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Modeling and Simulation of Wind Turbine in Wind-Diesel Hybrid System for rural application

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ABSTRACT

Wind energy is the most important renewable energy and it has been used widely all over the world. Wind diesel hybrid system that consists of diesel generators with wind turbine generators. Wind diesel hybrid system is mainly used to reduce fuel consumption with wind only mode (i.e. when diesel generator is not running).The wind diesel hybrid system gets maximum power from wind.This paper presents modelling and simulation of wind turbine in wind diesel hybrid system. Performance analysis is carried out using Matlab/Simulink software. This paper also explains the benefits and various application of battery energy storage system (BESS) in hybrid system.

Keywords: Wind energy, Wind speed, Pitch angle, Simulation, MATLAB/Simulink, Diesel Generator, Battery Energy Storage System

1. INTRODUCTION

The use of non-conventional energy sources is growing day by day. Wind power has become one of the most attractive energy resources as it is almost pollution-free (if noise is not considered as pollution) when used for electricity production. Wind is only an intermittent source of energy and wind power has proven extremely cost effective at good windy sites. Wind energy is one of the fastest growing renewable energies in the world. The generation of wind power is neat, clean and non-polluting; it does not produce any byproducts which is harmful to the environment.

The power in the wind is proportional to the cube of the speed and hence the presence of changing wind speed and weather systems can lead to variable power availability. Wind energy is deemed clean, unlimited, and environmental friendly. Such merits have attracted the energy sector to use renewable energy sources on a larger scale. However, all renewable energy sources have drawbacks. Wind source is dependent on weather and climatic conditions. The wind turbine arrests the winds kinetic energy due to blowing of wind in a rotor consisting of two or more blades which are mechanically coupled to an electrical generator in wind turbine.

2. HYBRID POWER SYSTEM

Hybrid power system involves a combination of two or more modes of electricity generation devices or sources such as wind turbines, PV, micro-hydro and/or fossil fuel generators. They are generally independent of centralized power grids and can be used in remote/rural areas. The use of RES in hybrid power generation systems reduces the reliance on expensive fuels while allowing for a cleaner generation of electrical power. HPS states limitations in terms of fuel flexibility, efficiency, reliability, emissions and/or economics as well as elimination of fuel transportation costs. Figure 1 shows the schematic diagram of a basic HPS involving various sources.

