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A Strategy Research on MPPT Technique in Photovoltaic Power Generation System

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Abstract

Output mode of photovoltaic cell is a complex transcendental equation, which is rather difficult to figure out by the numerical method. Traditional MPPT requests highly of initial value with low accuracy. In this thesis, simulation model of photovoltaic cell is built to simulate environmental situations under different lights and temperatures, taking advantage of particle swarm and ant colony intelligent algorithm to track the maximum power point of photovoltaic cell. Furthermore, a kind of intelligent perturbative tracking method is put forward combined with traditional perturbative tracking and intelligent tracking. The simulation result showing that intelligent perturbative tracking strategy has superior accuracy and adaptability than traditional MPPT method.

Keywords: *particle swarm, ant colony, MPPT, emulation, photovoltaic model*

1. Introduction

In 21st century, solar energy wins increasing attention due to cleaning, non-pollution and ceaseless usage etc. However, photoelectricity conversion efficiency of photovoltaic cell array is not high presently; we, in order to further improve applicable efficiency of solar energy, develop the intelligent tracking strategy of the maximum power point in photovoltaic system in hope of improving and optimizing existing MPPT method, whose possibility is proved through statistical analysis.

As the core component of the solar energy PV generation system of solar energy, property of photovoltaic cell is influenced by illumination intensity and temperature etc, whose volt-output characteristic shows complex nonlinearity. In order to keep maximum output power of photovoltaic cell, loading working point should be adjusted timely so as to adapt changes of output characteristic of solar energy. The existed common maximum power point tracking methods, which mainly include perturbative algorithm [1, 2], Optimum Gradient Approach [3] and IncCond [4], judge change direction of output power through measuring output voltage and current of cell, adjusting translocation of the cell working situation to the maximum power point. While this method has different disadvantages in practice, that it has difficult in comprehensive requirements for controlling complexity and accuracy.

In recent years, some researchers have applied swarm intelligent algorithm in the MPPT of photovoltaic system and won good achievements. For example, PSO and GA were introduced in [5] and [6] to track the MPP of photovoltaic system under mutation condition, which can capture the MPP more rapidly and accurately. However, the swarm intelligent algorithms are based on model, whose tracking accuracy is determined by accuracy of models and external conditions.

In this thesis, a new intelligent perturbative method is put forward combined with intelligent swarm algorithm and traditional MPPT method, which effectively promotes efficiency of the maximum power tracking.

In section 2, simulation model of photovoltaic cell is established under MATLAB environment, and its output characteristic is analyzed under different illumination intensity and temperatures. Section 3 presents and analyzes the existing MPPT methods, including traditional algorithm and the swarm intelligent algorithms. Section 4 and Section 5 put forward a intelligent perturbative tracking strategy based on the advantages of the two kinds of tracking

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method, and verify the superiority of it through experiments. Section 6 gives a conclusion to the whole paper.

2. Modeling the Photovoltaic Cell Simulation

2.1. Simulation Model

As shown in Figure 1, the equivalent circuit of a photovoltaic cell [7] is a current source in parallel with a diode, which includes a series resistance R_S giving a more accurate shape between MPP and the open circuit voltage. According to the characteristics of the circuit and the internal structure of photovoltaic cell, the I-V characteristics of the cell can be described as follows (1)~(8):

