Maximum Power Point Tracking in Wind Energy Conversion Systems Using Tracking Control System Based on Fuzzy Controller

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***Abstract*—In this paper, new method for maximum power point tracking based on fuzzy controller has been presented that is maximum power point tracking with high power coefficient without requiring mechanical sensors and knowing system characteristics. Wind energy conversion system is simulated by using tracking system based on fuzzy controller in MATLAB/ SIMULINK and simulation results prove the advantages of suggested tracking method such as increase of power coefficient in wind turbine and decrease of fluctuations about maximum power point.**

Keywords— Permanent magnet synchronous generator; maximum power point tracking; boost converter; fuzzy controller.

I. INTRODUCTION

Progressive development of energy requirement, limitation of fossil resources and pollution as a result of using or consuming fossil fuel, extra attention to using renewable energy resources, is necessary [1]. Among renewable energy, wind energy is the most economic methods for producing electricity. Because of turbine specifications and quick changes of wind, it is possible to receive optimum wind energy in wind energy conversion system through wind turbine action in the case of variable speed [2, 3]. During recent decades, an abundant method has been presented for controlling maximum power point tracking. Many of these methods require the knowledge of system specifications and mechanical sensors such as anemometer. This case causes increase of wind energy conversion system cost and decrease of accuracy as a result of approximation on wind generator characteristics. so extensive researches has been accomplished for improving tracking control methods of maximum power point without requiring wind speed measurement and knowledge system specifications and mechanical parameters of turbine with purpose of cost decrease and accuracy increase [3, 4]. As a whole, there are three tracking methods of maximum power point in wind energy conversion system. These methods are such as wind speed measurement (WSM) [4], power signal feedback (PSF) [5], perturbation and observation (P&O) or hill climbing searching (HCS) [6]. In [4] wind speed measurement method has been used for maximum power point tracking in wind energy conversion system. Fig. 1 shows a wind energy conversion system by control method based on wind speed measurement.

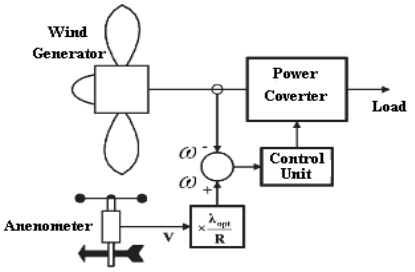

Fig. 1: Control system based on wind speed measurement method [5]

In wind speed measurement method, measured wind speed and required rotor speed for achieving maximum power will be calculated. In addition, measured actual rotor speed is compared with calculated optimum rotor speed and the resulting error is used for controlling a power converter. Wind speed measurement method has good efficiency with quick response and high efficiency. But this method requires an accurate anemometer that this case increases cost of system and decreases accuracy in system [3, 7]. In [5] power signal feedback method has been used for maximum power point tracking in wind energy conversion systems. In power signal feedback method, optimum power characteristic of wind generator versus rotor speed has been reserved in a micro controller memory. By measuring angular speed of wind generator, optimum output power of wind generator is calculated in on the basis of turbine output power characteristic and will be compared with measured actual output power. The resulting error is used for controlling a power converter. Fig. 2 shows a control system based on power signal feedback method.

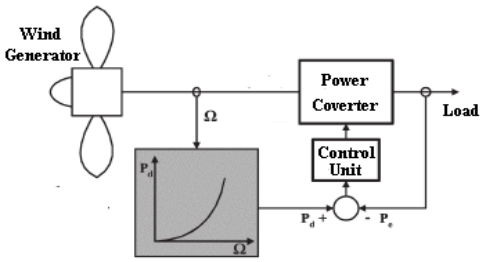

Fig. 2: Control system based on power signal feedback method [5]

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The main problem of this method is that power curve versus angular speed of turbine should be determined through simulation or practical test. So, this method is difficult and more expensive for performance [5].

In [6, 7] perturbation and observation method has been used for maximum power point tracking in wind energy conversion systems. In perturbation and observation method, rotor speed changes, then output power is observed in other to regulation of next change on rotor speed. Perturbation and observation method regulates turbine speed according with comparison result between calculated output powers consecutively in wind generator [6]. Fig. 3 shows a control system based on perturbation and observation method.

