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Performance Evaluation of DFIG Equipped Wind Turbine System Power Stabilization for Air Speed Fluctuations Using PI Controller

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Abstract— **The current age believes that, non-conventional sources can lead conventional sources for power generation with proper structured implementation. Wind energy is one of the key fields, where various conversion techniques have been proposed in order to produce electric power. In the past 30 years, the size of wind turbines and the size of wind power plants have increased significantly. Modern high power wind turbines are capable of adjustable speed operation and use doubly-fed induction generator (DFIG) systems. The DFIG is variable speed induction machine it is a standard, wound rotor induction machine with its stator windings directly connected to the grid and its rotor windings connected to the grid through an AC/DC/AC pulse width modulated (PWM) converter. The AC/DC/AC converter normally consists of a rotor-side converter and a grid-side converter. By means of the bi-directional converter in the rotor circuit, the DFIG is able to work as a generator in both sub-synchronous and over-synchronous operating area. Depending on the operating condition of the drive, the power is fed in or out of the rotor.**

This paper presents a complete performance evaluation of constant power generation capability of a DFIG based wind turbine system for variable speed air environment. The control structure consider here for stabilized power generation is the, change in pitch angle in accordance with the air speed fluctuations. To control the pitch angle effectively two separate PI controllers have been placed in DFIG for Pitch angle control and compensation.

Keywords: Non-conventional energy, wind power generator, DFIG, pitch angle control, PI controller.

I. INTRODUCTION

A wind energy conversion system mainly consists of the wind turbine, the generator and the power electronic converters. Figure 1 shows the basic mechanical electrical functional chain in wind power generation. The control characteristics of the electric generator and remaining control-related properties of wind-turbines, particularly blade pitch control or stall behavior, must be considered collectively.

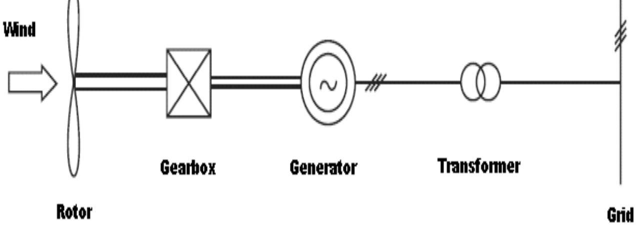

Figure 1 Mechanical-electrical functional chains in wind power generation.

II. Doubly-Fed induction generator (DFIG) system

Today, doubly-fed induction generators (DFIG) are more increasingly used for the large wind power generation. Since their power electronic equipment only has to handle a fraction (20–30%) of the total system power. This means that the losses in the power electronic equipment can be reduced in comparison to power electronic equipment that has to handle the full system power as for a direct driven induction generator, apart from overall cost effectiveness. The semiconductor AC/DC and then DC/AC conversion is used to control the bidirectional power delivered from/to the rotor circuit to/from the grid.

The DFIG is constructed from a wound rotor asynchronous machine shown in figure 2. Variable speed operation is obtained by injecting a variable voltage into the rotor at slip frequency. The injected rotor voltage is obtained using two AC/DC insulated gate bipolar transistors (IGBT) based voltage source converters (VSC), linked by a DC bus. The converter ratings determine the variable speed range. The gearbox ratio is set so that the nominal speed of the IG corresponds to the middle value of the rotor-speed range of the wind turbine. This is done in order to minimize the size of the inverter in the rotor circuit which will vary with the rotor speed range. With this inverter it is possible to control the speed (or the torque) and also the reactive power on the stator side of the induction generator (IG). The speed range, i.e., the slip, is approximately determined by the ratio between the stator to rotor voltage. The stator to rotor turns ratio can be designed so that maximum voltage of the inverter corresponds to the desired maximum rotor voltage to get the desired slip [28], [29].

