Review on Wind Turbine Emulator for Wind Generation System

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Abstract— The paper presents the development of a DC motor based Wind Turbine Emulator (WTE). The torque signal that represents the actual wind turbine with environmental effect was made to generate at the DC motor shaft. Particularly, the study incorporates the turbine power control strategy including the effect of stochastic and deterministic load components with the shaft dynamics. The WTE with the Wind Energy Conversion System (WECS) is studied to verify the effectiveness of the WTE in the presence of various wind characteristics. The envisaged wind system is based on a PMSG (Permanent Magnet Synchronous Generator) directly connected to the wind turbine shaft, while the DC output load is supplied by a rectifier and a chopper. The DC load is considered as a resistive load with wide values range. Experimental investigations are provided in partial load regime. The power optimization is performed through power loop in two ways: by controlling the electrical power or by controlling the electromechanical power.

Key words: Wind Turbine Emulator, Wind Energy Conversion System, Rotor blade, Wind Turbine

I. INTRODUCTION

The wind power generation has become the most promising technology today to generate electricity from the renewable energy sources. To study the steady state and dynamic behavior of a Wind Energy Conversion System(WECS) without the reliance on natural wind resources and actual wind turbine, a system representing the wind turbine and wind is essential. A Wind Turbine Emulator (WTE) is apiece of hardware that represents the static and dynamic characteristics of an actual wind turbine. Over the past years, researches made on WTE are abundant. Different kinds of prime movers have been used in realizing WTE. Although the WTEs with Permanent Magnet Synchronous Motors and Induction Motors are available, those with the DC motors are common. The converting technologies used with the DC motor drives are AC/DC thyristor based controller and DC/DC chopper. The issue related to thyristor rectifier and DC/ DC convertor for the effectiveness of WTE is analyzed. The effect caused by the interaction of the turbine and generator inertia at WTE is modeled by an equation. However the damping effect is not taken into consideration. In order to reflect the inertia of a small wind turbine, an inertia disk is considered. The dynamic effect on a wind turbine due to the wind shear and tower shadow is analyzed comprehensively using the turbine and tower parameters. A simple model to represent the effect of wind shear and tower shadow is adopted based on the harmonics of the turbine torque. However, those papers do not explicitly explain the reason for the particular model. Therefore, when turbulence is incorporated into wind model false interpretation in wind shear and tower shadow model may result. Also that model fails to accurately represent the torque dips caused by the tower shadow as in actual situation. The turbine power control strategies such as pitch control and stall control are considered. However, turbine power control strategies are not given much importance. The proposed work in this research reveals the simulation of WTE, taking into account of pitch control and additional wind effects with shaft dynamics.

II. WIND ENERGY CONVERSION SYSTEM STRUCTURE

The wind energy conversion structure is analogues to the based on the field system. Typical wind energy generating systems are classified as fixed and variable speed.

A. *Conventional fixed speed wind energy syste*

In conventional fixed speed type the wind turbine is directly or with gear is connected to grid as shown in Figure 1.

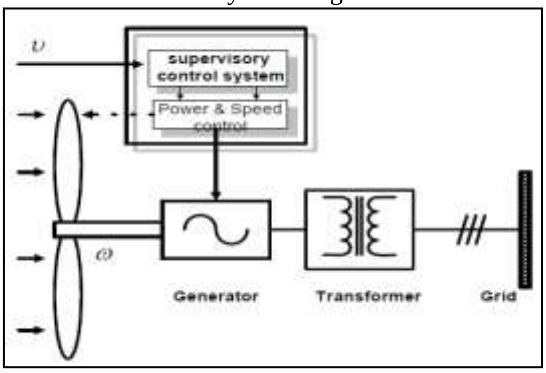

Fig 1: Fixed speed type wind energy conversion system.

The wind energy generating system has a supervisory control system located at the main level and turbine control system for power & speed control. The functions of supervisory control system are as –

- To generate reference signals sequentially for the power & speed control system for the wind turbine generator system to pass from one operating state to another.
- To perform the protective function. The turbine control system acts on turbine and its purpose to-regulate the torque, smoothen the wind turbine output power and to damp the electromechanical oscillation.
- To protect the costly mechanical equipments.

