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Design, construction and study of small scale vertical axis wind turbine based on a magnetically levitated axial flux permanent magnet generator

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ABSTRACT

A small scale vertical axis wind turbine (VAWT) with axial flux permanent magnet (AFPM) generator is designed and the magnetic levitation method is used to increase the efficiency of this type of wind turbine. Magnetic levitation is inserted by using rare earth permanent magnets, the repelling force of magnets are used to suspend the rotating part of both the turbine and generator. Moreover, this design of simple generator which can easily drive without a geared mechanism, lessen cost and the complexity of the system by reducing the quantity of driving components. Three phase output is obtained from the designed generator which is converted into direct current through a three-phase rectifier to charge the batteries. The performance of proposed prototype is also tested experimentally. From the results it is found that the designed wind turbine performs optimally and efficiently as predicted by the developed design process.

1. Introduction

In recent years rapid depletion of fossil fuels, increasing energy costs and environmental issues have become prominent issues due to excessive fossil fuel consumptions in different sectors. Therefore, the renewable resources are becoming a more viable technology for electrical power generation to meet those challenges. Among different types of renewable resources, wind turbines are capable of producing higher power in a smaller place when the wind turbine runs at nominal speed [1]. Although horizontal axis wind turbines (HAWT) are used commercially for higher capacity, the interest has now been growing for developing new technologies in small and medium size VAWT. Small scale VAWT needs more development for efficient use on domestic level [2].

The use of gear mechanisms is the major drawback of wind turbines which causes losses and also increases the cost of the wind turbine [3]. This gearbox can be replaced by using a direct drive generator system which reduces power losses, maintenance cost and hence the total cost. This model overcomes the issues of conventional AFPM by using a dual rotor plate configuration. Moreover bearings also can be replaced with magnetic levitation, which provides frictionless motion.

2. Turbine design

In VAWT the shaft is rotated around a vertical axis. To produce power, rotation of these turbines is perpendicular to the direction of wind. In a VAWT the generator is also connected perpendicular near the bottom of the turbine [4].

2.1. Power available in wind

The available energy in the wind is actually the energy contained in moving air particles such as oxygen, nitrogen and hydrogen. This energy is more commonly known as kinetic energy. Kinetic energy in a moving system can be calculated using the following formula;

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

Where, E is kinetic energy (J), M is system mass (Kg) and V is the velocity of the moving system (m/s). Power is the measure of energy produced or used over a period of time. The distance achieved by the air particles is the product of their velocity and the time they take to reach that particular distance. Equation (1) can be further developed to get an expression of power (P) for the wind turbine calculation;

$$P = \frac{1}{2} \rho A V^3 C_p \quad (2)$$

Where, ρ is the mass density of air at the sea surface (Kg/m^3) which is 1.225 kg/m^3, A is the cross-sectional area (m^2), V is the velocity of the moving system (m/s) and C_P is the power coefficient. The magnitude of the power depends heavily on the speed of the wind. A Small wind turbine needs strong wind in order to produce an extensive amount of power. Power coefficient (C_P) is used to calculate the amount of power captured by the turbine that was available in the wind as in the (3).

$$C_p = \frac{\textit{captured mechanical power by blade}}{\textit{Available power in wind}} \quad (3)$$

2.2. Determine the size of turbine

The length of rotor blades and the radius of the rotor are directly proportional to the output power of the turbine. The size of the wind turbine is also known as the swept area of that particular turbine. Fig. 1 shows the dimension of a wind turbine. Swept area of turbine differs according to the shape of rotor configuration. Because in HAWT the shaft rotates around horizontal axis so the swept area is calculated by a different formula with respect to VAWT [5]. The swept area of this turbine is calculated by using following formula;

$$A = 2RH \quad (4)$$

where, A is the turbine Area (m^2), R is the radius of turbine (m) and H is the height of the blade (m).

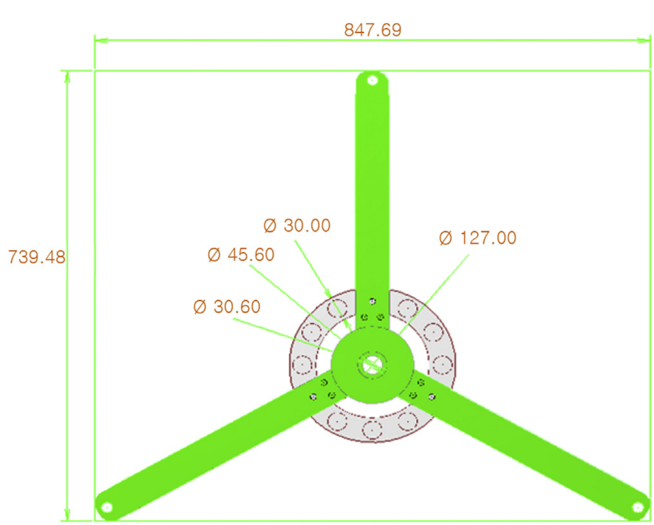

Fig. 1. Dimension of the wind turbine.

Because the area of turbine connects to the air to obtain its energy and convert into rotational energy, so if the area is greater it contacts more air and can obtain more power from the wind at the same wind speed.

2.3. Airfoil of the turbine

Darrieus type turbine blades use lift forces from wind to rotate the blades. The blades have an airfoil shape [6]. Turbine blade design has been selected keeping in mind the availability of data of the particular airfoil. The shape of blade and the thickness is determined by the data of such specific airfoil. There is enough data available to review the aerodynamic characteristics in documents issued by National Advisor Committee for Aeronautics (NACA) and Sandia National Laboratory. Fig. 2 shows the NACA airfoil design selected for wind turbine. In these documents for several NACA airfoils, lift and drag coefficient with Reynolds number and 0 to 180° ranging angle of attack are provided.

2.4. Solidity of the turbine

The smoothness of the rotor operation is directly affected by increasing and decreasing the number of blades of VAWT [7]. After determining the number of blades, the very important factor solidity is contemplated. Solidity is the ratio between the total area of blade and the radius of the turbine. Total area of blade includes number of blades and the chord length of the blade. Self-starting of the turbine can be effected by this non dimensional parameter. Solidity (σ) for a straight blade VAWT can be calculated as:

$$\sigma = \frac{Nc}{R} \quad (5)$$

where N is the quantity of the blade, C is the length of chord (m) and R is the radius of rotor (m). Power coefficient (C_P) also depends on the number of blades which decreases significantly as the number of blades decreases.

2.5. Efficiency of the wind turbine

In an energy conservation process such as turning mechanical energy into electrical energy in which partial power available in the wind is converted. The ratio between the power generated by a wind turbine and the power available in the wind is called the overall efficiency of wind turbine which is given as in (6).

$$\eta_{total} = \frac{P_{output}}{P_{input}} \quad (6)$$

There are two types of efficiency available in a wind turbine: the first one is the rotor efficiency (C_P) also known as power coefficient and the second one is the generator efficiency (η). The rotor efficiency of a wind turbine depends on the mechanical design of the rotor blades. On the other hand, the generator efficiency depends mostly on the electrical design of the generator. The output power of the generator is given as:

$$P_{output} = \frac{1}{2} \rho A v^3 C_p \eta \quad (7)$$

To get the rotor efficiency the mechanical power ($P_{mechanical}$) of the rotor has to be calculated. It can be calculated by measuring the rotational speed (ω) as well as the mechanical torque (T) of the rotor. So, mechanical power can be calculated as: