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MPPT Method of Wind Power based on Improved Particle Swarm Optimization

Zhou Tianpei*[1,2] ,Sun Wei[1]
[1]School of Information and Engineering, China University of Mining and Technology
Xuzhou 221008, China
[2]Xuzhou college of industrial and technology, Xuzhou 221140, China
Corresponding author, e-mail: zhoutianpei_001@163.com, sw3883204@163.com

Abstract

In order to improve the efficiency of wind energy, it is necessary to maximum power point tracking (MPPT). Aiming at shortage of the traditional particle swarm optimization algorithm for parameter sensitivity, easily local convergence, particle swarm optimization (PSO) algorithm with variable neighborhood based on saving preponderant velocities is proposed. Firstly, a compact formula for updating particles is researched, which is considering cognitive discipline of individual on its environment; secondly, a mutation operator with a small probability on the velocities which improve particle quality and a random vector generated for the rest velocities are proposed in order to make full use of good information of particle velocities; finally, the method is applied to maximum power point tracking control of the wind power generation system. The simulation results show that the proposed algorithm can achieve maximum power capture of wind power generation system, improve the dynamic response and efficiency compared with the traditional PSO algorithm.

***Keywords**: wind power generation, maximum power point tracking (MPPT), particle swarm optimization (PSO), variable particle neighborhood*

1. Introduction

It is great necessary for China to solve energy shortage and protect environment through developing wind power technology on a large scale because China's wind energy resource is very rich. While the wind is a very random energy, it has obvious nonlinearity as the weather conditions often change. In order to convert the wind energy into electrical energy at the maximum levels, maximum power point tracking (MPPT) control strategy is generally adopted in wind power generation system [1]. Tip speed ratio control, power signal feedback and climbing search method, are three kinds of common MPPT control strategies. But traditional MPPT control strategies have such shortcomings as estimation error and the high frequency jitter, which lead to low accuracy.

With the development of the intelligent optimization algorithm, some problems of MPPT control strategy can be solved through combining intelligence optimization algorithm with MPPT control strategy. Particle swarm optimization algorithm, as an effective optimization tool, has been applied in maximum wind energy tracking of wind power generation system. However, every particles change their current positions through the current speed in the traditional PSO algorithm. If the particle velocity $v_{ij}(t)$ is relatively small, the absolute value of the "social" items $p_{nj}(t)$- $x_{ij}(t)$ and "cognitive" items $p_{ij}(t)$- $x_{ij}(t)$ of the particles is also small, which lead to $v_{ij}(t)$ be unable to obtain larger value in the next generation, this means that particles lost the exploration ability, and cause premature phenomenon in the evolution [2-3]. Aiming at shortage of the traditional PSO algorithm for parameter sensitivity and easily local convergence, PSO algorithm with variable neighborhood based on saving preponderant velocities is proposed, and the location of particle is updated only by_depending on its speed and dynamic change in the best neighborhood position. And research results are applied to the MPPT control to verify the effectiveness and practicality of the algorithm.

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2. Maximum Wind Energy Tracking Prnciple

By Bates theory [4], the relationship between output mechanical power of wind turbine and wind speed is as follows, namely:

$$P = 0.5\pi\rho R^2 v^3 C_p(\lambda,\beta) \tag{1}$$

Where, P for the air density, usually is 1.25 kg/m^3; R for wind turbine blade radius; v for wind speed before entering swept surface of the wind turbine; C_P for wind power coefficient.

Wind power coefficient C_P is a nonlinear function of tip speed ratio λ and blade pitch angle β, namely [5]:

$$C_p(\lambda,\beta) = C_1\left(\frac{C_2}{\lambda_i} - C_3\beta - C_4\right)e^{\frac{C_5}{\lambda_i}} + C_6\lambda \tag{2}$$

Where, tip speed ratio $\lambda = \frac{\omega R}{v}$, ω for the angular velocity of the wind turbine blade's rotation; $\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08} - \frac{0.035}{\beta^3 + 1}$, C_1-C_6 are determined by the characteristics of the wind turbine [6].

There is an optimum tip speed ratio of wind turbine that make the value of wind power coefficient C_P maximum, this makes the wind turbines to capture maximum wind power. Therefore, the tip speed ratio for the best value has been the key to obtaining the maximum wind power, thereby enabling the value of wind power coefficient C_P maximum [7].

