International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-2 Issue-2, January 2013

Vector Control of Wind Turbine Generating System Using PI and Model Predictive Controller

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Abstract- ***Doubly fed induction generators (DFIG) are widely used in wind turbine generating systems (WTGS). The control of the active and reactive power is done with a rotor current controller. The problem in using a PI controller is the tuning of gain and cross-coupling on DFIG parameters in the whole operating range. A model predictive controller (MPC) is used for power control of DFIG. By using MPC peak over shoot and settling time have been reduced when compared with PI controller. This paper includes simulation of WTGS vector control using PI and MBPC and the performance evaluation of these two systems. And a model of PI controller based WTGS vector control has also been simulated using MATLB Simulink. Simulation results are presented to validate the proposed controllers.***

Keywords- ***WTGS, DFIG, Vector control, MPC.***

I. INTRODUCTION

The global energy consumption and pollution due to the use of energy increases exponentially. Since energy demand is directly proportional to energy production and pollution increases with increase in use of most of the conventional fuels we need energy with less impact on environment. In this scenario role of renewable energy technologies like wind, solar, biomass, etc. increasing. DFIG system used for WTGS has some advantages due to variable speed operation of generator and four quadrant active and reactive power operation compared with squirrel cage induction generator(fixed speed)[1], [2]. A model of DFIG based wind turbine is shown in Fig.1. The stator of the DFIG is connected directly to the grid and the rotor is connected through a bidirectional converter. Active and reactive power between the stator of the DFIG ac supply or standalone grid is controlled by controlling controller connected to the rotor.

The control of wind turbine generating system is commonly based on either stator flux oriented [3] or stator voltage oriented [4], vector control. The control is generally done by decoupling the rotor current into active and reactive power components. Now a days most of the commercial wind turbines are using PI controllers and vector control. The main disadvantages by using PI controllers are the cross coupling on DFIG terms in the whole operating range and tuning of the gains.

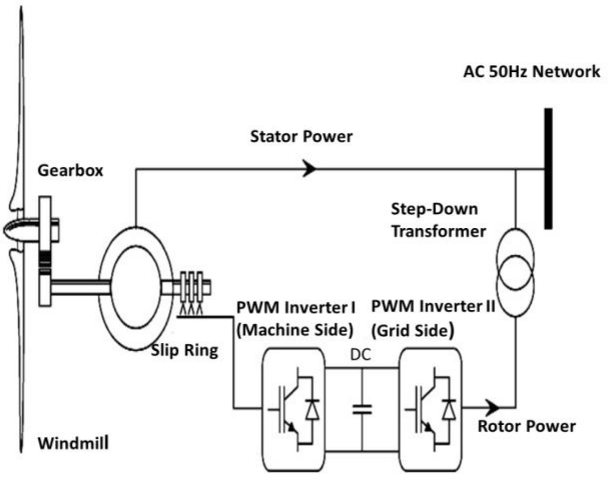

Fig.1. Model of DFIG Wind Turbine

A proportional-integral-derivative controller (PID controller) is a common feedback loop component in industrial wind power production control systems. The controller takes a measured active and reactive current and compares it with a reference set point value. The error signal produced is then used to adjust reference active and reactive power to its desired set point. Unlike other type of simpler controllers, the PI can adjust process outputs based on the history and rate of change of the error signal, which gives more stable and accurate control. PID controllers require only simple mathematics to design and can be easily tuned to the desired application, unlike more complicated control algorithms based on optimal control theory.

Predictive control is an alternative control technique that was applied in machine drives and inverters [6]. Predictive control can be commonly divided into long range predictive control, general predictive control, and model predictive control. Long range predictive control and general predictive control strategies have a satisfactory power response although the control does not predict the outputs (active and reactive power) and the power response can be degraded. Model based predictive control for control of DFIG is included in this paper. The control law is derived by optimization of an objective function that considers the control effort and the difference between the predicted outputs (active and reactive power) and the references. The prediction is calculated using a linearized state-space model of DFIG. MPC have better performance when compared with the response and settling time of PI, since the formulation is complex and computational cost is high its implementation is difficult.

