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Power Oscillation Damping In Doubly fed Induction Generator Based Wind Energy Conversion System

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Abstract

The major problem in wind energy conversion system (WECS) is that it makes the power system into unstable due to system uncertainties like intermittent wind power, generating and loading conditions which may cause the malfunction of power system soothing controllers, which are designed without considering such uncertainties. As a result we are facing the power oscillations in the system. To have a better enhancement of stabilizing controllers against system uncertainties and to damp the power oscillations, this paper proposes a new control methodology of doubly fed induction generator (DFIG) wind turbine equipped with power oscillation damper (POD). The concept behind this paper is that a controlled signals produced from power width modulation (PWM) are given to the both rotor side and Grid side converter. This controlled signal is produced by considering the change in grid voltage and change in rotor speed with the help of the controllers. Here PI and PID are used which are responsible for the input of PWM. In addition we are using the POD which consists of washout, compensators for better control signals. With the help of above mentioned things we are finally damping the power oscillation present in the WECS.

Index terms— Doubly fed induction Generator, PI Controller, PID controller, Power Oscillation Damper

I. INTRODUCTION

The developing rate of large scale wind-farm installations in numerous countries around the world has put wind energy at the lead of the renewable energy revolution. Large penetration of wind power in to electric power system will decrease amount of electric power supply from nonrenewable power plants. In the last ten years wind energy has become one of the most sources of power supply in the world. This development of wind energy conversion system in sharing the power generation and the technologies used in and conventional generators changes the power systems dynamic behavior. Wind energy is the fastest growing and most promising renewable energy source among other renewable energy source due to economically viable.

In olden days simple squirrel cage induction generators (SQIGs) were employed in wind forms which were operating at a substantially constant speed. Because of this reason the SQIGs are otherwise called as fixed speed induction generators (FSIGs)[1]. Fixed generation has little control capability and depends on the network for maintenance of desired levels of voltage to ensure successful operation. Even though FSIGs has an advantage of providing a small amount of contribution to network damping, it has the disadvantage of poor ability of surviving during network fault. The implementation of DFIG in wind energy conversion system improves the energy transfer efficiency. Along with that it provides the network support and operations depending on voltage control, damping and transient performance. With respect to the voltage control and fault ride through the recent grid codes have mentioned specified contributions to be made by wind farms of DFIG type, but they rarely take advantage of control possible capability of DFIG in network support [3]. Excitation control of the synchronous generator of a usual station can use only the magnitude of the rotor flux vector, since the position of the rotor flux is dictated by the physical position of the rotor itself.

In contrast, a DFIG has the potential of manipulating both the magnitude and the position of the rotor flux vector and as a effect of this possesses a much greater control capability compare to a normal synchronous generator. Oscillations with poor damping are the vital issue in power system stability and control. In particular, the undamped power oscillations with frequency between 0.2 and 2.0 Hz, i.e., local and inter-area oscillations may jeopardize the system operation and cause the system instability [4]. As a result, the wide area blackout may occur.

DFIG can provide better fault ride through and better voltage recovery of a network compared to an equivalent size conventional synchronous generators. In this paper it is shown that network damping is increased through the power oscillation damper. Especially, the doubly fed induction generator (DFIG) wind turbine is very popular among other wind power generations due to low installation cost, ability of active and reactive power control, and high energy transfer ability at various wind speeds[5],[6]. The DFIG wind turbine equipped with a power oscillation damper (POD) is applicable to deal with the problem of power system oscillation [7]. To effectively stabilize power oscillations in power systems with wind power generation, the coordinated control of DFIG wind turbine with POD should be performed. Uncertainties in power systems, like generating and loading conditions, intermittent wind power may also cause the malfunction of power system stabilizing controllers. This is because of the fact that the controllers are designed without considering such uncertainties [8]. To improve the robustness of stabilizing controllers against such system uncertainties, this paper proposes a new idea of coordinated robust control of doubly fed induction generator (DFIG) wind turbine equipped with power oscillation damper (POD) [9]. For better performance in order to damp the oscillation and have a control over the generator output the two types of controllers are used namely PI controller, PID controller [10]. The pulses given to both the rotor side converter and grid side converter through pulse width modulation are controlled by any one of the above mentioned controller. In this paper the power oscillation damping in DFIG based wind energy conversion system are model in MATLAB. Thus the simulation waveforms in the absence of controller and in the presence of controller either PI or PID are shown in this paper. The modeling and simulation results shows the variation among the controllers that how the power oscillations of the system is damped.

