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LOW VOLTAGE RIDE THROUGH OF A GRID CONNECTED DOUBLY FED INDUCTION GENERATOR WITH FIELD ORIENTED CONTROL

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ABSTRACT

This paper deals with a new solution for Low voltage ride through of a grid connected DFIG with field-oriented control (vector control). Control itself acting a very vitalpart in drives and wind turbine technology. Control of the DFIG when generating energy in a wind turbine is essential and obvious. The control techniques used for DFIG are vector control (field-oriented control) and direct control technique.In vector control of a DFIG, the components of the d and the q axis components of the rotor currents and voltages are measured with PI controllers. If a reference frame oriented with the stator flux is used, the active and reactive power flows of the stator can be measured by independently by resources of quadrature and the direct current, respectively. By means of the direct current, we can control the active power whereas the reactive power can be measured via the quadrature current.A Dynamic modelling of DFIG is presented. In our power system, in way to keep constant power, voltage and frequency we use DFIG. In this a complete study is done to study the field-oriented control characteristics of DFIG by using rotor current control loops and grid voltage-oriented vector control. This system modelled in MATLAB/Simulink environment.

KEYWORDS: *Low voltage ride through, Doubly-fed induction generator (DFIG), Field oriented control, Wind turbine power system.*

Article History

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INTRODUCTION FOR DFIGWIND TURBINE

The DFIG is a variable speed wind turbine together with induction machine where also rotor is linked to grid. Power is also provided from grid (or) distributed to grid through rotor. This power is called slip power. Frequency of slip power is varied in such a way that the rotor field frequency is kept constant. This difference of frequency of slip power is recognized by two power electronics back-back converters. Bidirectional flow of power in back-back converters gives work in sub synchronous mode as well as over synchronous mode. In DFIG the back-back converter is containing of one machine-side converter, a DC link capacitor and grid side converter. The part of machine-side converter is to switch speed (or) torque of DFIGand machine power factor. The role of grid side converter is to minimise DC link capacitor voltage ripple and also injects reactive power to the line. Operating speed range doesn't exceed 40% of synchronous speed. The cost and losses of converters in DFIM are lower in comparison to full power converters. DFIG can activate close to unity power factor. The below figure shows the block diagram of a Variable speed wind turbine system with DFIG.

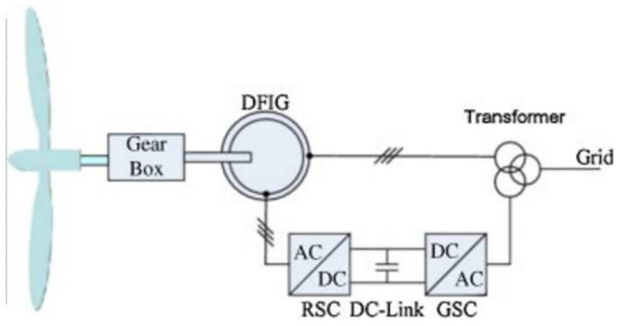


Figure 1: Variable Speed Wind Turbine with DFIM.

DYNAMIC MODELLING OF DFIG

This system consists of a wind turbine with DFIG. The principle of DFIG is that rotor windings are linked to the grid via slip rings and back-back voltage source converters that controls both rotor and grid currents. Thus, rotor frequency can freely differ from the grid frequency. By using converter to control rotor currents, it is possible to adjust active and reactive power fed to grid from stator independently if generator turning speed.

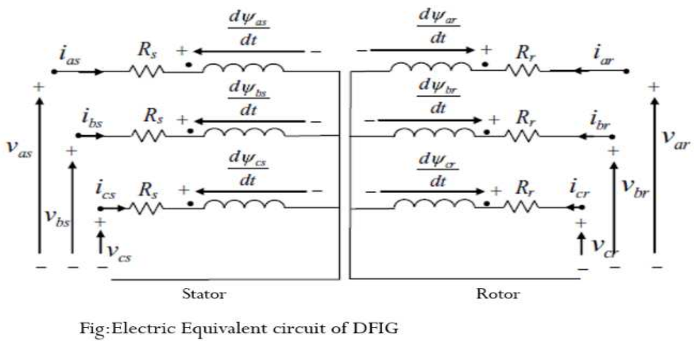


Figure 2

Applying KVL to Stator side

$$v_{as}(t) = R_s i_{as}(t) + \frac{d\psi_{as}(t)}{dt}$$

$$v_{bs}(t) = R_s i_{bs}(t) + \frac{d\psi_{bs}(t)}{dt}$$

$$v_{cs}(t) = R_s i_{cs}(t) + \frac{d\psi_{cs}(t)}{dt}$$

Similarly, to Rotor side

$$v_{ar}(t) = R_r i_{ar}(t) + \frac{d\psi_{ar}(t)}{dt}$$

$$v_{br}(t) = R_r i_{br}(t) + \frac{d\psi_{br}(t)}{dt}$$

$$v_{cr}(t) = R_r i_{cr}(t) + \frac{d\psi_{cr}(t)}{dt}$$

αβ Model

In developing the dynamic αβ model of the DFIG, space vector theory is useful to the basic electric equations of machine. The stator reference frame (α-β) is a stationary reference frame, the rotor reference frame (DQ) rotatesat ωm and the synchronous reference frame (dq) rotates at ωs. Subscripts "s", "r", "a" are used to denote that one space vector is reference to stator, rotor and synchronous refence frame respectively. By using direct and inverse rotational transformation, a space vector can be represented in any of these frames.

