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Improved Immune Clonal Selection Algorithm for Photovoltaic Maximum Power Point Tracking Control

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Abstract: Maximum power point (MPPT) real-time tracking for photovoltaic system is a kind of typical problem. This study is forward an Improved Clonal Selection Algorithm (ICSA) through introducing cloning operator to solve real-time MPPT. The algorithm which introducing reasonable clonal selection rate, clonal proliferation rate, mutation rate can effectively improve the convergence speed and avoid prematurity. The simulation model is established by using the equivalent circuit of photovoltaic cell in MATLAB/SIMULINK. The ICSA is implemented using m file under the MATLAB environment. Experimental results show that the proposed algorithm has a remarkable quality of the global convergence reliability and convergence velocity. This algorithm can effectively track the maximum power point in real-time in case of variable temperature and light intensity.

Key words: Photovoltaic cells, maximum power point tracking, clonal selection algorithm, simulation

INTRODUCTION

At present, the efficiency of photovoltaic power generation system is relatively low in China. Improving the solar photoelectric conversion efficiency and reducing the power generation system unit power cost is one of the emphasis and difficulty of solar photovoltaic power generation industrialization (De Soto *et al*., 2006; Enrique *et al*., 2007). The output characteristics of solar cell are strong nonlinear and time-varying. In order to realize the Maximum Power Point Tracking (MPPT), the real-time detection and control for the PV array output power is adopted by changing its load impedance. The literatures (Salas *et al*., 2006; Tafticht *et al*., 2008) introduced a variety of MPPT methods, mainly involved the disturbance observation method, a constant voltage method, fuzzy control method. The literature (Yu *et al*., 2004) proposing a new algorithm is the constant voltage method combination with incremental conductance method based on existing control algorithm and carries on the simulation analysis with PSIM software. In the practical application, these control algorithms has such defects as tracking low efficiency, slow response, low precision.

Clonal selection algorithm is developed on the basis of the clonal selection principle of biological immune system (De Castro and Zuben, 2002; Mo and Zuo, 2009). The population is formed by continuous vegetative propagation (cloning, mutation). The diversity of the group is improved through the antibody clone variability and the global population increases the immunity and gets evolution. Because clonal selection operator has the memory function, it makes the algorithm itself convergence to the optimal solution with one hundred percent probability (Xiao *et al*., 2007). Through reasonable choice the parameters of the algorithm, the improved clonal selection algorithm has been applied to the maximum power point tracking control of photovoltaic power generation in this study, the experimental results show that the algorithm has good static and dynamic performances.

SIMULATION MODEL

The solar cell model was established by taking Silicon photovoltaic cells as an example. Solar battery current density can be expressed by the following formula (Zhao and Liu, 2005):

$$J = J_{ph} - J_i = J_{ph} - J_0\left(e^{qU/kT} - 1\right) \quad (1)$$

where, U and J denote the solar battery terminal voltage and load current density, respectively, q denotes the electron charge constants (1.6×10^{-19} C).

In order to meet the engineering precision requirement, the current characteristic equation of photovoltaic cells also needs to increase the parameters

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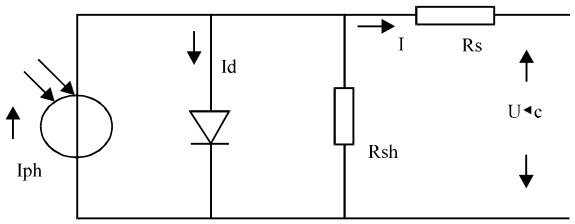

Fig. 1: Equivalent circuit model of PV array'

R_s and R_{sh}. The actual equivalent circuit is shown in Fig. 1. The equivalent current source constant I_{ph} and a forward diode are in parallel. The relationship between current and voltage of photovoltaic cells can derived from circuitous philosophy, as shown Eq. 2:

$$I = I_{ph} - I_o\left\{\exp\left[\frac{q(U + IR_s)}{AKT}\right] - 1\right\} - \frac{U + IR_s}{R_{sh}} \quad (2)$$

In the Eq. 2, U is the battery terminal voltage; K is the Boltzmann constant (1.38×10^{-23} J/K); T is the battery temperature; R_s is the series resistance; R_{sh} is the shunt resistor; I_{ph} is the photo-generated current; I_o is reverse saturation current; I is the battery output current; A is the diode emission coefficient.

