DYNAMIC MODELLING OF DOUBLY FED INDUCTION GENERATOR BASED WIND TURBINE SYSTEM

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Abstract- The dynamic model of doubly fed induction generator (DFIG) wind turbine including models for both mechanical components as well as for all electrical components. It is also consisting of controllers and protective device for this model during grid faults. The main aim of this paper is to modelling of a variable speed wind turbine with doubly-fed induction generator (DFIG). They are widely used in wind energy generation systems. Here, the rotor is considered fed by a voltage source converter (VSC) whereas the stator is connected to the grid directly. A mathematical model of the machine is written in appropriate d-q reference frame that is established to investigate simulations. The capacity of the wind power generation is 2MW. The voltage rating and frequency for this system are 690V, 50Hz. The location of wind turbine is selected at near the Sitaway Area, Rakhaing State (range from 4 to 8 m/s) which is one of the possible wind power generation sites in Myanmar. This paper describes modelling, simulation, reactive power control strategies and performance analysis of DFIG coupled with wind turbine.

Keywords- Doubly-fed Induction Generator, Modelling and Simulation, Reactive Power Compensation, Variable Speed Wind Turbine, Voltage Source Converter.

I. INTRODUCTION

Myanmar has many hilly regions in rural areas and costal region of 2832 km strip which are promising areas to harness wind energy sources. Among them, wind pattern in Myanmar is generally not regular and low in capacity to produce sustainable energy at the current availability of technology. The promising areas to harness wind energy sources are the hilly regions of Chin and Shan State, Coastal region. The results from the data of NEDO, (New Energy and Industrial Technology Development Organization) of Japan indicate that the feasible area to harness wind energy are in locations an average wind speed of 5.6 to 7.4 meters per second, Potential available wind energy along this coastal strip, with it's southwesterly wind for 9 months and northeasterly wind for 3 months, is around 365.1 TWhr/yr. But install capacity is only 0.5194 MW. Moreover, although Myanmar has no wind map for suitable site of wind power application, the data of yearly average wind velocity.

Relevant to good wind condition area, there is better wind power density in the reference table[4] This paper analyzes the behaviour of Doubly-Fed Induction Generators (DFIG) used with wind turbines to capture wind energy and transfer it to the grid. A fundamental concept in power at any given point in time, dependent in large part on understanding wind technology is wind energy capture.

As wind speed can vary greatly, wind turbines must be capable of operating over a wide wind speed range [1].General, the efficiency of variable-speed systems is higher compared to the one of fix-speed systems.

Table I
The Yearly Average Wind Velocity in Myanmar
(Source: NEDO, Japan)[4]

No	Location Size	Wind Speed
1	Myint kyina	1.3m/s
2	Lashio	0.3m/s
3	Mandalay	2.3m/s
4	Monywa	2.4m/s
5	Hakha	4.0m/s
6	Mekilia	4.8m/s
7	Taungyi	2.7m/s
8	Magwe	1.5m/s
9	Loikaw	1.7m/s
10	Sitaway	6.7m/s
11	Kyaukpyu	1.9m/s
12	Bago	1.2m/s
13	Yangon	2.5m/s
14	Pathein	2.2m/s
15	Mawlamyin	2.3m/s
16	Dawei	0.7m/s
17	Myeik	1.5m/s

In this paper, a doubly-fed induction generator (DFIG) is used to regulate the turbine speed. An alternative is to use an asynchronous generator with its rotor connected to a voltage source converter (VSC) via slip rings, a so-called doubly fed induction generator. In this concept, the VSC is connected to a control system that determines the voltage that the VSC impresses onto the rotor of the induction generator.

This concept also provides variable-speed capability, which makes it possible to optimize power production and electromagnetic torque.[3]

Most of the major wind turbine manufactures are developing new larger wind turbines in the 3-to-5-MW range[1].These large wind turbines are all based on variable-speed operation with pitch control using a direct driven synchronous generator (without gearbox) or a doubly-fed induction generator (DFIG). The main goal of this paper is to propose an integrated and particular DFIG model. Simulation was carried out on a 2 MW wind-turbine driven DFIG system. Results from modelling system show that the proposed DFIG model fairly approaches the actual DFIG.

II. DOUBLY FED INDUCTION GENERATOR

The doubly fed induction generator consist of a wound rotor induction generator with the stator windings directly connected to the constant frequency three phase grid and with the rotor windings mounted to a bi-directional back-to-back IGBT voltage source converter. The term 'doubly fed'refers to the fact that the voltage on the stator is applied from the grid and the voltage on the rotor is induced by the power converter.This systems allows a variable speed operation. The converter compensates the different between the mechanical and electrical frequency by injecting a rotor current with a variable frequency [1].