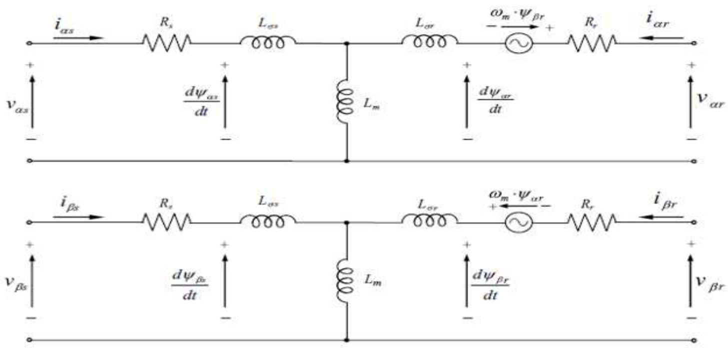


Figure 3

Applying KVL to Stator side and Rotor side using space vector notation

$$\vec{v}_s^s = R_s \vec{i}_s^s + \frac{d\vec{\psi}_s^s}{dt}$$

$$\vec{v}_r^r = R_r \vec{i}_r^r + \frac{d\vec{\psi}_r^r}{dt}$$

The flux is given by

$\Psi = L * i$

In space vector notation is given by

$$\vec{\psi}_s^s = L_s \vec{i}_s^s + L_m \vec{i}_r^s \quad \text{Stator reference frame}$$

$$\vec{\psi}_r^r = L_m \vec{i}_s^r + L_r \vec{i}_r^r \quad \text{Rotor reference frame}$$

Power expressions

S = P + JQ

By using space vector notation, the apparent power is given by

S = 3/2 (V * i)

S = 3/2[(V α*iα+ i β*V β) +J (V β*i α - V α *i β)]

Active power is

$P = 3/2(V\ \alpha * i\ \alpha + i\ \beta * V\ \beta)$

Reactive power is

$Q = 3/2(V\ \beta * i\ \alpha - V\ \alpha * i\ \beta)$

The electric powers on stator and rotor side are calculated as follows

$Ps = 3/2(V\ \alpha s * i\ \alpha s + V\ \beta s * i\ \beta s)$

$Pr = 3/2(V\ \alpha r * i\ \alpha r + V\ \beta r * i\ \beta r)$

$Qs = 3/2(V\ \beta s * i\ \alpha s - V\alpha\ s * i\ \beta s)$

$Qr = 3/2(V\ \beta r * i\ \alpha r - V\alpha\ r * i\ \beta r)$

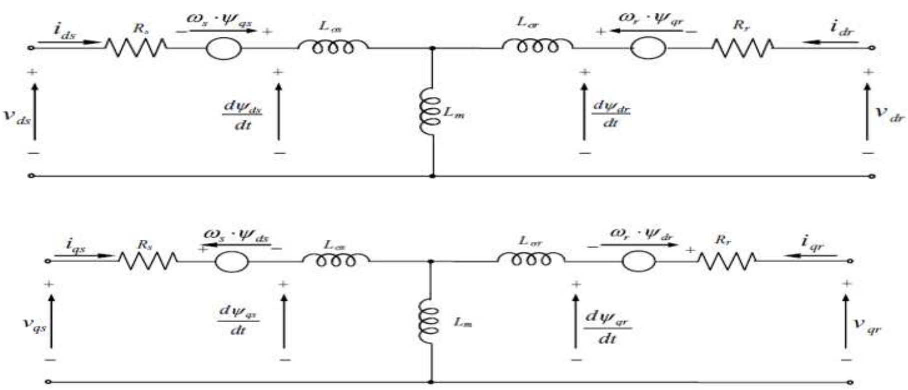
Electromagnetic torque can be found

$Tem = 3/2 * P * (im) * [\ (\Psi r.ir^*)]$

$Tem = 3/2 * P * (\Psi\ \beta r * i\ \alpha r - \Psi\alpha\ r * i\ \beta r)$

DQ Model

The space vector model of the DFIG can also be represented in a synchronously rotating frame.



