Comparative study of Decoupled controls of DFIG

Dr. K. H. Phanishree

Associate professor, Dept of electrical and electronics engineering, JNTUH, CEH Hyderabad, India

ABSTRACT

This paper focuses on performance analysis of decoupled controllers of DFIG system. Different algorithms like vector control and linear feedback control are implemented for rotor side converter to obtain the decoupled control of powers from stator to grid. Using DFIG with the independent control of active and reactive powers maximum amount of energy from the wind can be harnessed and power factor could be maintained at unity. To investigate the performance of the both the controllers different types of disturbances like step change in active power, reactive power and wind speed are simulated. Eigen value study has been carried out to while deciding the gain constants. Generally response of controller depends on machine parameters which may vary due to temperature variation and flux variations. In this paper dynamic performance of traditional PI control is compared with feedback linearization control in terms of reference point tracking and parameter variation.

Keywords: eigen values ,decoupled control ,DFIG, FBLC, parameter variation.

I. INTRODUCTION

Global concern about the environmental pollution and continuously increasing energy demand has led to the growing interest in innovative technologies for generation of clean and renewable electrical energy. Out of all the renewable energy sources, wind power is the most rapidly growing one in the industry. Two modes of operation can be used in electrical generation from wind namely, constant speed constant frequency and variable speed constant frequency. Variable speed constant frequency operation (VSCF) is becoming more attractive with the invention of modern power electronic devices and digital control systems. DFIG is a suitable generator for large size wind turbines (WT), to achieve all the benefits of VSCF systems. DFIG based VSCF operation has the advantages of higher energy capture, better stability and decoupled control of active and reactive powers, reduced mechanical stresses, lower acoustic noise and improved power quality.

The stator of doubly fed induction generator is connected to electrical utility and rotor is connected to electric utility via back-to-back PWM converters and a step-up transformer. Total control of the machine is achieved by a fractional power rated converter in the rotor circuit, which is the main advantage of doubly fed induction generator based wind power generation In this configuration Power factor control is also possible by decoupling the active and reactive powers with rotor side converter in DFIG. The induction machine can be synchronized with the grid by controlling rotor voltages and currents while the wind speed varies. This feature gives scope for the proper usage of the wind energy, since a variable speed drive can derive maximum power from the wind, as compared to a fixed speed drive. To achieve decoupled control of powers on stator side, vector control technique based on stator flux orientation is used for rotor converter control. To improve the performance of the DFIG further various authors proposed different control techniques [1-9]. [10-15]have studied the motor response, to different voltage/frequency inputs using the digital simulation of the original non-linear equations, and results are analyzed with the aid of transfer functions and eigen values obtained at a various operating points on the basis of the linearized version.

Further to enhance the dynamic response while achieving the decoupled control, feedback linearization is applied to rotor side converter control [16]-[18]. This paper focus on eigen value study along with the time response plots to understand the cause and nature of response .Further controllers effectiveness is tested against reference tracking and parameter variations.

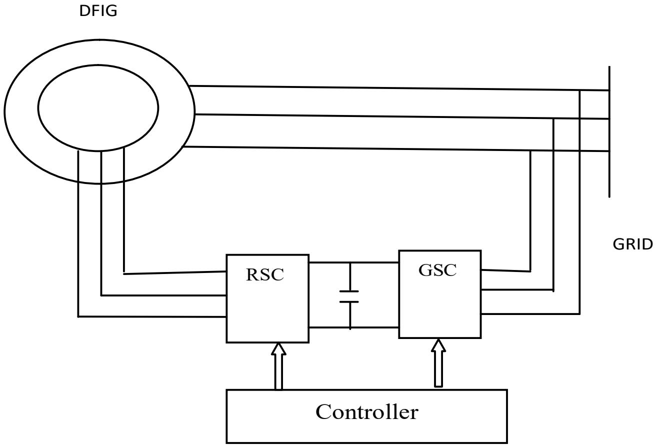

Fig.1 Block diagram of DFIG system

II VECTOR CONTROL

1 .Modeling of Rotor side converter

A DFIG control is divided into rotor and grid side controls. Rotor side control, controls the active and reactive powers of stator independently and the grid side converter controls, dc-link capacitor voltage and power factor.The doubly fed induction machine is controlled in a synchronously rotating d-q frame with the d-axis aligned along the stator-flux position. This permits the decoupled control of currents. By setting the stator flux vector to align with d-axis

