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Control and Modelling of Rotor and Grid Side Converters Control of Doubly Fed Induction Generator for the Application in Micro Hydro

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Abstract— Micro hydro power is considered as one of the lucrative options for electricity generation, it can work both autonomously and in Grid connected mode.Most of the MHP's are built on obsolete technology due to which only a portion of flow is utilized for power generation. In micro hydro power plant Voltage and frequency of induction generator are not constant due to change in discharge of water.To overcome these issues technology is moving from fixed speed operation (FSO) to variable speed operations (VSO). Doubly Fed Induction Generator (DFIG) is the most suitable option for variable speed operation .In this research paper working and operation of DFIG in MHP system in Grid connected mode is observed which allow to compensate the variations in acceptable proportion while guaranteeing a good quality of electrical outputs.A control algorithm is developed which enable the stator voltage and frequency of DFIG to a constant value in spite of speed variation in driving shaft and load changes. A vector control technique is adopted for the regulation of rotor side converter (RSC) and grid side converter(GSC) to keep the voltages and frequency with in limits and also ensure the reactive power exchange with the grid according to the reference value.Operation of the established model is tested by different operating conditions in Simulink MATLAB.

Keywords— Doubly Fed Induction generator (DFIG),variable speed operation (VSO), micro hydro power (MHP),Rotor side converter (RSC),Grid side converter (GSC).

I. INTRODUCTION

The demand in electrical energy is increasing day by day across the globe to fulfil this demand electrical power is generated from various natural resources.In which some methods are non environmental friendly like by using fossil fuels which results in carbon emission.To overcome this issue and to produce clean and green energy the world is moving toward renewable energy generation.solar,hydro,wind,biomass are the major resources from which power can be generated.

Hydro power play a vital role in fulfilling the gap between supply and demand of electric power.hydro power has the maximum potential to harvest energy from water and is most abundantly available in nature.By the end of year 2014, in the total electricity production hydro estimated share is 16.6% while the percentage share of hydro electricity generated from renewable resources is 72.8% [1].hydro power is generated on many levels from Mega watt to few kilo watt.the initial cost of giant hydro power is very high and require huge civil work on the other hand micro hydro power is the most lucrative option for small scale power generation and can be distributed easily without any complexities. In Europe the total installed capacity of micro hydro power is about 11500MW sharing 1.79% of electricity generation and 9.5% of total hydroelectricity[2].For countries where the gap between supply and demand of electric power is vast micro hydro provide the best solution for distributed generation.it can work both autonomously and in grid connected mode.Mostly two types of generators are run by hydro turbine synchronous generator and Induction generator Both generators operate at constant rotor speed. Normally the generated power is controlled by varying the degree of flow gate, these configurations are not well suited, too expensive, and having maximum mechanical stress.To utilize the maximum potential of micro hydro power plant a control scheme should be developed which will be able to operate in a varying angular speed without a mechanical gate control. With advancement in power electronics converters, in order to harvest maximum power from the source, technology is moving toward the variable speed operations [3] For this purpose, a variable speed operation is used as alternative solution for Micro-hydro power plant.

Variable speed operation can be obtain by various techniques.one is direct drive system with no gear box with bulky generator having many number of poles due to slow speed of hydro turbine,with full rated power electronic converters due to which the cost of system is high.Another method is gear drive train using gear boxes to attain variable speed operation.the size of generator along with size of power electronic converter is reduced resulting decrease in cost.the most suitable example for this method is best implemented in Doubly Fed Induction Generator (DFIG) which is very successfully implemented in wind power generation for variable speed operation.in this paper we will coupled hydro turbine with DFIG and will check its result while changing different parameters like head,discharge or reactive power exchange with the grid.

