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MATHEMATICAL MODELLING AND SIMULATION OF INDUCTION GENERATOR BASED WIND TURBINE IN MATLAB/SIMULINK

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ABSTRACT

In recent years, wind turbine has becoming a satisfactory alternative for electrical power generation by fossil or nuclear power plants, because the environmental and economic benefits. Still, try to improve wind turbines output and make them more commercial and reliable. Wind energy utilization is an improvisation on technology of wind turbine. It is estimated that, within the next two to three decades, wind energy technology will be durable for power generation. This paper presents mathematical model and simulation of Wind turbine based on induction generator. For the modelling we consider drive train, asynchronous or induction generator (IG). The presented model, dynamic simulation and simulation results are tested in MATLAB/SIMULINK. Also this work covers the variable wind speed and pitch angle observation. Difficulties parts of wind turbine are analyzed.

Keywords: aerodynamic, drive train, induction generator, MATLAB/SIMULINK.

INTRODUCTION

For the past few decades, the demands of energy have been gradually increasing, especially for electrical power and environmental issues and this has become a challenging issue for the world. Furthermore, pollution is growing parallel with the energy demand while sources of conventional energy such as fossil fuels are rapidly depleting. Over the last few decades, researchers have been conducting studies to improve the energy efficiency [1]. This has led to the discovery of various alternatives for renewable energy that is a combination of natural sources and it is used for electrical power generation. These natural sources are in form of sunlight, geothermal heat, wind, tide, water, and various forms of biomass. These sources are free of cost and reduce the greenhouse effect. Power generation from renewable energy, especially from wind energy is rapidly growing. Wind energy is one of the more popular sources of an environmental-friendly energy source and it has become an important part of the distribution of power in the world. Wind power or wind energy is produced from wind turbines where kinetic energy is converted to electrical energy using natural wind. Wind has been used for various purposes such as wind mills for mechanical power, water pump by wind power and ships that use sails. It is a substitution of fossil fuels because of minor impact upon the environment and is free to use. A wind farm consists of many standalone wind turbines together and the electrical power transmission line is connected using the wind turbines. The analytical news from the European Union (EU) provides a new construct that wind turbine is an expensive source of electrical power that is competitive with gas, coal and fossil fuel plants. The windmill has been developed day by day. At this present moment, the windmill has reached the modern era. At present, wind turbines are manufactured by new technology in a wide range. The rapid developments of wind turbine are with both, horizontal and vertical axis types. There are different sizes of wind turbines available nowadays. A small sized wind turbine can be used for battery charging, caravans, board and power traffic warning. Medium sized wind turbines are used for domestic power supply. These days, the wind farm has become an important source of renewable energy as well as electric power. Recently, many countries have come to depend on wind power. There are also several countries that are concerned about the changing of the global climate as well as wind energy. Installation of wind farms is increasing and the contribution of wind turbines is remarkable. Presently, wind energy is the faster growing source among the other alternatives sources of renewable energy [2].

A survey in 2010 has stated that wind power has produced 197 GW which is about 2.5% of the world's electricity. In the same year, China has surpassed the wind capacity of the United States of America (US) and China has become one of the world's big players in the field. The Denmark government produced about 28.1% of total power from wind farms and it was remarkable [3]. In the world, approximately 80% of wind energy is produced from among five countries which are Germany, USA, Denmark, India and Spain [4]. The United Nations (UN)-hosted Sustainable Energy Report in 2014 stated that these five countries have produced more than about 8 % of the total world power from last year. The wind capacity has reached a higher level of more than 318 GW at the end of 2013. This has shown that this type of energy is increasing every year. About 103 countries are producing wind power which helps to improve the current commercial growth rating. The evaluation from The World Energy Association stated that the wind power will be increased up to 700GW by the year 2020 [5]. Wind energy is a rapidly growing renewable source and the capacity of wind energy is dramatically increasing at present.

In Wind energy system, there are various kinds generator used such as double fed induction generator (DFIG), Asynchronous generator or induction generator (IG) and permanent magnet synchronous generator (PMSG). In this modelling, IG is used. The mechanical power is converted into electrical power through generator. It can be either alternating current (AC) generator or a direct current generator. The Alternating current generator can be asynchronous or synchronous generator. Most of the electrical machine drive on the action and reaction principle. For this reason, electromechanical energy transformation is reversible [6].

This paper presents the mathematical model and simulation of wind turbine based on Induction generator. In section 2, Mathematical model of wind turbine different section is presented and section 3 shows the simulation and results.