$$\emptyset_s = \emptyset_{ds} \quad , \quad \emptyset_{qs} = 0 \tag{1}$$

With the help of above condition and machine equations the below conditions can be derived

$$P_s = \frac{3}{2} V_s i_{qs} \tag{2}$$

$$Q_s = \frac{3}{2} V_s i_{ds} \tag{3}$$

The active and reactive powers expressions can be rewritten as

$$P_s = -\left(\frac{3}{2}\right)\left(\frac{L_m}{L_s}\right) V_s i_{qr} \tag{4}$$

$$Q_s = \left(\frac{3}{2}\right) V_s \left(\frac{\emptyset_s}{L_s} - \frac{L_m}{L_s} i_{dr}\right) \tag{5}$$

The RSC is used to control the active and reactive powers injected by the stator of the DFIG to the grid.

$$i_{qr}{}^{*} = -\frac{2}{3}\left(\frac{L_s}{L_m}\right)\frac{P_s{}^{*}}{V_{qs}} \tag{6}$$

$$i_{dr}{}^{*} = \frac{\emptyset_{ds}}{L_m} - \frac{\left(\frac{2}{3}\right)\frac{L_s}{L_m} Q_s{}^{*}}{V_{qs}} \tag{7}$$

The rotor currents of the DFIG are sensed and transformed to the d-q reference frame by using Park transformation and compared with reference values and given to a PI controller to form the voltage signals$V_{dr}{}^{1}$,$V_{qr}{}^{1}$ and these are compensated by the cross coupling terms to form the voltage references.

$$V_{dr}{}^{*} = V_{dr}^{1} - (\omega_e - \omega_r)\sigma L_r i_{qr} \tag{8}$$

$$V_{qr}{}^{*} = V_{qr}^{1} + L_r \sigma i_{dr}(\omega_e - \omega_r) + \frac{L_m}{L_s}\emptyset_{ds}(\omega_e - \omega_r) \tag{9}$$

From above relations stator active power is controlled by controlling the q-axis rotor current component and reactive power is controlled by controlling the d-axis rotor current component.

2. Response of Vector Controlled DFIG

To investigate the effectiveness of the vector controller numerical simulation was carried out on a typical grid-connected DFIG with wind turbine. In the simulation, the following disturbances were considered at different instants of time.

i) Step change in the active power set point

The step change in the DFIG's output active power is simulated at t=4sec from -500W to -1000W. The reactive power reference is kept at zero in this period. The wind speed is maintained at 8 m/s. The responses of the generator active power, reactive power are shown in Fig 2 and 3.The active power reference changes at t=4 sec, the DFIG's output reactive power also undergoes a small oscillation. Active power and reactive power are related to i_{dr} and i_{qr} respectively, so the changes in active power and reactive power are realized through changes in i_{qr} and i_{dr}.

ii) Step change in the reactive power set point

This scenario is simulated at t=5 sec, there is a step change in the DFIG's output reactive power set point. The stator output active power reference is maintained at -1000W. The initial stator reactive power reference is zero and changes to -1000Var at 5sec. The responses of the generator variables to the step change in the reactive power reference are shown in Fig 2-3 at t=5 sec. As the reactive power set point steps up at 5sec, the i_{dr}increases.

