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The Effect of Doubly-Fed Induction Generator (DFID) Based Wind Turbine and Its Application

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Abstract

Renewable Energy Sources are non-pollutant of environment and environmental friendly when compared to non-renewable sources of energy. Therefore, the integration of renewable energy sources like Wind Energy Conversion System with utility grid is inevitable. Wind Energy is predominant among the non-conventional sources of energy where different conversion technology have been proposed to generate electric power .The Doubly-Fed Induction Generator (DFIG) is popular technique for variable speed wind power generation owing to its flexibility, efficiency, less mechanical stresses, extensive control ability of the generated real and reactive power and cost effective rated power electronics converter.The report x-ray a background study of DFIG in order to introduce the basic features such as variable speed and normal operation of DFIG systems for wind power applications based on three-phase wound rotor induction generator.

Keywords: Word Energy, DFIG, Variable Speed, Renewable Energy

1.0 Introduction

Wind Energy is one of the major sources for non-conventional power generation and the capacity of wind turbines and the power plants are regularly on the increase. Wind Energy is one of the renewable sources of energy where different conversion designs have been suggested in an attempt to increase the production of electric power generated. The purpose for the development of Wind Turbine system is to continuously improve the output electrical power (Muller et al, 2002).

A Wind Farm is a set of Wind Turbines situated in the same location to generate electric power. A large wind farm may contain several individual of wind turbines and spread over a span of hundreds square-kilometers of area. Figure 1.1 shows a typical wind farm. A Wind Farm can be onshore or offshore with many of the largest onshore wind farm situated in Germany, United State of America, China, Denmark and Spain (Burton et.al 2001).

The use of Wind Farm have been in existence for the past 3000 years purposely for the grinding of grains or pumping of water, while wind energy has been a source of power in a sailing ships (Burton et.al 2001). The application of wind turbines to produce electrical power could be traced back to the late nineteenth century with the construction of 12KW DC wind farm generator by Brush in United State of America and the research carried out in Denmark by Lacour (Burton et.al 2001). In most of twentieth century, the interest of using wind energy became diminish as the energy generated from the wind turbines were replaced once people gained access to the power grid.

However, an exception was the 1250KW Wind Turbine with 53m diameter steel rotor constructed by Smith Putnam in 1941 in United State of America (Putnam 1948 cited in Burton et.al 2001:1). More-so, most of the wind turbines produced globally were low power ratings, ranging from 100KW-1.1MW and there was uncertainty as to which of the available design was most economical. With the government of United State of America funded research activities in mid-1980s, a small power rating (less than 100KW) and simpler wind turbines were constructed for commercial purposes. The interest to develop wind energy was due to the increase in the oil price in 1973 and the problem of availability of fossil-fuel (Burton et.al 2001).

In recent time, the main purpose to focus on the wind turbine to produce electrical power is owing to its environmental friendly and its inability to pollute the atmosphere. Wind has been the source of clean energy for more than one thousand years and over the last ten years, the use of wind energy on a large scale has been planed and implemented as a result of the improvement in wind turbine generator design in an attempt to increase the production of electric power generated.(ABB 2011).

Figure 1.0: Large Wind Farm to generate large Electrical Power.

1.1 Types of Wind Turbine

There are generally two classes of wind turbine. These are **Horizontal axis wind turbine (HAWT)** and **Vertical axis wind turbine (VAWT).** The Horizontal axis wind turbine rotates the wind turbine around the horizontal axis or parallel to the ground and can generate more power from a particular amount of wind than the Vertical axis wind turbine.

The Vertical axis wind turbine rotates the wind turbine around vertical axis and does not require orientation into the wind, since it can be rotated by wind by wind from any direction. The two types of wind turbine use principle of aerodynamics to convert the kinetic energy from wind to generate electrical power. However, all the modern commercial wind turbines are horizontal axis type due to its inherent advantages over the vertical axis type (Kothari and Umashankar 2014).

2.0 RELATED WORKS

In the paper presented by (Bindu and Mandadi 2014), authors used MATLAB/SIMULINK.' The authors were comparing the quality of energy produced from wind power systems by comparing three different types of induction generators that were used in the wind energy conversion system. The authors were of opinion that induction generators which are asynchronous generators are better used than the synchronous generators due to the numerous advantages of the former (Asynchronous generator).

In this work, the induction generators based wind turbine system were compared using Squirrel cage induction generator SCIG, Doubly-fed induction generator DFIG and Singly external feeding-Doubly fed induction generator SEF-DFIG. The authors argued that DFIG is better than others due to the flexibility of DFIG and are cheaper than SCIG and SEF-DFIG. Also, DFIG is used for variable wind speed which has the ability of high energy capturing and thereby improves efficiency.

