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An Improved MPPT Method of Wind Turbine Based on HCS Method by Using Fuzzy Logic System

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Abstract

In this paper presents a Maximum Power Point Tracking (MPPT) technique based on the Hill Climbing Search (HCS) method and fuzzy logic system for Wind Turbines (WTs) including of Permanent Magnet Synchronous Generator (PMSG) as generator. In the conventional HCS method the step size is constant, therefor both steady-state response and dynamic response of method cannot provide at the same time and in the fixed step size of HCS method. The propose method of this paper is improvement the performance HCS method, in order to reach this goal; the fuzzy logic system has been used. The fuzzy logic system based on operation condition determined the step size instantaneously, such as both steady-state response and dynamic response of method be proper at the same time, therefore, efficiency of the new method that used variable step size strategy, will be guaranteed, the results of simulation in environment MATLAB/Simulink software have been shown to be effectiveness of the proposed method.

Keywords: wind turbine, maximum power point tracking, hill climbing search method, fuzzy logic system

8. Introduction

One of the most important issues in wind energy systems is to capture as much energy as possible from the wind in the shortest time, which can be achieved through different Maximum power point tracking (MPPT) methods. The structure of an MPPT method consists of two main sections. In the first section, an algorithm is used to find the set point which has obtained the maximum power. The control signal is then created through different control methods in the second section. Thus, the developing an efficient MPPT method is achievable through improving effectiveness of each section. Most of previous studies are concerned to improve effectiveness of the first section. Studied MPPT methods up to now can be classified into tip-speed ratio (TSR) method, power signal feedback (PSF) method and hill-climb searching (HCS) method [1-4]. In MPPT-TSR method, desired optimum rotor speed to control the system is continuously computed by measuring the wind speed and optimal TSR. In MPPT-PSF method, desired optimum power (in MPPT-OP method) or torque (in MPPT-OT method) to control the system is obtained from the wind turbine’s optimum power or torque curve. In MPPT-HCS method, depending on the location of the operating point and the relationship between the power changes and speed, desired optimum signal is computed in order to drive the system to the point of maximum power. Although MPPT-TSR and MPPT-PSF methods are limited by difficulty in wind speed measurements and knowledge of the turbine’s characteristics, they are more efficient than MPPT-HCS method. Furthermore, proposed methods to estimate the wind speed [5, 6] and optimum operation characteristic from wind turbine [7, 8] with higher accuracy in-crease the desire to use these methods. These methods are always seeking a reference point to control the system, while the selection of the controller type (second section) affects the efficiency considerably. In comparison, the HCS algorithm is popular due to its simplicity and independence of system characteristics and it can avoid using wind speed. However, the step size of HCS algorithm is constant. Choosing an appropriate step size is not an easy task, where large step size means faster response and less steady-state efficiency while small step size improves steady-state efficiency but slows down the convergence speed. The conventional HCS algorithm cannot combine rapidity and efficiency, which means the algorithm cannot adapt well both in the situation that wind speed changes quickly and in the situation that wind speed is constant.

In this paper, a fuzzy-logical-controller based MPPT strategy for wind generation system is proposed, which can realize variable step-size control. The strategy is independent of the turbine's characteristics. Compared with conventional HCS algorithms with a big step size and a small step size respectively, the proposed algorithm is validated superiorly in MATLAB/Simulink environment. The simulation results indicate the proposed MPPT algorithm has three advantages: a) tracking MPP fast, b) the fluctuation magnitude of real power is small during steady state, and c) the wind energy captured is the most among the three MPPT algorithms.

In Section 2, the Wind energy background is presented. Fundamentals of the MPPT-HCS method for wind turbine are reviewed in Section 3. In Section 4, the architecture and training algorithm of the fuzzy logic system will be described. Simulation results are discussed in Section 5. Section 6 gives the conclusion of this paper.