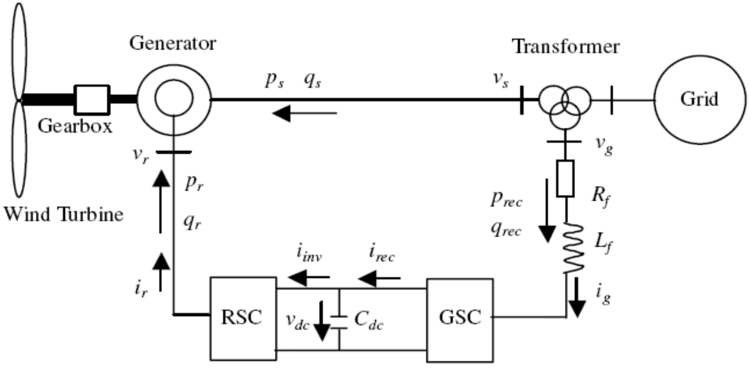

Figure 2 The DFIG wind turbine system.

A. *Speed Control for Optimum Power*

Wind turbines operate by exciting energy from the wind. The available energy in a wind stream is given by $P_{air} = \frac{1}{2}\rho A_r \omega^2$, where ρ is the air density, ω is the wind speed and A_r is the area swept by the wind turbine blades. However, the energy which can be extracted by the wind turbine is less than the energy in the wind. Therefore the power extracted by the aerodynamic rotor (P_m) is expressed with respect to the power available in the wind (P_{air}) as follows:

$$P_m = C_p - P_{air} \qquad (2.1)$$

C_p is called the power coefficient and depends on the tip-speed ratio (λ) which is the ratio between the velocity of the rotor tip and wind speed defined by:

$$\lambda = \frac{\Omega_r r_r}{\omega} \qquad (2.2)$$

where Ω_r is the aerodynamic rotor speed and r_r is the radius of the rotor. To extract the maximum power from the wind, the rotor speed should vary with the wind speed, maintaining the optimum tip speed ratio (λ_{opt}).In practical DFIG wind turbine the rotor torque is used as a set point reference. A typical set-point torque-speed characteristics applied for controlling DFIG wind turbines is shown in Figure 3. The cut-in and the rated speed limits are mainly due to converter ratings although the upper rotational speed may also be limited by an aerodynamic noise constraint. For low-medium wind speeds (A-B) the speed control defined by the set point torque is applied by controlling the injected rotor voltage. When the rotor reaches pint B, blade pitch regulation dominates the control and limits the aerodynamic power. For very high wind speeds the pitch-control will operate until the wind speed shutdown limit is reached.

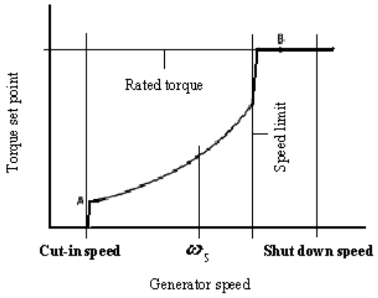

Figure 3 Torque-speed characteristic for turbine control strategy

B. *Control of DFIG Wind Turbine*

A simplified diagram of the control scheme used for the DFIG wind turbine is shown in Figure 4. In the configuration shown, the rotor side converter (C1) is used for both speed control and for power factor and/or voltage control. Converter C2 acts to transmit real power only. The generator control is based on a d-q coordinate system, where the q component of the stator voltage is selected as the real part of the bus bar voltage and d component as the imaginary part.

The new co-ordinate system decouples the speed control action from the power factor and/or voltage control. This allows the two rotor injection voltages – V_{qr} and V_{dr} to be regulated separately for speed control and/or voltage control, respectively.The DFIG wind turbine voltage control strategy is typically defined to provide power factor control of the induction generator, using converter C1. Terminal voltage control can also be provided through the rotor side converter and this scheme is illustrated in Figure 4. However, reactive power injection can be obtained from either the rotor side converter (C1) or the network side converter (C2).Using the rotor side converter (C1) is likely to be preferred to the network side converter for DFIG voltage control schemes. This is largely due to the reduction in the converter-rating requirement as reactive power injection through the rotor circuit is effectively amplified by a factor of 1/slip [28].

