Selective Control Approach for DFIG Powered by Parallel Inverters

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Abstract. The use of power electronics in the wind energy application is an essential part. In this work, parallel inverters are used to supply the DFIG with the goal to meet the high current demand. The disadvantage of this topology is the large number of power electronic devices (IGBTS) that lead to high power switching losses. The purpose of this paper is to use a control algorithm, named "selective control", to address this weakness. This technique makes it possible to activate or deactivate the inverters used according to the amplitude of the current demand. In other hand a maximum power tracking MPPT technique is used to extract the maximum power from the wind. The proposed system is simulated and tested by using the SimPowerSystem toolboxes in MATLAB. The results show the high effectiveness of the proposed control in terms of pursuing maximum power and reducing THD.

Keywords: Wind energy · Parallel inverter · DFIG · Selective control · Maximum power tracking MPPT · SimPowerSystem

1 Introduction

The future in the energy sector is to develop a clean and alternative energy source, which could regenerate naturally and meet the world's energy demand. Wind energy is one of the most useful renewable energies in the world. It has provided an economical solution, because it reduces the cost of electricity and creates jobs (Herbert et al. 2007). Wind turbines can operate in many applications (agriculture; Industry, commerce and residence). The global cumulative installed wind capacity has increased exponentially from approximately 23.9 GW in 2001 to 539 GW in 2017 (REN21 2018).

Variable-speed wind energy conversion systems (WECS) using doubly fed induction generator (DFIG) have become in the Foreground of the wind generator used in the world, because of their high-energy efficiency, controllability and improved power quality. The main advantage of DFIG is the size of the converter, which is considered as a small fraction, it is estimated by 20% to 30% of the overall power system. The power converter of the (DFIG) should have the ability to control the reactive power Q and the active power P injected to the grid regardless of the wind speed. For that, the self-commutated converter

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normally adopts pulse width-modulated (PWM) control methods, which is widely used in (WECS). This converter is based on semiconductor devices, which have the ability to turn ON/OFF and can operate at high switching frequencies, such as insulated gate bipolar transistor (IGBT), MOSFET, integrated gate-commutated thyristor (IGCT) and silicon carbide MOFET (Ma et al. 2015).

There are many proposed topologies, which use the IGBTs device. In (Chemidi et al. 2015), a matrix converter is used to control the DFIG in both modes of operations (sub-synchronous and super-synchronous). However, the major disadvantage of matrix converter that is more complicated in terms of control (Kolar et al. 2011). The simplicity of conventional back-to-back converter proposed in (Pena et al. 1996) make it very useful in (WECS). It is composed of two inverters sharing a common DC link. In this type of structure, the choice of inverter topology, depends on the power produced by the wind turbine, the grid voltage and IGBT characteristics. For low voltage a two-level inverter is enough as mentioned in (Teichmann and Bernet 2005). But for high voltage applications, it is necessary to use a multilevel inverter (Narimani et al. 2014). A lot of research is done to develop this type of inverter which is divided into three categories; neutral-point diode clamped structure, flying capacitor clamped structure, and cascaded converter cells (Ke 2015). However, all the previous structures are adopted for high voltage but they cannot operate in high current applications, because the current supported by one IGBT is limit.

As a solution of this weakness, this paper proposes a structure, which is composed of two parallel inverters with a common DC-link. The aim of this structure is to withstand high current intensity. To control this converter, a selective algorithm is proposed to minimize the switching losses of the IGBT.

2 System Description

The proposed WECS is composed of both mechanical, electrical and control parts. The mechanical part consists of three blades and a gearbox, because designing a low speed multipolar DFIG is not technically feasible. The mechanical part transforms wind kinetic energy to mechanical energy. The electrical part is made of a DFIG that transforms the energy captured by the mechanical part into electrical energy. This generator can produce power at constant voltage and constant frequency though the rotor speed varies (Pena et al. 1996). The stator winding of the DFIG is connected directly to the grid while the rotor winding is connected to the grid through the proposed parallel inverter, this converter is made from two parts: rotor side converter (RSC) and grid side converter (GSC). RSC is connected to the DFIG rotor and the GSC is connected to the grid. Concerning the control part, a decoupled d-q vector control technique is employed for the control of the rotor circuit. For controlling the RSC to achieve a maximum power, a maximum power point tracking (MPPT) technique is used to estimate the speed reference Ω_{ref}. Then a speed controller adjusts the speed of the DFIG to achieve the desired speed. Next, a current controller is used to control the active power P and the reactive power Q injected to the grid via the stator of the DFIG. The GSC is used to keep the voltage at the DC bus voltage constant regardless of the magnitude and direction of the rotor power. Finally, a proposed selective control is employed to turn ON/OFF converters of the rotor circuit. The control is done according to the power transferred to or from the grid. Figure 1 shows the configuration of the DFIG system connected to the grid utility.

