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Investigating PI & PID Controllers for DFIG Installed at Micro Hydro Turbine

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***Abstract*—**The power extracted from the water i-e hydropower is one of the clean and economical source for the generation of power. The flow of water does not remain constant throughout the year so we have to build large storage tanks i-e dams to store water for power generation. But building these large dams have limited this source of energy. Consequently, the trend is going to change by building small hydropower plants. There is no availability of storage of water for producing power then mostly small hydro power plants are built there which are also called as run off river plants. The flow of water vary throughout the year resulting in inconsistent generation of power.so there is a need of variable speed operation that can operate at different operating point to achieve maximum efficiency. So for varying speed operation the one of the famous operating system that is doubly fed induction generator can be used to achieve desired results. In this work the DFIG in a MHPP's is studied, there steady state and dynamic models are discussed. The 3 phase voltages and currents are transformed into 2 phase for ease in calculation by using Clark and park transformation. Then doubly fed induction generator has to operate at the required references which are reactive power, active power and also for speed. And eventually the model of vector control of doubly fed induction generator is achieved. The main objective of developing the model of doubly fed induction generator is to manage the two powers (i-e reactive and active power). The whole simulation should be carried out in MATLAB/Simulink. In this model of doubly fed induction generator we are using two different type of controllers, i-e Proportional integral and Proportional Integral Derivative controllers, to check the efficiency of the model. The results which are then obtained such as the torque, speed, rotor current, voltages on the rotor side as well as Bus voltage, reactive power on the grid side obtained from the two controllers are then compared with each other to see that which controller is giving good efficiency. Therefore, in this research, a predictive controller is proposed to manage the powers i-e active and reactive, of a hydropower plant using doubly fed induction generator.

***Keywords*—** PI, PID, Controllers, DFIG, MHPP, Micro Hydro, Turbine.

I. Introduction

Lack of energy is the main issue now days. Due to increase in environmental pollutions and power energy scarcity, the different companies relating to the power sectors are showing a great deal of interest on introducing the new technology of renewable energy which are making a good progress in energy sector. The sources of renewables are wind power, hydro power and solar power. The DFIG i-e dual fed induction generators have gained more popularity due to improved energy quality, improved controllability and its efficiency in micro hydro power plants.[1] Traditionally, hydropower plants used are mostly designed with synchronous generators having fixed frequency that of similar to the frequency of the power grid. Therefore, by using DFIG instead of synchronous generator increases the efficiency as in DFIG there is an option of changing the turbine speed while keeping the efficiency high. Whereas keeping in mind that the variation made in changing the speed should be up to 30% of the synchronization speed. There is certain equipment's such as electronic power transformer which is to be used along with DFIG for controlling the rotor voltages. But by introducing these converters which are to be connected to the DFIG makes the model more complex and there is an increase in power loss due to above equipment. Similarly, the power to be supplied to the rotor circuit needs slip rings along with carbon brushes and it then requires maintenance as there is a constant wear and tear in carbon brushes and slip rings.[2][3] As there is a lot of work done in the field of wind energy while using the very same technology i-e of DFIG so it will make easy for adopting the very same technology on the small scale hydro power plants.[4] Hydropower plant capacity depends on location; Water flow is not constant throughout the year, so the available energy and efficiency of water system generation also vary due to various factors such as head and flow, which need to adopt different methods to improve the efficiency and operation of the power system to make it to the optimum efficiency point. Many sites with moderate flow are available, but they cannot be exploited due to large deviations in flow and head that make them uneconomical to operate. A conventional power station controls the flow of water through the inlet gate slot that reacts slowly to changes in load variance and usually has a fixed time for seconds while controlling for power electronics and reaction times. Due to which variable speed hydroelectric control reacts relatively fast. The control of the generator is much less than that of a water turbine. Variable speed operation not only improves the efficiency of the generating system, but also increases the energy generation capacity and improves the use of the transmission network. Various methods have been proposed over the years to achieve efficient operation of hydroelectric systems. Some specifically focus on redesigning the generator for efficient operation of the hydropower system, while others focus on various control algorithms to achieve efficient operation.[5][6] DFIG is very popular in wind power applications and is an economical option for varying speed operation along with compact size of the transformer as compared to synchronous generators used by full-size transformers. This work performs a technical evaluation of DFIG for use in micro-hydropower systems, comparing the efficiency of operation of variable speeds using a variety of controllers. In these processes, separate units of high output reference speed were developed, then simulations were performed using DFIG to validate various parameters (such as power, torque, currents, voltage, etc.).[7]

II. RELATED WORK

In this work the problems relating to the frequency and voltages are resolved by using the new technology i-e DFIG instead of using the synchronous or induction type generators. The entire model is then validated in Mat lab/ Simulink software under different conditions such as discharge variations and reactive power. From the results obtained from the simulations of the DFIG model it is clearly observed that DFIG is able to control the various parameters effectively. And also that it is maintaining the referenced value of the voltage and frequency in between the power grid & DFIG. By doing so will give us small networks and distributed generation.[9] [10]

In This paper different control strategies have been proposed and implemented on a generator i-e DFIG producing 2 MW of power from wind energy by managing the rotor side converter variables. Generally, wind turbine run in Mppt mode for maximum efficiency. Generally, there are certain techniques for controlling the RSC to achieve the MPPT. These different techniques are then modeled and their simulation is done while keeping in mind the desired results of achieving the MPPT. All the simulation is done while keeping the range of speed of wind in between 3.2m/s and 25m/s. Also the voltage oriented control is used on the grid side of the DFIG while maintaining the DC bus voltage constant at the desired values. The different techniques used are then compared and analyzed .[11]

In this paper the main idea is by using two voltage source inverters that will supply to the DFIG. The feedback of the two voltage source inverters (VSI) are then electromechanically coupled so as to achieve the desired results. As a result of using two VSI method there produces a dual direct torque control. Stator and rotor vector control flux models are developed. the result shows a better performance and dynamic behavior in all the four quadrants. Moreover, it has shown a better performance in speed tracking performances. [12][13]

In this paper the new and advanced research is done in the area of control systems of the DFIG of the WECS. With this methodology of control, the simple techniques like the decoupling of torque and the reactive power is easy to achieve but there are certain techniques that provides better overall performance. While discussing the sensor less control scheme the MRAS and RCMO schemes provide good result in both cases that is in standalone and grid connected operations of DFIG. [14][15]

In this study the work is done in the area of control system of DFIG. The control system for various systems are discussed including standalone system, balanced and unbalanced grid with which the DFIG should be connected. Certain work is carried out in removing the oscillations in case of unbalanced loads. To achieve the above goals, the RSC or GSC control can be used. A greater degree of freedom is available using both cases simultaneously. They have also discussed the different parameters such as assistance services & support networks and their controls. Finally, it has been discussed for LVRT dfig’ s control systems. The commonly used elements in compliance with LVRT were discussed and also analyzed.[16]