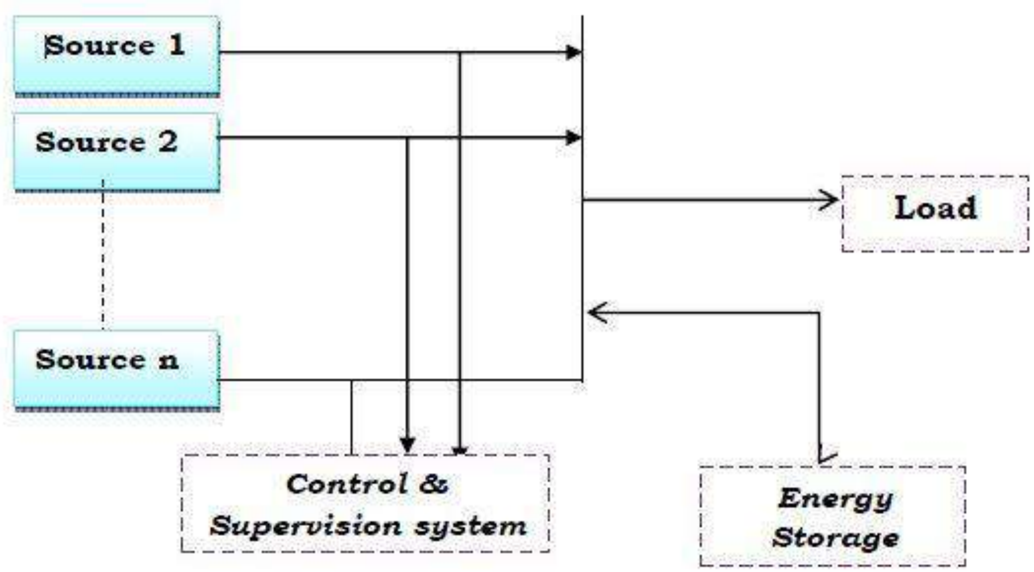

Figure 1 : Basic HPS

A hybrid power system mainly contains Alternating Current (AC) diesel generators, power converters an AC distribution system, a Direct Current (DC) distribution system, loads, RES, energy storage, dump loads, coupled diesel system, a supervisory control system. A schematic diagram of the possibilities available from a HPS is illustrated in Figure 2 showing the operation of each of these components and the interaction between them.

In a HPS, a diesel power generator acts as a back-up system in circumstances which may give RES. The system is usually modified so that the diesel generator is not always required, but in that case other components must be added. There are a number of wind turbines that supply DC power as their principal output. These machines are typically in the smaller size range of 10kW or less. With suitable controls or converters they can support both AC and DC loads.

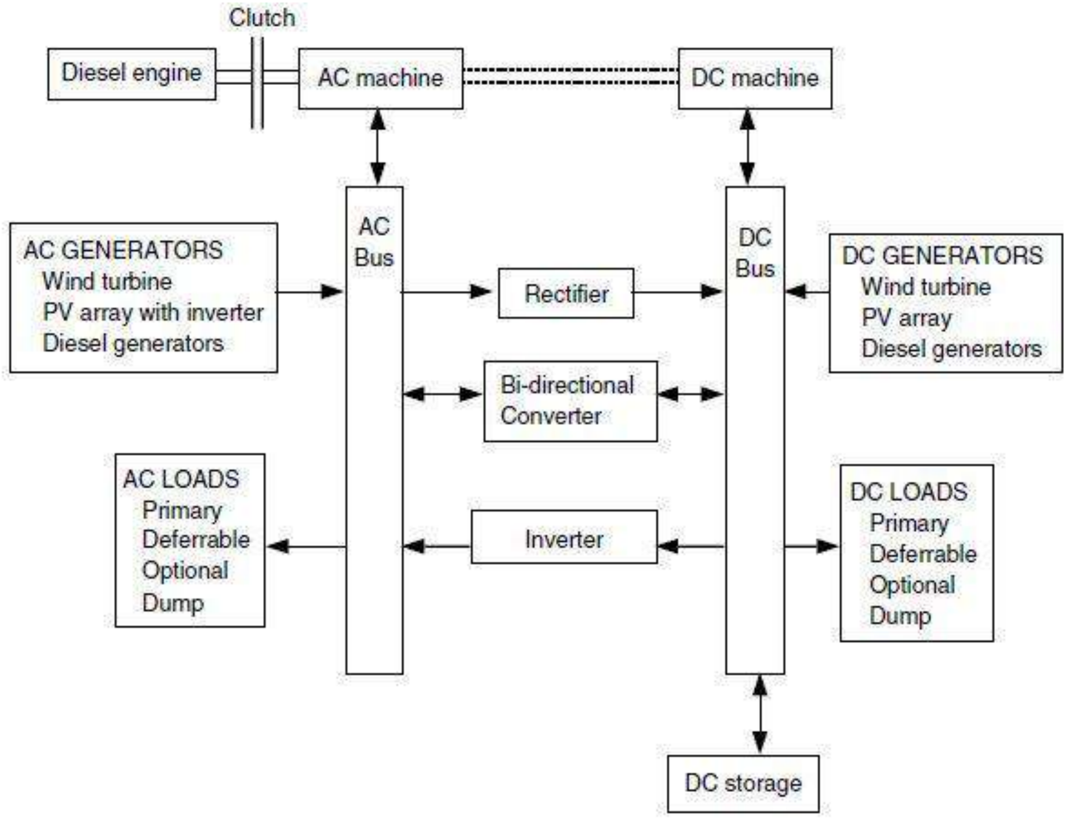

Figure 2 : HPS possibilities

3. WIND ENERGY CONVERSION SYSTEM

3.1 Wind resource

Wind energy is derived fundamentally from solar energy via a thermodynamic process. Sunlight warms the ground causing air above it to rise. The ensuing pressure differential causes air from elsewhere to move in, resulting in air motion (wind). Different regions on earth are heated differently than others—primarily a function of latitude. Air motion is also affected by the earth‘s rotation.