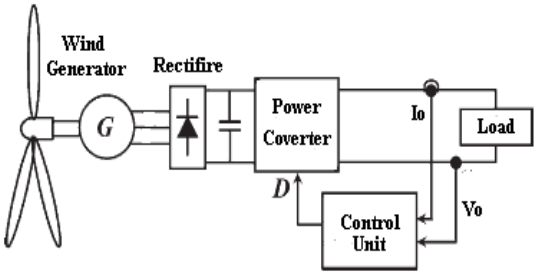

Fig. 3: Control systems based on perturbs and observes method [6]

Perturbation and observation tracking method has high certainty, low complexity and cost because of specifications such as lack of requiring an accurate Anemometer for measuring wind speed and also lack of requiring the knowledge of system specifications [4]. So, among mentioned tracking methods, perturbation and observation tracking method is the best choice for maximum power point tracking in wind energy conversion systems.

In this paper by presenting proper suggestions, the problem of perturbation and observation method has been removed and a complete method has been achieved for maximum power point tracking in wind energy conversion systems. For removing the present problem in perturbation and observation tracking method, suggestion of using variable changes step for constant changes step has been expressed for changing angular speed of turbine and tracking method has been presented based on fuzzy controller for getting maximum output power energy conversion system. Specifications of suggested maximum power point tracking method, is increase of power coefficient in wind turbine and decrease of fluctuations about maximum power point in addition to lack of requiring the knowledge of optimum power characteristic in wind generator and also lack of requiring wind speed measurement.

II. WIND SYSTEM MODEL

Parts of a wind energy conversion system are such as: wind generator, diode rectifier, DC- DC generator and tracking control system [8]. Fig. 4 shows the general structure of a wind energy conversion system. Wind generator is consisting of a wind turbine connected to permanent magnet synchronous generator.

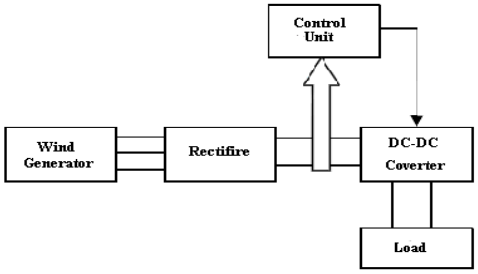

Fig. 4: structure of wind energy conversion system [6]

A. Control System Based on Perturbation and Observation Method

Received power of wind energy conversion systems from wind energy is not only dependent wind specifications but also depends on utilized control method in wind energy conversion systems [4, 7]. Extensive researches have been accomplished about tracking methods of output maximum power in wind energy conversion system. Among tracking methods, perturbation and observation method is the best choice for maximum power point tracking in wind energy conversion systems because of some specifications such as high confidentiality and low complexity and cost.

This method is based on creating changes is rotor speed of turbine with constant pitches and observing changes in power. In permanent magnet synchronous generator, output voltage is proportional with rotor speed. So, change of output voltage of generator causes change in angular speed of rotor. Voltage change is accomplished though regulating duty cycle of DC-DC converter. Fig. 8 shows maximum power point tracking algorithm in perturbation and observation method. In this algorithm In addition to power change, the way of changing speed in previous status is considered for determination of changing speed in next status.

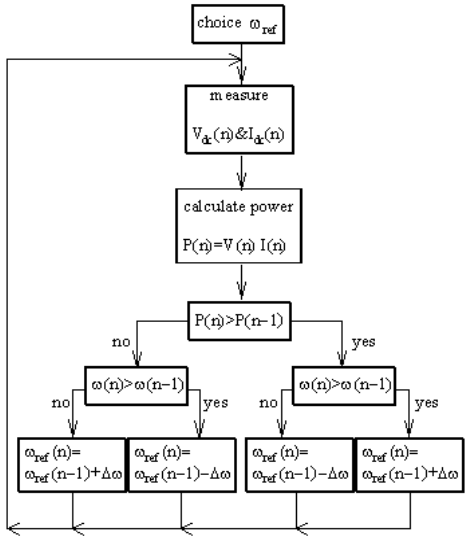

Fig. 8: Maximum power point tracking algorithms based on perturb and observe method

According to expressed algorithm, tracking method of perturbation and observation in each wind speed is through controlling output voltage surface of generator and consequently controlling angular speed of turbine is tracking maximum output power point. So, by changing duty cycle of converter, output voltage of wind generator will change and then output power is observed and increase or decrees of output voltage in wind generator will be distinguished in next status. If increasing of output voltage in wind generator causes increasing of power so, output voltage of wind generator will increase in next status and vice versa [4, 9].

There is a main problem in perturbation and observation method that influences its efficiency .this problem is presence of inverse relation between efficiency and convergence speed of control method [1, 5]. In tracking method of conventional perturbation and observation method, changes pitch is constant so, if the rate of changes pitch is great, convergence speed increases but efficiency decreases through fluctuation about maximum power point, and if the rule of changes pitch is small, fluctuation about maximum power point decreases, but convergence speed decreases for this reason , control method of disturbance and observation will not be prevented in maximum power point and fluctuations in disturbance and observation control method is an inevitable specification.

