A NEW RAPID MAXIMUM POWER POINT TRACKER FOR WECS USING FOA FUZZY LOGIC CONTROL

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ABSTRACT: *This paper presents a new maximum power point tracking (MPPT) controller based on a fuzzy logic control under fluctuating wind velocities in a wind energy conversion system (WECS) which consists of a wind turbine, directly coupled with a permanent magnet synchronous generator, rectifier, boost converter and resistive load. This controller can track the maximum power point by the tip speed ratio (TSR) method in which the optimum rotor speed according to wind speed is evaluated using the fruit fly optimization algorithm as an intelligent and effectiveness algorithm at which the TSR is in its optimal value and then compared with the actual rotor speed. The error and change in error are given as inputs to the fuzzy logic controller and its output is used to adjust the duty cycle of the boost converter, so that the maximum power is extracted. An example WECS with the proposed controller is simulated and evaluated in MATLAB softwareto confirm the effectiveness of the proposed controller under different conditions.*

Keywords: Wind Energy Conversion Systems (WECS), FuzzyLogic Control (FLC), Maximum Power Point Tracking (MPPT),Tip-Speed Ratio (TSR), Fruit Fly Optimization Algorithm (FOA).

1. INTRODUCTION

Nowadays, renewable energies have been attracting wide attention due to depleting fossil fuel reserves and environmental concerns. Following this, Wind Energy Conversion Systems (WECSs) are one of the most effective power generation systems that convert the wind energy into some specific forms of electricity.

In a WECS, the power generation is possible in two ways, constant speed operation and variable speed operation [1]. Hence, although the speed of the wind turbine could be fixed or variable, but maximization of the extracted energy is achievable with variable speed wind turbines only [2,3]. On the other hand, due to the nonlinear characteristics of wind turbine, there is a particular operating point at which the output power of the WECS is maximum for a given wind speed [4]. Therefore, the amount of power output that can be extracted from a WECS depends upon the accuracy with which the peak power points are tracked by the maximum power point tracking (MPPT) controller of the system [5].This has led to the development of control techniques to determine the optimal operating point of the wind turbine at any given time [4, 6].

Some of the MPPT control methods have been commonly used in the literature are tip-speed ratio (TSR) control, optimal torque (OT) control, fuzzy logic control (FLC), artificial neural network (ANN), power signal feedback (PSF) and search control method [1].A review of MPPT methods for wind energy systems is given in [3,5,7, 8].

The FLCs are one of the basic methods to represent linguistic information and to deal with uncertainty and imprecision. So, they have been widely used in process control and modeling problems. The determination optimal rule bases, membership functions and input/output scaling factors are some of the efforts for a better design of fuzzy logic controllers [9]. For this purpose, in this paper, an on-line MPPT control based on a FLC is proposed for a WECS operating at variable speed, while the fruit fly optimization algorithm (FOA) [10] is used as an intelligent and effective algorithm beside a FLC called FOA-fuzzy MPPT controller to achieve better design.

The concept of this paper is organized as follows: the structure of the system is presented in section 2. The details of the control system is described in section 3. The simulation results are given and analyzed in section 4. Finally the paper is concluded in section 5.

2. SYSTEM DESCRIPTION

The block diagram of the WECS under study with its control system is shown in Fig.1. The wind generation unit consists of a wind turbine, permanent magnet synchronous generator (PMSG), three-phase bridge rectifier, boost DC/DC converter and a load. The PMSG converts the mechanical power generated from wind energy by wind turbine to electric power. The uncontrolled rectifier converts the ac output voltage from the wind generation unit into dc voltage. The boost DC/DC converter controls this dc voltage while the maximum power from the wind is achieved by controlling its duty cycle, where a fuzzy control system is employed.

