Analysis of Pitch Angle Variation in Asynchronous Generator Wind Turbine
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Abstract:
This paper presents the analysis of pitch angle variation in Asynchronous generator wind turbine. The asynchronous generator wind turbine model consists of wind turbine profiles which attribute to the mechanical power and torque characteristics of wind turbine. The simulation model for Asynchronous generator wind turbine has been developed using a MATLAB/SIMULINK. The Asynchronous generator wind turbine model can work as induction generator. The wind turbine simulation model can display generated power and their values changes according to the wind velocity. The torque from the wind turbine simulator can be used to drive the asynchronous generator to generate the power fed into the load. The asynchronous generator wind turbine was tested upon step changes in the wind velocity as well as the blade pitch angle requirement of for power control. Simulation results obtained are encouraging.

Keywords — Wind energy, MATLAB/SIMULINK, pitch angle, induction generator, Wind velocity, Turbine power, Power coefficient, Tip speed ratio, Generator, Grid.

I. INTRODUCTION
Wind energy is one of the fastest growing renewable energies in the world. Wind as a source of power is very attractive because it is plentiful, inexhaustible, renewable and non-polluting. in recent years, due to decreases in fossil fuels, the energy shortage and environment pollution has affected the lives of the humans and social development. Conventional energy such as coal, oil and gas will be used out in a few years and will cause serious environmental problems. so the renewable energy, especially wind energy and solar energy have become more considerable all over the world [1]. a wind turbine is a rotary device that extracts energy from the wind and converts into rotary mechanical energy. Conventional wind energy is divided into three components. The first is the rotor which consists of two or three fibre glass blades joined to a hub that contains hydraulic motors that change each blade according to prevailing wind conditions so that the turbine can operate efficiently at varying wind speeds. the nacelle sits atop the tower and holds all the turbine machinery. Because it must be able to rotate to follow the wind direction, it is connected to the tower via bearings. the nacelle is the housing that protects the main frame and the components attached to it, the structural tower supports the rotor and the nacelle. The kinetic energy in the wind is converted into mechanical energy by the turbine shaft and gearbox arrangement because of the different operating speed ranges of the wind turbine rotor and generator. the generator converts this mechanical energy into electrical energy. The mechanical power obtained can be used to perform important tasks such as grinding of grain or pumping of water. the electricity generated can be used in daily life activities such as power homes, schools, hospital, industries, businesses etc [4].as the wind penetration increases, the structure and dynamics of the power system network will change significantly over the coming decades. due to the intermittent nature of wind power, the replacement of traditional synchronous generators with power electronic converter-based synchronous generators will introduce special challenges in; grid...
interconnections and bi-directional power control, tight voltage and frequency regulation, dynamic stability, low voltage fault ride through, satisfy grid code, system security, reliability, and protection. Therefore, a better understanding of the technology involved with the grid integration of the variable speed wind turbines and possible impacts of large scale wind integration to the power grid is mandatory to ensure reliable and secure operation of the power system[8].

II. WIND TURBINE COMPONENTS

Wind turbines are designed to exploit the wind energy that exists at a location. Aerodynamic modelling is employed for determination of optimum tower height, control systems, number of blades and blade shape. Conventional horizontal includes the blades can be divided into three components. The rotor component includes the blades for converting wind energy to low speed rotational energy and costs about 20% of the total cost of wind turbine. The generator component includes the electrical generator, the control electronics and most likely a gearbox for converting the low speed incoming rotation to high speed rotation suitable for generation of electrical energy. it approximately costs about one-third of total cost of wind turbine. The structural support component includes the tower and rotor yaw mechanism and costs about 15% of the wind turbine cost. Other equipment’s including electrical cables, ground support equipment and interconnection equipment.

The actual power output of a wind turbine generator (WTG) system depends on the actual wind speed, rated wind speed, cut in speed (i.e., speed at which system losses equal the extracted wind power) and cut out speed (i.e. speed at which the wind mill has to be shut down for safety reasons.) The power output can be approximated by the relation [6].

Actual power output = \( P_r \) for \( v > v_{col} \) \n= \( \begin{align*}
(A + Bv + cv^2) & \text{ for } v_{ci} < v < v_t \\
(\text{cut in wind speed} & v_t) \text{ for } v_t < v < v_{col} \\
0 & \text{ for } v > v_{col}
\end{align*} \)

Where
\( v = \text{actual wind speed} \)
\( P_r = \text{rated power output} \)
\( v_{ci} = \text{cut in wind speed} \)
\( v_t = \text{rated wind speed} \)
\( v_{col} = \text{cutout wind speed} \)

A, B, C are functions of \( v_{ci} \) and \( v_t \)

Fig. 3 shows three circular at inlet, turbine blade and exit of wind

III. WIND TURBINE OUTPUT EQUATION
The mass flow rate must be the same across the three areas i.e. inlet, turbine rotor and exit. Therefore

\[ \rho A_i v_i = \rho A_t v_t = \rho A_e v_e \] ........2

The rotor induces a velocity variation which is superimposed on the free stream velocity. The induced flow at rotor is \( v_t \), where ‘a’ is called the axial flow induction factor. Therefore

\[ v_t = v_i (1 - a) \] ........3

The air undergoes a change in velocity \( v_i - v_e \) from inlet to exit. The rate of change of momentum is equal to mass flow rate multiplied by change of velocity. Therefore

\[ \text{Rate of change of momentum} = (v_i - v_e) \rho A_t v_t \] ........4

The force which causes change of momentum is due to pressure difference across the rotor. The change in pressure is from \( p_i^+ \) to \( p_i^- \). Therefore

\[ (p_i^+ - p_i^-) A_t = (v_i - v_e) \rho A_t v_t = (v_i - v_e) \rho A_t (1-a) \] ........5