This model of DFIG is derived using space vector notation in synchronous reference frame

Figure 4

The stator and rotor voltages is given by

$$\vec{v}_s^{\,a} = R_s \vec{i}_s^{\,a} + \frac{d\vec{\psi}_s^{\,a}}{dt} + j\omega_s \vec{\psi}_s^{\,a}$$

$$\vec{v}_r^{\,a} = R_r \vec{i}_r^{\,a} + \frac{d\vec{\psi}_r^{\,a}}{dt} + j\overbrace{(\omega_s - \omega_m)}^{\omega_r}\vec{\psi}_r^{\,a}$$

Flux expression is given by

$$\vec{\psi}_s^a = L_s \vec{i}_s^a + L_m \vec{i}_r^a$$

$$\vec{\psi}_r^a = L_m \vec{i}_s^a + L_r \vec{i}_r^a$$

The power expression in DQ model is given by

Ps = 3/2(Vds*ids + Vqs*iqs)

Pr = 3/2(Vdr*idr + Vqr*iqr)

Qs = 3/2(Vqs*ids - Vds*iqs)

Qr = 3/2(Vqr*idr - Vdr*iqr)

Torque expression is given by

Tem = 3/2*P(Lm/Ls) *[(Ψqs*idr – Ψds*iqr)]

FIELD-ORIENTED CONTROLLING OF DFIG

Rotor Current Control Loops

Among the different control methods that have been developed for the DFIG, only the field-oriented control method is studied in this section. TheFOC of the DFIG is performed in a synchronously rotating dq frame, in which the d-axis is aligned, in this case, with the stator flux space vector. It will be shown later that the direct rotor current is proportional to the stator reactive power and that the quadrature rotor current is proportional to the torque or active stator power.

Vdr =Rr*idr + σLr d/dt*idr −ωrσLr*iqr+ Lm/Ls d/dt|$\vec{\psi}_s$ |

Vqr =Rr*iqr + σLr d/dt*iqr +ωrσLr*idr+ω Lm/ Ls |$\vec{\psi}_s$ |

Assuming that the voltage drop in the stator resistance is small, the stator flux is constant because the stator is connected directly to the grid at constant AC voltage.It is possible to perform dq rotor currents control, simply by using a regulator foreach current component. For the reference frame transformation, the angle θr must be estimated. The control must be performed in dq coordinates, but then the rotor voltage and currents must be transformed into DQ coordinates. A simple phase-locked loop (PLL) can be used to perform the stator voltage grid synchronization, providing robustness to the estimation and a rejection of small disturbances or harmonics. The current loops work with the rotor currents referred to the stator side, while the conversion to rotor-referred quantities is performed at the measurement stage for the currents and before the creation of the pulses for the converter for the voltages.

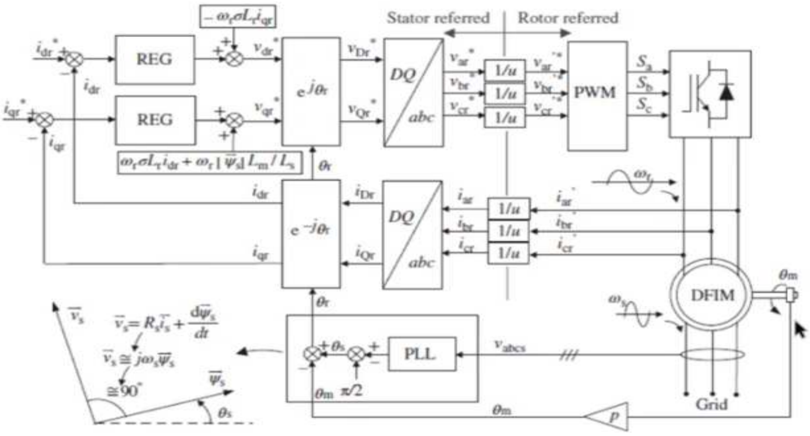


Figure 5: Current Control Loops of DFIG.

Power and Speed Control Loops

Once the current control loops and the flux angle calculation have been studied, the complete control system can be introduced. As the d-axis of the reference frame is aligned with the stator flux space vector, the torque expression in the dq frame can be simplified as follows:

$Tem = 3/2\ p\ Lm\ Ls\ (\psi qs*idr - \psi ds*iqr)$.

$Tem = 3/2\ p\ Lm\ Ls\ |\vec{\psi}s|\ iqr$. $\Rightarrow Tem = Kt*iqr$

This means that the q rotor current component is proportional to the torque, that is, with iqr it is possible to control the torque and, consequently, the speed of the machine if the application requires it. In a similar way, by developing the stator reactive power expression in the dq frame, we obtain a compact expression, which reveals that idris responsible of Qs.

$Qs = 3/2\ (vqs*ids - vds*iqs)$.

$Qs = -\ 3/2\ Lm\ Ls\ |\vec{\psi}s|$ □idr- $|\psi s|$ Lm □. $\Rightarrow Qs = KQ$□*idr- $|\psi s|$ Lm □

Therefore, it can be seen that both rotor current components independently allow us to control the torque and reactive stator power. However, with the Qs loop, it is possible to control the magnetizing of the machine. As discussed before, because the stator of the machine is connected directly to the grid, the stator flux amplitude is constant and provided by the grid voltage:$|\vec{\psi}s| = \psi ds = Ls*iqs + Lm*idr*\psi ds = 0 = Ls*iqs + Lm*iqr$ The stator flux level $|-\rightarrow \psi s|$ must be created by choosing ids and idr, distributing thus the required amount of current between the rotor and the stator. The equivalent closed-loop systems of the Qs and ωm loops, assuming that the current loops have been tuned much faster than the external loops and neglecting converter dynamics or measurement and computing delays. It can be seen that the simplified closed-loop systems yield into a first- and second order system that can be tuned by choosing the appropriate gains of the PI regulators.Finally, the most representative magnitudes of a vector controlled DFIG, operating at constant torque in motor mode at variable speed. The stator voltage is kept constant owing to the direct grid connection, while the stator currents are also constant because Tem and Qs are maintained constant. The speed ramp performed at the middle of the experiment provokes the variation of the rotor voltage and currents, which yields a variation of the rotor active and reactive powers.