In this paper the work is carried out on finding the position of the wound rotor induction generator’s rotor and this above operation is carried out without using sensors i-e it is sensor less operation. For achieving the above objectives, the MRAS technology is used .it is basically divided into two models. One model is the adaptive model which gives the rotor emfs and currents whereas the other model is the reference model which give the parameters that are directly available. A hysteresis or PI controller is used to control the operations. Stability analysis are also done on the model. The results shows that this method of finding the different parameters is an appropriate method for the vector control DFIG if the operation is carried out under the stability region.[17] [18]

In this research paper the sliding mode method while using the DFIG for controlling the active and reactive power is introduced in the wind energy system. In this paper certain control algorithm is applied in which the RSC is controlled. The MPPT is obtained by applying fixed flow oriented control technology on RSC. The main thing is to maintain the power factor of the DFIG and is to be kept near the unity for better results and this can be achieved by using fixed flow control technology. The result obtained clearly shows the regulation of speeds while maintaining the efficiency high and also maintained a balance in between the active power and reactive power.[19]

In this paper the strategy to control the DFIG id basically based on the sensor less control by controlling the direct voltage control. Basically it compensates the negative sequence in the rotor side converter by supporting the unbalanced load that are asymmetric. The main thing to obtain is the slip angle so that it become able to fully control the asymmetric loads. This paper is able to find the slip angle in the synchronous reference frame by measuring the value of the important parameter of the machine i-e the value of the stator inductance. This value of inductance can be measured by using real machine parameter. So after finding the said parameter and then integrating this parameter into the direct voltage control strategy which then results in negative compensation for long range of asymmetric loads.[20][21]

In this proposed work an advanced control technique is used making the operation of DFIG reliable. Basically an approach named general predictive control i-e GPC is used in this work. It is basically designed to make the torque of the generator smooth that is by removing the oscillation. The oscillation is due to the result of control signals. So when the current flows in the machine will contain low frequency harmonic contents which in result reduces the fluctuations and oscillations thereby making the electromagnetic torque of the machine smooth i-e free from oscillations. Simulations and results clearly shows that by applying this approach the oscillation in electromagnetic torque can be reduced up to much extent thereby making the machine more efficient.[22][23]

By the development of wind power generation, the Doubly Fed Induction Generator which is based on that wind power system may experience Sub Synchronous Resonance and High Frequency Resonance which are in the series and parallel compensated fragile network. Using Bode Diagram as an analysis tool, the principle and frequency of HFR have been demonstrated. Moreover, the HFR can be classified into two different types: The first one is Undamped HFR, which mostly exits in steady state. Other is Unstable HFR, which results in complete instability and divergence. The above mentioned types are not investigated before. Since Both the Undamped and unstable HFR are crucial to the quality of output wind power as well as the safety and reliability of operation of The DFIG system. It is good to investigate them by using The Nyquist Criterion from two perspectives. First is by determining either the Undamped or the unstable HFR happens, and the second is by estimating the amplitude of The Undamped HFR. The factors which influence, including the weak network shunt capacities. The current PI controller parameters are discussed while estimating the amplitude of the Undamped HFR, the experimental and simulation results of a 7.5 kw down-scaled DFIG setup are provided to validate the analysis on the Undamped HFR and unstable HFR.[24]

There is a comparison in the present paper mentioning the three different methods to control doubly fed induction generator (DFIG) in wind energy conversion systems (WECS). In an experimental setup which is based on a digital signal processor, namely Vector Control, direct torque control and last is direct power Control. These three are the most widespread and well-performing control approaches. The above mentioned methods are kneely reviewed and their performances is analyzed. After that their performances are compared on the basis of stimulation and experimental results. The obtained comparison's results whether it is qualitative or quantitative are likely to be more interesting for especially for the Engineers and Researchers working in the field of DFIG-based WECS.[25][26]

In this paper the work has been done regarding harnessing energy from the small rivers and streams which is the cleanest system of generating the power. As it doesn't require any storage of water so it can be installed easily. In this the water will pass directly through the turbine and will be directed again to the river or to any other stream for agricultural purposes. The design parameters are calculated by the help of Mat lab Simulink program. the turbine is selected on the basis of some important parameters which is flow rate and site head. There will be losses in the turbine because of variation of flow rate of water. There is also a loss of power in the penstock which ranges from 5 to 10 percent depending upon different factors. keeping in mind the efficiency of turbine and also generator the system is designed.in this proposed work it is proved that the construction of the micro hydro plant is feasible and that there is no major problems in the design.[27]

In this paper work is been carried out regarding the controls of the DFIG system as the conventional control system doesn't respond well to changes that comes in the frequency of the system. Actually in this paper the frequency response and the inertial response are studied by comparing the characteristics of DFIG and conventional power plan.in this work some auxiliary loop parameters and algorithms are introduced. As a result of which there comes improvement in different factors i-e frequency control, speed protection, rotational speed delay and also coordination control associated with the DFIG. The simulation results show that the proposed control system has a quick response to the errors relating to the frequency. Hence it is proved that it can also participate to the whole system's frequency up to much extent.[28][29]

As we know that everyone is looking for improving the efficiency of the system to get better results by giving less.so a good control system will give us a better efficiency and also reliability. In this paper different control strategy for doubly fed induction generator is proposed to achieve better performance. As DFIG works at different operating speed which means that there is a lot of variation in the speed and hence requires a complex control system. So in this paper a new approach is introduced i-e Field oriented control or in short we can say FOC .In this paper the proposed control is modeled in ma lab /Simulink and the control is simulated .The results obtained from simulating the above mentioned model shows that proposed control system is suitable for the DFIG operating at variable speed and also be able to control the other parameters such as active ,reactive power & Dc Bus voltage.[30]

III. MATHEMATICAL MODELLING

A. *Doubly Fed induction Generator*

DFIM (doubly fed induction machine) or WRIM (wound rotor induction machine) is a common terminology used to describe an electrical machine, which has been used for many decades in various applications, often in a megawatt range of energy and also less common in a group of a few kilowatts. This concept of the device is as an alternative to the most common and asynchronous & Synchronous machines. It can be useful in applications that have a limited speed range, which allows to reduce the size of the electronic transformer for power supply, for example, in variable speed generation, water pumping etc. The typical supply configuration for DFIM is shown in Figure III.1. The stator is supplied with a three-phase voltage directly from the network with a constant amplitude and frequency, which creates a magnetic field for the stator. The rotor is also provided with three-phase voltage efforts that take different amplitude and frequency in stable condition to reach different machine operating conditions (speed, torque, etc.). This is accomplished using a three-phase sequential transformer, as shown in the simple schematic figure of the figure. This transformer, along with the appropriate control strategy, is responsible for enforcing the rotating AC voltages required to control the overall operating point of DFIM management and to conduct energy exchange through the rotor to the grid. Although the voltage source transformer is displayed, different configurations or converter topology can be used.