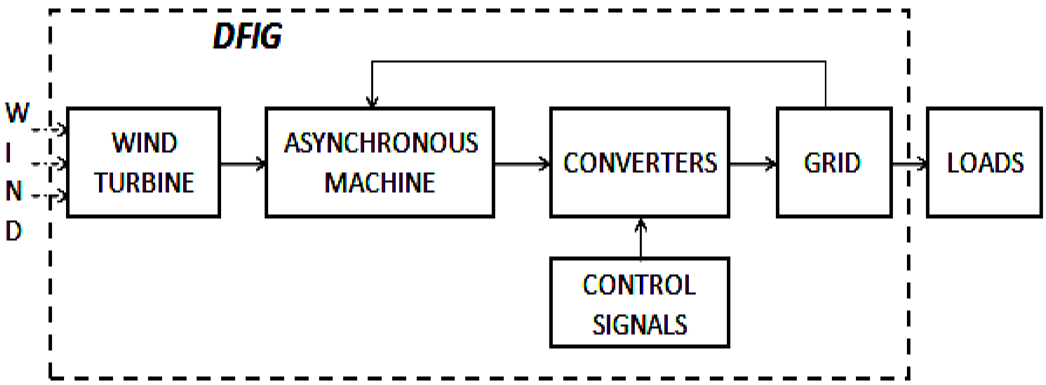

Fig.1 Block diagram of DFIG based WECS

This paper is organized as follows. Section II shows the model of Turbine. Section III presents the DFIG model. Section IV gives the DC link model. Section V presents the POD model. Section VI gives the details about the controller devices. Section VII shows the simulation results of different conditions of DFIG based Wind energy conversion system. Section VIII discusses about the conclusion.

II. TURBINE MODEL OF WECS

Kinetic energy of wind makes the turbine rotate and thereby produces the torque which results in the production of mechanical energy. The power coefficient C_P denotes the amount of kinetic energy which is converted into mechanical energy in the wind energy. This C_P depends on the blade pitch angle (θ) while considering pitch controlled turbines and also depends on the tip speed ratio (λ) of the blade. The following one is the expression for the mechanical power captured by the turbine from the wind is,

$$P_t = \frac{\rho C_p(\lambda,\beta) S V^3}{2} \tag{1}$$

The power co-efficient Cp in terms of (λ,β) is,

$$C_P = 0.22\left(\left(\frac{116}{\lambda i}\right) - 0.4 * \theta - 5\right) e^{\frac{-(12.5)}{\lambda i}} \tag{2}$$

The power coefficient is maximum at a particular tip speed ratio. In variable speed turbines maximum power can be capture by operating the blade speed with optimum tip speed ratio. To maintain an optimum level we have to change the turbine shaft speed according to the changes in the speed of the wind.

III. DFIG MODEL

In wind power generation, the wound rotor machine is used widely. It is to be noted that the wound rotor has to be fed from both rotor and stator side. Here stator is linked directly to the grid whereas the rotor is connected via back to back power convertor of variable frequency, in order to provide rotor power flow in both the directions. The classical theory, The d-q model, three to two and two to three transformations are used to analyze the Doubly fed induction machine operating principle. In the developed model the variables of both rotor and stator are referred to their corresponding natural reference frames in order to maintain the dynamic behavior of the machine in its realistic possible ways. We can also say that a stationary reference frame is used for the stator current and voltage, and a rotating reference frame at rotor electrical speed is used to denote the rotor current and voltage.