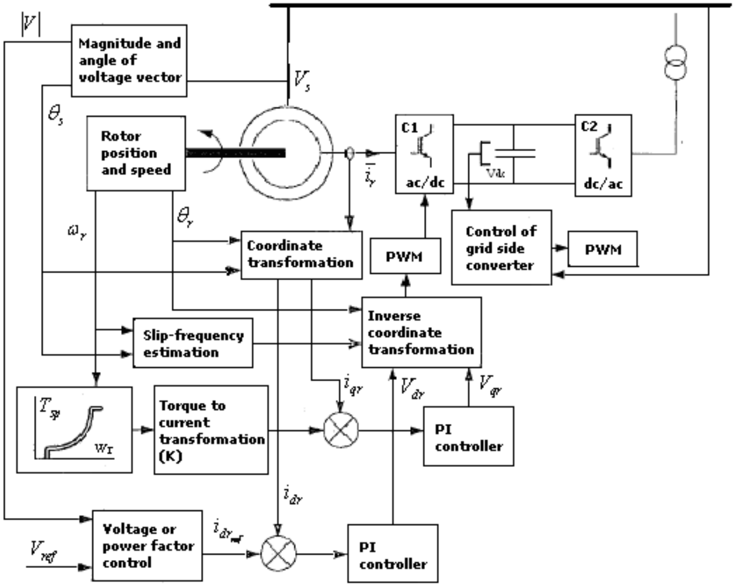

Figure 4 Simplified schematic of a DFIG wind turbine typical control system

III. IMPLEMENTATION OF DFIG SYSTEM FOR WIND TURBINE

A 9 MW wind farm consisting of six 1.5 MW wind turbines connected to a 25 kV distribution system exports power to a 120 kV grid through a 30 km, 25 kV feeder is developed. The proposed system having Wind turbines using a doubly-fed induction generator (DFIG) consist 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. As the main objective of this work is to evaluate the performance of DFIG in variable air speed environment, and to achieve this significant fluctuations in the air speed has been created in the simulation. The variable air speed situation generated is shown in figure (5).

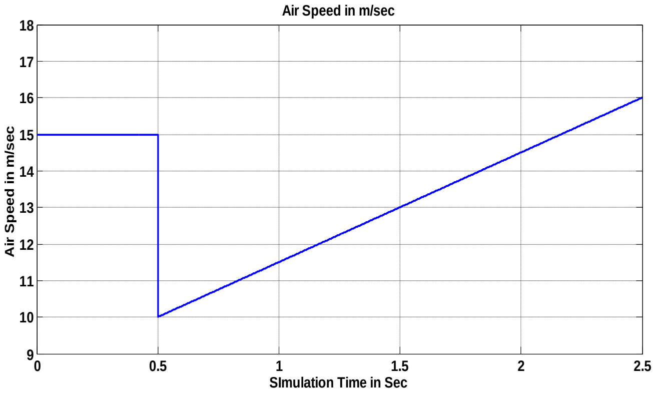

Figure (5) The variable air speed situation generated.

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The initial wind speed is maintained constant at 15 m/s and then it suddenly goes down to10 m/s, and after this point the air speed increases gradually to 16 m/s up to time 2.5 sec. The control system uses a torque controller in order to maintain the speed at 1.2 pu. The reactive power produced by the wind turbine is regulated at 0 Mvar. The sample time used to discretize the model is 50 microseconds. For a wind speed of 15 m/s, the turbine output power is 9 MW approximately, the pitch angle is 8.7 deg and the generator speed is 1.2 pu. Figure (6) shows the simulation model developed for the proposed work in MATLAB Simulink 2012b version.