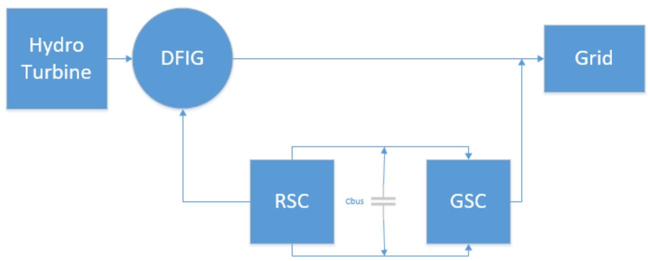

Figure III.1: General supply configuration of DFIM

As mentioned above, DFIM consists of two sets of three-phase windings. Each coil consists of three phases of three windings 120 turned from each other and can have pairs of electrodes, one in the stator and the other in the rotor. The stator can be connected to either delta or wye and the user can choose the connection based on the available voltages and specific DFIG ratings. It is common to use a connected Y-rotor, but usually there are only three slip rings, as no neutral point is needed. The flux produced by the stator rotates at a synchronous speed given by the number of poles and the frequency of currents in the stator and is given by

$$N_s = f_s * 60 / p$$

Where fs represents the stator frequency and p is the pole pairs. Similarly, the angular frequency of the currents and voltages of rotor is given by

$$\omega_r = \omega_s - \omega_m$$

Where ωs represents angular frequency of the stator current & voltages and ωm represents rotor mechanical angular frequency.

B. *Equivalent circuit of DFIG*

The DFIM equivalent circuit is similar to the induction machine induction circuit, but have an extra feature of voltage source in the rotating part of the circuit.

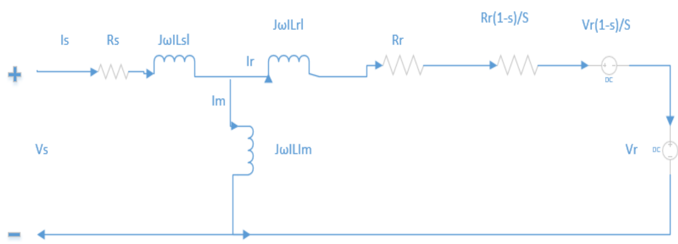

Figure III.2: Equivalent circuit of DFIG

It is common to divide the rotor resistance and voltage source into two parts to show the slip dependent part and the unreliable part. All quantities denote the stator side. The circuit appears in the figure III-2

Whereas in above figure L_{ls} is Stator leakage inductance, L_{lr} is Rotor leakage inductance, Lm is Magnetizing inductance, R_s is Stator resistance & R_r is the Rotor resistance.

Whereas the relation between the actual inductance and leakages inductances are given by the following equation

$$L_s = L_m + L_{ls}$$

$$L_r = L_m + L_{lr}$$

The static part that is the stator flux and rotor flux are given by below equations which are in phasor form:

$$\lambda_s = L_s * I_s + L_m * I_r$$

$$\lambda_s = L_m * I_s + L_r * I_r$$

The steady state voltages can be obtained from Kirchhoff's voltage law to be applied on the equivalent circuit of DFIG which are as under

$$V_s = R_s I_s + j\omega_s \lambda_s$$

$$V_r = R_r I_r + j\omega_r \lambda_r$$

C. *Active & Reactive power control*

As shown above, energy can be exchanged through the rotor and stator, depending on the operating mode. According to the agreement, the energy is positive when extracted from the machine and negative when extracted from the machine. DFIG's total energy balance is

$$P_s + P_r = P_{cu,\,r} + P_{cu,\,s} + P_{mech}$$

The equivalent circuit for the active power is shown in figure III.3

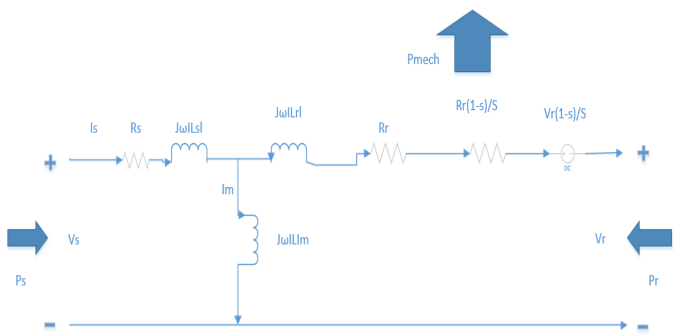

Figure III.3: Active Power Flow in equivalent circuit of DFIG

Whereas Ps is the stator power, Pr is the rotor power, Pcu, r is the copper loss in rotor, Pcu, s is the copper loss in the stator and Pmech is the mechanical power.

Reactive powers are important for magnetizing machines due to the production of electromagnetic torque inside machines due to magnetic flux reactions from stationary devices and rotors The reactive powers obtained by quadrature components use the energy fed by stators and rotors. Thus, the relationship of the interactive forces of the device is:

$$Qs = 3Im\{VsIs^*\}$$

$$Qs = 3lm\{VrIr^*\}$$
$$Q_{LIs} = 3|I_s|^2\omega L_{Is}$$
$$Q_{LIr} = 3|I_s + I_r|^2\omega L_m$$
$$Q_{VIr} = 3I_m(1-s)\, {V_r I_r}^* / _S$$
$$Q_{LIs} + Q_{LIr} + Q_{Lm} = Q_{VIr} + Q_s + Q_r$$

The equivalent circuit of reactive power is shown in figure III.4:

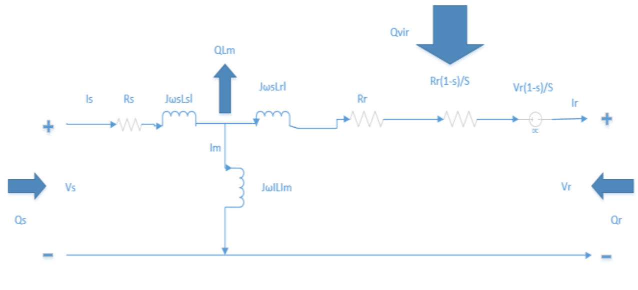

Figure III.4: Reactive Power Flow in equivalent circuit of DFIG

D. Vectrol control of Grid connected DFIG

The two converters connected from back to back are responsible for generating voltages of the same size, frequency, size and phase from the rotating circuit, and for ensuring that the power exchange between the rotating circuit and the grid is possible in both directions. The system is shown schematically in Fig III.5

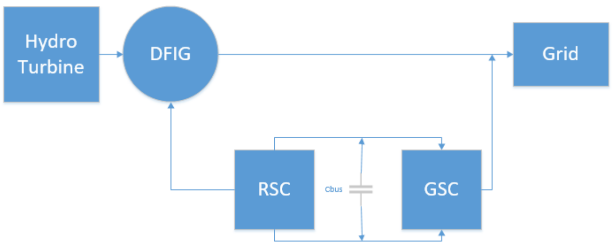

Figure III.5: Doubly Fed Induction Generator with MHPP

The basic idea behind DFIM's vector control is to control the d and q axis of converter currents. First of all, the transformer three phase currents are measured and converted into d and q components using Clarke and Park shifts. Park switching requires a variable frequency angle with same phase currents. The angle can be measured and matched with grid voltage or static flux. Secondly, the currents d and q have to be controlled to be of some desired value, which is defined by the user. The values are then compared with values which will be defined by the user. Different controllers are used to control these currents which are discussed in the controller section. Then the output current controllers, dq, are the components of d- and q-axis of the voltage to be produced by the transformer. The dq voltage values are converted to abc voltages, which are used as a reference to the sinusoidal PWM problem controlling the transformer. The angle of the Park conversions used is the same as the current transformation discussed above. In short the main idea is to control the currents by controlling the voltages.

