Research on the MPPT Algorithms of Photovoltaic System Based on PV Neural Network

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Abstract: In order to solve Maximum Power Point Tracking (MPPT) technology difficulties in photovoltaic system, 2-level neural network-genetic optimal algorithm is employed to estimate the photovoltaic battery model , taking into account possible influencing factors for battery output power such as light intensity, circumstance temperature, battery junction temperature, battery position. This method overcomes both power loss caused by oscillation around maximum power point with the traditional hill-climbing method and difficulty of training data with traditional neural network algorithm.

Key Words: Photovoltaic system, MPPT, Neural network, Genetic algorithm, Function transform of semiconductor memory

1 Introduction

Solar energy is a new energy with a great potential. Photovoltaic power generation is the main way to develop solar energy. All photovoltaic systems are desired to generate electrical energy as far as possible in the same condition such as light intensity, temperature and so on. All the things mentioned above is termed as MPPT-Maximum Power Point Tracking in theory and practices. MPPT control is responsible for detecting output power for photovoltaic array and predict possible maximum power in current work condition with certain algorithm to enable photovoltaic systems work in the best condition.

Various tracking methods are presented in domestic and foreign papers for this research. For example perturbation and observation method[1]is performed by adding or decreasing photovoltaic module MPP voltage repeatedly to track MPP. This method can be easily carried out, but working point adjacent to MPP trend to oscillate resulting power loss. The another example is incremental conductance method[2]which change control signal by comparing photovoltaic module to increase conductance suddenly. This method requires acquisition of voltage and current for photovoltaic array, high accuracy control, high speed responsibility and high accuracy sensor. Open circuit voltage method [3,4]is applied to obtain the voltage of MPP according to the relationship between open circuit voltage and the voltage of MPP when open circuit voltage is known. This method is economical, convenient, strong anti-interference, no oscillation, but does not work in continuous output system. Furthermore, because sampling techniques is employed, energy will be lost. And large memory space and high computing power are essential for this method.

This paper presents maximum power point tracking method based on genetic optimal algorithm with the characteristic of high accuracy, good robustness which can overcome power attenuation in tracking process for traditional method. Comparing to traditional neural network method, genetic optimal algorithm for maximum power point tracking[5] has less difficulty in acquiring training data, and broad applications.

2 Photovoltaic battery model and characteristic

2.1 Equivalent circuit of photovoltaic battery

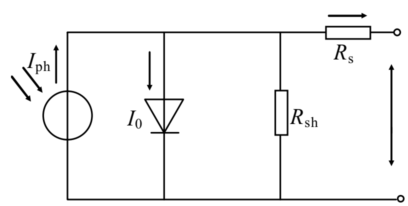

Fig.1 Equivalent circuit model of photovoltaic battery

A equivalent series resistance of ideal photovoltaic battery Rs is usually small, while its equivalent parallel resistance Rsh is large. Generally speaking, Rs and Rsh can be neglected for photovoltaic battery of monocrystalline silicon or polycrystalline silicon in engineering applications. Output characteristic equation for photovoltaic battery can be expressed as following:

$$I = I_{ph} - I_0\left\{\exp\left[\frac{q(V + R_s \cdot I)}{nkT}\right] - 1\right\} - \frac{V + R_s \cdot I}{R_{sh}} \quad (1)$$

Where I is output current of photovoltaic battery (working current), V is output voltage of photovoltaic battery (working voltage), I_{ph} is photo current, I_0 is directional saturation current (order of magnitude is 10^{-4}A for photovoltaic unit), I_d ($I_0\{\exp[q(V + R_s \cdot I)/nkT] - 1\}$) is junction current of diode, q is electric charge of electron （1.6×10^{-19}C）, R_s is series resistance of photovoltaic battery （less than 1 Ω ） n is characteristic factor of diode（the value is about 2.8 when T is equal to $300K$ ）, k is Boltzmann constant（$1.38e^{-23}$J/K）, T is temperature of photovoltaic battery, R_{sh} is parallel resistance of photovoltaic battery（order of magnitude is $k\Omega$ ）.