The voltage equations of DFIG are:

$$U_{ds} = R_s i_{ds} + \frac{d\psi_{ds}}{dt} - \omega_s \psi_{qs}$$
$$U_{qs} = R_s i_{qs} + \frac{d\psi_{qs}}{dt} + \omega_s \psi_{ds}$$
$$U_{dr} = R_r i_{dr} + \frac{d\psi_{dr}}{dt} - \omega_r \psi_{qr}$$
$$U_{qr} = R_r i_{qr} + \frac{d\psi_{qr}}{dt} - \omega_r \psi_{dr} \quad (3)$$

Similarly the equations for flux are

$$\psi_{ds} = L_s i_{ds} + M i_{dr}$$
$$\psi_{qs} = L_s i_{qs} + M i_{qr}$$
$$\psi_{dr} = L_r i_{dr} + M i_{ds}$$
$$\psi_{qr} = L_r i_{qr} + M i_{qs} \quad (4)$$

The expressions for mechanical equations and electromagnetic torque are:

$$c_{em} = \frac{3}{2} p \frac{M}{L_s} (i_{qr}\Psi_{ds} - i_{dr}\Psi_{qs})$$

$$C_{em} = J \frac{d\Omega g}{dt} + f\Omega_g + c_r \quad (5)$$

Where J is the inertia, Ωg is the speed of the generator, f denotes the mechanical damping coefficient and p is the number of pole pairs. Rs, Rr are the stator and rotor phase resistances respectively. ωs is the synchronous angular speed of the generator and ωr is the synchronous angular speed of the rotor. Likewise Ls is the stator inductance and Lr is the rotor inductance and M is the magnetizing inductance.

IV. MODEL OF DC LINK

The DC link consists of a capacitor that is placed in between the rotor and stator side converters. The following figure 2 is the representation of DC link model dynamics. In this Pr is the active power of RSC and Pg be the active power of GSC.

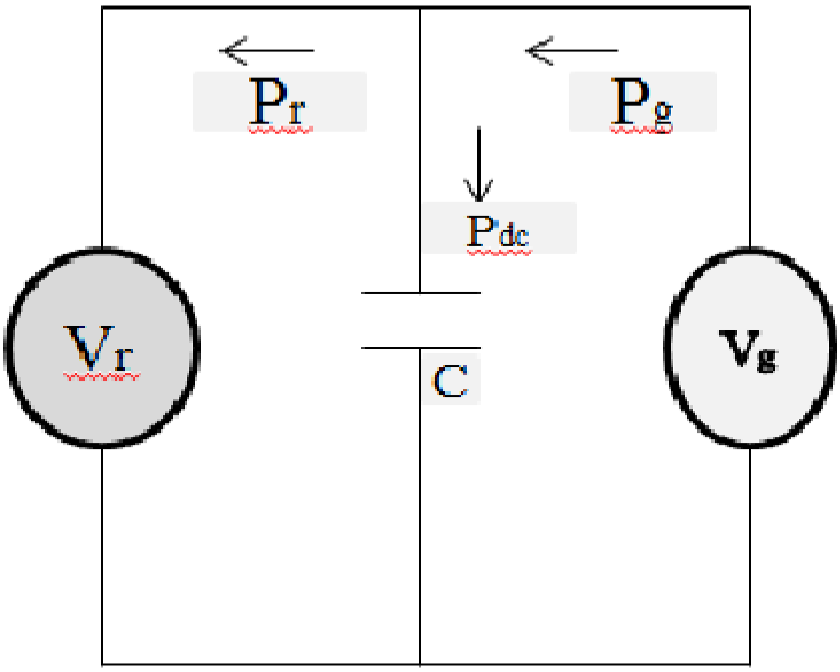

Fig.2 Representation of DC link model

DC link with Vr represents the RSC voltage phasors and Vg represents the voltage phasors of GSC. Vr = (1/√2)(vqr − jvdr), Vg = (1/√2)(vqg – jvdg). Vqr denotes the q-axis RSC voltage, Vdr denotes the d-axis RSC voltage. Vqg denotes the q-axis GSC voltage and Vdg represents the d-axis GSC voltage.

