Maximum Power Point Tracking in PMSG Using Fuzzy Logic Algorithm

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Abstract

In this paper, a novel maximum power point tracking (MPPT) for a PMSG-based variable speed wind power system is proposed using the fuzzy logic algorithm. The control algorithm is developed based on the normal hill climb searching (HCS) method, commonly used in wind energy conversion systems (WECS). The inputs of fuzzy-based controller are the derivations of DC output power and the step size of DC/DC converter duty cycles. The main advantages of the proposed MPPT method are no need to measure the wind velocity and the generator rotational speed. As such, the control algorithm is independent of turbine characteristics, achieving the fast dynamic responses with non-linear fuzzy systems. The effectiveness of the proposed MPPT strategy has been verified through the simulated results.

1. Introduction

With the rising cost and limited availability of fossil fuels, renewable energy sources especially wind energy has become an attracting research trend in the power electronics field [1]. With large and abrupt variation in wind speed, it is necessary to extract maximum power from the wind turbine under normal operation conditions. In order to extract maximum energy from wind, several maximum power point tracking (MPPT) control strategies have been developed in the literature [1-5]. The principle of a MPPT method is adjusting the generator rotational speed according to variations of wind speeds so that the tip-speed-ratio (TSR) can be maintained at its optimal value. Among previously developed wind turbine MPPT strategies, researchers focused on three common methods, named TSR control, power signal feedback (PSF) control and HCS control. However, the TSR control method [1] was limited due to the difficulty in wind speed and turbine speed measurements. To overcome this problem, the PSF control method was proposed [2] by generating a reference power demand using the wind turbine maximum power curve. However, the knowledge of the turbine's characteristics was required in this method. In contrast, the HCS control method was popularly used in WECS due to its simplicity and independence of system characteristics [3]. A comprehensive analysis of the influence of step size of DC/DC converter duty cycle on the tracking speed and MPPT efficiency was developed in [4]. In [5], a modified HCS control method was proposed without using the measured generator rotational speed. However, this control method was executed with a constant step size of DC/DC converter duty cycle that significantly limited the accuracy of MPPT method. To tackle this, a fuzzy logic-based MPPPT algorithm is proposed in this paper. The control algorithm is developed based on derivations of the DC output power to determine the step size of DC/DC converter duty cycles. The proposed MPPT algorithm works well without the wind speed or the generator rotational speed. The simulation results presented in the paper prove the excellent performances of the proposed MPPT method.

2. Fuzzy-based controller for PMSG

2.1. Wind Turbine Characteristics

The power captured by the wind turbine blades P_m is a function of the blade shape, the radius and the rotational rotor speed, given as

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

where: ρ is the air density (typically 1.25 kg/m^3).
β is the pitch angle (deg).
$C_p(\lambda,\beta)$ is the wind-turbine power coefficient.
R is the blade radius (m).
v is the wind speed (m/s).

The term λ is the tip-speed ratio, defined as:

$$\lambda = \frac{\Omega R}{v} \tag{2}$$

where Ω is the generator rotational speed (rad/s).

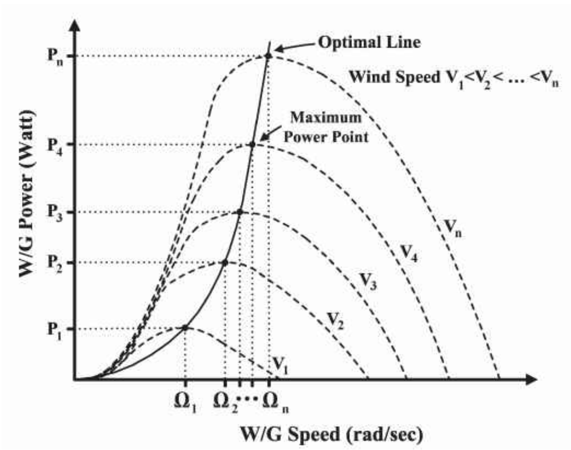


Fig. 1 Wind power curve at various wind speeds.

