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The control strategy speed of vertical axis wind turbines

Nguyen Van Huynh, Tran Thi Thanh Hai
[1]Thai Nguyen University of Technology, Thai Nguyen, Viet Nam

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ABSTRACT: A weakness of the wind turbine is that when the wind speed changes, the revolving speed of the wind turbine also changes. Rotating speed of turbine can be stablized by changes pitch angle of the turbine, changing the surface area of the wings facing the wind. The paper presents a control strategy speed of vertical axis wind turbines by using DC motor to controlling and changes pitch angle of the turbine.

KEYWORDS: Vertical axis wind turbines.

I. INTRODUCTION

Humans have known to use wind energy for a long time, but to a limited extent. Nowadays, countries in temperate and temperate regions are interested in wind energy sources and have had good results, especially in the production of large capacity wind generators, to integrate into the national power system.

Large capacity wind generators require a good speed control system to ensure that the rotational speed of the turbine shaft is within the specified limits. Currently, it is common to use the method of changing the turbine blade angle, adjusting the wind-catching surface area of the turbine blade to stabilize the speed.

With small capacity wind generators, changing blade angle often uses centrifugal method of rotating mass [6], [9]. When the wind speed changes, the rotation speed of the turbine changes, the centrifugal force of the rotating object also changes. If the wind is high, the wind speed increases, the centrifugal force increases, acting on the turbine blade rotating mechanism to reduce the surface area to catch the wind, leading to limiting the increase in turbine rotational speed. When the wind calms down, the wind speed decreases, the turbine blades automatically rotate back to the original position, to maintain the rotation speed of the turbine within the allowable range. With large-capacity wind generators, mechanical structures such as cam systems are often used to adjust the wing angle [6]. The structure of the machine using centrifugal force and the cam system to change the turbine blade angle is relatively simple, but it has the disadvantage ofcontrolling the turbine blades at the same time and because the mechanical structures are responsive, slow, adjustment accuracy is low, turbine speed variation range is too large.

In this paper, we propose a method using an electric motor to change the blade angle to control and stabilize the speed of the vertical axis wind turbine. The working principle of the system is as follows: Set a speed limit for the wind turbine shaft; when the wind speed is greater than the specified, the turbine shaft will rotate faster, the sensor receives the signal, sends it to the controller, the controller compares with the specified rotation speed, sends a signal to the engine, the engine rotates the turbine blades at an angle to reduce the wind surface; when the wind speed decreases, the motor will rotate the blade back. In this way, due to the use of an electric control unit, the response is fast, and the rotation speed of the turbine shaft is adjusted in time, greatly shortening the rotational speed range of the turbine.

II. THEORETICAL BASIS

Wind energy conversion follows the basic principles of wind utilization and the optimization of turbines.

Place the wind turbine in the flow of air, when the air approaching the turbine is trapped, the flow pressure increases and the velocity decreases, until the flow hits the turbine face giving the turbine power. The flow behind the turbine is turbulent, caused by the turbine's motion and the interaction with the surrounding air currents.

In principle, the flow must be maintained. Therefore, the obtained turbine power is limited. In the case of all wind energyis picked up by the turbine, the wind velocity behind the turbine will be zero. In order for the flow to be balanced between mass and velocity, the energy flowing through the turbine must be lost. For the optimal system, the maximum percentage of wind energy that can be obtained iscalculated according to the formula given by Carl Betz in 1927:

$$\frac{P_{max}}{A_r} = 0{,}593\frac{V_0^3}{2}$$

With: P is the energy density

A_r is the swept area of the turbine blade

V_0 is the initial wind velocity - Energy density per unit volume of air flow

The number 0.593 is called the Betz limit or the Betz coefficient.

By simple analysis of the dynamics for wind turbines, it is found that its maximum power factor is $\frac{16}{27}$ or 59.3%. This was proved by Betz (1927).

This is obviously the case for an infinite number of blades (zero resistance) which is a condition of an ideal wind turbine. In practice there are three factors that reduce the maximum power factor:

1-Behind the wind turbine exists eddy currents

2- The number of blades of a wind turbine is limited

3- $\frac{C_d}{C_l}$ ratio not equal to 0

With C_l is the lift coefficient, C_d is the drag coefficient.

$$C_l = \frac{F_l}{\frac{1}{2}\rho V^2 A}\ ;\ C_d = \frac{F_d}{\frac{1}{2}\rho V^2 A}$$ where:

ρ is air density (kg/m3)

V is air flow velocity (wind) without turbulence (m/s)

A isprojection area of the wing (air catch area) (m2).

F_l islifting force (N).

F_d isresistance (N).

Thus, when changing the windward surface area of the turbine blade, the wind energy efficiency of the turbine changes, that is, changes in the force acting on the blade to rotate the turbine. As the wind speed increases, the wind power increases, but the power on the turbine shaft hardly increases.