E. Vector Control of Rotor side converter:

Rotor side control the power of the active and reactive stators by adjusting the dq current in the rotor circuit. Active Power Control is used to control the speed of DFIM.

1) Arrangement of dq coordinate system:

The alignment of the rotor currents is done through two ways one way is through stator flux orientation and the other is grid voltage orientation. In the stator flow orientation, the stator flux is calculated and the d-axis of the rotating frame synchronized with the stator space vector is aligned. This is the traditional way to control DFIG. However, for mains voltage differences, the rotation speed is not constant, which adds angular interference, which is best suited for rigid gratings. While in the case of mains voltage orientation, the d axis of the synchronous frame is aligned with the mains voltage. The grid angle is as rough as the grid frequency. It results in more toleration for voltage drops. It also makes an ease to find the grid voltage.

2) Equations for vector control of RSC (Rotor Side Converter)

The RSC i-e rotor side converter controls the d & q axis of the rotor circuit. The real and reactive power of rotor circuit is given by.

$$Ps = \frac{3}{2} R\,(\mathrm{Vs}\,.\,\mathrm{Is}\,) = \frac{3}{2}(VdsIds + VqsIqs)$$
$$Qs = \frac{3}{2} S\,(Vs\,.\,Is) = \frac{3}{2}(\,VqsIds - VdsIqs)$$

Q axis becomes equal to zero after aligning the d axis.so the equation becomes

$$Ps = \frac{3}{2} Vds.\,Ids$$
$$Qs = -\frac{3}{2} Vds\,.\,Iqs$$

This gives the effective power that depends only on the d-axis current and the reactive power that depends only on the stator current q. Stator expression is needed based on the rotor to understand how to control the system. The stator flow 90°is shifted and lag behind the stator voltage. As we know that stator voltage axis are aligned to d axis so the equation becomes.

$$LsIds + UdrLm = 0$$
$$LsIqs + UqrLm = \lambda$$

Finding values of Ids and Iqs from above equations we get

$$Ids = -\frac{Lm}{Ls} Idr$$
$$Iqs = \frac{\lambda s - LmIqr}{Ls}$$

By rearranging the above equations, the final values for active and reactive becomes

$$Ps = -\frac{3}{2}\frac{Lm}{Ls} * VdsIdr$$

$$Qs = \frac{3}{2}\left[\frac{Lm}{Ls}VdsIqr - \frac{Vds^2}{2 * \omega sLs}\right]$$

As the above equations show, the real power is proportional to the rotor of the d axis, while the reactive power can be controlled by the rotor of the q axis, but it has an additional duration depending on the voltage and frequency. The control of reactive energy is then determined by the current classifications of circulation and active energy. The voltage to current ratio should be used when designing the rotor transformer control system.The following relationships are found for the reference frame dq for dynamic modeling of the rotor

$$Vdr = RrIdr - \omega r\lambda qr + \frac{d}{dt}\lambda dr$$

$$Vqr = RrIqr - \omega r\lambda dr + \frac{d}{dt}\lambda qr$$

Whereas the flux equations for rotor circuits is given by

$$\lambda dr = \left(Lr - \frac{Lm^2}{Ls}\right)Idr$$

$$\lambda qr = \left(Lr - \frac{Lm^2}{Ls}\right)Iqr + \frac{Lm}{Ls}\lambda qs$$

As we know that the stator flux derivative contained in the q axis equation is zero during normal operation. However, this is not the case for voltage changes at the ends of the stator. The term stator flow for the axis equation d is constant and can be compensated for controllers. So The final equation for the plant becomes as

$$Vdr = RrIdr - \omega r\sigma LrIqr + \sigma Lr\frac{d}{dt}Idr$$

$$Vqr = RrIqr - \omega r\sigma LrIdr + \sigma Lr\frac{d}{dt}Iqr$$

3) Calculation of Angle for RSC

Park conversions used in stator lateral transformer require a rotor angle. The angle of the rotor can be estimated from the below equations

$$\omega r = \omega s - \omega m$$

Similarly, for angles the equations are

$$\theta r = \theta s - \theta m$$

4) Speed Control

As described above, the current d-axis controls the active part of the power. The turbine can be considered a torque control engine and does not control speed. This can be a fast turbine water greater than 1.5 to 2.5 times the nominal speed, which requires it. For speed control. Typically, hydropower plants are used simultaneously working at a fixed operating speed at which the regulator regulates the speed. The governor increases the flow of water to increase the production of mechanical energy when he increases the load generator. In this case, DFIM should control the active stator power by adjusting the rotor currents.

F. Internal module control

There is a need of internal controller to control the internal model of the process based on internal model control. The control is basically a cascaded type of control. It consists of two types of loops i-e inner control loop and outer control loop. Basically the outer control loop is used to control the speed of the DFIG whereas the inner control loop works on the reference values which they get from the outer loops. The outer loop gets its actual value from the turbine model whereas the reference value is given to the controller. The controller start comparing these two value and in case the values do not get matched an error is produce as an output. This output becomes an input to the inner control loop which actually is controlling the current of the machine. The inner loops correct the current error and send a signal to the machine to correct the error either by increasing or decreasing the speed, power etc. The inner loop has to work faster than the outer loop so the bandwidth of the inner controller is more than the outer loop.

1) PI Controller

In case of PI controller, the control will depend on the two gains i-e Proportional & Integral. The control diagram of the PI controller is shown in figure III.6.

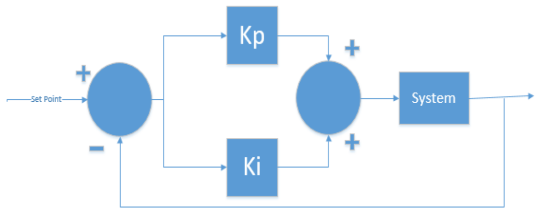

Figure III.6: Proportional Integral Controller

2) PID Controller

In case of PID controller, the control will depend on the three gains i-e Proportional, Integral & Derivative. The control diagram of the PID controller is shown in figure III.7.

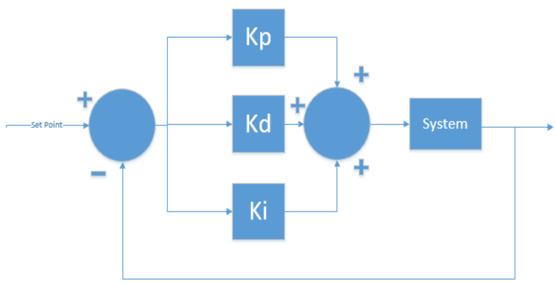

Figure III.7: Proportional Integral Derivative Controller

G. Grid side converter Vector Control (GSC)

The GSC is basically responsible for keeping the voltage across the capacitor. The power flows in between the Rotor side converter and Grid side converter. As there is a bidirectional flow of power across the rotor of the DFIG so if the power is coming from RSC to the capacitor then the grid side return the excess power to the main grid whereas if the power is flowing from the DC link capacitor towards RSC then Grid side supply the power to the rotor of the DFIG.