The wind turbine power coefficient is maximized for a tip-speed ratio value, λ_{opt}. The wind generator (WG) power curve for various wind speeds are show in Fig. 1. For each wind speed, there exists a specific point in the WG power curve where the output power is maximized by controlling WG load. Consequently, the generator rotational speed can be adjusted to optimal point while wind speed is continuously changing (MPPT control). The value of tip-speed ratio is maximum and constant for all maximum power points (MPPs). The power coefficient curve at various generator speeds is show in Fig. 2.

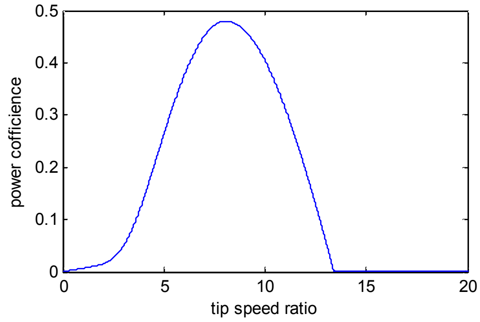


Fig. 2 Power coefficient curve at various generator speeds.

2.2. Proposed MPPT method

The proposed control system consists of a wind turbine, a permanent magnet synchronous generator (PMSG), an uncontrolled three phase diode bridge rectifier, a DC-DC converter (buck converter), and a DC load. The MPPT algorithm is constructed based on a novel fuzzy logic control that directly adjusts the DC/DC converter duty cycle to control generator rotational speed. With a given wind speed, the MPPT algorithm operates and controls the DC load current by changing DC/DC converter duty cycle. Consequently, the generator rotational speed is controlled, and hence the DC output power at the load side can be achieved with the maximum value.

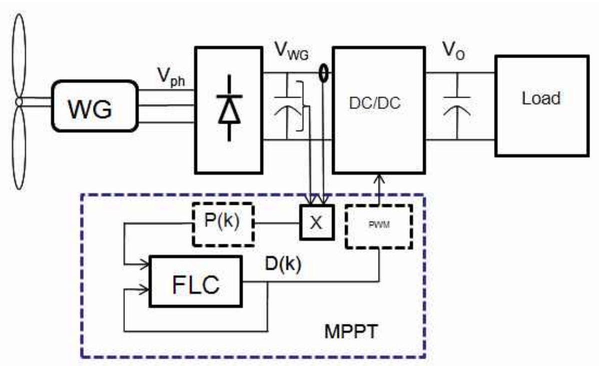


Fig. 3 A Maximum Power Point Tracking in Variable Speed Wind Turbine System with novel FLC model.

Taking into consideration on the wind turbine characteristics depicted in Fig. 1, maximum power points are identified by the following equation

$$\frac{dP}{d\Omega}=0 \qquad (3)$$

According to equation (3), there is a relation between DC power and the generator rotational speed at the maximum power point. In the proposed FLC model, the derivations of the DC output power and DC/DC converter duty cycle are used as inputs of fuzzy sets. The relationship between DC output power and DC/DC converter duty cycle at maximum power point is required to design fuzzy rules. According to [5], the equivalent equation has been proved and shown as follows:

$$\frac{dP}{d\Omega}=0 \Leftrightarrow \frac{dP}{\mathrm{dD}}=0 \qquad (4)$$

where D is the DC/DC converter duty cycle.

A detailed description of the proposed MPPT process is depicted in Fig. 4.

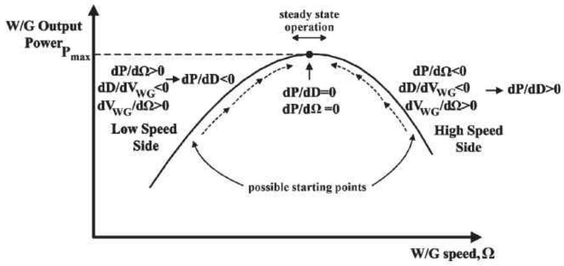


Fig. 4 Maximum power point tracking process.

