Electrical Power and Energy Systems 69 (2015) 327–334

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

An active power control strategy for a DFIG-based wind farm to depress the subsynchronous resonance of a power system

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ARTICLE INFO

Article history:
Received 30 January 2014
Received in revised form 3 January 2015
Accepted 3 January 2015
Available online 11 February 2015

Keywords:
Doubly fed induction generator
Wind farms
Subsynchronous resonance
Auxiliary damping control
Parameter optimization

ABSTRACT

This study presents a novel auxiliary damping control strategy to depress subsynchronous resonance (SSR) oscillations in nearby turbine generators. In the proposed control strategy, SSR damping is achieved by adding turbine generator speed as a supplementary signal at the active power loop of the rotor-side converter (RSC) of doubly-fed induction generator (DFIG)-based wind farms. To design the SSR auxiliary damping controller, a transfer function between turbine generator speed and the output active power of the wind farms was introduced to derive the analytical expression of the damping coefficient. Then the damping effect of the active power of the DFIG-based wind farms was analyzed, and the phase range to obtain positive damping was determined. Next, the PID phase compensation parameters of the auxiliary damping controller were optimized by genetic algorithm to obtain the optimum damping in the entire subsynchronous frequency band. The last, the validity and effectiveness of the proposed auxiliary damping control were demonstrated on a modified version of the IEEE first benchmark model by time domain simulation analysis with the use of DigSILENT/PowerFactory.

Introduction

Series capacitive compensation is an important approach to improve the transfer capability and transient stability of existing transmission systems. However, the extensive use of series compensation can cause SSR, in which electrical networks exchange energy with the generator shaft system at frequencies less than the nominal frequency of the transmission line; this phenomenon results in turbine-generator shaft failure and instability of the power system [1,2].

To prevent the turbine-generator shaft from failing and to depress SSR oscillations, flexible AC transmission system (FACTS) devices (e.g., SVC, TCSC, STATCOM) [3–12], are widely utilized to effectively relieve SSR. These devices should be enhanced with an auxiliary damping controller to provide the extra damping characteristic. Although, the FACTS devices can depress SSR, but installation of such device is expensive, so utilizing FACTS may not be cost effective.

Wind energy is the fastest-growing form of renewable energy in the world because it is clean, non-polluting, and abundant. Wind farms with a scale of hundreds of MW level are increasingly being developed and connected to power systems. Doubly fed induction generators (DFIGs) are widely used in wind power plants because of their capability to decouple control of real and reactive power. With the integration of large-scale wind farms into power systems, some researchers have used the control capability of DFIG to damp power system oscillations; however, most studies have focused on damping inter-area low-frequency oscillations [13–16], whereas relatively very few studies have reported on damping SSR. Ref. [17] proposed the auxiliary control of a DFIG-based wind farm to damp SSR oscillations in nearby turbine generators by addition of a supplemental signal at the grid-side converter of the DFIG. However, the auxiliary controller requires the precise measurement of the angular speed deviation of each shaft segment. The controller parameters are obtained by a time-consuming trial-and-error approach, and the damping mechanism is also not analyzed. Therefore, the use of DFIG-based wind farms to damp SSR oscillations in the entire subsynchronous frequency band and the damping mechanism should be further analyzed.

This study presents the application of auxiliary damping control to the rotor-side converter (RSC) of a DFIG to damp SSR. A transfer function between turbine generator speed and the output active power of wind farms was introduced to derive the analytical

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http://dx.doi.org/10.1016/j.ijepes.2015.01.002
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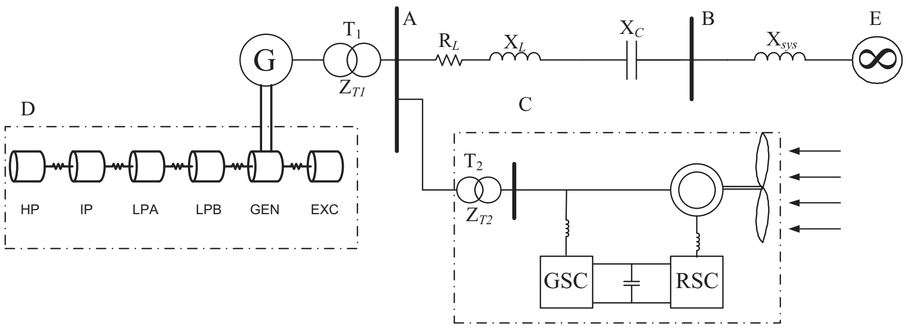

Fig. 1. Schematic of a DFIG-based wind farm connected to the IEEE first benchmark model.

expression of damping. The effect of the active power of the DFIG-based wind farms on system damping was analyzed, and the phase range to obtain positive damping was determined. Then, a new auxiliary damping control strategy was proposed. The PID phase compensation parameters of the auxiliary damping controller were optimized by genetic algorithm to obtain optimum damping in the entire subsynchronous frequency band. Finally, the IEEE first benchmark model, modified by the inclusion of the DFIG-based wind farms, is used to demonstrate the performance of the proposed auxiliary damping control to suppress SSR oscillations by time domain simulation analysis with the use of DigSILENT/PowerFactory.

