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# Modeling and Simulation of WECS for Optimizing Reactive Power in DFIG Using Optimized Grid Filter

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**Abstract - Wind energy is one of the capable source of renewable energy as it is nonpolluting and abundant in nature. A large number of wind farms are located around the world. There may be problems associate with fixed speed wind turbine system. So in order to increase the wind energy capture, many new wind farms are employed with variable speed wind turbine. Most of these variable speed wind turbine based on Doubly-Fed induction Generator (DFIG). DFIG is more advantageous compared to other methods because it has a better speed control and a reduced flickering of voltage. Because of the increase in technology of variable speed Wind Energy Conversion Systems (WECS), advance power electronics technology is implemented in the WECS. Wind turbines which employ a doubly-fed induction generator (DFIG) usually have a wound rotor induction generator and an AC/DC/AC IGBT based PWM converter. In this paper analyze the existence of the two possibilities to generate the demanded reactive power for the DFIG system controlled by the RSC or controlled by the GSC each of in terms of the DFIG loss and the power converters loss. The WECS system model is designed and simulated to optimize the reactive power in DFIG using Optimized grid Filter.**

***Key Words*: Doubly-Fed induction Generator (DFIG), Rotor side converter (RSC), Grid Side Converter (GSC), Reactive Power**

## 1. INTRODUCTION

Renewable energy like solar, wind, and tidal currents of oceans is sustainable, inexhaustible and environmentally friendly clean energy. Due to all these factors, wind power generation has attracted great interest in recent years. Undoubtedly, wind power is today's most rapidly growing renewable energy source. The wind power industry is growing expeditiously and the modern wind turbines are efficient, reliable, potent and profitable [1]. Research to extract the maximum power out of wind energy is an essential part of making wind energy much more viable and attractive.

Unlike a conventional power plant that uses synchronous generators, a wind turbine can operate as fixed-speed or variable-speed. In a fixed-speed wind turbine, the stator of the generator is directly connected to the grid. However, in a variable-speed wind turbine, the machine is controlled and connected to the power grid through a power electronic converter.

There are various reasons for using a variable-speed wind turbine. (1) Variable-speed wind turbines offer a higher energy yield in comparison to constant speed turbines. (2) The reduction of mechanical loads and simple pitch control can be achieved by variable speed operation. (3) Variable-speed wind turbines offer acoustic noise reduction and extensive controllability of both active and reactive power. (4) Variable-speed wind turbines show less fluctuation in the output power [1, 2]. The permanent magnet synchronous generator (PMSG) and doubly-fed induction generator (DFIG) are the two machines on which the variable-speed wind turbines are based.

In WECS power electronic convertors play an important role in maintaining frequency, voltage of the network and reactive power in the network. The losses in the system can be reduced by using filters, the proposed system compares the current ripples and supportive reactive power ranges between the conventional L and optimized LCL filter [3]. If the reactive power is injected from the grid-side converter, then the loss distribution is evaluated both for the generator and the wind power converter in terms of the reactive power evaluated by either the rotor-side converter or the grid-side converter with various grid filters

## 2. PROBLEM IDENTIFICATION AND OBJECTIVE

The population is rapidly increasing and the need for energy is also increasing. Other than hydro power, wind and photovoltaic energy holds the most potential to meet our energy demands. Wind energy is capable of supplying large amounts of power but its presence is highly unpredictable as it can be here one moment and gone in another. However by effective control system and high efficiency converters, the system's power transfer efficiency and reliability of this intermittent source can be improved significantly.

The main objective of the project is to model and simulate the Doubly-Fed induction generator with Optimized grid filter for Wind Energy Conversion System (WECS) in order to reduce the reactive power and upgrade the technology.

Below are the major steps which are followed in achieving this control objective.

- To review literature on the various techniques/algorithms of DFIG for WECS.

- Annual energy loss could be reduced to acceptable limits with optimized filter and there by more energy production for wind turbine.
- Demanded reactive power is generated in DFIG machine and is controlled by means of either RSC or GSC, each of turn analyzed in turn of DFIG loss and power converter loss.
- Implementation of optimized LCL filter for loss reduction in DFIG, using MATLAB/SIMULINK.