FOC OF THE GRID SIDE SYSTEM

Control is a necessary part of the grid side system. In this section, a FOC based schema is studied. This control method is widely extended among the control strategies for grid connected converters. It provides good performance characteristics with reasonably simple implementation requirements. The field-oriented control method follows the philosophy of representing the system that is going to be controlled in our case the grid side system in a space vector form.

Grid Voltage Oriented Vector Control:

The grid side converter is in charge of controlling part of the power flow of the DFIG. The power generated by the wind turbine is partially delivered though the rotor of the DFIG. This power flow that goes link and finally is transmitted by the grid side converter to the grid. The simplified block diagram of the grid side system, together with a schematic of its control block diagram, is given in below.

The pulses for the controlled switches (Sa_g, Sb_g, Sc_g) of the 2L-VSC, that is, the output voltage of the converter, are generated in order to control the DC bus voltage (Vbus) of the DC link and the reactive power exchanged with the grid (Qg). This is done, in general, according to a closed loop control law. Some typical controls are vector control or direct power control. However, this section only studies the grid voltage-oriented vector control (GVOVC). Control of Vbus is necessary since, the DC link is mainly formed by a capacitor. Thus, the active power flow through the rotor must cross the DC link and then it must be transmitted to the grid. Therefore, by only controlling the Vbus variable to a constant value, this active power flow through the converters is ensured, together with a guarantee that both grid and rotor side converters have available the required DC voltage to work properly. Therefore, the grid voltage-oriented vector control (GVOVC) block diagram is shown in below.

Figure 7 shows the Vbus and Qg references, it creates pulses for the controlled switches Sa_g, Sb_g, and Sc_g. Thus, the modulator creates the pulses Sa_g, Sb_g, Sc_g from the abc voltage references for the grid side converter: V*af, V*bf, and V*cf. In this way, these abc voltage references are first created in dq coordinates (v*df, v*af), then transformed to ab coordinates (v*af, v*bf), and finally generate the abc voltage references. Then, the dq voltage references (v*df, v*af) are independently created by the dq current (i*dg, i*qg.) controllers.

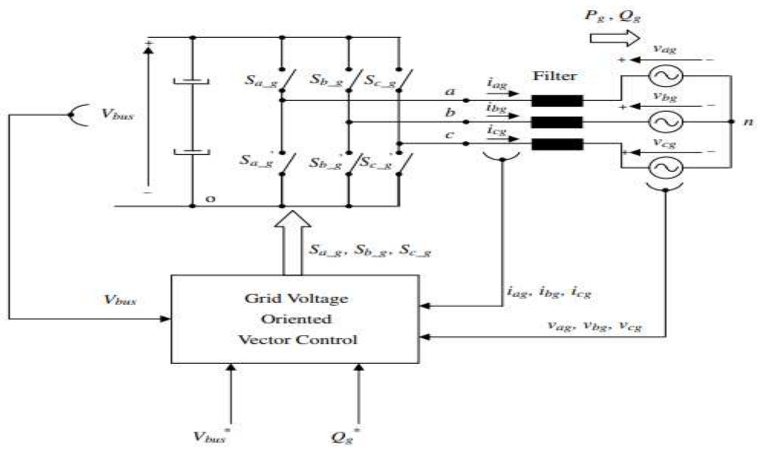


Figure 6: Grid Side System Control.

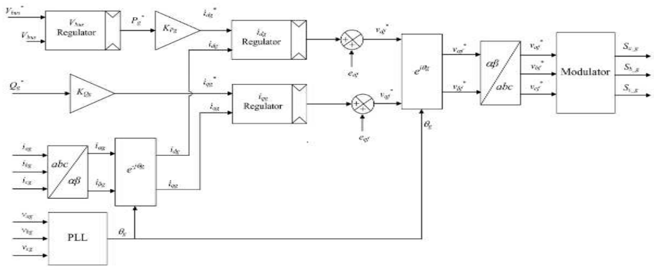


Figure 7: Block Diagram of GVOVC.

ANALYSIS OF VOLTAGE DIPS IN DFIG

Voltage dips are the most common power disturbance. A Voltage dip is a short temporary drop in the voltage magnitude in the distribution or consumer's electrical system. It may be caused by various faults in the transmission and distribution networks, huge current drawn in another part of the system due to an overloaded, a short circuit, energizing of a transformer, starting machine or any other temporary high current intake systems. Due to voltage sag occurs in the DFIG based in wind turbine, two major issues are generated in the DFIG based wind turbine. The first one is stator and rotor over current, and the second one is over voltage occurred in the DC link. The nature of voltage dips can be influenced by the symmetry of a network fault. Two types of voltage dips are depicted: Symmetrical voltage dips and asymmetrical voltage dips.

