Refs. [24,34] within the frame of research work [43], this article rather focuses on emphasizing the need for coordination between WPPs in TFR and POD provision, in order not to lead towards unstable power system operation. With this aim, it is believed that the work presented in this article provides to TSOs new insights into the need for AS coordination between WPPs in power systems with large displacement of conventional power plants by wind power.

The article is organized as follows. Section 2 briefly presents the enhanced AS from WPPs. Section 3 focuses on the WPP model and its control architecture. A set of simulations, considering different wind power penetrations levels and WPPs' locations, is carried out to reflect how power system stability may be affected when WPPs are required to simultaneously contribute with specific AS. The results show that it is not enough only to require WPPs to exhibit technical capabilities to provide enhanced services, but it is also crucial to coordinate the AS's provision between WPPs in order to ensure a future resilient power system. Finally, conclusive remarks are reported.

2. Enhanced ancillary services from WPPs

The technical capabilities required today in the GC are active/reactive power control, frequency/voltage control and fault ride-through control. In general, the active and reactive power control at the point of common coupling (PCC) is guaranteed at the WPP level by a dedicated controller. Fault ride-through is typically provided at the WT control level due to the fast response times e.g. Refs. [3,9], while voltage control at PCC is usually performed at WPP level [38]. The frequency control can be performed either in the WT level [6,8,16] or in the WPP level [12,15,24]. Today, the above