Based on the relevant parameters and the above formulas, the simulation model of photovoltaic cells is established in MATLAB/SIMULINK. The MPPT simulation experiment based on ICSA is analyzed in the next section of MATLAB simulation analysis in this study.

ALGORITHM IMPLEMENTATIONS

Principle of improved algorithm: Clonal selection algorithm is a kind of immune algorithm which is based on the clonal selection theory. Castro first proposed the clonal selection algorithm CLONALG used for optimization and learning. The principle of clonal selection algorithm: When the lymphocyte achieves the ability of recognition antigen, B cells are activated to produce replication value-added B cell clones. The mutation clonal cell produces the antibodies and memory cells for specific antigen. Clonal selection theory describes the basic characteristics of the specific immunity which shows only the immune cells are able to recognize the antigen and proliferation. Clonal selection corresponds to affinity maturation process. Under the action of clonal selection mechanism, the antibodies of lower antigen affinity experience the process of proliferation, replication and mutation and their affinity maturation gradually improves and matures. The process of affinity maturation is essentially a Darwin type of selection and mutation process. The response type of Clonal selection can be regarded as Darwinian evolution of a microscopic world.

Algorithm implementation steps: Ignore the humidity, shading and other external factors and only considering the effects of temperature and light intensity on the system. The goal of the system is: when a new batch of antigen (T, S) intrudes the photovoltaic system, it can find the most appropriate antibody by the fastest respond rate; this made the Photovoltaic cells' output power reaching its maximum value. The specific flow chart of the algorithm is in Fig. 2.

The implement steps are as follow:

Step 1: **Immune recognition:** As we know immune recognition is the core function of the immune system. The essence of recognition is to make a distinction between "itself" and "not-self". "Itself" stands for the organization of the organism, "not-self" stands for the exotic harmful pathogens or the lesions in the organism. Taking the temperature T and light intensity S as the Antigen (Ag) and regarding the output voltage (VO) of Photovoltaic cells as the Antibody (Ab), this is the translation of the immune system

Step 2: **Obtaining vaccine pool:** The Vaccination can get the good initial population which has been verified. Because the external temperature and light intensity are time-varying, the immune response in certain time interval can keep the system working normally. According to the data coming from the immune response, the system produces the Antibody to get the vaccine pool and completes the extraction of the memory cells

Step 3: **Affinity detection between antigen and vaccine:** Select the m best individuals as the part of the initialization population from vaccine pool and the rest antibody is randomly generated in allowable range. Then the initialization population X will be created and expand to expected scale in group

Step 4: **Calculation of antibody concentration:** Estimate the each antibody concentration in the population and arrange by descending order according to the concentration

Step 5: **Colonal selection:** Selecting the n greater concentration cells as activated cell population

Step 6: **Clone expansion:** Cloning the n activated cells and generating temporary clone population C, where the cloning scale is a monotonically increasing function of antigen affinity

