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Manufacturing a Yaw controlled Small Scale Wind Turbine in Egypt

By

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Abstract:

In this paper, we discuss the future plans of our research group at the National Research Center. One aim is put forward as our focus in this research work. We would like to make the manufacturing of small scale wind turbines possible in remote areas in Egypt using locally available parts and tools. Many internet sites and references are revised for the realization of this aim. A wide search for the know-how is underdone to understand how to build a similar prototype of a wind turbine to the ones found over the internet with the same properties or at least comparable to them. The different electrical components of a wind turbine and their functions are illustrated. The possibility of controlling the direction of the yaw of a wind turbine is explained and the effect of it on the overall performance of the wind turbine is shown.

Keywords:

Yaw Control, Wind Turbine, Renewable Energy and Green Farms

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1. Introduction:

A few numbers of studies were carried out on wind power and its applications in Egypt. Mayhoub and Azzam researched the potential of using wind energy to produce electricity along the coast of the Red Sea and the Mediterranean in addition to some interior parts of Egypt (1997). A study to use wind energy turbines to produce electricity for some areas inside Egypt which are isolated from the national grid of electricity was discussed by Ahmed and Abouzeid (2001). The use of wind energy to produce electricity along the Red Sea coast was scrutinized by a study made by Shata & Hanitsch (2006a). With respect to the coast of the Mediterranean Sea, Shata & Hanitsch (2006b) have evaluated the potential of generating electricity from the wind in ten locations and found that three locations are well suited for wind electricity generation. Recently, a working paper was published by the German University in Cairo which addresses the potential of using wind energy to generate electricity inside Cairo [1]. All the studies were exclusively concerned with the assessment of the wind potential either in coastal or desert remote areas as well as the potential of using wind energy inside Cairo.

In this paper, the internal electrical connections and electrical controlling components of a wind turbine are explained. The equations governing the way to control the output power of a wind turbine are illustrated. Practical realization of controlling the yaw drive and the effect of this on the output power are analyzed. Finally conclusions are driven and shown.

2. Problem Investigation:

2.1. Internal Circuitry of a Wind Turbine:

In fig. 1, an illustration of the internal electrical connections made to control a wind turbine is shown. The control of the wind turbine is scrutinized to understand it. Three sensors are used which are a temperature, a dogvane and an anemometer sensors. The temperature sensor is used to know the temperature of the turbine so that it would initiate an emergency shut down for the turbine in the case of over heat. The dogvane sensor is used know the direction of the wind so as to direct the yaw to its direction. The anemometer sensor is used to measure the wind speed after the wind passes through the blades of the wind turbine. It is worth mentioning that the position of the anemometer affects severely the measurement of the wind speed. Several studies were conducted to research the effect of the position of the anemometer and dogvane sensors on the accuracy of the measurements taken. These inaccurate measurements severely affects the control decisions taken by the CPU (Fig. 1). The CPU contains a PLC which controls the direction of the wind turbine and its starting up and shutting down conditions. Two probes are used to control the wind turbine namely the rotor speed probe and the yaw shaft revolving probe. The rotor speed probe initiates a start up of the wind turbine to generate electricity when the rotor speed exceeds a cut in velocity. The rotor speed probe continue to measure the speed of rotor so that when the speed of the rotor exceeds a certain cut off velocity the PLC uses the regulating direction motor to move the rotor away from wind flow. If the speed of rotor continue to increase above a certain threshhold, an emergency shutdown would be initiated. If the rotor speed falls below the cut off velocity again the wind turbine is started up. The yaw shaft revolving probe is used to know the position angle of the yaw at any point in time. A rectifier/inverter is used to transfer the electricity produced by the wind turbine to a form which is suitable to be saved in batteries for later use [2].