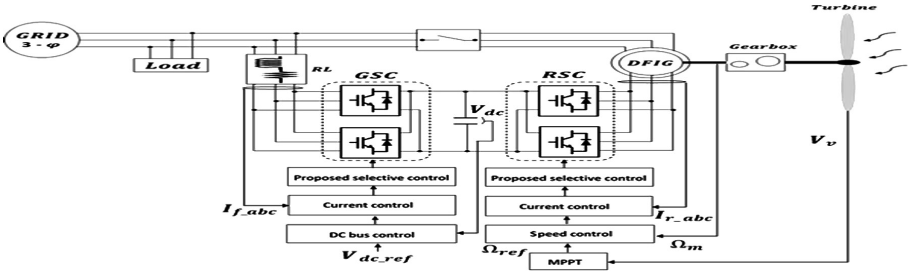

Fig. 1. Wind turbine system connected to the grid utility.

3 Control of the DFIG

In this article, an independent control of the active and the reactive power is done by the decoupled vector control approach. The back-to-back converters are controlled independently which allows us to split into two parts the control of WTCS: the RSC control and the GSC control.

3.1 RSC Control

By considering the network voltage constant, neglecting resistance of the stator winding and aligning the stator flux with the d axis. The model of the DFIG in synchronous frame will be simplified as below:

$$\begin{cases} V_{sd} = 0 \\ V_{sq} = \omega_s \varphi_{sd} \\ V_{rd} = R_r I_{rd} + \sigma L_r \frac{di_{rd}}{dt} - \sigma L_r \omega_r i_{rq} \\ V_{rq} = R_r I_{rq} + \sigma L_r \frac{di_{rq}}{dt} + \sigma L_r \omega_r i_{rd} + g \frac{MV_{sq}}{L_s} \end{cases} \tag{1}$$

The active power, reactive power and the electromagnetic torque of DFIG stator will be expressed by following equations:

$$\begin{cases} P_s = \frac{3}{2} V_s I_{sq} \\ Q_s = \frac{3}{2} V_s I_{sd} \\ C_{em} = -\frac{3}{2} \frac{Mp}{L_s} I_{rq} \varphi_{sd} \end{cases} \tag{2}$$

From the previous equations, it is obvious that the active and reactive power are decoupled while, they are controlled by the quadrature and direct current respectively. For that a proportional-integral (PI) controller is used. The direct axis reference current is chosen to keep the reactive power zero, while the quadrature axis reference is selected to extract the maximum power. This can be achieved for a particular wind speed, so an MPPT technique with a speed controller are used. There is a lot of research to develop the MPPT algorithm for WECS (Abdullah et al. 2012). In this paper, a simple MPPT algorithm is used, which is called Tip speed ratio (TSR) control (Loucif et al. 2014). A proportional-integral (PI) is used as a speed controller. Figure 2 shows the structure of the RSC control

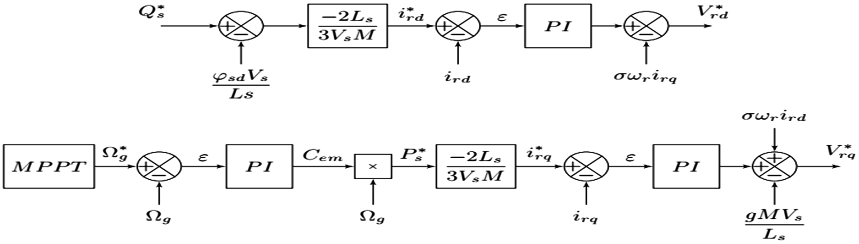

Fig. 2. RSC control schema blocks.