Symmetrical Voltage Dips

A voltage dip is a sudden drop of one or more voltage phases such a dip is said to be a three-phase symmetrical or balanced dip. If the drop is same in three phases. At the time of starting high current or high inrush currents should be taken by the equipment such as transformer, welding machines, arc furnaces, heavy loads.

Symmetrical Voltage Dips Analysis in a Wind Turbine Based on DFIG

Generally, voltage dips are performed at source side. In normal operation the stator voltage is reduced suddenly to smaller value. In order to keep this voltage, the stator flux can develop rapidly a smaller value. To avoid this problem there is a solution to protection i.e. crowbar protection. In this case we have chosen one diode bridge, one switch and one resistor.

In the Simulink first we have to create the voltage dip for resistance by including harmonic which is the fundamental. For positive sequence we have to apply ten times more than phase shift, voltage protection is 0 to 3 and after time 3sec this can appear. The remaining voltage of grid is 0.1 and create ramp 15pu/sec and variation time is 3.5 till 4.17. Now include a crowbar protection and connecting it to control this element we use step signal. We need to implement the control of RSC. Once voltage protection is detected then crowbar protection is activated by means of resistance. The stator flux is damp quickly. The RSC but in general the grid codes tell us that need to provide all the currents we can create reactive current id reference.

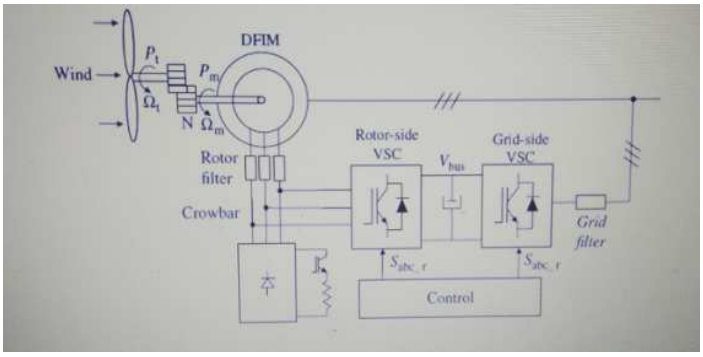


Figure 8

Asymmetrical Voltage Dips

A voltage dip is not same in all the three phases such a dip is said to be unbalanced or asymmetrical dip. The most common faults for electrical networks are single line to ground short circuit, short circuit between two lines.

Asymmetrical Voltage Dips in Wind Turbine Based DFIG

In this the control strategy used is dual vector control. We need positive and negative sequence of voltage and currents to the DFIG we should include negative sequence current loops in order to proper control of the generator. The below figure shows the dual vector control block diagram of DFIG.

An unbalanced voltage implies the presence of a negative sequence that causes oscillations in the torque, over currents in the stator and over voltages in the rotor. The most of these problems can be overcome by negative sequence in the current references. The current references are the addition of two sequences- one synchronized with the positive sequence of the grid voltage, and the other synchronized with the negative one. The original control loop is then substituted by two control loops, one working in a positive rotating reference frame and the other working in an inversely rotating frame. This method is called dual control method. The below figure shows a typical schema of a dual control. The boxes in light gray are the two current controls: the top one regulates the positive sequence, while the bottom one regulates the negative sequence. The measured current must be split into its two sequences before introducing it to the current regulators. Represent the voltage dip a symmetrical voltage dip that one to be emulate in our system. We left positive sequence we use fundamental and harmonic generation. In order to create a symmetry, we are going to use first order with an amplitude of 0.2 for resistance and phase shift 0for negative sequence voltage. For negative sequence we represent the control loops at grid voltage.

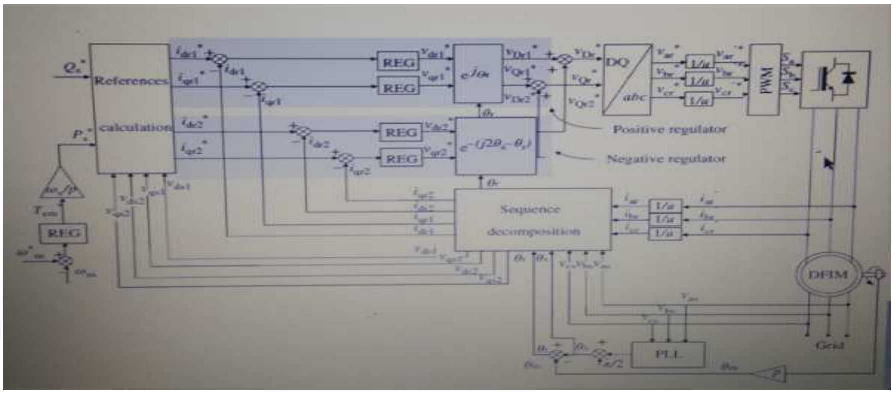


Figure 9: Dual Vector Control Block Diagram of DFIG.

