Proceedings of National Conference on Emerging Trends in Electrical Technology (NCEE-2017)

International Journal for Modern Trends in Science and Technology
Volume: 03, Special Issue No: 02, March 2017
ISSN: 2455-3778
http://www.ijmtst.com

Implementation and Simulation Comparisons of Induction Generator Wind Power Systems

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To Cite this Article
P Srilekha, G Tejaswini, Ch Lakshmi Prasanna, and Krishna Mohan Tatikonda,, “Implementation and Simulation Comparisons of Induction Generator Wind Power Systems”, *International Journal for Modern Trends in Science and Technology*, Vol. 03, Special Issue 02, 2017, pp. 45-49.

ABSTRACT

The wind energy has become the most potential renewable energy source recently. The technological and industrial development in the wind power generation indicates that wind power should be seen as one of the main domestic sources for electricity generation in all countries. This paper gives an overall observation of the most commonly used electrical machines i.e.; the squirrel-cage induction generator (SCIG) and the doubly fed induction generator (DFIG) in the wind generation systems using the Matlab / simulink, a simulation of wind farm with the two types of generators has been made in order to compare the results and to comment on the best option based on the output characteristics of the generator and wind turbine.

KEYWORDS: *Wind Power System, DFIG, FOC Control, MPPT Technique.*

I. Introduction

Wind power is the most reliable and developed renewable energy source. The share of wind power with respect to total installed power capacity is increasing worldwide. As induction generator has some advantages when compared to synchronous generator in terms of size, cost and maintenance they are mostly employed. SCIG employs fixed straight forward power conversion and it’s widely accepted in fixed speed applications and the main drawback of SCIG power system is requirement of external reactive power compensator.

On the other hand the DFIG based wind turbine with variable speed variable pitch control scheme is the most popular wind power generator in the power industry .Modern variable speed wind power system predominantly based on the DFIG technology are equipped with back to back ac/dc/ac power electronic convertor whose intermediate dc voltage and excellent controllability renders them technically attractive to incorporate energy storage devices such as flywheels, super capacitors, batteries etc., it is shown that a DFIG based wind power storage system can deliver a pre specified amount of power to the grid despite of wind power fluctuation .

First this paper experimentally set up the wind turbine operation and later emulates the power operation curve for optimal power control and next the modelling and simulation of SCIG and DFIG wind systems were studied. This paper is organized as follows using wind turbine emulator the wind turbine is modeled and simulated. SCIG and DFIG based wind power system has been constructed and simulated in Matlab.

II. Wind Turbine

Wind turbine is a device that converts wind's kinetic energy into electrical power. Wind turbines are manufactured in a wide range of vertical and horizontal axis types. The smallest turbines are used for applications such as battery charging for auxiliary power for boats or caravans or to power traffic warning signs. Slightly larger turbines can be used for making contributions to a domestic power supply while selling unused power back to the utility supplier via the electrical grid. Arrays of large turbines, known as wind farms, are becoming an increasingly important source of intermittent renewable energy and are used by many countries as part of a strategy to reduce their reliance on fossil fuels.

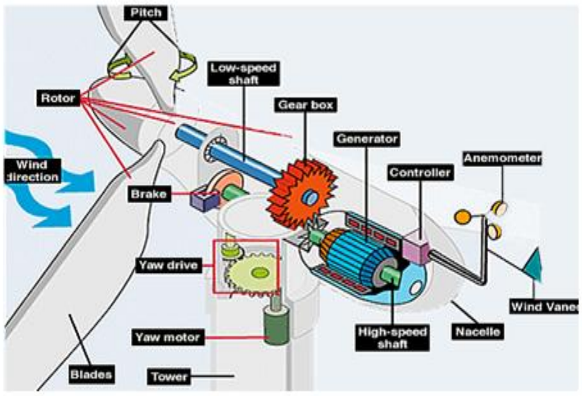

Fig 1: Wind Turbine

The power contained in wind is given by kinetic energy of the flowing air mass per unit time. Where P wind is the power contained in wind, d is the air density, A is the rotor area and V wind is the wind velocity.

$$P_m = C_p(\lambda, \beta) \cdot 1/2 \rho A v^3 w$$

SCIG:

Fixed speed wind turbine equipped with SCIG has the advantages of being simple, robust and reliable. However, it also contains some disadvantages of uncontrollable reactive power output, mechanical stress and limited power quality control. Owing to its fixed speed operation, fluctuations in wind speed are further transmitted as fluctuations in the mechanical torque and then in the electrical power output. In order to overcome the above mentioned problems associated with fixed-speed wind turbine system and to maximize the wind energy capture, variable speed wind turbines based on DFIG are becoming employed. Differences come from such categories as speed control, reduced flicker, and four-quadrant active and reactive power capabilities. Both DFIG and SCIG are classified as induction machine but there is a little difference in their rotor sides.