2. System Overview

2.1. Wind Turbine Characteristics

According to aerodynamic characteristics of the wind turbine, the amount of power captured by the wind turbine delivered by the rotor is calculated by following formula [9]:

$$P = \frac{1}{2}\rho A v^3 C_P(\lambda, \beta) \tag{1}$$

Where $C_p(\lambda, \beta)$ is the wind turbine power coefficient which is a function of λ and β, ρ is the air density, R is the radius of wind turbine blade, V is the wind speed, β is the blade pitch angle, and λ is the tip speed ratio:

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

Where w is the wind turbine rotational speed. There exits an optimal tip speed ratio λ_{opt} that can maximize C_P and P. Then, the maximum wind power P_{max} captured by wind turbine can be described as

$$P_{Max} = \frac{1}{2}\rho A v^3 C_{P\_max} \tag{3}$$

The output mechanical power versus rotational speed characteristic of wind turbine for different wind speeds is shown in Fig. 1, in which the dotted line shows the maximum power points for different wind turbine rotational speed w and different wind speed V. Each P–w curve is characterized by a unique turbine speed corresponding to the maximum power point for that wind velocity. The peak power points in the P–w curves correspond to dP /dw =0 [10].

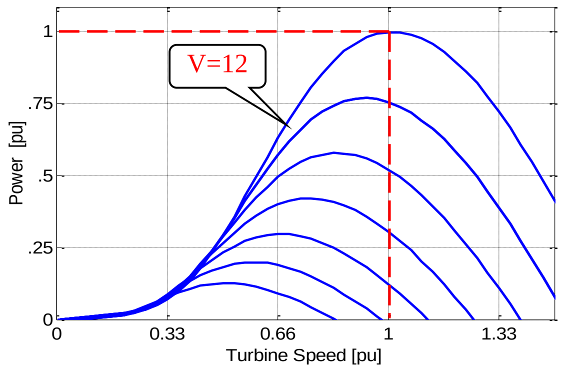

Fig.1. Power – rotation characteristic of wind turbine

2.2. Wind Generation System

Direct driven PMSG wind generator can connect a utility grid through various converter topologies, where double PWM converters are a common topology for PMSG wind generation systems. The double PWM converters own a flexible structure for different control methods and can be used to adjust the motor speed and control the power injected into a utility grid. In this paper, the configuration of the imitation platform for the PMSG wind generation system is shown in Fig. 2.

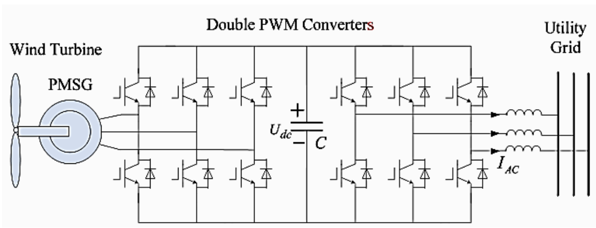

Fig.2. PMSG wind generation system with double PWM converters.

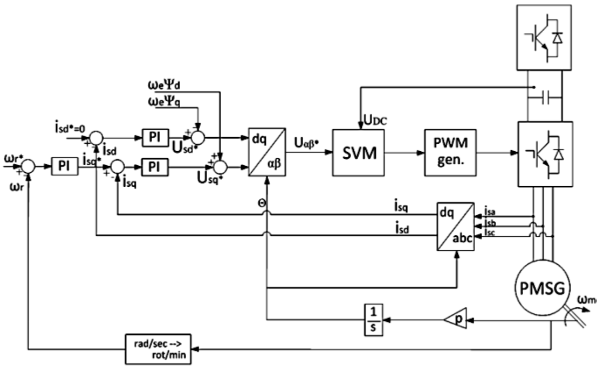

Fig. 3. Turbine-side converter control model for simulation.

In the operation control process, two PWM converters play different roles. The grid-side converter uses vector control technology based on decoupling control of active power and reactive power, which can smooth the output active power and provide reactive power support for the utility grid. Another task of the grid-side converter is to maintain the stability of the DC bus voltage. The turbine-side converter controls PMSG using vector control technology based on rotor flux oriented control. Then, the rotational speed can be adjusted to maintain the best tip speed ratio and to achieve the maximum wind power tracking when wind speed changes. The simulation model diagram of turbine-side converter control is shown in Fig. 3. From Fig. 3, we can see that the turbine is operated in the rotational speed control mode. The reference rotational speed is dynamically modified as the wind speed changes.