Another study carried out on Simulation and Performance Analysis of SFIG and DFIG Systems for Wind Turbine by (Awasthi, Tiwari and Diwan 2012). The authors carried out the analysis of simulation and performance of singly-fed induction generator SFIG and Doubly-fed induction generator DFIG based wind turbines with the view to compare the two in terms of operational performance, applications, efficiency and cost effectiveness. The authors argued that in a fixed speed wind turbine, the generator is connected directly to the grid with the speed locked to the grid which cannot be controlled, thus, leads to the fluctuation in the power supplied to the grid during turbulence of the wind, thereby affecting the quality of power to the grid. Therefore, the modern high wind power turbines operates with variable speed system and make use of singly-fed induction generator (SFIG) and Doubly-fed induction generator DFIG.

The authors were of opinion that the singly-fed induction generator, like squirrel cage induction generator were used in smaller systems with unsurpassed advantages in terms of cost and low maintenance. However, SCIG has the problem of high slip value that leads to higher heat dissipation thereby reduces efficiency and increases the cost in an attempt to reduce the heat dissipation. The authors in their submission, agreed that the Doubly-fed induction generator (DFIG) based Wind Turbine is more efficient and cost effective than SFIG because DFIG techniques allows the power electronics converters to generate or absorb reactive power thereby removing the need for capacitor banks as in the case of squirrel cage induction generator in SFIG systems. Also, the authors concluded that the wind speed variation that are used in DFIG operation reduces mechanical stress during the gusts of wind, thereby reduces torque variation or pulsation and hence improving the quality of electrical power supplied to the grid.

3.0 METHODOLOGY

The method used in the modelling of this work involved step by step approach in order to study and practice the tutorials in simscape power system, thereafter, some of the models in the simscape power system were implemented before started the modelling of the Doubly-Fed Induction Generator DFIG-based wind turbine system. Part of the modelled circuits include Simple three-phase model, interfacing the electrical circuits with other simulink blocks to mention few. In building a simple three-phase model, figure 3.0 and 3.1 showed the circuit to be modelled, the modelled circuit while the simulation result is shown in figure5.0- figure5.5