To find \( p_i^+ - p_i^- \) we can use Bernoulli’s equation. As per Bernoulli’s equation, under state conditions the total energy in the flow (i.e. sum of kinetic energy, static pressure energy and gravitational potential energy) remains constant provided no work is done on or by the fluid. Thus for a unit volume of air

\[ P_i^+ - P_i^- = \rho A_t v_t (1-a) \]
\[
\frac{1}{2} \rho v^2 + p + \rho g h = \text{constant} \quad \cdots \cdots 6
\]

Upstream conditions give
\[
\frac{1}{2} \rho v_i^2 + p_i + \rho g h_i = \frac{1}{2} \rho v^2 + p_i^* + \rho g h_i \quad \cdots \cdots 7
\]

Assuming the flow to be incompressible \( (\rho_i = \rho_t) \) and horizontal \( (h_i = h_t) \) we get
\[
\frac{1}{2} \rho v_i^2 + p_i = \frac{1}{2} \rho v_t^2 + p_i^* \quad \cdots \cdots 8
\]

Downstream conditions give
\[
\frac{1}{2} \rho v_e^2 + p_i = \frac{1}{2} \rho v_t^2 \quad \cdots \cdots 9
\]

Subtracting Eq. (9) from Eq. (8)
\[
p_t - p_i = \frac{1}{2} \rho (v_i^2 - v_e^2) \quad \cdots \cdots 10
\]

Subtracting Eq. (10) into Eq. (5) we get
\[
\frac{1}{2} \rho (v_i^2 - v_e^2) A_t = (v_i - v_e) \rho A_t v_i (1-a) \quad \cdots \cdots 11
\]

Eq. (11) gives
\[
v_e = (1-2a) v_i \quad \cdots \cdots 12
\]

Thus half of axial speed loss occurs upstream of rotor and half downstream. From Eq. (5) the force \( F \) on air is
\[
F = (p_t^* - p_i) A_t = 2 \rho A_t v_i^2 a (1-a) \quad \cdots \cdots 13
\]

The rate of work done by force \( F \) is \( F v_i \). The power extracted from air is \( P_i \) and is given by
\[
P_i = F v_i = 2 \rho A_t v_i^3 a (1-a)^2 \quad \cdots \cdots 14
\]

Power coefficient \( C_p \) is defined as
\[
C_p = \frac{P_i}{\frac{1}{2} \rho v_i^2 A_t} \quad \cdots \cdots 15
\]

In Eq. (15), \( \frac{1}{2} \rho v_i A_t \) represents power available in air. Combining eq. (14) and (15)
\[
C_p = 4a (1-a)^2 \quad \cdots \cdots 16
\]

For maximum value of \( C_p, \frac{dC_p}{da} \) should be zero.
\[
C_p = 4a (1-a)^2 - 4a (1+a^2 - 2a)
\]
or
\[
C_p = 4a^3 - 8a^2 + 4a
\]

\[
\frac{dC_p}{da} = 12a^2 - 16a + 4 = 0
\]
or
\[
3a^2 - 4a + 1 = 0
\]

Which gives \( a = \frac{1}{3} \) \quad \cdots \cdots 17

Therefore
\[
C_{p, \text{max}} = 4 \left[ \left( \frac{1}{3} \right) (1 - \frac{1}{3}) \right] = \frac{16}{27} = 0.593 \quad \cdots \cdots 18
\]

This means that an ideal turbine cannot extract more than 59.3% of power in the undisturbed wind. This is known as Betz Criterion (named after German aerodynamicist Albert Betz)[6].

**IV Simulation Results for Asynchronous Generator wind Turbine Model**

Study is done by keeping following parameters as

- Fixed parameters = pitch angle in degree,
- Variable parameter = Wind speed in meter per second (m/s). The value of power for asynchronous generator wind turbine model is shown in Table-1.
Table-1 : Simulation Results of Generated Power (P) in Watts for Asynchronous Generator Wind Turbine Model

<table>
<thead>
<tr>
<th>Wind Speed (m/s)</th>
<th>P at Pitch angle =7</th>
<th>P at Pitch angle =8</th>
<th>P at Pitch angle =9</th>
<th>P at Pitch angle=10</th>
<th>P at Pitch angle=11</th>
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V Graphically Representation of AGWT- Model Result

The graphs between power and wind speed for asynchronous generator wind turbine model are shown in figures 4 to 9.
Fig. 4: Power v/s Wind Speed Curve

Fig. 5: Power v/s Wind Speed Curve

Fig. 6: Power v/s Wind Speed Curve

Fig. 7: Power v/s Wind Speed Curve

Fig. 8: Power v/s Wind Speed Curve

Fig. 9: Power v/s Wind Speed Curve
VI. CONCLUSION

This paper has presented the simulation of Asynchronous generator wind turbine model by using a MATLAB/Simulink. Variable values of power are obtained for fixed pitch angle and different wind speed. This paper gives the brief description of the output characteristics of wind turbine as well as asynchronous generator. Also describes the effect of changes the value of wind speeds and pitch angle on output characteristics. This Asynchronous generator wind turbine Model is designed to give maximum power at different values of pitch angle and wind speed.

REFERENCES


