

Study on Model and Control System of Variable-Speed Pitch-Controlled Wind Turbine

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Abstract:-This paper studies the model of variable-speed pitch-controlled wind turbine, and establishes its mathematical model. Based on this model, For extracted maximum power from the wind, a kind of multi-controller with speed and pitch controller is designed. The model and its control system is studied and simulated in with Matlab.

Key-words: wind energy, variable-speed pitch-controlled wind turbine, MPPT, multi-controller, Matlab

1. Introduction

Because of the exhaustion of the fossil energy in recent years and its harm to environment, people begin to find renewable energy to replace it. Green energy-wind energy becomes the emphasis in the energy strategy of countries for its renewable and non-pollution. Wind turbine is the system that converts wind energy to electric energy. Now in the market there are two kinds of wind turbine, ie fixed-speed and variable-speed. Fixed-speed is widely used in the past years because its control system is simply. But this kind of wind turbine can only run at a narrow range of wind speed and its efficiency is low. Variable-speed has more advantages than fixed-speed wind turbine such as the increased energy captured from the wind, reduction of fatigue damage on rotor blades and drive train, improvement on operational flexibility. More and more people come to study this kind wind turbine[1]-[8].

The paper studies model and control system with variable-speed pitch-controlled wind turbine. The mathematical model of this kind wind turbine is established. A multi-controller with speed controller and pitch controller is designed. The main objective is to maximize the efficiency on energy extraction and controller design also considers the wind turbine operation range.

2. Model and Control Objectives Description

2.1. System Modeling

A wind turbine generally consists of a rotor, a gearbox, and a generator that is shown in Fig.1[9].

The aerodynamic power capture by the turbine is given by the expression:

$$P_a = \frac{1}{2} \rho \pi R^2 C_p (\lambda, \beta) v^3 \tag{1}$$

Where ρ is air density, R is rotor radius, C_p is power coefficient and v is wind speed.

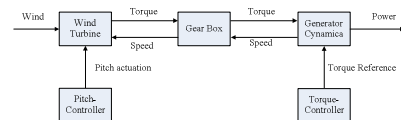


Fig.1 The structure of WECS

From the expression, we can see the power extracted from the wind, P_a , is proportional to the cube of the wind speed v . The power coefficient, C_p , depends on the blade pitch angle β , and the tip-speed ratio λ , which is defined as the ratio between the blade tip-speed $\omega_r R$ and the wind speed v . Its surface for wind turbine considered in this study is shown in Fig.2.

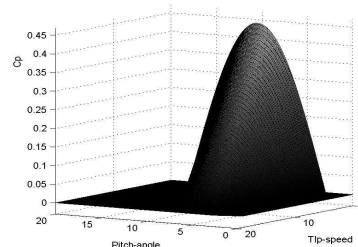


Fig.2 CART WECS torque coefficient

Depending on the relationship:

$$P_a = \omega_r T_a \tag{2}$$

We can get the aerodynamic torque expression as

below:

$$T_a = \frac{1}{2} \rho \pi R^2 C_q(\lambda, \beta) v^2 \quad (3)$$

where

$$C_q(\lambda, \beta) = \frac{C_p(\lambda, \beta)}{\lambda} \quad (4)$$

A three –mass model of WECS is shown in Fig.3. It runs at wind speed v and rotor speed ω_r .

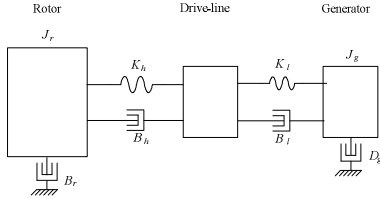


Fig.3 The model of wind turbine

The dynamic response of the rotor is shown below:

$$J_r \dot{\omega}_r = T_a - T_l - K_r \omega_r \quad (5)$$

where J_r is rotor inertia, T_a is aerodynamic torque, T_l is low-speed shaft torque, K_r is the rotor external damping, T_l is deduced from the torsion and friction effects due to difference between ω_r and ω_l :

$$T_l = B_l(\theta_r - \theta_l) + K_l(\omega_r - \omega_l) \quad (6)$$

Where B_l is low speed shaft stiffness, K_l is low speed shaft damping, θ_l is low-speed shaft angle,

θ_r is the rotor angle,

Considering the generator electromagnetic torque as an input parameter, the dynamic response of generator is shown to be:

$$J_g \dot{\omega}_g = T_h - T_g - K_g \omega_g \quad (7)$$

where J_g is generator inertia, T_h is high-speed shaft torque, T_g is generator torque, K_g is the generator external damping, ω_g is the generator speed.

