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Analysis of Power Generation Characteristics of Distributed Wind Generation System Considering the Hydrogen Production Load

LI ZHENG[2,3]

Abstract. Due to the advantages of low starting wind speed, no wind direction limit, wide running range and simple control, the vertical axis wind power generation system is booming recently. Based on the speed ratio control method to achieve maximum power generation, a vertical axis wind turbine generator is researched in this paper. Firstly, the mechanical torque of the turbine is calculated and the mathematical model of the wind turbine is established. Secondly, the mathematical model of the generator is established. Finally, combined with the load characteristics of electrolytic hydrogen production, the simulation analysis is carried out based on the model of wind power generation system. The results show that the proposed model and simulation analysis method are realistic and provide reference for the simulation analysis and energy storage application of this kind of generator systems.

Key words. generation system, speed ratio, electrolytic hydrogen, generator system.

1. Introduction

The vertical axis turbine has many advantages such as no need to install the yaw device when measuring wind direction, simple structure, low noise, safe and reliable, adaptable [1].Domestic and foreign scholars have carried out exploration in different directions in terms of vertical axis of wind power generation technol-

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[2]Workshop 1 - School of Electrical Engineering, Hebei University of Science and Technology, Shijiazhuang 050018, China

[3]Corresponding author: LI Zheng; e-mail: `Lzhfgd@163.com`

ogy research which mainly focused on three points , one is the turbine simulation numerical operation. The vertical axis wind turbine was modified by Han Yi, and the tangential velocity of the wind turbine blade was introduced into the model of the classical double actuation plate [2-4]. One is research of the wind turbine power generation characteristics and control algorithm. Another is to study the wind turbine can withstand external conditions and operating environment [5]. It is in fact indispensable to carry out research of wind power generation system combined with hydrogen load characteristics.

In this paper, the wind turbine model is analyzed and calculated by Fluent software, and the mechanical torque of the fan is obtained, the mathematical model of the wind turbine is established afterwards. At the end of this paper, combined with the energy storage requirements, according to the wind the relationship between voltage and current in hydrogen production, the resistance change law is obtained. Through the mathematical model is established in Simulink, the simulation calculation is verified, with the effectiveness analysis provided for these research.

2. Structure of Wind Turbine

The Senegal wind turbine is used for the analysis in this paper which running stably, and the power generation efficiency is higher at the low speed ratio. 2D model is shown in Fig. 1. The left figure shows the blades, which is mainly by a semi-disc and a rectangular flat plate[6]; the right figure is the top view of the turbine, which has three blades in one layer, and the three blades are placed every 120 degrees in order to achieve a dynamic balance when the wind turbine is running. The 3D model is shown in Fig. 2.

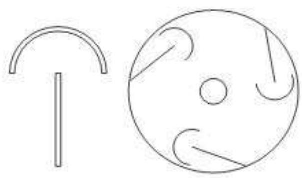

Fig. 1. 2D model of Senegal type

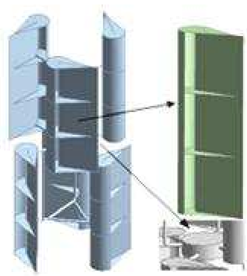

Fig. 2. 3D model of Senegal type wind turbine

3. Basic Operation Principle

3.1. Control Equation

Computational fluid dynamics (CFD) is a changing process of analyzing fluid velocity, temperature or pressure in space[7]. It is a continuous process of variation, in which the three conservation laws namely the law of conservation of mass, the law of conservation of momentum, and the law of conservation of energy satisfied.

(1) The mass conservation equation:

$$\tau = \tau_0 \left(1/2 - \xi\right) , \tag{1}$$

$$E = E_0 \left(1 - \gamma\tau\right) , \tag{2}$$

$$E = E_0 \left(1 - \alpha \left(1/2 - \xi\right)\right) , \tag{3}$$

$$h(\xi) = h_0 \left[1 - \left(1 - \beta_1\right)\left(\xi + 1/2\right)\right] \cdot \left[1 - \left(1 - \beta_2\right)\left(\eta + 1/2\right)\right] , \tag{4}$$

$$\rho = \rho_0 \left[1 - \left(1 - \beta\right)\left(\xi + 1/2\right)^2\right] , \tag{5}$$

where$f$ is the unit mass force, p is the dynamic pressure, τ is the viscous stress, k is the heat transfer coefficient, e is the generalized internal energy of unit mass fluid.