## 3. PROPOSED ALGORITHM

### A. *WECS Configuration:*

DFIG itself controls the reactive power using power electronics converter. Frequency and voltage has to be maintained constant. Power electronic converters are broadly classified into Rotor side converter (RSC) and Grid side converters (GSC). RSC will inject required current into the rotor to maintain constant frequency, whereas GSC will maintain constant grid voltage.

DFIG runs in three modes

- Sub Synchronous
- Synchronous
- Super Synchronous

In **Sub synchronous mode** the rotor rotates at less than synchronous speed, hence to get stator frequency equal to network frequency we inject rotor current into rotor to generate required rotating magnetic field in the air gap. In this mode active power flows from stator to the grid, and also active power flows into the rotor through back to back converters to the rotor.

In **synchronous mode** the rotor rotates at synchronous speed, no need to inject current into the rotor to generate rotating magnetic field in the air gap. In this mode of frequency the system equal to the frequency of the network. In this mode total active power flows from stator to grid.

In **super synchronous mode** the rotor rotates at greater than synchronous speed, rotor rotates at speed greater then synchronous speed, hence active power is induced in rotor winding which is supplied back to grid, through back to back converter. Also active power supplied to grid through stator.

In back to back converter consists of two converter one acts as rectifier and another acts as inverter vice-versa. Rotor side converter will inject current into the rotor to maintain constant grid frequency and grid side converter will maintain constant grid voltage and stator reactive power.

The stator reactive power depends on flux density in the air gap, flux density in turn propositional to voltage to frequency ratio. Hence by maintaining constant voltage to frequency ratio stator side reactive power and voltage maintained constant.

Filters are used in WESC for reducing harmonics, losses in the system and supports reactive power to the system. For the megawatt-level wind power converter, due to the quite low switching frequency of the power switching device(usually several kilohertz), a simple filter inductor consequently becomes bulky, expensive, and it may also bring poorer dynamics into the system. Hence we use optimized filter to bring good dynamics performance into the system. The loss distribution is evaluated both for the generator and the wind power converter in terms of the reactive power done by the rotor side converter or grid side converter with various grid filters. Overexcited reactive power injected from the grid side converter has lower energy loss per year compared to the overexcited reactive power covered by the rotor side converter.

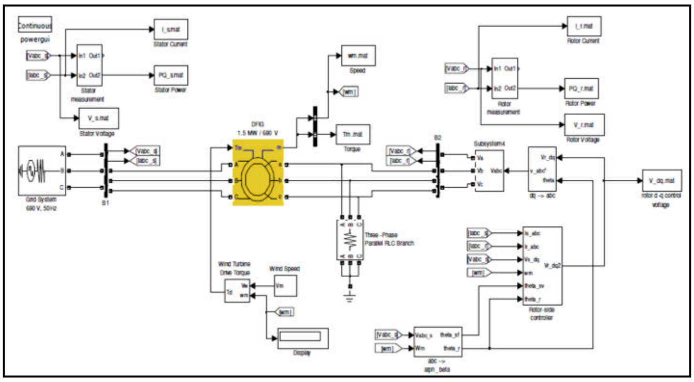

Figure 1: Block diagram of WECS

### B. *Loss Model of the DFIG System*

The common-adopted methodology to compensate the reactive power is from the stator of the induction generator, due to the fact that it introduces a small increase of the rotor-side current because of the winding ratio between the stator and the rotor of the DFIG. However, this approach not only affects the loss of the RSC, but also imposes the loss of the DFIG itself [18].

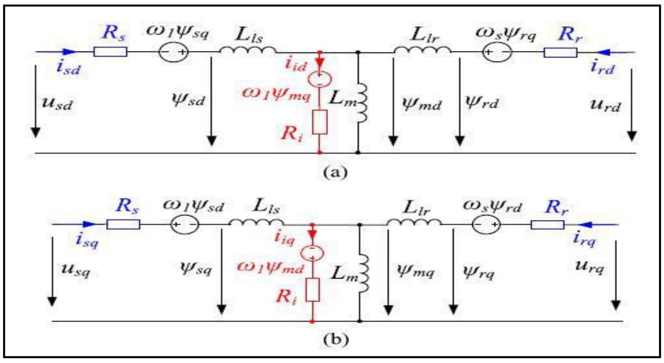

Figure 2: DFIG equivalent circuit considering copper loss and iron loss. (a) *d*-axis circuit. (b) *q*-axis circuit.