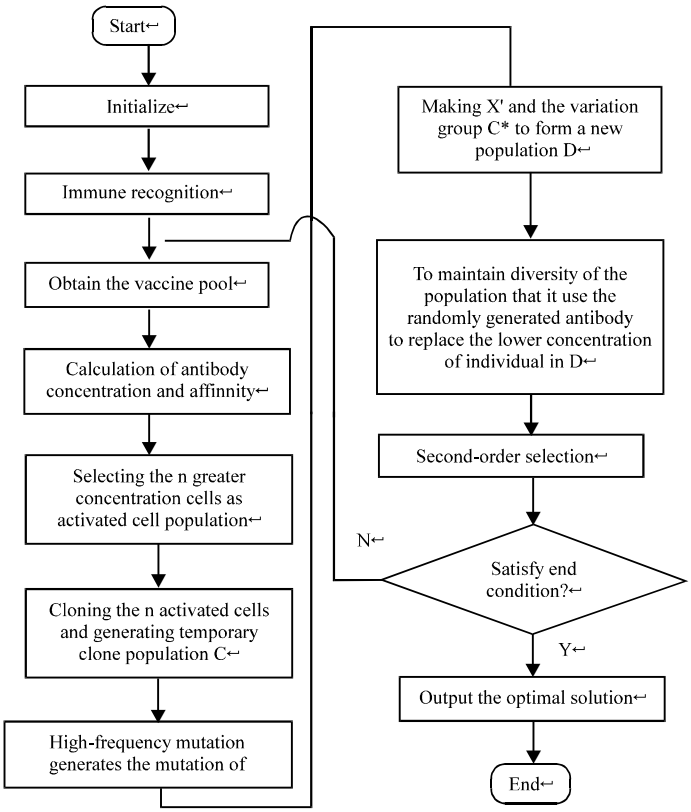

Fig. 2: ICSA optimization flow chart

Step 7: **High-frequency mutation:** Submitting the clone groups to high-frequency mutation pattern and generating the mutation population C*

Step 8: **Immune supplement:** Making X' and the mutation group C* to form a new population D and X' is a subset or universal set of X. In order to keeping the population diversity, use the antibody of generating randomly to replace the lower concentration of individual in D

Step 9: **Second-time selection:** The individual concentration is checked again in the updated population. Judging whether the terminal condition is satisfied or not. If the terminal condition is satisfied, the problem is resolved, namely the maximum power point has found, otherwise, return to step 2 continuing

Step 5-8 is activation cell clonal selection process. The selection principle of terminal condition in step 9 is that the PV system can output the maximum power. So, we can compare the result of second-time selection with two adjacent power value according to step 8. If the current power value is greater than the last power value, then return step 2, or save the number of iterations. When iterations is more than the set threshold, it should take termination of the algorithm running.

Parameters selection and control: Parameters selection will have a certain impact on its performance during the running of algorithm. Reasonable selection of control parameters will make the algorithm search for the best solution in optimal trajectories. Main parameters of the algorithm in this study include: population size of antibodies P, population size of activated cells Ps, expansion of cell clones G, mutation rate P_m and immune supplement number P_r, selection of affinity A, calculation of antibody concentration F and selection of clone operator and clone scale etc.

Affinity and antibody concentration calculation: The evaluation of antibody is usually denoted by affinity in the immune calculation. It refers to the bond strength or the matching degree or the similar degree between antibody and antigen. In this study, antibody affinity is defined as:

$$A = \frac{K_T}{|e_T| + \eta} + \frac{K_S}{|e_S| + \eta} \quad (3)$$

where, e_T is e_T = T-T', e_S is e_S = S-S', T and S are current immune response antigens, T' and S' are the antigens which corresponding antibody in the vaccine pool; K_T and K_S are constant value which is used to increase the error sensitivity; η is a small positive constant to avoid the emergence of zero denominator.

The concentration of the antibody is used to represent the size of an antibody and the very similar antibody. In this study, the concentration of antibody is defined as:

$$F_i = P_i \Big/ \sum_{k=1}^{P} P_k \quad (4)$$

where, P_i is the output power of the i-th antibody, P is the number of antibody population size.

Mutation operator and clone size selection: Mutation is a key operation which makes the algorithm evolving and increasing the search capability during the algorithm running. Selection of mutation operator: mutation rate is Pm, the Variable Xi mutation can be expressed as $X'_i = X_i(1+Pm.Rand())$.

Cloning makes the selected activation cell to copy a certain amount, to expand the search space, to provide conditions for seek optimal solution. Select the clone size:

$$N_c = \sum_{i=1}^{n} \text{round}\left(\frac{\beta \times N_i}{i}\right) \; i = 1, 2... \quad (5)$$

where, $\beta \epsilon (0, 1)$ is a clone constant, deciding clone size and this study takes 1; Ni is the population size that will be cloned; i is the serial number; N_c represents the total number of clone size while the number of each cloning is the clone amplified multiples G mentioned below.

