Maximum Power Point Tracking of Wind Energy Conversion System using Fuzzy- Cuckoo Optimization Algorithm Strategy

Mohammad Sarvi¹, Mohammad Parpaei²

¹ Electrical Engineering Department, Imam Khomeini International University, Qazvin, Iran. Email: sarvi@eng.ikiu.ac.ir
² Electrical Engineering Department, Imam Khomeini International University, Qazvin, Iran. Email: parpaei@edu.ikiu.ac.ir

Abstract

Nowadays the position of the renewable energy is so important because of the environment pollution and the limitation of fossil fuels in the world. Energy can be generated more and more by the renewable sources, but the fossil fuels are non-renewable. One of the most important renewable sources is the wind energy. The wind energy is an appropriate alternative source of fossil fuel. The replacement rate of renewable energy to fossil fuels is rising, although the production cost is higher than fossil fuels. To further reduce cost of wind production, many methods have been proposed. One of the suitable approaches is the maximum power point tracking strategy. In this paper, a new intelligent maximum power point tracker called Fuzzy- Cuckoo strategy for small- scale wind energy conversion systems is proposed. The maximum power point tracker proposed uses measured wind speed to detect the maximum output power and its respective optimal rotational speed. The main contribution of the proposed approach is to exactly track the maximum power point, so the output power fluctuations captured by wind turbine are less than conventional approaches. The simulations are performed in MATAL/SIMULINK software. The superiority of the proposed approach is validated in two situations, low and rapid changes in wind speed. The maximum power point of wind energy conversion systems can be tracked by the proposed approach in any situation. The higher accuracy of the Fuzzy- cuckoo strategy than the conventional trackers is another advantage of the proposed approach.

Keywords: Intelligent controller, Metaheuristic optimization approach, Wind energy conversion systems.

© 2013 IAUCTB-IJSEE Science. All rights reserved

1. Introduction

Fossil fuel reserves reduction causes that the whole countries, especially the countries that have not enough fossil fuel sources, pay special attention to the renewable energy as a second energy source. China and USA are two countries that concentrate on the wind energy conversion systems (WECS) than other countries. WECSs are used to change the wind energy to electrical energy by electrical machines such as the permanent magnet synchronies generators (PMSGs). The small- Scale WECSs are suitable alternative sources for urban regions or remote places that connection to power grid is impossible [1]. The main disadvantage of the renewable energy is that the electricity production costs from various renewable energy sources are higher than fossil fuel. To improve this problem, maximum power point tracking (MPPT) is a matter that is expressed. The maximum power point trackers control the WECSs at the optimal output power. There are many approaches to track the maximum power point, but all approaches are based on three main classifications. The first strategy is the methods based on iteratively search, the second strategy is the methods based on the static parameters of the wind turbine and wind speed, and the third strategy is the methods based on hill- climb searching (HCS)

In this paper, a novel strategy based on an intelligent optimization algorithm, namely Cuckoo optimization algorithm (COA), and the fuzzy logic controller is proposed. The proposed approach is based on the optimum relationship based (ORB). The main contribution of the proposed approach is to exactly track the maximum power point, so the output power fluctuations captured by wind turbine are less than the conventional approaches such as PSO and fuzzy logic trackers. The higher accuracy of the Fuzzy-Cuckoo strategy than the conventional trackers is another advantage of the proposed approach.

This paper has been organized as follows: section 2 describes the wind energy conversion system. Section 3 introduces the Cuckoo optimization algorithm. Section 4 presents the proposed maximum power point tracker. The simulation results in several case studies are given in Section 5, and finally section 6 states the conclusion.

2. Description of Wind Energy Conversion System

The proposed approach will be applied to the following WECS as Figure 1. As shown in Fig.1, PMSG is coupled to a wind turbine. The mechanical output power is transferred to the electrical power by PMSG. The AC electrical power produced by PMSG will be rectified by a three-phase diode bridge rectifier, and the rectified power is fed to the boost converter.