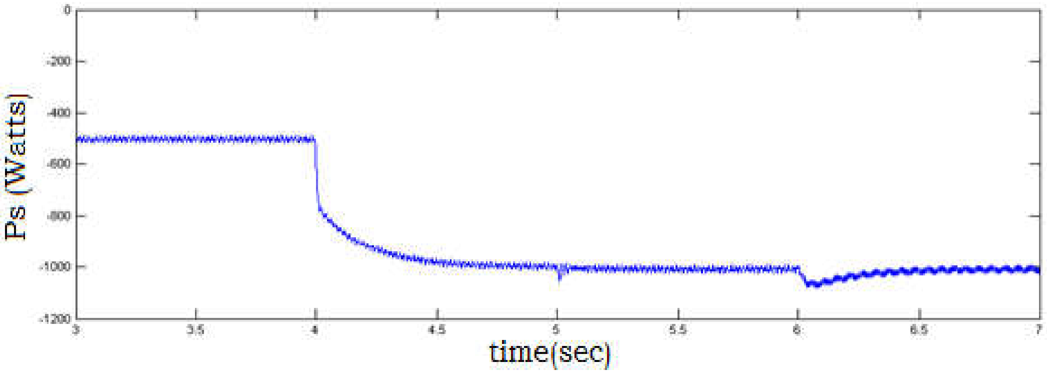

Fig.2 Stator active power

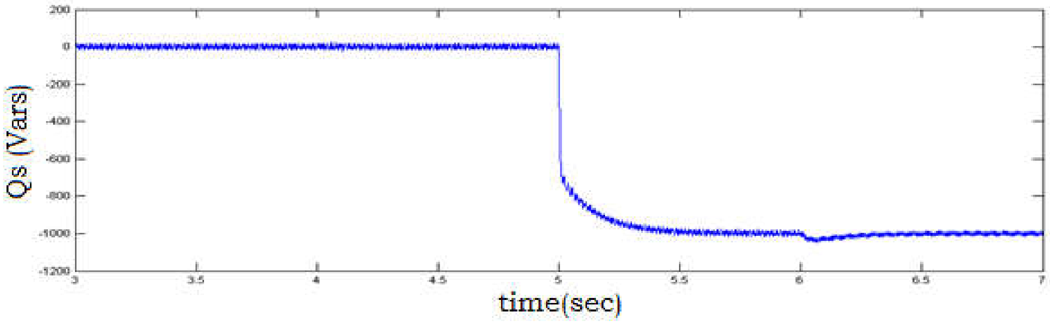

Fig.3 Stator reactive power

III FEEDBACK LINEARIZATION CONTROL

A conventional Proportional-Integral (PI) controller usually consists of inner current control loops and an outer voltage control loop in a cascade structure. So traditional vector control approach is not effective for the system control where the dynamics of both the loops are interactive. The essence of feedback linearization is that the dynamics of the non-linear system are modelled and are algebraically transformed into a set of linear equations. Henceforth, linear control techniques can be applied to the transformed systems. The detailed modelling of feedback linearization control algorithm is presented in [17]for doubly-fed induction generator is based on the model of DFIG,

$$v_{dr} = \sigma L_r v_1 + R_r i_{dr} - (\omega_e - \omega_r)\sigma L_r i_{qr} \tag{10}$$

$$v_{qr} = \sigma L_r v_2 + R_r i_{qr} + (\omega_e - \omega_r)\sigma L_r i_{dr} + (\omega_e - \omega_r)L_0^2 i_{ms}/L_s \tag{11}$$

Where $\sigma = (1 - \frac{L_m^2}{L_s L_r})$, V_{qr}^1 and V_{dr}^1 are the rotor side controller voltages referenced to q and d axes.

