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Survey on Harmonics Rejection in Stand-Alone Doubly-Fed Induction Generators with Nonlinear Loads

Pankaj Tiwari [1], Vivek Kumar Koshta [2]
[1]*M.Tech Scholar, Department of Electrical Engineering, Corporate Institute of Science and Technology BHOPAL, pt89121@gmail.com, India;*
[2,] *Assistant Professor, Department of Electrical Engineering, Corporate Institute of Science and Technology BHOPAL, vivekkoshta@yahoo.com, India;*

Abstract – *This paper studies a new control method to compensate the harmonic components in case non-linear loads are connected to the stand-alone Doubly-Fed Induction Generator (DFIG). Doubly fed induction generator (DFIG) still shares a large part in today's wind power market. It provides the benefits of variable speed operation cost-effectively, and can control its active and reactive power independently.*

Keywords*: Doubly-fed induction generator, harmonics rejection, nonlinear load, resonant regulator, stand-alone system,*

I. Introduction

In recent years, the Doubly-Fed Induction Generator (DFIG) has been widely applied to wind energy conversion systems. The most important benefit of the DFIG is the small rate of power converter compared to the nominal power of machine (around 30%), so it can be used in high power applications in both grid and stand-alone mode.[6] Wind power generation based on the doubly-fed induction generator (DFIG) has gained increasing popularity due to several advantages, including smaller converters rating around 30% of the generator rating, variable speed and four quadrants active and reactive power operation capabilities, lower converter cost, and power losses compared with the fixed-speed induction generators or synchronous generators with full-sized converters. Several novel control strategies have been investigated in order to improve the DFIG operation performance.[7]

In case of the unbalanced load, the balanced stator voltage can be obtained by producing the negative sequence line current of LSC, which has the same magnitude and opposite phase with the corresponding component of load current [5]. Another compensating method for this case is based on the rotor side control (RSC) which generates the harmonic components for the rotor current.[6]

Taking into account the non-linear load condition, the configuration of stand-alone DFIG system that feeds the three-phase diode rectifier is shown in Fig. 1. Due to the effect of non-linear load, the stator voltage and current are polluted by the positive (6n+1) and negative (6n–1) order harmonics as analyzed in [10], so that the other loads connected to DFIG are impacted seriously. Therefore, many researchers have been interested in how to eliminate these harmonic components. For aircraft applications, a design method of LC filter which plays a role of a low pass filter to reject these harmonics is introduced in detail [6]. Unfortunately, the power drop on internal resistance and the resonance problem may reduce the efficiency and stability of system. In addition, the control strategies based on either RSC or LSC has been investigated to deal with the harmonic problem. In [6] has introduced how to improve the quality of stator current using the current controller in LSC which operates as an active power filter. In this method, the harmonics of line current are generated following the harmonics of load current by using only PI controllers, so the steady-state error for magnitude and phase is not guaranteed. In order to avoid this inconvenience, a resonant controller is employed to eliminate the steady-state error at the selective frequencies for RSC current controller.

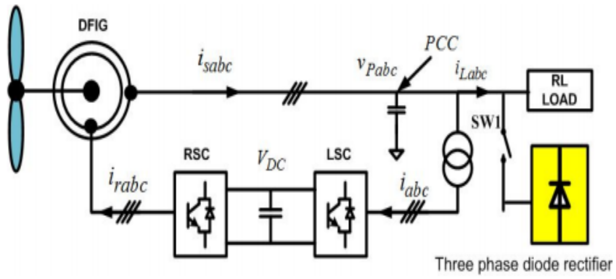

Fig.1Configuration of stand-alone DFIG system feeding non-linear load

In [6], only one single resonant compensator (PI-R) is capable for eliminating one pair of stator voltage harmonics. The harmonics of rotor current is produced to eliminate both fifth and seventh voltage at the point of common coupling (PCC). However, the induced harmonics of rotor current and stator current effect seriously to the rotor.