WIND TURBINE MODEL

Wind turbines is the system where electricity produced by using mechanical components and electrical generator. Wind passes over the blades of WT. Lift and exerting a turbine force are generating. In nacelle, the rotating blades turn a shaft that goes into a gearbox. The drive train is increasing the rotational speed that appropriate for wind turbine generator and rotational speed converted into electricity. Wind power extract from the wind by the rotor which is limited by the Betz limit (maximum 59%), Therefore, the mechanical power is expressed in Equation. (1)

$$P = 0.5. C_p. (\lambda, \beta). \rho. A. v^3 \quad (1)$$

Where $C_p(\lambda, \beta)$ is the power coefficient, ρ is the air density ($1.25 kg/m^2$), V_w is wind speed(ms^{-1}), and A swept area A is given the equation $A = \pi R^2$.Where R is the radius of blade(m). Figure 1 shows the global scheme of variable speed wind turbine.

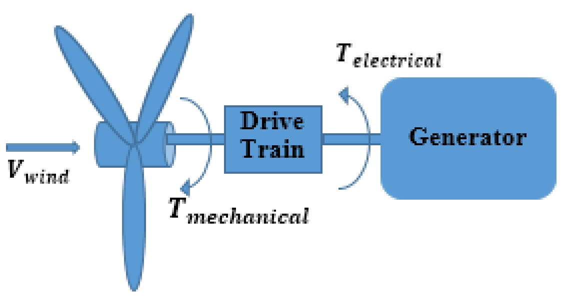

Figure-1. Wind energy scheme.

Aerodynamic model

The blades of wind turbine extract the kinetic energy from the wind and converted mechanical energy. The kinetic energy is equal to the mass of air m and the wind speed in Equation. (2)

$$E = \frac{1}{2}. m. v^2 \quad (2)$$

The moving air power is equal to

$$P_w = \frac{dE}{dt} = \frac{1}{2}. m. v^2 \ (2) \quad (3)$$

Where m is the mass flow rate per second. The air passes across an area A. From the Equation. (3)

$$P_w = \frac{1}{2} m. A. \rho. v^2 \quad (4)$$

Where ρ is the air density ($\rho = 1.225 kg/m^2$)
The power extracted from the wind by the blades

$$P_{Blade} = C_p(\lambda, \beta). P_w = C_p(\lambda, \beta). \frac{1}{2} m. A. \rho. v^3 \quad (5)$$

where C_p is the power coefficient. The power coefficient given two function. β (in degree) is the pitch angle of the rotor blades. The theoretical value of power coefficient is$C_p = 0.593$. λ is defined the tip speed

$$\lambda = \frac{\omega_m R}{v} \quad (6)$$

Where ω_m is the angular velocity of the rotor and R is the length of the rotor blade. The rotor torque given the Equation.

$$T_w = \frac{P_{Blade}}{\omega_m} = \frac{\pi C_p(\lambda, \beta) \rho R^2 A v^3}{2\omega_m} \quad (7)$$

The power coefficient C_p is defined as a function of the blades angle and the tip-speed ratio

$$C_p(\lambda, \beta) = c_1(c_2. \frac{1}{\gamma} - c_3. \beta - c_4. \beta^x - c_5) e^{-c_6 \frac{1}{\gamma}} \quad (8)$$

With γ defined as $\frac{1}{\gamma} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{1 + \beta^3}$ (9)

Where the coefficients are equal to $C_1 = 0.5, C_2 = 116, C_3 = 0.4, C_4 = 0, C_5 = 5, C_6 = 21$ ($C_4 = 0$ that why x is not used)

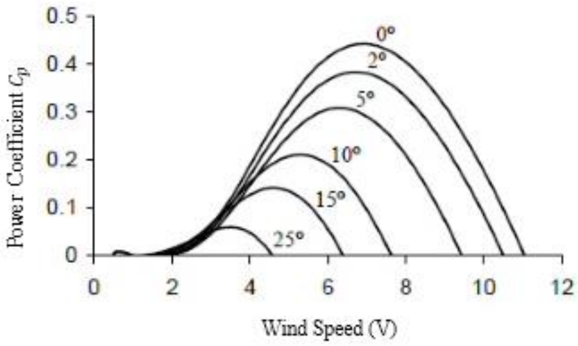

Figure-2. Power coefficient $C_p(\lambda, \beta)$ of different pitch angle.

Figure-2 shows the power coefficient (C_p) with wind speed. The power coefficient depends on the pitch angle of the blades. The C_p is increasing with the pitch angle decreasing. The C_p depends on the wind turbine. From the Figure 2, the maximum C_p is in certain wind speed. At a time, power coefficient is decreasing when wind speed cut out speed.