2.3. Issues with MPPT

To maintain the best tip speed ratio and to achieve MPPT control, the rotational speed needs to be adjusted as the wind speed changes in practical operation. The issue with MPPT is how to determine the optimal rotational speed for different wind speed. Many MPPT algorithms have already been proposed. Among them, the HCS method is popularly applied for the method is simple, fast and it can operate independently from predefined wind turbine characteristic. However, the step size of the conventional HCS algorithm is constant and it cannot change suitably as the environment changes.

This paper presents a fuzzy logical control algorithm to determine the reference rotational speed which can realize variable step-size control as wind speed changes. The inputs variables of Fuzzy Logical Control (FLC) algorithm are rotational speed variation ΔW and mechanical power variation ΔP. The step size of each instantaneous can be calculated through fuzzy logic rules. The proposed FLC algorithm is described in detail in Section 4.

3. Basic Principle of HCS Algorithm

The process of the conventional hill climbing searching algorithm used for the maximum power point tracking can be explained using Fig. 5. The basic principle of the HCS algorithm is: if the previous increment of rotational speed Δw results in an increase of mechanical power ΔP, the search of Δw continues in the same direction; otherwise, the search reverses its direction. The algorithm is described in detail as follows.

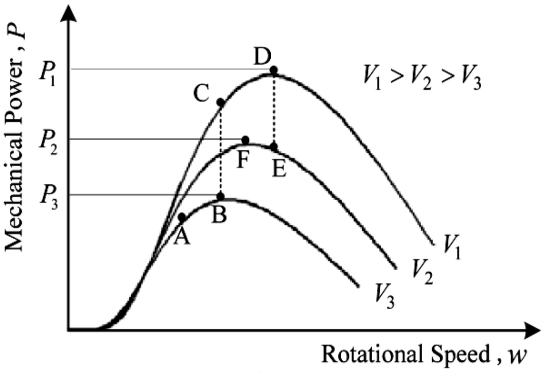

Fig. 5. Principle illustration of HCS control algorithm

Assume that the wind turbine is operating at point A in the characteristic curve shown in Fig. 5. The wind turbine rotational speed is increased and the corresponding mechanical power is detected. If the power is increased compared with that in the earlier step, the search process is in the correct direction, and the wind turbine rotational speed is increased again. If the power is decreased compared with that in the earlier step, the search will be in the opposite direction. This process is continued until the powers slope becomes zero, indicating that the HCS algorithm succeeds to reach the maximum power point, which corresponds to point B.

If the wind speed changes from v3 to v1, the turbine operating-point will jump to point C from point B instantly. Then P−w slope is positive and the turbine rotational speed is increased. The slope is observed until it becomes zero. Then the wind turbine can track the maximum power point, i.e., it will operate at point D. Now if there is a decrease in wind speed from v1 to v2, the operating-point could eventually shift from point D to point F, depending on the same principle.

4. Introduction to FLC Algorithm

The conventional HCS algorithm implementation is simple and is independent of turbine characteristics, but there still exist issues like the selection of step size. A big step size can track the MPP fast but at the same time it can result in severe oscillations around the maximum power point. Reducing the perturbation step size can minimize the oscillations around MPP.

However, a small step size can slow down the MPPT process especially when wind speed varies fast. To give a solution to this conflicting situation, a fuzzy logical control algorithm which has a variable perturbation step size is proposed in this paper. The FLC algorithm can effectively track the MPP fast and smoothly.

In the part of setting reference wind turbine rotational speed, the conventional HCS algorithm is replaced by the proposed FLC algorithm, which can realize variable step-size control. Through fuzzy control, the step size can be large when the operating point is far away from the MPP while the step size can become small when the operating point comes close to the MPP. Therefore, the FLC algorithm can dynamically change its step size, depending on the turbine operation condition.