The output power derived by the wind turbine blades is expressed as [16]:

$$ P = \frac{1}{2} \times A \times \rho \times C_p \times V_r^3 $$

(18)

Where \( P \) is the output power (in watt), \( \rho \) is the air density (in kg/m³), \( C_p \) is the power coefficient, and \( V_r \) is the wind speed (in m/s). \( A \) is area swept by the blades (in m²) determined as:

$$ A = \pi \times R^2 $$

(19)

Where \( R \) is radius of blades (in m).

Power coefficient \( C_p \) is a nonlinear function of the pitch angle \( \beta \) and tip speed ratio \( \lambda \) as follows:

$$ C_p = 0.5176 \left( 116 \left( \frac{1}{\lambda^4} \right) - 0.4 \times \beta - 5 \right) \times \exp \left( -21 \left( \frac{1}{\lambda^4} \right) \right) + 0.0068 \lambda $$

(20)

$$ \lambda = \frac{R \omega}{V_r} \quad \text{and} \quad \frac{1}{\lambda^3} = \frac{1}{\lambda} + 0.08 \times \beta - 0.035 \left( \beta^3 + 1 \right) $$

(21)

where \( \lambda \) is the tip speed ratio (TSR), \( \beta \) is the pitch angle (in degree), and \( \omega \) is the rotational speed of turbine (in rps).
Fig. 2 shows the output power captured by wind turbine versus rotational speed. According to this figure, the output power function has a one global optimum point, and it is a non-linear function of the rotational speed.

3. Cuckoo Optimization Algorithm

Cuckoo optimization algorithm (COA) is a new intelligent evolutionary algorithm that is proper for continuous non-linear problems. It is inspired by the special kind of bird called Cuckoo. The superiority of COA has been proven than particle swarm optimization (PSO) and genetic algorithm (GA) by [17]. The main advantage of the COA is that this optimization algorithm is robust to dynamic changes. The special lifestyle of Cuckoo has been formulated as an optimization algorithm in order to find the maximum/minimum value of objective functions. The following section meticulously describes the COA.

To start the optimization process, it is necessary to initialize the starting points as an array. Each of the evolutionary optimization algorithms specifies a special name for this array. For instance, in PSO, DE, GA this array is called “Particle Position”, “Stochastic Population”, and “Chromosome”, respectively. In cuckoo optimization algorithm, this array is also called “Habitat”.

In order to solve a N-dimensional optimization problem, we need to form an array of 1×N as follows:

\[ x_i^t = (x_{i1}^t, x_{i2}^t, ..., x_{iN}^t) \]  

(23)

Where d is dimension of the objective function, i is i\textsuperscript{th} habitat, and t is t\textsuperscript{th} generation. Therefore, a candidate habitat matrix of size \( N_p \times N_d \) (\( N_p \) is the number of habitats) is randomly generated.

In nature, each cuckoo lays 5 to 20 eggs, so the number of eggs is randomly determined from 5 to 20 for each cuckoo at each generation of the optimization process. Each cuckoo lays in the special distance from its habitat called egg laying radius (ELR) as follows:

\[ ELR = K \times \frac{\text{Number of current cuckoo's egg}}{\text{Total number of egg}} \times (x_u - x_l) \]  

(24)

Where \( K \) is an integer number, \( x_u, x_l \) are upper and lower of variable limits, respectively.

Cuckoos lay their eggs in other host bird’s nests according to their ELR. Some of the eggs in host bird’s nests will be recognized and thrown out by host bird, so p\% of all eggs will be killed. When the cuckoo’s eggs hatch, they throw the host bird’s eggs out from nests. Cuckoo’s chicks grow in the host bird’s nests. When they become mature, they immigrate to new area with more food and more similarity of eggs to host bird’s eggs. To immigrate, the best value experienced will be determined as a new area that other cuckoos immigrate to there. When they want to immigrate to a new area, they do not fly all way to the destination habitat. They only fly a part of whole way with a deviation like Figure 3.

