International Journal of Electrical Engineering.
ISSN 0974-2158 Volume 8, Number 4 (2015), pp. 315-328

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A Study On Performance Of Induction Generators In Wind Power Systems And System Harmonic Reduction By Using Shunt Active Filter

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ABSTRACT:

The main reason behind using the induction generators integrated with the wind turbine is to extract maximum power. In order to achieve the maximum power we must select the best induction generator available with us. So that we go for comparing the performance of two induction generators i. e. squirrel-cage induction generator (SCIG) and doubly fed induction generator (DFIG). Through this we can connect the IG directly to the grid and have a proper control over the active and reactive power. These two systems are modeled by using the mat lab and then it is tested with the maximum power extraction algorithm. In order to get proper control over the voltage and power at the generator terminals we propose field oriented control. Here we employ IGBT instead of ac/dc/ac converter which uses pulse width modulation (PWM) for better interfacing between the IG and the grid. But practically loads are not always linear and they sometime changes to non-linear conditions so we must compensate the non-linearity characteristics such as the harmonic content and also the improvement in the power factor by connecting shunt active filters across the non-linear loads.

Keywords: Squirrel cage induction generator (SCIG), Double fed induction generator DFIG), Active filters, Field oriented control (FOC), Pulse width modulation (PWM).

1. INTRODUCTION

Due to increasing demand of power day to day, we need to generate adequate amount of power suitable for meeting the demand without sacrificing the consumer needs. But at the same time we need to concentrate on the energy resources available around us.

In the previous decades we used to generate huge amount of power from conventional energy sources, but due to extinction of these resources we need to move over other forms like wind energy, solar energy and many other renewable energy resources.
With huge increasing interest towards the wind energy systems we should design it in such a way that it can extract maximum power from available energy. In order to generate the power we use induction generators instead of synchronous generators because they require less maintenance, low cost, small in size[1], [2]. Usually SCIG are used for fixed speed wind turbine application but due to variation of wind speed and also requirement of reactive power support for the grid we may not be able to use this SCIG much on this[3], [4], [5].
The DFIG which is having capability to operate at different wind speed and ability to produce more output with available energy so that's why it is being preferred well than SCIG. In order to connect this variable power to the grid we are going to use a converter which uses IGBTs and for this pulses are generated through PWM. This also uses FOC control for connecting the stator side voltage [6], [7] to the grid through a choke coil.
We know that the performance of SCIG and DFIG can be easily understood by comparing the SCIG with and without STACOM and in the similar manner DFIG with and without STATCOM. By this the line voltage profile can be clearly understood and also manipulated.

2. TURBINE MODELING

The amount of power generated mainly depends on the wind speed. Whenever the wind hits the turbine blades the blade rotates overcoming the inertia of moving parts. Due to this rotation the shaft which connects the turbine blades to the gear box will increase the number of rotations made by the turbine and will give the mechanical output to the induction generator proportional to the amount of input energy.
This generator will convert mechanical energy into electrical energy which is being connected to the grid. The available wind power[3], [8] is given by the relation

$$P_w = \frac{1}{2}\rho A V_w^{\,3} \qquad (1)$$

Where V_w is the available wind power is the air density is the wind velocity.
And turbine power, wind power are related as

$$P_t = C_p(\lambda, \beta)\, P_w \qquad (2)$$

Here C_p is defined as the power coefficient[8] which determines the amount of wind power being utilized, this can also be stated as the efficiency of wind turbine. The speed ration is given by

$$\lambda = \frac{R_{blade}\omega_r}{V_\omega} \qquad (3)$$

The value of λ depends on blade length and velocity of wind.
We know that Pt=TtWt and from this $Tt = \frac{P_t}{\omega_t}$

$$T_r = \frac{P_r}{\omega_r} = \frac{1}{2}\rho\pi R_{blade}^3 \frac{C_p}{\lambda} v_\omega^2 = \frac{1}{2}\rho\pi R_{blade}^3 v_\omega^2 C_m \qquad (4)$$

The value of power coefficient is about 0. 59 according to betz law and in practical cases its value ranges from 0. 2 to 0. 4.