Drive train

In this paper, the mathematical model is presented two mass drive drain. The mathematical model are expressed by [7] .Two-mass model of wind turbine shown in Figure-3.

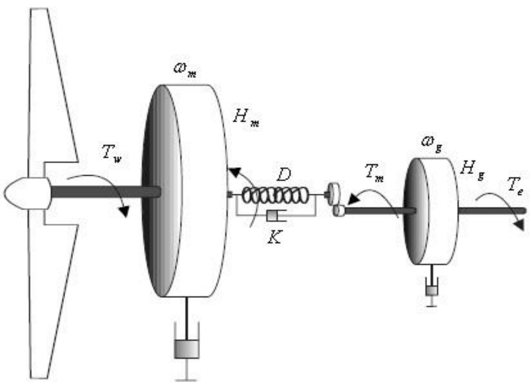

Figure-3. Two-mass model wind turbine [8].

The motion of the induction generator is given by

$$H_g \frac{d\omega_g}{dt} = T_e + \frac{T}{n} \tag{10}$$

An additional the motion of the windmill shaft is adopted

$$H_m . \frac{d\omega_m}{dt} = T_w - T_m \tag{11}$$

The mechanical torque T_m is given the equation

$$T_m = K\frac{\theta}{n} + D.\frac{\omega_g - \omega_m}{n} \tag{12}$$

$$\frac{d\theta}{dt} = \omega_g - \omega_m \tag{13}$$

Where, gear ratio n, θ is the angle between generator and turbine rotor, ω_g, ω_m are the turbine and generator speed respectively. The inertia constant of turbine and generator are H_m, H_g respectively, D and K are the damping and train stiffness constants

Induction generator

The perfect induction generator model is the complicated part in wind generation system [9]. IG consists with electromagnetic state variables, stator, rotor and electromagnetic transients. This model is also known as the fifth order model [10]. The slip ratio of the rotor is defined.

$$s = \frac{\omega_s - \omega_g}{\omega_s} \tag{14}$$

The slip output is positive in monitoring mode generating mode define negative. The electrical torque is given

$$T_e = \varphi_{qr} I_{dr} - \varphi_{dr} I_{qr} \tag{15}$$

Finally, the generator power is given by the Equation. (15)

$$P = V_{ds} I_{ds} + V_{qs}\, I_{qs} \tag{16}$$

The inductance stator and rotor position change with time as well rotor position. Park's transformation is usually used to overcome the complexity of the model. If such a transformation is used, the final equations are [11]. The magnetic flux of the generator equation as bellows:

$$\varphi_{ds} = X_s I_{ds} + X_m I_{dr} \tag{17}$$

$$\varphi_{qs} = X_s I_{qs} + X_m I_{qr} \tag{18}$$

$$\varphi_{dr} = X_r I_{dr} + X_m I_{qs} \tag{19}$$

$$\varphi_{qr} = X_r I_{qr} + X_m I_{qs} \tag{20}$$

The voltage of

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$$V_{ds} = -R_s I_{ds} + \omega_s \varphi_{qs} - \frac{d\varphi_{ds}}{dt} \quad (21)$$

$$V_{qs} = -R_s I_{qs} + \omega_s \varphi_{ds} - \frac{d\varphi_{qs}}{dt} \quad (22)$$

$$0 = -R_r . I_{ds} + s.\omega_s.\varphi_{qr} - \frac{d\varphi_r}{dt} \quad (23)$$

$$0 = -R_r . I_{ds} - s.\omega_s.\varphi_{qr} - \frac{d\varphi_r}{dt} \quad (24)$$

For the simulation of induction generator in wind turbine,V_{qs} And V_{ds} are the quadrature axis and stator direct voltage respectively. In addition, the I_{ds} and I_{qs} are the stator direct and quadrature axis current respectively. The sub-indexes (d, q) are the stator and rotor quantifies. φ Represented the magnetic flux.

SIMULATION AND RESULTS MATLAB/SIMULINK

In this section, the Wind energy conversion (WEC) model present in Fig.4. Basically it consist aerodynamic, drive train and induction generator. Usually the wind turbine operate at 3m/s to 25m/s. 10m/s wind speed was set in this simulation, Some portions of wind turbine like transmission and distribution system are were operate in (KV) range. The pitch angel of wind turbine was varying but in constant pitch angle, the power capture form wind is available. The generator power shown in Figure-5. For the variable wind turbine, the power output of wind turbine is fluctuating.

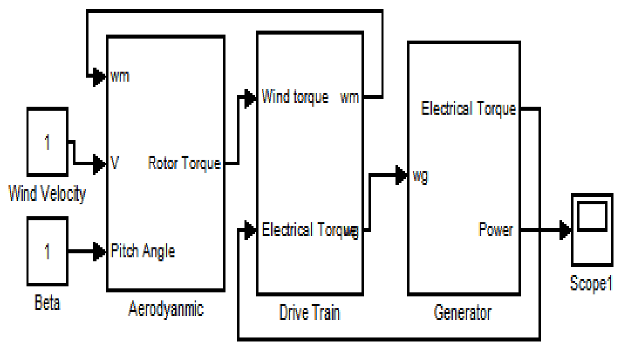

Figure-4. Wind energy conversion using MATLAB/SIMULINK.

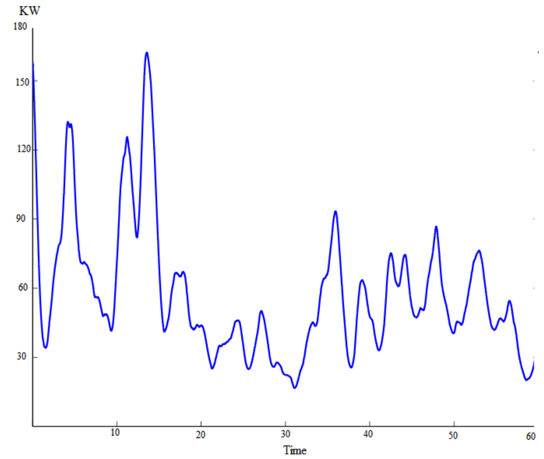

Figure-5. Generator power of wind turbine.

CONCLUSIONS

A wind energy conversion system consisting of the blades, mechanical parts and induction generator was modelled. To test the performance of the proposed model, wind turbine responses both to a step increase in wind speed and blade pitch angle were simulated. In both cases, the proposed model gave valuable insight into the performance of the variable speed wind turbine. As expected, the power generated increases with the wind speed, confirming the need of some sort of power control. On the other hand, an increment in the blade pitch angle proved to shed the aerodynamic power. As a normal dynamic simulation time step was adopted, this model was proven to be computationally efficient. Based on the obtained rigorous wind turbine model.

REFERENCES

[1] G. BoroumandJazi, R. Saidur, B. Rismanchi, and S. Mekhilef, "A review on the relation between the energy and exergy efficiency analysis and the technical characteristic of the renewable energy systems," Renewable and Sustainable Energy Reviews, vol. 16, pp. 3131-3135, 2012.

[2] F. Ponta, J. Seminara, and A. Otero, "On the aerodynamics of variable-geometry oval-trajectory Darrieus wind turbines," Renewable energy, vol. 32, pp. 35-56, 2007.

[3] M. Jureczko, M. Pawlak, and A. Mężyk, "Optimisation of wind turbine blades," Journal of Materials Processing Technology, vol. 167, pp. 463-471, 2005.

[4] T. Ackermann and L. Söder, "Wind energy technology and current status: a review," Renewable and sustainable energy reviews, vol. 4, pp. 315-374, 2000.

[5] J. Huang and M. B. McElroy, "A 32-year perspective on the origin of wind energy in a warming climate," Renewable Energy, vol. 77, pp. 482-492, 2015.

[6] Z. Lubosny and Z. Lubosny, Wind turbine operation in electric power systems: advanced modeling: Springer Heidelberg, 2003.

[7] B. Boukhezzar and H. Siguerdidjane, "Nonlinear control of variable speed wind turbines without wind speed measurement," in Decision and Control, 2005 and 2005 European Control Conference. CDC-ECC'05. 44th IEEE Conference on, 2005, pp. 3456-3461.

[8] B. Boukhezzar, L. Lupu, H. Siguerdidjane, and M. Hand, "Multivariable control strategy for variable speed, variable pitch wind turbines," Renewable Energy, vol. 32, pp. 1273-1287, 2007.

[9] M. Karrari, W. Rosehart, and O. Malik, "Comprehensive control strategy for a variable speed cage machine wind generation unit," Energy Conversion, IEEE Transactions on, vol. 20, pp. 415-423, 2005.

[10] M. Martins, A. Perdana, P. Ledesma, E. Agneholm, and O. Carlson, "Validation of fixed speed wind turbine dynamic models with measured data," Renewable Energy, vol. 32, pp. 1301-1316, 2007.

[11] O. Chee-Mun, "Dynamic simulation of electric machinery: using Matlab," Simulink, Editorial Prentice Hall, 1998.