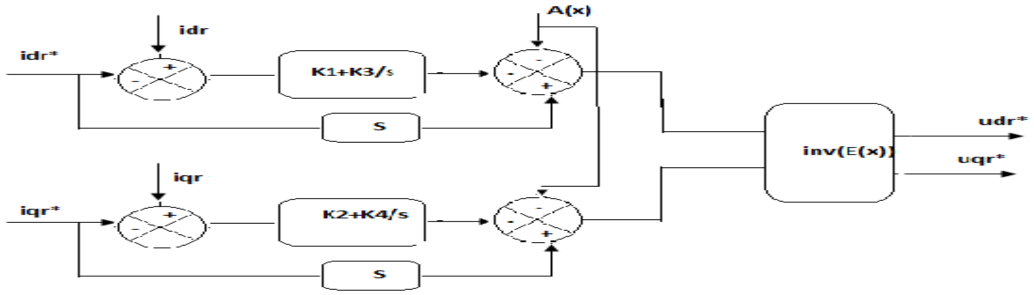

Fig.4 Block diagram of Feedback linearization control strategy

3. Response of linear feedback controlled DFIG

The response of DFIG with feed-back linearization algorithm is shown in Fig 5-6.Using the feedback linear control algorithm decoupled control of powers is being achieved. The set values of active, reactive power are maintained with the same reference values at the same instant as that of vector control. This controller has shown a good tracking of the reference values with fast response. Active power and reactive power responses just follows i_{qr} and i_{dr} wave forms respectively. By applying V_{qr}, V_{dr} components, obtained by the algorithm, the reference values of active and reactive powers are achieved.