1) Equations for vector control of GSC (Grid Side Converter)

In order to find the equations for active and reactive power we should align the d-axis of the rotating frame with grid voltage space vector as a result of which the q-axis becomes equal to zero. The equations are given below as

$$V_{df} = R_f i_{dg}(t) + L_f \frac{di_{dg}(t)}{dt} + V_{dg} - \omega_a L_f i_{qg}$$

$$V_{qf} = R_f i_{qg}(t) + L_f \frac{di_{qg}(t)}{dt} + V_{qg} - \omega_a L_f i_{dg}$$

As we know that q component is equal to zero so the equation becomes;

$$V_{df} = R_f i_{dg}(t) + L_f \frac{di_{dg}(t)}{dt} + V_{dg} - \omega_a L_f i_{qg}$$

$$V_{qf} = R_f i_{qg}(t) + L_f \frac{di_{qg}(t)}{dt} + \omega_a L_f i_{dg}$$

Now by calculating the equation for active power and putting the above values the equation becomes;

$$P_g = \frac{3}{2} v_{dg} i_{dg} = \frac{3}{2} |v_g^{\to s}| i_{dg}$$

Similarly finding the equations for reactive power and putting the above values of voltage the equation becomes;

$$Q_g = -\frac{3}{2} v_{dg} i_{qg} = -\frac{3}{2} |v_g^{\to s}| i_{qg}$$

As it is clearly shown in the above equations that active power is depending on the d-axis current. Hence the active power can be controlled easily by controlling the d-axis current. Similarly, in case of reactive power, it is depending on the q-axis current so by controlling the q-axis current the reactive power can be controlled.

2)DC link Voltage controller

As we know that the DC link capacitor is of great concern in the model of DFIG. As it decides and allows the bidirectional flow of power across the rotor. There are two conditions that are going to occur over the DC link. First is when the DFIM is acting as a generator. In this case the supply is fed to the rotor. The supply came to the rotor by passing through grid side converter, DC Link then rotor side convert and then to the rotor. In this case the GSC act as a rectifier whereas the RSC act as an inverter. Secondly when the speed of the generator increases the it will start supplying power to the grid. In this case the RSC act as a rectifier whereas the GSC act as an inverter. While leaving the setting according to the 1st condition the power will not flow to the grid and as a result the DC link voltage will start increase. As a result, active power cannot be fed back to the grid. Whereas active power is controlled by the d-axis current. So this operation can be made to operate smoothly by using a controller which constantly compare the value of DC bus link with the reference value. As result of which changing of converter into rectifier and inverter works smoothly and the DC link remains in Equilibrium.

IV. RESULTS

This section discusses the implementation of design of the Doubly fed Induction Generator in the software MATLAB. The design is implemented in the Simulink/mat lab software and results are obtained which will be discussed later in detail. First of all, the whole Simulink model is discussed and after that the control block of the DFIG will be discussed. After that we will discuss the whole model using PI controller in the control block and its results will be discussed with respect to time and discharge of water. Same we will do Using PID controller in the control block and its results will be discussed with respect to time and discharge of water. After discussing the results of both controllers we will then compare the results of both controllers and see which one is better and which one is not in efficiency and working

A. Discharge of water

At start the discharge is 8m^3/sec. After 3sec the discharge is changed to 5m^3/sec. Similarly, the discharge is changed again to 12m^3/sec at 4.5 sec. The graph between time and discharge is shown below. In this graph the variation in the flow of water is shown with respect to time in figure IV.1 .

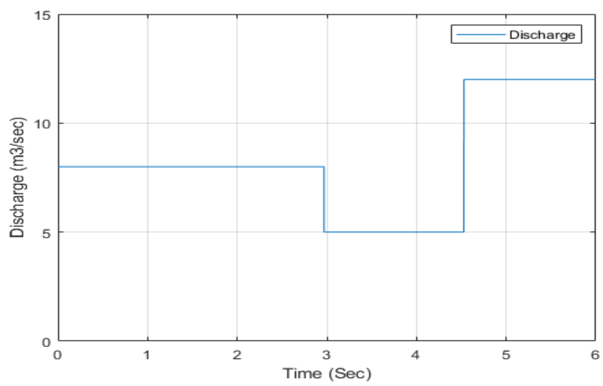

Figure IV.1: Discharge of water

B. Comparison of PI and PID Controllers

Now we will discuss the DFIG using both the controllers that is Proportional Integral Derivative controller (PID) and Proportional Integral controller (PI). We will discuss the different parameter of the model which is speed, torque, Id, Iq, Vs etc. of both controllers and will compare the results of both controllers with each other. We will see what changes comes in these parameters when the discharge of the water gets changes and which controller is performing better.

Figure IV.2 & IV.3 shows the speed of DFIG. It is clearly shown in the graph at 3 secs and at 4.5 sec that there is no change in the speed of machine due to the change in the flow of water which means that the dfig is maintaining the constant output. The PID controller starts tracking the reference line earlier than PID controller.

1)Speed of DFIG (Omega):

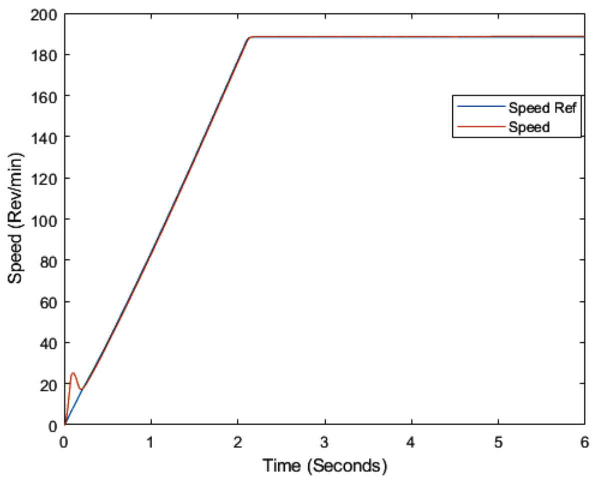

Figure IV.2: PID Controller

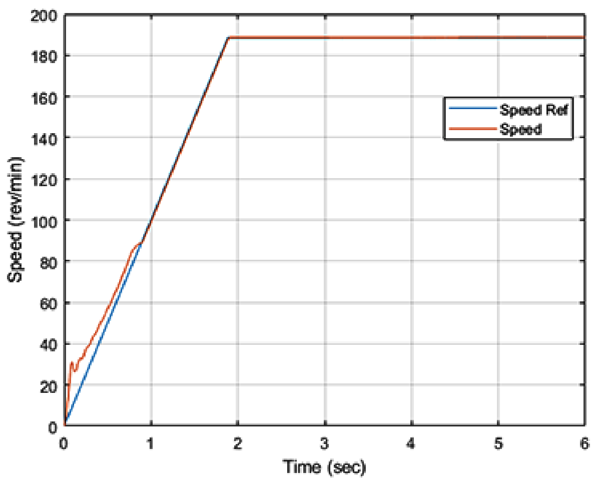

Figure IV.3: PI Controller

2) Torque in DFIG (Tem)