Manuscript published on 30 December 2012.
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Fuzzy logic can also be used for the power control of DFIG. These strategies have satisfactory power response, although the errors in estimation of parameters can degrade the system response. Direct power control (DPC) was based on the principles of direct torque control [5]. This method calculates the rotor voltage space vector based on stator flux estimated and power errors. Moreover, the conventional DPC complicates the AC filter design because of its variable switching frequency. This paper contains the Simulink model WTGS using PI based vector control and analysis of settling time and peak over shoot of WTGS using MPC and PI controller.

II. DFIG DYNAMIC MODELLING

The wound rotor induction machine stator is connected to the low voltage balanced three-phase grid and the rotor side is fed via the back-to-back IGBT voltage-source inverters with a common DC bus. The network side converter controls the power flow between the DC bus and the AC side and allows the system to be operated in sub synchronous and super synchronous speed. The rotor excitation is provided by the machine side power converter. The general model for wound rotor induction generator as follows.

Stator Voltage Equations

$$v_{qs} = p\lambda_{qs} + w\lambda_{ds} + r_s i_{qs}$$
$$v_{ds} = p\lambda_{ds} + w\lambda_{qs} + r_s i_{ds} \qquad (1)$$

Rotor Voltage Equations

$$v_{qr} = p\lambda_{qr} + (w - w_r)\lambda_{dr} + r_r i_{qr}$$
$$v_{dr} = p\lambda_{dr} + (w - w_r)\lambda_{qr} + r_r i_{dr} \qquad (2)$$

Power Equations

$$P = v_{ds} i_{ds} + v_{qs} i_{qs}$$
$$Q = v_{qs} i_{ds} - v_{ds} i_{qs} \qquad (3)$$

Torque Equation

$$T_e = M\frac{P}{2}\left(i_{qs} i_{dr} - i_{ds} i_{qr}\right) \qquad (4)$$

Stator Flux Linkage Equations

$$\lambda_{qs} = (L_{ls} + L_m) i_{qs} + L_m i_{qr}$$
$$\lambda_{ds} = (L_{ls} + L_m) i_{ds} + L_m i_{dr} \qquad (5)$$

Rotor Flux Linkage Equations

$$\lambda_{qr} = (L_{lr} + L_m) i_{qr} + L_m i_{qs}$$
$$\lambda_{dr} = (L_{lr} + L_m) i_{dr} + L_m i_{ds} \qquad (6)$$

III. WTGS USING PI CONTROLLER

Simulink diagram of grid side converter (GSC) is shown in the Fig. 2. The stator flux is aligned with the axis, and it is assumed that the network is stable and the stator flux constant set. Furthermore the generator stator resistance is negligible. Since the stator flux is aligned with the axis we can write $\lambda_{sd} = \lambda_s$ and $\lambda_{sq} = 0$ by applying this condition stator voltages are

$$v_{ds} = 0 \qquad (7)$$
$$v_{qs} = w_s \lambda_s \qquad (8)$$
$$\lambda_s = L_s I_{ds} + M i_{dr} \qquad (9)$$
$$0 = L_s I_{qs} + M i_{qr} \qquad (10)$$
$$T_e = M\frac{P}{2}\left(\lambda_s i_{qr}\right) \qquad (11)$$

From the above equation it is clear that the electromagnetic torque can be controlled directly by acting on the current i_{qr}, so the reference current is:

$$i_{rqref} = \frac{2L_s w_s}{3pMU_s} C_{emref} \qquad (12)$$

Where U_s is the amplitude of the stator voltage assumed constant.

Equation (3) of the reactive power of the stator becomes:

$$Q_s = \frac{U_s}{L_s w_s}\left(U_s - MW_s i_{dr}\right) \qquad (13)$$

From equation (12), we note that the reactive power of the stator can be controlled by varying the current i_{dr} to guarantee operation at unity power factor set point Q_{rsref} so the reference current on the axis is:

$$i_{rqref} = \frac{U_s}{MW_s} \qquad (14)$$

The GSC is connected between the DC link voltage and the electrical network via an R, L filter. This converter has two roles: to maintain the DC link voltage constant regardless of the magnitude and direction of flow of the power of the DFIG rotor and maintain a unity power factor at the connection point with the grid. By applying park transformation, grid side converter voltage components are given by $v_{gd} = 0$,$v_{gq} = U_g$ with U_g is the amplitude of voltage.

