A NOVEL MPPT FOR PERMANENT MAGNET DIRECT DRIVE WIND ENERGY CONVERSION SYSTEM BASED ON FUZZY LOGIC WITH GENETIC ALGORITHM

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Abstract -This paper proposes an novel maximum power point tracking (MPPT) method for the wind energy conversion system using a Fuzzy with Genetic Algorithm. The proposed output max-imitation control is achieved without mechanical sensors such as the wind speed or position sensor & the new control system will deliver maximum electric power with weightless, high efficiency, and high reliability. The MPPT algorithm is successfully demonstrated both in the case when no distress were present, as it is to prerequisite for successful implementation, in cases when significant levels of wind disturbances are present. The effectiveness of the proposed algorithm is verified by simulation and experiments based on a wind turbine system.

Index Terms — Boost converter, maximum power point tracking (MPPT), partial shading, Genetic algorithm(GA),fuzzy logic controller, WECS.

1.INTRODUCTION

Renewable energy resources, especially wind energy, are at-tracking great attention with the depletion of existing fossil fuel deposits and increasing concerns about CO2 emissions. Since the late1990s, variable speed constant frequency (VSCF) wind energy conversion systems (WECS) have been widely adopted in order to maximize wind energy utilization. The doubly-fed induction generator(DFIG) and direct-drive permanent magnet synchronous generator (PMSG) are the most popular systems for VSCF wind energy conversion. The Permanent magnet direct drive - WECS has attracted more and more attention due to its advantages of high efficiency and high reliability. The configuration of a typical direct-drive WECS with PMSG is shown in Figure 1. The PMSG converts the mechanical power from the wind turbine into outputpower of ac, which is then converted into dc power through a converter with a dc link to supply the load. By using an additional inverter, the PMSG can supply the ac electrical power with constant voltage and frequency to the power grid. To maximize the use of wind energy when the wind speed is below the rated speed, the maximum power point tracking (MPPT) of the system is indispensable. The Fuzzy logic with Genetic algorithm based MPPT is realized by controlling the dc-ac converter which is connected to the generator of the proposed system . In Previous research has focused on several types of MPPT methods, namely optimum tip speed ratio (TSR) control, hill climb searching (HCS) control, power feedback control and fuzzy-logic-based control

Figure.1 configuration of PMDD –WECS
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The control is easy to understand but hard to achieve due to the need to know the exact wind speed and wind turbine characteristics. HCS control on the other hand does not require any prior knowledge about the system and is absolutely independent of the turbine, generator and wind characteristics [13]. However, two serious problems with the HCS method are the speed-efficiency tradeoff and the wrong directionality under various wind change. These strategy is optimized in various papers [13,14], but the algorithm and control procedure are commonly complex, which make it difficult to execute. The power feedback control is implemented according to calculations based on the generator speed. The wind speed is not needed, but the wind turbine characteristics are indispensable [15]. Furthermore, the power losses should be considered in order to determine the accurate given maximum power. However, the power losses change with the generator rotor speed, which makes it difficult to determine the maximum power point accurately. The fuzzy-control-based MPPT scheme is good, but somewhat complex to implement [8]. However, the adaptive fuzzy controller for MPPT control designed by Galdi et al. in [16–18] can implement sensorless peak power tracking and overcome some disadvantages of classical methods. The maximum power can be estimated through a Takagi-Sugeno-Kang (TSK) fuzzy controller by measuring the rotor speed and power generated by the generator without measuring wind speed and wind turbine parameters. To overcome these drawbacks of the traditional HCS and power feedback MPPT methods, some effective measures are taken in this paper. Its objective is to implement the fuzzy logic with genetic algorithm based MPPT method combining the advantages of the power feedback method and the HCS method without knowing the wind speed and turbine characteristics. Besides, the proposed method can extract the maximum power point more exactly and steadily than traditional HCS control, especially when the wind speed changes fastly. Furthermore, the GA based MPPT control will not be influenced by the change of power losses through estimating the exact loss torque compared to the power feedback MPPT. The proposed MPPT method is implemented in a WECS based on a PMSG and compared with the fuzzy logic control to verify the GA based MPPT efficiency. The experimental results of the proposed system demonstrate the feasibility and effectiveness of the proposed mppt algorithm.

