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Simplified Modelling of Grid Connected DFIG Based Wind Turbine for Stability Improvement

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***Abstract*-This paper proposes a Stator Voltage Orientation (SVO) based control strategy for DFIG based wind turbine to ensure the stability. This model does not consider DFIG flux and fast current control dynamics and hence it is simple. But, it considers the effects of operating points, grid intensities, and control loop. The proposed model is sufficient to examine the oscillation modes and to derive a control strategy that regulates the operating point of DFIG in the zone of stability. The proposed SVO based control strategy ensures a seamless and efficient control of active and reactive power and it is employed in the dc link voltage control system of the DFIG. The prescribed system is modeled and simulated in MATLAB/SIMULINK and the results are obtained.**

I.INTRODUCTION

In standard motor operation, the stator flux rotation is quicker than the rotor rotation. This prompts the stator flux to induce rotor currents, which formulate a rotor flux with the magnetic polarity contrary to the stator. In this way, the rotor is kept along behind stator flux, with the currents in the rotor provoked at the slip frequency.

Any multiphase electric machine can be reformed to a wound-rotor doubly fed electric motor or generator by replacing the rotor assembly to a multiphase wound rotor winding set. If the rotor winding set can transfer bi-directional active or working power to the electrical system, the translation result is a wound-rotor doubly fed electric motor or generator with immense speed and power grade than the primary singly fed electric machine. These benefits can be obtained without core saturation, all by electronically controlling total motor power for full variable speed control.

An induction generator generates electrical power when its in synchronous speed. For a typical four-pole motor (two pairs of poles on stator) operating on a 60 Hz electrical grid, the synchronous speed is 1800 rotations per minute (rpm). The same four-pole motor operating on a 50 Hz grid will have a synchronous speed of 1500 RPM. The motor normally turns moderate than the synchronous speed; the difference between synchronous and operating speed is called "slip" and is customarily expressed as percent of the synchronous speed. For case, a motor operating at 1450 RPM that has a synchronous speed of 1500 RPM is operating at a slip of +3.3%.

In generator operation, a prime mover (turbine or engine) urges the rotor beyond the synchronous speed (negative slip). The stator flux still induces currents in the rotor, but since the defending rotor flux is now cutting the stator coils, an active current is produced in stator coils and the motor presently operates as a generator, sending power behind to the electrical grid. The essential principle of induction generators is the conversion between mechanical energy to electrical energy. This necessitates an external torque applied to the rotor to turn it faster than the synchronous speed. However, indefinitely increasing torque doesn't lead to an indefinite increase in power generation. The rotating magnetic field torque worried from the armature works to counter the motion of the rotor and block over speed because of induced motion in the reverse direction. As the speed of the motor raises the counter torque attains a max value of torque (breakdown torque) that it can operate until before the operating situations become unstable. Ideally, induction generators operate properly in the stable region among the no-load condition and maximum torque region.

The stability of DFIG under weak ac grid connection by neglecting flux as well as fast current control dynamics. The effects of Phase locked loop (PLL), rotor side converter (RSC), active power control (APC), reactive power control (RPC) are included. Stator voltage orientation (SVO) based vector control scheme is used in this paper. Eigen value comparison is utilized to ensure the performance of the machine. Two oscillation modes concerned in frequency scale for stability analysis. In (1) focused on Vector control and decoupling control strategies are focused in this paper. With the change in inductance value, active power control under transient state can be illustrated.

Magnetizing current of the induction machine places a vital role on transient state. By varying the rotor speed kinetic energy may be absorbed or released from or to the grid respectively. In (2) discussed about low power wind turbine uses squirrel cage induction machine is directly connected to the grid. By adjusting the poles we can get variable speed operation.