II. RELATED WORK

To harvest maximum energy from water many researcher's focus on redesigning of generators while many worked to improve the control strategy for voltage and frequency regulation.the aim is to develop a more efficient model for hydro generation with maximum efficiency and less losses.to get a more efficient model technology is shifting from fixed speed operation to variable speed operation in order to generate more power from the available resources. For variable speed operation DFIG is the most feasible option for micro hydro power generation.DFIG give a constant output at varying flow rate and speed with in acceptable proportions.some researcher develop a model for VSO in micro hydro in which DFIG is autonomously [4] and in some cases it is taken in Grid connected mode connected with the utility Grid[5] while in [6] the DFIG is working hybridly with solar PV system.

The work done by sirodez [7]is that generator speed is kept constant to its nominal speed by using a governor system by regulating water flow. The governor is controlled by using a microcontroller device to accelerate the response due to load variation and act as a monitoring device. The generator speed is maintained to a constant value by regulating the wicket gate opening through microcontroller. The response time of the governor is 20 secs to return the generator speed to its nominal speed, with load variation given to generator is every 20%.

Another method for regulating the voltage and frequency is proposed by C.P.Ion [8] based on impedance controller also known as dump Load (DL). The regulation of electrical parameters is ensured by using VSI in combination with DL. Results of the simulation shows that when a load of 900W is connected at 2.1 sec and disconnected at 5.4 sec, after load is connected the generator voltage drop to 370 v from rated voltage 400v for 0.2 sec in around 1 sec the voltage is return to its nominal value by the diminishing the power through DL.

The main goal is to maintain voltage and frequency in pre defined values despite of change in site parameters like load,flow head etc.Tradionally there are two ways to achieve this goal one is to regulate the flow that run the turbine by using speed regulator and another is by using electronically controlled addional load[7,8].The draw back to these system are that we have maximum mechanical stress and only a portion of water is utilized for power generation and high cost. DFIG provide the most appropriate solution for voltage regulation in variable speed operation.This method is based on generator control which is robust and more efficient then other.

III. DOUBLY FED INDUCTION GENERATOR

A. *DFIG in Grid Connected Mode*

Doubly fed induction generator is basically a wound rotor induction machine (WRIM) which can run both as a generator and motor.DFIG can be operated in sub-synchrounous, synchrounous and super-synchrounous mode.DFIG supply power at constant voltage and frequency with rotor rotating at variable speed[4].It can work both in Grid connected mode and in islanded mode specially in remote areas.DFIG has both stator winding and rotor winding.In grid connected mode the stator windings are directly connected with the grid for bidirectional power flow and magnetization of the machine,while Rotor winding is coupled with Grid through back to back bidirectional PWM power electronic converters as shown in fig (1).These converters are two level voltage source converter (VSC) namely as rotor side converter (RSC) and grid side converter (GSC) with a DC link between them.By adopting vector control strategy the bidirectional VSC assure the generation at standard Grid voltage and frequency regardless of variation in rotor speed.the main purpose of converters is to neutralize the difference between the rotor speed and the reference synchronous speed.

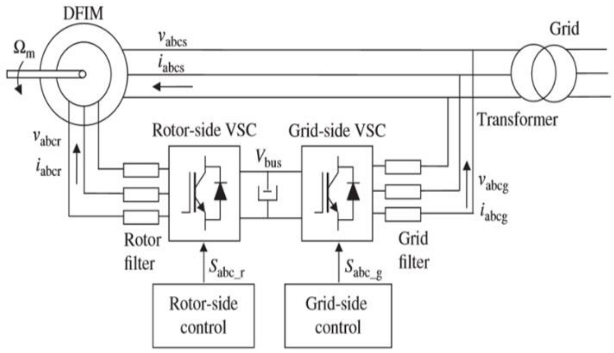

Figure 1. DFIG in Grid Connected Mode

B. *Bidirectional back to back PWM Converters*

The converters used in in this topology are two 3 phase back to back bidirectional PWM converter which are coupled through DC link as shown in Fig (2).controlled exchange of active and reactive power between rotor side and grid side occur through these converters and in addition these converters ensures control output voltage,frequency and phase for Rotor circuit.For fast switching modern power electronic converters uses IGBT's along with free wheeling diode for bidirectional power flow.In this simulation ideal two level VSC is considered.the converters linked with DFIG and utility grid is rotor side converter(RSC) and Grid side converter (RSC).RSC is responsible for controlling the generated torque and imaginary power exchange between the stator of DFIG and Grid by generating three phase voltages with variable frequency and magnitude.while GSC maintain fixed value of DC link Voltage.