The set of the fuzzy logical controller is described as follows: the input variables are ΔP(k) and Δw(k), while the output variable is Δwref(k). ΔP(k) and Δw(k) can be obtained by

$$\Delta P(K) = P(k) - P(k-1) \quad (4)$$

$$\Delta w(K) = w(k) - w(k-1) \quad (5)$$

The member function of input variables of fuzzy logical controller with MATLAB is defined as follows: there are three member functions of input variable ΔP(k): P (positive), Z (zero) and N (negative) respectively, as shown in Fig. 6, and also, there are three member functions of input variable Δw(k) are P (positive), Z (zero), and N (negative), respectively, as shown in fig. 7. The member functions of output variable Δwref, are s (small), m (medium) and b (big), respectively, as shown in Fig. 8.

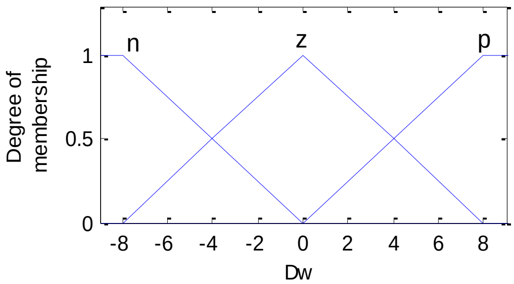

Fig.6. Member functions of input variables ΔP(K).

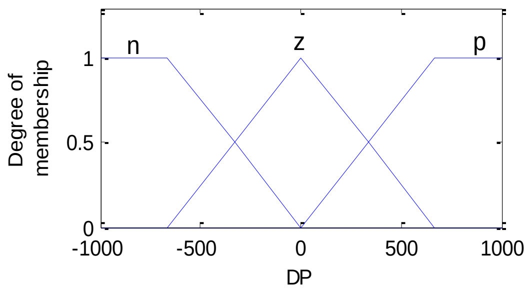

Fig.7. Member functions of input variables Δw(K).

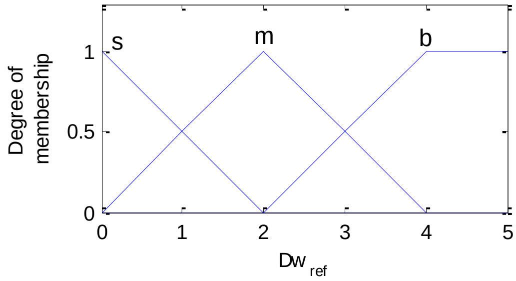

Fig.8. Member functions of input variables Δwref (K).

Table.1.
Rules for the fuzzy logical system

Delta-W	Delta-P		
	n	z	P
n	B	M	B
z	M	S	M
p	B	M	B

The fuzzy logical control rules are based on the properties of wind turbine, as shown in Table 2. Then the newly setting reference rotational speed can be updated.

The relationship between turbine mechanical power and turbine rotational speed can be expressed in (6) to (8) depending on the P−w curve.

$$\Delta p . \Delta\omega_r > 0, \quad (w < wmpp) \quad (6)$$

$$\Delta p . \Delta\omega_r = 0, \quad (w = wmpp) \quad (7)$$

$$\Delta p . \Delta\omega_r < 0, \quad (w > wmpp) \quad (8)$$

Where wmpp denotes the turbine rotational speed corresponding to the MPP.

5. Simulation result

In this section, the performance of the proposed controllers designed in Section 5 is validated via computer simulations. This is done by considering the proposed dynamic model for wind turbine includes PMSG. All simulations are executed using the MATLAB Simulink mathematical analysis soft-ware. Simulation data can be found in appendix A.

Fig. 7 have been shown results of simulation HCS method for two different step size and the proposed method when the wind speed change in second 30th from 10 m/s to 12 m/s, so figures shown how performance of proposed method and HCS method with to differ step size.