Assuming the gearbox is ideal with transmission ratio n , we can get the relation:

$$n = \frac{T_l}{T_h} = \frac{\omega_g}{\omega_l} \quad (8)$$

The Eqs. (1) — (8) is mathematical model of WECS.

2.2 Control objectives

The control system of WECS controlled the power

interchanged between the wind and generator and to make the WECS run at optimum operation point. WECS operation can be divided into three modes which is shown in Fig.4.

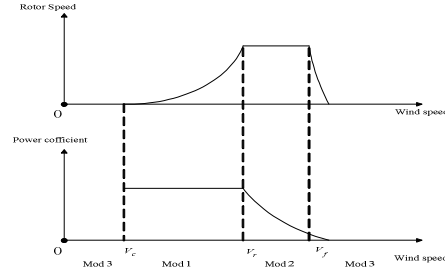


Fig.4 Operation Modes of Wind Turbine

- Mode 1: operating at variable speed/optimum tip-speed ratio:

$$v_c \leq v \leq v_r$$

- Mode 2: operating at constant speed:

$$v_r \leq v \leq v_f$$

- Mode 3: stopping the system:

$$v_f \leq v \text{ or } v_c \geq v$$

Where v is wind speed, v_c is cut-in wind speed, v_r is the rate wind speed, v_f is the cut-out wind speed.

Control system design objective for WECS can be defined as below:

- Maximize the power between the cut-in and rate wind speed.
- Limit and smooth the power between the rate and cut-out wind speed.
- Stop the system at other wind speed area

3. The Control System Design

3.1 Control Strategy

In the aim of getting the control objectives in section 2.2, the control system that includes two controllers namely speed controller and pitch controller. In mode 1, the speed controller is active; the optimum pitch angle is zero in the power optimization. In the mode 2, both controllers are active and cross-coupled to each other. The structure of multi-controller is shown in Fig.5.

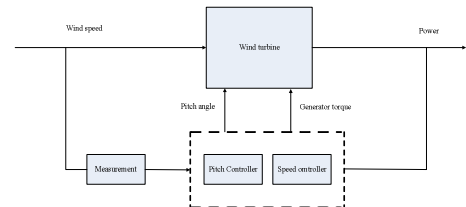


Fig.5 The structure of multi-controller

3.2 Speed Controller

In order to get the maximum power form the wind, the generator should adapt its speed to maintain the

optimum C_p (tip speed ratio). The structure of this controller is present in Fig.6. Based on measured wind speed and using the optimum C_p , the reference generator torque for generator is obtained. The Equ.7 is the mathematical model of generator. The controller is a PI controller.

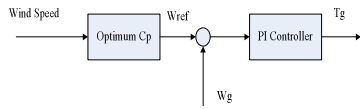


Fig.6.The structure of Speed controller

3.3 Pitch Controller

For limiting the output of the WECS when the wind speed is above the rated speed, the pitch controller has to modify the pitch angle. The structure of this controller is shown in Fig7. The error signal between the measured power and rated power is applied in gain scheduling (computed by C_p), which it produces the reference pitch angle. A PI controller corrects the error between the actual pitch angle and the reference.

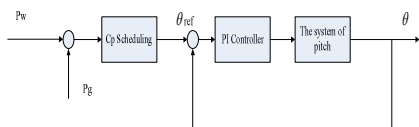


Fig.7.The structure of Pitch controller

4.Simulation Results and Discussion

The simulation analysis is carried out in Matlab-Simulink simulation environment. The parameters of the WECS in this simulation are shown in Table1. The simulation is divided into two part: the wind turbine run in mode 1 and mod 2. In the first part, the ability of the wind turbine system to follow the MPPT (maximum power point tracking) is evaluated. In the second part, the WECS system is running in mode 2, the smoothing and limiting ability of the power extract from the wind is evaluated.

The simulation result is shown in Fig.8 and Fig.9. Wind speed changes from 0m/s to 20m/s. When wind speed is under rated wind speed, the power obtain from the wind is tracking the maximum power and C_p is keeping a constant. Meanwhile, the speed controller is under operation at this time. When the wind speed is more than rated, the pitch controller is working and the power is a constant. The simulation test the controller has a good performance of MPPT in mod

1 and good ability of limiting power mod2.