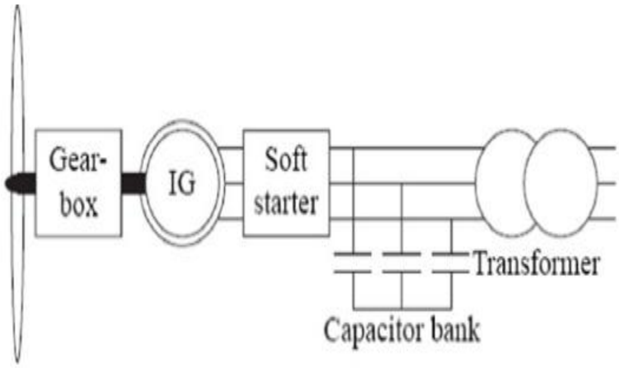

Fig 2: SCIG-Wind Turbine

This leads to many differences in steady-state electrical characteristics, mechanical curves and dynamic responses when connected to the grid. A study concerning methodologies of speed control of DFIG to produce electrical energy on network is given in. Impacts of AC/DC/AC converter on the steady-state characteristics of DFIG were also studied. We analyzed the output of DFIG as changing d-q components of rotor voltage based on the d-q frame in order to compare active powers in the rotor side and the stator side.

DFIG:

A doubly fed induction generator is basically a wound rotor induction generator fed by both stator and rotor, in which the stator winding is directly connected to the grid and the rotor winding is connected to the grid through AC/DC/AC converters. These converters are divided into two components: the rotor side converter and the grid side converter. A capacitor between the converters plays a role of a DC voltage source. A coupling inductor is used to link the grid side converter to the grid.

Doubly fed electrical generators are similar to AC electrical generators, but have additional features which allow them to run at speeds slightly above or below their natural synchronous speed. This is useful for large variable speed wind turbines, because wind speed can change suddenly. When a gust of wind hits a wind turbine, the blades try to speed up, but a synchronous generator is locked to the speed of the power grid and cannot speed up. So large forces are developed in the hub, gearbox, and generator as the power grid pushes back. This causes wear and damage to the mechanism. If the turbine is allowed to speed up immediately when hit by a wind gust, the stresses are lower and the power from the wind gust is converted to useful electricity.

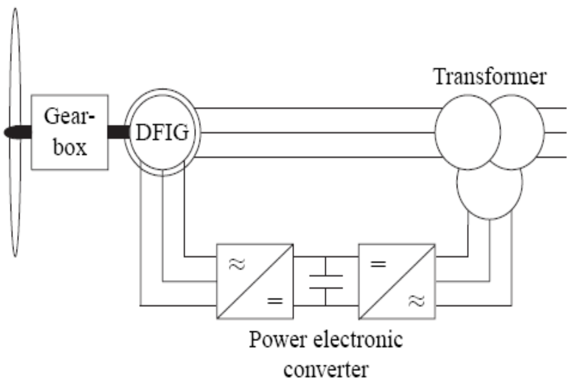

Fig 3: Schematic Diagram for DFIG based wind turbine

One approach to allowing wind turbine speed to vary is to accept whatever frequency the generator produces, convert it to DC, and then convert it to AC at the desired output frequency using an inverter. This is common for small house and farm wind turbines. But the inverters required for megawatt-scale wind turbines are large and expensive.

Doubly fed generators are one solution to this problem. Instead of the usual field winding fed with DC, and an armature winding where the generated electricity comes out, there are two three-phase windings, one stationary and one rotating, both separately connected to equipment outside the generator. Thus the term "doubly fed".

One winding is directly connected to the output, and produces 3-phase AC power at the desired grid frequency. The other winding (traditionally called the field, but here both windings can be outputs) is connected to 3-phase AC power at variable frequency. This input power is adjusted in frequency and phase to compensate for changes in speed of the turbine.

Adjusting the frequency and phase requires an AC to DC to AC converter. This is usually constructed from very large IGBT semiconductors. The converter is bidirectional, and can pass power in either direction. Power can flow from this winding as well as from the output winding.

III. CONTROL SCHEME

Control plays a very important role in modern wind energy conversion systems. In fact, the principle target of control is to enable us to obtain as much quantity of energy from the wind as is possible during certain weather conditions, and deliver it to the grid at the best possible conditions. As well as, to keep the system on a safe working area to reduce aerodynamic and mechanical loads, and to protect the electrical devices, for example, pitch controlled that spin the blades in its own axis to regulate the position of it, or stall controlled which makes us loose aero dynamical power, this type of control will have constant pitch. Additionally, the control can be used to perform as reactive power suppliers or consumers according to the power system requirements .The control can be divided in 2 levels, high level control system and control of the converter. The control system of each individual DFIG wind turbine generally consists of two parts: the electrical control of the DFIG and the mechanical control of the wind turbine blade pitch angle. Control of the DFIG is achieved by controlling the Rotor side Converter (RSC), the Grid side converter (GSC), and the ESS. The control objective of the RSC is to regulate the stator-side active power Ps and reactive power Qs independently. The control objective of the GSC is to maintain the dc-link voltage Vdc constant and to regulate

The reactive power Qg that the GSC exchanges with the grid.