Regulating the DC link voltage is then accomplished by an external loop (relative to the inner loop control of current), for maintaining a constant voltage on the DC link, with a PI controller generating the reference current in the capacitor. The Fig. 3 shows the block diagram of the control of the DC link voltage.

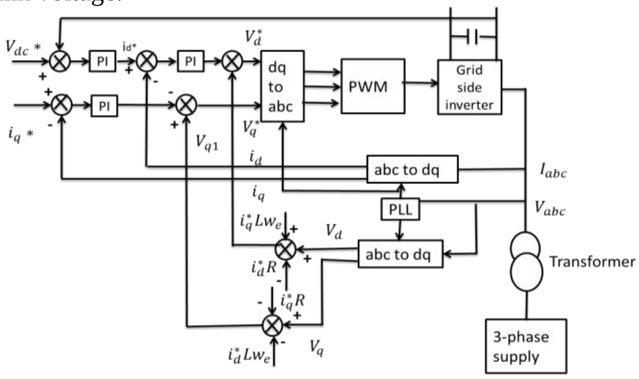

Fig 2.Vector control structure for GSC

$$P_{red} = i_{red} v_{dc} \qquad (15)$$
$$P_c = i_c v_{dc} \qquad (16)$$
$$P_{ond} = i_{ond} v_{dc} \qquad (17)$$

These powers are related by:

$$P_{red} = P_c + P_{ond} \qquad (18)$$

Neglecting all losses to the Joule power exchanged between the rotor of the DFIG and the grid (losses in the capacitor, the converter and filter):

$$P_g = P_{red} = P_c + P_{ond} \qquad (19)$$

The capacitor reference power is related to the reference current flowing in the capacitor[10].

$$P_{cref} = i_{ond} v_{dc} \qquad (20)$$

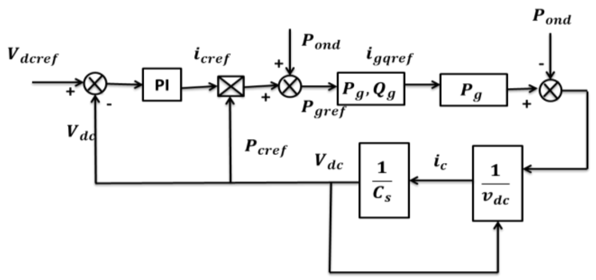

Fig.3.Control loop of the DC link voltage

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In fig.3 appears P_{ond} available power corresponding to the rotor power.

IV. WTGS USING MPC

The model predictive control (MPC) commonly consists of two main elements: the model of the system being controlled and the optimizer that determines the optimal future control actions. The system model is used to predict the future behavior of the system with control law obtained by optimizing a cost function. The cost function considers the effort needed to control the deviation between the expected and the real values. The receding horizon principle is used for the first element of the optimal sequence is applied. In any plant, new measurements are made for each sample of success and then the procedures are repeated. The main steps of MPC are estimates of output and determining the control law. There are various MBPC techniques for output prediction using the state space model or the transfer function of the system [7]. In this paper, the output prediction is derived from the state space model and it is given by

$$Y = P_{px}x_k + HU + Dw_{dk} \qquad (21)$$

Where

$$Y = [y(k+1)\ \ y(k+2)\ \ \ldots\ldots y(k+n_y)]^T \qquad (22)$$

$$U = [u(k)\ u(k+1)\ \ldots\ldots u(k+n_y-1)]^T \qquad (23)$$

$$P_{px} = [C_dA_d\ \ C_dA_d^2\ \ C_dA_d^3\ \ldots\ldots C_dA_d^{n_y}\ ]^T \qquad (24)$$

$$H = \begin{bmatrix} C_dB_d & 0 & 0 & \cdots \\ C_dA_dB_d & C_dB_d & 0 & \cdots \\ C_dA_d^2B_d & C_dA_dB_d & C_dB_d & \cdots \\ \vdots & \vdots & \vdots & \vdots \\ C_dA_d^{n_y-1}B_d & C_dA_d^{n_y-1}B_d & C_dA_d^{n_y-1}B_d & \cdots \end{bmatrix} \qquad (25)$$

$$D = \begin{bmatrix} C_d & 0 & 0 & \cdots \\ C_dA_d & C_d & 0 & \cdots \\ C_dA_d^2 & C_dA_d & C_d & \cdots \\ \vdots & \vdots & & \vdots \\ C_dA_d^{n_y-1} & C_dA_d^{n_y-1} & C_dA_d^{n_y-1} & \cdots \end{bmatrix} \qquad (26)$$