V. MODEL OF POD

Fig.3, shows the POD structure which is a second-order lead/lag compensator with one input. The POD consists of a stabilizer gain (k_{stab}), a washout filter with T_w as time constant, and two-phase compensator blocks with time constants T1 T2 T3 T4 , and .

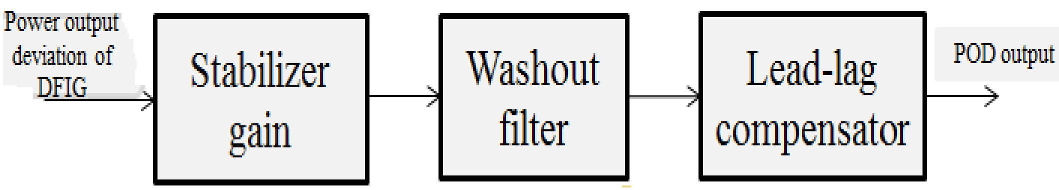

Fig.3 Block diagram of POD model

The washout block ensures that the POD output is zero in the steady state. The input signal is the electrical power output deviation of DFIG. The output signal is subject to an anti-windup limiter where and are minimum and maximum of, respectively, Determines the amount of damping introduced by POD while the phase compensator block provides the appropriate lead/lag compensation of the output signal. Note that, the structure of POD is similar to that of conventional PS.

VI. CONTROLLING DEVICES

This Section Explains about the two types of controllers that is PI and PID that are used in the MATLAB Simulink for damping the power Oscillations in the wind energy conversion system. The reason for going to the PID controller is also clearly pointed out in this section.

A. Proportinal-Integral controller

In order to increase the speed of the response, the combination of the integral and proportional terms is very important. Along with this, the combination also eliminates the steady state error. The P and I blocks of the PI controller is the reduced form of PID controller.

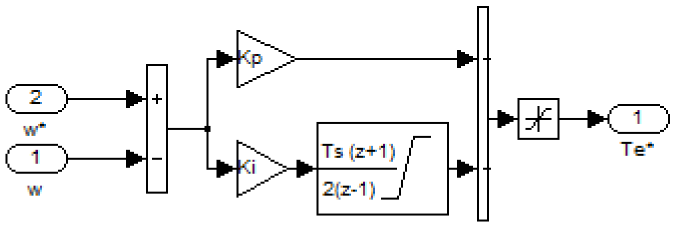

Fig.4. PI controller

The following one is the PI controller expression of proportional term and integral terms:

$$u(t)=kp\ e(t)+ki \int e(t)dt$$

here kp and ki are the proportional and integral constants respectively, that are used to get the desired output by adjusting them.

B. Challenges Of PI Control.

In employing PI we have some difficulties in practical:

The designer has to balance the influence and the interaction taken place between the two tuning parameters. The integral term is responsible for the increase in the rolling or oscillatory performance of the process response.

It is difficult to have apt tuning values because of the fact that two tuning parameters interrelate with each other. The value and importance of design and tuning recipe will also increase as the controller’s complexity increases.