The power converter consists of two converters, the rotor side converter and grid side converter which are controlled independently of each other. Depending on the operating conditions of the drive, power is fed into or out of the rotor in an over synchronous operation, it flows from the rotor via the converter to the grid whereas it flows in the operation direction in a sub synchronous operation. In both cases, sub synchronous and over synchronous_ the stators feed energy into the grids.[2]

The DFIG has several advantages. It has the ability to control reactive power and to decouple active and reactive power control by independently controlling the rotor excitation current. The DFIG has not necessarily to be magnetised from the power grid, it can be magnetised from the rotor circuit, too. It is also capable of generating reactive power that can be delivered to the stator by the grid-side converter. However, the grid-side converter normally operates at unity power factor and is not involved in the reactive power exchange between the turbine and the grid. In the case of a weak grid, where the voltage is fluctuating, the DFIG is ordered to produce or absorb an amount of reactive power to or from the grid, with the purpose of voltage control. The size of the converter is not related to the total generator power but to the selected speed range and hence to the slip power. Thus the cost of the converter increases when the speed range around the synchronous speed becomes wider. This figure show operating principle of doubly fed induction generation [1].

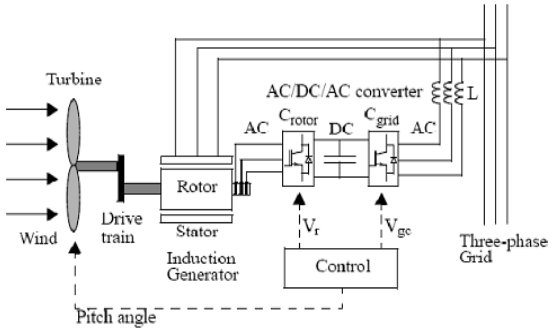


Fig. 1 Doubly fed induction machine based wind turbine

III. WIND TURBINE MODEL

The output power of the turbine is given by the following equation [2]

$$P_m = C_p(\lambda,\beta)\frac{\rho A}{2}V^3 \quad (1)$$

Where,

P_m = Mechanical output power of the turbine (W),
C_p = performance coefficient of the turbine,
ρ = the air density (kg/m^3),
A = the turbine swept area (m^2),
V = wind speed (m/s),
λ = tip speed ratio of the rotor blade tip speed to wind speed and
β = the blade pitch angle (deg).[3]

Wind power coefficient C_p is dependent upon λ If pitch angle β id incorporated C_p becomes a function of λ and β i.e

$$C_p = f(\lambda,\beta) \quad (2)$$

$$\lambda = \frac{R\omega_t}{v_w} \quad (3)$$

Where, λ is the ratio of turbine blades tips speed to wind speed, β is the blade angle and ω_t is the turbine blades rotational speed. In a wind turbine, C_p can be represented by a nonlinear curve in terms of λ in place of different β or the following relationship. [4]

$$C_p = (0.44 - 0.0167\beta)\sin\left[\frac{\pi(\lambda-2)}{13-0.3\beta}\right] - 0.00184(\lambda-2)\beta \quad (4)$$

IV. DYNAMIC MODEL OF DFIG

The dynamic performance of ac machine is somewhat complex because the three phase rotor windings move with respect to three phase stator windings. Hence a three phase machine can be represented with an equivalent two phase machine replacing the variables associated with the stator windings of a machine with

variables associated with fictious windings rotating with the rotor at synchronous speed[7].The analysis can be simplified greatly by transforming the three phase stator and rotor windings (with angular displacement) to a fictious two phase stator and rotor (with no displacement).These fictious two phase windings are called d-q windings.The stator and rotor a,b and c phase voltage equations can be transformed to the d-q axis[8].