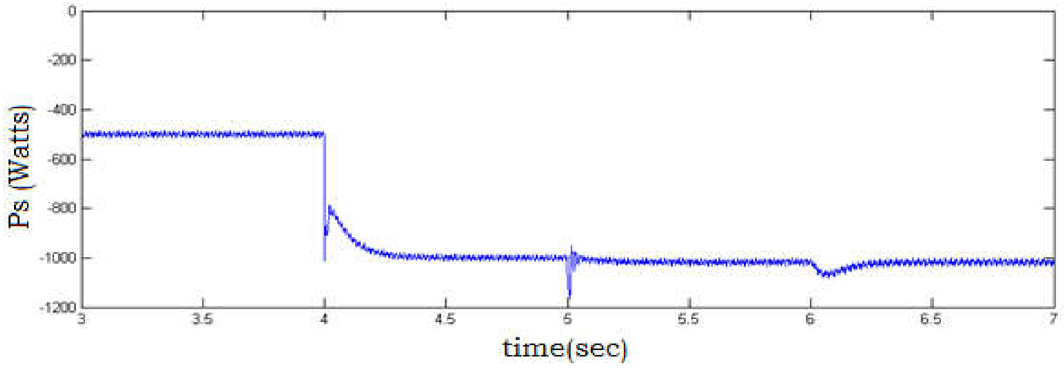

Fig.5 Stator active power

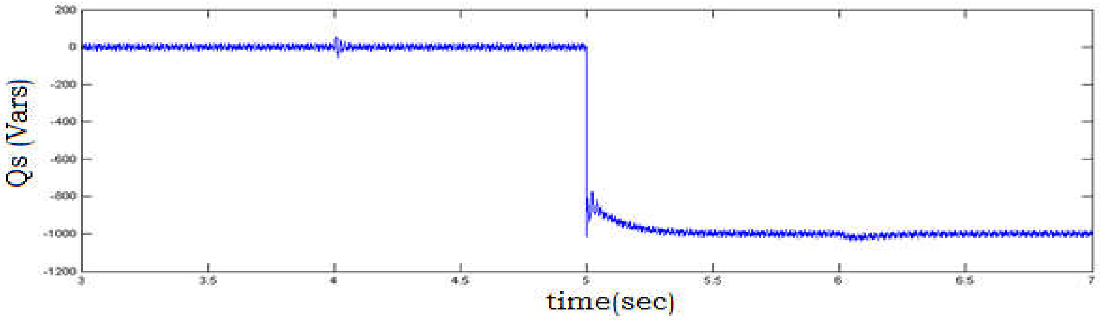

Fig.6 Stator reactive power

To show the effect of gain values of proportionality constant(K2) of the controller, pole zero maps are drawn. Thse plots are obtained from MATLAB/Simulink enviornment considering i_{qr} as the input and V_{qr} as the output.When the propotional gain values are increased from 10 to 100, the poles are moving away from the unit circle and is shown in Fig.7. Unit circle in the Z-domian is same as that of imaginary axis in the s-domain. High values of gains gives a fast responce as the time constants are decreasing. This fact is confirmed by observing time responce plot. The time to reach the steady state with K2=10 is 0.25 sec, where as with the gain 50 is 0.15 sec.When gain is increased further, once again poles are moving towards the unit circle and at the same time responce time is also increasing.So proportional gain(K2) is chosen as 50.Next observation made using the eigen values of the system is for lower values of the gain, real poles are becoming complex conjugates.When the poles are complex conjugates responce involves oscillations which is also observed in time responce plot for K2=10.

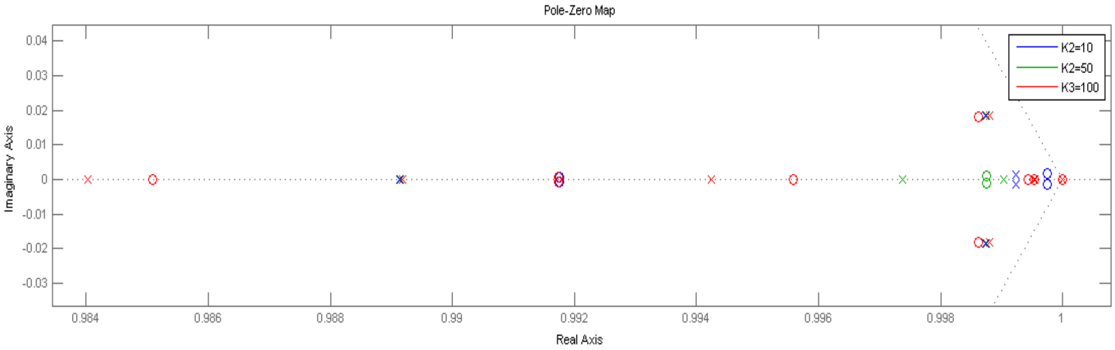

Fig.7 Pole zero map for variation of poportional constant

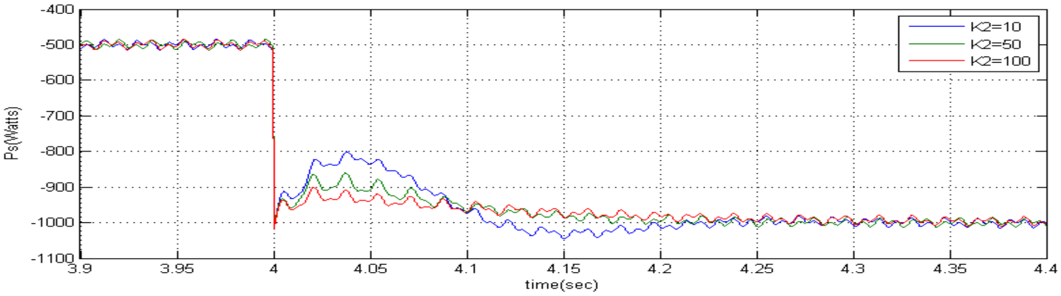

Fig.8 Time domain plot for various proportional constants:Stator active power

Table No .1 Eigen Values for various proportional constants

S.No	Eigen values(K2=10)	Eigen values(K2=50)	Eigen values(K2=100)
i)	-0.0002	-0.0002	-0.0002
ii)	0.9987 + 0.0184i	0.9988 + 0.0183i	0.9988 + 0.0183i
iii)	0.9987-0.0184i	0.9988 - 0.0183i	0.9988 + 0.0183i
iv)	0.9840	0.9840	0.9840
v)	0.9891	0.9891	0.9892
vi)	0.9992 + 0.0014i	0.9974	0.9942
vii)	0.9992 - 0.0014i	1.0000	1.000
viii)	1.0000	0.9990	0.9996
ix)	0.9995	0.9995	0.9995
x)	0	0	0

Similarly the effct of integral constant K4 is also studied using pole zero map drawn for the transfer function i_{qr} vs V_{qr}.K4 value increases from 10 to 100 gradually steady state error is decreasing and responce time is also decreasing.So integral constant is chosen as 100.