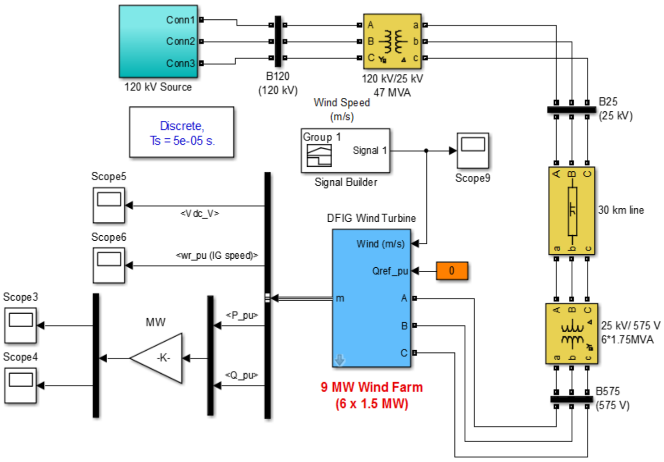

Figure (6) Developed Simulation Model of the proposed work.

Figure 7, shows the pitch angle control structure of a conventional DFIG wind turbine system, in which two PI controller were used for pitch angle control and its compensation.

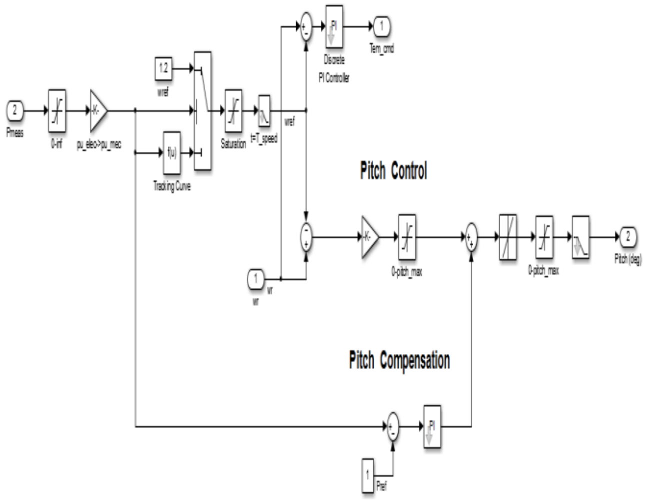

Figure (7) Pitch angle control structure of a conventional DFIG wind turbine system.

IV. RESULTS AND DISCUSSION

Let's observe the turbine response to a change in wind speed. Initially, wind speed is set at 15 m/s, then at t = .5 seconds, it suddenly goes down to10 m/s, and after this point the air speed increases gradually to 16 m/s up to time 2.5 sec. The resultant responses are shown from figure (8) to figure (12).

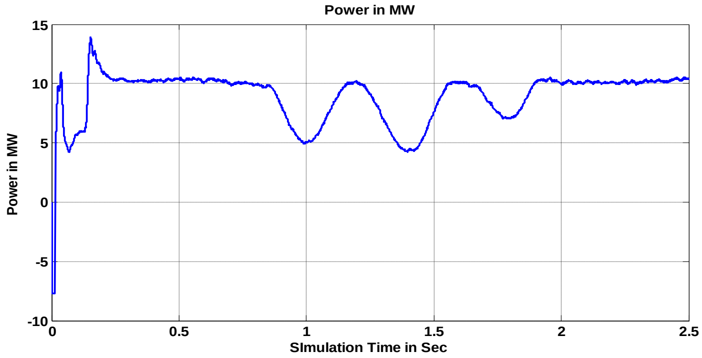

Figure (8) Plot of output power from DFIG.

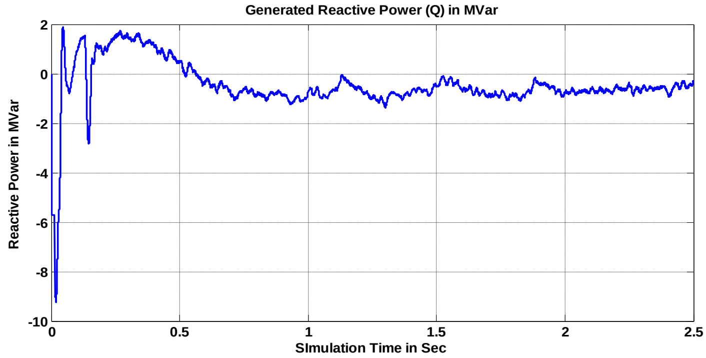

Figure (9) Plot of Reactive power from DFIG.