Other parameters selection: Other parameters specific configuration of clonal selection algorithm in the simulation are as follow: the population size M = 10, the number of memory unit P_S = 3, the size of activation cell, the scale of cloning temporary population G is 10, 5, 5, respectively; the mutation rate P_m is 0.01, immune complement number P_r = 3.

MATLAB SIMULATION ANALYSIS

The improved clonal immune selection algorithm was written in m file of MATLAB for photovoltaic maximum power point tracking control. Simulation platform is shown in Fig. 3. It has friendly man-machine interface which can realize the fast simulation.

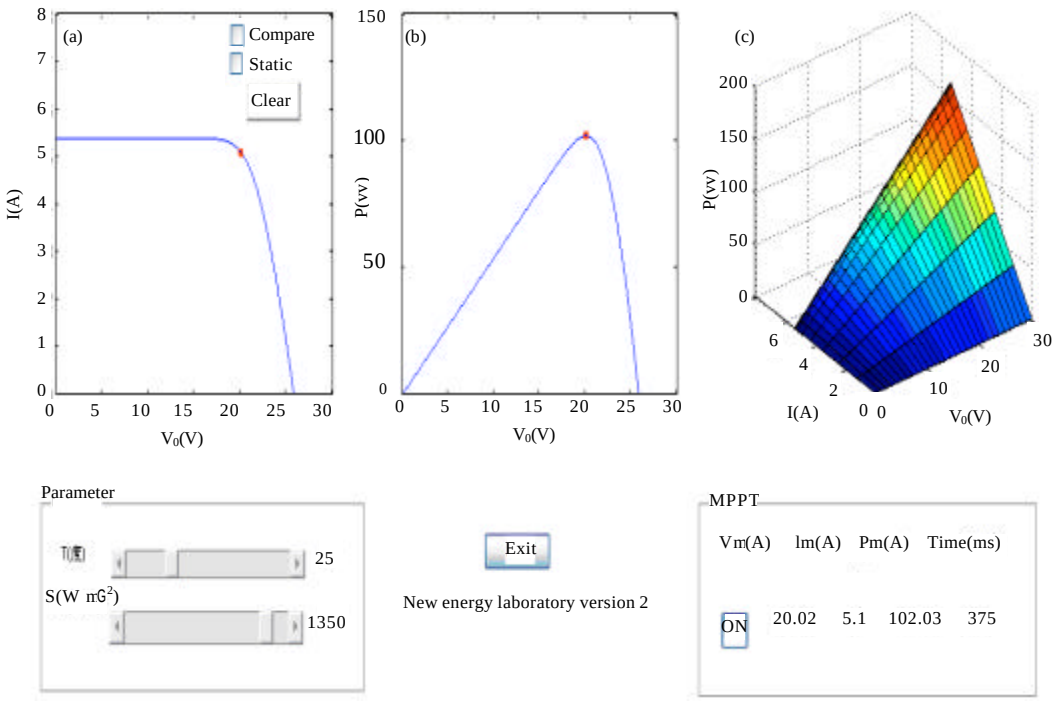

Fig. 3(a-c): Simulation graphical interface

Algorithm validity of verification: The performance of ICSA algorithm can be validated by simulation characteristic curves of PV system. These were the photovoltaic simulation characteristic curves under the different light intensity and temperature conditions. Among them, Fig. 4 is the U-I and U-P characteristic curves in the case of 1 Kw m^{-2}, the temperature increasing gradually from 0-100°. Figure 5 is the U-I and U-P characteristic curves in the case of 25° and the light intensity increasing gradually from 150-1500 W m^{-2}. Where, "*" is the maximum power point.