3. WECS USING SCIG

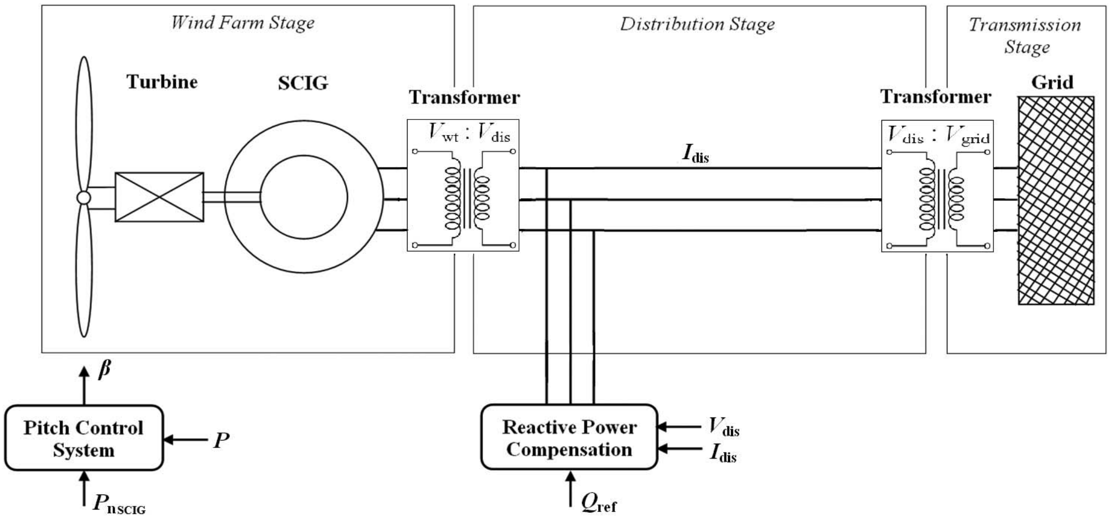

Fig. 1. SCIG wind power system model

In the above Fig. 1 the SCIG is connected to turbine. Here we are providing reactive power compensation because most of the loads are inductive in nature and therefore there is necessity to provide reactive support for preventing the system from instability.

In the first stage the turbine shaft is connected to the SCIG and it produces the power proportional to wind velocity. As this voltage is of less magnitude we need to increase the voltage magnitude by implanting a transformer. In the second stage which is of medium voltage in between the grid and the transformer we provide reactive power compensation, it is also known as distribution stage. At last the third stage consisting of grid, where the voltage is sufficiently high for maintaining proper voltage levels. This is the case when the wind velocity is almost constant and the SCIG are favorable for constant speed application only, but this is not the case when the wind velocity is varying with respect to time.

4. DOUBLE FED INDUCTION GENERATOR

DFIG can be operated at variable wind speed without any stability[1], [3], [7] problems.

The requirement of reactive power compensation is avoided by using the DFIG, here both the active and reactive power are controlled independently. On the stator side we connect RL circuit with the choke for controlling voltage and reactive power. When we are controlling the voltage on the stator side and rotor side of the DFIG the current is regulated in a better manner. In this model the wind turbine connects the wound rotor induction generator and this induction generator is connected to ac/dc/ac converter consisting of IGBT based on pulse width modulation converter on both sides of the stator and rotor of the IG.

We connect a dc link capacitor between the stator and rotor converters. Now after converting variable voltage and frequency into constant voltage, frequency which is suitable for the grid standards, this is being connected to the stator side converter of the distribution transformer. This configuration is as shown in Fig. 2.

The stator side and rotor side control system are very important for converting variable quantity into standard values. The equivalent circuit for the DFIG is shown in Fig. 3. And the expressions for voltage, current and flux [4] are given below

$V_{ds}=R_sI_{ds} - \omega_s\Psi_{qs} + d\Psi_{ds}/dt$

$V_{qs}=R_sI_{qs} + \omega_s\Psi_{ds} + d\Psi_{qs}/dt$ (5)

