Electrical Power and Energy Systems 55 (2014) 714–722

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Contribution of type-2 wind turbines to sub-synchronous resonance damping

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ARTICLE INFO

Article history:
Received 12 March 2013
Received in revised form 16 September 2013
Accepted 12 October 2013

Keywords:
Wound rotor induction machine
Rotor resistance control
IEEE first benchmark model
Sub-synchronous resonance
Type-2 wind turbine

ABSTRACT

The rapidly increasing level in wind power penetration is leading to a modification of power system dynamics. Transmission system operators are concerned about this, and are requiring wind farms to comply with some grid codes. For this reason, it is important to determine the grid support capabilities of wind farms, in order to fulfill all current and future requirements. The aim of this paper is to demonstrate that partial-variable speed wind turbines (WT) employing a wound rotor induction generator equipped with an controllable external resistor (so-called Type-2 WTs) are capable to damp Sub-Synchronous Resonance (SSR) occurring on close synchronous generators, when they are connected through a series compensated transmission lines to the main grid. The IEEE first benchmark model (IEEE-FBM) for SSR studies is adopted as test case and modified with an aggregated Type-2 WPP model connected to the system. A damping control algorithm based on adjusting the average value of the external rotor resistance via the control its chopper's duty cycle is presented and implemented using PSCAD/EMTDC software. Detailed computer simulations suggest effective contribution of Type-2 WT to damp SSR affecting synchronous generators.

1. Introduction

Wind energy has become one of the most important and promising sources of renewable energy all over the world, mainly because it is cost-effective and it does not emit pollution [1]. In some countries such as Denmark, Portugal or Spain, the penetration levels of wind energy in 2012 has reached 21%, 18% and 16%, respectively, providing a substantial amount of their electricity demand [2].

As the level of wind power penetration into the utility networks increases, modern wind power plants (WPPs) have nowadays to comply with more restrictive grid codes established by transmission system operators (TSOs). Thus, WPPs must be able not only to generate active power, but also to provide ancillary services to the grid such as fault ride-through capability [3,4], frequency regulation [5] and voltage/reactive power control capability [6–8], as do conventional power plants based on synchronous generators [9]. In addition, in the near future, WPPs will require the capability to damp power system oscillations contributing to power system stability [4]. As an illustration, the European agency ENTSO–E states, in the report "ENTSO-E Network Code for Requirements for Grid Connection Applicable to all Generators," that power system stabilizing capability is a requirement for any generation units (including wind farms) larger than 10 MW (in the case of UK, Baltic countries and Nordic Area) and 50 MW for the Continental Europe Area [10].

Several research groups have investigated both the impact of large scale wind power integration on power system dynamic and transient stability [11–13] and the contribution of different wind turbine technologies to damp the low frequency oscillations of power systems [14–17]. Moreover, different control strategies for low frequency damping oscillations using flexible AC transmission systems (FACTS) devices have been studied [18–21]. Likewise, FACTS devices have been used in order to damp Sub-Synchronous Resonance (SSR) oscillations occurring in a power system series compensated lines [22–24].

On the other hand, the risk of sub-synchronous resonance oscillations in different wind turbines technologies have been studied in [25]. A more detailed analysis of such dynamic response for Type-1, Type-3 and Type-4 wind turbines connected to the grid through a series compensated transmission line can be found in [26–28,16,29–31], respectively. It is worth to remark that such

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0142-0615/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijepes.2013.10.025

Nomenclature

DFIG	doubly fed induction generator
FACTS	flexible AC transmission systems
IEEE-FBM	IEEE first benchmark model
SSR	Sub-Synchronous Resonance
TSOs	transmission system operators
WAMS	Wide Area Measurement System
WPPs	wind power plants
WRIG	wound rotor induction generator
WTs	wind turbines

wind turbine interaction has occurred few time ago in 2011 at Oklahoma State (US), which was detected by OGE company by means of Wide Area Measurement Systems (WAMS) devices installed on the network [32].

Although Type-2 wind turbines are not the most commonly realization used by wind power industry, they share a considerable part of the world wind market [33]. For instance, the OptiSlip trademark by Vestas Wind Systems is available in United States since 2001 [34] and it is still manufactured and installed in several wind farm projects [35]. Type-2 WTs are variable slip wind turbines employing a Wound Rotor Induction Generator (WRIG). They are based on a modification of the generator torque–speed curve via an external resistance placed in the rotor circuit allowing a small slip variation (±10%).