As shown in fig. 7, for the HCS method, when the step size is small (step = 1), however the steady state response is proper and has the small oscillation, but response speed is slow. And also, when the step size is big (step =3), however the response speed is fast, but steady state is not good and has an oscillation. The slow response speed in the small step size case and the

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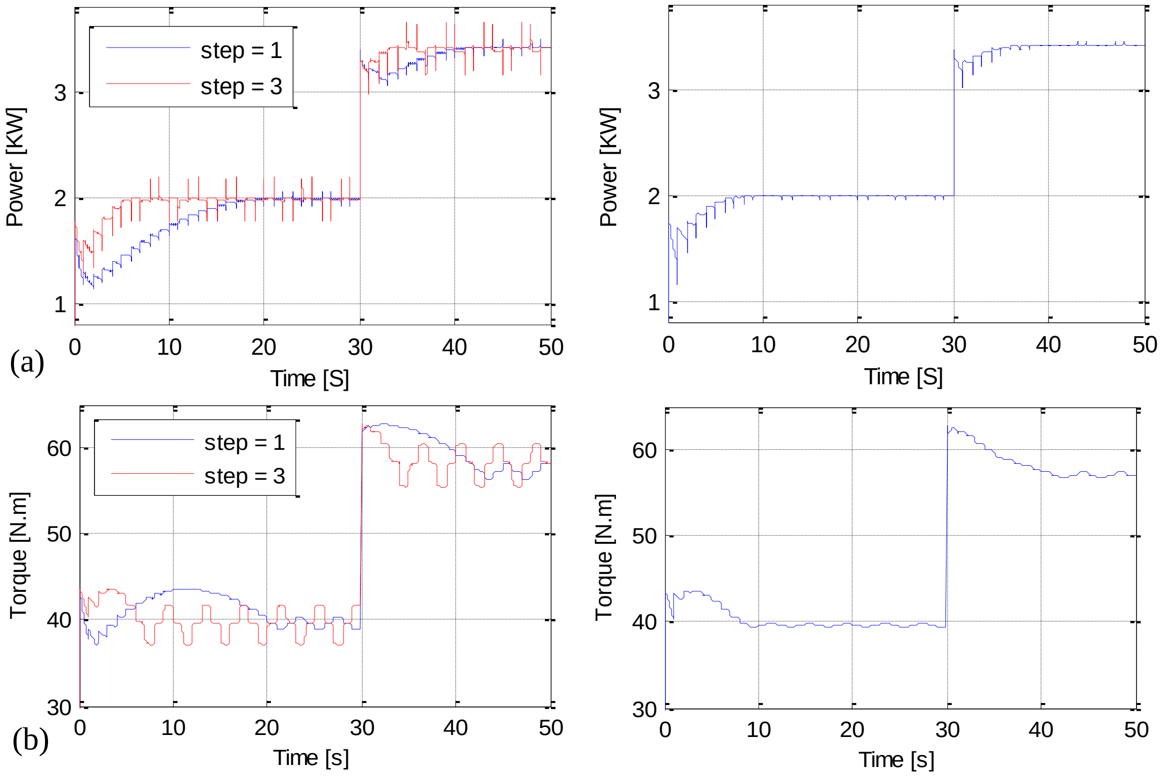
steady state oscillation in the big step size case, have been caused decrease the efficiency of HCS method, while the result of the proposed method have been denoted the to be effectiveness its. In the proposed method both steady state response and dynamic response are suitable which this is leaded to increase the efficiency of MPPT.

Table (II) compression some of MPPT methods for consideration the Convergence speed, Steady state Variation, Sensed parameters, Implement Complexity and periodical tuning. It is clear that if any MPPT method needs to speed sensor (wind speed or rotor speed); the implement complexity is high and also need to tune periodically.

Table.2.
Comparison Different MPPT methods

method	Convergence speed	Steady state Variation	Sensed parameters	Implement Complexity	periodical training
TSR	High	Low	Wind, Rotor speed	High	Yes
HCS	Medium	Medium	Voltage, Current	Low	No
PSF	High	Low	Rotor speed	Medium	Yes
Proposed method	High	Low	Voltage, Current	Low	No