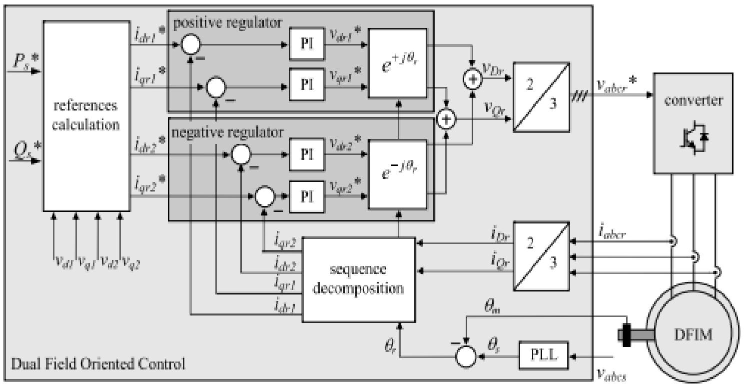


Figure 10: Schematic Diagram of Dual Control.

SIMULINK DIAGRAM

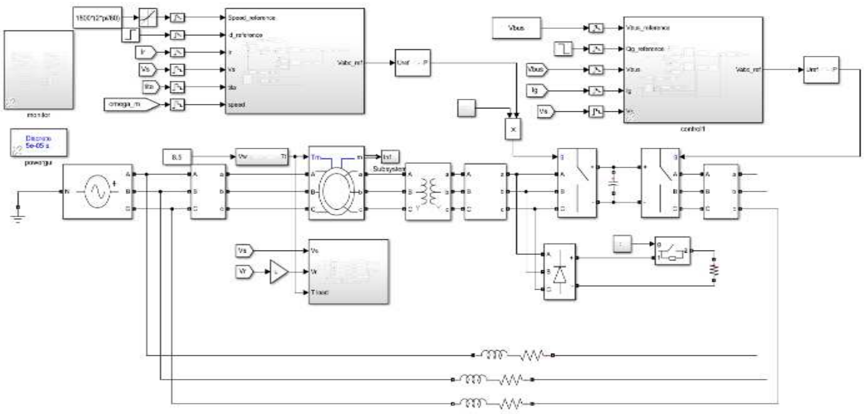


Figure 11

SIMULATION RESULTS

Consider a DFIG based wind turbine system having Normal power of 2MW, Terminal voltage of 690V is connected to 120Kv,50Hz Grid via Two step up Transformer of rating 690V/25Kv and 25Kv/120Kv. The normal wind speed is 10m/sec. No of poles pairs is 2. Nominal DC link voltage is 1.2Kv. DC link capacitance is 10mF. Stator resistance is 0.0048 p.u and Rotor resistance is 0.0044 p.u. Mutual inductance is 6.77 p.u inertia coefficient is H=5sec.

OUTPUT WAVEFORMS

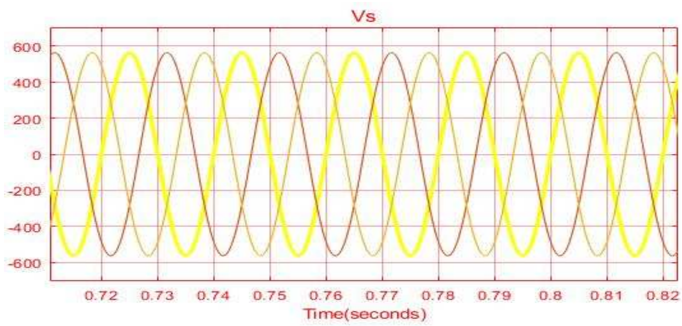
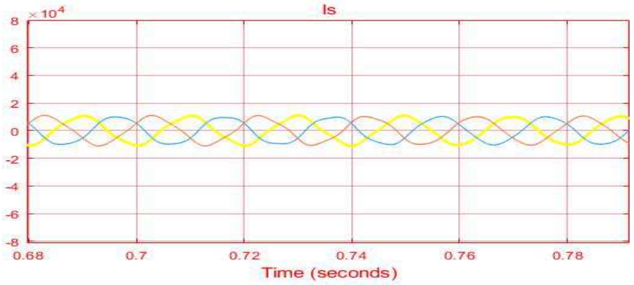


Figure 12



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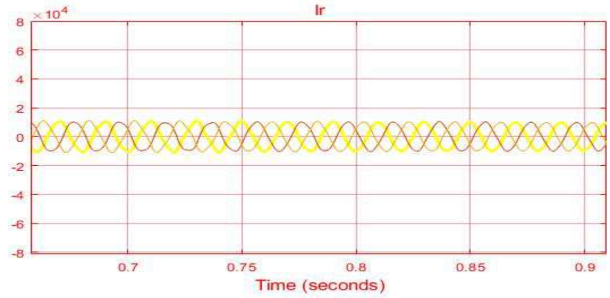

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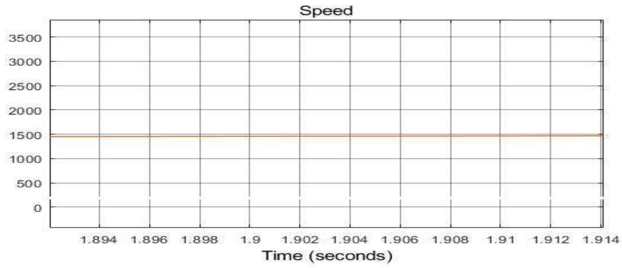