Loss dissipation inside the induction generator generally consists of the copper loss and iron loss as shown in Fig

2. If the stator voltage-oriented vector control is applied, the stator side active power *Ps* and reactive power *Qs* are independently in line with the stator *d*-axis current $i_{sd}$ and *q*-axis current $i_{sq}$. Due to the flux equation existing in the DFIG, the relationship between the rotor and stator current under *d*-axis and *q*-axis is

$$i'_{rd} = -\frac{L_{ls}+L_m}{L_m} i_{sd} \qquad (1)$$

$$i'_{rq} = \frac{U_{gm}}{\omega_1 . L_m} - \frac{L_{ls}+L_m}{L_m} i_{sq} \qquad (2)$$

Where $L_{ls}$ and $L_m$ denote the stator leakage inductance and the magnetizing inductance, $U_{gm}$ denotes the rated grid phase voltage, *ω*1 is the fundamental electrical angular frequency, and the subscript *d* and *q* denote the value at *d*-axis and *q*-axis circuit, respectively

The copper loss $P_{cu}$ is resistive losses occurring in the winding coils and can be calculated using the equivalent *dq* axis circuit stator resistance $R_s$ and rotor resistance $R_r$.

$$P_{cu} = \frac{3}{2}.[(i_{sd}^2 + i_{sq}^2).R_s + (i_{rd}^2 + i_{rq}^2).R_r] \qquad (3)$$

Induction generator is jointly dependent where $i_s$ and $i_r$ denote the stator current and the rotor current, respectively. It can be seen that the copper loss of the on the stator active power and reactive power.

Generally, the iron loss is produced by the flux change, and it consists of eddy current loss and hysteresis loss, both of which are tightly connected with the operation frequency and flux density [19]. This method needs to know the empirical formula in advance, and the calculation is normally done according to the finite-element method. Alternatively, iron losses can be estimated from the electrical point of view [20], [21]. In other words, it can be expressed by the equivalent iron resistance *Ri* in parallel with the magnetizing inductance as shown in Fig.2.

The voltage equations for the additional iron resistor are

$$\left.\begin{aligned} R_i.i_{id} &= \frac{d\psi_{md}}{dt} - \omega_1.\psi_{mq} \\ R_i.i_{iq} &= \frac{d\psi_{mq}}{dt} + \omega_1.\psi_{md} \end{aligned}\right\} \qquad (4)$$

Where $i_i$ is the equivalent iron loss current and $\psi_m$ is the magnetizing flux. Moreover, with the aid of the relationship between the stator flux and magnetizing flux.

$$\left.\begin{aligned} \psi_{md} &= \psi_{sd} - L_{ls}.i_{sd} \\ \psi_{mq} &= \psi_{sq} - L_{ls}.i_{sq} \end{aligned}\right\} \qquad (5)$$

Where ψs is the stator flux.

Due to the stator voltage orientation, *ψmd* is nearly zero, and *ψmq* is a constant value because of the stiff grid with the constant voltage and constant frequency. Substituting (5) into (4), the iron current can be deduced

$$i_{id} = \frac{\omega_1 L_{ls}}{R_i}.i_{sq} + \frac{U_{gm}}{R_i} \qquad (6)$$

$$i_{id} = -\frac{\omega_1 L_{ls}}{R_i}.i_{sd}$$

According to (6), it is noted that the *d*-axis iron loss current depends on the reactive power *Qs* , while the *q*-axis iron loss current is related to the active power *Ps* . As a consequence, the iron loss *P*fe can be calculated as

$$P_{fe} = \frac{3}{2}.[(i_{id}^2 + i_{iq}^2).R_i] \qquad (7)$$

In respect to the losses of the power converters in the DFIG system, if the reactive power is provided by the RSC, the loss model of the generator and the RSC is included is show in Fig. 4. If the reactive power is provided by the GSC, loss model of the GSC only included, so LCL filter is connected to grid side only.

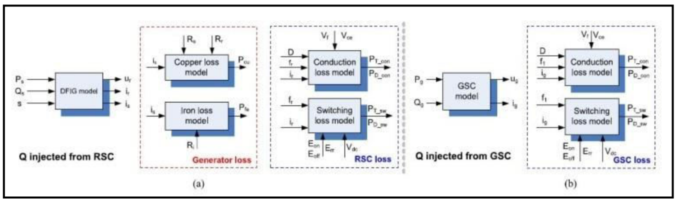

Figure 3: Framework of power loss estimation. (a) Reactive power is injected by the RSC. (b) Reactive power is injected by the GSC.