II. Literature Survey

Van-Tung Phan et al.[1] “Harmonics Rejection in Stand-Alone Doubly-Fed Induction Generators With Nonlinear Loads”, A novel $6n \pm 1$ harmonics rejection method for the stand-alone DFIG with nonlinear loads has been proposed. The proposed rejection method is developed based on the PI-R rotor current controller in the fundamental frame. In this frame, each resonant filter adopted in the rotor current controller is capable of rejecting one pair of the positive and negative stator voltageof rejecting one pair of the positive and negative stator voltage harmonics. The algorithm is totally applicable to the DFIG in term of harmonics rejection, which is clarified by experimental verifications for fifth and seventh harmonic components.

Yi Zhou et al.[2] “Operation of Grid-Connected DFIG Under Unbalanced Grid Voltage Condition”, In this paper, the control objective is focused on how to improve the performance of DFIG itself under unsymmetrical voltage, integrated with a strong power grid. In future, the control objective can be focused on how to use DFIG to improve grid performance when it is connected with a weak power grid, such as to limit the grid voltage unbalance, etc.

Rub´en Pe˜naet al.[3] “Control System for Unbalanced Operation of Stand-Alone Doubly Fed Induction Generators”, Anewcontrol system for the compensation of the negative sequence components in stand-alone operation of DFIGs has been proposed. Using the proposed methodology, the stator voltage is balanced and the torque pulsations, produced by the doublefrequency components in the currents and flux are eliminated. Experimental results have been presented that show the excellent performance achieved with the proposed control system.

Amit Kumar Jain et al.[4] “Wound Rotor Induction Generator With Sensorless Control and Integrated Active Filter for Feeding Nonlinear Loads in a Stand-Alone Grid”, A vector control scheme for stand-alone generators based on a wound rotor induction machine with rotor side control has been developed. The objectives of the stand-alone generator such as establishment of a local grid and regulation of its voltage and frequency are achieved using a novel and simple sensorless scheme. The active filter concept is added in the control scheme of the line side converter to improve power quality. Detailed experimental results are presented which validate and demonstrate the performance and features of the control scheme.

Van-Tung Phan et al.[5] “Control Strategy for Harmonic Elimination in Stand-Alone DFIG Applications With Nonlinear Loads”, The effect of nonlinear loads on the quality of the stator output voltage at the PCC in the stand-alone DFIG is investigated clearly in this paper. To improve the PCC voltage quality, a new fundamental reference frame control scheme for fifth and seventh voltage harmonics elimination is proposed. The proposed harmonics elimination method is developed based on the PI–R rotor current controller implemented in the fundamental frame. The PI–R controller in this frame has the possibility of eliminating both seventh positive and fifth negative harmonic components of the stator voltage at the PCC without decomposing the measured rotor current. Both simulations and experimental results are shown to confirm the feasibility and effectiveness of the proposed control algorithm. In addition, experimental tests are also performed with the conventional PI regulator to compare with the proposed PI–R controller. The obtained results demonstrate that the proposed control scheme has more satisfactory performance in harmonic elimination. The control principle of proposed method can be applied to eliminate 11th, 13th, 17th, 19th. . . voltage harmonic components on the fundamental reference frame using the proposed PI–R controller tuned at 12 and 18 multiples of synchronous frequency.

III. DOUBLY FED INDUCTION GENERATOR

Wind turbines use a doubly-fed induction generator (DFIG) consisting of a wound rotor induction generator and an AC/DC/AC IGBT-based PWM converter. The stator winding is connected directly to the 50 Hz grid while the rotor is fed at variable frequency through the AC/DC/AC converter. The DFIG technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind.