C. *Proportinal-Integral-Differential controller*

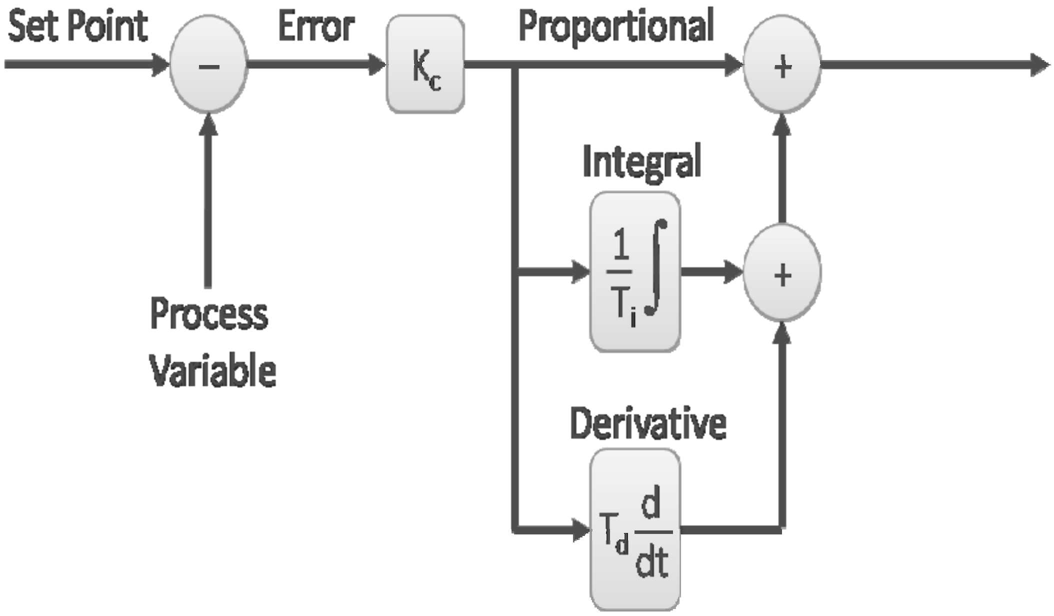

Fig.5.PID controller

The PID controller algorithm consist three separate constant parameters; therefore sometimes it is also called as three-term control: the proportional values, the integral values and derivative values, each of them are denoted as P, I, and D respectively. These values are disturbed by terms of time. That is P is depends on the present error, where I depends on the past errors accumulation, and finally based on the current rate of change D is a prediction of future errors. Control valve position, a damper or the amount of power supplied to a heating element are some of the control elements through which the alteration of the process is carried out as a result of adding the actions of P, I and D.

Without talking into consideration the system operation, the PID controller is assumed to be best suited for control. By adjusting the proportional, integral and derivative gain constants in the algorithm, the desired response to the specific process conditions will be provided by the controller. The response to error can be viewed as responsiveness, the overshoot grade and the system oscillation grade. But, the PID algorithm does not ensure the best control of the system or system stability.

VII. SIMULATION RESULTS

In this simulation part, the simulation results of the Proportional-Integral and Proportional-Integral-Derivative Controllers are compared to show the system performance enhancement using doubly Fed Induction Generator based wind energy conversion system.

A. ***Proportional-Integral Controller.***

We know that when the wind strikes the blade of the wind turbine it makes it to rotate, that is the mechanical energy produced in wind turbine. This mechanical energy is then passed to the DFIG through shaft. In DFIG this mechanical energy is used to produce the power. In this model the generated power is given to the grid through converter station. The converter station consists of rotor side and grid side converters. Here the DC link made the connection between these two converters. Likewise stator of the DFIG is fed by taking power from grid. The following figures fig.6 and fig.7 shows the output waveform of power and voltage of the normal DFIG wind energy conversion system without any controller.

