Abstract: This paper proposed fuzzy logic approach to construct maximum power point tracking algorithms. A scheme composed of two fuzzy systems is here. The first fuzzy system is based on a modified hill climb search algorithm to conclude the power set point. The second is fuzzy logic controller that uses a pitch angle control to track the power set point. Simulation shows that the proposed scheme can improve the system efficiency and performance.

Keyword: wind energy conversion system, fuzzy logic controller, pitch angle control, Matlab/Simulink.

1. INTRODUCTION

Wind energy conversion systems (WECS) are widely accepted as cost effective, environmentally friendly alternatives to conventional energy system. WECS have enjoyed an increased growth due to the technological enhancement and cost reduction. In order to maintain such expansion, WECS performance should be improved further. Our objective is to propose a new fuzzy algorithm that improves the performance and efficiency of WECS [1].

The mechanical output power at a given wind speed is drastically affected by the turbine’s tip speed ratio (TSR) [2], which is defined as the ratio of turbine rotor tip speed to wind speed. At a given wind speed the maximum turbine conversion efficiency occurs at an optimal TSR. Therefore, as wind speed changes, accordingly in order to maintain the optimal TSR and thus to extract the maximum power from the available wind resources [3].

The research has focused on three types of maximum power point tracking (MPPT) methods, TSR control method, power signal feedback (PSF) control method and hill-climb searching (HCS) method. TSR control regulates the wind turbine rotor speed to maintain an optimal TSR [2].

As shown in Fig. 1, both the wind speed and turbine speed need to be measured for TSR calculation, and the optimal TSR must be given to the controller. The wind speed measurement [3], adds to system cost and presents difficulties in practical implementations. Furthermore, this technique can’t adapt itself for the parameters’ changes of the wind turbine which lead to change the optimal TSR. PSF control requires the knowledge of the maximum power curve of the wind turbine [4].

The overcome the previous drawbacks, the HSC control has been proposed to continuously search for the peak output power of the wind turbine [5]. HSC control works when the wind turbine inertia is very small so that the turbine-speed reacts to wind speed almost “instantaneously”. For large inertial wind turbines, the system output power is interlaced with the turbine mechanical power and rate of change in the mechanically stored energy, which often renders the HSC method in effective [6].

![Fig. 1 Tip speed ratio control of WECS.](image1)

![Fig. 2 Power signal feedback control.](image2)

The HCS control algorithm continuously searches for the peak power of the wind turbine. It can overcome some of the common problems normally associated with the other two methods. The tracking algorithm, depending upon...
the location of the operating point and relation between the changes in power and speed, computes the desired optimum signal in order to derive the system to the point of maximum power. Fig.3 shows the principle of HCS control and Fig.4 shows a WECS with HCS controller for tracking maximum power points.

2. MPPT control methods for DFIG based WECS

Double fed Induction Generator is favored more and more in developing new designs because of higher efficiency, high power density, availability of high-energy material at reasonable price, and possibility of smaller turbine diameter in direct drive applications. Presently, a lot of research efforts are directed towards designing of WECS which is reliable, having low wear and tear, compact, efficient, having low noise and maintenance cost; such a WECS is realizable in the form of a direct drive DFIG wind energy conversion system.

The power electronics converter configurations most commonly used for DFIG WECS are shown in fig.5.

2.1 Hill climbs search control

HCS control method of MPPT control are proposed wherein output power information required by the MPPT control algorithm is obtained using the dc link current and generator speed information. These two signals are the inputs to the MPPT controller whose output is the command speed signal required for maximum power extraction. The optimum speed command is applied to the speed control loop of the grid side converter control system. In this method, the signals proportional to the is computed and compared with the previous value. When the result is positive, the Pm process is repeated for a lower speed. The outcome of this next calculation then decides whether the generator speed is again to be increased or decreased by decrease or increase of the dc link current through setting the reference value of the current loop of the grid side converter control system. Once started, the controller continues to perturb itself by running through the loop, tracking to a new maximum once the operating point changes slightly. The output power increases until a maximum value is attained thus extracting maximum possible power. The HCS control method presented in operates the generator in speed control mode with the speed reference dynamically modified in accordance with the magnitude and direction of change of active power. Optimum power search algorithm proposed here uses at peak power point. The algorithm dynamically modifies the speed command in accordance with the magnitude and direction of change of active power in order to reach the peak power point [7].

In the proposed MPPT method combines the ideas of sliding mode (SM) control and extremism seeking control (ESC). In this method only the active power of the generator is required as the input. The method does not require wind velocity measurement, wind-turbine parameters or rotor speed etc. The block diagram of the control system is shown in. When the sign of derivative of changes, a Fig.6 In the figure $P_{opt}$ is the acceleration of $P_{opt}$. When the sign of derivative of $x$ changes a sliding mode motion occurs and $\omega_{k}$ is steered towards the optimum value while $P_{e}$ tracks $P_{opt}$. The speed reference for the vector control system is the optimal value resulting from the MPPT based on sliding mode ESC.
2.2 Pitch Angle control using Fuzzy logic controller