3.2. Transient Simulation Analysis

In order to visually reflect the absorption of wind energy, transient analysis of the wind turbine by FLUENT. Fig. 3 shows the torque coefficient in the case of wind speed 6.7m/s and the tip speed ratio of 0.5. When the wind speed and the turbine rotation period is constant, rotate one cycle through three cycles. By the influence of the aerodynamic performance, the upper and lower flow fields of the wind turbine are coupled with each other to produce a more complicated nonlinear variation than the calculated torque of the wind turbine, the torque fluctuation range is smaller and the mechanical power is more stable however.

Torque coefficient of the wind speed is 8.5m/s is shown in Fig. 4. The simulation time is set to 4s. The turbine torque coefficient changes periodically, and the torque coefficient becomes smaller as the *TSR* increases as the time increases. With the increase of the tip speed ratio, the wind energy utilization rate increases first and then decreases, and the maximum value is obtained at about 0.5 as shown in Fig. 5.

Fig. 6 shows the pressure distribution of two-layer wind turbine at the wind speed is 8.5m/s which shows the force characteristics of the blades. The left side of the turbine subject to greater pressure in the upwind side. As shown in blade 1, the pressure on the left side is far larger than the it on the right side whereas the pressure of the blade away from upwind side have a little change. So do the bottom

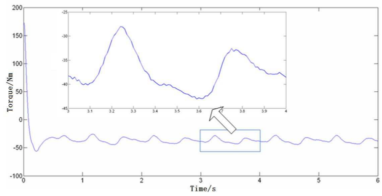

Fig. 3. Torque with 0.5 tip speed ratio

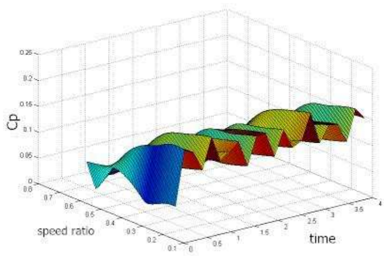

Fig. 4. Torque coefficient with 8.5m/s wind

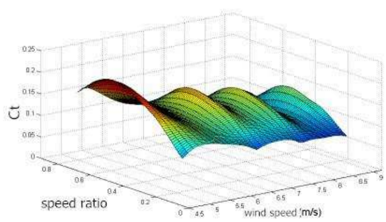

Fig. 5. Wind energy utilization

blades, due to the greater force in front of the semicircular arc plate, run speed and torque of blade 4 reduced, conduct the negative power.

The speed of the wind turbine is shown in Fig. 7. The force is limited because of the small intermediate speed. Large speed in front of the running blade 3 due to the angle between the direction of wind wheel speed and wind direction is less than 90 degrees. The superposition makes a certain resistance, blade 1 suffered a shock by wind directly at the same time so that the speed reduced seriously to obtain greater power.

In comparison, when the upper side of the wind wheel is conducting negative power with the angle difference between the two layers is 60 degree, the propulsion is greater than the resistance, which make the wind turbine perform positive work for stable operation.