The net effect is that certain parts of the world experience higher average winds than others. The regions of highest winds are the most attractive for extracting its energy: Theoretically, the power which can be extracted from the wind is proportional to the cube of the velocity. The power that can be extracted in practice, however, is somewhat less than proportionally related to the cube of velocity according to ***Equation 3-1***.

$$\mathbf{P = 1/2C_P\ \rho\ A\ V^3}$$

Where

C_p = power Coefficient

ρ = Air density

A = Area swept by wind

V = Wind speed

From ***Equation 3-1*** the power in the wind is proportional to:

- The area of windmill being swept by the wind.
- The cube of the wind speed.
- The air density - which varies with altitude

3.2 Wind turbine

Wind turbine is an important element in a wind power system to generate electricity. It consists of a rotor mounted to a tower with two or more blades mechanically connected to an electric generator. The gearbox in the mechanical assembly converts slower rotational speeds of the wind turbine to higher rotational speeds on the electric generator. The rotation of the electric generator's shaft generates electricity whose output is maintained by a control system. Currently, two types of configurations for wind turbine exist, which are the vertical-axis wind turbines (VAWT) configuration and the widely used horizontal-axis wind turbine (HAWT) configuration. HAWT has the ability to collect maximum amount of wind energy for a given time of day and season and their blades can be adjusted to avoid high wind storm. Wind turbines operate mainly in two modes namely constant or variable speed turbine. For a constant speed turbine, the rotor turns at constant angular speed regardless of wind variations. One advantage of this mode of operation is that it eliminates the use of expensive power electronic converters. Its disadvantage is that it constrains rotor speed so that the turbine cannot operate at its peak efficiency in all wind speeds. For this reason, a constant wind speed turbine generates less energy at low wind speeds than does a variable wind speed turbine which is constructed to operate at a rotor speed proportional to the wind speed below its rated wind speed. The output power or torque of a wind turbine is determined by several factors. These include various parameters related to rotor such as turbine speed, rotor blade tilt, rotor blade pitch angle size and shape of turbine, area of turbine, rotor geometry whether it is a HAWT or a VAWT, and wind speed. A relationship between the output power and the various variables state the mathematical model of the wind turbine. In this research a model describing Horizontal Axis Wind Turbine (HAWT) was used to develop a controller that optimizes power generated by wind turbine.

4. MODELING OF WIND TURBINE

The mathematical formulation of turbine model considering the variation of wind speed is described. For an object having mass m and velocity V_w under a constant acceleration, the kinetic energy W_w is given by

$$W_W = \quad 1/2 \ m\, v^2 \qquad (1)$$

The mechanical power Pm in the wind is given by the rate of change of kinetic energy, i.e

$$P_W = \ dw_W/dt = \ 1/2 dm/dt \ V_w^{\,2} \qquad (2)$$

But mass flow rate dm/dt is given by

$$dm/dt = \rho \ A \ V_w \qquad (3)$$

where A is the swept area of the turbine and ρ is the density of air. With this expression, Equation 3 becomes

$$P_m = 1/2\ \rho\ A\ V_w^3 \qquad (4)$$

The actual mechanical power P_m removed by the rotor blades, in watts, is the difference between the upstream and the downstream wind powers, i.e.

$$P_m = ½\ \rho\ A\ V_w\ (V_u^2 - V_d^2) \qquad (5)$$

From equation 5, V_u is the upstream wind velocity at the entrance of the rotor blades in m/s and V_d is the downstream wind velocity at the exit of the rotor blades in m/s.