3. Research Method

3.1. Update Formula of Particles

From a sociological point of view, although there are some common social cognitive parts between different individuals, each individual considers itself based on their own interests, that is, as soon as possible to find the most optimum point. A simple particle update formula is proposed, and the location of particle is updated only by depending on its speed and dynamic change in the best neighborhood position, where the neighborhood of the particles expands with gradually improvement of particle level of recognition, and its concrete representation as follows [8]:

$$v_{ij}(t+1) = x(v_{ij}(t) + r\cdot(P_{ij}(t) - x_{ij}(t))) \tag{3}$$

$$x_{ij}(t+1) = x_{ij}(t) + v_{ij}(t+1) \tag{4}$$

Where: x and r respectively for compression coefficient and cognitive coefficient, P_i(t) for the optimal particle position in the neighborhood of x_i(t), short for particle neighborhood optimal value.

3.2. Newborn Particle Preservation Strategy

For the newborn particles x_i(t+1) of Equation (4), the newborn particle preservation strategy is proposed in order to meet superior inferior in the nature, the method is as follows: x_i(t+1) only is retained when x_i(t+1) is superior to x_i(t).

$$x_i(t+1) = \begin{cases} x_i(t+1) & f(x_i(t)) > f(x_i(t+1)) \\ x_i(t) & \text{others} \end{cases} \tag{5}$$

3.3. Method for Determining Particle Neighborhood

As neighborhood particles, num(t) particles are randomly selected from the particle swarm:

$$num(t) = num0 + \frac{t}{T}(num_{\max} - num0) \quad (6)$$

Where: T for the maximum iterations of particles, $num0$ and num_{max} respectively for initial neighborhood size and maximum size the neighborhood of particles.

3.4. Update of Particle Velocity

Considering advantages and disadvantages between newborn particles and previous particles, particles velocity of particle swarm optimization algorithm can be divided into two categories, one is able to improve the quality of particles, namely new particles that are generated through the velocity vector are superior to the previous particles, which is called superior particle velocity; other is not able to improve the quality of particles, which is called inferior particle velocity [10]. Based on this, a new update strategy of particle velocity is proposed, its idea is as follows: superior particle velocity is retained and the small probability mutation is operated, but in contrast inferior particle velocity is replaced by random vectors that are generated by particles in the particle swarm.

P(t) is set as the particle swarm of the t generation, x_i(t)∈P(t), v(t+1) for the speed set corresponding to the newborn particle swarm, v_i(t+1)∈ v(t+1), and the update method of v(t+1) is as follows:

Step 1: judging advantages and disadvantages between x_i(t) and newborn particle x_i(t+1), if x_i(t+1) is superior to x_i(t), go to Step 3;

Step 2: two particles x_{k1}(t+1) and x_{k2}(t+1) are randomly selected from particle swarm P(t+1), the velocity v_i(t+1) is initialized by $v_i(t+1)=r_1(x_{k1}(t+1) - x_{k2}(t+1))$, where r_1 for a random number between [0,1].

Step 3: v_i(t+1) is retained and the small probability mutation is operated.

3.5. Analysis of Convergene

Theorem: If x, r of Equation (3) and (4) of particles satisfy $0 < x < 1$ and $0 < r < 2x + 2$, method for determining particle neighborhood optimal value (num >1) can make the particle swarm converge with probability 1.

Prove: as long as neighborhood optimal value of each particle P_i(t) can converge to global optimal points P_n, the particle swarm can convergence. Therefore, P_n need be proved that it can be selected as the neighborhood optimal value by each particle in the particle swarm.

By method for determining particle neighborhood, the probability that P_n is selected as the neighborhood optimal value at a time is P_s=|num|/|P(t)|, where, |P(t)| for the size of the particle swarm, the probability that P_n is selected as the neighborhood optimal value at n time is

$$\lim_{n\to\infty} P(n) = \lim_{n\to\infty} p_s \sum_{k=0}^{n-1} (1-p_s)^k = \lim_{n\to\infty} p_s \cdot \frac{1\cdot(1-p_s{}^{n-1})}{1-(1-p_s)} = 1 .$$

4. The Proposed Algorithm

The relationship between C_P and λ is the one of the basic properties of wind turbine, tip speed ratio λ determines the size of wind power coefficient C_P under certain condition that blade pitch angle β is fixed [11]. By taking advantage of PSO algorithm with variable neighborhood, the wind turbine can be running at optimal tip speed ratio, and C_P can maintain the maximum value even though wind speed greatly changes, so as to achieve the purpose of maximum power point tracking. Wind power coefficient C_P is defined as the objective function, and tip speed ratio is defined as the variable. MPPT control algorithm is shown in Figure 1, the specific steps are as follows:

Step 1:initializing particle swarm, the particle velocity for zero, individual optimal value for the particle itself, capacity of Reserve set N=50, the population size N=50, the maximum evolution algebra T_{max}=100, the maximum particle velocity v_max=2, compression coefficient x =0.7, cognitive coefficient r =1.25, inertia weight w =0.4, C_1=2, C_2=2 ;