CLOSED LOOP CONTROL DIAGRAM FOR ROTOR SIDE CONTROLLER:

In the RSC, the controller is used for controlling rotor power Ps and the power Qs in terms of controlling rotor regulation and rotating reference frame.

By considering the simplified equivalent circuit for stator winding as shown in figure 2 and write the equations by using KVL as

$$\bar{V}_r = \bar{I}_r R_r + \frac{d\psi_r}{dt} \quad (11) \qquad \bar{\psi}_r = L_r \bar{I}_r + M\, \bar{I}_s e^{-j\epsilon}$$

(12)

Substituting the value of $\bar{\psi}_r$ in above equation e get

$$\bar{V}_r = \bar{I}_r R_r + \frac{d}{dt}(L_r \bar{I}_r + \frac{M}{L_s}\bar{\psi}_s e^{-j\epsilon} - \frac{M^2}{L_s}\bar{I}_r$$

$$= \bar{I}_r R_r + \frac{d}{dt}\left(L_r \bar{I}_r - \frac{M^2}{L_s}\bar{I}_r\right) + \frac{d}{dt}\left(\frac{M}{L_s}\psi_s e^{-j\epsilon}\right)$$

Fig 4 shows the overall RSC control scheme which is having two cascade loops. The active and reactive powers of the DFIG is controlled by the outer loop and direct axis current component Idr*, quadrature axis current component Iqr* are generated. Inner-loop current regulation is the second cascaded control loop. Vdr0 and Vqr0 are the from the two regulated current controllers outputs. And these signals are used for generating Pulses to RSC converter by PWM technique.

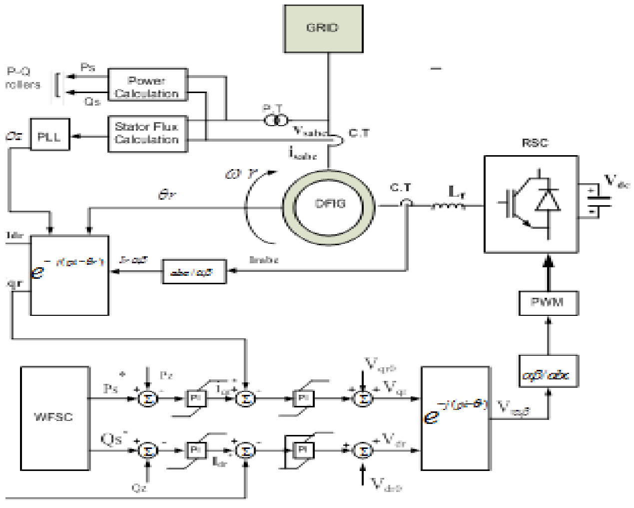

Fig 5 Control Diagram for the rotor side controller

CLOSED LOOP CONTROL DIAGRAM GRID SIDE CONVERTER:

Controlling of the reactive power Qg which is exchanged between the stator side converter and the grid with the help of dc link voltage is the complete control scheme for the GSC.

Form the equivalent circuit shown in figure 2. Applying KVL to above circuit we get

$$v_a = I_a R_f + L_f \frac{dI_a}{dt} + v_{ag} \qquad (13)$$

$$v_b = I_b R_f + L_f \frac{dI_b}{dt} + v_{bg} \qquad (14)$$

$$v_c = I_c R_f + L_f \frac{dI_c}{dt} + v_{cg} \qquad (15)$$

Transform the above three phase coordinates in to two phase d-q transformation and separate real & imaginary terms we get