2.3 FLC model

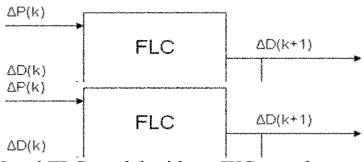


Fig. 5 Novel FLC model without WG speed measurement

The inputs of FLC are derivations of the DC output power and the duty cycle between sampling instant k^{th} and $(k-1)^{th}$, calculated as

$$\Delta P(k)=G_p[P(k)-P(k-1)] \qquad (5)$$

$$\Delta D(k)=G_D[D(k)-D(k-1)] \qquad (6)$$

where G_P and G_D are the input scaling gains of the controller.

The scaling gains are used in the FLC to adjust values $\Delta P(k)$, $\Delta D(k)$ in the range of [-1,1]. Design of the fuzzy sets includes 27 rules. The output of FLC is $\Delta D(k+1)$ since that value the control signal D(k) is computed by the following

$$D(k+1)=D(k)+G_D\Delta D(k+1) \qquad (7)$$

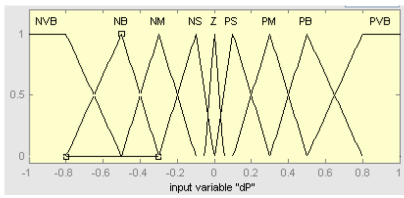


Fig. 6 Membership function for input ΔP

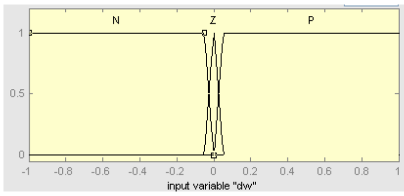


Fig. 7 Membership function for input ΔD

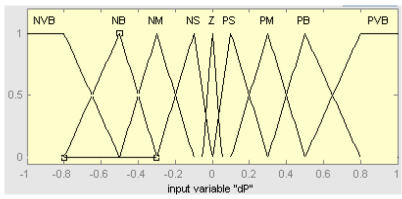


Fig. 8 Membership function for output ΔD

2.4 Simulation models and results

A wind turbine model and a PMSG model with parameters shown in Table 1 and Table 2 is constructed and used to test the performance of the proposed fuzzy logic control system.

The control system consists of three parts: Wind turbine model shown in Fig. 10, fuzzy logic controller presented in Fig. 11, and generator and power converter model depicted in Fig. 12.

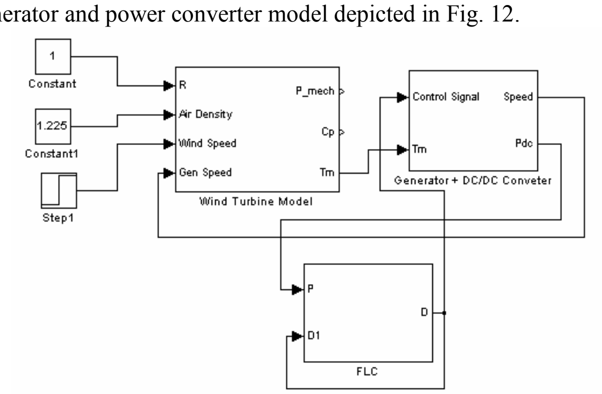


Fig. 9 Simulation model of MPPT PMSG System in Matlab/Simulink.