3.2 GSC Control

The main purpose of the GSC is to ensure a constant voltage at the DC link and guarantee a unity power factor at the grid side. The control of the GSC is based on the following real power from the grid side to the DC link. RSC. By applying the voltage vector control (Gaillard 2010), the voltage source will be oriented on the quadrature axis. The model of the filter will be simplified as below:

$$\begin{cases} V_{fd} = -R_f I_{fd} - L_f \frac{dI_{fd}}{dt} + \omega_s L_f I_{fq} \\ V_{fq} = -R_f I_{fq} - L_f \frac{dI_{fq}}{dt} - \omega_s L_f I_{fd} + V_{sq} \\ \frac{dV_{dc}}{dt} = \frac{1}{C}(I_{RSC} + I_{GSC}) \end{cases} \tag{3}$$

$$\begin{cases} P_f = \frac{3}{2} V_{sq} I_{fq} \\ Q_f = \frac{3}{2} V_{sq} I_{fd} \end{cases} \tag{4}$$

The direct and the quadrature current acts on reactive and active power respectively. According to (Gaillard 2010), if the set of power losses in the capacitor, inverter and RL filter are neglected, the active filter and the capacitor power is expressed by the following equations:

$$\begin{cases} P_f = P_{cap} + P_{RSC} \\ P_{cap} = V_{dc} I_{cap} \end{cases} \tag{5}$$

Figure 3 shows the structure of the GSC control. The filter current and the DC bus voltage are controlled by the outer loop and the inner loop respectively. The outer loop use an IP controller, it reduces the overshoot at the DC link voltage. This type of controller is discussed in (Loucif et al. 2015).

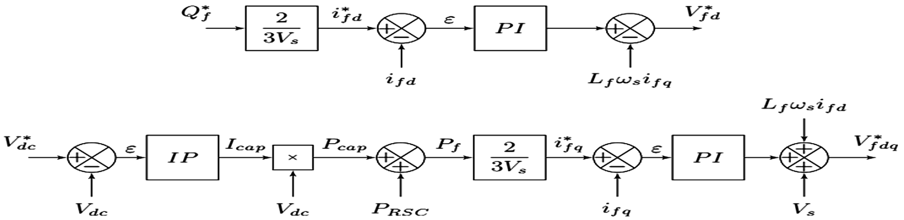

Fig. 3. GSC control schema blocks.

3.3 Proposed Selective Control

With the parallel back-to-back inverter, it is possible to use a low power IGBTs for high power. In WECS, the produced power depends on the wind speed variations. So, the two inverters are not needed all the time. Thus, the contribution of this paper lies in using a selective technique. The aim of this algorithm is to turn on/off the inverters of the parallel structure without affecting the operation of the WECS. The same working principle of the selective technique is applied to control the RSC and the GSC. If the exchanged current is less than the limit of the used IGBTs, the selective control turns off one of the inverters of the concerned side converter. The algorithm of selective control is shown in Fig. 4, the main advantage of the proposed control is to reduce the power loss.

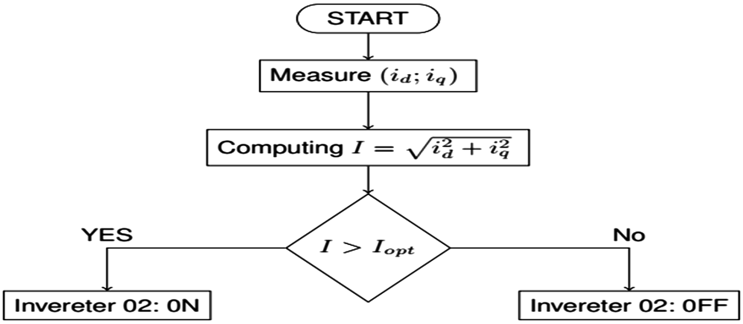

Fig. 4. Selective control diagram.

4 Simulation Results

In this section, the WTCS is developed and simulated in Simulink environment and SimPowerSystems MATLABs block set. This simulation is done by using a discrete solver with a fixed step. The DFIG studied in this paper is rated at 2 MW and its parameters are given in the appendix. The DC bus voltage is set at 1200 V. The grid voltage is considered balanced where the RMS value between phases is 690 (V) and the frequency is 50 (Hz). The simulation is performed with a variable wind speed, varying between 7.8 m/s and 10.2 m/s as shown in Fig. 5.