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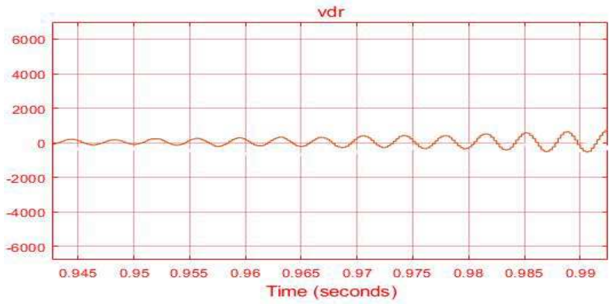

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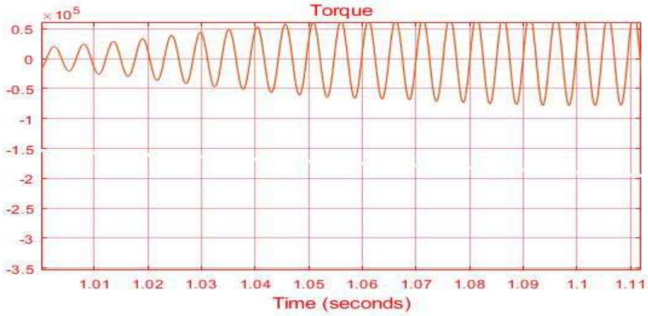
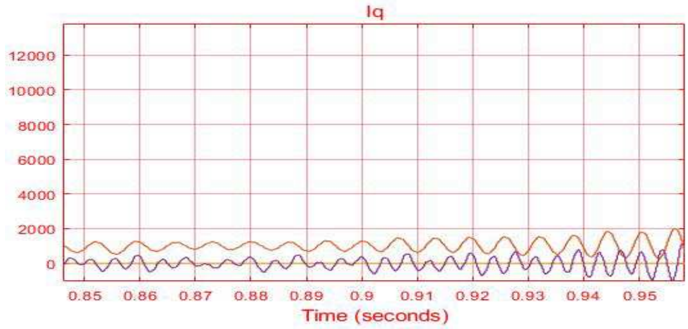


Figure 17



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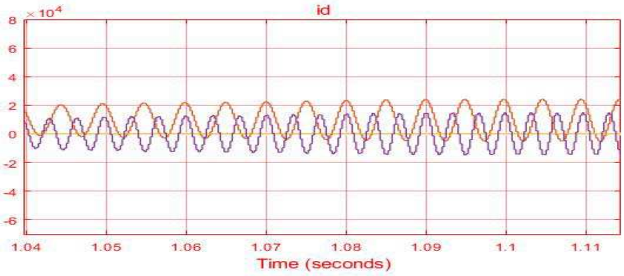

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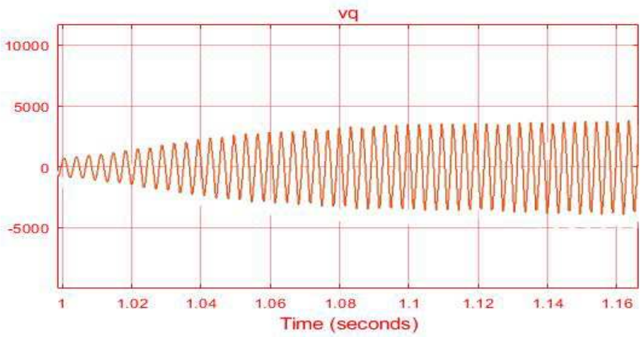

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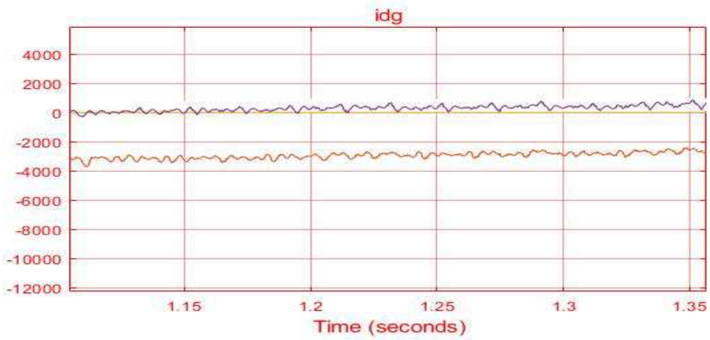