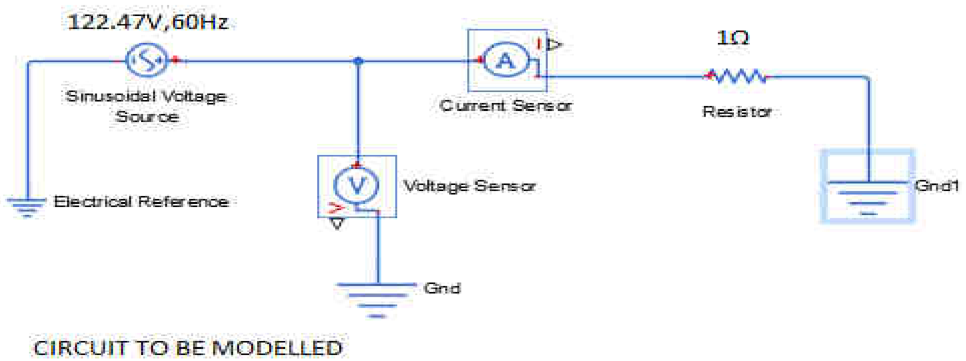

Fig3.0: Circuit to be modelled

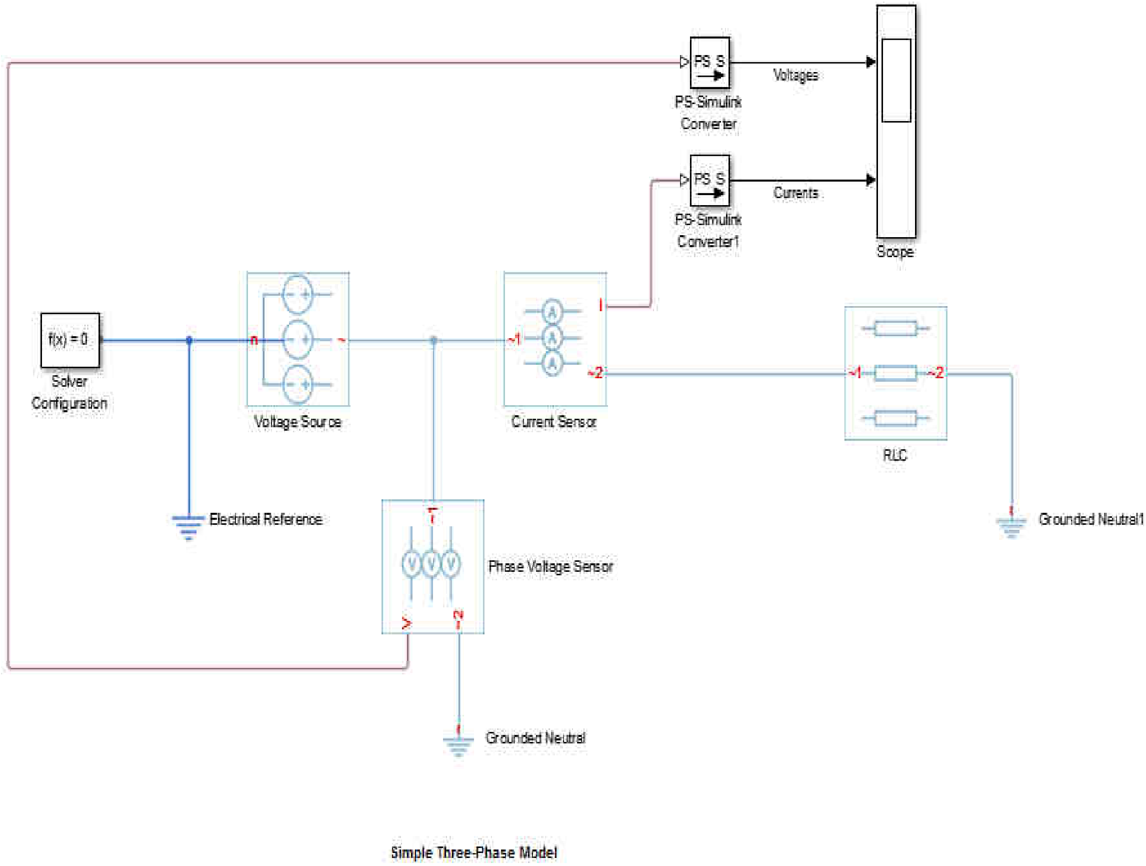

Fig 3.1: Modelled Circuit

In this modelling technique, a steady state condition was first assumed and later considered the dynamic performance. The Wind Farm-DFIG Detailed model of the MATLAB/SIMULINK was adopted and some modifications were made to the adopted model. The blocks on the model were selected from the Simulink library, and the initial state vector was regenerated to avoid error in the simulink when the simulation will be started to run. To regenerate the initial state vector of the model, the initial option under the 'Load from workspace' part of the Data Import/Export section of the model configuration parameters tool were unchecked. The instructions at the initialization file for the model were strictly followed to effect the regeneration of the initial state vector after the modification to the model (Gagnon, R 2016).

3.1 DESCRIPTION OF WIND FARM DFIG MODEL

A Wind Farm having 6 wind turbines with each having 1.5MW power rating and altogether producing 9MW at 10MVA which gives 0.9 power factor lagging are connected to a 25KV distribution network and transmits electric power to 120KV grid via step up transformers and 20km line long,25KV feeder(Gagnon, R 2016). Figure 3.2 below shows the block diagram of a variable speed wind energy conversion system using DFIG. The wind turbine is based on Doubly-Fed Induction Generator (DFIG) which consists of a variable speed, wound rotor induction generator (WRIG) and AC/DC/AC insulated gate bipolar transistor (IGBT)-dependable, pulse width modulation (PWM) converter. The stator windings of the DFIG are directly connected to 50Hz grid and its frequency is locked with the frequency of the grid while its rotor windings are connected to the grid via a three-phase variable frequency AC/DC/AC converter through the slips (Awasthi, Diwan and Awasthi 2013). Because the electrical characteristics of generator are isolated from the power system, the frequency of the generator can vary due to the changes of wind speed but the grid frequency does not change (Fox et.al 2007 cited in Anaya-Lara et.al 2011).

The Wind Turbine and the Gearbox in fig.3.2 below typify the mechanical unit of the system while the DFIG and the back-to-back converter which consists of the rotor side converter (RSC) and grid side converter (GSC) are the electrical unit of the system. The three-phase transformer is a step up transformer to boost the power from the converter before feeding the grid. The Doubly-Fed Induction Generator permits the optimum extraction of energy from the wind for

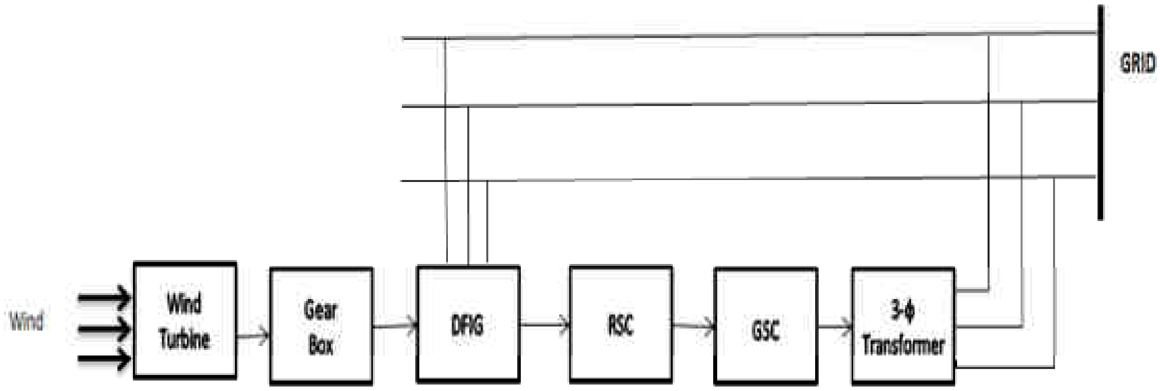

Figure 3.2: Block diagram of a variable speed wind turbine system using DFIG. (Source: Kothari and Umashankar 2014)