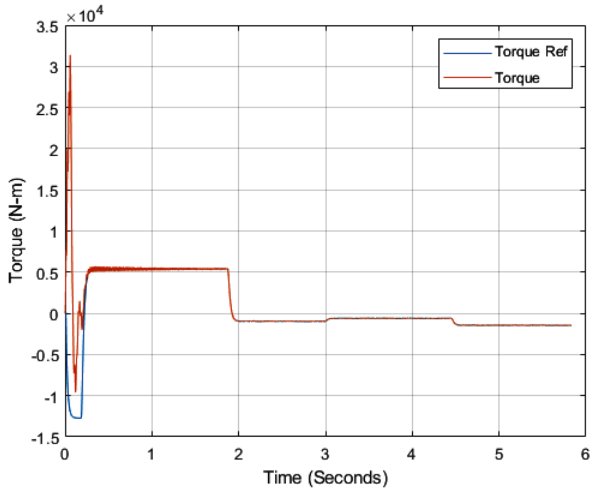

Figure IV.4: PID Controller

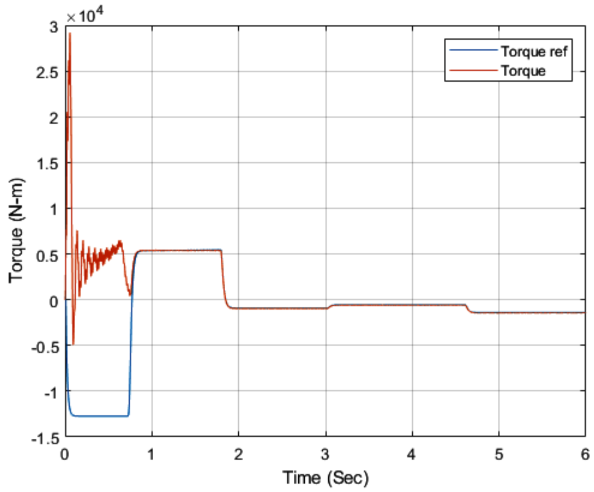

Figure IV.5: PI Controller

In figure IV.4 & IV.5 the torque of the machine is drawn with respect to time. At 3sec as we know that the discharge is decreased as a result the torque get decreased. Then at 4.5sec the discharge is increased as a result the torque also get increased. Note that the values of torque are in negative which means that the machine is operating as a generator. And If we compare the results of both controllers, the PID controller start tracking earlier than the PI controller with less oscillations.

3) Rotor direct current (Idr)

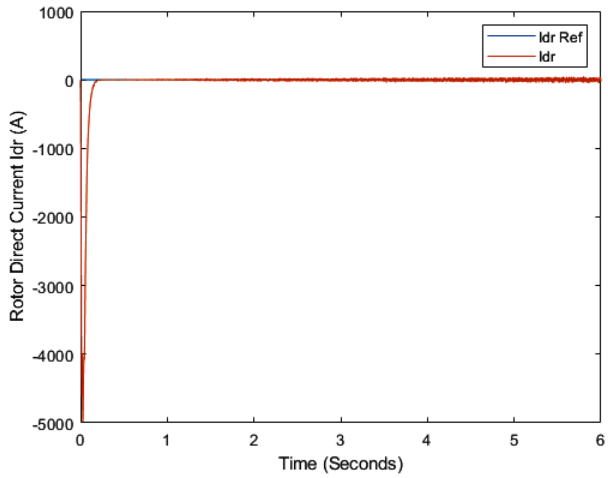

Figure IV.6: PID Controller

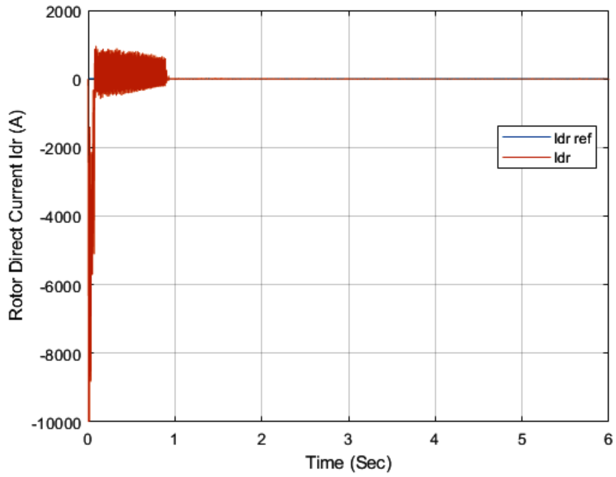

Figure IV.7: PI Controller

In figure IV.6 & IV.7 the graph of rotor direct current is plotted against the time. The reference rotor direct current is set equal to zero. The rotor direct current is following the reference value which is equal to zero. As it is clear from the graphs that PID controller is suppressing the harmonics in the start very well as compared to the PI controller. As it is clear from the graph the PID controller starts tracking earlier than the PI controller with less harmonics.

4) Rotor Quadrature Current (Iqr)

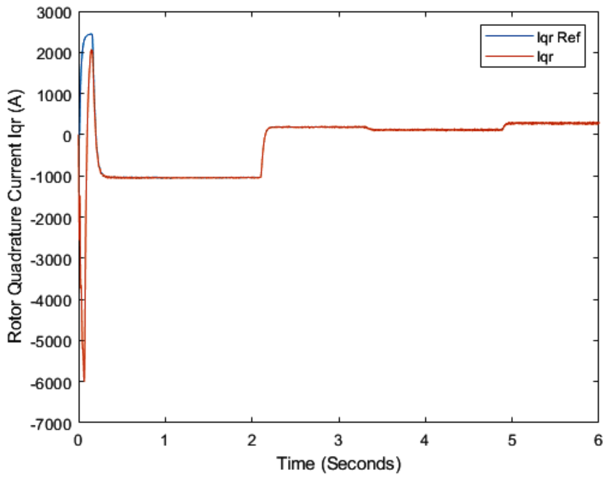

Figure IV.8: PID Controller

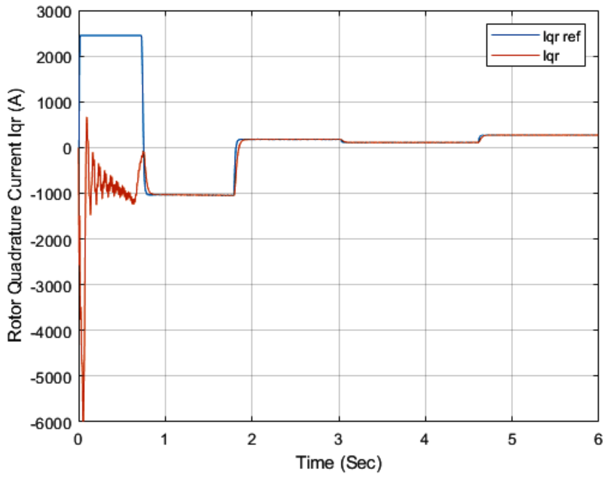

Figure IV.9: PI Controller

In figure IV.8 & IV.9 the graph is plotted in between rotor quadrature current and time. It is clear from the graph that Iqr changes accordingly to the change in the discharge of water in order to keep the output constant. At 3 secs when the discharge is decreased the Iqr also decreases similarly at 4.5sec when the discharge is increased the Iqr also get increased. The PID controllers starts tracking more earlier than the PI controller and with no harmonics.