From the mass flow rate, Equation 3 can be written as

$$\rho\ A\ V_w = \rho\ A(V_u + V_d)/2 \qquad (6)$$

V_w being the average of the velocities at the entry and exit of rotor blades of turbine. With this expression, Equation 6 can be simplified and becomes

$$P_m = 1/2\ Cp(\rho;\ \beta)\ \rho\ A\ V_w^3 \qquad (7)$$

Cp is performance coefficient of the turbine (also known as power coefficient). The power coefficient Cp represents a fraction of the power in the wind taken by the turbine and has a theoretical maximum of 0.593. cp is often called the Betz limit after the Germany physicist Albert Betz who worked it out in 1919.

The power coefficient can be expressed by a typical empirical formula as

$$Cp = ½\ (\lambda - 0{:}022\beta^2 - 5.6)e^{-0.17\lambda} \qquad (8)$$

where _ is blade pitch angle (deg) and _ is the tip speed ratio of the turbine, defined as

$$\lambda = R_m\ W_b\ /\ V_w \qquad (9)$$

where Wb is the turbine angular speed (rad s^{-1}) and R_m is turbine radii(m). The mechanical power generated by the turbine rotor to the initial power of the wind turbine power coefficient Cp say that a non-linear relationship between the tip speed and blade pitch angle. Figure 3. shows that at different blade angle, the power coefficients vary with tip speed ratio. From Figure 3, it can be seen that the variation of power coefficient versus the blade pitch angle β. Where β gradually increases, the curve of Cp will decrease significantly. Generally, to achieve the maximum wind power, β value should be very small. If β is at a given value, then Cp has a maximum value C_{pmax}.

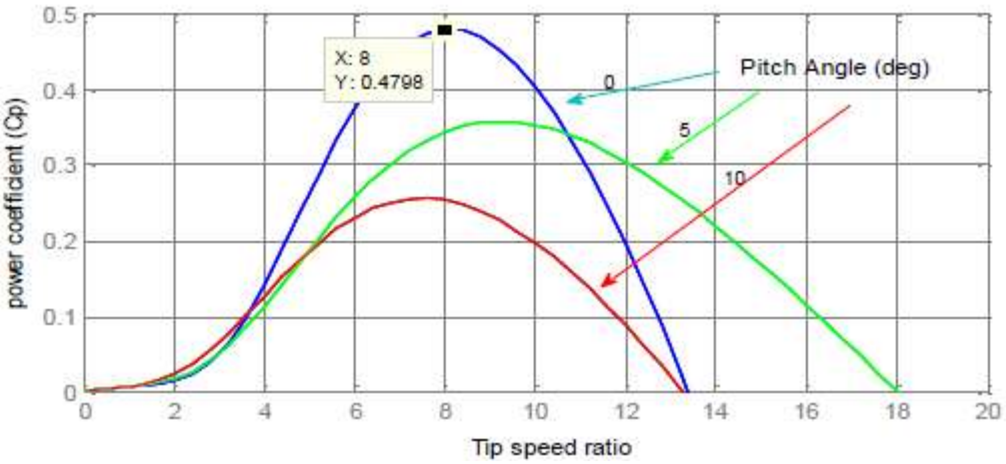

Figure 3: Power coefficient characteristics of a wind turbine.

According to Equation 8, the most important parameters to achieve the maximum power of wind turbine is Cp curve, so that maximum power output of wind turbines occurs when Cp is maximum. From the graph, at a constant β, the optimum Cp occurs at different values of β. So if the wind speed is considered constant, besides considering other parameters,Cp value will depend on the wind turbine rotor speed. Thus, by controlling the rotor speed, turbine power output is controlled. In addition, for each specific wind speed, there is only one rotor speed which leads to maximum power.

Figures 3 and 4 show the curves of the wind turbine power- rotor speed and turbine torque rotor speed for the different wind speeds. From the figures, it is clear that for the different power curves, the maximum powers are achieved at the different rotor speeds. Therefore, the rotor speed should be operated at the optimum speed.