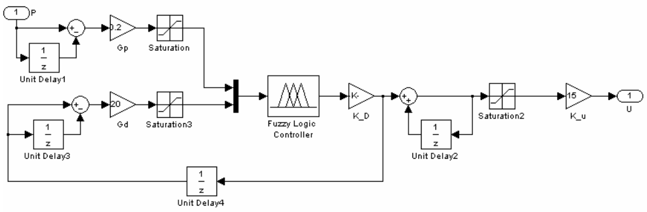


Fig. 10 Wind turbine Model

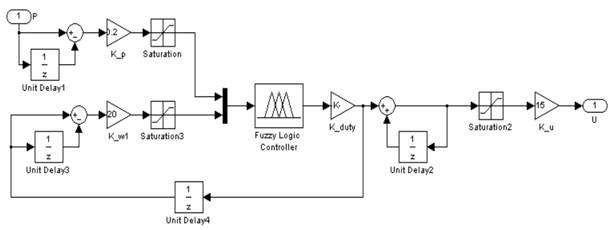


Fig. 11 Fuzzy Logic Controller model

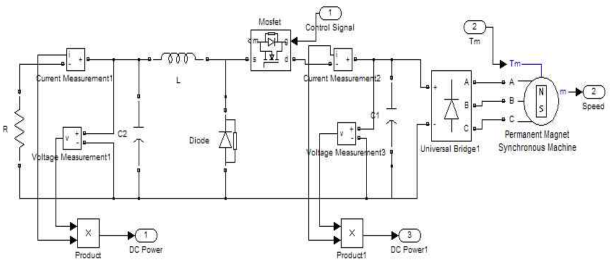


Fig. 12 Generator and Power converter model

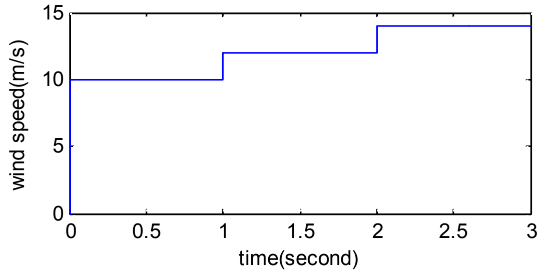
Table 1. Wind turbine parameters

Turbine Rotor blade radius, R	1 m
Moment of Inertia, J	0.3 kg.m^2
Maximum Power Coefficient, $C_{p(max)}$	0.48
Rate wind speed	12 m/s

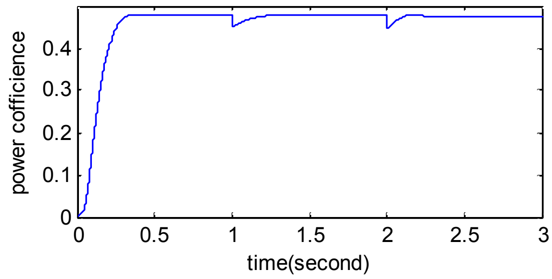
Table 2. PMSG parameters

Stator resistance, R_s	0.0918 Ω
Stator inductance	0.000975 H
Moment of inertia, J	0.003945 kg.m^2
Electric Power, P_e	6 kw
Rate speed, ω_m	2300 rpm

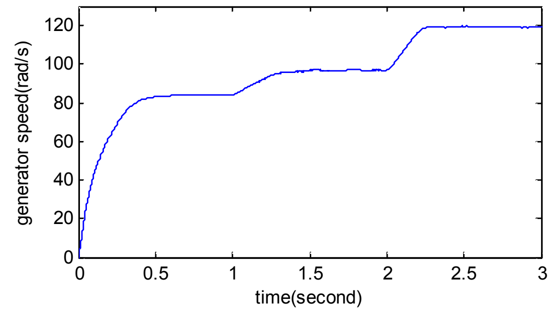
Fig. 13(a) shows a wind speed profile with specific step changes. More clearly, wind speed is increased from the initial value 10 m/s to 12 m/s, 14 m/s at t=1s, t = 2s, respectively. The power coefficient C_P reaches to maximum value (approximate 0.48) in a stable manner. At a time the wind speed suddenly changes, the WG rotor speed remains still unchanged because of considerable wind turbine inertia, therefore C_P decreases suddenly. However, by adopting the MPPT algorithm, generator rotational speed changes to an optimal value and hence C_P returns to the maximum value. The performance characteristics of C_P are show in Fig. 13(b).



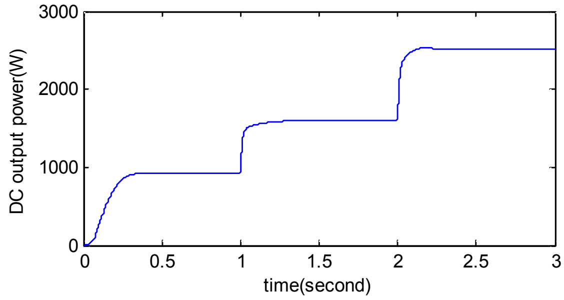
(a)



(b)



(c)



(d)

Fig. 13 (a) Wind speed profile.
(b) Performance of power coefficient.
(c) Generator rotational speed.
(d) DC output power.