As can be seen from the Fig. 4, the working current slightly increases but the working voltage and output power decreases intensely when the light intensity is 1 Kw m^{-2} and the temperature gradually increasing. Figure 5 shows that the system working current and

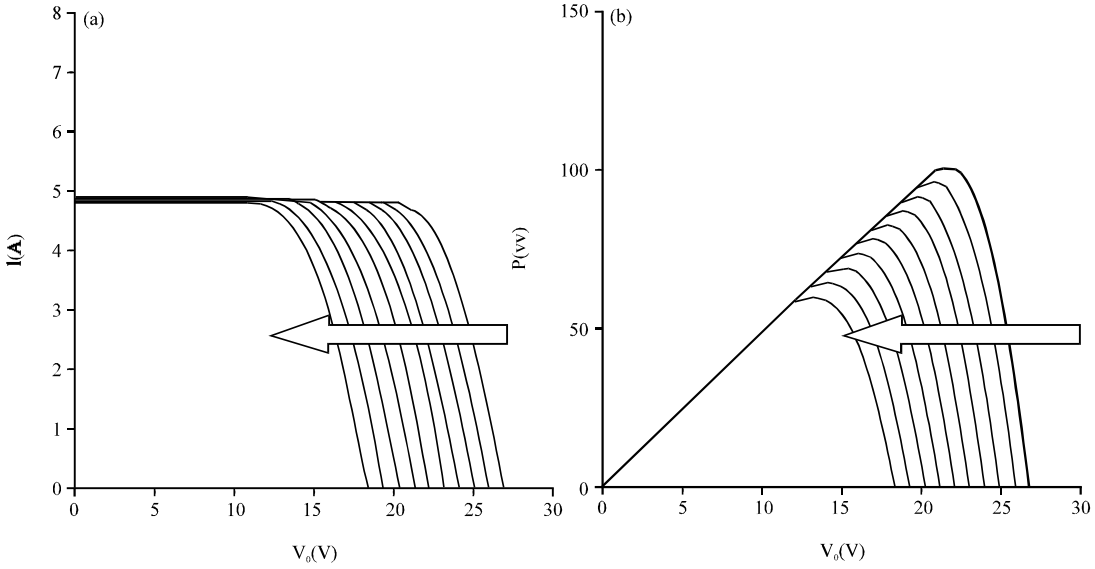

Fig. 4(a-b): Simulation results of temperature gradually enhanced, S = 1 kW m^{-2}

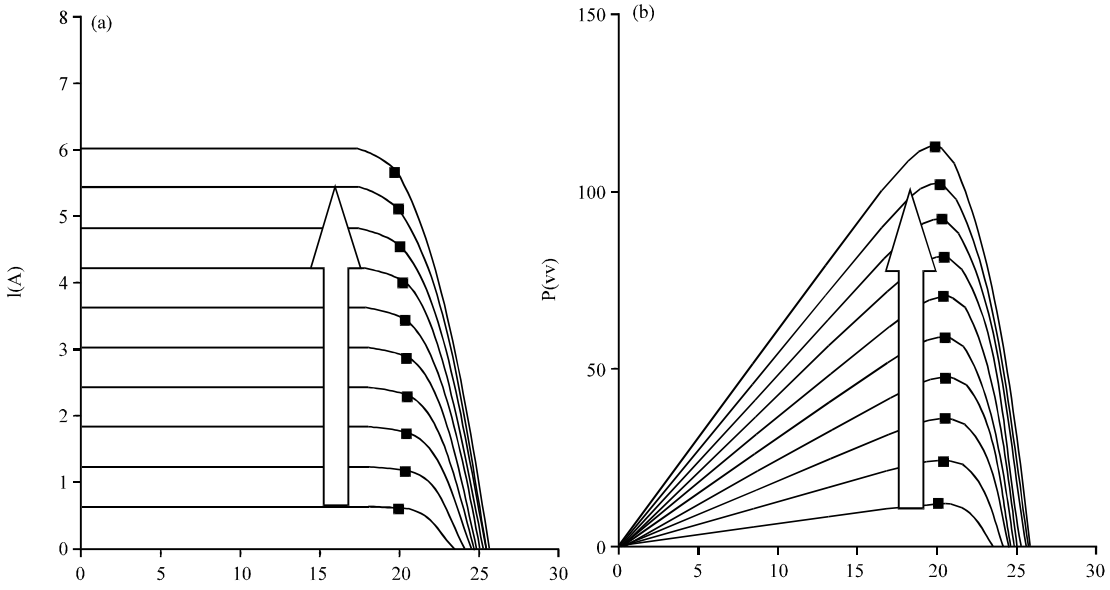

Fig. 5(a-b): Simulation results of light intensity gradually enhanced, T = 25?