3.1.1 MODELLING OF WIND TURBINE

The figure 3.3 below shows how the mechanical energy captured by the aerodynamic are converted into electrical energy by the Doubly-Fed induction generator. A wind turbine power coefficient C_P depends a Tip-speed ratio λ and pitch angle β. This implies

$C_P = f(\lambda,\beta)$ and the aerodynamic wind turbine power $P_t = 0.5C_P(\lambda,\beta)\rho AV^3$ (1)

Where

$A = \pi R^2$ =Rotational area of the rotor(m^2)

ρ = Air density(kg/m^3)

R = Radius of the turbine blade(m) and

V = Wind speed(m/s).

The Tip-Speed Ratio, λ is given as

$$\lambda = R\omega_r/V \quad (2a)$$

$$\omega_r = \lambda V/R \quad (2b)$$

Where ω_r = The rotor speed(rad/s)

The turbine torque is obtained as

$$T_t = P_t/\omega_t \quad (3)$$

The wind turbine is coupled to the shaft of the generator via a gearbox because the wind speed is slow and cannot rotate the shaft of the generator. Therefore, the gearbox is required and the gear ratio G is needed to set the speed of the generator shaft to the desired range of the speed.

Assuming no transmission losses, the turbine torque T_t at the turbine side of the gearbox is obtained as

$T_G = T_t/G$ (4)

Equations (1) to (4) are transformed into dynamic model of a wind turbine as showed in figure 2.3

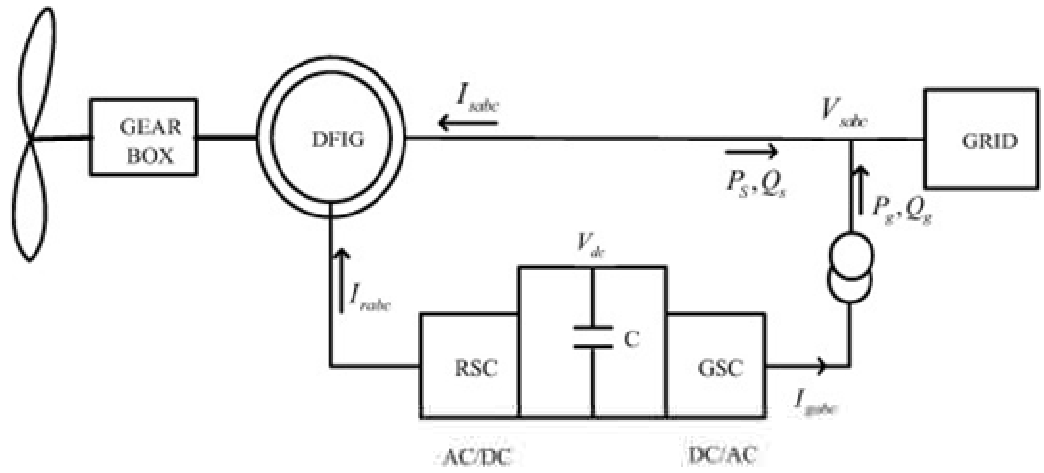

Fig 3.3: Block diagram of a wind power station (**Source:** Mehdipour, Hajizadeh and Mehdipour 2017)

3.1.2 Modelling of DC—Link Capacitor

The dc-link model describes the voltage variations of the dc-link capacitor as a function of the input power to the dc-link(Ledesma and Usaola 2005 cited in Fletcher and Yang 2010).

The energy stored in a capacitor at time t, is given as

$W_C = \int P_c \, dt = \int i_c v_c \, dt$ (5)

The Capacitor current, $i_c = C\frac{dv}{dt}$ (6)

Where

C = Capacitance (F)

V_c = dc voltage of the capacitor (V)

W_c = Energy stored in the capacitor (J)

P_c = Input power to the dc=link = $P_{RSC} - P_{GSC}$

P_{RSC} = Input Power from rotor side converter

P_{GSC} = Output power from grid side converter

Substitute equation (6) into equation (5)

Therefore, equation (5) becomes

$W_C = \int P_c \, dt = \int i_c v_c \, dt = \int C\frac{dv}{dt} v_c \, dt = \int C v_c dv_c = ½CV^2$ (7)

Hence $P_c = dW_c/dt$ (8)

Therefore, the voltage of the dc-link varies as P_c and the dc-link voltage is constant when $P_c=0$.

Simulation methods for Doubly-Fed Induction Generator (DFIG)

There are three simulation methods or model presently available in the simscape power systems to model voltage source converter-based wind turbine systems connected to the power grid, and these depend on the frequencies range represented (Gagnon, R 2016). The available methods are: Detailed model, Average model and Phasor model.