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Adjustable speed generator (ASG) has low cost, stress and high power quality as compared to fixed speed generator (FSG). Two threshold voltages and two time delays are concerned. Electromechanical and var (3) control oscillations are the two methods to be operated in two control modes. They are power factor control mode (PF) and voltage control mode (VC) is mainly focused on artificial modulation. Stabilizing source at low cost is the major issue on this paper. maximum power(4) transfer limit can be predicted by calculating the power voltage stability. At low SCR, gain of PLL may affect the voltage source converter (VSC) operation. Park transformation is utilized to represent d and q co-ordinates. Bandwidth of the (5) PLL is close to DC link voltage control when stability reaches very high values. By validating feasibility and correctness of proposed VSC by using Eigen value comparison. Loss of stability (LOS) and voltage collapse are the main concepts were focused on this paper. LOS can't be avoided but we can maintain the specified distance to the stability boundary. As much as possible low value of SCR may leads to increase the LOS. Two (6) major incidents such as low voltage ride through (LVRT), zero voltage ride through are not considered in this paper. Four types of generator are mainly used. They comprise wind turbine, generator, pseudo governor, and rotor. Controlling (7) the reactive power (RPC) stability of DC link voltage control (DVC) can be maintained. Damping and restoring components were discussed in this paper. When grid strength is low then no of damping components reduced. It may deteriorate the system stability.

While bandwidth of the RPC close DVC effects will be reduced to pre-defined value. Power system modal analysis (8) considering doubly-fed induction generators One and two mass model were used as with or without stator over three variable oscillating modes. At lower grid strength DFIG can't be operated as stable mode. They are

1. Stator current
2. Turbine angle
3. Generator speed
4. Rotor flux.

When inductance is high then the control system becomes more unstable. Stability limits are increased by slower PLL and large transient's angle between PLL and capacitor. Two back to back PWM voltage (9) fed inverters are connected to feed isolated load power at variable speed. Sub and super synchronous operations at low distortion currents are places important role. Tracking (10) the optimal wind power by using auxiliary power which is connected parallel with main load. Indirect stator oriented vector control scheme is used. Stability and damping of system is independent of d component when grid flux is oriented with control scheme. Certain value of d component, rotor current causes the system to become unstable.

1. Isolating DFIG from grid
2. Rotor over current during fault condition is the main target for the power system.

Minimized control strategy is used to overcome those difficulties. Local load can be supplied by inertia of the wind turbine when wind turbine is less then demand. In equality between wind power and demand load is the main drawback of the grid.

Complex terminal voltage may affect the PLL performance of the machine. Rotor current can be suppressed by torque of the machine. Damping of the dominant oscillation mode first decreases and then increases with RPC gain increasing. The concerned two oscillatory Eigen values of detailed and proposed model under different operating points and grid strengths, respectively. The proposed model dominant Eigen values are quite close to the detail model for a wide range of operating points and grid strengths. It means the proposed model holds similar stable region to the detailed model and is suitable for small-signal stability analysis in the concerned time scale.

In (12) has proposed work Operating point, grid strength and control loop are included for stability studies. When the grid strength decreases, damping of PLL based mode can be reduced. Due to DFIG's faster response, variable speed operation exists on wind turbine. Synchronizing and damping component analysis are survived in this proposed project.

Electromagnetic electric machines, doubly fed machines require torque current and magnetic flux to produce torque. Because there are not permanent magnets in the doubly fed machine, magnetizing current is required to produce magnetic flux. Magnetizing current and torque current are orthogonal vectors and do not add straight. Since the magnetizing current is much humbler than the torque current, it is only significant in the efficiency of the machine.

II.WIND ENERGY

Wind power is extricated from air flow using wind turbines or sails to generate mechanical or electrical energy. Wind gardens consist of multiple single wind turbines which are connected to the electric power transmission network. Coastal wind is an economical source of electricity, aggressive with or in many places affordable than coal or gas plant. Maritime wind is equable and effective than on land, and offshore farms have less visual influence, but configuration and subsistence costs are considerably larger. Small onshore wind farms can feed some energy into the grid or provide electricity to isolated off-grid locations. The working principle of the wind turbine includes the following conversion methods. There are three main turbine types available. They are

- Squirrel-cage induction generator
- Doubly fed induction generator
- Direct-drive synchronous generator

The first one which is the easiest and traditional system consists of a conventional directly grid-coupled squirrel cage induction generator. The slip and the resultant rotor

International Journal of Engineering Research & Technology (IJERT)
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speed of the Generator vary with the amount of power generated. The rotor speed deviation is small, approximately 1% to 2%, and hence this is normally assigned to as a constant speed turbine. The other two generating systems are variable –speed systems. In the doubly fed induction generator, a back to back voltage source converter supplies the three-phase rotor winding, resulting that the mechanical and electrical rotor frequency are decoupled and the electrical stator and rotor frequency can match independently of the mechanical rotor speed. In the direct-drive synchronous generator, the generator is totally decoupled from the grid by power electronics, as a converter is connected to the stator winding and different converter is connected to the grid. Thus, the total power produced by the wind power is transferred by an HVDC link.