Power system model with DFIG based wind farm

To evaluate the effectiveness of the proposed strategy on auxiliary damping control, the well-known IEEE first benchmark model, modified by the inclusion of DFIG-based wind farms, is used (Fig. 1). The system consists of an 892.4 MWA turbine generator connected to an infinite bus through a radial series-compensated line. The rated voltage is 539 kV, and the frequency is 60 Hz. A DFIG-based wind farm (200 MW from the aggregation of 2 MW units) is connected to bus A via a transformer. Fig. 1 shows that G represents the turbine generators; C, the DFIG-based wind farms; D, the turbine shaft system; and E, the infinite power grid. $R_L + jX_L$ is the power transmission line impedance, X_c is the captance of the series compensation capacitor, and X_{sys} is the reactance of the transmission line to the infinite power grid. The complete electrical and mechanical data are given in Appendix.

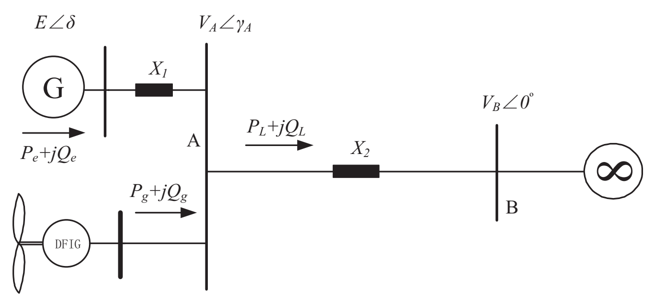

Fig. 3. Schematic of the simplified system model.

Turbine generator shaft system model

The turbine generator shaft system consists of six shaft segments, namely, a high-pressure turbine (HP), an intermediate-pressure turbine (IP), a low-pressure turbine (LPA), a low-pressure

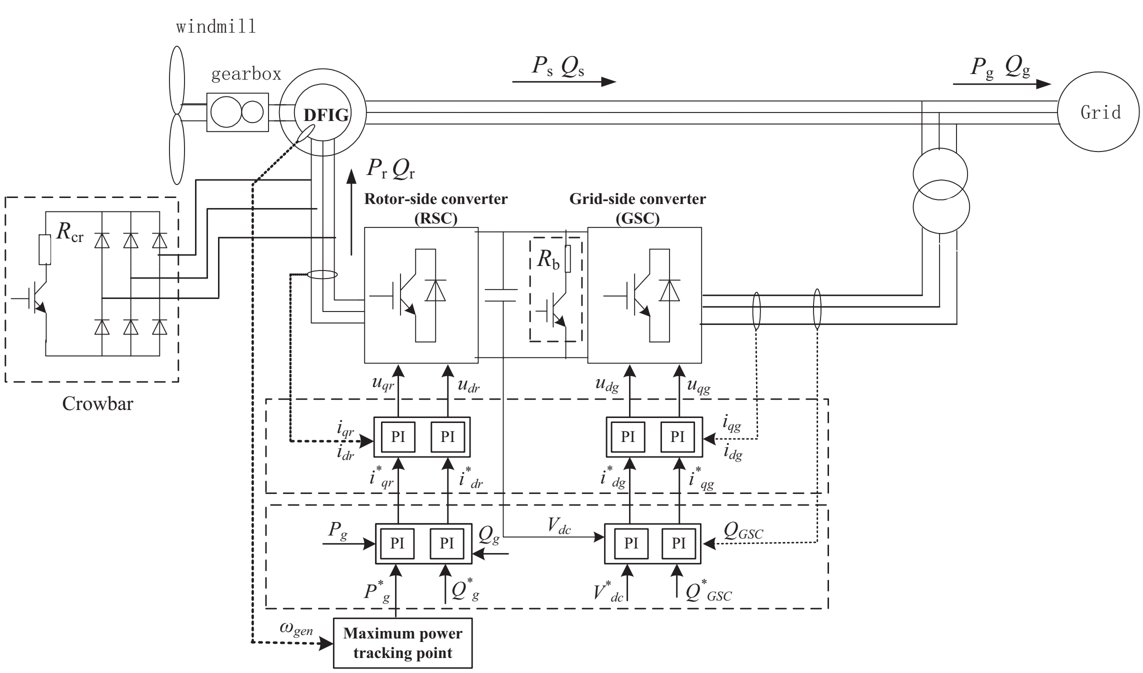

Fig. 2. Schematic of the DFIG wind turbine.