$$I = I_L - I_0(e^{q(V+IR_S)/nkT} - 1) \quad (1)$$

$$I_L = I_{L(T1)}(1 + K_0(T - T_1)) \quad (2)$$

$$I_{L(T1)} = G * I_{SC(I1,nom)} / G_{(nom)} \quad (3)$$

$$K_0 = (I_{SC(T2)} - I_{SC(T1)})/(T_2 - T_1) \quad (4)$$

$$I_0 = I_{0(T1)} * (T/T_1)^{3/n} * e^{-qV_g/nk(1/T - 1/T_1)} \quad (5)$$

$$I_{0(T1)} = I_{SC(T_1)} / (e^{qV_{OC(T1)}/nkT_1} - 1) \quad (6)$$

$$R_S = -dV/dI_{V_{OC}} - 1/X_V \quad (7)$$

$$X_V = I_{0(T_1)} * q/nkT_1 * e^{qV_{OC(T_1)}/nkT_1} \quad (8)$$

Where, I_L : photocurrent of the PV panel; I_0: saturation current of the diode; R_S: series resistance; $V + IR_S$: the voltage across the diode; KT/q: the voltage equivalent of temperature; G : irradiance; T: temperature of panel(K); k: Boltzmann constant ($1.38 \times 10^{-23} J/K$); q: elementary charge ($1.6 \times 10^{-19} C$); n: diode factor (usually between 1 and 2); I_{SC}: short circuit current; V_{OC}: open circuit voltage, normally provided by PV panel manufacturers.

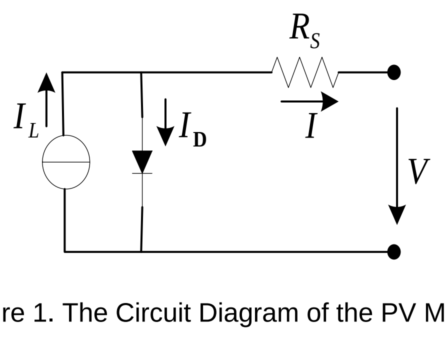

Figure 1. The Circuit Diagram of the PV Model

2.2. Analyzing the Output Characteristics of the Photovoltaic Cell

The photovoltaic cell is by nature a non-linear power source. As it is well known, the MPP of a PV power generation system depends on temperature, irradiance and other external conditions. By using (1)~(8), the simulation model of the photovoltaic cell is built up and used to analyze its output characteristics. Figure 2 shows P-V curves at the same irradiance value (1 kw/m^2), but at various temperatures (0～75$°C$), and Figure 3 shows at constant temperature (25$°C$), but under increasing irradiance (0.25～1kw/m^2).

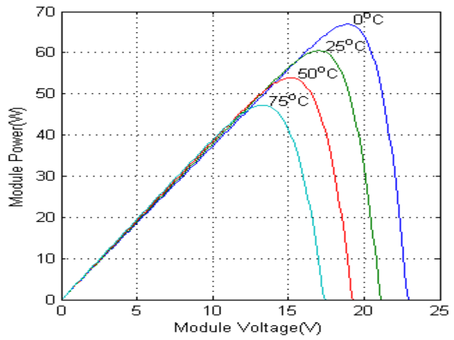

Figure 2. PV Curves at Various Temperatures (Temperature is 0～75$°C$; Irradiance is 1 kw/m^2)

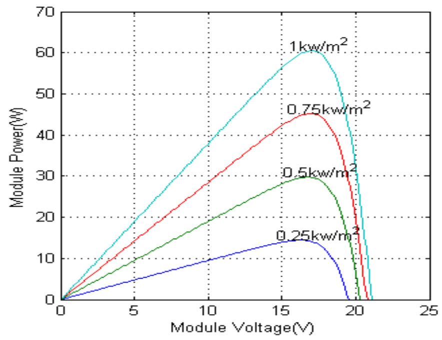

Figure 3. PV Curves at Various Irradiation Levels (Temperature is 25$°C$; Irradiance is 0.25～1kw/m^2)

As seen in Figure 2 and Figure 3, under different conditions, there is a unique point on the curve, called the maximum power point (MPP), at which the photovoltaic cell operates with maximum efficiency and produces maximum output power. At the same irradiance value, the voltage of the MPP decreases as the temperature increases, the same as the maximum output power. Under the conditions of constant temperature and increasing irradiance, needless to say there is any change of the voltage at which the MPP occurs, however, the value of the maximum output power increases obviously.

Figure 2 and Figure 3 also show that photovoltaic cell is neither steady voltage source nor constant flow source, it is a kind of nonlinear direct-current power supply. In the beginning, the output current curve is a comparatively constant value, which rapidly falls to zero when the voltage rises high to an extent. Therefore, photovoltaic cell has the unique maximum power point under certain temperature and illumination strength. The open-circuit voltage Voc and short-circuit current Isc change with changing exterior conditions, at left side of the maximum power point, output power of photovoltaic cell increases along with increase of voltage at the working point; while at the right side, it decreases along with increase of voltage at the working point.