Generally both the control systems are utilized in such a fixed type wind energy conversion system.

B. Variable speed wind generating system

A variable speed wind generating system connected to the grid is shown in Figure 2.

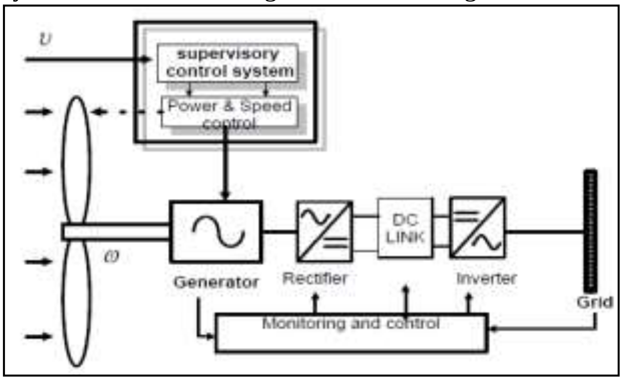

Fig. 2: Variable speed type wind energy conversion

In variable speed type grid connected wind energy conversion system has rectifier on generator side which converts the generator voltage or current to a dc link. Thus controls the generator operation and the wind turbine. The dc link decouples the grid frequency and generator frequency. The performance of dc link is influenced by the voltage and current level within it. The grid is supplied via the inverter. Thus the system has speed regulator, power regulator, pitch angle regulator and inverter controller as the main controller during power system operations.

III. Basic Principles of Wind Turbine

The power extracted from wind through a turbine is given by the following equation.

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

Where, ρ is the air density (kg/m^3), A is the effective area of turbine (m^2), V is the wind speed (m/s) ands defined as power coefficient which depends on tip speed ratio (λ) and pitch angle (β).

$$\text{Tip Speed Ratio } (\lambda) = \frac{\text{Turbine Tip Speed (m/s)}}{\text{Wind Speed (m/s)}}$$

The approximate relationship for power coefficient, Cp for a turbine is given.

$$C_p = \frac{1}{2}(\gamma - 0.022\beta^2 - 5.6)e^{-0.17\gamma}$$

$$\gamma = 2.237\, V_\omega / \omega_\beta$$

where, V_w is the wind speed (m/s), W_B is the blade angular velocity (rad/s), y is the reciprocal of the tip speed ratio and B is the pitch angle (rad).

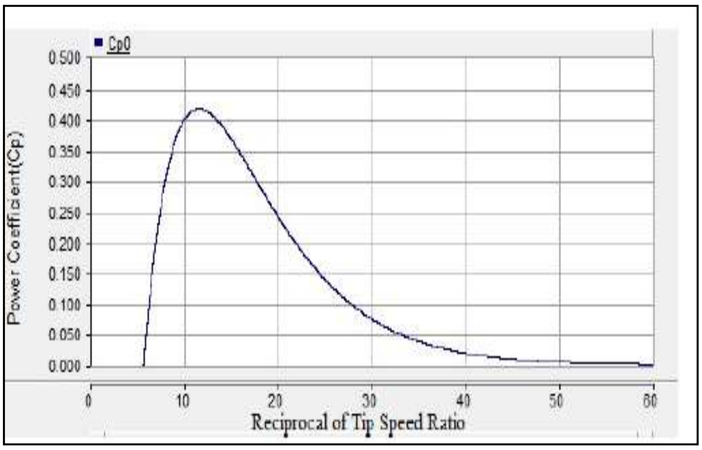

Fig. 3: Performance curve of a wind turbine

When the generated power increases above the rated power of the generator, the extracted power by the wind turbine is controlled to avoid over loading of the generator. This can be achieved by pitch control or stall control. The relation between the generated power and wind speed for pitch controlled and stall controlled wind turbine is shown in Fig 4. The four regions of operation in a WECS are denoted.