A prototype of wind turbine is built and shown in Fig. 7. It consists of three blades, a servo motor, a controller, rotor rotation sensor, a generator, and some mechanical components. The blades are developed based on the NACA (National Advisory Committee for Aeronautics) airfoils with a specification of length, width, and thickness of 50, 10, and 1.2 cm, respectively. A GW Servo 503 is used to control the pitch angle of the blade. The controller is developed based on a microcontroller AVR8535 and C++ programming language. A rotary encoder is used to measure rotational speed of wind turbine rotor. Fig. 8 shows a diagram block of pitch angle control of wind turbine using a fuzzy logic controller (FLC) for low rated wind speed. The pitch angle of the blade is controlled to maximize the rotational speed of wind turbine and thus the output mechanical power of wind turbine. From Fig. 8, a measured rotational speed of wind turbine rotor in rpm from rotary encoder is compared to the desired rotational speed. The FLC processes error, a delta error, and wind speed data of, respectively. The FLC produces the optimal pitch angle of blade (β) with the variation of wind speed. In this paper, a wind turbine mechanical power is maximized. The wind turbine mechanical power (P) can be expressed using [8]:

\[
P = \frac{1}{2} \rho_{air} A_p v^3 C_p(\beta, \lambda)
\]

where \( \rho_{air} \) is air density, \( A_p \) area swept by the blades, \( v \) is wind speed velocity, and \( C_p(\lambda, \beta) \) is the power coefficient of the wind turbine with the tip speed ratio of \( \lambda \) and the blade pitch angle of \( \beta \). The tip ratio of \( \lambda \) is defined by using [8]:

\[
\lambda = \frac{\omega \ R}{v}
\]

where \( \omega \) is the turbine rotor speed and \( R \) is the radius of the wind turbine blade. To maximize the wind mechanical power, the power coefficient of the wind turbine is optimized via controlling the pitch angle of the blade.

To control the pitch angle of the blade, the FLC is developed. There are three steps to develop the FLC: (i) determining the inputs, (ii) setting up the rules, and (iii) designing a method to convert the fuzzy result of the rules into output signal, a so called de-fuzzification [9]. Mamdani method with a middle of maximum method (MOM) is used in this paper [9]. To determine a membership function of the inputs and the outputs, a wind test to the wind turbine prototype is carried out in a wind tunnel. The wind turbine rotor speed is measured with the wind speed variation from 0 to 6 m/s and adjusted pitch angle from 0 to 90°.

Based on the measured wind turbine rotor speed, the membership function of the inputs is developed. In this paper two types of membership functions are built which consider 0 the data set of pitch angle from 0 to 90° and 5.6 to 61.6 for first type (FLC-1) and second type (FLC-2), respectively. Fig. 9(a) and 9(b) shows the input membership function of error and delta error of the wind turbine rotor speed for both FLC-1 and FLC-2. A wind turbine rotor speed set point of 150 rpm is chosen. The output membership function is shown in Fig. 9(c) and 9(d) for the FLC-1 and FLC-2, respectively. Table 1 lists the control rule of the input and the output variable for both FLCs.

![Fig. 7 A prototype of wind turbine](image)

![Fig. 8 A block diagram of pitch angle control of wind turbine using FLC.](image)

![Fig. 9(a)](image)
RESULT

The input wind speed variation of 4-6 m/s is used to test the wind turbine performance as in Fig. 3. The wind turbine performance using pitch angle control of FLC-1 and FLC-2 are compared to the performance without control at a fixed pitch angle of 28°. Fig. 11 shows the mechanical power responses of without controller and with controller of FLC-1 and FLC-2. From Fig.11 it can be calculated the total mechanical power ($P_{tot}$), average power ($P_{avg}$), standard deviation ($\sigma$) and uncertainty ($\mu$) of the measured mechanical power as in Table 2.

It is apparent from Fig. 11 and Table 2 that the use of FLC-1 cannot improve the wind turbine performance. The FLC-1 fails as controller due to the selection of data set of pitch angle from 0 to 90°. It is found that at low rated wind speed, only certain range of angle can produce the wind turbine rotation (i.e. data set of FLC-2). The use of FLC-2 can improve the performance compared to without controller. The average power increases from 14.0 to 14.5 watt for without controller and FLC-2 respectively. It is also shown that the standard deviation = 4.03 to 3.8 % and also the uncertainty improves from = 0.25 to 0.24 %, respectively. Thus, the use of FLC-2 is suitable for performance improvement of the wind turbine of the low rated wind speed.

CONCLUSION

The wind turbine with pitch angle fuzzy logic-based control for variable low rated wind speed has been developed and demonstrated. The use of pitch angle fuzzy logic-based control can improve mechanical power response performance of wind turbine compared to the use of a fixed pitch angle or without control. It is shown that at varying low rated wind speed of 4-6 m/s, the
average power increases from 14.0 to 14.5 watt and the uncertainty improves from 0.26 to 0.24 % for the use of fuzzy logic controller and without control at a fixed pitch angle, respectively. This prototype is suitable to be implemented to maximize the mechanical power of wind turbine in the low rated wind speed areas.

REFERENCE


AUTHOR

Chitesh Dubey received the B.E degrees in Electrical & Electronics Engineering from SSCET, Bhilai in 2007 and Pursing M.E. Degree in Power System Engineering from SSCET, Bhilai. During 2008, he joined as Lecturer in EEE department of CIT Rajnandgaon.

Yogesh Tiwari is currently worked as an Asso. Prof. in EEE Department of SSCET Bhilai. He received the B.E degrees in Electrical Engineering from BIT, Durg in 1997 and M.Tech. Degree in Instrument & Control Engineering from BIT, Durg in 2006. Pursuing PhD in Electrical Engineering from C.V. Raman University Bilaspur. He has over 4 year industrial & 10 year teaching experience. He has published near 15 research papers in national & international conferences & journals.

Dr. Anup Mishra received his Ph.D degree in 2010 from BUIT, Bhopal and M.Tech degree in 2006 with Instrumentation and control from BIT, Durg. He completed his B.E in 1997 from BIT, Durg. He has teaching and research experience of more than 13 years. He has published more than 10 Research papers in reputed International Journals & Conferences. At present, he is working as professor and H.O.D. in Electrical and Electronics Department of BIT, Durg (C.G.)