Voc is mainly influenced by temperature of photovoltaic cell, which Isc, the illumination intensity. Switch voltage of the solar panel board will not be influenced greatly when the illumination intensity changes, while the supplied maximum current value will be greatly changed, thus, illumination intensity is am important factor influencing output power of the solar energy board.

It is known that solving equation of the maximum power point of photovoltaic model is a complex transcendental equation, which can not be figured out by ordinary ways, the solving process of value solution relies on choosing initial value, which can not guarantee its accuracy. So we have to pursue a kind of comparatively superior solution to track position of the maximum power point of solar energy.

3. Brief Introductions to Existing Tracking Method

3.1. Perturbative Algorithms with Variable Steps

Perturbation with variable steps is most extensively applied method to track the maximum power in photovoltaic industry at present, which takes ratio of changing value of power P and voltage V (dP/dV) as step length adjusted by output voltage V, the basic theory of it. It can be seen in P-V characteristic curve of photovoltaic cell that symbols of (dP/dV) at right and left of the maximum power point are opposite, and the farther it is to the maximum power point, the bigger the absolute value, the step length is bigger, with dP/dV as adjusting value of voltage V. The absolute value of slope turns smaller approximate to the maximum power point with small step length and smaller step length at the maximum power point, and an extreme small extent vibrates at two sides of it finally, which overcomes problems which are difficultly confirmed in the ordinary perturbative observational method. Furthermore, an upper limit is fixed to adjusting step length of voltage in the thesis so as to avoid influence of oversize voltage adjusting step length upon accuracy and stability of the system, which flaw chart is shown in Figure 4.

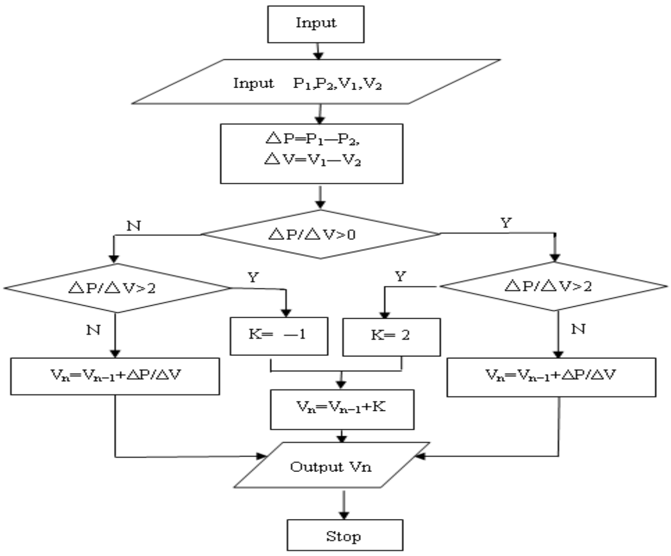

Figure 4. Flow Chart of Perturbative Algorithm of Variable Steps

3.2. Intelligent Algorithm
3.2.1. Particle Swarm Algorithm

Particle swarm algorithm [8] is a kind of parallel overall random searching algorithm based on swarm intelligence, with characteristics of simple structure, few adjustable parameters, fast searching speed, intense generality and high robustness etc, which renews its speed and position continuously according to formula (9) and (10) so as to find the optimal solution.

$$v_i^{t+1} = w \cdot v_i^t + c_1 \cdot rand() \cdot (p_g^t - x_i^t) + c_2 \cdot rand() \cdot (p_i^t - x_i^t) \quad (9)$$

$$x_i^{t+1} = x_i^t + v_i^{t+1} \quad (10)$$

Particle swarm algorithm adjusts transferring speeds of p_g and p_i according to values of memory factors c_1 and c_2. In order to keep diversity of particles, we make random treatment to status of particle by *rand*（）.