Where n_y represents the prediction horizon output, Y is the predicted output $x_k = \bar{x}(k)$, and $w_{dk} = \bar{w}_d(k)$. The value of prediction horizon n_y is critical for the performance of the control, because the selection of a high value improves the stability of the system, but may increase the computational costs excessively. Another factor that must be taken into consideration when choosing n_y is the confidence implanted by the designer in the model representation of the plant. When there is no guarantee that the model precision describes the plant, smaller n_y must be chosen.

The control law is obtained by minimizing the quadratic cost function which exists in the error between the prediction based on the model and future references. The quadratic function in its matrix form is given by

$$J = (Y - w)^T W_y (Y - w) + U^T W_u U \qquad (27)$$

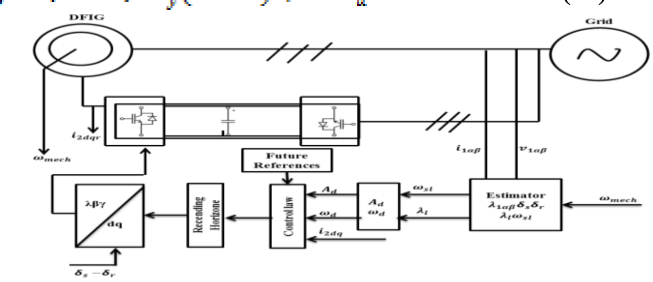

Fig. 4. Block diagram of proposed predictive power control strategy.

Where $w \in R^{(n_y \times q)\times 1}$ represents the vector of the future output references to be controlled, $W_y \in R^{(n_y\times q)(n_y\times q)}$ stands for a positive-defined matrix that allows an emphasis on each of the controlled outputs and its predictions, $W_u \in R^{(n_u\times n_u)}$ stands for a positive-defined matrix, usually diagonal, which weighs the control efforts of inputs, $U \in R^{(n_u\times n_u)}$ is the input, q is the number of outputs, and n_u is the control horizon. The control law using the minimal value of the cost function is achieved making $\partial J/\partial U$=0 and isolating U Thus, this expression is given by

$$U = (H^T W_y H + W_u)^{-1} H^T W_s (w - P_{px}x_k - Dw_{dk}) \qquad (28)$$

The diagram of the MBPC applied to the DFIG power control is shown in Fig. 4. The converter, which is connected to the grid controls the voltage of the link DC.

V. SIMULATION RESULT

The simulation of proposed control strategy used the MATLAB/ Sim Power Systems package.