The Detailed model is a discrete signal and contains the full representation of insulated gate bipolar transistor (IGBT) converters. The model was discretized at a very small step time of $5\mu s$ for the system to achieve acceptable accuracy within the switching frequencies of 1620Hz and 2700Hz. This model is ideal for observing harmonics and the dynamic performance of the control system within a short period of time that is less than one second, and 200ms was adopted in this project.

The Average model also uses discrete signal like the detailed model but the insulated gate bipolar transistor voltage-sourced converters are presented as the equivalent voltage sources generating the alternating signal voltage over one cycle of the switching frequency. Average model does not represent harmonics but protected the dynamics arising from the control and power system interaction. This model permits longer steps time about $50\mu s$ and thereby allowing simulations of several seconds.

The Phasor model is another method available in the simscape power system to model voltage source converters-based wind turbine system that is connected to the grid and the model uses continuous signal. Phasor model is ideal for the simulation of electromechanical oscillations of low frequency within a long time. In this simulation technique, the voltage and current waveforms are represented by phasor quantities at the supply frequency of 50Hz. The Detailed and Phasor model are adopted for the modelling in this project.

4.0 THE EFFECT OF DFIG AND ITS APPLICATION

Efforts of the researchers are now directed toward the Grid Connected Energy Storage. The problem of grid connectivity of renewable energy is due to the intermittency of power supply to the grid owing to the unpredictable nature of wind (Santhosh and Meenakshy 2016). The problem of power fluctuation to the grid can be completely resolved or reduced to minimal if energy storage can be provided at the grid to compensate for the additional power needed from the grid during the power fluctuation. In the work of (Stone 2016) on Grid Connected Energy Storage Research and the Willenhall Test bed Facility. An overview of UK electrical energy system was carried out for long and short term future, 2MW,1MWh grid connected battery was presented. The author mentioned all the sources of electricity generation and that the consumers of the electricity generated are industries, commercial and domestic but the generation of electricity will reduce by 30% by year 2020 due to the ageing infrastructure or obsolete power equipment and there is no planning for upgrading of the existing infrastructure or replacement. Again, the author argued that the global generation of energy are being affected by the ageing equipment and the prices of energy in the international market.

Therefore, Energy Storage (ES) should be adopted to support the grid during the pick load rather than new generation or reinforcing the existing installation, since more generation will lead to more cabling and more challenges. The author is of opinion that several efforts are put in place by the National grid to ensure that consumers energy demand are met and to achieve this the voltage and frequency at the grid must be kept constant or controlled. This implies that there should be stability in the power supply to the grid. The author concluded that this can be achieved by the provision of Energy Storage in the grid. In the author’s submission, he listed some of the areas Energy Storage can be useful such as the renewable energy generated can be turn off by energy storage devices when excess power is supplied to the grid and supply the additional power required by the grid during fluctuation or when lesser power is supplied to the grid (This is termed as capacity firming).

Energy Storage can be controlled to take the advantages in the difference of energy price in the open market, frequency regulation and power stability on the grid can be achieved through energy storage devices (Stone 2016).