Tab. 1.Parameter of the wind turbine

Parameters	Value
R(m)	35.25
Cut-in/(m/s)	4
rated/(m/s)	12.2
Cut-out/(m/s)	25
Drive-train ratio	1: 90
Optimum tip-speed	10
C_p	0.44
J_t (kg·m ²)	320000
J_g (kg·m ²)	60

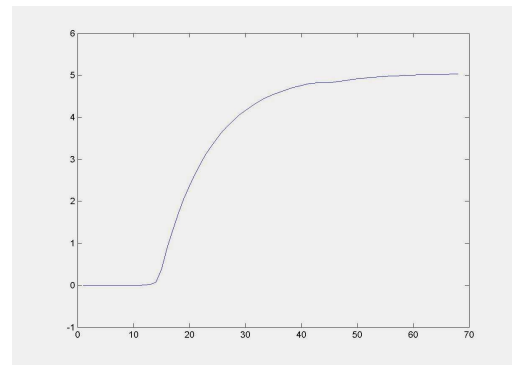


Fig.8 The rotor speed

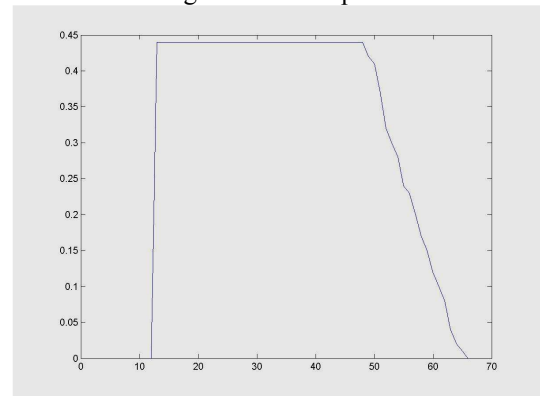


Fig.9 The C_p curve

5. Conclusion

The model and control system of wind turbine is study in this article. A multi-controller is designed in this article. From the simulation result, we can see this multi-controller get a good performance in MPPT and power limiting. This multi-controller can be satisfied in a wide operation range.

Reference:

[1] Soderholm, P., Ek, K., Pettersson, M.Wind power development in Sweden: Global policies and local obstacles Renewable and Sustainable Energy Reviews 2007;11 (3), pp. 365-400
 [2]Valenciaga,F., Puleston, P.F., Battaiotto, P.E.,Mantz, R.J. An adaptive feedback linearization strategy for variable speed wind energy conversion

- systems. *International Journal of Energy Research* 2000; 24 (2), pp. 151-161
- [3] Mayosky, M.A., Cancelo, G.I.E. Direct adaptive control of wind energy conversion systems using Gaussian networks *IEEE Transactions on Neural Networks* 1999;10 (4), pp. 898-906
- [4] Johnson, K.E., Fingersh, L.J., Pao, L.Y., Balas, M.J. Adaptive torque control of variable speed wind turbines for increased region 2 energy capture. 43rd AIAA Aerospace Sciences Meeting and Exhibit - Meeting Papers, 2005 pp. 1933-1943
- [5] Cárdenas, R., Peña, R. Sensorless vector control of induction machines for variable-speed wind energy applications, *IEEE Transactions on Energy Conversion* 19 (1), 2004;pp. 196-205
- [6] Dambrosio, L., Fortunato, B. One-step-ahead adaptive control of a wind-driven, synchronous generator system *Energy* 1999 24 (1); pp. 9-20
- [7] Dadone, A., Dambrosio, L. Energy Conversion and Management Estimator based adaptive fuzzy logic control technique for a wind turbine-generator system 44 (1),2003; pp. 135-153
- [8] Zhang, Q.-Z., Gan, W.-S., Zhou, Y.-L. Adaptive recurrent fuzzy neural networks for active noise control , *Journal of Sound and Vibration* 2006,296 (4-5), pp. 935-948
- [9] Boukhezzar, B., Siguerdidjane, H., Maureen Hand, M. Nonlinear control of variable-speed wind turbines for generator torque limiting and power optimization , *Journal of Solar Energy Engineering, Transactions of the ASME* 128 (4), pp. 516-530