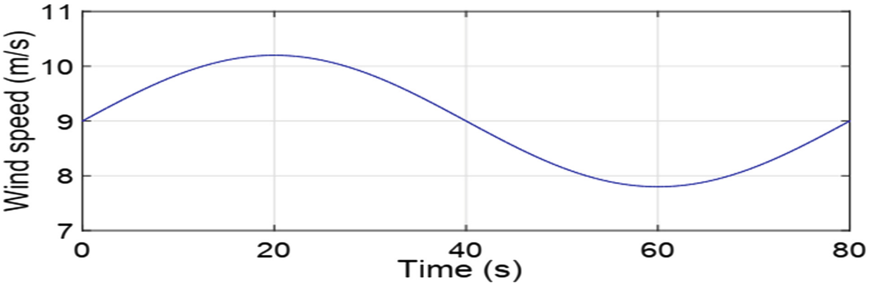

Fig. 5. Wind speed profile.

Figures 6 and 7 shows the performance of the MPPT used where the Cp is varied around the max and the measured speed track the reference speed under different wind speed.

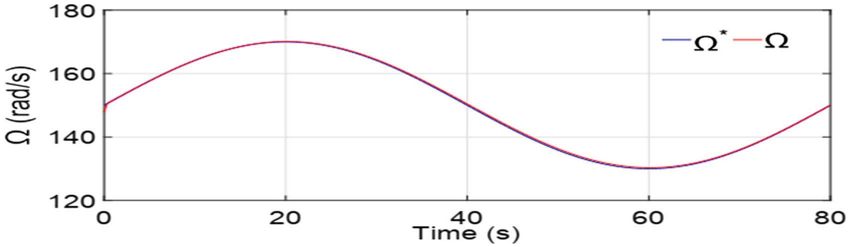

Fig. 6. Generator speed variation according to the wind profile.

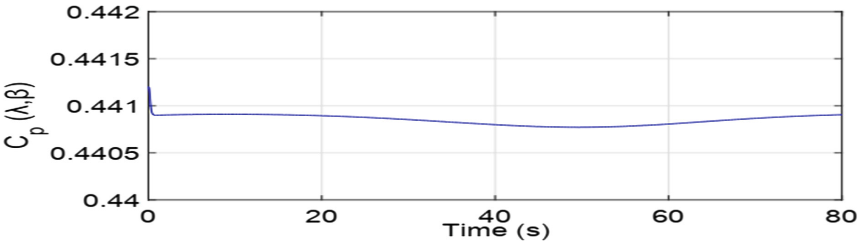

Fig. 7. Power coefficient Cp using the MPPT technique.

Figure 8 shows the efficiency of the IP controller in elimination of the over shoot. Where it is less than 10% of the DC bus voltage and the DC link is quickly stabilized at the reference value (1200 V).

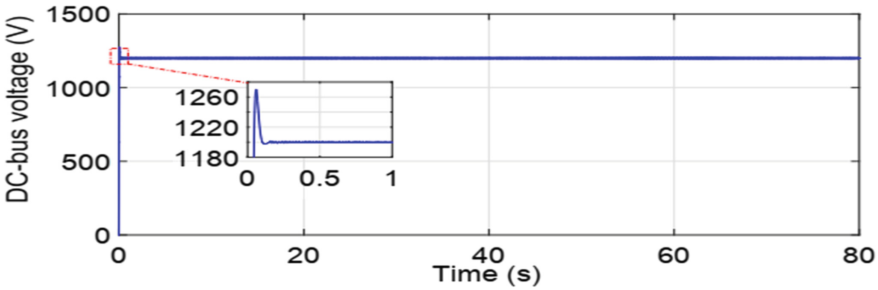

Fig. 8. DC bus voltage.

Figure 9 presents the power exchanged to the grid. When the mechanical speed is less than the synchronous speed (sub synchronous mode), the rotor absorb power from the grid but if the generator speed is greater than the synchronous speed (super synchronous mode) the rotor produces power.

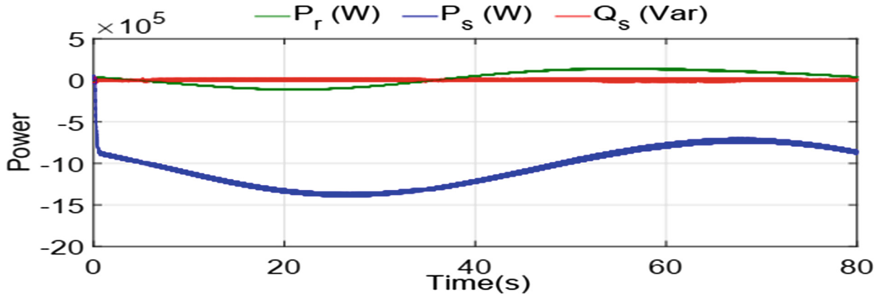

Fig. 9. Exchanged power between the DFIG and the grid.