Step 2: fitness value of the objective function corresponding to newborn particles is calculated by using equation (2), the position of particles is updated by newborn particle preservation strategy, and the particle velocity is updated by method for the small probability mutation of superior particle velocity and inferior particle velocity random generation;

Step 3: particle neighborhood optimal value $P_i(t)$ is updated by method for determining particle neighborhood;

Step 4: the position and velocity of particles is updated by equation (3) and (4);

Step 5: determine whether terminated conditions satisfy demand, if satisfied, the optimal solution is output, otherwise, go to Step 2.

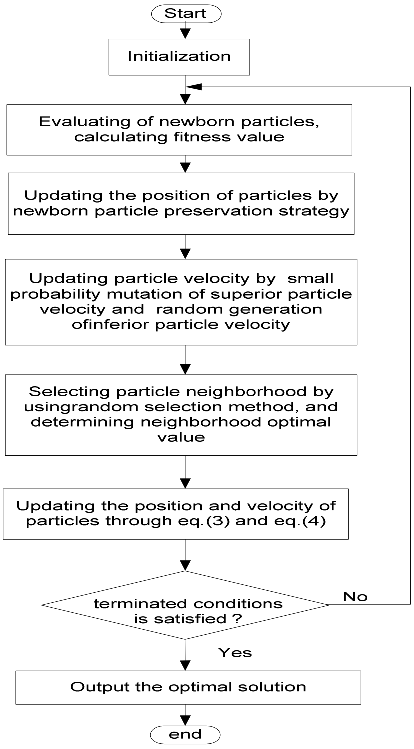

Figure 1. MPPT Control Algorithm based on Improved Particle Swarm Optimization

5. Results and Analysis

5.1. Simulation Control Model

MPPT simulation module of wind power generation system is established in the Matlab environment based on the above mathematical model, which is shown as Figure 2.

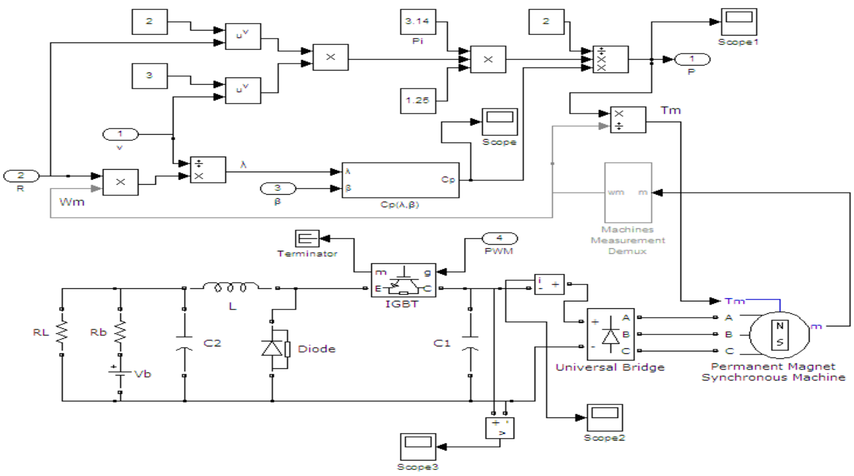

Figure 2. MPPT Simulation Module of Wind Power Generation System

5.2. Simulation Results

Simulation parameters if wind power system are set as the parameters in Table 1 [12], wind speed is given through Ramp module in the Simulink toolbox.

Table 1. Wind Power System Simulation Parameter

Parameter	Value
Impeller radius R	9 m
blade pitch angle β	0°
Generator rated power P_N	15KW
Generator pole number p	3
stator resistance R_S	0.356Ω
rotor resistance R_r	0.321Ω
Stator winding leakage reactance L_S	0.0722H
rotor winding leakage reactance L_r	0.0528H
magnetizing inductance L_m	0.0428H
Generator inertia J_g	1.55kg·m^2

As wind speed changes randomly, the sampling time of the controller is set to 0.01s, namely the controller outputs a control signal to the system per 0.01s, and to track the maximum output power of wind turbine. For tracking the maximum power point, duty ratio control signal will be sent to the Buck converter, and the system operation state will be adjusted to the optimum through adjusting the duty ratio. As long as the wind power coefficient is adjusted to C_{Pmax}=0.48, the wind turbine will be able to achieve the maximum power point tracking.