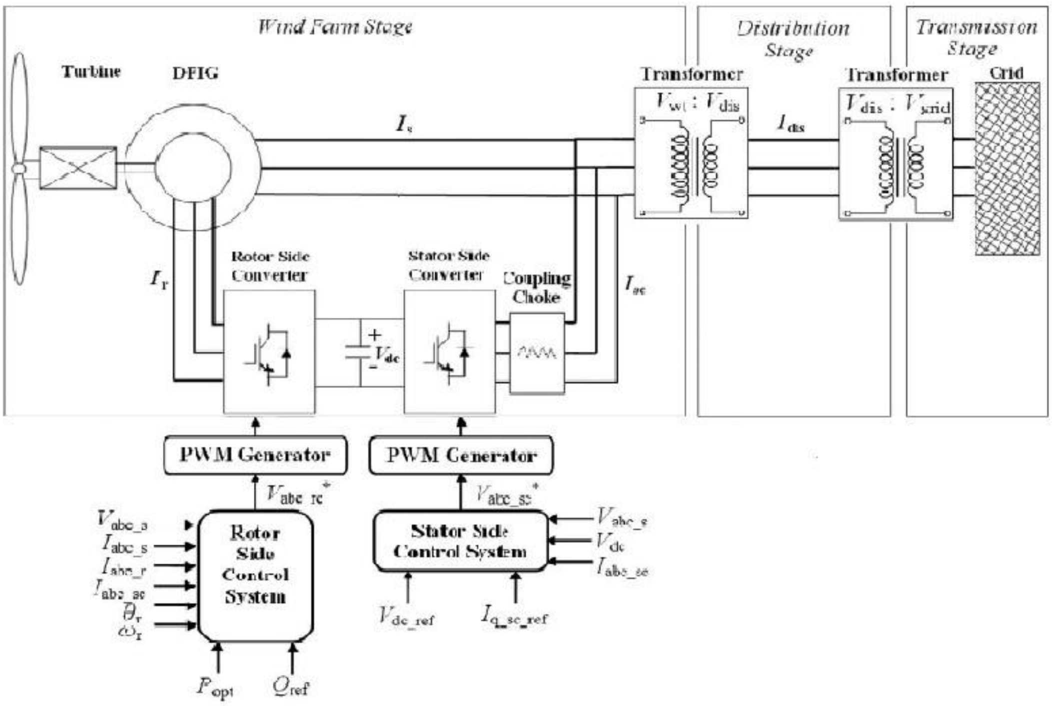

Fig. 2. Wind Turbine Doubly Fed Induction Generator System Configuration

$V_{dr} = R_rI_{dr} - s\omega_s\Psi_{qr} + d\Psi_{dr}/dt$

$V_{qr} = R_rI_{qr} + s\omega_s\Psi_{dr} + d\Psi_{qr}/dt$ (6)

$\Psi_{ds} = L_sI_{ds} + L_mI_{dr}$

$\Psi_{qs} = L_sI_{qs} + L_mI_{qr}$ (7)

$\Psi_{dr} = L_rI_{dr} + L_mI_{ds}$

$\Psi_{qr} = L_rI_{qr} + L_mI_{qs}$ (8)

$T_e = 1.5\,(n_p\,(\Psi_{ds}I_{qs} - \Psi_{qs}I_{ds}))$ (9)

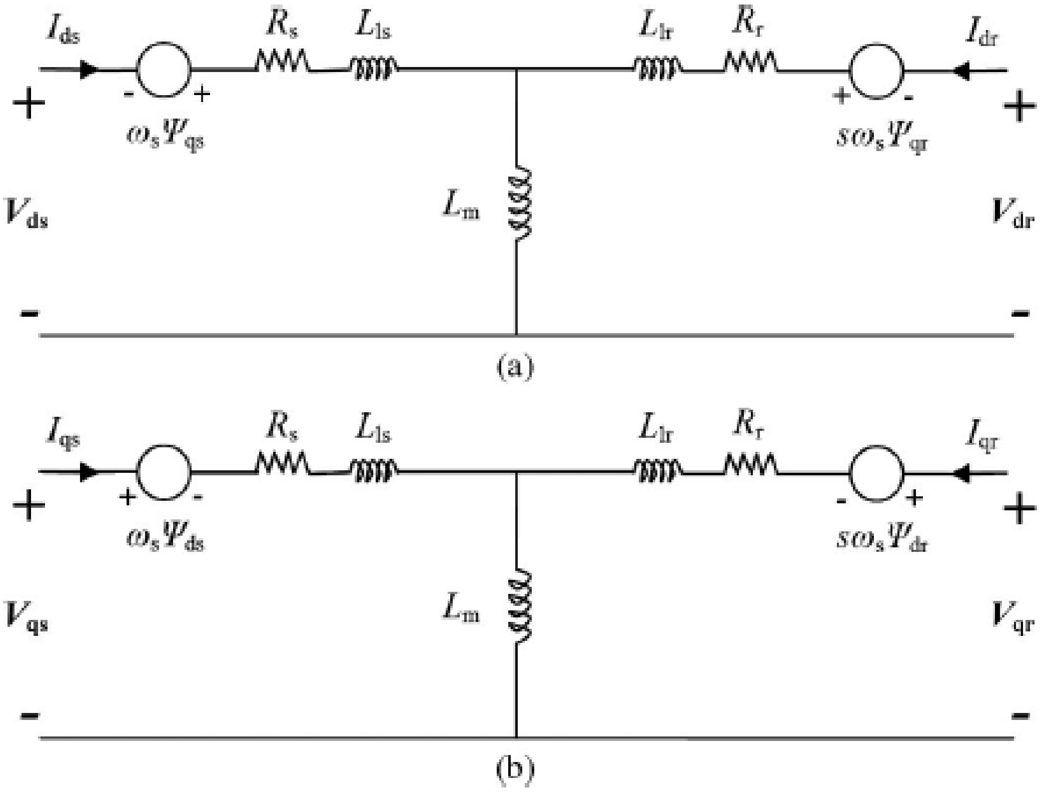

Fig. 3. Equivalent circuit of DFIG a. d-axis and b. q-axis models

From the above equation Lr, Ls are rotor and stator inductances, and the expression for slip of IG is given by, $S\omega_s = \omega_s - \omega_r$, Where Wr, Ws represents the rotor and stator speeds.