2. Wind Turbine Model

2.1. Wind Turbine Model

The mechanical power extracted by a wind energy conversion system can be given by:

\[ P = \frac{\rho \pi R^2 C_p(\lambda, \beta) v^3}{2} \]

where \( \rho \) is the air density, \( R \) is the radius of wind turbine blades, \( v \) is the wind velocity, and \( C_p \) is the power coefficient of WECS which is a nonlinear function of the tip speed ratio \( \lambda \) and the blade pitch angle \( \beta \). \( \lambda \) is defined as:

\[ \lambda = \omega_r R / v \]

where \( \omega_r \) is angular speed of the rotor. Based on (1) and (2), the torque output by wind turbine can be expressed as:

\[ T = \frac{\rho \pi R^2 C_p(\lambda, \beta) v^3}{2\lambda} \]

The \( C_p \) versus tip speed ratio (TSR) curve is shown in Figure 2 by assuming that the blade pitch angle \( \beta \) is constant. According to (2), the rotor speed can be regulated to keep \( \lambda \) remain the optimum value \( \lambda_{opt} \) and then the power efficient remain the maximum \( C_p_{max} \). The maximum power output by wind turbine is given by:

\[ P_{max} = \frac{\rho \pi R^2 C_{p_{max}} \omega_{opt}^3}{2\lambda_{opt}} = k_{opt} \omega_{opt}^3 \]

and then the maximum torque is:

\[ T_{max} = \frac{\rho \pi R^2 C_{p_{max}} \omega_{opt}^3}{2\lambda_{opt}} = k_{opt} \omega_{opt}^3 \]

where \( k_{opt} \) is a WECS constant determined by the wind turbine characteristics.
Figure 3a illustrates the power versus rotor speed curves calculated by Equations (1) and (2) when the wind speed varies. From the power (P) versus speed curves, the torque (T) versus speed characteristics curves shown in Figure 3b are obtained. The maximum power (Pmax) curve and maximum torque (Tmax) curve are shown with dotted lines in Figure 3a and Figure 3b, respectively. As shown in Figure 3a, if the wind speed is v1 the maximum power (Pmax) would be captured when the rotor speed is ωr1 and the system operating point is A. When the wind speed varied from v1 to v2 and the rotor speed is fixed at ωr1, but the system operating point is jumped to B, which does not correspond to the maximum power tracking - MPT. Then the rotor speed should be controlled to increase from ωr1 to ωr2 which results in the maximum power Pmax at operating point C. The WECS torque (T) operating point is shown in Figure 3b in accordance with power operating point shown in Figure 3.

Figure 3. Wind turbine characteristics
(a) Power versus rotor speed; (b) Torque versus rotor speed.

2.2. PMSG Model

The voltage equations of the PMDD in dq-axes rotating reference frame are:

\[
\begin{align*}
\frac{du_{ds}}{dt} &= -R_s i_{ds} + \frac{1}{L_{ds}} (u_{ds} - R_s i_{ds} + p \psi_{ds} - \omega_s \psi_{qs}) \\
\frac{du_{qs}}{dt} &= -R_s i_{qs} + \frac{1}{L_{qs}} (u_{qs} - R_s i_{qs} + \omega_s \psi_{ds})
\end{align*}
\]

where uds, uqs are the stator winding voltages in dq-axes, ids, iqs are the stator winding currents of WECS in dq-axes. ψds, ψqs are the stator winding magnet fluxes in dq-axes. oe is the rotor speed, and Rs is the resistances of the stator winding. The magnet flux equations of PMSG in a dq-axes rotating reference frame are given by:

\[
\begin{align*}
\psi_{ds} &= L_{ds} i_{ds} + \psi_f \\
\psi_{qs} &= L_{qs} i_{qs}
\end{align*}
\]

where ψf is the permanent magnet flux. Ld, Lq are the stator winding inductances in dq-axes. The steady state power of the PMSG can be derived based on Equations

\[
P = \frac{1}{2} \left( u_{ds} i_{ds} + u_{qs} i_{qs} \right) = R_s \left( i_{ds}^2 + i_{qs}^2 \right) + \frac{p}{2} \omega_s \left( \psi_{ds} i_{qs} - \psi_{qs} i_{ds} \right)
\]