## 4. SYSTEM MODELING

The main focus of this dissertation is to provide a control algorithm for wind energy systems to optimize reactive power in the system and control the reactive power. RSC will maintain constant frequency of the system and GSC will control the constant grid voltage and reactive power

The system model consists of

- Wind turbine and DFIG.
- Back to Back Converters.
- Controller Scheme

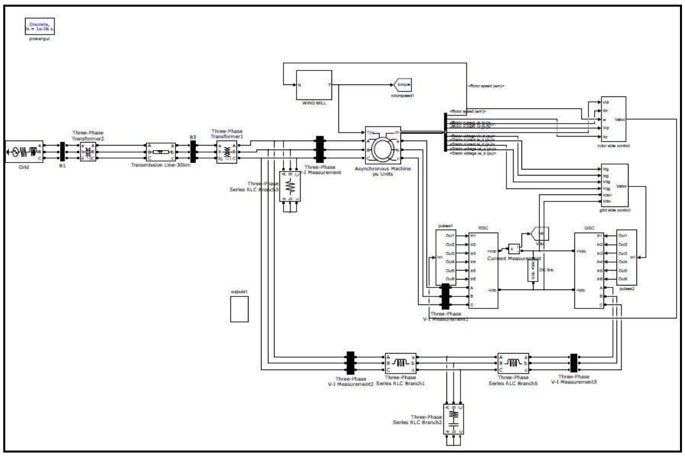

Figure 4: Complete WECS Model developed in Matlab/Simulink

### A. *Wind Turbine and Generator:*

The wind turbine and generator model (Figure 4.1) are built in Simulink with the use of the block models available in Simulink library browser. Several modifications have been made internally in these models to make it compatible with the system. First, the wind turbine model was changed from a per unit system to a real value system in order to make the turbine compatible with the real value components of the WECS. Second, the original model parameter is changed as per the design.

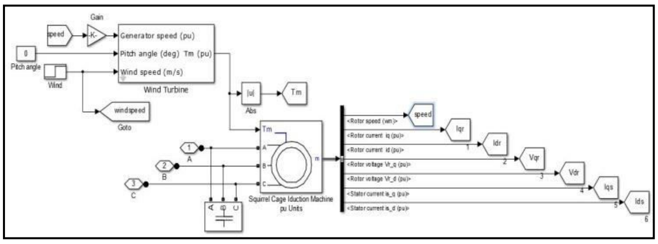

Figure 4.1: Wind Turbine and DFIG Model in Simulink.

### B. *Back to Back Converters:*

To extract the useful power from the wind by varying the generator speed, a power electronics interface between the generator and the grid must be used to provide the system with a control parameter

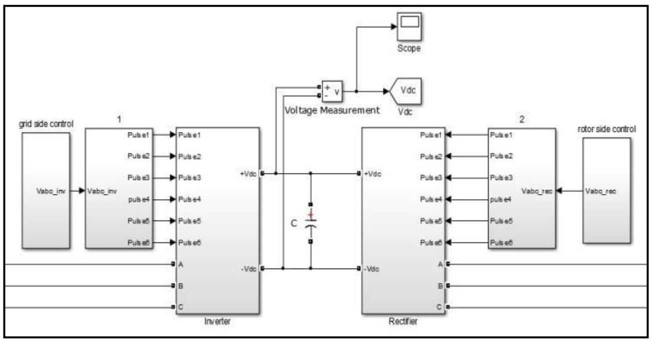

Figure 4.2: Back to Back Converters Model in Simulink

### C. *Rotor Side Control Model:*

Rotor side control generates control signal for the PWM pulses to generate required frequency of AC current injected into the rotor winding**.** This model consists of two loop 1) current control loop 2) speed control loop. In Current control loop grid voltage and current are measured, reference reactive power and actual reactive power are compared to generate error; this error is reduced by PI controller.

In speed control loop, we compare reference speed and actual speed to determine error, this error reduced by PI controller. The dq0_to_abc Transformation block performs the reverse of the so-called Park transformation, which is commonly used in three-phase electric machine models. It transforms three quantities (direct axis, quadratic axis, and zero-sequence components) expressed in a two-axis reference frame back to phase quantities.