5. ROTOR SIDE CONVERTER CONTROL SCHEME

If we neglect the derivative part of eq (5) then the modified equation can be written as shown below

$\Psi_{ds} = (V_{qs} - RsI_{qs})/\omega_s$

$\Psi_{qs} = (V_{ds} - R_sI_{ds})/ (-\omega_s)$ (10)

The DFIG is used mainly to regulate the voltage and frequency of the grid side under variable wind speed and also maintaining the active and reactive power required for the load side. It has been stated that Vs=Vds and Vqs=0 so $\psi_s = \psi_{qs}$ and $\psi_{ds} = 0$ and we introduce stator voltage oriented vector control to this. From the equation (9)-(13) the reference current at the rotor side converter is given by

$$I_{dr\_ref} = -\frac{2L_sT_e}{3n_pL_m\psi_s} \quad (11)$$

Where

$P_{e\_ref} = P_{opt} - P_{loss} = T_e\omega$

$P_{loss} = R_s I_s^2 + R_r I_r^2 + R_c I_{sc}^2 + F\omega_r^2$ (12)

Here I_{sc}, R_c and F represents the stator current, choke resistance and the friction factor, and P_{opt}, $P_{e\text{-}ref}$ and P_{losss} are the optimal output active power, reference active power and power loss.

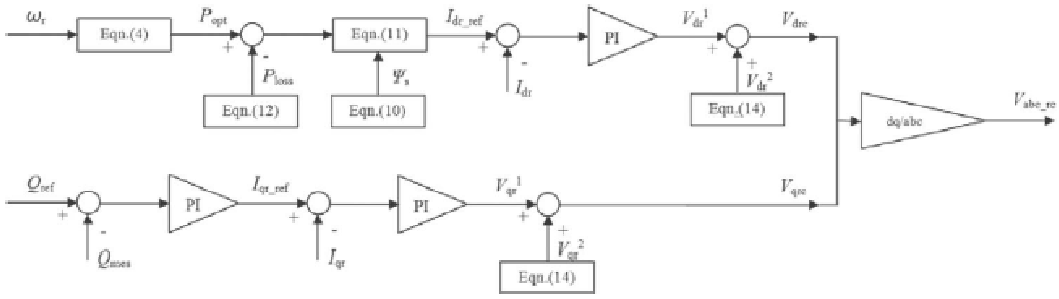

Fig. 4. Rotor side converter control scheme

The active power is used as command in order to determine current reference Idr-ref. as we made the stator side reactive power to zero the output reactive power is the stator reactive power itself. The modified expressions are given by

$$Q_o = Q_s + Q_{sc} = Q_s = I_m[(V_{ds} + jV_{qs})(I_{ds} + jI_{qs})^*]$$
$$= -V_{ds}I_{qs} = -V_{ds}\frac{1}{L_s}(\psi_s - L_m I_{qr}) \quad (13)$$

So by this we can get the Iqr-ref and later rotor side converter voltage signal Vdr1 and Vqr1 are obtained by regulating the currents.

From (6) and (8) the coupling voltages are given by

$$V^2_{dr} = R_r I_{dr} - s\omega_s L_r I_{qr} - s\omega_s L_m I_{qs}$$
$$V^2_{qr} = R_r I_{qr} + s\omega_s L_r I_{dr} - s\omega_s L_m I_{ds} \quad (14)$$

Where superscripts 1 and 2 represents the current regulation and cross coupling components. The voltage signal at the rotor side converter in dq-axes is given by

$$V_{drc} = V_{ds} = V^1_{dr} + V^2_{dr}$$
$$V_{qrc} = V_{qs} = V^1_{qr} + V^2_{qr} \quad (15)$$

Here rc represents the converter at rotor side. Now after converting *dq-abc* frame the rotor side voltage is obtained. Fig. 4 Shows the rotor side converter control scheme.

6. STATOR SIDE CONVERTER CONTROL

When we use a RL choke between the stator and the stator side converter a cross coupling model is preferred for determining the voltage signal of stator side converter as shown in Fig. 5 and the equations are given by

$$V_{dsc} = V_{ds} - V_{dch}$$
$$V_{qsc} = V_{qs} - V_{qch} \quad (16)$$

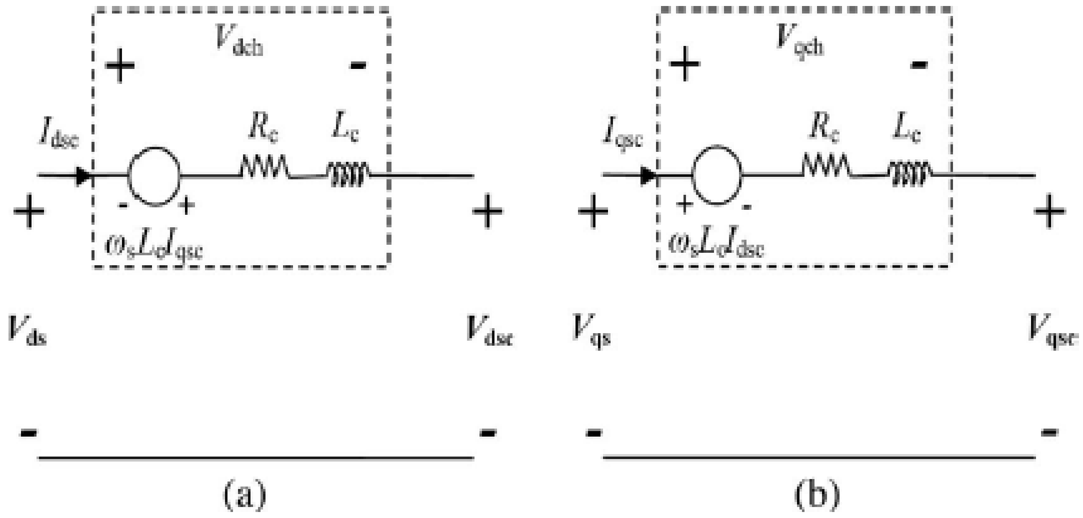

Fig. 5. Stator side Converter Control Scheme (a) d-Axis Model (b) q-Axis Model

Here the subscripts sc and ch represents the stator converter and choke variables.
Now the coupling part of voltage signal V_{dch}^2 and V_{qch}^2 is given by

$$V_{dch}^2 = R_c I_{dsc} - \omega_s L_c I_{qsc}$$
$$V_{qch}^2 = R_c I_{qsc} + \omega_s L_c I_{qsc} \qquad (17)$$

But the values of V_{dch}^1 and V_{qch}^1 are calculated by regulating I_{dsc} and I_{qsc} in which $I_{qsc-ref}$ is given directly while and the value of $I_{dsc-ref}$ is determined through dc-link voltage Vdc.

So the stator side converter voltage signals V_{dsc} and V_{qsc} are determined as shown below

$$V_{dsc} = V_{ds} - V_{dch}^1 - V_{dch}^2$$
$$V_{qsc} = V_{qs} - V_{qch}^1 - V_{qch}^2 \qquad (18)$$

The stator side voltage converter signals which are mentioned above are shown in Fig. 6.

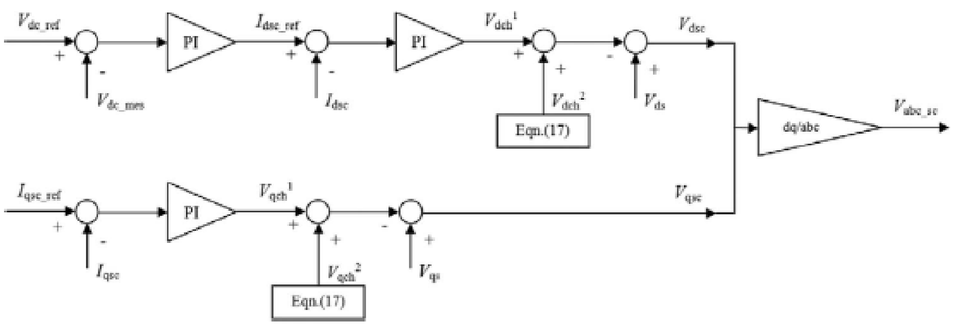

Fig. 6. Stator side converter control model

7. SIMULATION OF DFIG

After simulation of the DFIG model we can achieve the optimal power without putting any burden of reactive power on induction generator, and also we can even control the active and reactive power flow. In the simulink model we are introducing the switching frequency of about 27times that of the grid frequency. The control and power circuits are discretized at different steps for achieving accuracy[3]. If voltage is maintained at prescribed levels then we can also maintain the reactive power demand if required. So here in this case we implement the DFIG which can able to meet the required reactive power demand without having any dependency on external circuit like the STATCOM in the case of SCIG. This can be shown in Fig. 7.

