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DESIGN OF DFIG-BASED WECS USING RESONANT FEEDBACK COMPENSATORS UNDER UNBALANCED GRID VOLTAGE CONDITIONS

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Abstract—This paper presents an independent operation of the rotor-side converter (RSC) and grid-side converter (GSC) for a doubly fed induction generator (DFIG)-based wind energy conversion system under unbalanced grid voltage conditions. In this paper, the RSC is controlled to achieve four different control targets, including balanced stator current, sinusoidal rotor current, smooth stator active and reactive powers, and constant DFIG electromagnetic torque. The GSC is commanded to keep the dc voltage at a constant value. Additional feedback compensators using resonant regulators for the RSC are employed, and the decompositions of the positive and negative sequence components and calculations of the rotor negative current references can be avoided. Another similar compensator is used in the GSC to suppress the dc voltage fluctuates and remove the GSC reactive power oscillations without the stator or rotor power information. The proposed method can make the RSC and GSC available to an independent operation with a simple implementation for higher reliability. The experimental results demonstrate the effectiveness of the proposed control strategy for both the RSC and GSC under unbalanced grid voltage conditions.

Index Terms—Doubly fed induction generator (DFIG), independent operation, resonant regulator, unbalanced grid voltage, wind energy conversion system (WECS).

1. Introduction

During the past years, more attention and interest have been paid to wind energy utilization due to its economic and environment advantages. Indeed, by the end of 2011, 238.5 GW of wind turbine capacity was installed across the world [1]. Nowadays, many wind farms are based on doubly fed induction generator (DFIG) technology due to its advantages compared to others generators, where the dimension of the electronic power converter is reduced to about 25% to 30% of the generator rating, which leads to lower converter costs and power losses [2]. Several research works have been undertaken to enhance the operation efficiency of wind energy conversion systems (WECSs) [2–19]. It is well established that a DFIG-based WECS, acting under variable speed, allows extraction of the maximum available wind power [5–7]. For this goal, various methods have been presented in the literature. Among them, we highlight the direct control of the rotor current scheme [8], direct torque control [9,10], torque and reactive stator power control [11,12], active and reactive stator power control [2–4,13–18], and speed control [19]. To overcome the drawbacks of this last one, the speed and reactive stator power or flux control can be also considered. Practice in this field has shown that stator power control is more efficient because it allows us to directly impose the power factor and to easily limit the active power transient from the WECS in the case of overpowering. The vector control (VC) method is the classical stator power control of a WECS based on a DFIG. This control scheme is generally derived from a simplified and decoupled DFIG model [3,4,13,14,18] where some existing interactions are simply ignored. This VC control exhibits low performances and low robustness compared to those of control methods based on the DFIG nonlinear model. For this, two main methods have been proposed. One is based on the optimal switching table of the switches' states related to the rotor side converter where the control errors of the stator powers are minimized using the DFIG electrical states [2,16,17]. This method is valid only in the case of the conventional DC/AC converter and requires complicated online calculations, and it displays oscillations when the generator operates near its synchronous speed [15]. The second method concerns sliding mode control (SMC) [15]. In this work, the controller is derived in the stator reference frame. This latter one is independent of the angular position of the vector, related to some electrical quantities, which is essential when a synchronous coordinate transformation is used.

2. The considered WECS

2.1. Preliminary considerations

The scheme of the used WECS-based DFIG is given in Figure 1, where the stator is directly connected to the grid and the rotor windings are also coupled to the network through an AC/AC converter. Under the effect of the wind, the turbine produces a torque τw on its shaft that rotates at speed ωw.

2.2. DFIG state space model In order to control the DFIG, its state space model is carried out in the (d, q) reference frame linked to the vector of stator voltage that is represented by the components (vdsvqs). The considered state vector gathers the components of rotor currents (idriqr), the rotor flux (φdr, φqr), and the rotor rotating pulsation ω. Moreover, the rotor voltage components (vdrvqr) are the vector control.

3. PROPOSED CONTROL STRATEGY OF THE DFIG SYSTEM

In order to avoid the complex reference calculation and sequential decomposition, Fig. 1 presents the overall schematic diagram of the proposed control scheme based on the resonant feedback compensators to implement the independent operation of the RSC and GSC. As can be seen, the proposed control strategy consists of two regulators: 1) a current PI controller; and 2) a resonant feedback compensator. The control strategy is implemented in the positive sequence voltage oriented dq+ reference frame, where the fundamental frequency components behave as dc signals, and the negative sequence components are converted into ac signals pulsating at 2ω1 .