The Static characteristic of wind turbine can be described with the relationship in the wind as in

$$P_{wind} = \frac{1}{2}\rho\pi R^2 V_{wind}^3 \qquad (1)$$

Where ρ is air density (1.225 kg/m3), R is the rotor radius in meters, and Vwind is the wind speed in m/s.

It is not possible to extract all kinetic energy of wind and is called Cp Power Co-efficient. This power co-efficient can be expressed as

$$P_{mech} = C_p P_{wind} \qquad (2)$$

$$P_{mech} = \frac{1}{2}\rho\pi R^2 V_{wind}^3 C_p \qquad (3)$$

Where P_{mech} is mechanical power.

By using the turbine rotational speed, the mechanical torque is given by

$$T_{mech} = P_{mech}\frac{P_{mech}}{\omega_{turbine}} \qquad (4)$$

Where ω turbine – mechanical torque.

III.DOUBLY FED INDUCTION MACHINE

When the grid strength decreases, damping of PLL based mode can be reduced. Due to DFIG's faster response, variable speed operation exists on wind turbine. Synchronizing and damping component analysis. The efficiency is similar because the total current is split between the rotor and stator winding sets while the electrical loss is proportional to the square of the current flowing through the winding set.

- DFIG has the high operational efficiency
- reactive power support
- Variable speed operation exists.

Various types of energy storage elements are utilized for DFIG excitation. The proper control strategy is employed to control these elements in certain level. When use of these control strategy will arise variable stable issues. The drive chain and pitch control bandwidth of DFIG WT are close to rotor swing mode.

III.A DFIG classification

I. Brushless doubly fed induction generator

One of the stator winding sets (power winding) is connected to the grid and the other winding set (control winding) is supplied from a frequency converter. The shaft speed is adjusted by varying the frequency of the control winding. As a doubly fed electric machine, the rating of the frequency converter need only be fraction of the machine rating

II. Brushless wound rotor doubly fed induction generator

The brushless wound-rotor synchronous doubly fed induction generator incorporates the electromagnetic structure of the wound-rotor doubly fed electric machine, but replaces the traditional multiphase slip ring assembly with a brushless instantaneous control means to in dependently power the rotor winding set with multiphase AC power as hypothesized by electric machine.

IV. PI CONTROLLER

P-I controller is mainly used to eliminate the steady state error resulting from P controller. However, in terms of the speed of the response and overall stability of the system, it has a negative consequence. This controller is essentially used in areas where a speed of the system is not an issue. Since P-I controller has no capability to predict the future errors of the system its posterior decrease the rise time and eliminates the oscillations. If applied, any amount of wagers set point overshoot. PI controller will eliminate cracked oscillations and steady state error resulting in operation of the on-off controller and P controller respectively. However, introducing integral mode has a negative effect on the speed of the response and overall stability of the system. Thus, PI controller will not enhance the speed of response. It can be anticipated since PI controller does not have means to predict what will happen with the error in near future. This problem can be solved by introducing derivative mode which has the ability to predict what will happen with the error in near future and thus to decrease a reaction time of the controller.

PI controllers are very often used in industry, especially when a speed of the response is not an issue.

A control without D mode is used when:

a) Fast response of the system is not required

b) Large disturbances and noise are present during operation of the process

c) There is only one energy storage in the process (capacitive or inductive)

d) There are large transport delays in the system

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IV.A HOW TO TUNE THE PI-CONTROLLER

There are more ways to do that. A more or less automatic routine is presented in Ziegler-Nichols method.
A simple rule is:
1) Turn OFF the integration part of the controller

2) Try to tune in the proportional gain, Kp, until the result is OK!

3) If 2) do not accomplish your control target, then turn ON the integrator part by Reduce Kp to the half of what you have already found and then turn slowly turn down for the tau_N-value!