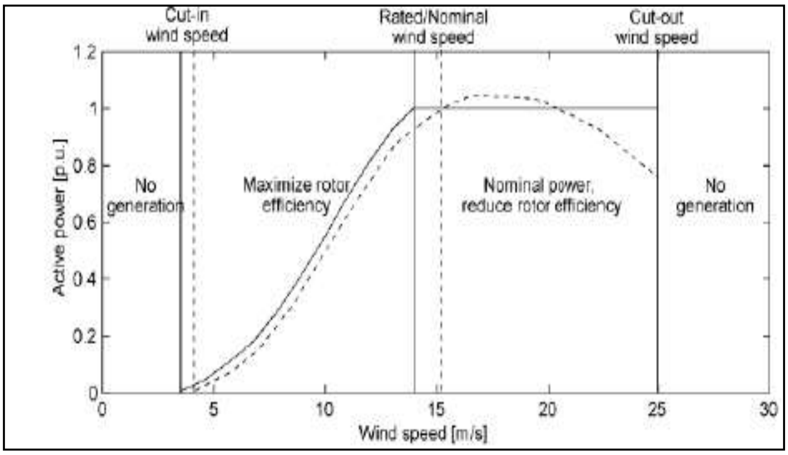

Fig. 4: Typical power curves for a stall controlled (dashed) and pitch controlled (solid) wind turbine

IV. TYPES OF WIND TURBINE

Wind turbines can rotate about either a horizontal or a vertical axis, the former being both older and more common. They can also include blades (transparent or not) or be bladeless. Vertical designs produce less power and are less common.
There are different designs of wind turbines and they are broadly classified in two categories which is based on orientation of the axis of rotation they are:-

- Horizontal axis wind turbines (HAWTs)
- Vertical axis wind turbines (VAWTs)

A. Horizontal axis

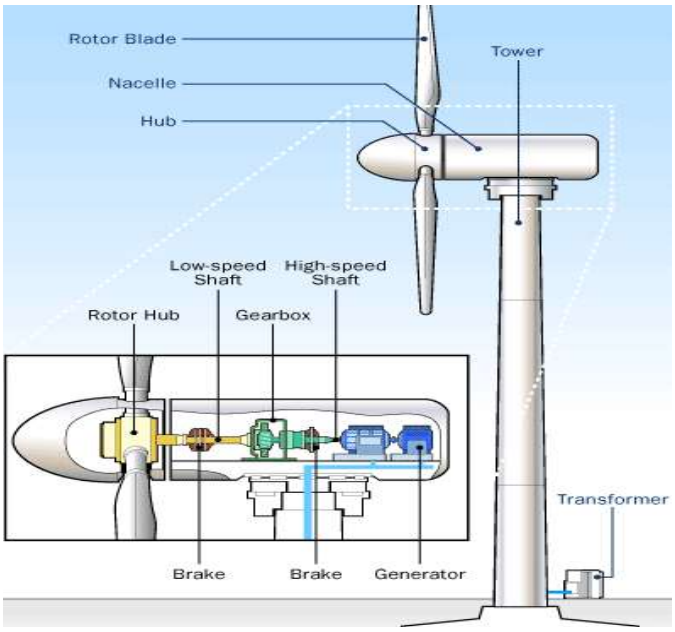

Fig. 5: Components of a horizontal axis wind turbine (gearbox, rotor shaft and brake assembly) being lifted into position

Horizontal-axis wind turbines (HAWT) have the main rotor shaft and electrical generator at the top of a tower, and must be pointed into the wind. Small turbines are pointed by a simple wind vane, while large turbines generally use a wind sensor coupled with a servo motor. Most have a gearbox, which turns the slow rotation of the blades into a quicker rotation that is more suitable to drive an electrical generator.