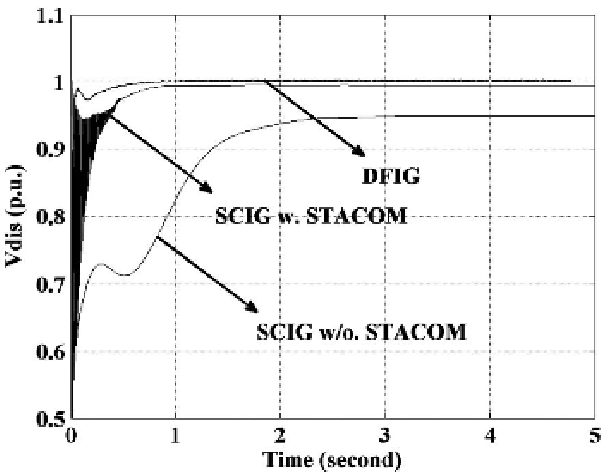

Fig. 7. Distribution voltages for SCIG system with and without STATCOM and DFIG

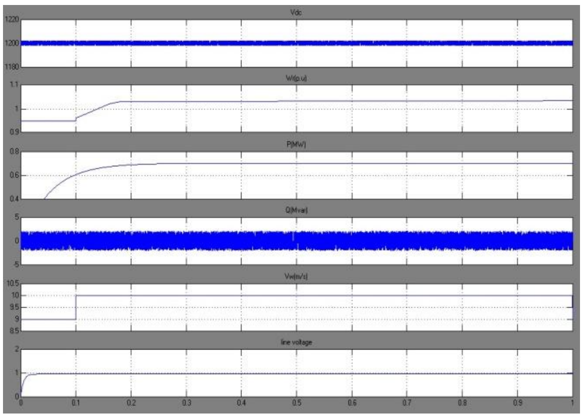

Fig. 8. wind step response (a) dc-link voltage Vdc (b)rotor speed Wr (c)active power P (d) reactive power Q (e) wind speed Vw. (f) distribution line voltage.

When the variation of wind speed is in a step manner then we can observe the steady increase in the Vdc and also in terms of active and reactive power as these are a

function of wind velocity. Here we consider a constant amount of wind velocity after 0. 1sec and due to this the rotor speed is increasing in a linear manner which reflects on the Vdc. This variation of rotor speed and the voltage can be observed from Fig. 8.
In this case the wind velocity keeps on varying with respect to the time and they may be in terms of gusty winds. when the wind speed is varying then the quantities like Vdc, Wr, P and Q as shown in Fig. 9.
Here in the dynamic response the system always tries to reach a new steady state value under the varying wind speed after few seconds. With the reduction in the inertia constant the converging time also gets reduced and reaches a new steady state value in less duration of time so that the dynamic performance can be improved.
The wind speed is maintained constant in the dynamic response of the system which makes the system to recover approximately in 0. 1s.

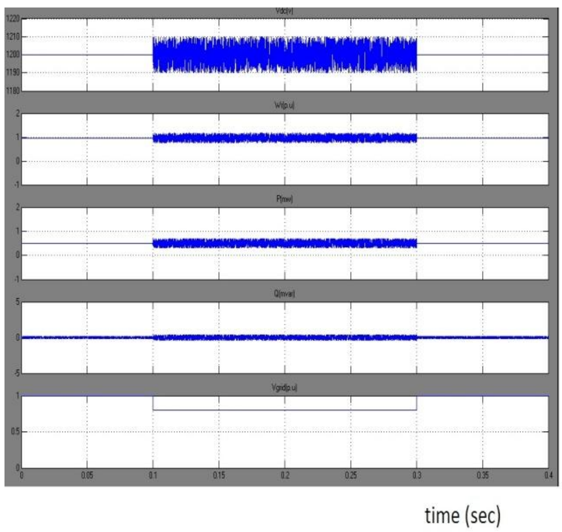

Fig. 9. Dynamic response to grid voltage drop (a). dc-link voltageVdc (b). rotor speed Wr (c). active power P (d.) reactive power Q (e). grid voltage Vgrid