5.0 Result for simulation of modelled block

5.1 Simulation of Simple three-phase model

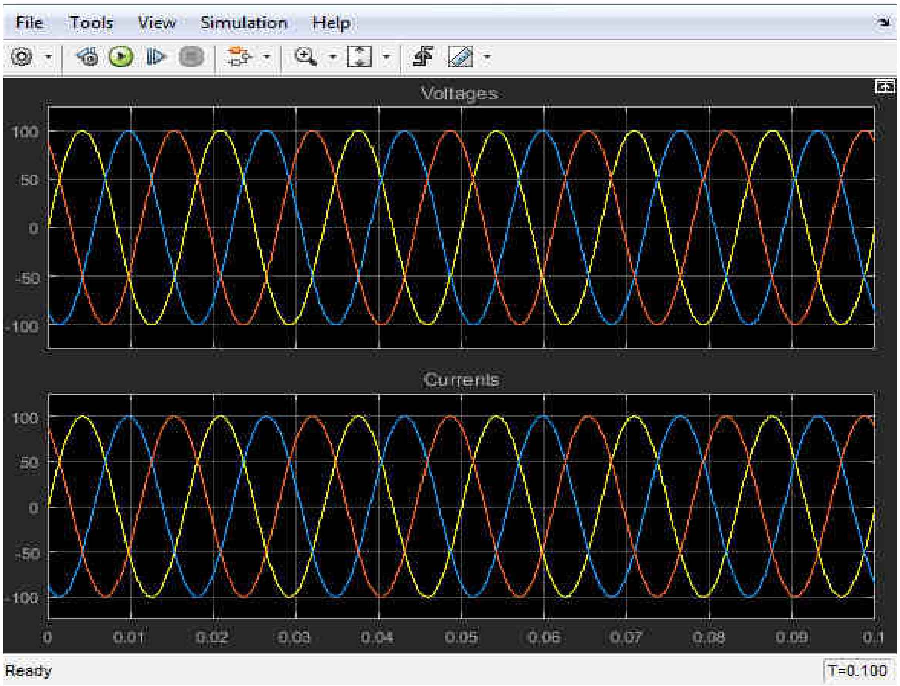

Fig 5.0: Simulation result of the three phase model for pure resistive load

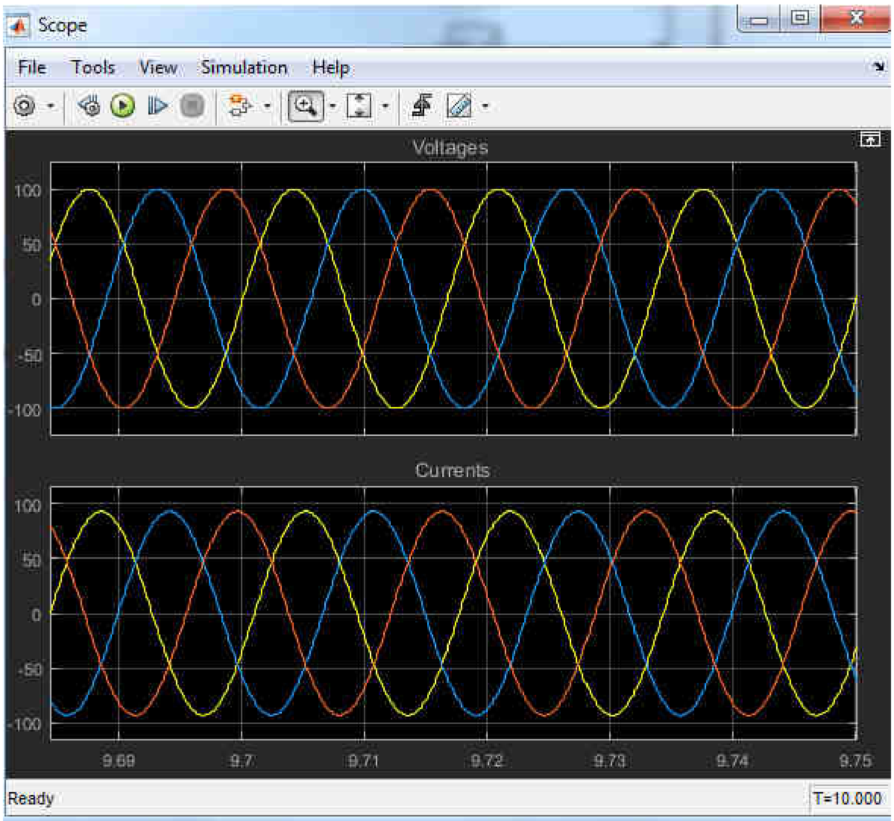

Fig 5.1: Simulation result of the three phase model for RL circuit

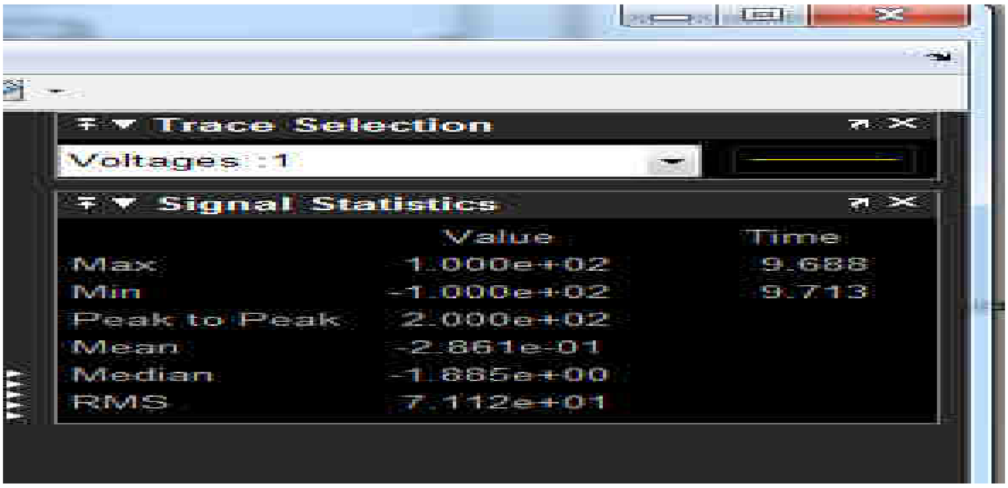

Fig 5.2: Simulation result of the three phase model for RL circuit

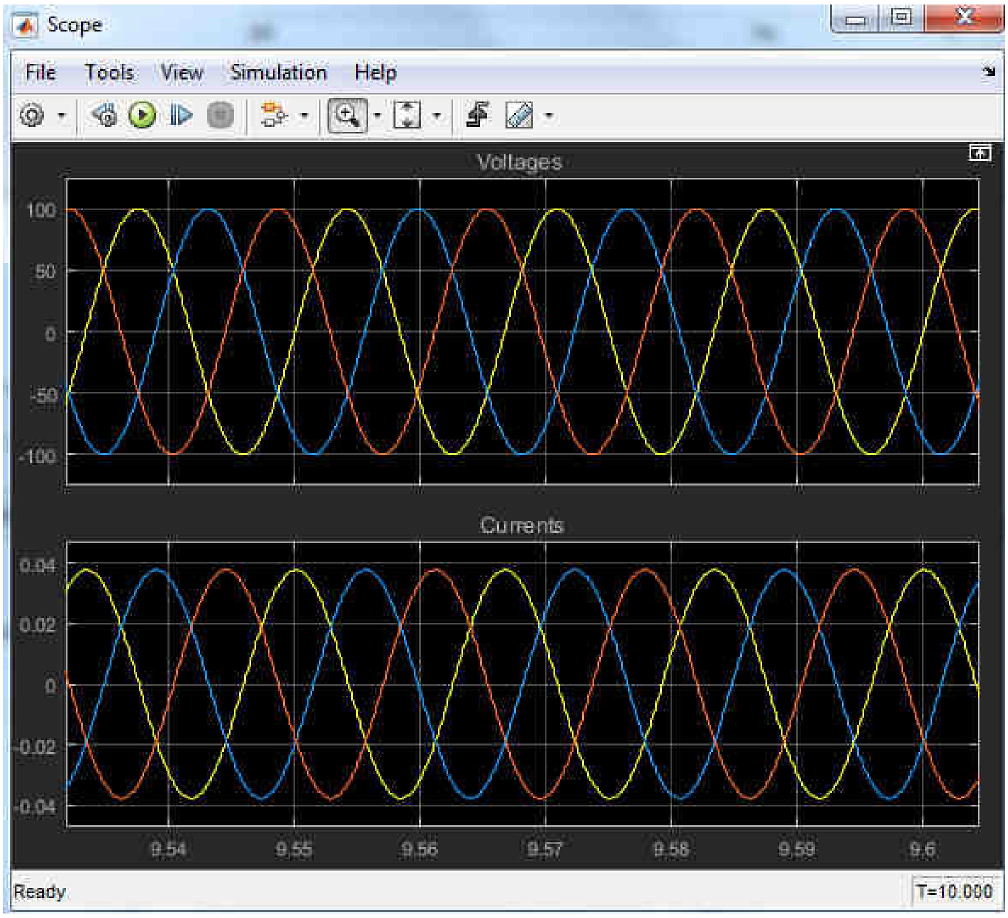

Fig 5.3: Simulation result of the three phase model for RC circuit

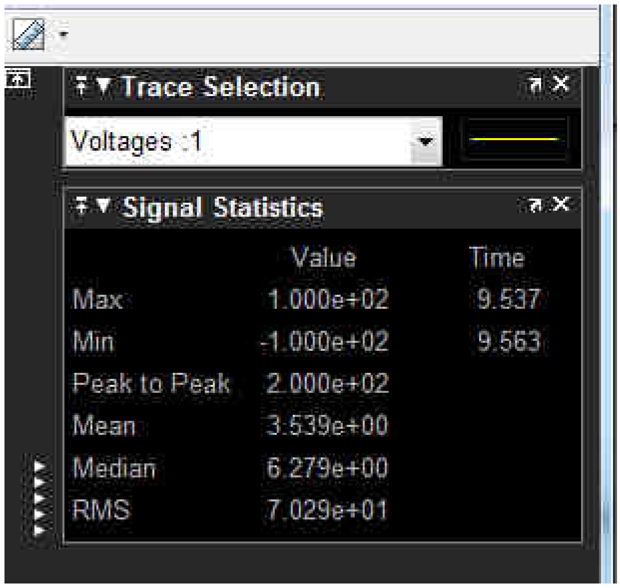

Fig 5.4: **Simulation result of the three phase model for RC circuit**

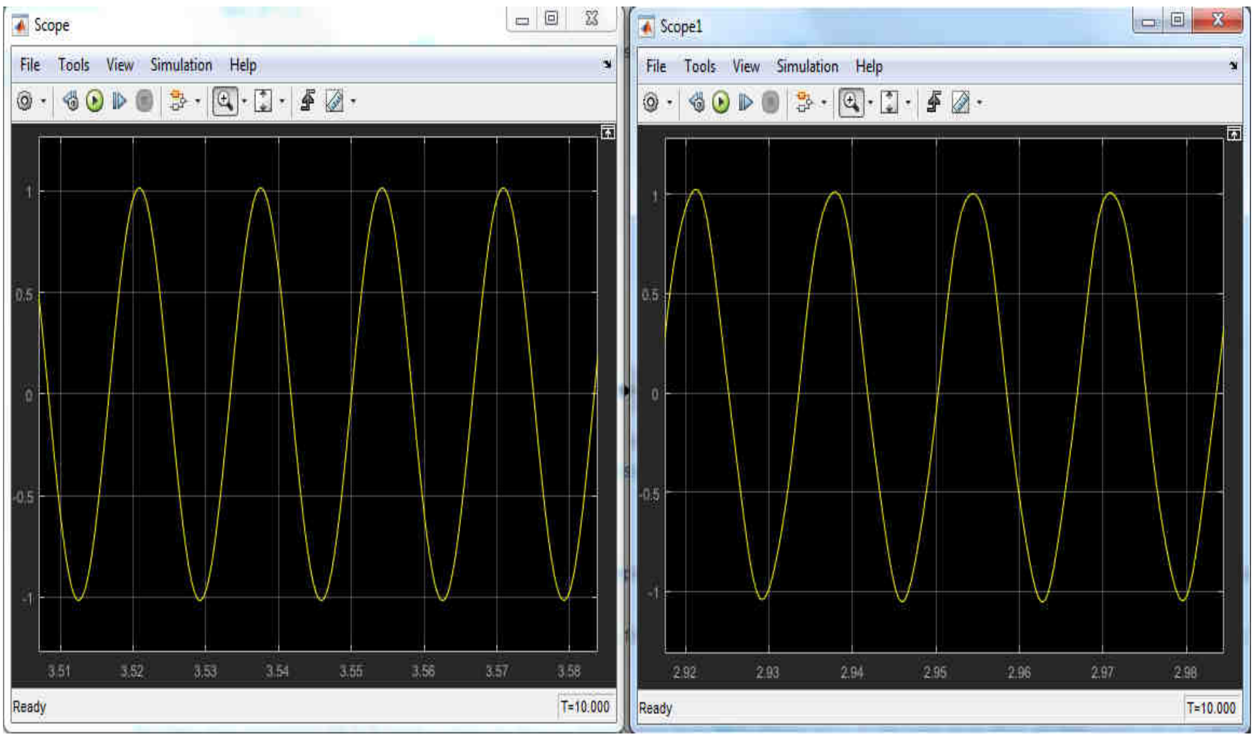

Fig 5.5: Simulation result for build and simulate simple circuit

6.0 Conclusion

A background study was carry out to investigate and evaluate DFIG-based wind turbine system and its recent development concerning hardware components, design, modelling, implementation, principle of operation, limitation of the system, cost effectiveness in terms of power electronics converter application and optimal power generation. A Literature