In the second simulation process, wind speed changes simultaneously as illustrated in Fig. 14(a) with the initial speed of 10 m/s. It is clear that the power coefficient C_P also reaches the maximum value (approximate 0.48) even though the wind speed is changed. As can be seen in Fig. 14(a), the value of C_P is little reduced in some intervals due to sudden changes of the wind speed. However, the generator rotational speed change to an optimal value, therefore C_P returns to maximum value. The performance characteristics of C_P are show in Fig. 14(b).

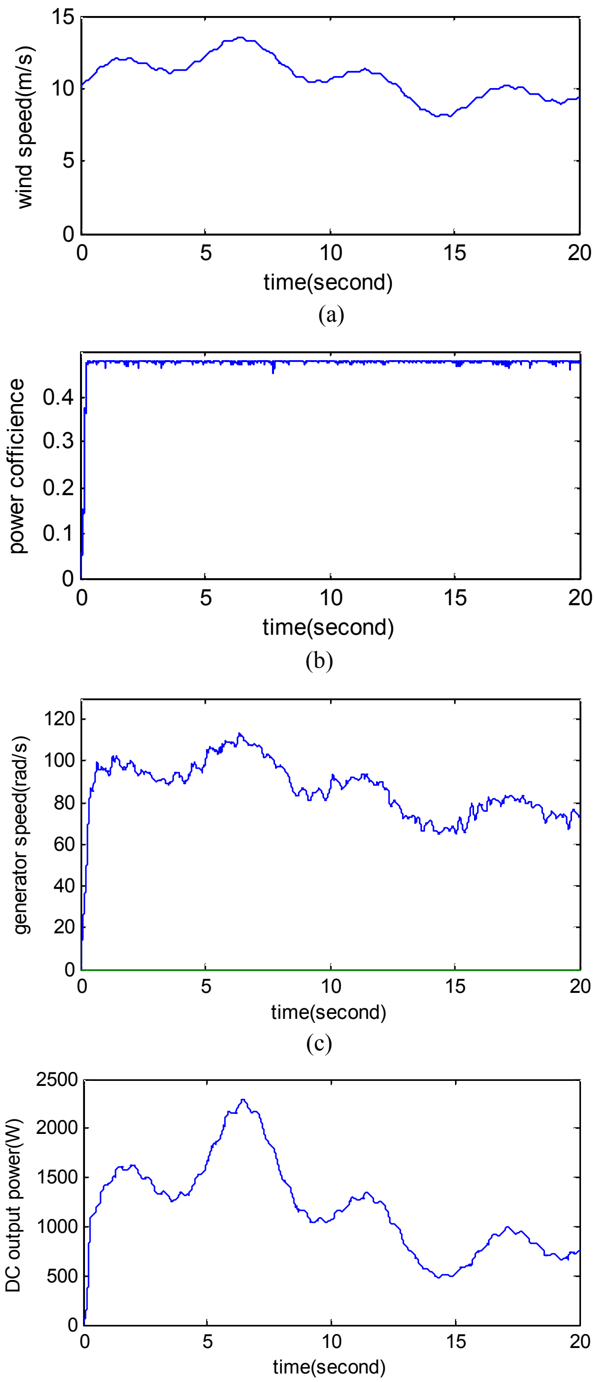


Fig. 14 (a) Wind speed profile.
(b) Performance of power coefficient.
(c) Generator rotational speed.
(d) DC output power.

3. Conclusion

A novel fuzzy logic-based MPPT for PMSG variable speed wind turbine system has been proposed in this paper. The proposed system requires neither the knowledge of WG characteristic nor measurements of the wind speed and the WG rotor speed. It has been shown that the turbine power output non-linearly depends on its WG rotor speed and the wind speed. Fuzzy control approach is quite suitable for searching the optimal WG rotor speed at which the turbine operates with the maximum power value. The performance of the proposed system has been verified under the changes of wind. The proposed MPPT algorithm shows good performances under various operating conditions.

Reference

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