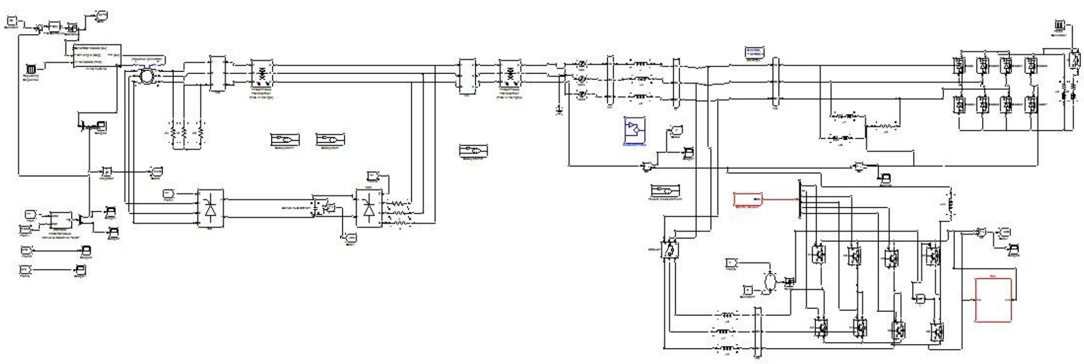

Fig. 10. Simulation model for the DFIG connected to unbalanced load due to variation of electrical parameters in one of the phase

The system may not operate satisfactorily for long duration of time, sometimes it may experience the unbalance condition due to occurrence of fault in any one of the phase. So due to this the electrical parameters will change and we are considering such changes for studying the performance of DFIG connected to grid. The DFIG in connected to the gird through back to back converter and a DC link which serves for continuous conduction of the devices. It is the connected to the distribution transformer. Here a unbalanced condition and a non-liner load are connected and the simulation is being carried out.

The non-linear devices here used are IGBT and the pulses are generated through SVM.

The wind energy conversion system is connected to the grid through stator and rotor converter control circuit and later it is connected to the load and these loads may be linear or non-linear. when the situation arises due to connection of non-linear load then it may induce harmonics into the system and under such circumstances we need to mitigate these harmonics by connecting a shunt active filter which is helpful in reducing the harmonic content. If the fault occurs due to this non-linear loads then a circuit breaker is connected with the SAF which operates from 0. 2 to 10 sec. So with in this time the fault is isolated and the harmonics are also mitigated and thereby improving the power quality of the system.

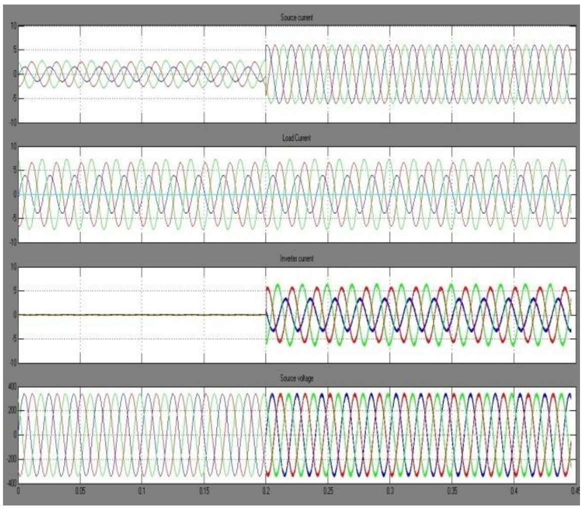

Fig. 11. Unbalancd Load Connected To DFIG

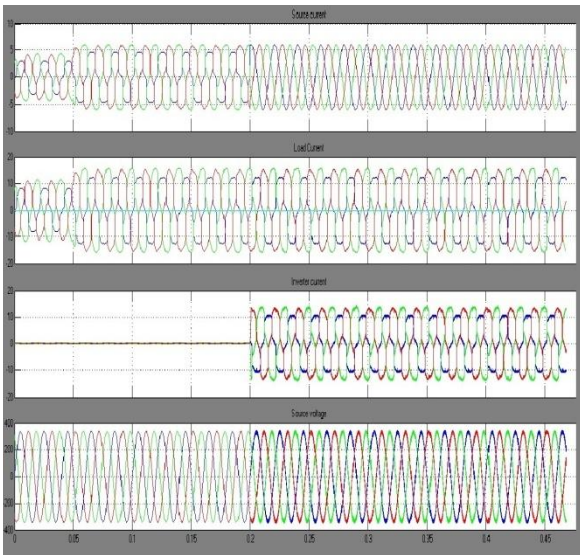

Fig. 12. Non-Linear Load Connected To DFIG

As shown in the Fig. 11 the source current is having distorted waveform due to the presence of unbalanced condition in the system. This can be overcome by injecting the current into the system with the help of shunt active filters. Whenever a unbalance condition prevails in the system them breaker will gets operated and the SAF will inject the necessary current into the system for improving the waveform there by improving the power quality, power factor and reduces THD shown in fig. 13.
Similarly when a non-linear load is connected to the system as shown in Fig. 12 which introduces harmonics due to switching action of devices and it may effect the operating characteristics of the equipments. So, this harmonic problem can be overcome by SAF as stated above.