4. Fuzzy logic controller

The five main steps of fuzzy controller are input and output variables, fuzzy rule, fuzzification, inference, and defuzzification. The maximum power point \( P_{\text{m, optimum}} \) and its respective rotational speed \( \omega_{\text{optimal}} \) are calculated by COA. These values are compared with the actual values of the output power \( P_{\text{m, actual}} \) and of the rotational speed \( \omega_{\text{actual}} \), respectively. As seen in Figure 4, we have two input variables for fuzzy logic controller; the first input is the difference between the maximum power point and the actual power point as Equation (8). The second input is the difference between the optimal rotational speed that belongs to the maximum power point and the actual rotational speed as Equation (9).
A mamdani inference is used as fuzzy inference system. Fuzzy controller based on these inputs and fuzzy rules change the duty cycle of boost converter. The input and output membership functions are shown in Figures 5 and 6. Fuzzy rules are shown in Table 1.

5. Simulation results

In order to validate the performance of the proposed approach, the proposed Fuzzy- Cuckoo tracker is applied to the wind turbine with following parameter values:

Table 2. Parameter values of the simulated system

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air density ( (\rho) )</td>
<td>1.2929 (Kg/m²)</td>
</tr>
<tr>
<td>Radius of blade ( (R) )</td>
<td>7.4 (m)</td>
</tr>
<tr>
<td>Pitch angle ( (\beta) )</td>
<td>0</td>
</tr>
<tr>
<td>Stator phase resistance</td>
<td>0.98 (Ω)</td>
</tr>
<tr>
<td>Stator phase resistance</td>
<td>2.83 (mH)</td>
</tr>
<tr>
<td>Pole pairs</td>
<td>3</td>
</tr>
<tr>
<td>Inertia</td>
<td>30 (kg.m²)</td>
</tr>
<tr>
<td>Parameter values of BOSST converter</td>
<td></td>
</tr>
<tr>
<td>Inductance</td>
<td>400e-6 (H)</td>
</tr>
<tr>
<td>Capacitance</td>
<td>800e-6 (F)</td>
</tr>
<tr>
<td>Load</td>
<td>30 (Ω)</td>
</tr>
</tbody>
</table>

The simulations are performed in MATLAB environment. The schematic diagram of the proposed MPP tracker is completely shown in Figure 7.

A three- phase diode bridge rectifies the voltage generated by PMSG, and the dc- link capacitor \( C_{dc} \) is used to smooth the voltage ripple of the dc voltage generated by the three- phase diode bridge rectifier. Finally, the boost converter is used to control wind turbine in the maximum power point by adjusting the duty cycle.

To confirm the ability of the proposed MPP tracker, in the first case, wind speed pattern will be changed slowly as Fig.
Fig. 9- a shows the output power of wind turbine tracked by the proposed Fuzzy- Cuckoo controller, and Figure 9- b shows the optimal rotational speed calculated by cuckoo optimization according to the wind speed pattern (as Fig.8).

As it is clearly observed, the proposed fuzzy-cuckoo outperforms PSO and fuzzy MPP trackers. Figure 11 shows that fluctuations of the proposed approach are also less than PSO and fuzzy, as well as higher mean value of the output power.

One of the difficulties in MPPT trackers is the fast variations of the wind speed. In this case, for further demonstration, the fast variations of the wind speed are applied to the MPP trackers. Figure 12 shows the fast wind variations, and Figure 13 shows the power tracked by fuzzy- cuckoo, PSO, and fuzzy trackers.

As it is shown in Fig. 13, the proposed fuzzy-cuckoo controller outperforms the conventional MPP trackers such as PSO and fuzzy trackers.

6. Conclusion

In this paper, an accurate MPP tracker called Fuzzy-cuckoo controller has been applied to the small-scale WECS with a PMSG and a three-phase diode bridge rectifier. The proposed MPP tracker uses Cuckoo optimization algorithm to detect the maximum power point of the mechanical power curve and its respective rotational speed. The wind speed is measured by anemometer as an input of the Cuckoo optimization algorithm. The difference of the optimum output power that is calculated by the Cuckoo optimization algorithm and actual output power has been fed the Fuzzy as the first input, and the difference of the rotational speed that belongs to the optimum output power and actual rotational speed has also been fed the Fuzzy as the second input. Finally, the output of Fuzzy logic has been used as a set-point. The implementation of the
The proposed MPP tracker is very simple because only the measurement of the wind speed and the rotational speed are required. In comparison with other conventional MPP trackers such as PSO, and Fuzzy trackers, the proposed MPP trackers are more accurate and robustness (Figures 11 and 13).

References