2.2 Electrical characteristic of photovoltaic battery [6]

When the light intensity and temperature is constant, the characteristic curve of photovoltaic battery can be expressed as shown in Figure 2, which shows the relationship among output current, voltage, power of the photovoltaic battery.

Output power of photovoltaic battery depends on light intensity, spectral distribution of solar energy, temperature. Standard condition (termed by European Commission as Standard 101) provides that light intensity S=1000W/m^2, spectrum AM1.5, photovoltaic battery temperature T=25℃. In this case, maximum power outputted by photovoltaic battery is called peak power with Watts peak（Wp）.

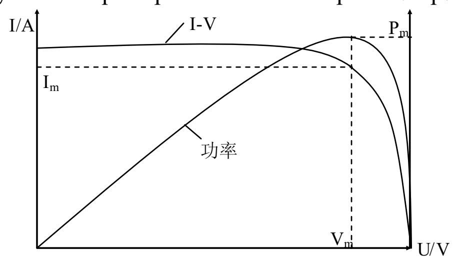

Fig. 2: Characteristic curve of photovoltaic battery

As shown in Fig.2, voltage current characteristic of photovoltaic battery is obvious nonlinear because photovoltaic battery is neither constant voltage source nor constant current source, and is impossible to provide arbitrarily large power for load. Photovoltaic battery is nonlinear dc power supply, whose output current can be regarded as constant for most of the operating voltage range. However, when output voltage is close to open-circuit voltage, current falling rate is great. Voltage watt characteristic is also nonlinear, furthermore, the relationship between voltage and power is more complicated to estimate under different light intensity and temperature conditions. According to theoretical derivation and practical experience, photovoltaic array is greatly influenced by light intensity, environment temperature, location, angle and so on. These factors lead to work characteristic variation, so there exist serious nonlinear. This paper presents a precise model estimation for photovoltaic battery based on neural network technology.

3 Neural network model estimation

Neural network model belongs to black box model. The corresponding output can be obtained with known input by network topology and convenient learning and training process so as to estimate output of many measurable or unmeasurable state. Artificial neural network characteristics including large scale concurrent ability, error tolerance, self-organization and good adaptation ability, have become efficiency tool to solve many complicated problems. This paper employs 2-level neural network to estimate the photovoltaic battery model as shown in Fig.3 and Fig.4. This method has high accuracy, high speed responsibility and good prediction and so on.

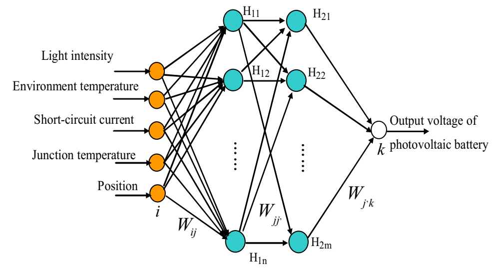

Fig.3 Neural network equivalent model of photovoltaic battery

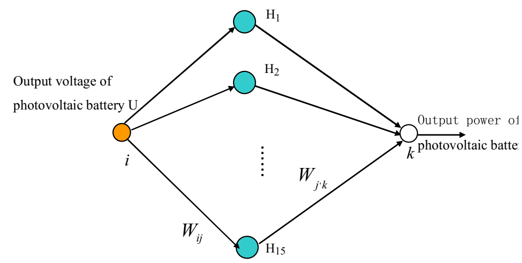

Fig.4 P-V neural network of photovoltaic battery

This paper employs neural network 1-15-1 for P-V characteristic of photovoltaic battery as shown in Fig.4. Neurons in hidden layer are asymmetrical function tansig, and output layer is linear function purelin. Training algorithm can employ function trainlm of Matlab neural network toolbox. Terminal training step parameter is 10000, terminal condition of training error is as following:

$$E_P = \frac{1}{P}\sum_{i=1}^{P} e_i^2 \le \varepsilon = 0.000001 \qquad (2)$$

Training samples of neural network should include P-V value under various conditions. In this paper, light intensity is 1000W/m^2, training samples are acquired in environment temperature of 25℃. After 471 iterations, experiment results closely achieve given target values as shown in Fig.5