review was carried out to evaluate related works on Doubly-Fed Induction Generator (DFIG). Comprehensive research on the design and modelling of Wind Farm-DFIG Detailed model were also carried out to be able to modify the existing model in MATLAB/SIMULINK. Therefore, the DFIG-based wind turbine system connected to distribution network for variable speed was modelled and simulated using fundamental principle in MATLAB/SIMULINK. The simulation results were extensively analyzed to demonstrate the operation and performance of DFIG. The simulation results showed the validity of the model.

References

ABB (2011) The lists of references illustrated [online] available from www.last.potsdam.de/sites [3 October 2016]

Awasthi, A; Diwan,R and Awasthi, M.(2013) 'Study for Performance Comparison of SFIG and DFIG Based Wind Turbines'.International Journal of Latest Trends in Engineering and Technology (IJLTET), 2(4).

Awasthi, A; Tiwari, S; and Diwan, R(2012) 'Simulation and Performance Analysis of SFIG and DFIG Systems for Wind Turbines'.International Journal of Engineering Research and Technology (IJERT), 1(9).

Bindu, G.H and Mandadi, P.N(2014) 'Design and Modelling of Induction Generator Wind Power Systems by using MATLAB/SIMULINK'. International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering. 3(8).

Burton,T ; Sharpe,D; Jenkins,N and Bossanyi,E. (2001), Wind Energy Handbook.England,: John Wiley & Sons Inc.

Fletcher, J and Yang, J(2010) 'Introduction to Doubly-Fed Induction Generator for Wind Power Applications'. Glasgow, United Kingdom www.intechopen.com

Gagnon, R; Saulnier, B; and Forcione, A (Hydro-Quebec) (2016) Wind Farm Using Doubly-Fed Induction Generators. MATLAB/SIMULINK

Muller, S; Deicke, M and De-Doncker, R.W(2002) 'Doubly Fed Induction Generator Systems for Wind Turbines'. IEEE Industry Applications Magazine.

Santhosh, R.R and Meenakshy, K(2016) 'A Unique Grid Power Controller for DFIG Based Wind Turbine Generator System with or without Battery Storage Device". International Journal of Innovative Research in Science, Engineering and Technology 5(5).

Stone, D.A(2016). 'Grid connected energy storage research and the Willenhall Test bed facility'. Institution of Engineering and Technology (IET)