Considering both that such wind turbine technology is already installed in various wind farms and the fact that it can be still installed in some wind farms in developing countries because of its characteristics (simplicity, robustness, reliability and low cost), this wind turbine topology could be demanded to support power system stability. Therefore, it is of interest to determine if such technology is capable to contribute to damp SSR.

This paper proposes an untapped capability of Type-2 based WPPs to suppress power oscillation damping. It focuses on demonstrating that Type-2 based WPPs are able to help close synchronous generators when they engage in SSR, unlike other studies which only consider WT connected through a series compensated line. On this basis, a simple damping control algorithm for a Type-2 wind turbine based on the measurement of a remote input signal is proposed. A Wide Area Measurement System (WAMS) [36,37] is assumed to be present in the controller implementation. The advantage of using this technology is the possibility of obtain real-time measures from remote locations, giving a more accurate vision of the power system dynamics. However, there are some drawbacks mainly related with time delays and system reliability. To validate such concept, the IEEE first benchmark model (IEEE-FBM) for SSR studies [38] is adopted and modified with an aggregate Type-2 WPP model connected to the system.

This paper is organized as follows. In Section 2, a brief overview of SSR oscillations is presented. In Section 3, the power system model as well as the Type-2 wind turbine employed for this study is described. The proposed damping control algorithm is discussed in Section 4 and the simulation results are displayed in Section 5 using PSCAD/EMTDC software. Finally, the conclusions of Section 6 close the paper.

2. Sub-synchronous resonance

According to IEEE SSR Working Group definition, SSR is defined as an electric power system condition where the electric network exchanges energy with a turbine generator at one or more of the natural frequencies of the combined system below the synchronous frequency of the system [39]. The first appearance of the phenomenon of SSR occurred at the Mohave power plant in United States of America when two successive shaft failures came about in 1970 and 1971 [38]. Since then, extensive research have been conducted to understand the SSR phenomenon and reduce its severity by introducing countermeasures to increase the damping capability of the electrical power system.

The most common example of giving rise to undesirable SSR oscillations is due to electrical systems that include series-capacitor compensated transmission lines. Nevertheless, any system condition that provides the opportunity for an exchange of energy at a given sub-synchronous frequency is considered as a potential source to excite power system oscillations [40].

Series capacitive compensation is considered as a highly effective and economical means of improving the power system stability by increasing available transmission capability (ATC) of long transmission lines. However, the aforementioned SSR oscillations caused by the interaction between the series capacitor and the system inductance, have hindered the widespread use of series compensation in electrical power networks.

There are many ways in which the system and the generator may interact leading to different kind of causes for SSR. However, the interactions considered to be small disturbance conditions are typically classified into two categories, namely Induction Generator Effect (IGE) and Torsional Interaction (TI) [41].

IGE occurs because the rotor spins faster than the rotating magnetic field produced by the sub-synchronous armature currents, and consequently, the rotor resistance sub-synchronous to current viewed from the armature terminals is negative. Hence, when this negative resistance exceeds the sum of armature and network resistances at a resonant frequency, self-excitation will be produced resulting in excessive voltages and currents. On the other hand. TI is the interplay between the electrical and mechanical systems. It occurs when the induced sub-synchronous torque in the generator is electrically close to one of the natural modes of the generator shaft, thereby setting up the conditions for an exchange of energy at a sub-synchronous frequency and causing serious damage to the turbine-generator shaft.

Considering that some wind turbine technologies employ asynchronous generators which can be seen as negative resistances from grid side because of the slip, they could engage into IGE-SRR. This issue has been studied in literature [25]. It is worth to remark that TI-SRR mainly requires high-order model of the mechanical part which is not commonly used in wind turbines analysis. Therefore, such type of SSR could be analyzed in a power system with a conventional synchronous generators where the mechanical part is modeled in detail [31]. In this paper, the contribution of Type-2 WTs to damp TI-SRR occurring in the conventional generators is assessed.

3. System modeling

3.1. Power system model

With the aim to evaluate whether Type-2 turbines capability to damp SSR, a modified IEEE-FBM [38] with an aggregated Type-2 based WPP connected to the system is used for this study (see Fig. 1).