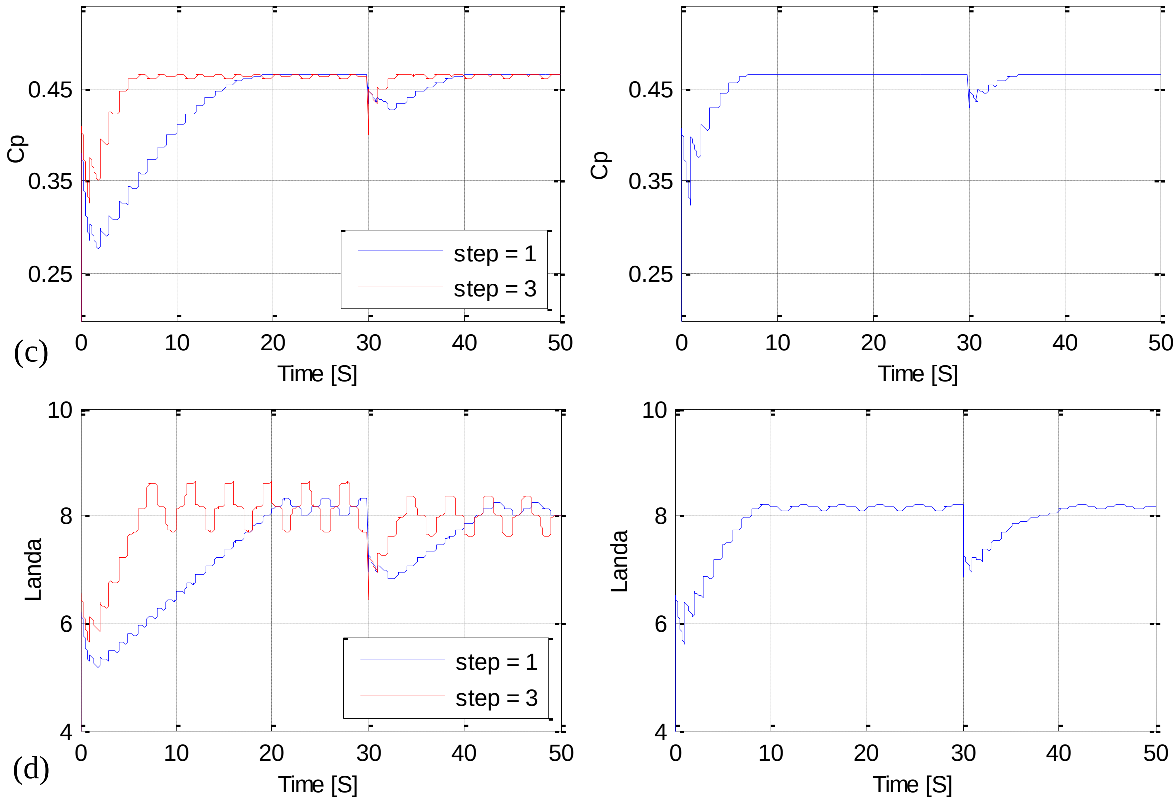


Fig. 7. Comparison of HCS method and proposed method in start-up and change wind speed, a) output power, b) Torque, c) power coefficient (C_P), d) optimum tip-speed ratio (λ)

6. Conclusions

In this paper In order to improving tracking the maximum power point based on HCS method, the fuzzy logic system has been used, in fact, fuzzy logic system determine the step size of HCS method based on operation condition, so the efficiency of HCS method will be improved with variable step size, which can consider both tracking speed and steady-state. The proposed method also, can change its perturbation step size dynamically depending on the change of wind speed, which enables the turbine to track the MPP quickly and smoothly. The effectiveness of the proposed method is verified in MATLAB/Simulink environment with Sim-Power-Systems and Fuzzy-Logical Toolbox. The simulation results indicate that the proposed method based MPPT algorithm shows good performance. The wind turbine could track the optimum operating point swiftly using the proposed algorithm and the steady-state power would not fluctuate fiercely. In general, the proposed FLC MPPT algorithm can enhance the efficiency of wind turbine operation compared with the conventional HCS strategy.

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Appendix A

Table.3.
PMSG and turbine parameter

Pole pairs	P = 5
Synchronou resistance	Rs = 1.5 ohm
Synchronou reactance	Ls =7.7 mH
Flux	f = 0.74 Wb
Blades radius	R = 1.6 m
Inertia	J = 1.25 kg/m^2
Nominal wind speed	V = 12 m/s