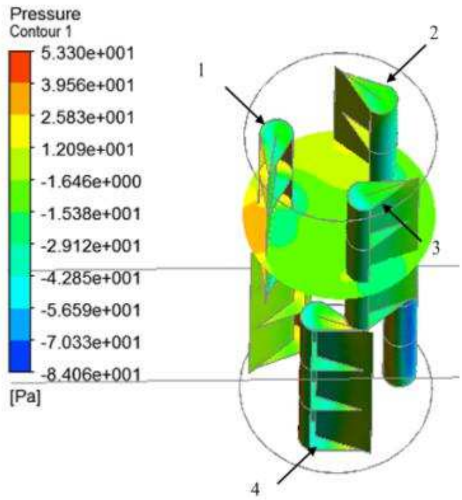

Fig. 6. Pressure distribution of wind speed is 8.5m/s

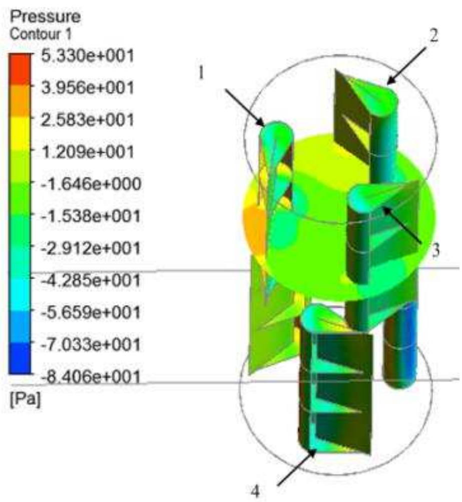

Fig. 7. Velocity flow chart of wind speed is 8.5m/s

4. Turbine System Modeling

4.1. Wind turbine mathematical model

The modeling of the wind turbine model is mainly based on the wind energy utilization factor formula and the wind energy utilization curve. The mathematical model of wind energy utilization is established by using the curve fitting method. Based on these, the wind speed and the wind speed are taken as the input quantity and the mechanical torque is used as the output quantity to establish the wind turbine model which can be fitted as:

$$C_p = -0.697\lambda^3 - 0.111\lambda^2 + 0519\lambda + 0.004 \tag{6}$$

4.2. Model construction

The simulation model built in Simulink is shown in Fig. 8. The core modules are the wind turbine torque fitting and power generation. The vector control method is applied to the PMSM in this paper in order to make the data more accurate. Double closed loop control scheme of PI is applied in vector control which is composed of the current PI control module, speed PI control module, SVPWM module and PMSM. The control process is to compare the actual speed of the motor and the reference speed, based on the relationship between torque and speed, the reference value of stator current torque component iq is calculated by the speed PI controller. In the case of given stator current excitation component, the rotating current signal i_d??i_q are converted into the current signal i_α, i_β in the two phase stationary reference system by coordinate transformation. Finally, it is sent into the SVPWM, the control pulse of SVPWM can control the switch state of the three-phase inverter, so the actual current of the stator three-phase winding is obtained.

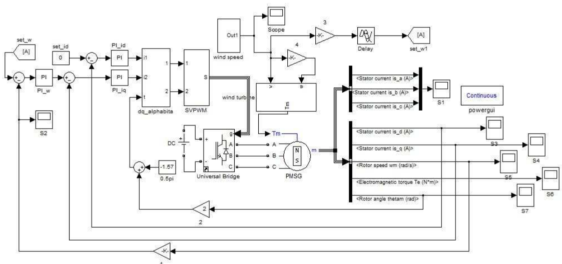

Fig. 8. Power generation system simulation model

4.3. Model of energy storage

The electrolytic hydrogen generation system mainly consists of four parts that are classified as the electrical part and the electrochemical part. This section is mainly focused on the electrical part, specifically based on the electrolyzer in the voltage and current curve, and the change of resistance obtained.

The parameters of the electrolytic cell are listed in Tab. 1, where$u_{el}$is the total voltage, u_{cell} is the theoretical voltage required for 1mol water electrolysis, i_{e1} is the current in the electrolytic cell, r_i is the resistance in the electrolytic cell,T_{e1} is the temperature in the cell, S_i and t_i are the overvoltage parameter, A is the area of the electrode.

Table 1. Parameters of electrolytic cell.

Name	Voltage	Unit	Name	Voltage	Unit
T_{el}	Channel 1	$^\circ C$	A	0.25	m^2
r_1	25	Ωm^2	r_2	-1.1×10^{-7}	$\Omega m^2/^\circ C$
a_1	7.3×10^{-5}	V	s_2	0.00138	$V/^\circ C$
a_3	-1.6×10^{-5}	$V/^\circ C^2$	t_1	0.016	m^2/ A
t_2	-1.3	$m^{2\circ} C$ / A	t_3	4.12×10^2	$m^{2\circ} C^2$/ A

According to the formula and table, voltage curve and current curve in the electrolytic cell at 25°C are simulated and the equations and the calculation results are as follows:

$$y = 30 \times (1.229 + 2.81 \times 10^4 x + .01845 \times log(2.4928x + 1)) \tag{7}$$

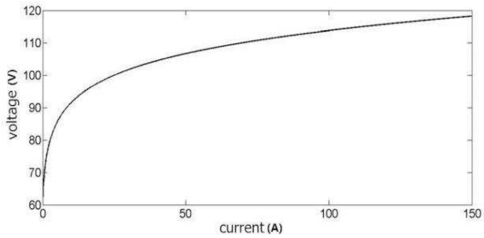

Fig. 9. Curves of voltage and current in electrolysis cell

On the basis of Fig.8, the stator current of the phase A of the motor is led out at the motor detection end. The electrolytic cell voltage is calculated by using the electrolysis hydrogen circuit model E_W and is represented by the oscilloscope S_EW. The circuit shown in Fig. 10