III. Control System Based on Fuzzy Controller

Suggested solution in this paper is using variable changes pitch instead of constant changes pitch in perturbation and observation method. By using variable change pitch in perturbation and observation tracking method it is possible to solve this problem and in this respect higher convergence speed is gotten and method efficiency increases.

In this regard we use a fuzzy controller for determination of variable pitch. Tracking control method based on fuzzy controller has the same reason of perturbation and observation method that uses changes of duty cycle in converter for maximum power point tracking. Diagram block of suggested tracking method has been shown in Fig. 9.

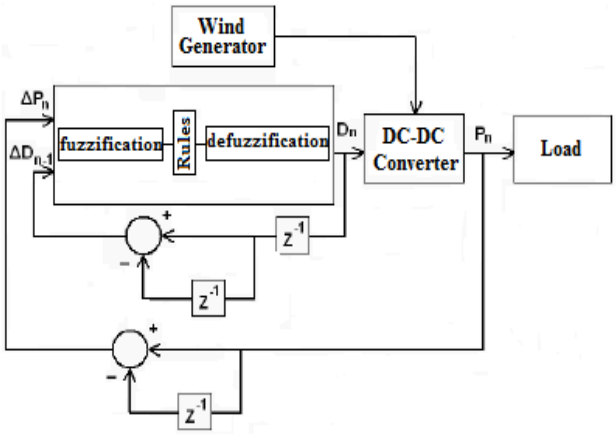

Fig. 9: block diagram of maximum power point tracking system based on fuzzy controller

In this method inputs is output power changes of turbine and changes of duty cycle in converter and output is duty cycle of converter. Fuzzy rules used in fuzzy controller are shown in Table I. In this table:

nl: high negative, nm: medium negative, ns: small negative, z: zero, ps: small positive, pm: medium positive, pl: large positive

vs: very small, ms: medium small, bav: below average. av: average, aav: above average, ml: medium large, vl: very large.

TABLE I. Fuzzy Rules

$\Delta D_n/\Delta P_n$	nl	nm	ns	z	ps	pm	pl
nl	vl	vl	ml	bav	ms	vs	vs
nm	vl	ml	aav	bav	bav	ms	vs
ns	ml	aav	aav	av	bav	bav	vs
z	vs	ms	bav	av	aav	ml	vl
ps	ms	bav	bav	av	aav	aav	ml
pm	vs	ms	bav	aav	aav	ml	vl
pl	vs	vs	ms	aav	ml	vl	vl

In fuzzy controller method, changes of output power and changes of duty cycle in converter has been observed in each moment and has been identified by using rules table and membership functions and by applying fuzzy extractive method of duty cycle for converter in next status.

IV. Simulation Results

In other to scrutiny proficiency of suggested maximum power point tracking method, wind energy conversion system like Fig. 4 first is simulated by conventional perturbation and observation tracking method in MATLAB/SIMULINK and output specifications are studied [7] then, system is simulated by tracking method based on fuzzy controller and the results of simulation is compared with conventional method. Wind energy conversion system is such as: wind turbine, permanent magnet synchronous generator, diode rectifier and DC-DC converter. Power capacity and parameters of wind turbine is shown in Table II and specifications of permanent magnet synchronous generator is shown in table III [7]. By coding in Matlab software, maximum power point tracking system has been performed by two conventional perturbation and observation method and method based on fuzzy controller. Angular speed curves of wind turbine for different wind speeds and by conventional perturbation and observation tracking method is shown in Fig. 10. According to Fig. 10, it is found that by using conventional perturbation and observation tracking method in wind energy conversion systems, convergence speed decreases. Angular speed curves of wind turbine for different wind speeds and by tracking method based on fuzzy controller is shown in Fig. 11. As has been seen in Fig. 11, by using tracking system based on fuzzy controller, convergence speed increased. For comparing proficiency of two methods, power coefficient curves of the wind turbine and output power of wind turbine have been shown in Fig. 12. As has been seen in Fig. 12, by using tracking system based on perturbation and observation method, power coefficient of wind turbine with optimum rate that is 0.48 is so far.

Fluctuations about maximum power point increased and convergence speed decreased. So, received power of wind turbine will not be more than wind energy. The reason is using constant changes pitch for changing duty cycle of converter in purpose of regulating rotor speed of turbine. By using tracking system based on fuzzy controller, power coefficient of wind turbine increases and approached its maximum rate. So received power of wind turbine for each wind speed, increases by using fuzzy controller method and fluctuations of turbines output power decreases about maximum power point by using suggested method. So suggested method efficiency is more than conventional perturbation and observation method. Also, by changing wind speed, output power of system will approach maximum rate by using tracking method based on fuzzy controller with much speed.