5) Three Phase Stator Voltages

In figure IV.10 & IV.11 the graph is plotted in between Three phase stator voltage and time. It is clear from the above graph that regardless of the changes in discharge of the water it gives a constant three phase output voltages to the Grid.

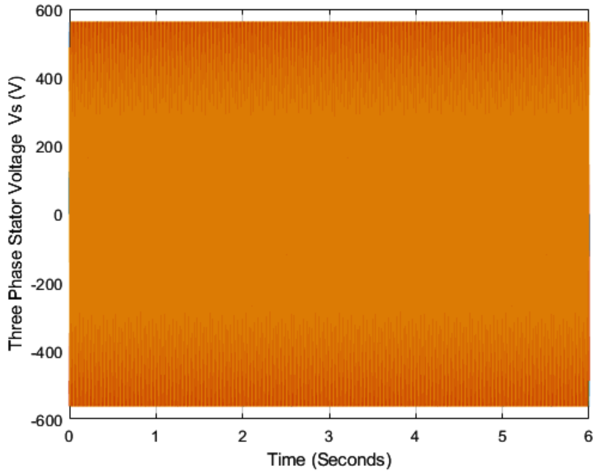

Figure IV.10: PID Controller

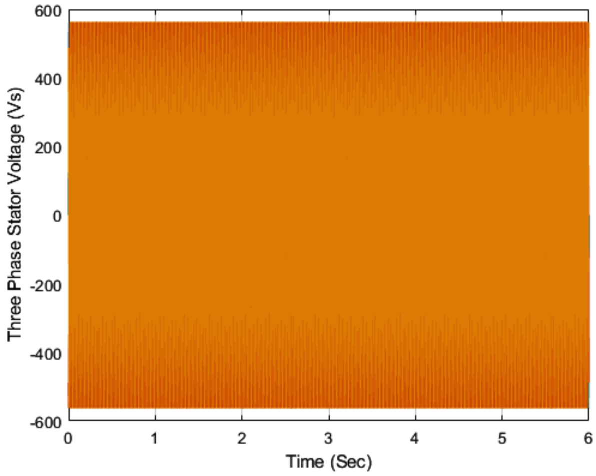

Figure IV.11: PI Controller

6) *Three Phase Rotor Current (Ir)*

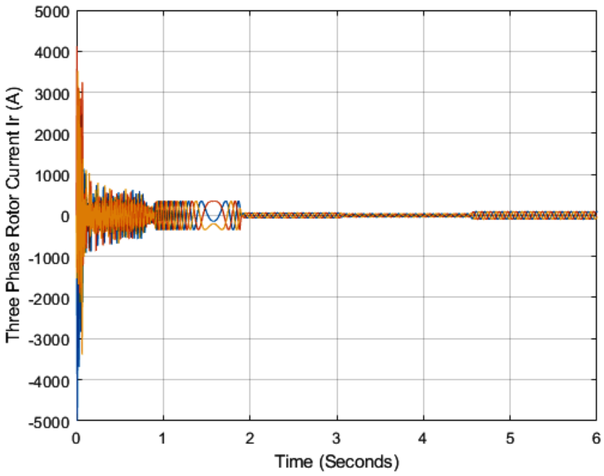

Figure IV.12: PID Controller

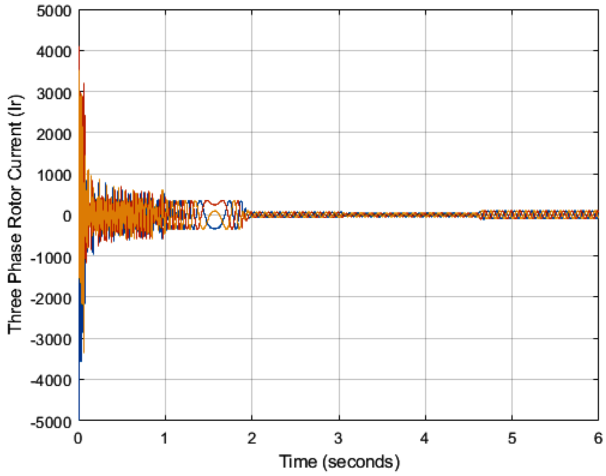

Figure IV.13: PI Controller

In figure IV.12 & IV.13 the graph is plotted in between Three phase rotor current and time. In the above figure it is clearly shown that as the discharge decreases the rotor current also decrease which is at 3sec.Similarly at 4.5sec the discharge is increased and as a result the rotor current also increases. As it is clear from the graph that the PID controller graph looks much smoother than PI's graph which means there is much less harmonics in PID as compared to PI controller

7) *Bus Voltage (Vbus)*

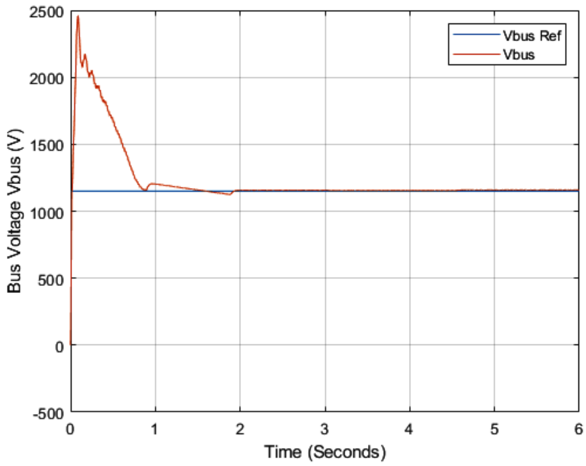

Figure IV.14: PID Controller

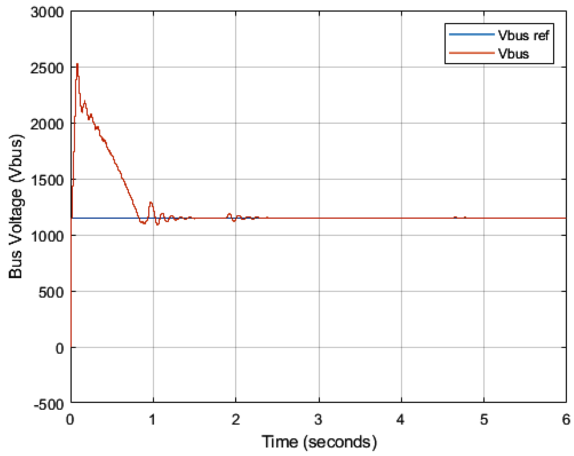

Figure IV.15: PI Controller

In figure IV.14 & IV.15 the graph is plotted in between Bus voltage and time. It is clearly shown from the above graph that reference value is set at 1150 V. The bus voltage is tracking the reference voltage. As it is clear from the graphs that PID controller is suppressing the harmonics in the start very well as compared to the PI controller

8) *Quadrature Grid Voltage Reference (Vqg_ref)*

In figure IV.16 & IV.17 the graph is plotted in between grid quadrature voltage reference and time. In the above graph it is shown that there comes a change in the value of voltages. The grid quadrature voltages changes with the change in the rotor current which ultimately changes with the change in the discharge of the water. So when the discharge of the water get changes the grid quadrature voltage also get changes. As it is clear from the graphs that PID controller is suppressing the harmonics in the start very well as compared to the PI controller