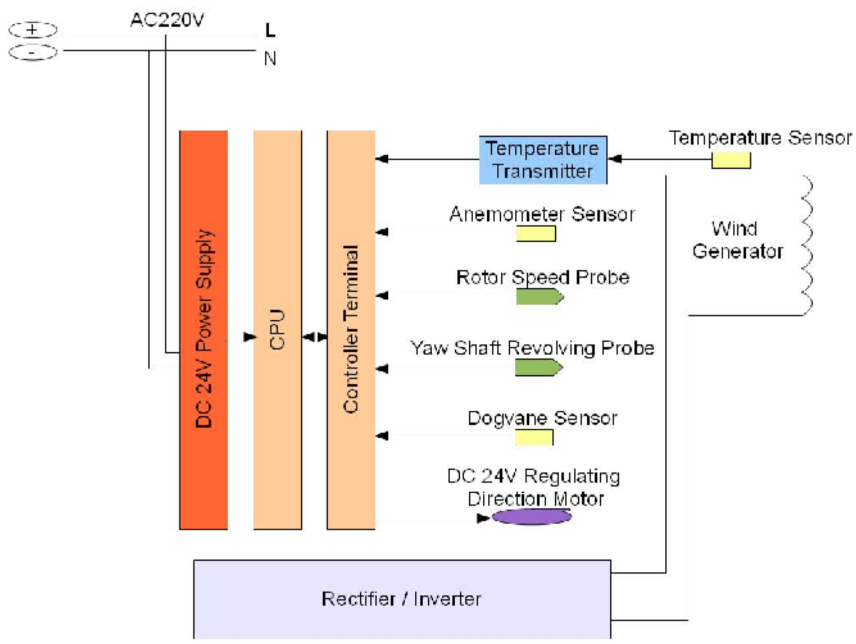

Figure 1: *An illustration of the internal connections of a Wind turbine and the function of each part.*

2.2. Theoretical Controlling of a Wind Turbine Power Output:

Upwind turbines face into the wind; the yaw drive is used to keep the rotor facing into the wind as the wind direction changes. Even a perfect wind turbine cannot fully capture the power available in the wind. In fact, theory shows that the theoretical maximum aerodynamic efficiency, which is called the Betz Limit, is approximately 59% of the wind power. The aerodynamic efficiency is the ratio of turbine power to wind power and is known as the turbine's power coefficient C_p , C_p can be computed as [3]:

$$C_p = P / P_{wind} \qquad (1)$$

where P is the power captured by the turbine and P_{wind} is the power available in the wind for a turbine of a certain size. The power P_{wind} is given by [3]:

$$P_{wind} = \frac{1}{2} \rho A v^3 \qquad (2)$$

where ρ is the air density, A is the 'swept area' of the rotor, and v is the instantaneous wind speed. The swept area is the area of the circle described by the blade tip, or πR^2 , where R is the rotor radius. In (2), the wind speed v is assumed to be uniform across the rotor swept area.
For a variable speed wind turbine, the objective would be to maximize the power coefficient. The turbine's power coefficient is a function of the turbine's tip-speed ratio which is defined as [3]:

$$\lambda = \frac{\omega R}{v} \qquad (3)$$

ω is the rotational speed of the rotor, and R and v are the rotor radius and instantaneous wind speed, respectively. Thus, the tip-speed ratio is the ratio of the linear (tangential) speed of the blade tip to the wind speed, where R is fixed for a given turbine, v is always time-varying, and ω is timevarying for a variable-speed turbine.
Another objective is to limit the turbine power so that safe electrical and mechanical loads are not exceeded. Power limitation can be achieved by yawing the turbine out of the wind which can reduce the aerodynamic torque below what is theoretically available from an increase in wind speed. Note that the power P is related to rotor speed ω and aerodynamic torque τ_{aero} by [3]:

$$P = \tau_{aero} \omega \qquad (4)$$

If the power and rotor speed are held constant, the aerodynamic torque must also be constant even as wind speed varies. It is desirable to produce as much power as the turbine can safely produce, the limit of which is known as the turbine's rated power. Power control is achieved by keeping the generator torque τ_c as [3]:

$$\tau_c = K\,\omega^2 \qquad (5)$$

where ω is the measured rotor speed, and K is given by [3]:

$$K = \frac{1}{2}\rho\pi R^5 \frac{C_{Pmax}}{\lambda_{\$}^3} \qquad (6)$$

where C_{Pmax} is the maximum power coefficient achievable by the turbine, and $\lambda_{\$}$ is the tip speed ratio at the maximum power coefficient. The torque control given by (5) and (6) can be shown to achieve C_{Pmax} by examining the dynamics of a single degree-of-freedom rotational system. In this case, we relate net torque and angular acceleration by [3]:

$$\dot{\omega} = \frac{1}{J}(\tau_{aero} - \tau_c) \qquad (7)$$

where J is the rotational inertia of the system. Combining (7) with (1)-(6), we find that [3]:

$$\dot{\omega} = \frac{1}{2J}\rho\pi R^5 \omega^2 \left(\frac{C_P}{\lambda^3} - \frac{C_{Pmax}}{\lambda_{\$}^3}\right) \qquad (8)$$

Thus [3],

$$\dot{\omega} < 0 \quad \text{when} \quad C_P < \frac{C_{Pmax}}{\lambda_{\$}^3}\lambda^3 \quad \text{and} \quad \dot{\omega} > 0 \quad \text{when} \quad C_P > \frac{C_{Pmax}}{\lambda_{\$}^3}\lambda^3$$

and we see that the control law given by (5) and (6) causes the turbine to accelerate toward the desired set point when the rotor speed is too slow and decelerate when the rotor speed is too fast.

2.3. Practical Controlling of a Wind Turbine Power Output:

The effect of yawning the wind turbine to keep the rotor facing the wind is explained. The wind speed is a vector which has the magnitude of the wind speed and the direction of the wind flow. The rotor speed is another vector which has the magnitude of the rotor speed and the direction of rotation of the rotor. As shown in fig. 1, a PLC is used to drive the yaw to make the rotor face the wind inflow.

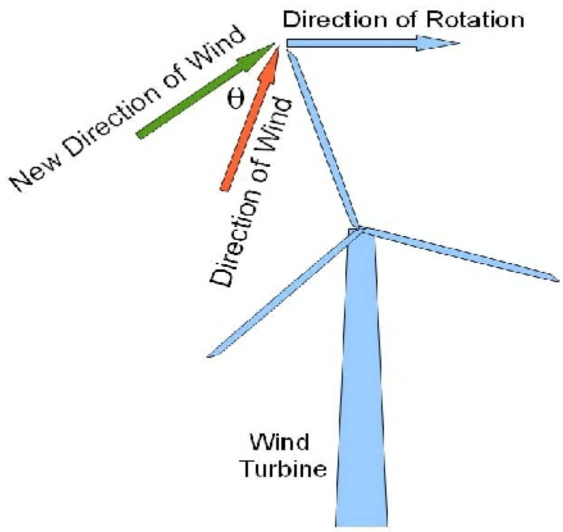

Figure 2: *A diagram shows the direction of rotor speed, direction of wind speed. A new direction of wind speed is seen after driving the perpendicular vector on the rotor speed away from the wind directon by an angle* θ.

In fig. 2, the wind speed is represented by a red arrow while the rotor speed is represented by a blue arrow. The two arrows are perpendicular on each other. Now if the magnitude of the wind speed increases above a predefined limit then a PLC is used to drive the rotor away from the wind direction. The new wind direction (green arrow in fig. 2) makes a yaw angle θ with the perpendicular arrow (red arrow) on the direction of rotor speed (blue arrow). The projection of the the new wind direction along the line perpendicular on the direction of rotor speed has a smaller magnitude. The yaw direction is used to increase or decrease the yaw angle to change the magnitude of the perpendicular wind speed vector on the rotor speed and so change the output power. We expect the magnitude of the perpendicular wind speed vector to be proportional to cosine the yaw angle θ.