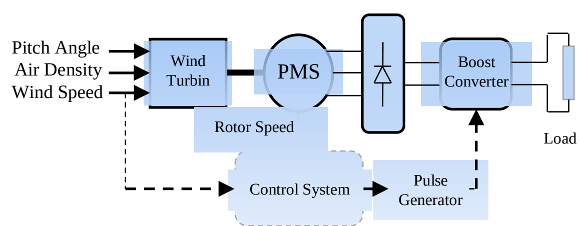

Figure 1. Wind Energy Conversion System (WECS)

2.1 WIND TURBINE MODEL

The power extracted from a wind turbine is a function of several factors, such as the wind power available, the power curve of the machine, the air density that varies with altitude and the ability of the machine to react to wind speed variations [11, 12]. The mechanical power (P_m) extracted from a wind turbine can be given by (1) [13, 14]:

$$P_m = 0.5\pi R^2 \rho C_p(\lambda,\beta) v_\omega^3 \quad (1)$$

where v_w is the wind velocity (or speed) (m/s), β is the blade pitch angle (deg), λ is the tip speed ratio, ρ is the air density (kg/m^3), R is the turbine radius (m) and C_p is the power coefficient of WECS which is a nonlinear function of the tip speed ratio λ and the blade pitch angle β. λ is defined as (2):

$$\lambda = {}^{\omega_r R}/_{v_w} \quad (2)$$

where ω_r is the turbine rotational speed (in radians per second). Since, gradually increasing β will decreases C_p, so in order to achieve the maximum wind power, β value should be considered very small (equal to zero) [1]. The C_p versus tip speed ratio (TSR) curve is shown in Fig. 2 by assuming that the blade pitch angle β is zero. According to (2),and considering that here is only one rotor speed for each specific wind speed which leads to maximum power, the rotor speed can be regulated to keep λ in its optimal value λ_{opt} and then remain the power coefficient in its maximum value C_{pmax} [15]. Therefore, the maximum power output of wind turbine is given by (3):

$$P_{max} = 0.5\pi R^2 \rho C_{p,max}(\lambda_{opt}, \beta) v_\omega^3 \quad (3)$$

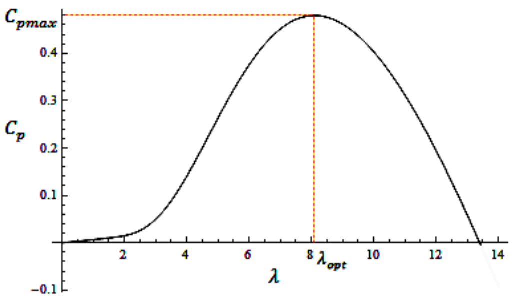

Fig. 2. Curve of C_p-λ.

3. CONTROL SYSTEM

3.1 Fruit fly Optimization Algorithm

Fruit Fly Optimization Algorithm (FOA) is a new intelligent algorithm in optimization problems and the process of finding the maximal value and minimal value of a function, which is based on fruit fly's food searching behavior. Since, the fruit flies can successfully pick up various scents floating in the air with their olfactory organs, so they can smell food sources from far away and fly towards those directly [10].

Fruit fly's food finding characteristics are summarized and programed into the following steps:

1) Generate initial fruit fly location randomly.

$InitX\_axis;\ InitY\_axis$

2) Assign a direction and distance for every fruit flies randomly.

$$X_i = X\_axis + Random\ value$$

$$Y_i = Y\_axis + Random\ value$$

3) Estimate the distance to the origin ($Dist_i$) and then calculate the smell concentration judgment value (S_i).

$$Dist_i = \sqrt{{X_i}^2 + {Y_i}^2}$$

$$S_i = \frac{1}{Dist_i}$$

4) Calculate the smell concentration ($Smell_i$) of the individual location of every fruit flies by substituting the smell concentration judgment value (S_i) into fitness function (or smell concentration judgment function).

$$Smell_i = Function(S_i)$$

5) Identify the fruit fly with a maximal smell concentration among the fruit fly swarm and keep X, Y coordinates.

$$[bestSmell bestIndex] = max(smell)$$

$$Smellbest = bestSmell$$

$$X\_axis = X(bestIndex)$$

$$Y\_axis = Y(bestIndex)$$

6) Repeat the implementation of steps 2-4 to find a new fruit fly with maximal smell concentration, then judge whether its smell concentration is superior to the previous one, if so, implement step 5.