Figure 10 shows the current controlled by the selective technique at the RSC. If the maximum current is greater than 1200 (A) the proposed selective control activates both inverters of the RSC, the current of the inverter stays less than the limit of the IGBT. Else, if the current is less than the previous limit, the RSC works with one inverter only.

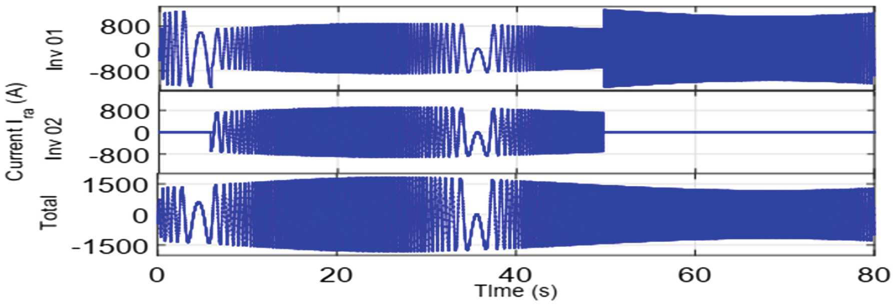

Fig. 10. Rotor currents inverter using proposed selective control.

Figure 11 presents the current controlled by the selective technique at the GSC. The current limit is set to 100 (A).

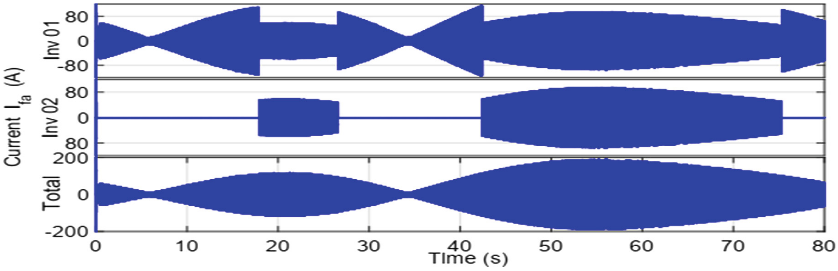

Fig. 11. Filter currents inverter using proposed selective control.

The efficiency performance of the proposed control is shown in Fig. 12. The THD is lower when both inverters are OFF. In all others states, the THD is less than 5% which corresponds to the international laws (Jana et al. 2017).

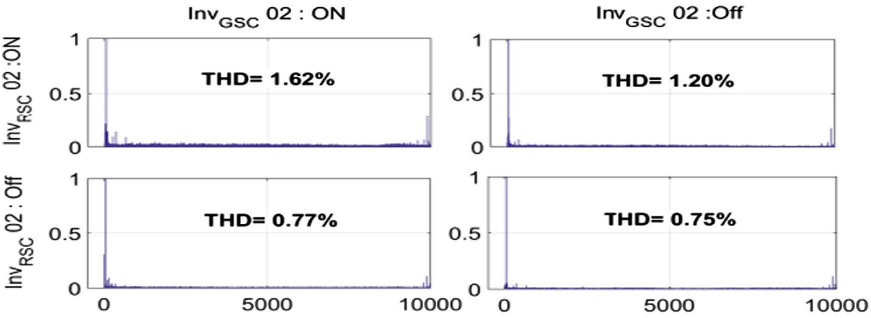

Fig. 12. Frequency analyses of the stator current.

5 Conclusion

This paper presented a study of a WTCS system, based on DFIG. A parallel Back-to-Back is used in order to increase the current limit of the conventional converter. The TSR technique is found capable to drive the DFIG to track the maximum power from the available wind regime. A direct current control is applied with a proposed selective technique to decrease the THD. The simulation results show the stability of the system and the good performance of the proposed control. The parallel converter is one of the solutions to high wind power applications. The proposed selective control has proven its ability to reduce power losses in the system by reducing the THD.

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