Proportional + Integral (PI) controllers were developed because of the desirable property that systems with open loop transfer functions of type 1 or above have zero steady state error with respect to a step input

. The PI regulator is : $\frac{U(s)}{E(S)} = K_p + \frac{K_1}{S}$ (5)

As the name suggests it is a combination of proportional and an integral controller the output (also called the actuating signal) is equal to the summation of proportional and integral of the error signal. Now let us analyze proportional and integral controller mathematically. As we know in a proportional and integral controller output is directly proportional to the summation of proportional of error and integration of the error signal, writing this mathematically,

$$A(t)\infty \int_0^t e(t)dt + A(t)\infty e(t) \qquad (6)$$

Removing the sign of proportionality,

$$A(t) = K_i \int_0^t e(t)dt + K_p e(t) \qquad (7)$$

Where K_i and k_p proportional constant and integral constant respectively.

Wind turbines are designed and operated to produce electrical energy as cheaply as possible. Wind turbines are, therefore, generally designed such that they yield rated power output at wind speeds around 12–15 m/s. As discussed in previous sections, the exact value of such a wind velocity varies with producer and size due to the difference in the power curve. It does not pay to design turbines that maximize their output at stronger winds, as such powerful winds are rare. In a case of stronger winds, it is necessary to lose part of the excess energy of the wind in order to avoid injury to the wind turbine.

V.PROPOSED DESIGN

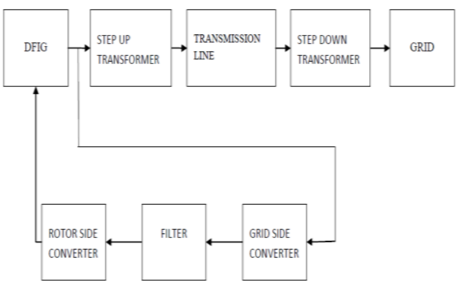

Figure 1. Over All Block Diagram

V.A DFIG (DOUBLY FED INDUCTION GENERATOR):

In this generator, multi-phase wound type of rotor is used to twice the synchronous speed of rated torque. The power density of the machine is high when it is operated at rated frequency. Mechanical efficiency of the Machine is depending on the power coefficient. Pitch angle, as well as tip speed ratio, gives power coefficient of the rotating wind turbine. Doubly fed machines are typically used in applications that require the varying speed of the machine's shaft on a limited scale around the synchronous speed, for example, ± 30% because the power rating of the frequency converter is reduced similarly. Today doubly fed drives are the most common variable speed wind turbine concept. The efficiency is similar because the total current is divided between the rotor and stator winding sets while the electrical loss is proportional to the square of the current flowing through the winding set.

V.B ROTOR SIDE CONVERTER (RSC):

The rotor-side converter is used to control the wind turbine output power and the voltage (or reactive power) covered at the grid terminals. The actual electrical output power, measured at the grid terminals of the wind turbine, is combined with the total power losses and is compared with the reference power. The crowbar will short-circuit the rotor windings through a small resistance when excessive currents or voltages are detected. In order to be able to continue the operation as quickly as possible, an active crowbar has to be used. The active crowbar can eliminate the rotor short in a controlled way and thus the rotor side converter can be started only after 20-60 ms from the start of the grid disturbance when the surviving voltage stays above 15% of the nominal voltage.

V.C GRID SIDE CONVERTER (GSC):

The converter is used to regulate the voltage of the DC bus capacitor. This model allows using the converter to generate or absorb reactive power. Measurement systems measuring the d and q components of AC positive-sequence currents to be controlled as well as the DC voltage Vdc. Ignoring the slip ring assembly and considering similar air-gap flux density, the physical size of the magnetic core of the wound-rotor doubly fed electric machine is diminutive than other electric machines because the two active winding sets are individually placed on the rotor and stator frames, respectively, with virtually no real-estate penalty.

$$Ud = -L\, di_d/dt - Ri_d + \omega_1 Li_q + v_d \qquad (8)$$

$$Uq = -L\, di_q/dt - Ri_q - \omega_1 Li_d + v_z \qquad (9)$$

$$C\, d/dt v_{dc} = i_{dc} - i_L \qquad (10)$$

where u_d, u_q the d-q components of bridge arm output voltage v_d, v_q: the d-q components of grid voltage i_d, i_q: the d-q components of input currents.

International Journal of Engineering Research & Technology (IJERT)
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Vol. 5 Issue 03, March-2016

V.D SVO BASED CONTROL TECHNIQUE

RSC control includes two cascaded control loops, one for APC and the other for RPC. APC is sighted at controlling active power sent to the grid from both stator and GSC tracking the reference produced from maximum power tracking curve for given rotor speeds. Terminal voltage control, as one scheme of RPC, is utilized to maintain the voltage of WT terminal bus within given values.GSC controller controls active and reactive power flow connecting the GSC and the grid.