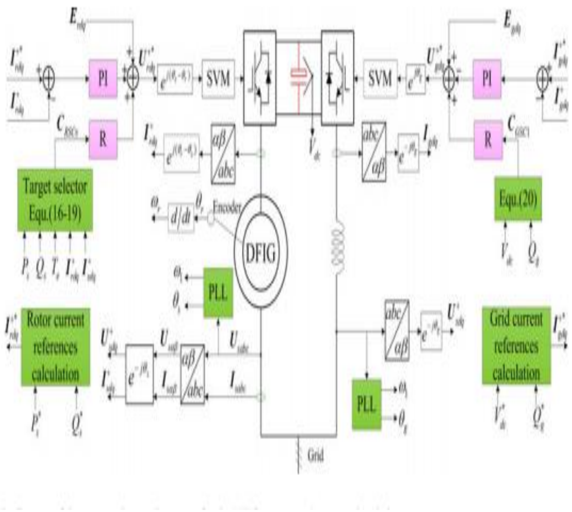

Fig. 1. Schematic diagram of the proposed control strategy for the DFIG system under network unbalance

In Fig. 1, the PI controllers are used to regulate dc signals, and the resonant feedback compensators, consisting of resonant regulators, as illustrated in [12] and [18], can provide an infinite gain at the double fundamental frequency. It should be noted that the resonant regulators are sensitive to frequency variations, which may degrade the control performance on the frequency variation condition. An adaptive resonant regulator was proposed in [23] and [24], in which the resonant frequency can be updated based on the frequency information detected by the phase-locked loop (PLL). Besides, a resonant-based PLL, as shown in [18] and [25], was introduced to achieve an accurate and rapid track for the network frequency and phase angular under unbalanced grid voltage conditions. For the RSC, the PI controllers are used to regulate the average stator active and reactive power and the resonant feedback compensators are designed to achieve four different control targets, i.e., balanced stator current, sinusoidal rotor current, smooth stator active and reactive powers, and constant generator torque. The measured currents and the calculated powers and torque can be directly set as the input of the resonant feedback compensators. Thus, the sequential decompositions and the complex calculations for the negative sequence rotor current references in the proposed control strategy can be avoided. For the GSC, the PI controllers are employed to regulate the GSC average active and reactive powers for a constant dc voltage, while the resonant feedback compensators are used to reduce the dc voltage fluctuates and remove the GSC reactive power oscillations. The dc voltage Vdc and the GSC reactive power Qg are directly used as the input of the resonant feedback compensators. As can be seen, no power information needs to be transferred from the RSC to the GSC in this proposed control strategy. Thus, an independent operation of the RSC and GSC can be obtained for DFIG systems under unbalanced grid voltage conditions.

4. SIMULATIONAL RESULTS

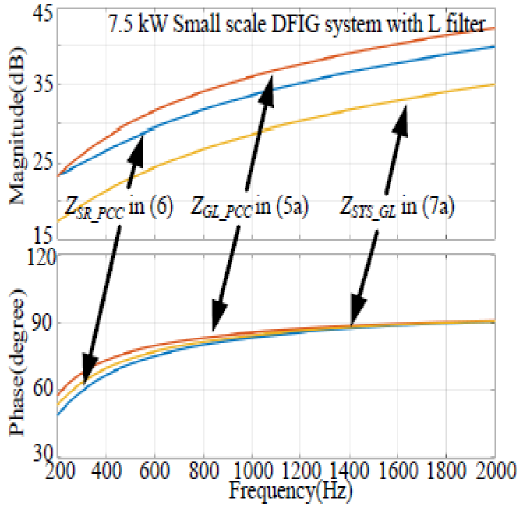

Fig. 4.1 Bode diagramsofsmall scale DFIG system with L filter in the high frequency range.

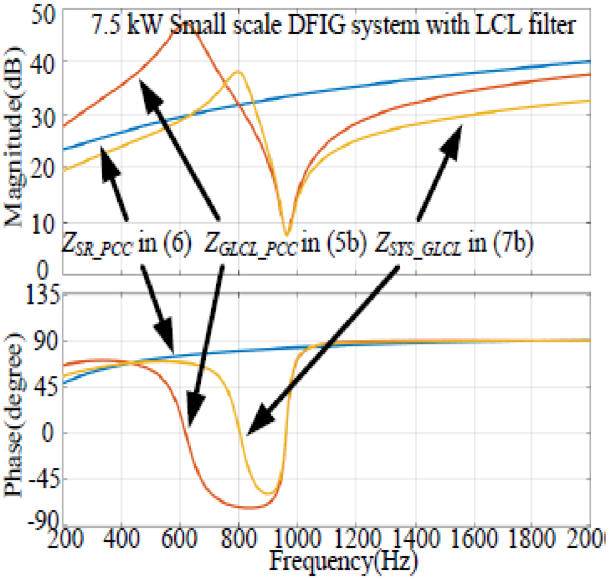

Fig. 4.2 Bode diagramsof small scale DFIG system with LCL filter in the high frequency range.

5. Conclusion

In this paper, we have developed a sliding mode control of the powers provided by a WECS incorporating a DFIG without using any estimation model of rotor flux or any rotor current sensor. The proposed control law can be qualified as low-cost SMC. Indeed, the synthesis of the controller is carried out based on the nonlinear and coupled DFIG model. On one hand, we have established the global stability of the control law even in the presence of disturbances affecting the plant model (i.e. parametric variations, flux estimation error, modeling errors, and unbalanced voltage grid). On the other hand, we have verified the boundedness of the electrical states when the proposed control law drives the plant. It is proved that the components of the rotor flux remain near their nominal values when our low-cost SMC is applied. Our low-cost SMC is developed based on this latter point, the robustness of the SMC, and the DFIG state model, which contain as states only the stator powers, the rotor flux components, and rotating pulsation. Rotor current components are not used (thus, no rotor current sensor is used).

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