3.2 Fuzzy logic MPPT controller

The fuzzy logic control is one of the basic methods to represent linguistic information and to deal with uncertainly and imprecision, so, it is widely used in the control process. In this paper, a fuzzy controller is employed to track the maximum power from the wind by using its rotor speed.

At first, the optimum rotor speed in a specific wind speed which leads to $\lambda_{opt}$is estimated by FOA, then this error between the actual rotor speed and the estimated speed is applied as an input to the FLC system. The change in this error is considered as another input of the FLC system. The output of the FLC system is given to the pulse generator which generates duty cycle of the boost DC/DC converter. The maximum power is extracted by adjusting the duty cycle. So that, by adjusting the duty cycle of the boost DC/DC converter, the rotor speed is controlled to get optimum TSR and so to achieve the maximum power from the wind.

Seven fuzzy subsets are considered for the membership functions of the error input (input1) and the output called Very Negative (VN), Negative (N), Small Negative (SN), Zero (Z), Small Positive (SP), Positive (P), Very Positive (VP), and three fuzzy subsets for the membership function of the error changes input (input2) called Negative (N), Zero (Z), Positive (P) are shown in Fig.3.Table I represents the rules governing the controller's operation as well.

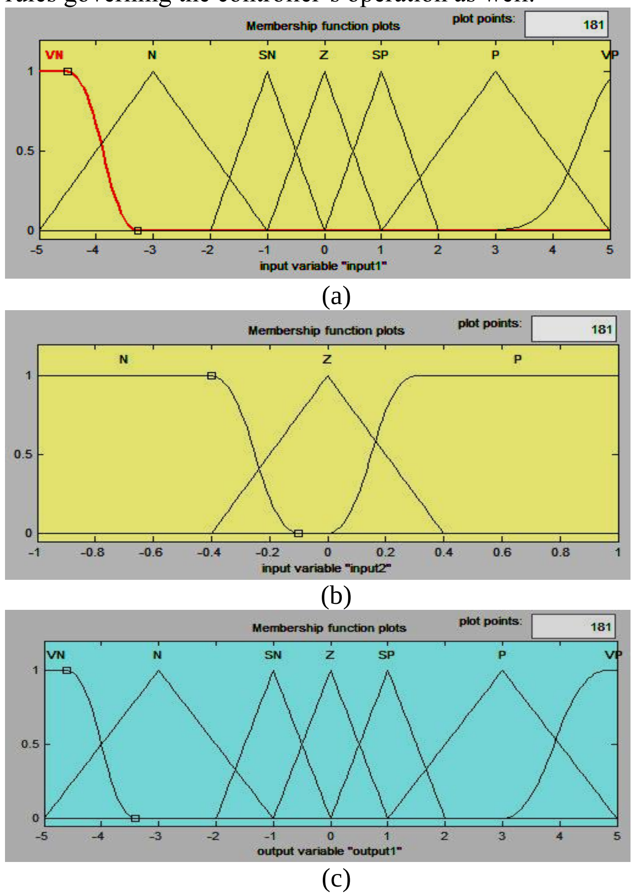

Fig.3. FLC membership functions of (a) error; (b) error changes; (c) output.

Table I. Fuzzy rules

Derivative of error		Negative	Zero	Positive
Error	VN	VP	VP	VP
	N	SN	SN	VN
	SN	N	SN	VN
	Z	Z	Z	Z
	SP	SP	SP	P
	P	P	VP	VP
	VP	VP	VP	VP

4. SIMULATION RESULTS

The Performance of the FOA-fuzzy MPPT controller has been simulated and implemented using MATLAB/SIMULINK simulation.