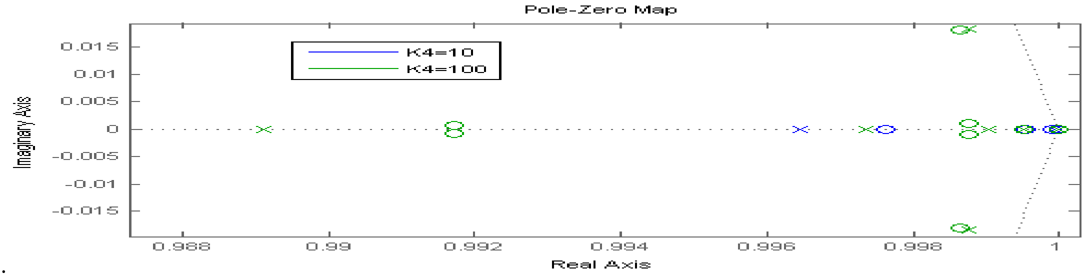

Fig.9 Pole zero map for variation of integral constant

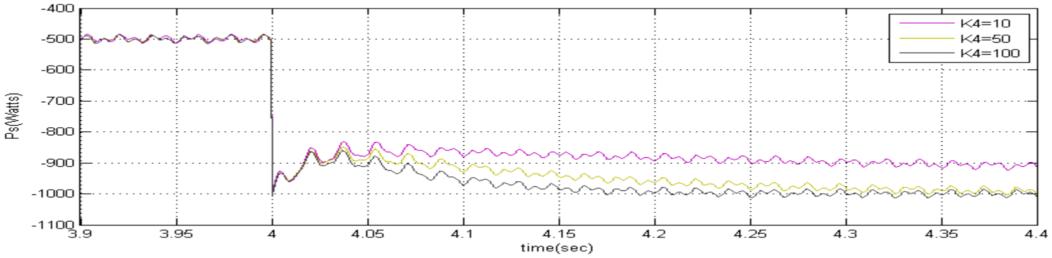

Fig.10 Time domain plot for various values of integral constant: Stator active power

IV Comparative study of FBLC and PI Controller

A comparative study of vector controlled DFIG and linear feedback controlled DFIG is made based on three different aspects like reference tracking, robustness against parameter variation and wind speed variations. The responses of active and reactive powers with both the controller are presented in Fig.11-12.

i) Reference tracking

Using the linear feedback controller the reference signals are attained with peak over shoot and therefore the response is fast. With FBL controller, reference value is achieved with in 0.3 sec where as PI controller takes almost 0.6 sec. The fast response is due to the presence of the derivative in the feedback controller. Even coupling effect also gets reduced to a large extent in feed back controller.