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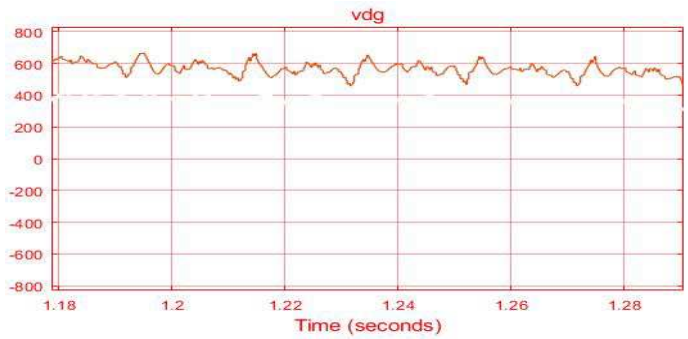
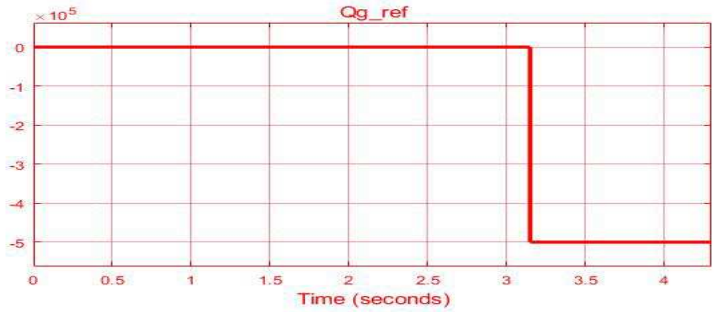


Figure 22



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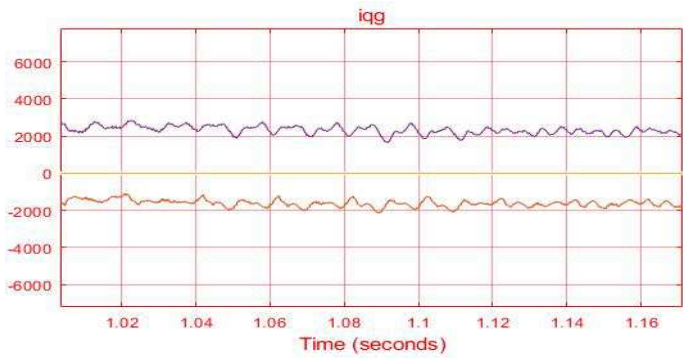

Figure 24

Figure 25

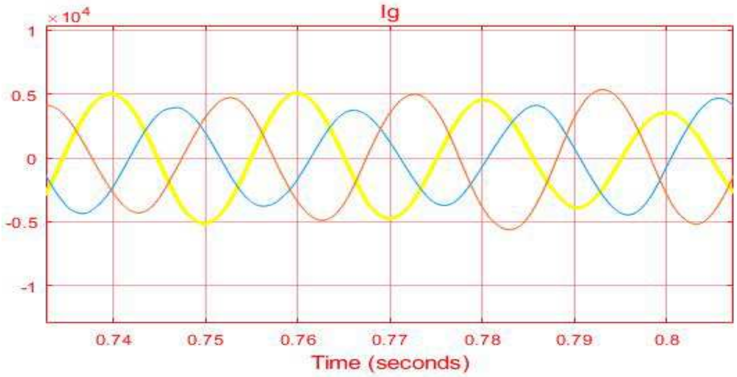

Figure 26

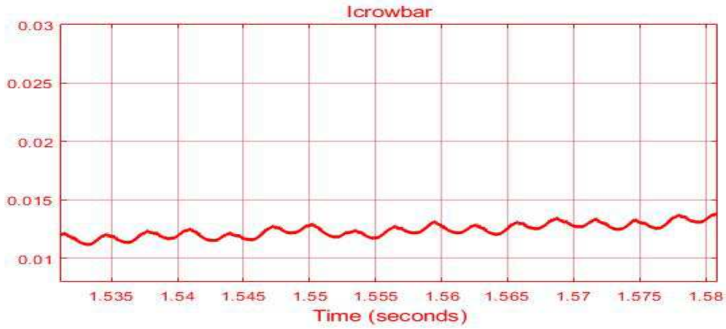

Figure 27

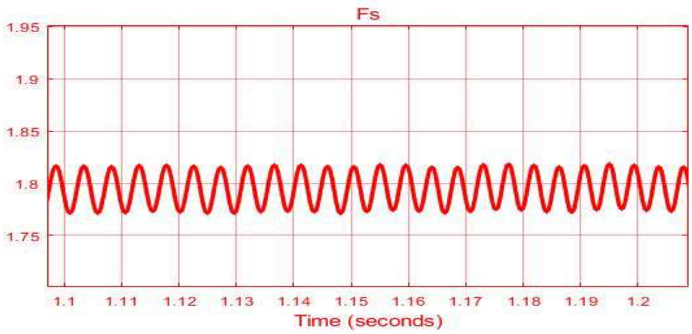

Figure 28

CONCLUSIONS

The DFIG with variable speed ability has higher energy capture efficiency and improved power quality and voltage. The DFIG are more advantages in wind power systems. DFIG wind turbine equipped with Field-oriented control described in this paper is able to provide LVRT and wind turbine stay connected to the grid and limits the rotor currents in an acceptable range. The FOC regulates the active and reactive power by setting reference rotor dq current components in synchronous reference frame. The reference frame can be oriented with stator flux or with grid voltage. Generally, voltage dips are performed at source side. In normal operation stator voltage is reduced to small value, in order to keep this voltage a stator flux can develop a small value. To avoid this problem a crowbar protection is used. In this paper a FOC method topology is explored. The dynamic performance with proposed controller is investigated using voltage sag and step response to reactive power injection. Simulation and experimental results verify the effectiveness and viability of the proposed method.

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