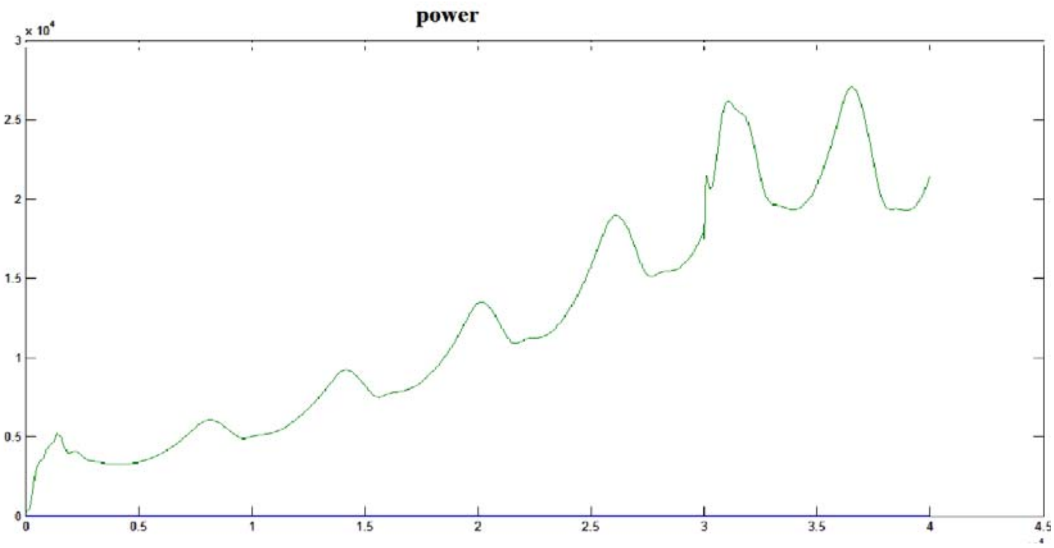

Fig .6 Power output waveform of DFIG without controller.

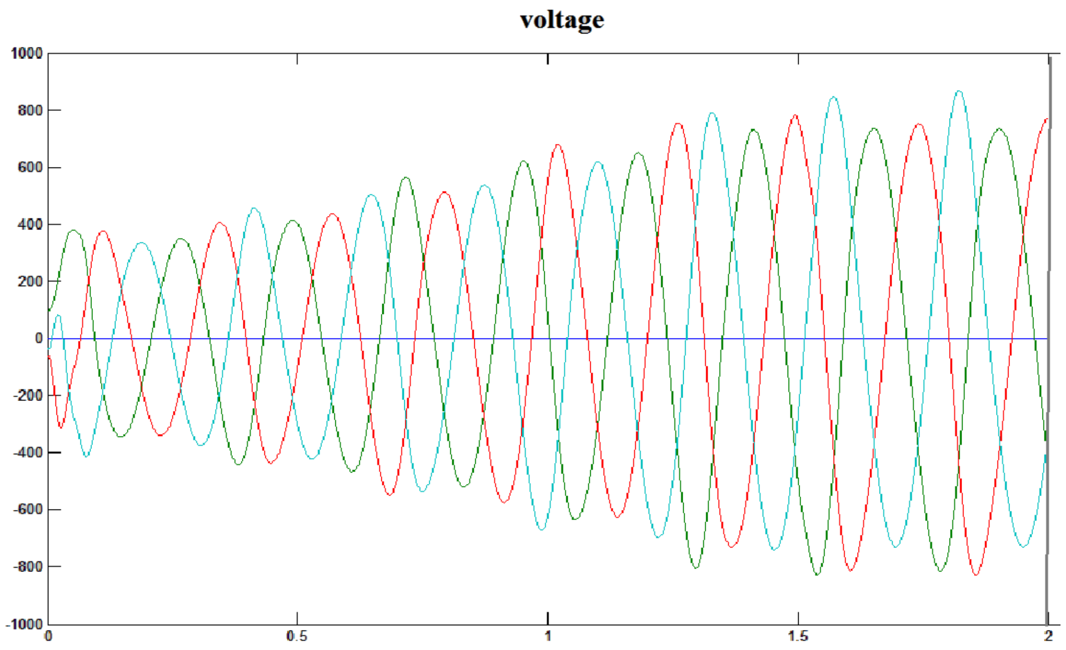

Fig.7 voltage waveform of DFIG without controller

In this model the controlled signals G pulses and R pulses are given to the grid side converter and rotor side converter respectively.

These signals are produced using PI controller in order to damp the oscillation. The controlled signals from PI controller and POD damp the oscillation present in the power fed to the grid from DFIG. The following fig.8 and fig.9 represented the power and voltage output waveform graphically where the oscillation is got damped compared with DFIG without controller.