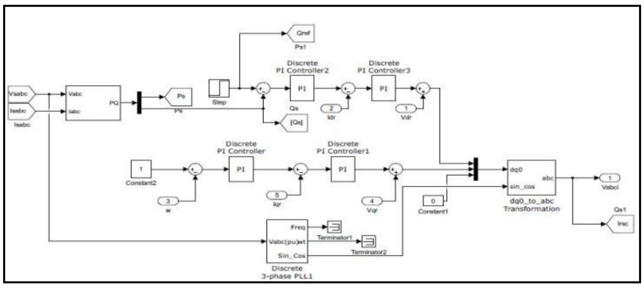

Figure 4.3: Rotor Side Control Model in Simulink

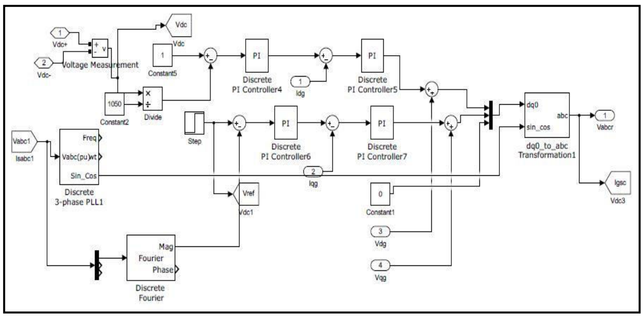

Figure 4.4: Grid side control model in Simulink

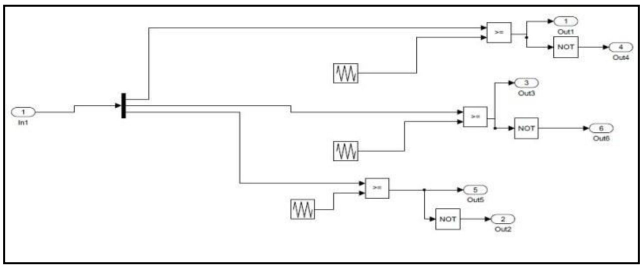

Figure 4.5: Pulse Generator Model in Simulink

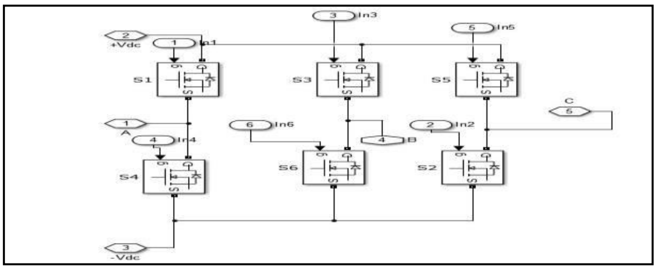

Figure 4.6: Converter control model in Simulink

## 5. RESULTS AND DISCUSSION

### A. DFIG Simulation Results:

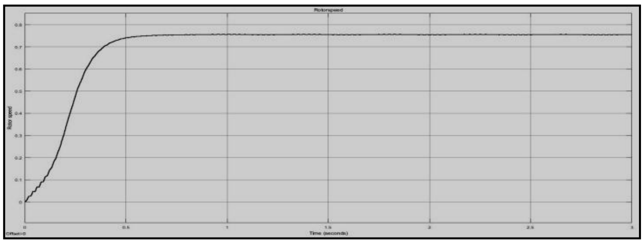

Fig: 5.1

Fig: 5.1 Response of DFIG rotor speed (11 m/s).Rotor speed will increase with wind speed. Fig: 5.2 Response of DFIG torque (10m/s).

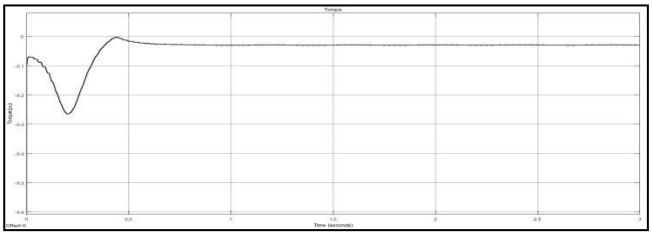

Fig: 6.2

If wind speed exceeds the base wind speed, the rotor speed will go above 1pu and it will provide the additional flux formation in rotor side in opposite direction. Hence rotor flux will cancel the sum amount of stator flux. So frequency of the stator side will maintain constant.

When the torque generated by the wind turbine for wind speed 11m/s. Torque will settled to constant, when rotor rotates at synchronous speed. If the DFIG running in generator mode then torque value will be negative.

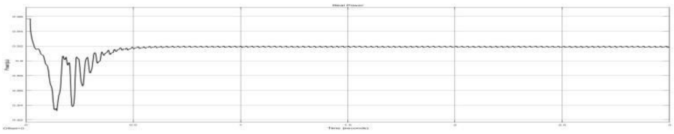

Fig 6.3: Response of DFIG real power (10 m/s). When wind turbine runs at 10 m/s DFIG will generate real power.

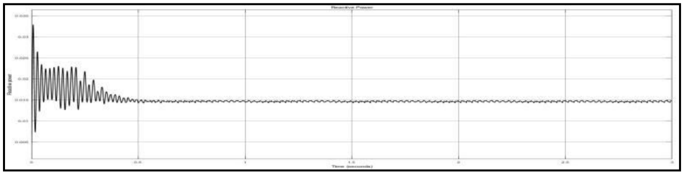

Fig: 6.4: Response of DFIG reactive power. When wind turbine runs at 10 m/s DFIG will generate reactive power.

### D. *Results of DFIG System Loss:*

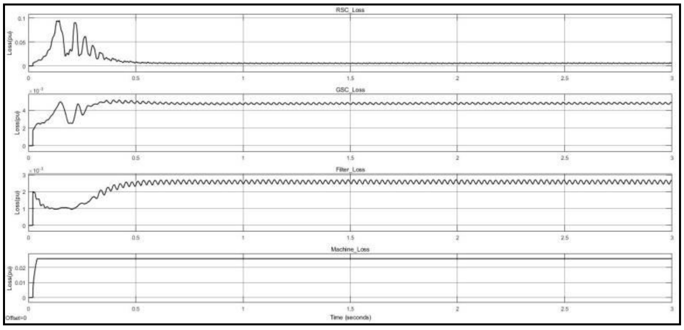

Fig 6.5: Loss breakdown at normal operation without compensating reactive power. Wind turbine running at 11 m/s, losses occurs at RSC, GSC, Filter, and machine side.

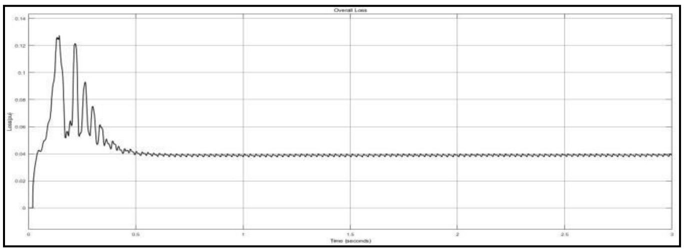

Fig 6.7: Overall loss breakdown at normal operation without compensating reactive power. Wind turbine running at 11 m/s, losses occurs at RSC, GSC, Filter, and machine side.

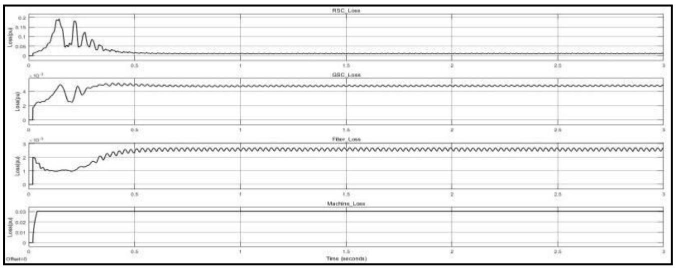

Fig 6.8: Loss breakdown when compensating reactive power from RSC. Wind turbine running at 11 m/s, losses occurs at RSC, GSC, Filter, and machine side.

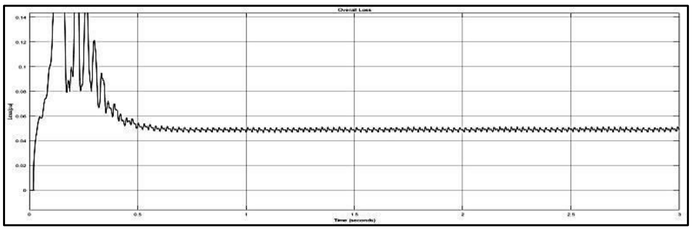

Fig 6.9: overall loss breakdown when compensating reactive power from RSC. Wind turbine running at 11 m/s, losses occurs at RSC, GSC, Filter, and machine side.