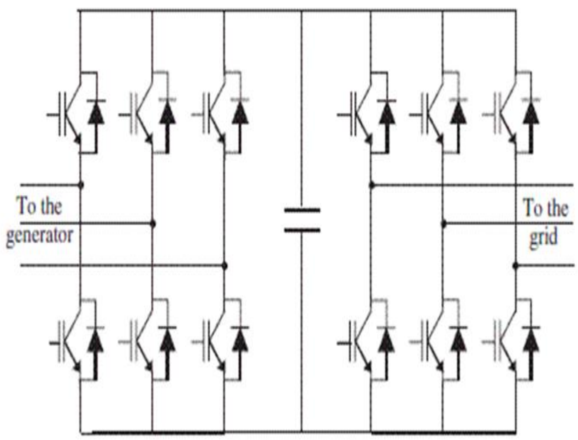

Figure 2. Bidirectional PWM converter

C. Hydro Turbine Model

In hydro generation the running water hit the turbine which in result convert the rotational mechanical energy into electrical energy.Turbines are categorized into different types based on their operational values of head and flow rate.the best turbine which will coupled with DFIG will be the Kaplan turbine which is a reaction turbine.from fig (3) it is clear that kaplan turbine have maximum operational area,it best work for low head and high flow rate and its efficiency remains constant for wide ranges[9].

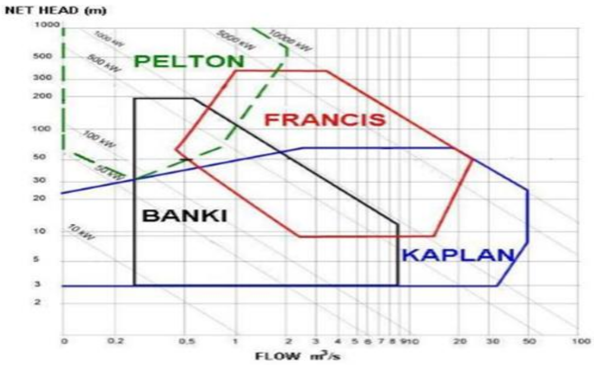

Figure 3. Conditions for hydro turbine selection

In kaplan turbine water flow is adjusted through wicket gates and propeller (runner gate).water is directly in contact with wicket gate which then fall on runner blades resulting in rotation of turbine.the wicket gate angle changes according to the desired flow of water as shown in fig (4).the pressure at the outside is decreased by installing a nozzle at the outlet which results in increase in pressure due to difference between inlet and outlet enabling the turbine to harvest more energy from water.Mathematically Power from a hydro Turbine can be derived as

$$P_{hydro} = \rho * Q * g * H \quad (1)$$

Where ρ is the density of water,Q is discharge of water,g is acceleration due to gravity and H is head.The efficiency can be calculated as

$$\eta = \frac{P_{turbine}}{P_{hydro}} \quad (2)$$

Efficiency of most of Kaplan turbine is 0.85 or more [10]. $P_{turbine}$ can be calculated as

$$P_{turbine} = T * \omega \quad (3)$$

Where T is the torque of the turbine and ω is the rotational speed of the turbine.modelling of Kaplan turbine which include penstock,wicket gate,hydraulics and mechanical modelling is done in [9].As in this paper our more focus is on control side so we consider a simple model of Kaplan turbine which is run by water flow.