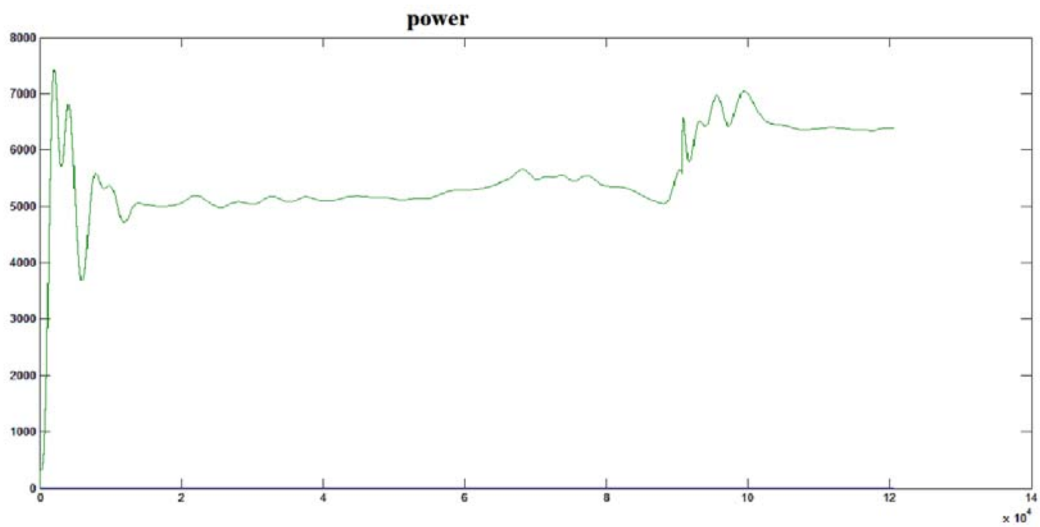

Fig.8 Power output waveform of DFIG with PI controller.

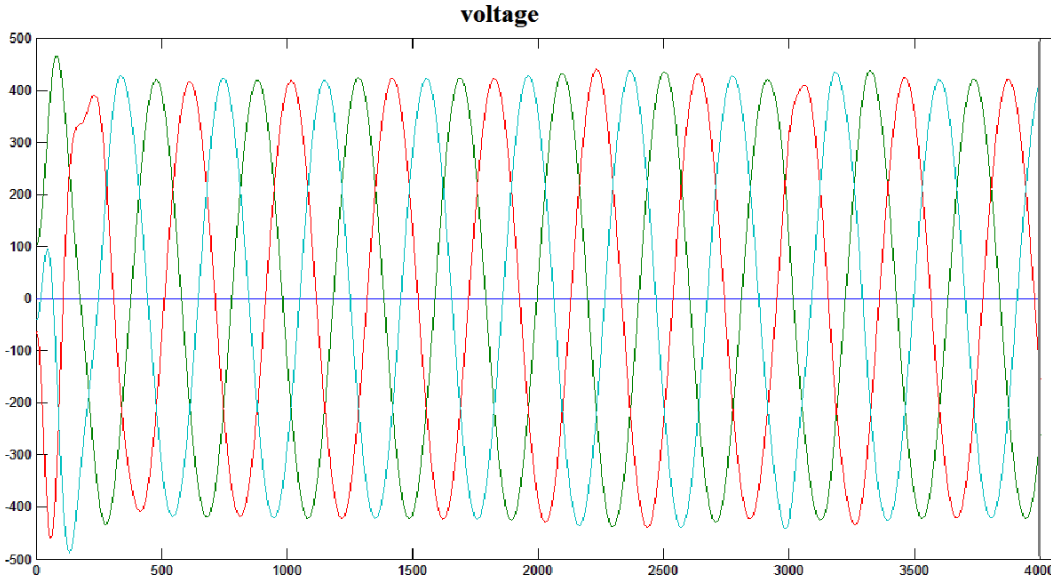

Fig .9 Voltage waveform of DFIG with PI controller.

B. ***Proportional-Integral-Derivative Controller*.**

Since the power fed to the grid is still having oscillations in it even though after using PI controller in this paper we go for an alternate controller that is PID. The following fig.10 shows the very much oscillation reduced power compared with the power waveform of DFIG with PI controller.