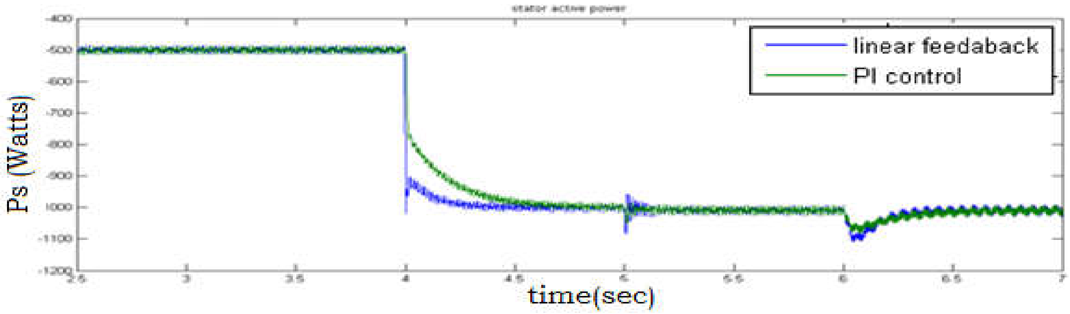

Fig.11 Stator active power

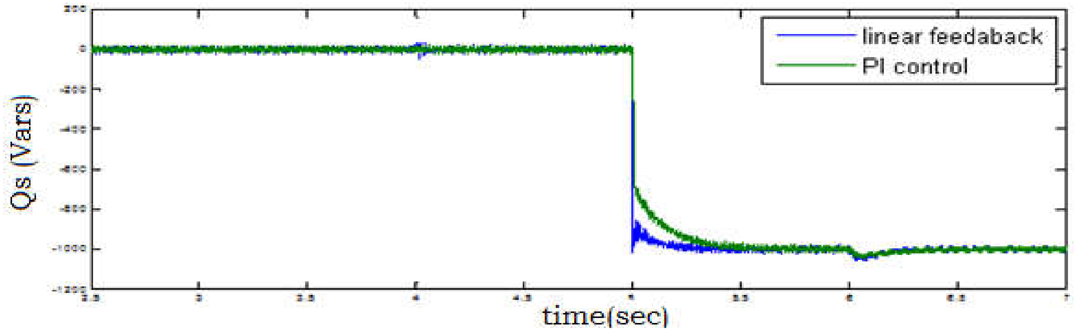

Fig.12 Stator reactive power

ii) Machine Parameter variation and wind speed variation

In order to test the robustness of the controllers for parameter variation, the values of stator resistance, rotor resistance are doubled maintaining the remaining parameters constant. The results are shown in the following Fig 13-16. The test shows that in case of feedback controller the response is almost unaltered where as PI regulator responds slowly. At t=6sec input wind speed is changed from 8m/s to 12m/s(quite often the case).The response of FBLC is fast compared PI controller.