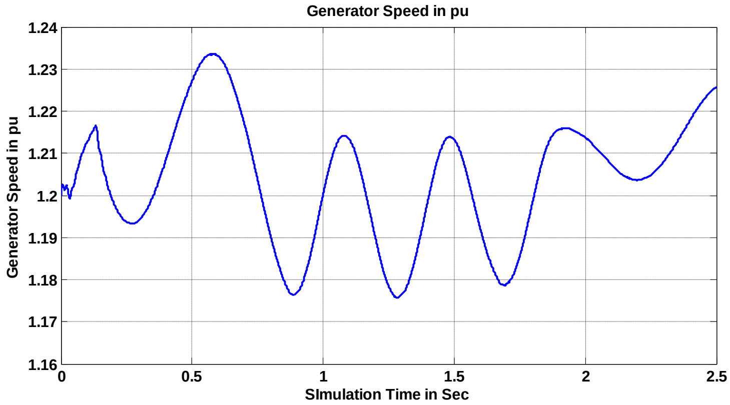

Figure (10) Plot of generator speed.

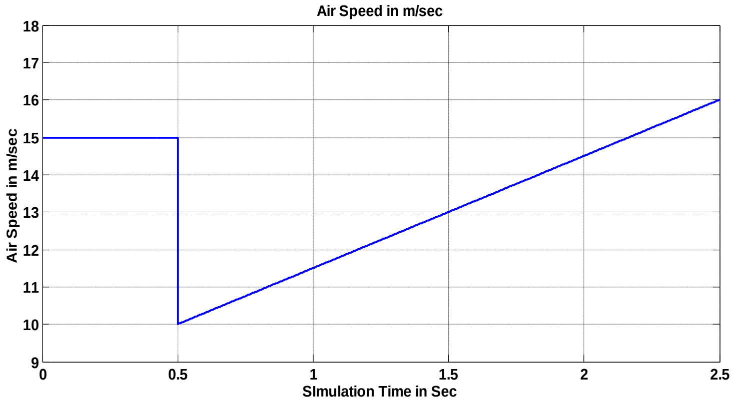

Figure (11) Plot of change in Wind speed.

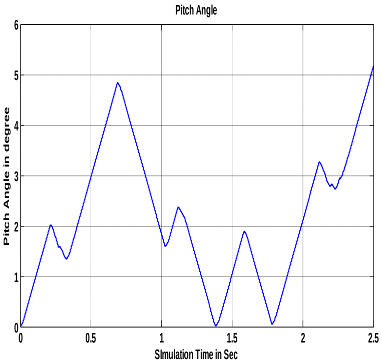

Figure (12) Plot of change in pitch angle by PI controller.

Initially when wind speed is kept constant on 15 m/s, the generated active power starts increasing to reach its rated value of 10 MW. At t= .5 second, as the wind speed suddenly downed to 10 m/s, even then also the power was stabilized around 10 MW, but as the wind speed gradually increases from 10 m/s to 16 m/s, around t = .7 sec there is high oscillation in power occurs, this oscillation remains till t = 2 sec. After t = 2 sec the power generated by the system again tends to stabilize at 10 MW. Although during the period of power oscillation PI controller tries to limit mechanical power by rapidly changing the pitch angle, but the effort was not found enough to overcome this oscillation.

V.CONCLUSION

In this paper a complete system for the DFIG based wind turbine for wind energy generation via, constant power generation has been successfully evaluated to investigate and analyze the capability of PI controller based pitch angle control in variable wind speed environment. In the result section it has been shown that, the developed system can able to provide approximate constant power output at the steady state but not able to maintain power stabilization and hence provides high oscillation during the wind speed variation especially in case of gradual increase in wind speed. This small problem can be further resolve by fusion of using advance controllers like fuzzy controller with PI controllers for efficient pitch angle control.

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