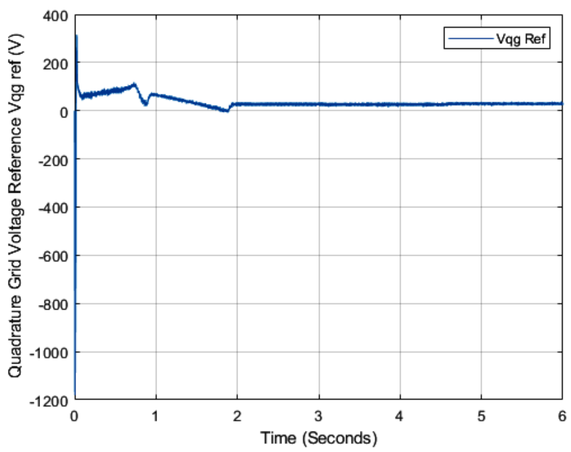

Figure IV.16: PID Controller

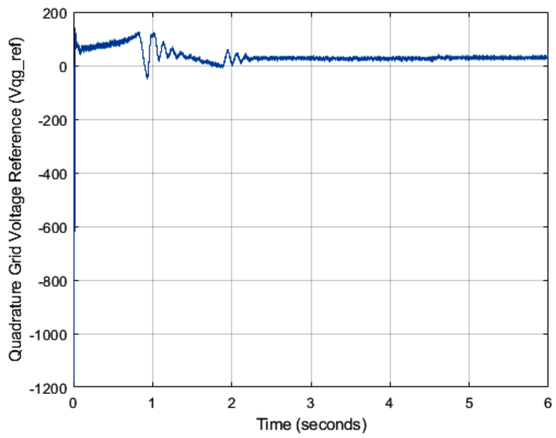

Figure IV.17: PI Controller

9) *Grid Reactance Reference Power (Qg_Ref)*

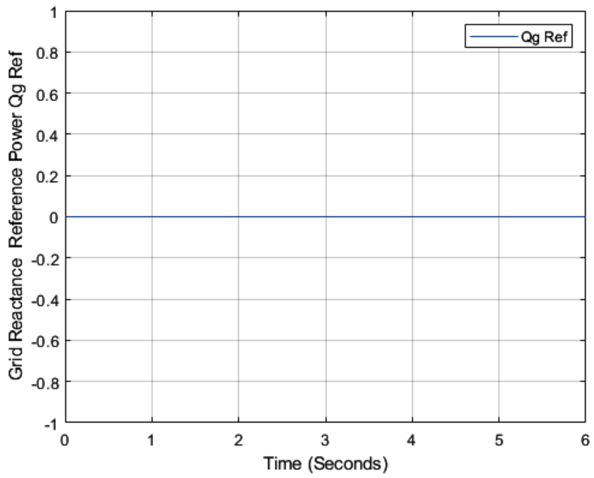

Figure IV.18: PID Controller

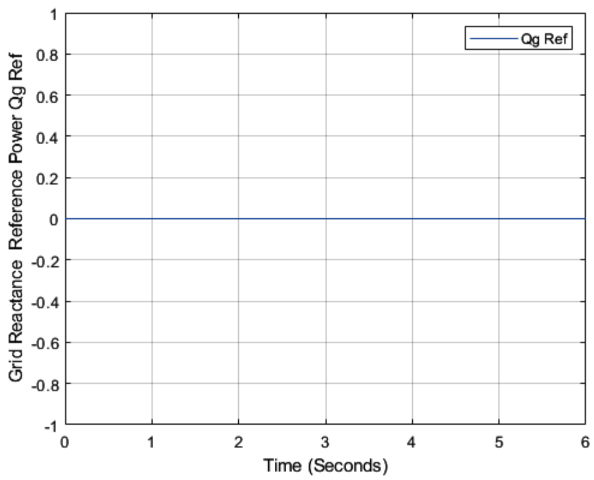

Figure IV.19: PI Controller

In figure IV.18 & IV.19 the graph is plotted in between grid reactance reference power and time. In the above figure the reactive power reference is set to zero. We can change it according to our requirements.

10) Direct Grid Voltage Reference (Vdg_ref)

In figure IV.20 & IV.21 the graph is plotted in between grid direct voltage reference and time. Above graph shows the of direct grid voltage reference which is very small equal to Zero almost. As it is clear from the graphs that PID controller is suppressing the harmonics in the start very well as compared to the PI controller.

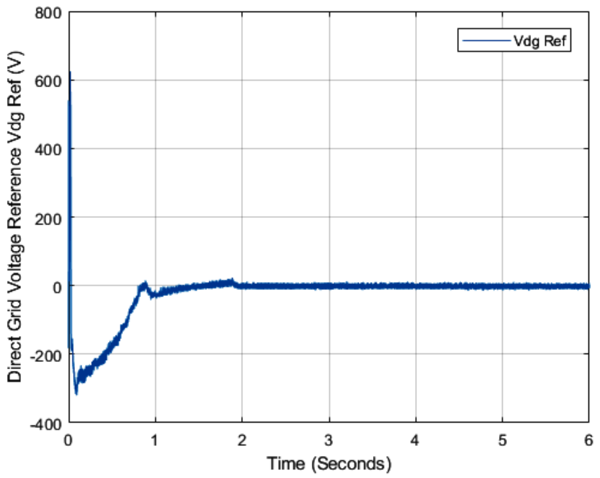

Figure IV.20: PID Controller

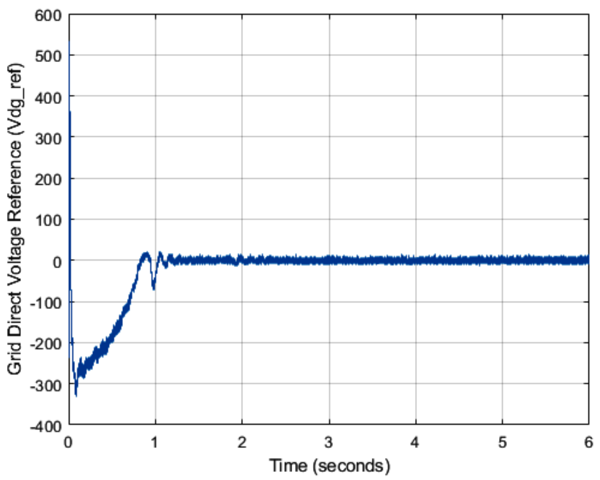

Figure IV.21: PI Conrtroller

CONCUSLION

The objective of this work was to improve the efficiency of doubly fed induction generator installed at the run off river plants/small scale hydro power plants. In this thesis work is based on the control strategies. Two types of control strategies are introduced in this work which are PI and PID controllers. Simulation of the whole DFIG model is carried out separately by both the controllers. After simulating the model by both controllers the results obtained are compared with each other. Results clearly show that the PID controller is working more efficiently than PI controller. The PID controller start tracking earlier than the PI controller. Similarly, the fluctuations in PID controller model results are seen less than the PI controller results.

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