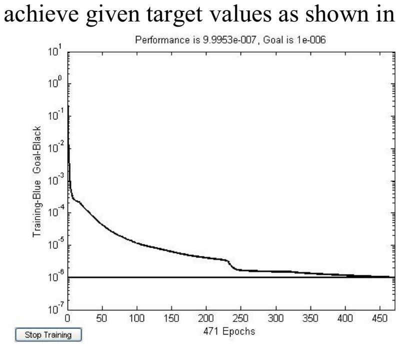

Fig.5 The process chart of neural network training

Training results fitting target value are showing in Fig.6, and residual error between training results and target value is showing in Fig.7.

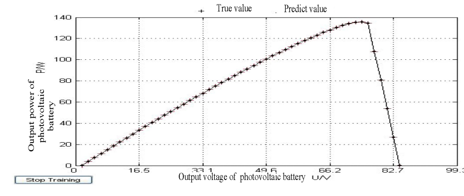

Fig.6 Fitting curve for neural network training results and target value

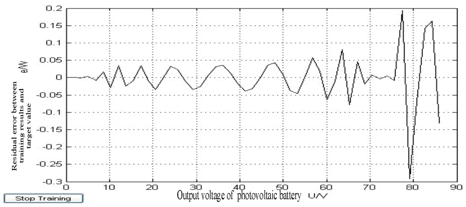

Fig.7 Residual error between training results and target value

As can be seen from Fig.7, Residual error only ranges from -0.3W~0.2W, which reaches the desired effect.

4 On-line control realized by the function transform of semiconductor memory technology

According to the principle of the function transform of semiconductor memory technology[7], The controller of circuit diagram can be designed as shown in Fig.8. Its domination principle can be illustrated as following: the given signal can be converted into digital signal with A/D converter and can be regarded as input address for memory. In addition, the voltage of maximum power point can be deduced with experience, and output controlled quantity can be pre-stored in memory specified location. In this case, there exists a mapping relationship between the memory address and stored data, i.e. $A \to D$. So the stored data D (controlled quantity U) can be outputted under the control of the timing pulses. And output data can be directly employed to control device which achieves on-line control.

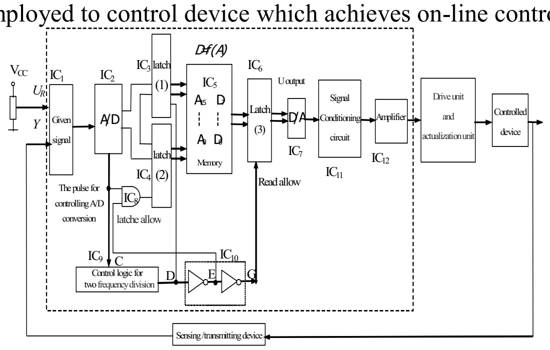

Fig.8 The MPPT controller of electrical circuit schematic based on the function transform of semiconductor memory

5 Genetic optimal estimation for MPP

5.1 Genetic optimal for MPP design

There exists error between maximum power point in the memory table and true value. In order to obtain terrific tracking accuracy, genetic algorithm is used to search optimization in this paper. Genetic algorithm is a reference to natural selection and genetic mechanisms developed randomized search algorithm which is different from traditional algorithm. Genetic algorithm does not depend on gradient information, but to use certain coding techniques to stimulate numeric strings called chromosomes for simulating the group evolutionary process made from numeric strings. A new string group with good adaptability can be formed by recombining organized and random information.

Genetic algorithm optimal is employed to obtain high accuracy result with global optimum for MPP tracking process of photovoltaic array. This algorithm adopts parallel searching, and hardly be influenced by continuous differentiability of fitness function. This algorithm has many characteristic including good versatility, expansibility, compatibility with other technologies.