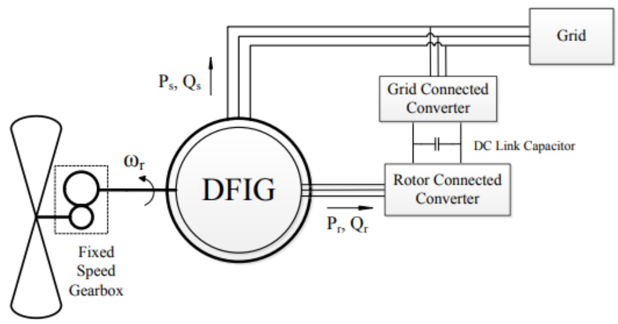

Fig.2 Typical DFIG-based wind turbine system

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The optimum turbine speed producing maximum mechanical energy for a given wind speed is proportional to the wind speed. Another advantage of the DFIG technology is the ability for power electronic converters to generate or absorb reactive power, thus eliminating the need for installing capacitor banks as in the case of squirrel cage induction generator.

The DFIG system is a viable alternative for variable speed over a range at minimal investment. So currently it is the preferred choice generator for medium and high capacity wind turbines. The DFIG system can operate over a wide speed range in both sub synchronous as well as super synchronous speeds. Figure 2 shows the block diagram of DFIG based wind turbine system.

III.1. Operating Principle of DFIG

The stator is directly connected to the AC mains, whilst the wound rotor is fed from the Power Electronics Converter via slip rings to allow DIFG to operate at a variety of speeds in response to changing wind speed. Indeed, the basic concept is to interpose a frequency converter between the variable frequency induction generator and fixed frequency grid. The DC capacitor linking stator and rotor-side converters allows the storage of power from induction generator for further generation. To achieve full control of grid current, the DC-link voltage must be boosted to a level higher than the amplitude of grid line-to-line voltage. The slip power can flow in both directions, i.e. to the rotor from the supply and from supply to the rotor and hence the speed of the machine can be controlled from either rotor- or stator-side converter in both super and sub-synchronous speed ranges. At the synchronous speed, slip power is taken from supply to excite the rotor windings and in this case machine behaves as a synchronous machine. The mechanical power and the stator electric power output are computed as follows $Pr=Tm*\omega r$ (1) $Ps=Tem*\omega s$ (2) For a loss less generator the mechanical equation is $J (d\omega r/dt) =Tm-Tem$ (3) In steady-state at fixed speed for a loss less generator $Tm=Tem$ and $Pm=Ps+Pr$ (4) And it follows that: $Pr=Pm-Ps=Tm\ \omega r- Tem*\omega s =-S\ Ps$ Where $S= (\omega s- \omega r)/ \omega s$ is defines as the slip of the generator.

III.2. Back-to-Back AC/DC/AC Converter Modeling

Mathematical modeling of converter system is realized by using various types of models, which can be broadly divided into two groups: mathematical functional models and Mathematical physical models (either equation-oriented or graphic-oriented, where graphic-oriented approach is actually based on the same differential equations).

III.3. Advantages

The main advantages of the DFIG system are:

- The rotor speed can be variable within a range of 30% of the synchronous speed [4].
- The power electronic converter handles only a fraction (25–30%) of the total power. So the losses in the converter are reduced.
- With proper modeling and control algorithms, independent control of the active and reactive power is possible. Also advanced control strategies like harmonic compensation can be implemented.
- Reduction in the cost of the converter and the variable speed gearbox.

III.4. Disadvantages

The main disadvantages of the DFIG system are:

- The rotor is connected to the converter via slip rings which have high wear and tear and require frequent maintenance.
- The speed range of the generator in limited on the rating of the converter.
- As gearbox is used, it adds to the investment, weight, and energy losses.

IV. Conclusion

This paper presents a stand-alone doubly-fed induction generator (DFIG) supplying a balanced three-phase diode rectifier. These harmonics are rejected by using the rotor current controller in the fundamental synchronous reference frame. This paper brief studied of Stand-Alone Doubly-Fed Induction Generators with Nonlinear Loads. Different research papers are reviewed related to the Harmonic rejection in Stand-Alone Doubly-Fed Induction Generators with Nonlinear Loads in this paper.

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