Obviously, the first term of (8) is the copper losses of the PMSG, then the electromagnetic torque of PMSG can be obtained by considering the copper losses and the equation is expressed as:

\[
T_e = P - R_s \left( i_{ds}^2 + i_{qs}^2 \right) - \frac{p}{2} \omega_s \left( \psi_{ds} i_{qs} - \psi_{qs} i_{ds} \right)
\]

where np is the pole pairs of the PMSG, or is the mechanical rotor speed of PMSG.

3. Proposed MPPT Algorithm

3. Fuzzy Logic With Genetic Algorithm

3.1. Objective Function

A Nonlinear optimization problems can be stated in mathematical terms as follows:

Find

\[
X = (x_1, x_2, \ldots, x_n)
\]

such that \( F(X) \) is minimum or maximum

Subject to

\[
g_j(X) \geq 0, \ j = 1, 2, \ldots, m \text{ and } x_jL \leq x_i \leq x_jU, \ \ j = 1, 2, \ldots, n
\]
Where $F$ is the objective function that is to be minimized or maximized, $x_j$'s are variables, $g_j$ is constraint function, $x_jL$ and $x_jU$ are the lower and upper bounds on the variables.

In this the objective function of the research work considered is

$F(X) = \text{Maximization of wind power}$

The variable $x_i = \text{wind current, } I_w$

The constraint is $I_{\text{wmax}} \geq I_w \geq I_{\text{wmin}}$.

Here, $x_jU = I_{\text{wmax}} = I_{\text{sc}}, \text{ short circuit current of WECS}$ & $x_jL = I_{\text{wmin}} = 0$.

### 3.2. Overview of Genetic Algorithm

GA based optimization is an adaptive heuristic search technique that involves generations, systematic evaluations and enhancement of potential design solutions until a stopping criterion is met. There are 3 fundamental operators involved in the search process of a genetic algorithm: 1) selection, 2) crossover and 3) mutation. Selection is a process which chooses a chromosome from the current generation’s population for inclusion in the next generation’s population according to their fitness. Crossover operators are combined in two chromosomes to produce a new chromosomes (offspring). Mutation operators to maintains genetic diversity from one generations of populations to the next and aims to achieve some stochastic variability of GA in order to get a quicker convergence.

The genetic algorithm implementations steps are as follows:

Step 1: Define objective function and initialize the design parameters.

Step 2: Generate initial population for evaluation

Step 3: The population by objective function for process is to be evaluated

Step 4: Test convergence. If satisfied then stop the process else continue.

Step 5: Start reproduction process by using genetic operators:

1) Selection, 2) Crossover, and 3) The Mutation

Step 6: Evolve new generation of the process. Go to step 3.

The genetic algorithm (GA) parameters used in this research work are given in Table I. Genetic Algorithm Parameters.

<table>
<thead>
<tr>
<th>Various speed in (M/sec)</th>
<th>Parameters</th>
<th>Methods For Finding Global Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$P_w$ in Watts</td>
<td>Binary search</td>
</tr>
<tr>
<td>9.6</td>
<td>476</td>
<td>485</td>
</tr>
<tr>
<td>10.2</td>
<td>530</td>
<td>543</td>
</tr>
<tr>
<td>12.4</td>
<td>570</td>
<td>590</td>
</tr>
<tr>
<td>14.6</td>
<td>645</td>
<td>660</td>
</tr>
</tbody>
</table>

Table II: Comparison between GA and binary search method

The performance of the Genetic algorithm is validated graphically by comparing its output (marked in green color) with that of the fuzzy logic with hill climbing method (marked in red color). In all the cases, Genetic algorithm gives the optimum power (global peak) which is matched with the result of fuzzy logic with hill climbing method. The comparison between GA and fuzzy logic with hill climbing method are done. It is observed that the error of this work did not exceed 2%.