The simulation process is set as follows: the initial value of wind speed is zero when t≤0, and wind speed steps into v=7m/s at t=0s, the wind speed once again steps into 9m/s at t=1.5s, wind speed drops to v=7.5m/s at t=2s, wind speed rises to v=8.5m/s at t=3s. The change of wind power coefficient is shown as Figure 3. The change of control signal(duty ratio) verus wind speed is shown as Figure 4. MPPT output by using proposed method compare with by using traditional method is shown as Figure 5. The value of C_P is collected when four kinds of wind speed stably run, wind power coefficient C_P that using traditional PSO algorithm and using improved PSO algorithm respectively are shown as Table 2 and Table 3.

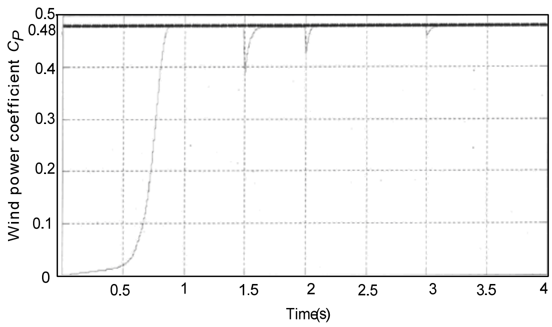

Figure 3. The Change of Wind Power Coefficient

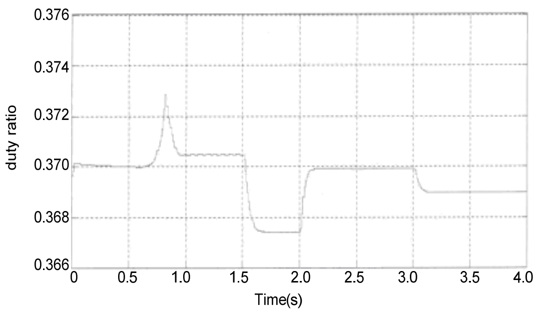

Figure 4. The Change of Control Signal (duty ratio) Versus Wind Speed

Table 2. Wind Power Coefficient using Traditional PSO Algorithm

wind speed (m/s)	wind power coefficient	optimal wind power coefficient	error
7	0.47	0.48	2.08%
9	0.4667	0.48	2.77%
7.5	0.4711	0.48	1.85%
8.5	0.4693	0.48	2.23%

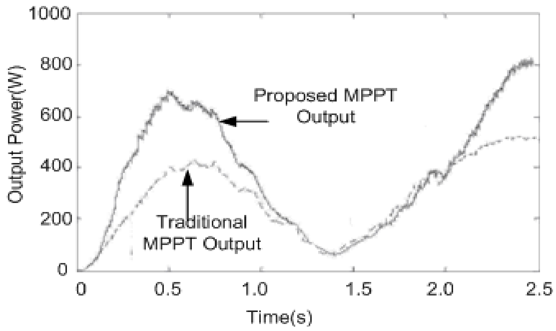

Figure 5. MPPT Output by using Proposed Method Compare with by using Traditional Method

Table 3. Wind Power Coefficient using Improved PSO Algorithm

wind speed (m/s)	wind power coefficient	optimal wind power coefficient	error
7	0.4792	0.48	0.167%
9	0.4771	0.48	0.396%
7.5	0.479	0.48	0.208%
8.5	0.4786	0.48	0.292%

As can be seen from Figure 3, wind power coefficient of wind turbine has small fluctuation after wind speed changes every time, but its value basically maintained near C_{Pmax}=0.48, which shows that the proposed MPPT method can achieve properly the wind energy maximum power point tracking control, and the control precision is relatively high. As can be seen from Figure 5, the proposed MPPT method can effectively improve the output efficiency of start-up phase and the low wind speed phase, as well as of operational phase and the high wind speed phase. As can be seen from the Table 2 and Table 3, the error between wind power coefficient and optimal wind power coefficient in Table 3 is much less than those in Table 2, the quality of the tracking control is effectively improved, energy loss is reduced, thus effectiveness and practicality of the algorithm are validated.

6. Conclusion

Considering shortage of the traditional PSO algorithm for parameter sensitivity, easily local convergence, PSO algorithm with variable neighborhood based on saving preponderant velocities is proposed through analyzing individual limitations to cognitive environment and making full use of good information of particle velocities, method for determining particle neighborhood optimal value and updating particle position is improved, and the algorithm is applied to maximum power point tracking control of the wind power generation system. Simulation results show that: 1) the algorithm can effectively avoid the disadvantages that traditional PSO algorithm is easy to fall into local convergence, and global search capability of algorithm is improved; 2) new update formula of particles can reduce the algorithm dependence on parameters, and operability of the algorithm is improved.

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