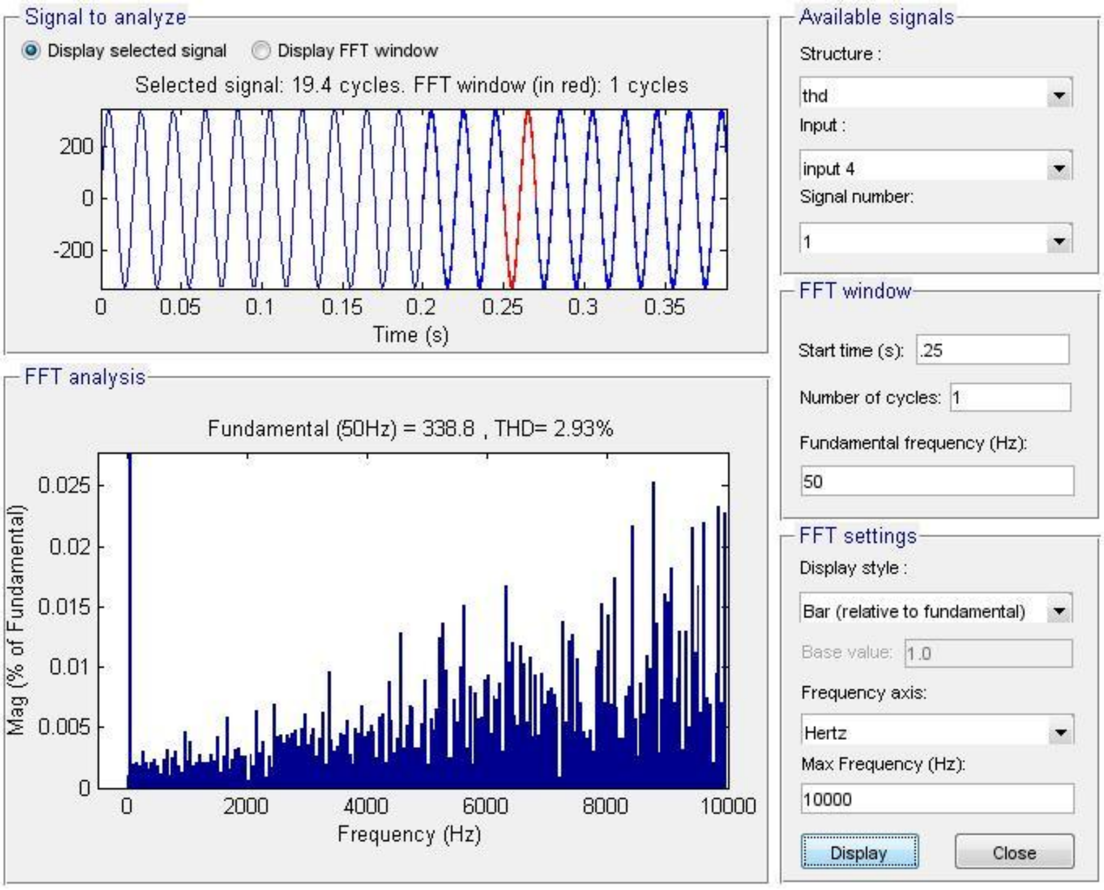

Fig. 13. THD improvement for non-linear load

Table I Simulation and control parameters

Parameter	Value
Power System Sample Period $T_{s\ Power}$	5e-6 sec
Control System Sample Period $T_{s\ Control}$	1e-4 sec
Switch Frequency F_{sw}	1620HZ
Transmission Distance D_{tran}	30 km
Reactive Power Regulator Coefficients K_P;K_i	0. 05;5
1Dc Link Voltage Regulator Coefficients K_P;K_i	0. 002;0. 1
Rotor Side Current Regulator Coefficients K_P;K_i	0. 3;8
Stator Side Current	2. 5;500

8. CONCLUSION

On comparing the performance of SCIG and DFIG we conclude that the DFIG can able to meet all the requirements like active, reactive power control, distribution line voltage and frequency with varying speed at the WECS. It can also able to sustain or meet the non-linear loads and suppress the harmonic content in the line by connecting shunt active filters. Suppose there is any occurrence of fault in the system and due to this the system becomes unbalance and in such situation it injects current in respective phases for making them as balanced one.

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