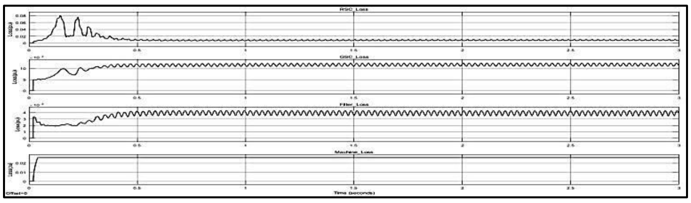

Fig 6.10: Loss breakdown when compensating reactive power from GSC with L filter. Wind turbine running at 11 m/s, losses occurs at RSC, GSC, Filter, and machine side.

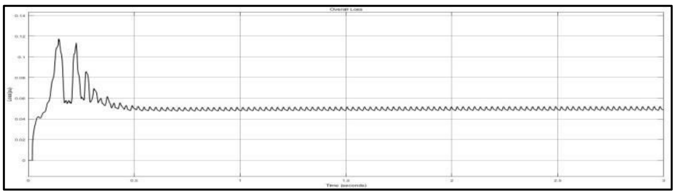

Fig 6.11: overall loss breakdown when compensating reactive power from GSC with L filter. Wind turbine running at 11 m/s, losses occurs at RSC, GSC, Filter, and machine side.

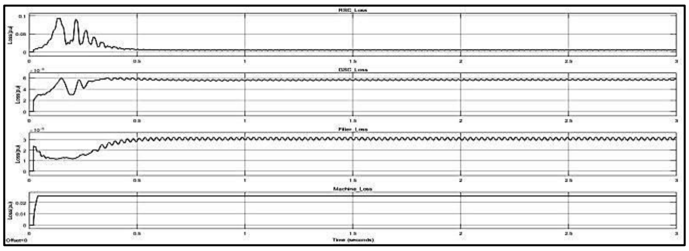

Fig 6.12: Loss breakdown when compensating reactive power from GSC with LCL filter. Wind turbine running at 11 m/s, losses occurs at RSC, GSC, Filter, and machine side.

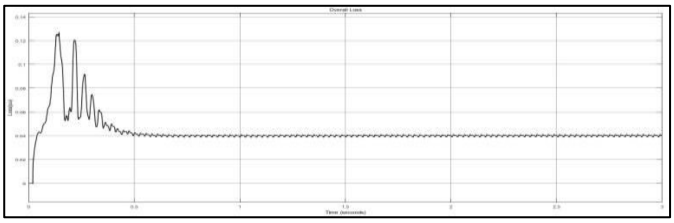

Fig 6.13: overall loss breakdown when compensating reactive power from GSC with LCL filter. Wind turbine running at 11 m/s, losses occurs at RSC, GSC, Filter, and machine side.

## 6. CONCLUSION

This paper has studied the existence of the two possibilities to generate the demanded reactive power for the DFIG system controlled by the RSC or controlled by the GSC each of them is analyzed in terms of the DFIG loss and the power converters loss. It is concluded that although the compensation from the GSC significantly increases the power loss of the GSC itself, it will still have lower total loss dissipation of the whole DFIG system, as the compensation approach by the RSC will impose the DFIG loss as well as the RSC loss.

In this paper shows loss breakdown at rated wind speed (13m/s) with various reactive power compensation schemes of DFIG , GSC, RSC, Grid Filter, Total system and loss breakdown at NOR with different wind speed DFIG itself, RSC, GSC, Grid filter, Total system, are plotted .

It is noted that if the OE reactive power is compensated from the GSC, the LCL filter consumes lower power loss due to the smaller ESR compared to the pure L filter, for the loss distribution of the whole DFIG system, compared with the loss of the DFIG itself and the power converters, the Loss dissipated in the DFIG is dominant.

Simulation results of the DFIG show the reactive power is controlled in the system and power electronics converter will maintain the frequency of the system by injecting the current into the rotor; grid side converter will maintain constant grid side voltage.

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