In the dq reference frame rotating synchronously with the stator voltages equations for a DFIG can be written as follows[9]

$$V_{ds} = R_s i_{ds} + \frac{d\varphi_{ds}}{dt} - \omega_s \varphi_{qs} \quad (6)$$

$$V_{qs} = R_s i_{qs} + \frac{d\varphi_{qs}}{dt} + \omega_s \varphi_{ds} \quad (7)$$

$$V_{dr} = R_r i_{dr} + \frac{d\varphi_{dr}}{dt} - (\omega_s - \omega_r)\varphi_{qr} \quad (8)$$

$$V_{qr} = R_r i_{qr} + \frac{d\varphi_{qr}}{dt} + (\omega_s - \omega_r)\varphi_{dr} \quad (9)$$

The stator flux can be expressed as:

$$\varphi_{ds} = L_s i_{ds} + L_m i_{dr} \quad (10)$$

$$\varphi_{qs} = L_s i_{qs} + L_m i_{qr} \quad (11)$$

The rotor flux can be expressed as

$$\varphi_{dr} = L_r i_{dr} + L_m i_{ds} \quad (12)$$

$$\varphi_{qr} = L_r i_{qr} + L_m i_{qs} \quad (13)$$

The active and reactive power at the stator

$$P_s = v_{ds} i_{ds} + v_{qs} i_{qs} \quad (14)$$

$$Q_s = V_{qs} i_{ds} - V_{ds} i_{qs} \quad (15)$$

The active and reactive power at the rotor

$$P_r = v_{dr} i_{dr} + v_{qr} i_{qr} \quad (16)$$

$$Q_r = V_{qr} i_{dr} - V_{dr} i_{qr} \quad (17)$$

Where ω_s the stator flux pulsation, ω is the rotor electrical speed. In steady state conditions, by neglecting the stator phase resistance and by introducing the magnetizing current [10]

$$i_{ds} = \frac{\varphi_{ds}}{L_m} \quad (18)$$

the stator voltage and current components become[2]

$$V_{ds} = 0 \quad (19)$$

$$V_{qs} = |V_s| = \omega\varphi_{ds} \quad (20)$$

$$i_{ds} = \frac{L_m}{L_s}(i_{ds} - i_{dr}) \quad (21)$$

$$i_{qs} = \frac{-L_m}{L_s} i_{qr} \quad (22)$$

$$P_s = \frac{3}{2}\left(v_{ds} i_{ds} + v_{qs} i_{qs}\right) \quad (23)$$

$$Q_s = \frac{3}{2}\left(v_{qs} i_{ds} - v_{ds} i_{qs}\right) \quad (24)$$

$$P_s = -\frac{3}{2}|v_s|\frac{L_m}{L_s} i_{qr} \quad (25)$$

$$Q_s = \frac{3}{2}|v_s|\frac{L_m}{L_s}\left(\frac{|v_s|}{\omega_s L_m} - i_{dr}\right) \quad (26)$$

V. PROPOSED DESIGN MODEL FOR WIND TURBINE GENERATING SYSTEM

A 2MW wind farm connected to a 33-kV distribution system exports power to a 33-kV grid 400-kW resistive load is connected at bus B690. The wind turbine has a protection system monitoring voltage, current and machine speed. The DC link voltage of the DFIG is also monitored. Wind turbines use a doubly-fed induction generator (DFIG) consisting of a wound rotor induction generator and an AC/DC/AC IGBT-based PWM converter. The stator winding is connected directly to the 50 Hz grid while the rotor is fed at variable frequency through the AC/DC/AC converter. The DFIG technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind.

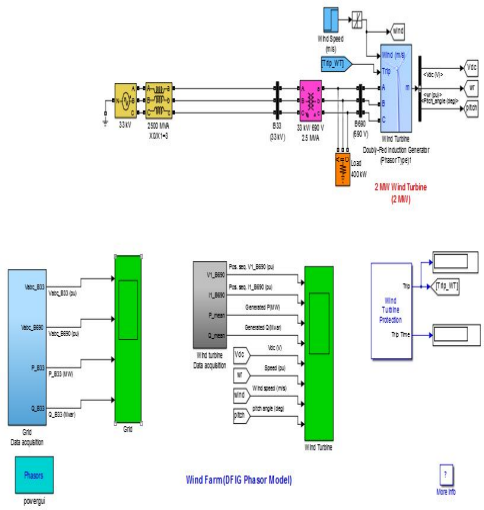


Fig. 2 Matlab model design for proposed wind turbine generating system

IV. TECHNICAL DATA FOR GENERATOR AND CONVERTER

Doubly fed induction generator needs the following parameter. They are generator data, converter data and other parameters.

Table II

Nominal Power	2 MW
Line to line voltage	690V
Frequency (f)	50 Hz
Stator Resistance(R_s)	0.00488pu
Rotor Resistance(R_r)	0.00549pu
Magnetizing Inductance (L_m)	3.95279pu

Table III

Max.Power	0.5pu
Grid-side coupling inductor (L,R)	0.15pu, 0.0015pu
Grid coupling transformer turn ratio	3
Nominal DC bus voltage	1200V
DC bus capacitor	10000e-6

Doubly-fed induction generator also has control parameters. They are grid voltage regulator gains, power regulator gains, DC bus voltage regulator gains and roto side current regulator gains. r side current regulator gains.