TABLE II. THE PARAMETERS OF THE WIND TURBINE

Rated power	1 Kw
Rated Wind Speed	9 m/s
Pitch angle	0 deg
Optimum power coefficient	0.48

TABLE III. THE PARAMETERS OF PERMANENT MAGNET SYNCHRONOUS GENERATOR

Rated power	1 kW
Stator resistor	0.318 Ω
D-axis inductance	4.04 mH
Q-axis inductance	5.28 mH
Rotor flux	0.26 Wb
Inertia	0.0078 Kg.m^2
Number of pole	4

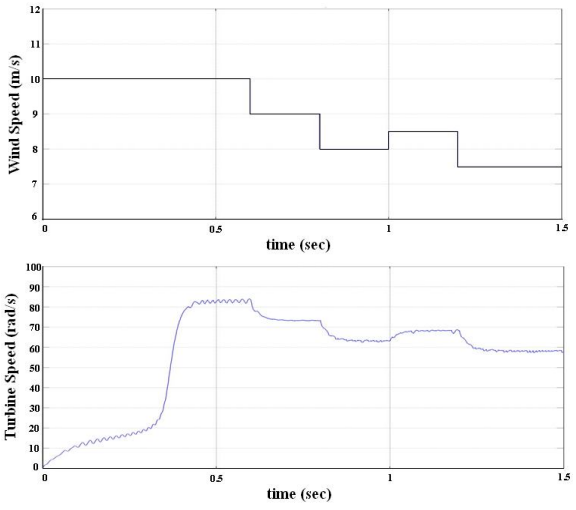

Fig. 10: The curve of rotor speed versus time

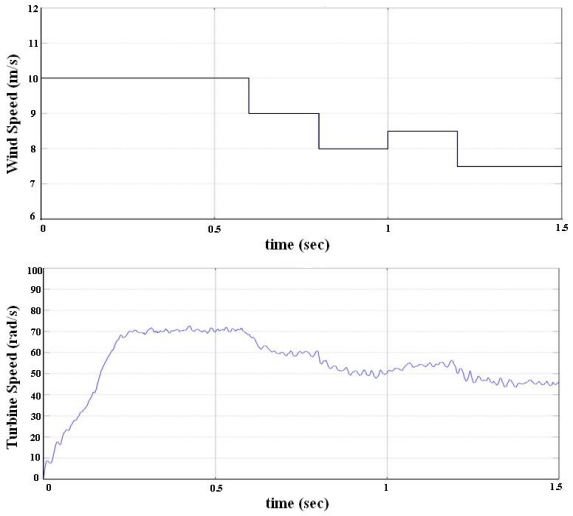

Fig. 11: The curve of rotor speed versus time

V. CONCLUSIONS

In this paper, new method of maximum power point tracking with modified perturbation and observation method with variable pitch has been presented for wind energy conversion system with variable speed. This method is independent of turbine and generator specifications. For decrease of cost and increase of system confidentiality, suggested power maximum point tracker, does not have any mechanical sensor. Results of simulation showed that suggested maximum power point tracking method can search automatically optimum points and by decrease of fluctuations about maximum power point and increase of convergence speed, track maximum output power for climatic circumstances changes such as wind speed.

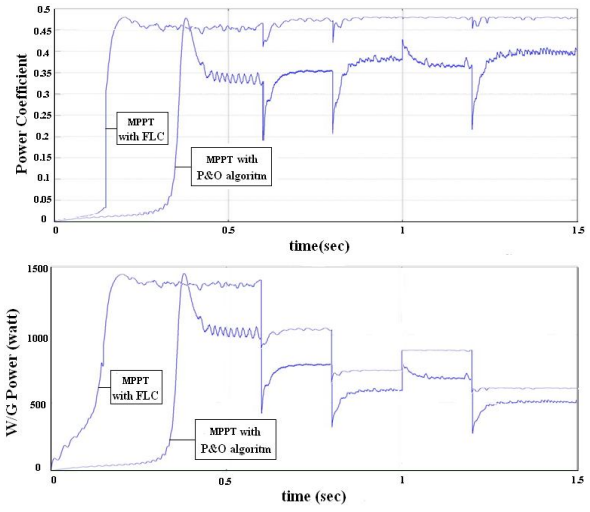

Fig. 12: The curves of power coefficient and output power of wind turbine versus time.

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