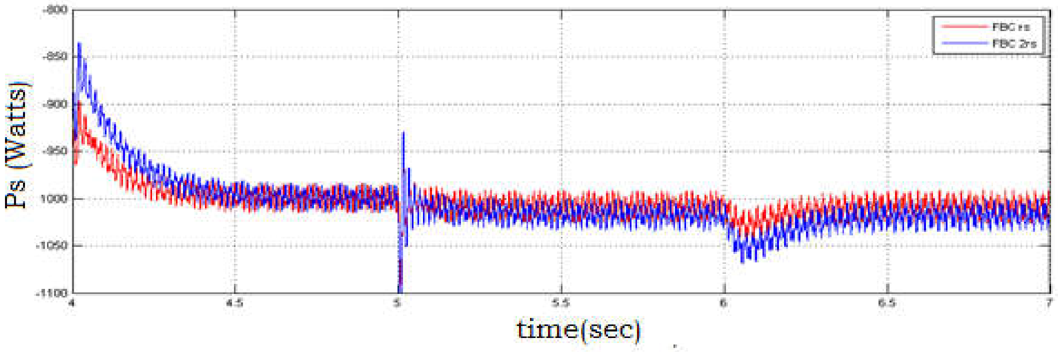

Fig.13 Response of active power with FBLC for R_s variation

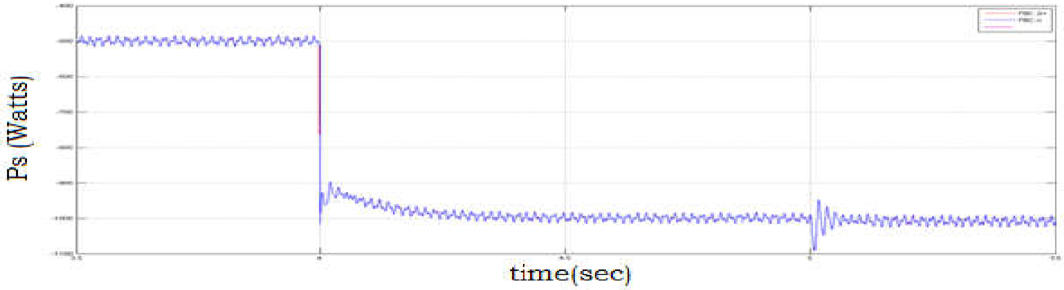

Fig.14 Response of active power with FBLC for R_r variation

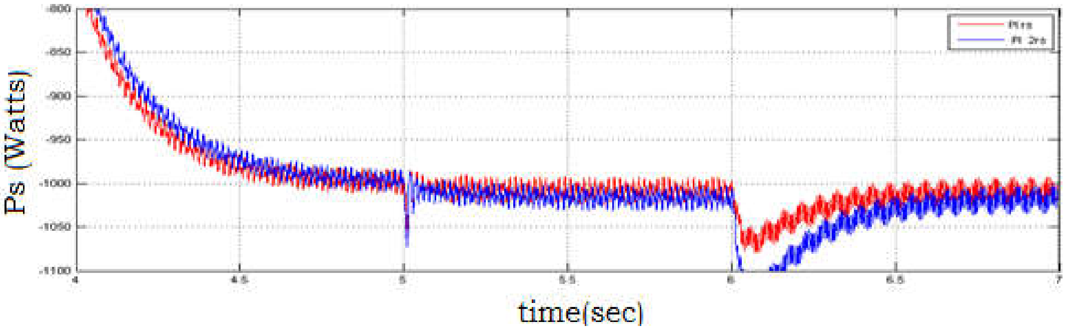

Fig.15 Response of active power with PI for R_s variation

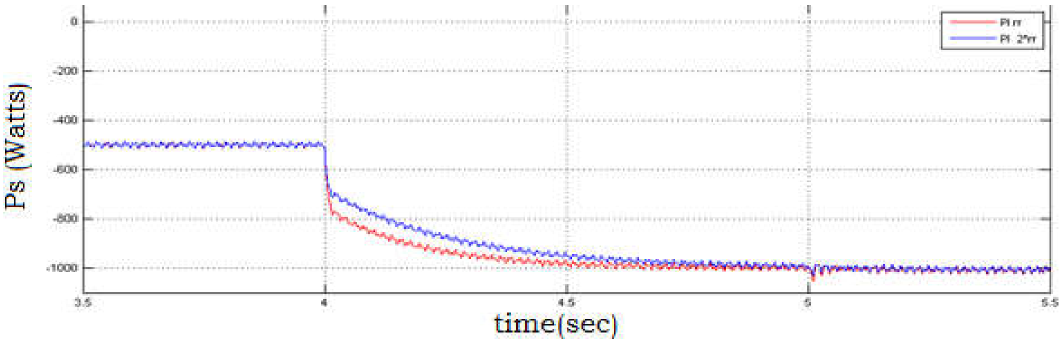

Fig.16 Response of active power with PI for R_r variation

V CONCLUSIONS

To achieve the decoupled control, Linear feedback control technique and PI control approach have been simulated .These controllers are tested for three scenarios. In all the three scenarios, FBLC controller has shown a very good dynamic response in terms of low response time and reduced error in the steady state and perfect decoupling between active and reactive powers. Further investigations are made on the proportional and integral gain values of FBLC (feedback linearization control) using eigen values, pole zero maps and time response plots. It is observed that low values of proportional gain shows complex poles and oscillatory nature in system time response. Increment in the gain of proportional constant moves the eigen values away from unit circle and gave fast response in time domain plot..Similarly, low values of integral gain shows steady state error in time response plane. Increasing gain to a suitable level gave fast and reduced steady state error as poles are moving away from the unit circle in Z-plane. The effect of derivative term in feedback control shows over shoot in the response. Due to which response is fast compared to PI control. A detailed comparative study is carried out for PI control approach and FBC approach based on reference tracking, sensitivity to wind speed variation and robustness against parameter variation. Time response plots have shown that FBC is more efficient in reference tracking. This controller responds fast to input wind speed variations, which is very necessary in maximum power point tracking of wind turbine. This controller is robust against machine parameter variations.

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