Maximum Power Point is locked in PV characteristic curve by adopting GA toolbox in Matlab under the condition of light intensity being 1000W/m^2 , temperature being 25℃. In genetic optimal process, toolbox functions are adopted for searching, including function crtbp for population-initialized, function ranking for the fitness assignment, function select for group selection, function recombine for population reorganization, function mut for group variation and so on.

Genetic algorithm optimization process is showing as following in Fig.9

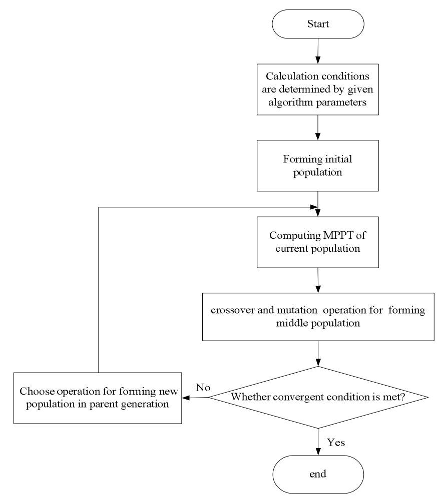

Fig.9 The flow chart of genetic algorithm optimization for MPPT

(1) Coding

Coding is employed for genetic algorithm including binary coding, Gray code, floating-point coding and so on. In this paper, real coding is employed in this algorithm.

(2) Fitness function design

Weight and threshold W1，W2，b1，b2 obtained from neural network training are put into the equation (2):

$$Y^{m+1}(P) = f(W^{m+1}Y^{m}(P) + b^{m+1}) \qquad (2)$$

And fitness function can be obtained as shown in equation

$$y = purelin(W_2[\tan sig(W_1 * x, b_1)], b_2) \qquad (3)$$

(3) Initialize all the population in random way.

(4) Choose operator and use stochastic tournament selection .

(5) Crossover operation adopted is a novel heuristic arithmetic crossover[8,9,11] taking into account the global optimization and local search capabilities to enable GA converge fast. So crossover trial vectors are different from the parent vectors.

(6) Mutation operation adopts closed crossing avoidance. When the fitness of crossover parent are same, mutation operation do not adopt uncrossed operation, but process a little non-uniform self-adaption mutration[9,10].

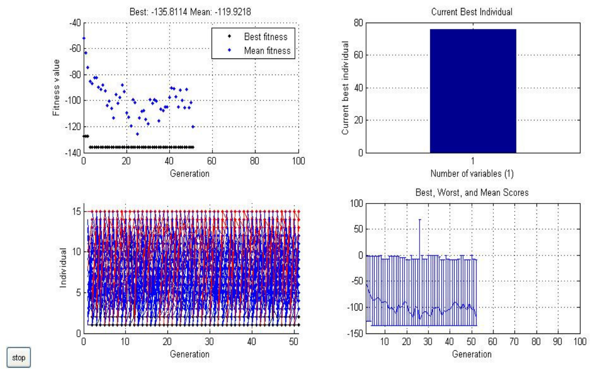

Fig.10 Schematic diagram of genetic algorithm training process

6 Conclusion

6.1

Maximum power point tracking technology is becoming one of research focuses in photovoltaic power. The paper proposes a method which adopts 2-level neural network genetic algorithm optimal to track maximum power point accurately. This method overcomes both power loss caused by oscillation around maximum power point with the traditional hill-climbing method and difficulty of training data with traditional neural network algorithm. This paper contains two innovations:（1）In order to enable model more accuracy, battery model is estimated with 2-level neural network genetic algorithm, taking into account possible influencing factors for battery output power such as light intensity, circumstance temperature, battery junction temperature, battery position. Furthermore, the nonlinear characteristic between output power and output voltage is fitted with PV network genetic model, which supports obtaining maximum power point with neural network genetic optimal.（2）Genetic algorithm is employed to search optimizing for maximum power of PV curve. After 52 generations, maximum power obtained is 135.8114W, and according voltage is 72.13824V. Comparing to maximum power point, error ration is only 1.45%, which obtains tracking effect with high precision and system stability is improved.（3）On-line control for maximum power point of photovoltaic system is carried out by using function transform technology of semiconductor memory.

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