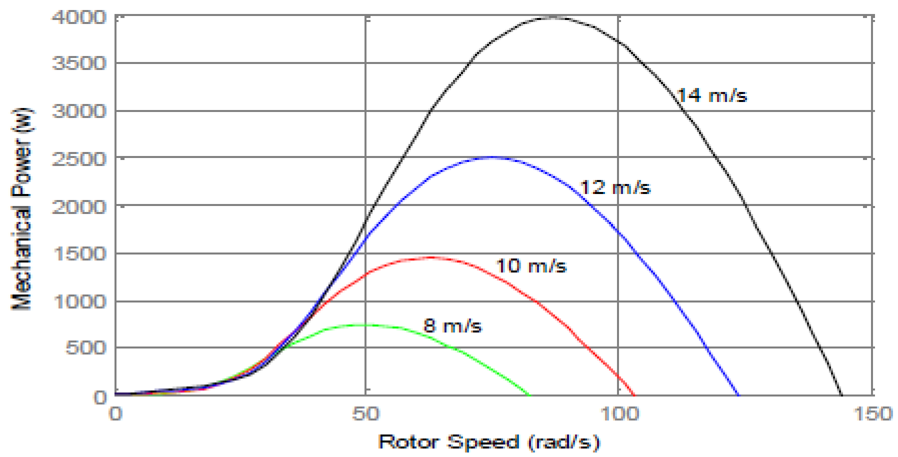

Figure4: The Torque curves for different wind speeds and zero pitch angle

5. BATTERY ENERGY STORAGE SYSTEM:

There is currently considerable interest in electrical energy storage technologies for a variety of reasons. These include an ever increasing reliance on electricity in industry, the commercial sector and homes, the growth of renewable energy sources to meet the growing demand for electricity, and all combined with ever more stringent environmental requirements. The need of energy storage is to transfer the excess power during weak loads or excess supply from RESs to the peak periods. The energy from the RESs has to be transformed into a storable energy form first and then transformed when storing is needed.

There are many energy storage techniques. To mention some:

- Battery Energy Storage System (BESS)
- Pumped Hydroelectric Storage System (PHSS)

- Superconducting Magnetic Energy Storage System (SMESS)
- Ultra-capacitors, etc.

There are different types of batteries, but the most commonly used rechargeable batteries include:
- Lead acid battery
- Nickel cadmium (NiCad) battery
- Nickel metal hydride (NiMH) battery
- Lithium ion battery
- Lithium-polymer battery
- Zinc-air battery

6. SIMULATION DETAILS

The MATLAB SIMULINK (2015b) software is used to simulate and to measure the active and reactive power.

Table1 Parameters

Sr.No.	Parameter	Values
1.	Wind Speed	12m/sec.
2.	Pitch angle	0deg.
3.	Voltage (line to line)	575V
4.	Frequency	60 Hz
5.	Nominal Power	4 MVA