3.2.2. Ant Colony Algorithm

With inspiration of biological evolution theory, ant colony algorithm was put forward by Italian scholar Dorigo M etc in 1991, which is a kind of parallel positive feedback emulation algorithm with strong robustness, with certain advantage in aspect of optimal problem of complex solution combination. The ant colony algorithm [9], based on different starting points randomly caused by each ant, searches path information by use of pheromone density and formula constituted by idea function, renews pheromone continuously, and figures out the optimal answer according to the pheromone density. Because basic ant colony algorithm is built in disperse field, while output curve of photovoltaic model is a successive curve in practice, we bring in the ant colony algorithm in continuous field, and introduce Gaussian Mutation to optimize its algorithm so as to realize tracking the maximum power point combined with practical situation of photovoltaic electricity generation.

3.3. Conclusion on Existing Algorithm

As an emerging bionics algorithm, the intelligent swarm algorithm is much simpler and more feasible than traditional MPPT algorithm, with high suitability. When exterior condition mutates, it can be located near the maximum power point without erroneous judgment and delay. The tracking working sketch of the above 3 tracking methods in changing illumination is shown in Figure 5.

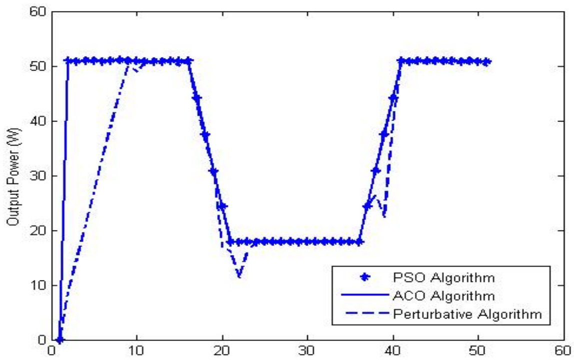

Figure 5. Comparison of 3 Tracking Methods in Changing Illumination

4. Intelligent Perturbative Stratrgy

Because the illumination intensity changes constantly within a day, especially in climate cloud, morning and night, it changes more frequently. So as for the photovoltaic cell array, the P-V curve changes continuously. Due to limit of the perturbative algorithm with variable steps, its next step length should be determined by result compared with the former sampling point, the tracking maximum power point under mutating climate is determined to be delayed.

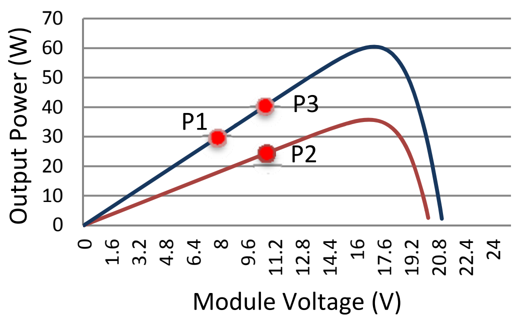

Figure 6. Situations of Possible Erroneous Perturbation Judgment when Illumination Mutates

It can be seen from Figure 6 that the existing working voltage is recorded as V_1, and the array output power as P_1. When perturbative direction of voltage moves to V_2, if the illumination does not change, the array output power is P_3, because $P_3 > P_1$, the controlling working voltage continues to move left. If the illumination intensity decreases from S_1 to S_2, the relevant output power of V_2 should be P_2, because $P_2 < P_1$, the system will judge errs of voltage perturbation direction so as to control the working voltage move left back to V_1. If the illumination continue to fall, continuous errs would occur to the control system so that the working voltage traverses between V_1 and V_2, and the maximum power point of the array can not be tracked.

When exterior environment mutates, the intelligent algorithm can realize rapid tracking because its optimizing process is built upon model and can find control voltage of the maximum output voltage point in the photovoltaic model in the first time. Meanwhile, errors between model and real component are calculated in it so that unnecessary consumption caused by certain control violation of the real component towards the output power point which can not reach necessary maximum power. Moreover, when the controller has tracked the maximum power point and the climate has turned stable, application of swarm intelligence would cause unnecessary calculation; the maximum power point of the real component can be well tracked and be controlled at a quite high accuracy only by a little perturbation of small step due to characteristic of photovoltaic model near the maximum power point.