Wind energy harvesting equipment systems vary widely in size, shape and form of final energy received. In general, the wind energy exploitation equipment system has the following parts: Wind power collector, primary movement, and final energy generating device.

Wind generator system, the final form of energy is electricity; the wind collector is a wind turbine; primary motion is the rotation of the turbine shaft; The device that produces electricity is a generator. In order for the generator to work well and be able to connectto the national grid, the primary motion - the rotation of the turbine shaft must have a reasonable rotational speed and little change.

III. DETERMINE THE CONTROL BLADE ANGLE OF THE VERTICAL AXIS WIND TURBINE

Consider a vertical axis wind turbine consisting of 5 blades with a rectangular flat profile. The control problem here is that in the process of turbine working, it is necessary to continuously change the blade angle of each blade to suit their position and correspond to the installed power of the turbine.

To determine the control blade angle, we analyze the dynamics of the turbine blade at any position as shown in Figure 1:

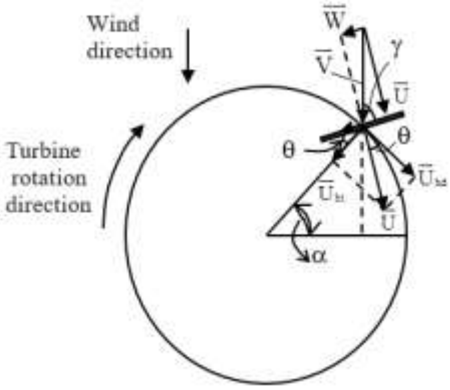

Figure 1. Wind vane dynamics at one position

In there:

α is the positioning angle at the center

θ is the wing angle (the quantity to be controlled)

γ is the angle of incidence

$\vec{V}$ is the wind speed

Assuming the wind speed acting on the turbine blade is $\vec{V}$, we analyze it into two components, a component parallel to the blade surface is $\vec{W}$, a component perpendicular to the blade surface is $\vec{U}$

$$\vec{V} = \vec{U} + \vec{W}$$

With the wing profile being flat, the component $\vec{W}$ will cause drag Fd and the component $\vec{U}$ will cause wing lift F_l, only the component F_l can cause wing movement.

We break it down $\vec{U}$ into two components:

$$\vec{U} = \vec{U}_{hd} + \vec{U}_{ht}$$

Where: $\vec{U}_{hd}$ is the speed in the tangent direction

$\vec{U}_{ht}$ is the speed in the radial direction

The radial component causes the centripetal force on the wing, the tangential component causes the force to move the wing and we call it the effective force F_{hd}.

We have: $F_{hd} = \frac{1}{2}\rho C_{hd} A U_{hd}^2$

where: ρ - air density (kg/m^3)

U_{hd} - wind speed tangentially (m/s)

A - Area of the wind vane (air catch area) (m^2).

C_{hd} – Effective force factor.

According to the theory of optimization of wind energy conversion efficiency, at a certain location (α determined) the value of F_{hd} must reach the maximum value $F_{hd\max}$ and from the expression of F_{hd} we see that F_{hd} has a large value when U_{hd} reaches the maximum value.

From Figure 1, we have:

$U = V\sin\gamma$; $U_{hd} = U\cos\theta = V\sin\gamma.\cos\theta$

With : $\gamma = \theta - \alpha + 90°$

$$\Rightarrow U_{hd} = V\sin\gamma.\cos\theta =$$
$$= V\sin(\theta - \alpha + 90°).\cos\theta = V\cos(\theta - \alpha).\cos\theta$$
$$\Rightarrow U_{hd} = \frac{V}{2}[\cos(2\theta - \alpha) + \cos\alpha]$$

When α is determined, then U_{hd} reaches its maximum value when $\cos(2\theta - \alpha) = 1 \Rightarrow \theta = \frac{\alpha}{2}$

From the relationship between the wing angle θ and the positioning angle α, we can determine the control wing angle at any position of the wing.

In the following, we determine the control blade angle of a turbine blade at 10 positions as follows:

Positioning angle α(degrees)	0	36	72	108	144	180	216	252	288	324	360
Wing angle θ(degrees)	0	18	36	54	72	90	108	126	144	162	180

With the remaining blades of the turbine, we also control the blade angle similarly when in the respective positions.

The wing angle above corresponds to the wind speed equal to the rated wind speed $V = V_0$, in case the wind speed isgreater than the wind speed $V > V_0$, we see: $\cos(2\theta - \alpha) < 1 \Rightarrow \theta \neq \frac{\alpha}{2}$

Thus, the force F_{hd} will be stabilized and the speed of the turbine will also be stable.