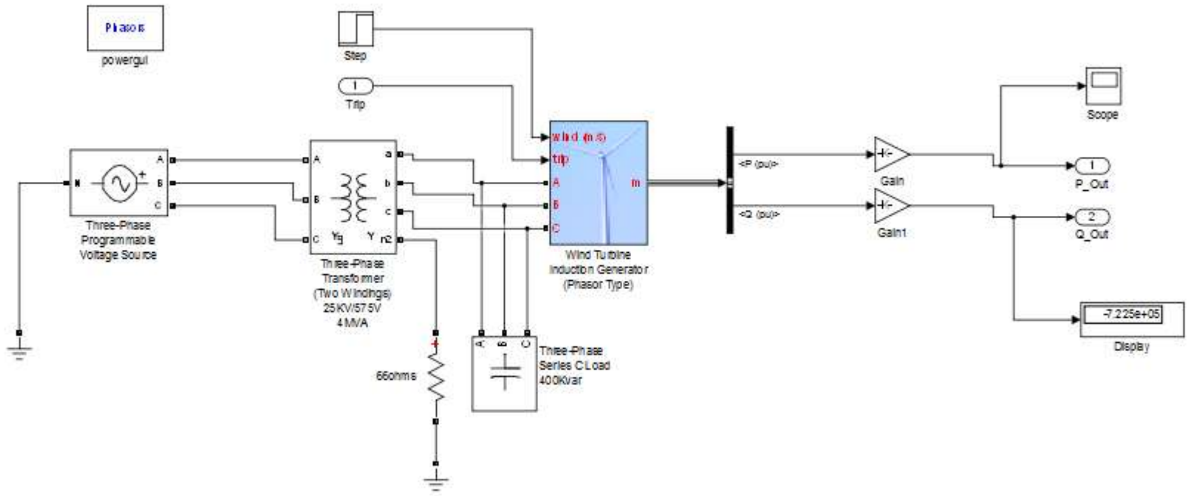

Fig 5. Simulation diagram of Wind Turbine

7.RESULTS

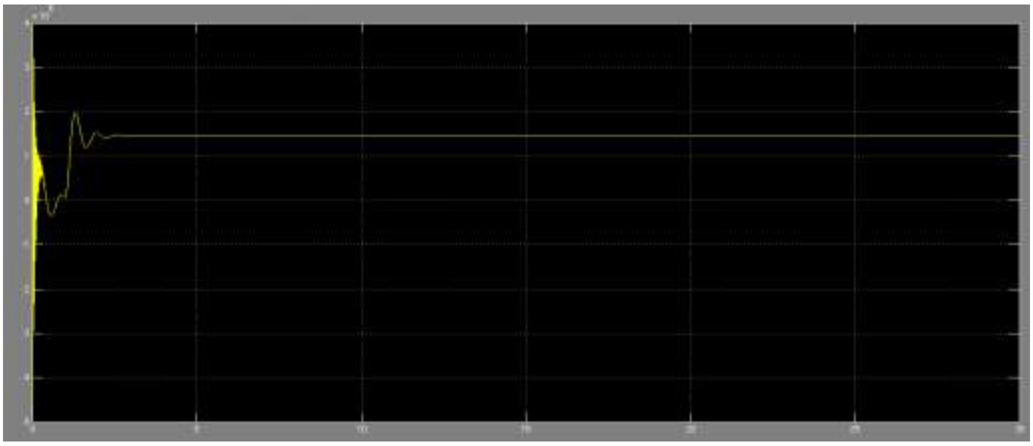

Fig.6 Active power Vs Time Waveform(wind turbine)

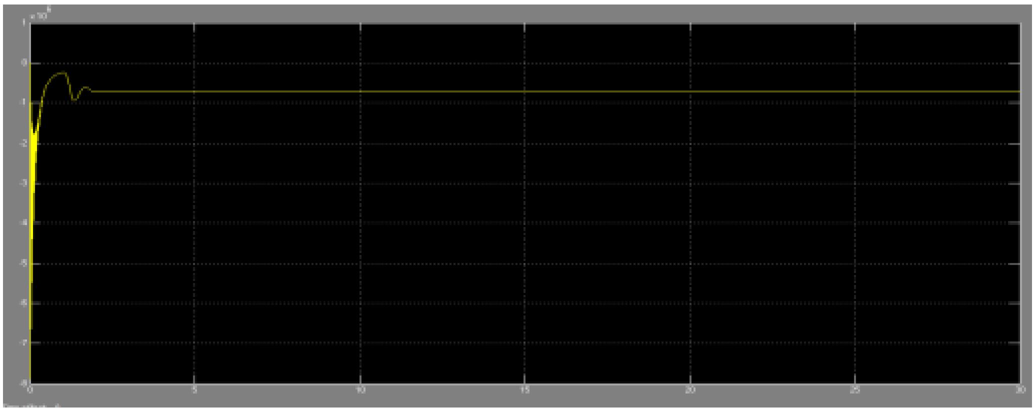

Fig 7.Reactive power Vs Time waveform(Wind turbine)

8. CONCLUSION

This paper also provides a clear understanding of the output characteristics of wind turbine and the effect of change of wind speed and pitch angle on these characteristics. Modeling and simulation has been conducted for investigating performance of a wind energy system. The modeling and simulation is performed using MATLAB/Simulink. Active and Reactive power output has been taken for values of wind speed with pitch angle.

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