### 3.3 MODIFIED HILL-CLIMBING FUZZY-BASED TECHNIQUE

Modification of the hill-climbing searching method uses a FLC-based algorithm. The proposed controller is designed to take advantage of hill climbing simplicity and eliminate all the mentioned drawbacks.
\[ \Delta P = P(k) - P(k - 1) \]
\[ \Delta I = I(k) - I(k - 1) \]
and the output equation is
\[ \Delta D = D(k) - D(k - 1) \]
where \( \Delta P \) is the wind output power change, \( \Delta I \) is the output current change, and \( \Delta D \) is the boost converter duty cycle change. To ensure that the WECS output power does not diverge from the optimum point during varying \( \Delta P \) passes through a gain controller to reverse its direction. The variable inputs and output are divided into four fuzzy subsets: positive big (PB), positive small (PS), negative big (NB), and negative small (NS). Therefore, the fuzzy rules algorithm requires 16 fuzzy control rules; these rules are based on the regulation of hill-climbing algorithm. To operate the

\[ \Delta D = \frac{\sum_{i=1}^{N} \mu(D_i)D_i}{\sum_{i=1}^{N} \mu(D_i)} \]

where \( \Delta D \) is the fuzzy controller output and \( D_i \) is the center of max–min composition at the output membership function. The FLC computes variable step sizes to increment or decrement the duty cycle, therefore the tracking time is short and the system performance during various speeds is much better than with conventional hill-climbing algorithm. Moreover, divergence problem no longer exist since the controller input, change of power (\( \Delta P \)).

4. Proposed MPPT Method

The control configuration of the MPPT for PMDD wind energy conversion system based on fuzzy logic with GA is shown in Figure . The generator speed is measured to calculate the optimum torque and then obtain the optimum current. Only the double current
loops are needed in this MPPT strategy. Compared to the power feedback control method which needs the power loop, the proposed method is more convenient and responds more quickly.

4.1 Simulation Results

This system used for various type of application here we used for voltage source converter based grid, street lighting system and the irrigation motor. Here we discussed the above systems performance and the PMDD WECs with fuzzy logic and the GA.

The voltage and current of an grid is shown in fig.4. the performance for street lighting systems inverter voltage under with and without filter are shown in figure 5.
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5. Conclusion

This paper proposed a novel optimum current given MPPT control method for a permanent magnet direct drive wind energy conversion system. The strategy is based on the idea of the power feedback MPPT method and fuzzy with GA based MPPT method and combines the advantages of both of them. A method for estimating the system loss torque is proposed and the improved MPPT is adopted periodically to ensure obtaining the exact wind turbine parameters. The traditional power feedback MPPT needs the characteristics of the wind turbines. Besides, the given optimum power which is changed due to the change of the losses varying with the generator speed which will reduce the effectiveness of the MPPT control. The GA based MPPT will deteriorate its performance under rapidly changing wind conditions. The maximum power coefficient kopt is obtained by fuzzy logic with GA based MPPT. Then the optimum current given MPPT is adopted with no need of the wind turbine characteristics. The loss torque used in the proposed method can be regarded as a constant and the MPPT effectiveness will not be influenced by the generator speed. For verifying the effectiveness of the proposed MPPT method, simulation models are built and experiments are carried out. Both simulation and the experimental results demonstrate that the proposed GA based MPPT method is effective under the environment with quickly changing wind speed. Furthermore, the proposed strategy is compared with the binary search method in the experiment and the results show that the generated power with the proposed MPPT control is comparable with the hill climbing method which tracks the optimum value in real time. Besides, the WECS output power pulsation of the proposed method is smaller than other method.

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