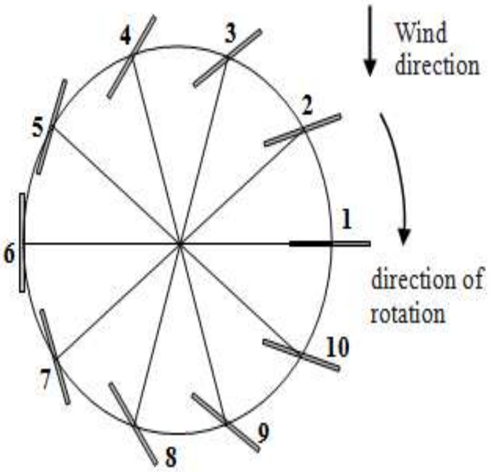

Figure 2. Wings in 10 different positions

IV. SYSTEM MODELING AND SIMULATION

The structure diagram of the system is shown in Figure 3

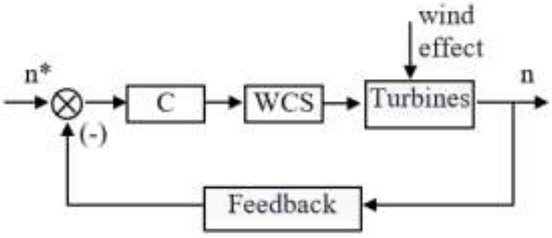

Figure 3. System structure diagram

In there:
C - Controller

WCS - Wing angle control system of vertical axis wind turbine. In which, there are 5 position control systems to control the wing angle of 5 wings independently.

For the turbine block, the input signal is the control blade angle of the 5 blades and the impact noise that changes the rotation speed of the turbine here is the wind speed, the output signal of the turbine is the rotation speed.

So: $n = K(\theta_1 + \theta_2 + \theta_3 + \theta_4 + \theta_5)$

where $K = f(v)$ varies depending on wind speed; $\theta_1;\theta_2;\theta_3;\theta_4;\theta_5$ is the control angle of 5 turbine blades.

The system simulation diagram with the classic PID controller is shown in Figure 4.

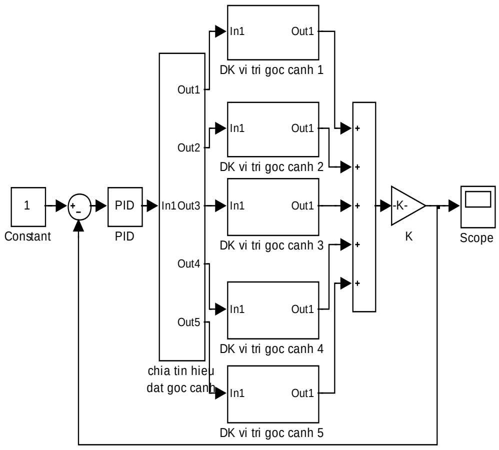

Figure 4. System simulation diagram

We run the simulation with different noise values of wind speed (K). The simulation results are shown in Figures 5 and 6. Of which, Figure 5 is for the case of unchanged set value, and Figure 6 is for different set values.

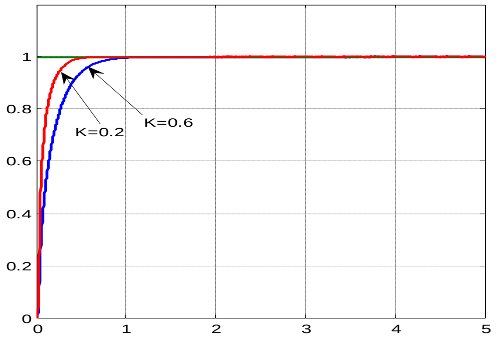

Figure 5. Simulation results when K=0.2; K= 0.6 with constant set value

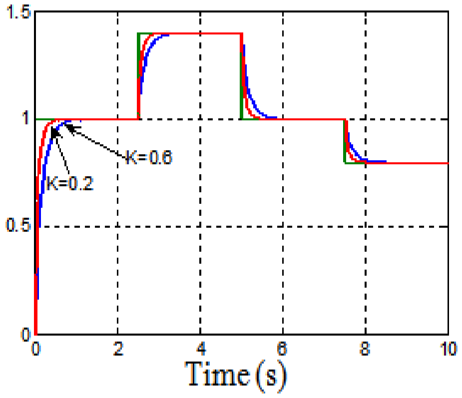

Figure 6. Simulation results when K=0.2; K= 0.6 with variable set value

V. CONCLUSION

From the simulation results, we can see that when the wind speed changes, the turbine speed remains stable and follows the set value through the change of the turbine blade angle. However, when the wind speed changes too large and randomly, the controller

Classic PID controller does not meet the quality requirements, but it is necessary to use intelligent controllers built on the basis of modern control theory.

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