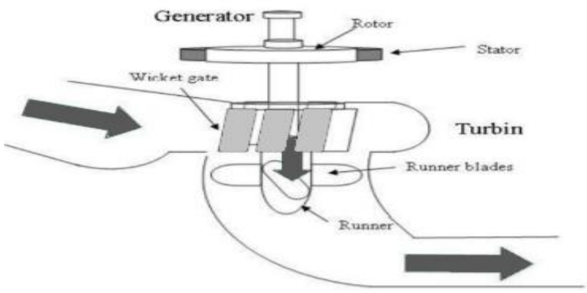

Figure 4. Working of Kaplan Turbine

IV. VECTOR CONTROL OF DFIG

DFIG control is more complicated and complex as compared to other induction generator.for variable speed operation of DFIG the control strategy needs to be more accurate and reliable.Researchers have developed many control strategies for DFIG control [11][12][13].the control strategy adopted in this research is Vector control method which is also known as field oriented control (FOC).Fast and dynamic response of generator is achieved through vector control.In vector control the three phase of generator is transformed into two synchrounously rotating reference frame d-q reference frame (parks and clarks transformation). The d-q circuits are decoupled like DC machine due to which machine response is linear faster and dynamic.By adjusting the voltage extend and phase angle of d-q axis the torque and machine flux is controlled independently.

A. Control of Rotor side Converter

The d-q axis current of rotor circuit is adjusted by rotor side converter (RSC) in which d axis is aligned with stator space vector.Based on this arrangement the d component of synchronously rotating d-q axis is in direct relation with stator reactive power and the q component of rotor current is responsible for controlling stator active power or torque. Rotor voltage is obtained from rotor current and stator flux as

$$\boldsymbol{v_{dr} = R_r i_{dr} + \sigma L_r \frac{d}{dt} i_{dr} - \omega_r \sigma L_r i_{qr} + \frac{L_m}{L_s} \frac{d}{dt} \psi_s} \quad (4)$$

$$\boldsymbol{v_{qr} = R_r i_{qr} + \sigma L_r \frac{d}{dt} i_{qr} - \omega_r \sigma L_r i_{dr} + \omega_r \frac{L_m}{L_s} \psi_s} \quad (5)$$

From the above equations d-q current control strategy for rotor currents is developed.The values of rotor current from DFIG is converted into stator reference frame which is then compared with the reference values of d-q currents as shown in Fig (5).the error from reference value and measured valued is the input to the PI regulator.The output from PI regulator and with cross coupling term gives the desire voltage values.the resulted voltage values are again transformed into three phase quantities before applying it to the converter or generator.

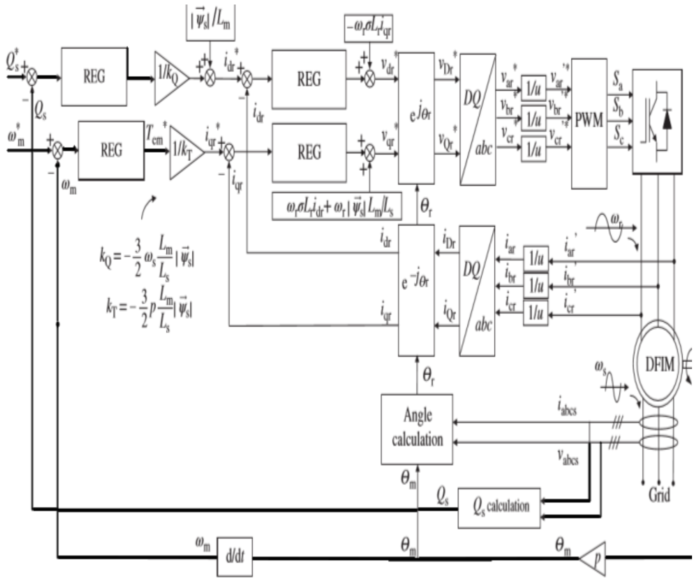

Figure 5. Rotor side converter control

For reference frame transformation, rotor angle θ_r must be estimated.a simple Phase lock loop (PLL) can be used for this purpose.In d-q reference frame the equation for toque is

$$\boldsymbol{T_{em} = -\frac{3}{2}p\frac{L_m}{L_s}\psi_s i_{qr}} \quad \rightrightarrows \quad \boldsymbol{T_{em} = K_T i_{qr}} \qquad (6)$$

It is clear the $\boldsymbol{i_{qr}}$ component is responsible for speed and torque control.the equation for reactive power is expressed as

$$\boldsymbol{Q_s = -\frac{3}{2}\omega_s \frac{L_m}{L_s}\psi_s\left(i_{dr} - \frac{\psi_s}{L_m}\right) \rightrightarrows Q_s = K_Q\left(i_{dr} - \frac{\psi_s}{L_m}\right)} \quad (7)$$

It is conculded from the above equation that Reactive power of stator circuit is controlled by $\boldsymbol{i_{dr}}$ component.