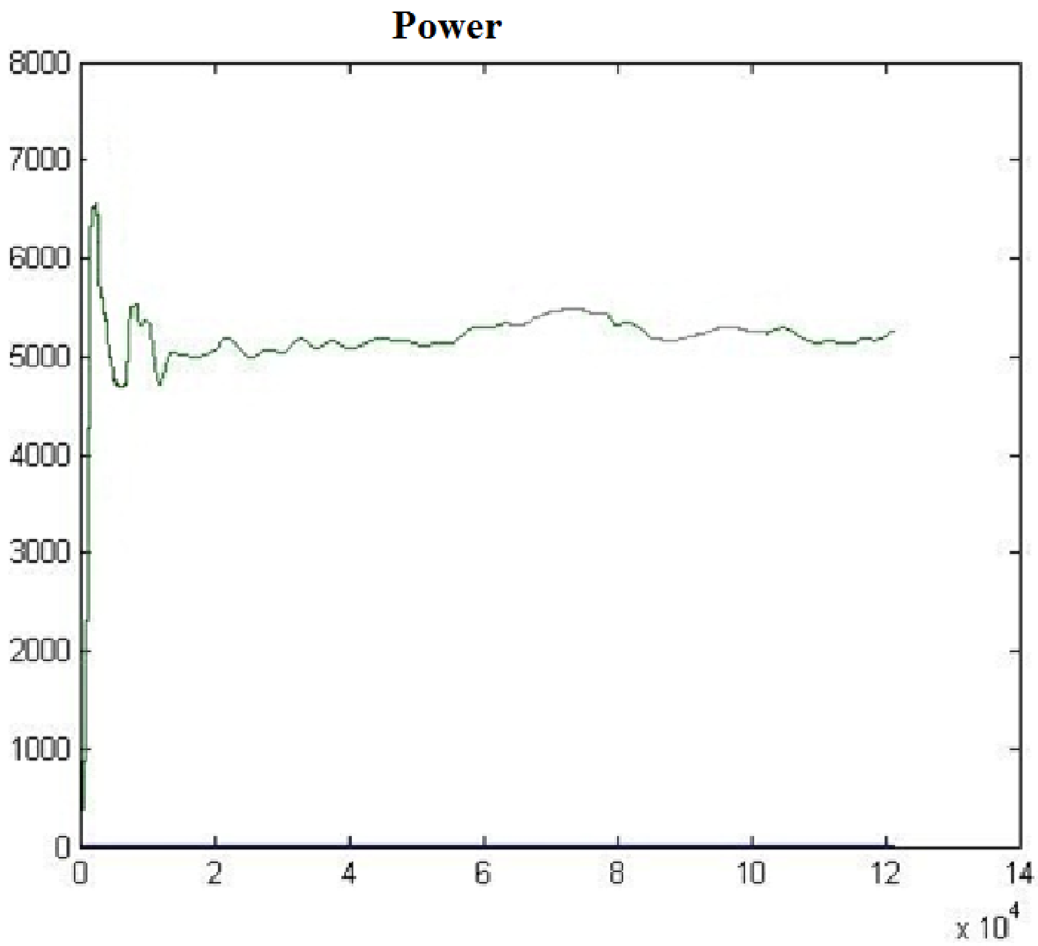

Fig.10 Power output waveform of DFIG with PID controller.

VIII. CONCLUSION

It has been shown that the conventional method in which they are using normal wind turbine arrangement along with synchronous generators but now it is replaced by doubly fed induction generators and along with that with the help of a power oscillation damper the overall efficiency is improved and also the overall operation cost gets decreased.

In this project the power oscillations due to intermittent wind is damped compared with conventional ordinary wind turbines by replacing them with doubly fed induction generators. For the better result in this project the controller is used. The final power output of DFIG without controller and with PI controller and PID controller are compared. The overall models like DFIG and controllers are designed in MATLAB simulink. This project has presented a brief idea about the wind energy conversion system, modern wind turbines and its classification. Then about the modeling of DFIG, controllers like PI and PID its advantages and disadvantages.

Finally the increase in the efficiency by damping the power oscillations is showed. From these things DFIG is better than conventional type wind turbines is proved.

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