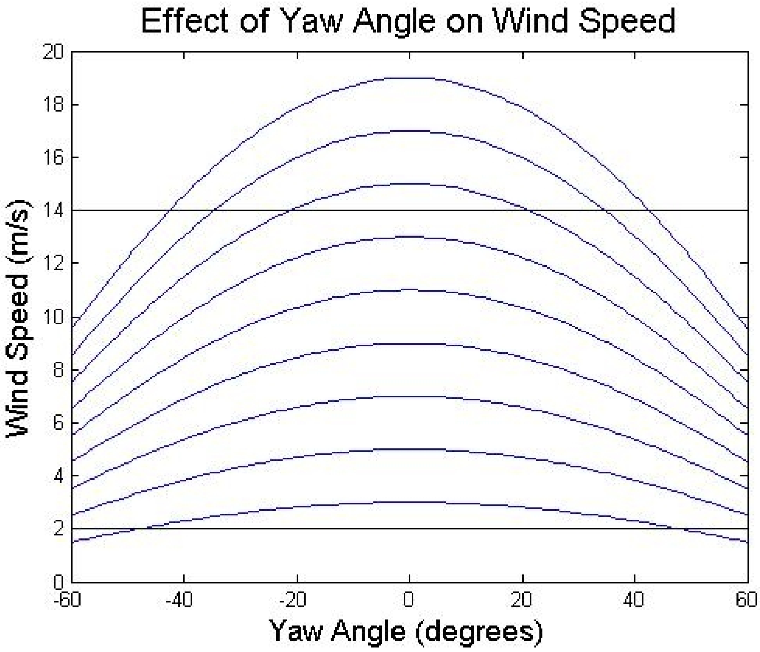

Figure 3: *A graph showing the change in the magnitude of the wind speed vector which is perpendicular on the rotor speed as θ changes.*

In fig. 3, the change in the magnitude of the projection of the wind direction along the line perpendicular on the direction of rotor speed is shown against the change in the yaw angle. As mentioned earlier the drawn curve should obey $\cos(\theta)$ where θ is the angle between the wind direction and the line perpendicular on the direction of rotor speed. The effect of changing the yaw angle and the accuracy of the control decisions is evident in these curve. The range of wind speeds at which the power output of a wind turbine is maximized is from 2m/s to 14m/s. Two parallel lines are drawn at these two speeds designating the maximum and minimum limit. As seen, even for wind speeds above 14m/s, changing the yaw angle would decrease the perpendicular projection of the wind speed on the rotor speed making it suitable for obtaining maximum power from the wind. The wind resources in a site are critically influenced by the wind speed (also called wind velocity) due to the existence of a cubic relationship between the wind speed and the wind power and consequently a small increase or decrease in wind speed can considerably increase the generated power. We can derive the following relationships [3, 4]:

since $P_{wind} \alpha v^3$ and $v \alpha \cos(\theta)$

then $P_{wind} \alpha \cos^3(\theta)$

A minimal change in the angle of the yaw shaft would limit the power output to a safe upper threshhold for a wind turbine.

3. Conclusion:

There is a growing need for teaching the public in remote areas in Egypt about way to design and built a wind turbine. The wind turbine is vital in remote areas to provide electricity for home appliances and small pump to get water from underground. The internal electrical components of the wind turbine are shown. The sensors, actuators and probes which are used to determine temperatures, wind speed, wind direction, yaw angle and rotor speed are explained. The importance of the CPU not only in logging all the data collected about the wind turbine but also in using this data to change the direction of the yaw angle and control the output power of the wind turbine is shown. The equations governing the controlling of the wind turbine are analyzed. The effect of changing the yaw angle on the output power is shown to obey the $\cos^3(\theta)$ relationship.

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