B. Grid Side converter Control

Grid side converter is responsible for maintaining constant DC voltage across the bus and to ensure bidirectional power flow between RSC and GSC with controlled imaginary power.the derived equations for voltages from dynamic model of GSC is expressed below

$$\boldsymbol{v_{df} = i_{dg}R_f + \frac{di_{dg}}{dt}L_f - \omega_s L_f i_{qg} + v_{dg}} \qquad (8)$$

$$\boldsymbol{v_{qf} = i_{qg}R_f + \frac{di_{qg}}{dt}L_f - \omega_s L_f i_{dg}} \qquad (9)$$

Grid voltage oriented vector control (GVOVC) strategy is adopted in this work.the equations for real and reactive power of grid terminal is derived as

$$\boldsymbol{P_g = \frac{3}{2}v_{dg}i_{dg} = \frac{3}{2}v_g i_{dg}} \qquad (10)$$

$$\boldsymbol{Q_g = -\frac{3}{2}v_{dg}i_{qg} = -\frac{3}{2}v_g i_{qg}} \qquad (11)$$

The three phase current Ia,Ib,Ic is transformed into synchronously rotating d-q coordinate which is the input to the regulator as shown in block diagram Fig 6.then dq reference voltage $(v*_{df}, v*_{qf})$ is generated from dq current controller $(i*_{dg}, i*_{qg})$ .abc reference voltages are generated from dq reference voltages through transformation which is then used to generate reference pulses for Grid side converter.For current and voltage transformation the angle θ_g of grid voltage is estimated by using phase lock loop (PLL).

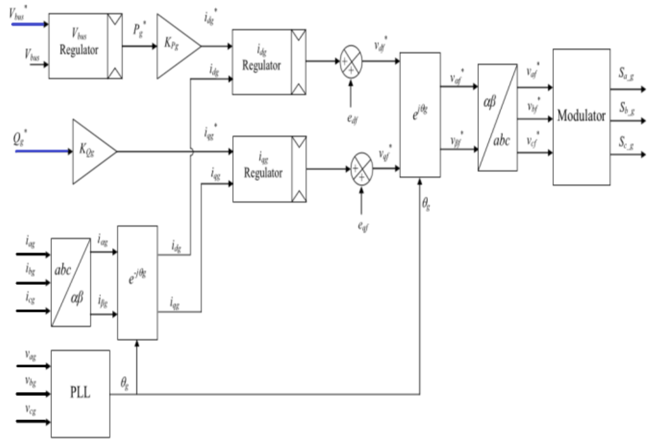

Figure 6. GVOVC of GSC

V. SIMULATION

A control model for DFIG driven by hydro turbine is developed in matlab Simulink,a control model for rotor side converter and grid side converter is developed separately and then coupled with generator and Grid.the variable speed operation of DFIG run by hydro source is analyzed by varying different site parameter like discharge,head with in acceptable limits.

A. Discharge of water

The main purpose of this work is to implement variable speed operation in micro hydro operations.for this purpose a simple turbine model is considered which is running on variable flow.the flow rate changes after every 2.5 sec.