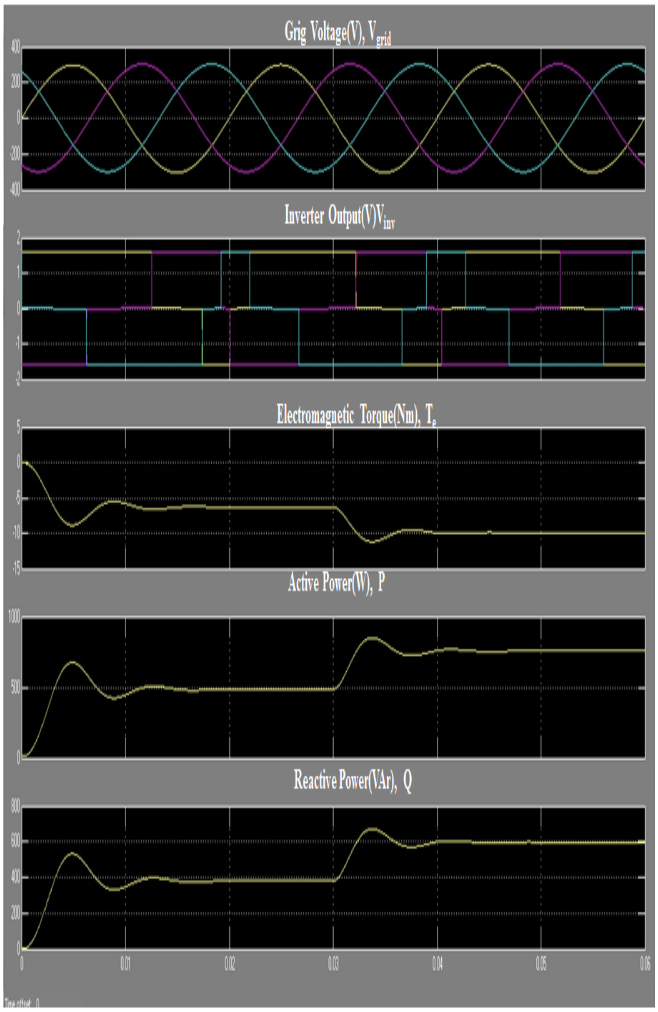

Fig. 5. Simulink model result of PI based Vector control

The simulation of PI controller has been done in MATLAB file and MATLAB SIMULINK model. Simulation of MBPC is done by using MATLAB M file.

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Fig.5 shows the simulation output diagram for WTGS based on DFIG using vector control using PID controller. From the output diagram it is clear that according to the change in the torque from the prime mover electromagnetic output torque changes there by active and reactive power also changes. By using the vector control, output is controlled to accepted level with proper settling time.

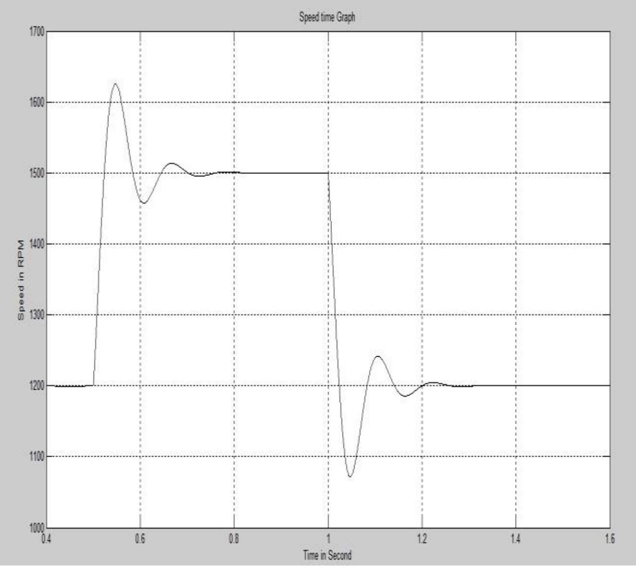

Fig. 6. Rotor Speed vs time

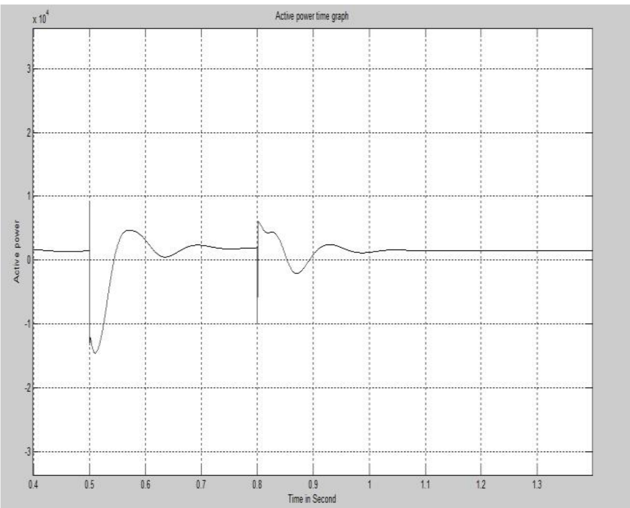

Fig. 7. Active power when wind speed changes, using PI controller

By analyzing Fig. 7 & 8which shows the output using PI controller it is clear that settling time and peak over shoot is high when compared with output obtained with MPC. But one high impulse produced for few seconds. And it will not affect the performance of whole system.

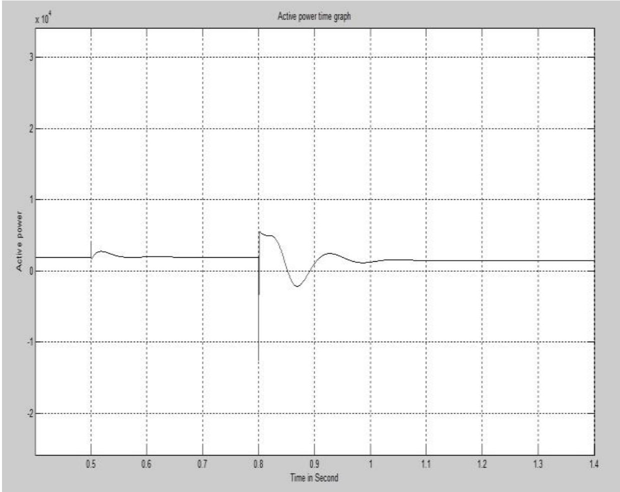

Fig.8. Active power when wind speed changes, using model predictive controller

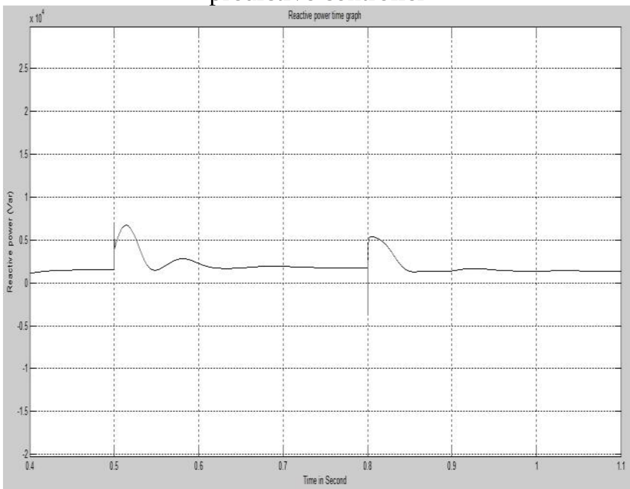

Fig. 9 Reactive power when speed changes, using model predictive controller

The fig 9 and 10 shows the reactive power variation according to the wind speed. By analyzing these two graphs it is clear that peak over shoot and settling time reduces when MPC used instead of PI controller. But it can be observed that change in the settling time is not significant in reactive power control.

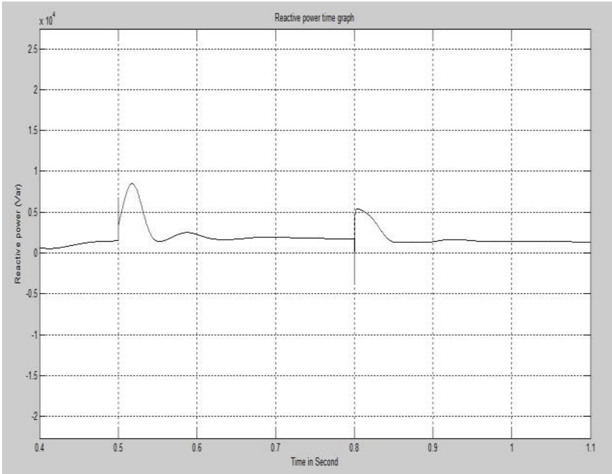

Fig.10. Reactive power when speed changes, using PI controller.

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VI. CONCLUSION

This paper presented two different types of controllers used in vector control of WTGS and the comparison of these techniques. In this paper, simulation of control of wind energy using model predictive controller and PI controller has been done. Output for the active and reactive power are plotted for MPC and PI controller and analyzed. Peak over shoot and settling time are reduced by using MPC. This will improve the system efficiency during variable wind speed condition than by using PI controller.

VII. ACKNOWLEDGMENT

We take immense pleasure in conveying my thanks and deep sense of gratitude to our teachers for their exhilarating supervision, timely suggestions and encouragement during all phases of this work.

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