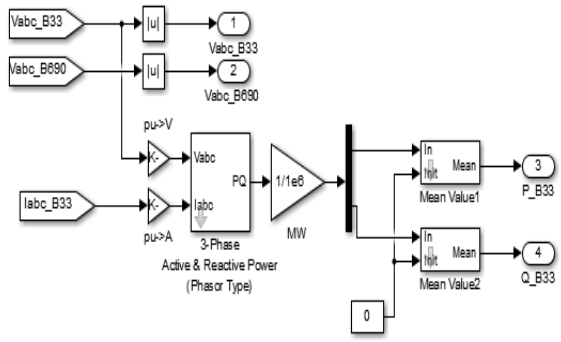


Fig 3.Block diagram of generated active and reactive power from wind

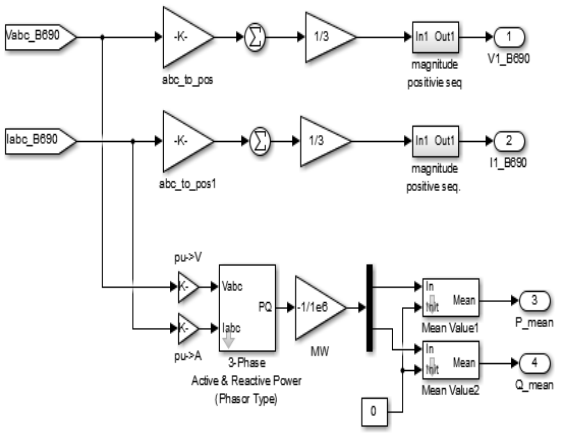


Fig 4.Block diagram of grid side data acquisition

VI. SIMULATION RESULTS OF 2MW WIND FARM WITH GRID SYSTEM

Initially, wind speed is set at 6m/s, then wind speed increases suddenly at 14 m/s at t=11s. Start simulation and shows the wind turbine voltage, current, generated active and reactive powers, DC bus voltage and turbine speed.

At t =15 s, the generated active power starts increasing smoothly (together with the turbine speed) to reach its rated value of 2 MW in approximately 15 s.

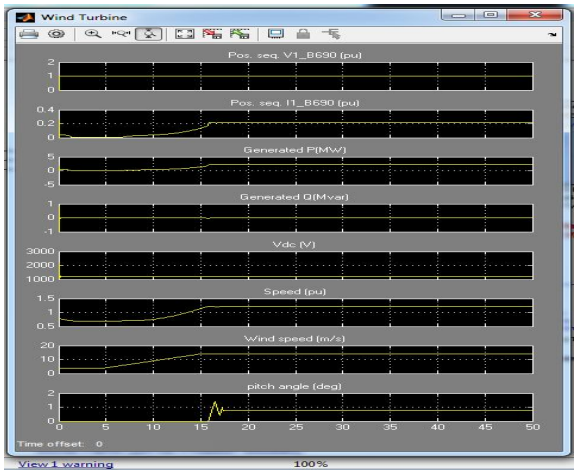


Fig. 5 Performance of a doubly fed induction generator wind turbine (wind speed=6m/s)

Over that time frame of the turbine speed will have increased from 0.8 pu to 1.21 pu between 5s to15s. Initially, the pitch angle of the turbine blades is zero degree and then the wind speed changes the pitch angle at this condition. At t=15s, it increase suddenly 0.76 deg after that the pitch angel will reach to a stable limit.

The reactive power is controlled to maintain a 1 pu voltage. At nominal power, the wind turbine absorbs 0Mvar to control voltage at 1pu. If it is changed the mode of operation to "Var regulation" with the "Generated reactive power Q_{ref} " set to zero, it will observe that voltage increases to 1.021 pu when the wind turbine generates its nominal power at unity power factor.