VI. PULSE WIDTH MODULATION TECHNIQUE

It is a method of changing the duration of a pulse with reverence to the analog input. The duty cycle of a square wave is modulated to encode a specific analog signal level. This pulse width modulation tutorial gives you the basic principle of formation of a PWM signal. The PWM signal is digital because, at any given instant of time, the full DC supply is either ON or OFF completely.PWM method is commonly used for speed controlling of fans, motors, lights in modifying intensities, pulse width modulation controller etc. These signals may also be used for estimated time-varying of analog signals. Below you can see the pulse width modulation generator circuit diagram (pulse width modulator) using op amp. PWM is employed in a wide variation of applications, ranging from measurement and communications to power control and conversion. Pulse width modulation dc motor control is one of the popular circuits in Robotics.

VII. FRAME TRANSFORMATION:

The dq0 transform (often called the Park transform) is a space vector transformation of three-phase time-domain signals from a stationary phase coordinate system (ABC) to a rotating coordinate system (dq0).
The transform applied to time-domain voltages in the natural frame (i.e. ua, ub and uc) is as follows:

$$\begin{bmatrix} u_d \\ u_q \\ u_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos(\theta-\frac{2\pi}{3}) & \cos(\theta+\frac{2\pi}{3}) \\ -\sin\theta & -\sin(\theta-\frac{2\pi}{3}) & -\sin(\theta+\frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} \quad (11)$$

Where, the angle between the rotating and fixed coordinate system at each time t and δ_A is an initial phase shift of the voltage.

The inverse transformation from the dq0 frame to the natural abc frame:

$$\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta & 1 \\ \cos(\theta-\frac{2\pi}{3}) & -\sin(\theta-\frac{2\pi}{3}) & 1 \\ \cos(\theta+\frac{2\pi}{3}) & \sin(\theta+\frac{2\pi}{3}) & 1 \end{bmatrix}\begin{bmatrix} u_d \\ u_q \\ u_0 \end{bmatrix} \quad (12)$$

As in the Clarke Transform, it is interesting to note that the 0-component above is the same as the zero sequence component in the symmetrical components transform. For example, for voltages Ua, Ub and Uc, the zero sequence component for both the dq0 and symmetrical components transforms is,

$$\frac{1}{3}(U_a + U_b + U_c) \quad (13)$$

VII.INVERTER

Inverter or power inverter is a device that changes the DC sources to AC sources. Inverters are employed in a wide range of applications, from small switched power supplies for a computer to large electric utility applications to carry bulk power. This makes them very suitable for when you need to use AC power tools or appliances. Power inverters produce one of three different types of wave output:

- Square Wave
- Modified Square Wave (Modified Sine Wave)
- Pure Sine Wave (True Sine Wave)

The three different wave signals describe three different qualities of power output. Square wave inverters result in uneven power delivery that is not efficient for running most equipment. Square wave inverters were the first types of inverters made and are antiquated. Modified square wave (modified sine wave) inverters deliver power that is compatible and efficient enough to run most devices fine. Some sensitive devices require a sine wave, like certain medical equipment and variable speed or rechargeable tools

VIII.RESULTS:

VIII.A SIMULINK DIAGRAM:

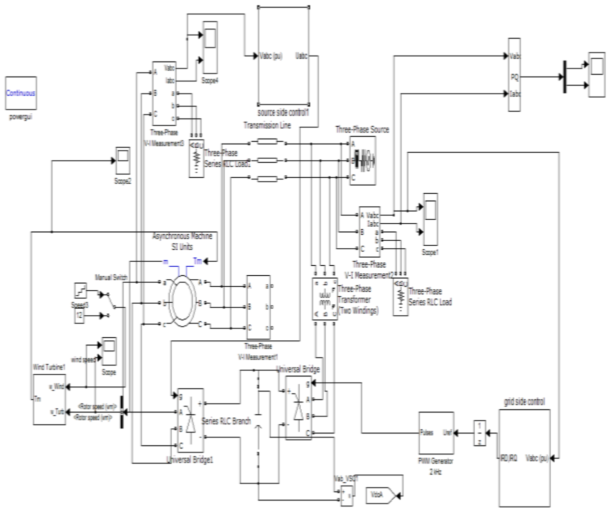

Figure 2. Over All Simulink Diagram

To extract maximum power at unity power factor from a PMSG and feed this power (also at unity power factor) to the grid, the use of back-to-back connected PWM voltage source converters are proposed. Moreover, to reduce the overall cost, reduced switch PWM voltage source converters (four switch) instead of conventional (six switch) converters for variable speed drive systems can be used. It is shown that by using both rectifier and inverter current control or flux based control, it is possible to obtain unity power factor operation both at the WTG and the grid. Other mechanisms can also be included to maximize power extraction from the VSWT (i.e. PPT techniques) or sensor-less approach to further reduce cost and increase reliability and performance of the systems.

VIII.B INPUT SIDE SIMULATION:

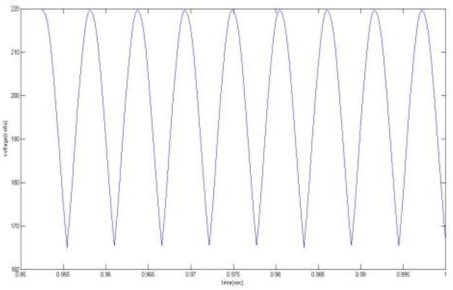

Figure 3. Input Side Wave Form

In above figure x- axis represents time (sec) and y-axis represents voltage (volts). At input side the value of voltage varies abnormally with the change of time. By using the active filters we can get the alternative wave forms with change of input signals.

VIII.C MACHINE SIDE SIMULATION:

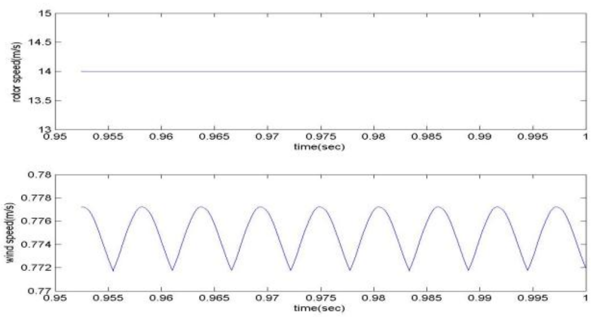

Figure 4. Machine Side Simulation

In above fig x-axis represents time and y-axis represents wind speed and rotor speed. In the first fig. Rotor speed is maintaining at constant level due to use of drive chain. Wind speed is varies from 0.778 to 0.772 m/s. when using the drive chain wind speed as well rotor speed alternatively change.

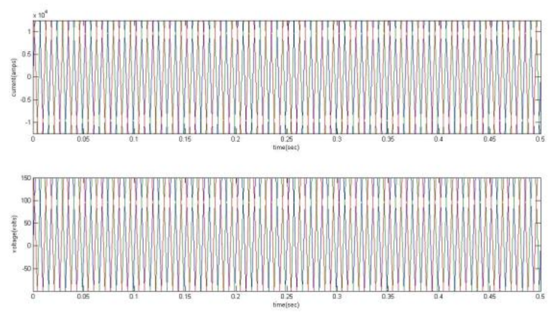

Figure 5. Source Side Current Simulation

At source side simulation the values of current and voltage get varied when grid side control is implemented. Voltage during the operation will vary enormously with time. . By making decisive switching actions in the early morning before the demand increments, the system gain can be maximized early on, helping to settle the system for the whole day. To balance the equation, some pre-fault reactive generator use will be required.

VIII.D REACTIVE POWER CONTROL:

Transmission connected generators are generally required to support reactive power flow. For example, on the United Kingdom transmission system generators are needed by the Grid Code Requirements to supply their rated power between the limits of 0.85 power factor lagging and 0.90 power factors leading to the assigned terminals. The system operator will perform switching actions to maintain a secure and economical voltage profile while controlling a reactive power balance equation:

Generator MVARs + System gain + Shunt capacitors = MVAR_Demand + Reactive_losses + Shunt_reactors.

IX. CONCLUSION

This paper proposes a simplified model and respective control strategy for DFIG based wind turbine. In the simplified model flux and current control dynamics are neglected. This helps in obtaining a simple and stable representation of the system hence a stable control is implemented based on this model. The proposed model and control is realized in the MATLAB/SIMULINK environment and simulated. The dynamics of the system has been well defined and control of DFIG has been exceptionally well with the proposed idea.

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