In this simulation, the wind speed has changed in two steps. Wind speed at time t= 1s and t = 2s is changed from 7 m/s to 9 m/s and then to 8 m/s. With these changes in wind speed, the performance of wind turbine with FOA-fuzzy MPPT controller is analyzed. The various results obtained from the simulation diagram (Fig. 1) are shown in figures 4-6. Fig.4 shows the mechanical output power tracked from the wind turbine according to the wind speed variations. As was said, the power coefficient is the most important parameters for optimum performance and obtaining the maximum power from the wind turbine which is shown in Figs. 5. Optimum tip speed ratio λ_{opt} related to the maximum power coefficient$C_{p,max}$ is shown in Fig. 6 as well.

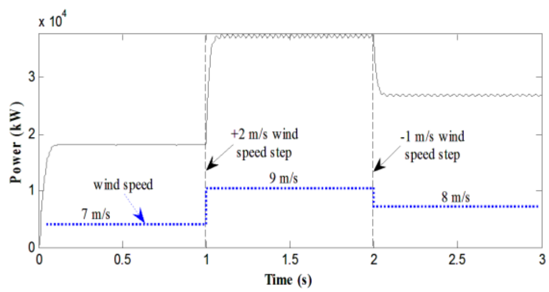

Figure 4. The simulated output power (MPPT with the proposed controller)

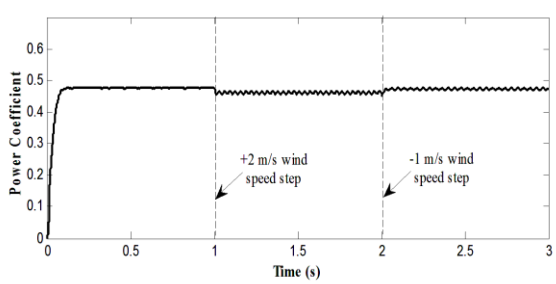

Figure 5. The simulated power coefficient of the turbine during step changes in wind speed.

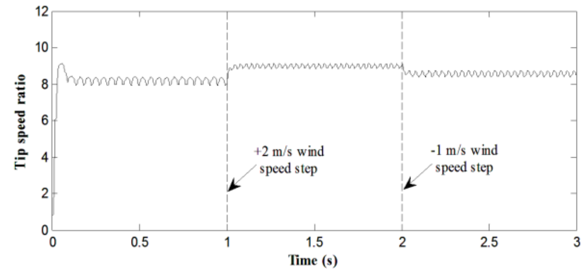

Figure 6. The simulated optimum tip speed ratio of the turbine during step changes in wind speed.

To further verify the validity of the proposed MPPT controller, the mechanical output power tracked from the wind turbine during various wind speeds is compared with the ones obtained using perturbation and observation (P&O) algorithm [3] and without control in Fig. 7.This results show and confirm the efficiency and high accuracy of the proposed FOA-fuzzy MPPT controller.

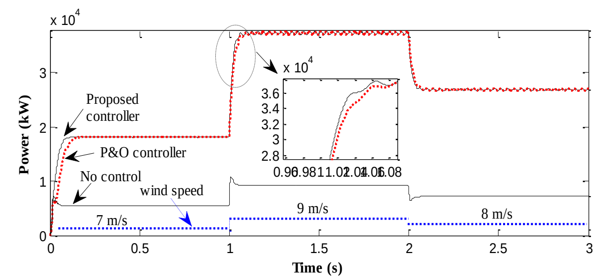

Figure 7. Comparing the simulated output power (MPPT with proposed controller, P&O algorithm and without control) under step variations of wind speed.

5. CONCLUSION

In this paper, we have proposed a fruit fly-fuzzy logic MPPT controller which can extract maximum power. So that, the FOA optimization algorithm tracks and obtains optimum rotor speed and so optimum TSR according to wind speed. Then this error between the actual rotor speed and the optimum speed with its derivative are applied to the FLC system. The FLC system by adjusting the boost converter duty cycle tracks the maximum operating point. The performance and accuracy of the proposed controller is described and verified through the simulation and compared with P & O algorithm during different conditions of wind speed too. The results of simulations indicate and conform efficiency and benefits of the proposed MPPT controller.

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