B. Vertical axis

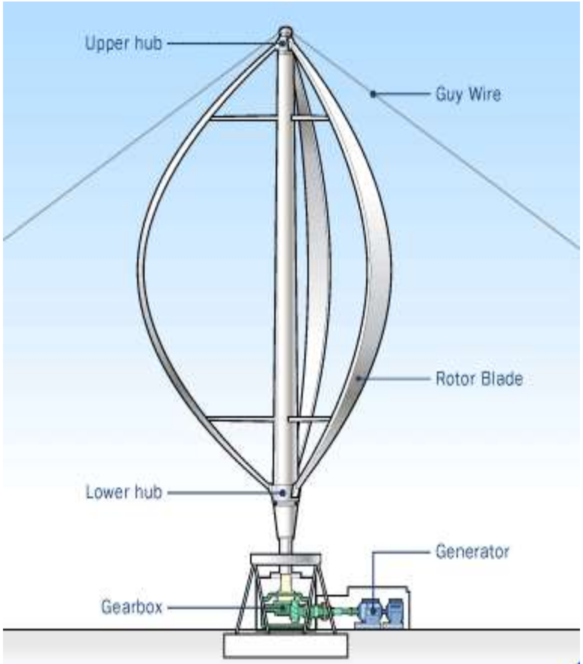

Fig. 6: Components of vertical axis wind turbine (upper hub, guy wire, rotor blade, lower hub, generator, gearbox)

Vertical-axis wind turbines (or VAWTs) have the main rotor shaft arranged vertically. One advantage of this arrangement is that the turbine does not need to be pointed into the wind to be effective, which is an advantage on a site where the wind direction is highly variable. Also, the generator and gearbox can be placed near the ground, using a direct drive from the rotor assembly to the ground-based gearbox, improving accessibility for maintenance. However, these designs produce much less energy averaged over time, which is a major drawback.

V. TYPES OF ROTOR BLADE

Most modern WPP's have three rotor blades. Building large machine with even number of rotor blades is avoided due to stability reasons. The reason is that at the instant when the upper most blade bends backwards, because it gets the maximum power from the wind, the lower most blade passes into the wind shade in front of the tower. A rotor with an odd number of rotor blades can be considered to be similar to a disc when calculating the dynamic properties of the WPP.

There are different designs of wind rotor blades and they are broadly classified in four categories:-

A. One-bladed WPPs

Single blade WPPs are not widely used now, even though they appear to save the cost of another rotor blade. Stability becomes an increasing problem and therefore requires a counterweight on the opposite side of the single blade. One bladed turbines also have higher rotational speeds and thus emit more noise.

B. Two-bladed WPPs

Two bladed WPPs means lesser material than the three bladed ones. A rotor with two blades has to spin faster to perform the same amount of work as a three bladed rotor. Two bladed rotor capture slightly less energy, approximately 97% of as much as three bladed design can with the same rotor diameter.

C. Three-bladed WPPs

Currently most large WPPs are three bladed designs with upwind rotor and with electrical motors to operate the yaw mechanism. Three blades effectively eliminate the gyroscopic imbalance, compared to the two blades rotor hub. Noise and wear are generally lower, and efficiency higher, with three instead of two blades.

D. Multi-bladed WPPs

Wind turbines rotor with large numbers of blades are generally used as 'water pumping wind mills'. Multi blades wind mills continue to be used on farm lands to pump water. Many are still in use today, in countries like Argentina and South Africa. Multi bladed WPPs are not used for electric power production.

VI. EMULATOR CONCEPT

The emulator is based on the energy conversion (wind turbine) system. The lab system is realized by replacing the wind, gearbox and turbine rotor with a PC, ac-dc converter (dc drive) and dc motor. The PC implementing MATLAB/Simulink uses a wind shear/tower shadow model, an inertial model, steady state characteristics, and a variable wind to control the dc system to emulate the driving torque of a wind turbine. These models will be briefly outlined as will the computer hardware components along with the drive components and control methodology used.

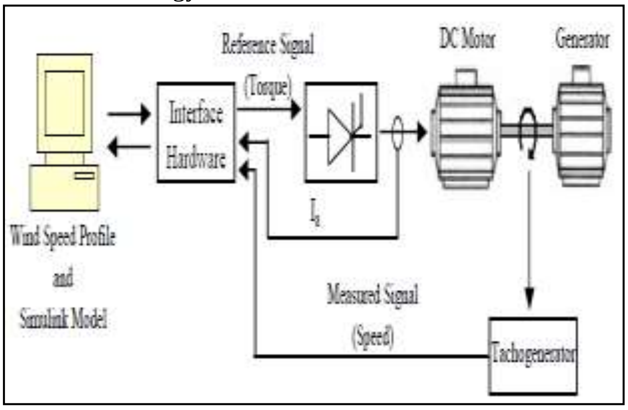

Fig. 7:

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