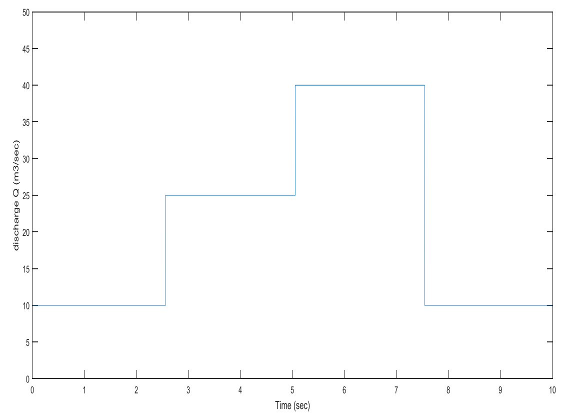

Figure 7. Discharge of water

B. Speed control of DFIG

We obtained a constant speed operation despite of the change in flow after every 2.5 sec as shown in simulation result Fig 8.the initial perturbation for 1.7 sec is due to the direct start up of the generator from the grid.the speed is maintained to a constant value of 189 m/sec with change in flow after 2.5 sec.

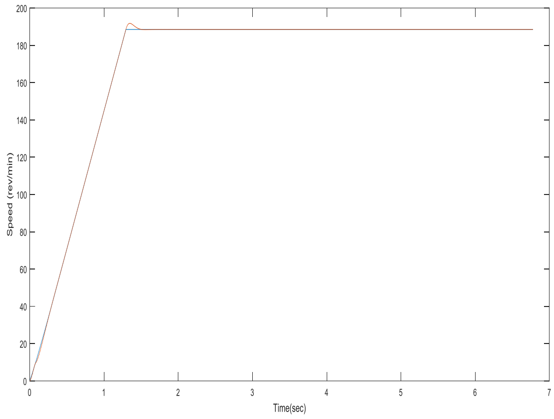

Figure 8. Speed control of DFIG

C. *Torque control of DFIG*

The torque of the machine changes according to the change in flow rate.In order to maintain constant speed operation and constant output voltage the torque increases with increase in flow rate as shown in simulation result

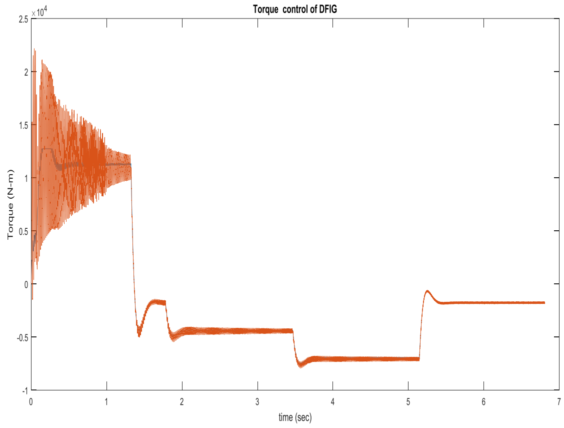

Figure 9. Torque of DFIG

D. *Three phase stator voltage*

The three phase stator voltage is maintained to a constant value of 320v despite of changes in flow rate.

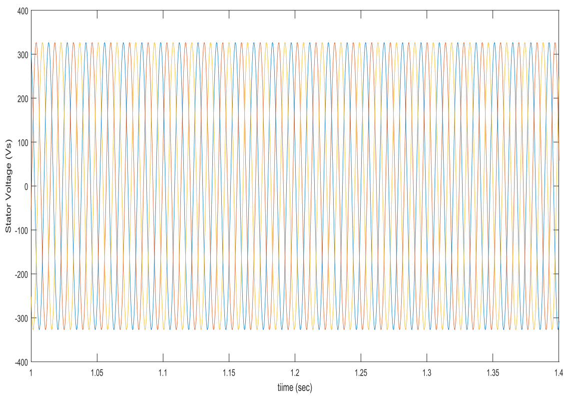

Figure 10. Three phase stator voltage

E. *DC Bus voltage*

Grid side converter is responsible for maintaining constant DC bus voltage between rotor side converter and grid side converter.it maintain a fixed voltage across the terminal by storing or releasing energy from the capacitor.1150v fixed dc value is maintained after initial perturbation in this work.

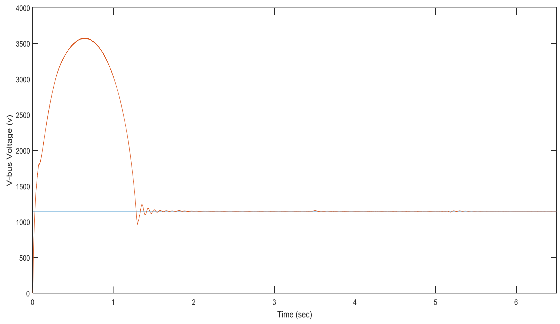

Figure 11. DC bus voltage

F. *Three phase rotor and Grid Current*

The values of grid and rotor currents are in direct proportion with the change in flow rate.both values increases with increase in flow and vice versa in order to maintain constant amplitude of voltage at the output.

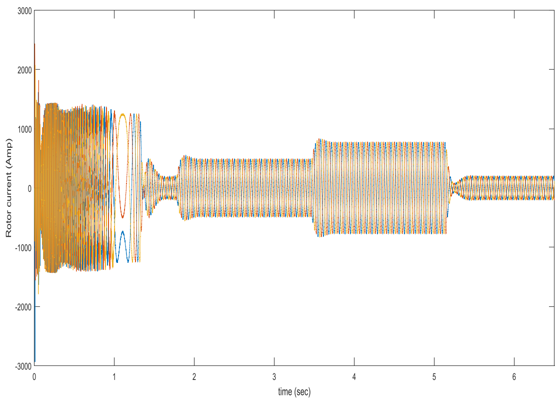

Figure 12. Three phase rotor current

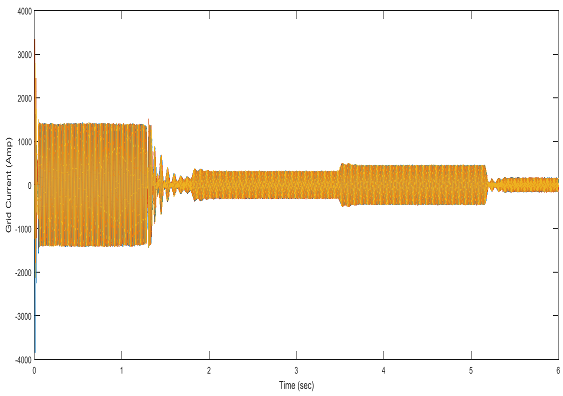

Figure 13. Three phase grid current

G. Reactive power Reference

reactive power exchange between grid and DFIG is zero by setting the reference value of reactive power exchange to zero.but it can be change according to grid code and demand.

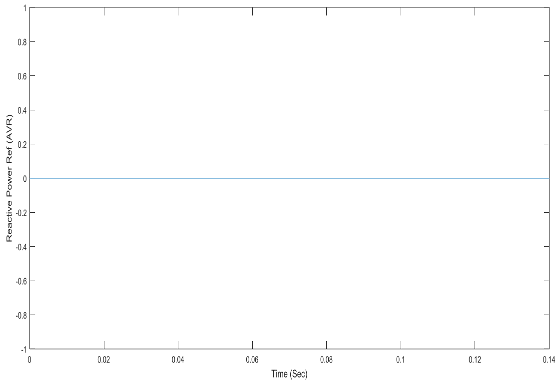

Figure 14. Change in reactive power Reference value

TABLE I. SYSTEM PARAMETERS OF DFIG

Frequency	50 Hz
Rated stator voltage	400v
Rated Power	2 MW
Rated rotational speed	1500 rpm
Pole pair	2
Stator and Rotor turns Ratio	1.0/3.0
Bus voltage (DC)	1150.0 V
Inertia	127 j
Switching frequency	4 kHz
Grid side filter resistance	20 micro ohm
Grid side inductive filter	400 micro ohm

CONCUSLION

In this work a control logic is developed for a variable speed operation for a limited speed range as an alternative solution for micro hydro operation.the variable speed operation can be used in both Grid connected mode or in isolated mode.A better quality of power is generated by DFIG with back to back power electronic converter connected to the machine and grid.the simulation results shows that proposed model is a valid solution for variable speed operation of micro hydro power generation.

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