Thus, the intelligent perturbative algorithm is put forward combined with characteristics of several algorithms, which is applied under greatly-changing exterior environment so as to pursue faster location near the maximum power point, and then the perturbative algorithm of variable steps is applied in tracking; while the perturbative algorithm of variable steps is applied in tracking under stable situation. At the same time, because the swarm intelligence tracking has been located near the maximum power point, perturbative observation through reducing each changing step length or directly applying small step length with needed accuracy can be taken in tracking so as to further promote accuracy of algorithm while tracking variable-step perturbation.

5. Result and Analysis of Emulation Experiment

In order to further analyze efficiency of the new tracking algorithm in process of tracking the maximum power put forward in the thesis comparatively, we simulate changes of illumination and temperature under cloudy weather in summer (a could sails), and track the maximum power point by use of the above algorithm, shown as Figure 7.

The controller collects a sample per minute, because the illumination intensity is mostly influenced by cloud, which is opposite to temperature, thus, 70 points are selected as the temperature curve within [25-0.0005, 25+0.0005]^0C in the thesis; the former 10 points increase successively from 0(W/M^2) to [0.8+0.001,0.8-0.001] (W/M^2), while points 10-25 decrease successively from [0.8+0.001, 0.8-0.001] $(W/M^2)$to [0.3+0.001,0.3-0.001](W/M^2), points 45-55 return back to [0.8+0.001,0.8-0.001] (W/M^2).

The tracking result of the maximum power point in experimental algorithm can be shown in Figure 8.

It can be seen from the Figure 8 that perturbative method can tracks the maximum power point after a period of time when a mutation occurred, which shows obvious sluggish. That's to say, when exterior condition mutates, perturbation can not track the maximum power point promptly;

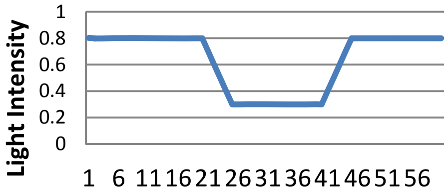

Figure 7. Experiment Illumination Condition

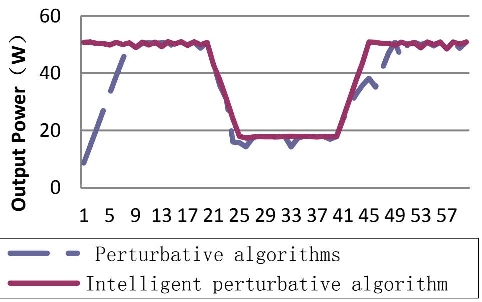

Figure 8. The Comparison between Intelligent Perturbative Algorithm and Perturbative Algorithms

while the intelligent perturbative algorithm can rapidly locate it, which is comparatively stable near the maximum power point, with tracking higher accuracy and speed than the perturbative algorithm.

6. Conclusion

Perturbative tracking of variable steps, as a kind of the existing classic maximum power tracking method, can effectively track the maximum power point in the stable environment with simple realization principles and low hardware requirements, but it cannot rapidly track the goal when external environment mutates. Intelligent swarm algorithm has strong optimal-searching properties and can rapidly track changes of the maximum power point due to climate mutation, overcoming limitation of perturbation with variable steps, but it's tracking accuracy is determined by accuracy of models and external conditions.

Intelligent perturbative strategy increases choice of algorithm, combination of advantages between intelligent algorithm and perturbative algorithm would strengthen adaptively of the strategy, find location near the maximum power point rapidly in perturbation, adjust in a small scope through improving perturbation of variable steps so as to reach higher accuracy and effectively reach the target of fast and accurately tracking the maximum power point.

Intelligent algorithm has strong optimal-searching ability and can effectively settle optimization of nonlinear complex systems, and more intelligent methods will be used for tracking maximum power point in the future.

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