$$v_{sd} = I_{sd} R_f + L_f \frac{dI_{sd}}{dt} - w_s L_f I_{sq} + v_g$$

$$v_{sq} = I_{sq} R_f + L_f \frac{dI_{sq}}{dt} - w_s L_f I_{sd} \quad (16)$$

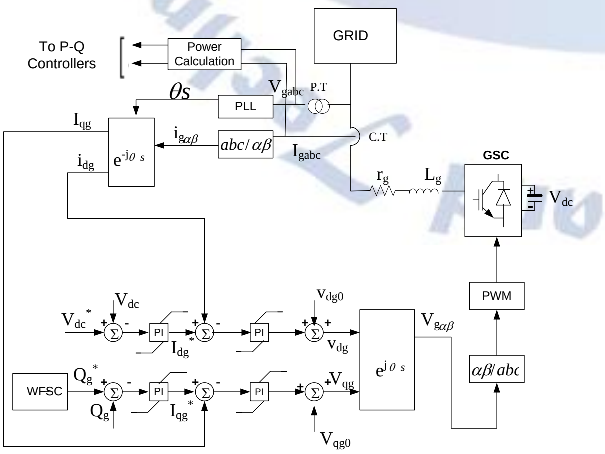

Fig 6: Grid side controller (GSC) scheme

Fig 6 shows the complete closed loop control diagram for the grid side converter and it having two cascaded control loops. The reactive power is indirectly controlled by the dc link voltage controlling done by the outer control loop for generating the reference signals of the d-axis current component idg* and q-axis current component iqg* for the inner-loop current regulation. Then these signals are used for generating pulses with the help of PWM technique

$$P_{ei,\max} = P_{mi,\max} - P_{Li} = P_{si,\max} + P_{ri,\max}$$

The stator active power Ps can be written as

$$P_s = \frac{3}{2}(v_{ds}i_{ds} + v_{qs}i_{qs}) = \frac{3}{2}[\omega_s L_m (i_{qs}i_{dr} - i_{ds}i_{qr}) + r_s(i_{ds}^2 + i_{qs}^2)]$$ The rotor side active power can be expressed as:

$$P_r = \frac{3}{2}(v_{dr}i_{dr} + v_{qr}i_{qr}) = \frac{3}{2}[-s\omega_s L_m (i_{qs}i_{dr} - i_{ds}i_{qr}) + r_r(i_{dr}^2 + i_{qr}^2)]$$

IMPLEMENTATION, RESULTS & DISCUSSION

Simulation studies are carried out to verify the effectiveness of the proposed control schemes under various operating conditions.

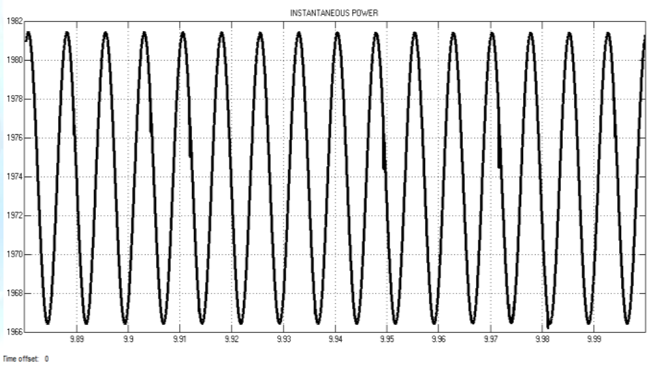

Fig 9: Simulation Result for WECS Power

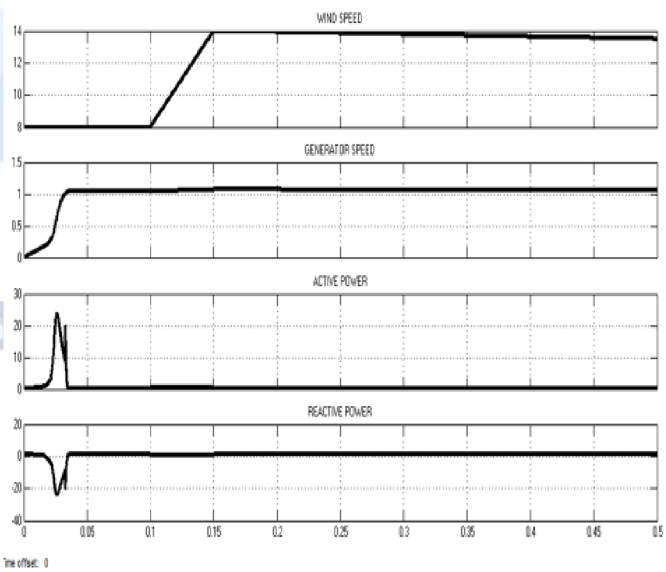

Fig 10: Simulation Results for SCIG based Wind Turbine

IV. CONCLUSION

This paper has presented the comparison of the wind turbine systems by using SCIG and DFIG based generator systems. The experimental results were investigated and a turbine model based on SCIG and DFIG wind power system are modelled and simulated in matlab/Simulink. An optimal active power vs generator speed and also for wind speed were obtained. The SCIG system needs external reactive power source to support the voltage of the grid initially and by pitch control we can control the SCIG based wind power system at different wind speeds. Whereas DFIG does not need any external compensation to maintain the distribution voltage. Both the voltage control schemes for the converters consist of a current regulation part and a cross coupling choke.

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