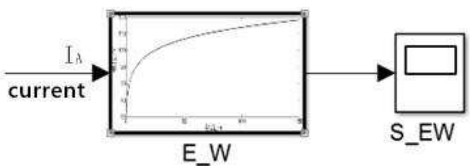

Fig. 10. Power generation model by adding the energy storage load

5. Simulation Results

The wind turbine output torque is change when the wind speed changes, as shown in Fig. 11. The variation of wind speed in 5s is simulated in this paper. Based on this, the calculation and analysis of power generation characteristics are carried out. The simulation time is set to 1s, and the power generation characteristics of the turbine are simulated. In Fig. 12, from the top to the bottom is the current on the stator d axis, the current on the stator q axis, the motor speed, the electromagnetic torque, and the rotor angle.

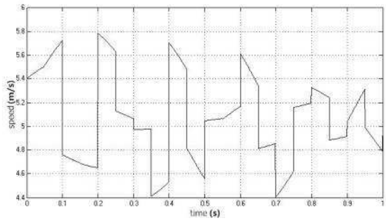

Fig. 11. Wind velocity variation curve

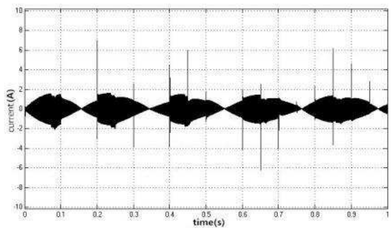

Fig. 12. Stator current curve in d axis

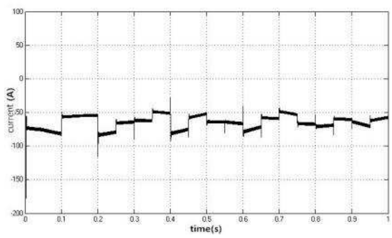

Fig. 13. Stator current curve in q axis

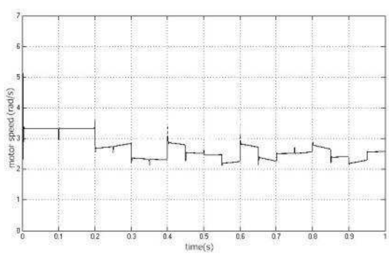

Fig. 14. Motor speed curve

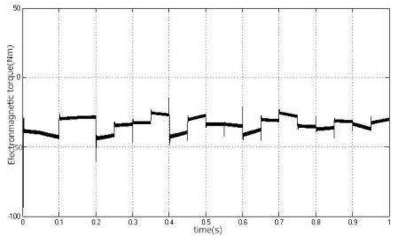

Fig. 15. Electromagnetic torque curve

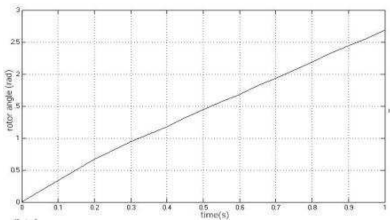

Fig. 16. Rotor angle curve

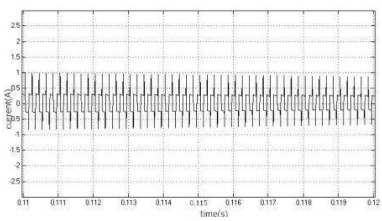

Fig. 17. Stator current of the d-axis of an enlarged curve

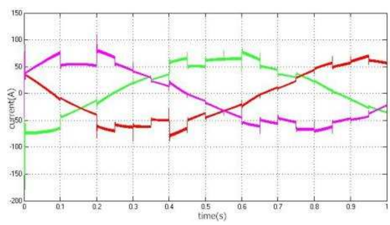

Fig. 18. Three phase current variation curve of generator

6. Conclusion

The simulation model of the vertical axis wind power generation system is established. The wind energy utilization coefficient curve, wind speed model, generator model curve are obtained. Finally, the energy storage model is established, and the simulation result curvesare obtained according to the power generation characteristic formula. The results show that the simulation process of the wind power generation system is correct and reasonable, and the operating parameters of the electrolytic hydrogen in the energy storage module are realistic,which providesthe reference for subsequent designs and optimization.

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