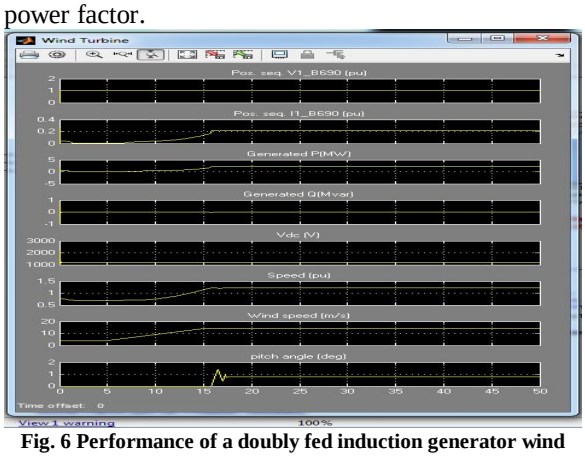


Fig. 6 Performance of a doubly fed induction generator wind turbine(wind speed 12m/s)

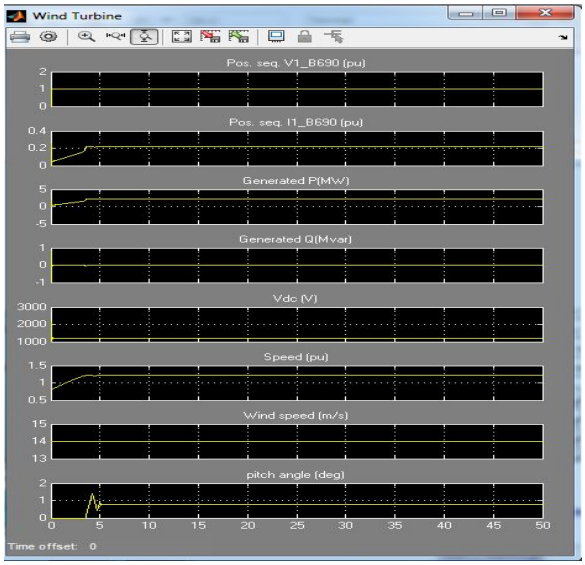


Fig. 7 Performance of a doubly fed induction generator wind turbine(wind speed=14m/s)

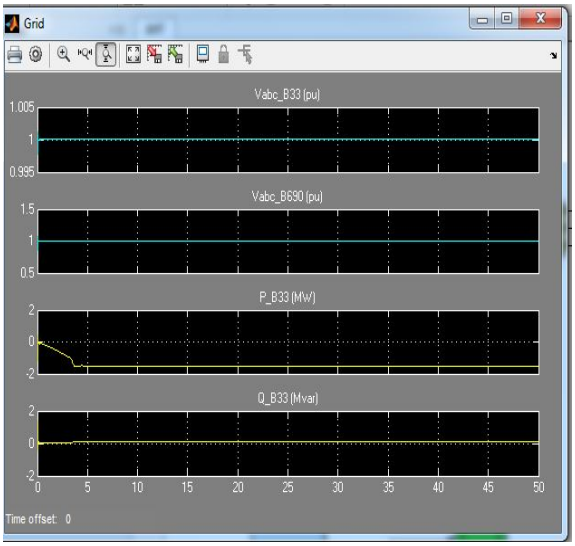


Fig. 8 Performance of a doubly fed induction generator wind turbine(wind speed=14m/s)grid side

This fig 8 show rated wind speed at t=14m/s produced rated output voltage, distribution line rated voltage, power and reactive power.

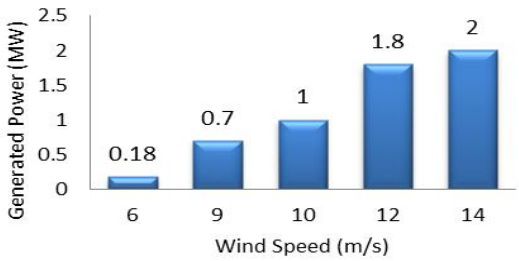


Fig. 9 Generated rated power at different wind speed

CONCLUSION

The dynamic modelling of a doubly-fed induction generator driven by a wind turbine has been described. This paper discussed the different wind speed simulated for DFIG wind turbine system at proposed area in Myanmar. Especially, Generated power, DC voltage, wind speed, pitch angle and grid side voltages are identified by using MATLAB simulation model. Due to the advances in power electronics it is advantaged to use the doubly fed induction generator system with variable speed connected to the electrical grid through an AC-DC-AC converter, that improving the efficiency of the power conversion. The DFIG is able to provide a considerable contribution to grid voltage support during short circuit periods. By considering the results it can be said that DFIG proved to be more reliable and stable system when connected to grid side with the proper converter control systems.Due to above this control system,the result will give the optimal condition for the overall generation. It is certain that the advertence technology and knowledge of grid connected DFIG wind turbine generating system can be got from this paper.

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