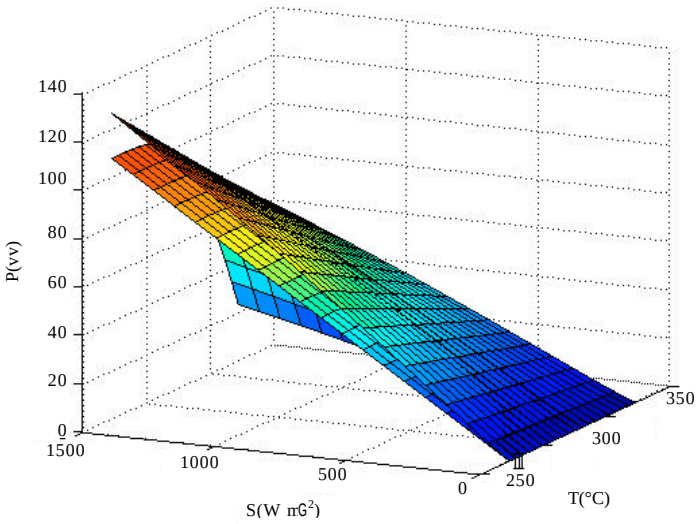

Fig. 6: Power output comparison with different algorithm

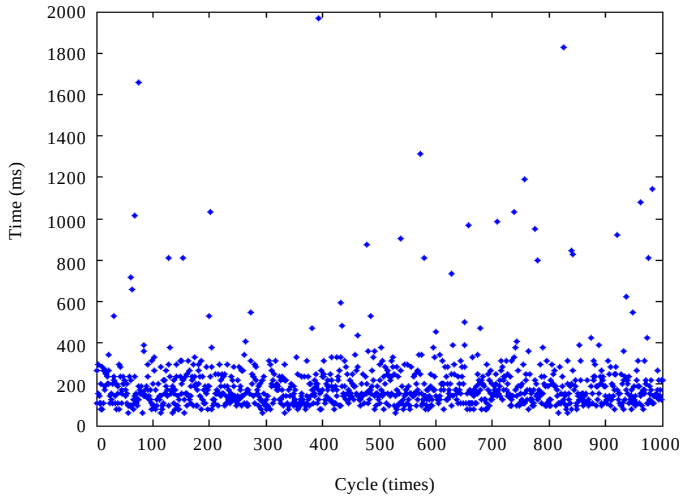

Fig. 7: Real-time performance of 1000 times experiment

output power significantly increasing when the intensity gradually increasing and the temperature at 25°. The conclusions obtained from Figure 4 are same with the results of Clonal selection optimization algorithm. When the temperature is 25° and light intensity is 1500 W m^{-2}, the Fig. 5 shows that the working current is about 6.34A, the working voltage about 19.45 V, the maximum output power about 124.20 W which agreeing with the P-V characteristic curves. The results demonstrate the ICSA algorithm for MPPT is effective.

Under the conditions of temperature 25°, light intensity is 1500, 1200, 850 W m^{-2}, respectively, the output power is shown in Table 1. In Fig. 5, their out power is about 124.20, 91.54 and 74.02 W.

As shown in Fig. 6, Curved surface 1 is the simulation result of maximum power point tracking with ICAS algorithm; curved surface 2 is normal algorithm. In the whole range of the working environment, it can be seen from the chart that the curved surface 1 is always located on the surface 2 that is to say, the algorithm which is proposed in this study has more obvious advantages for maximum power point tracking than other traditional algorithm.

Real-time performances analysis: In order to verify real-time performance of improved clonal immune selection algorithm, we random selected 1000 groups of temperature and light intensity to implement maximum power point tracking and recorded the track of time, as shown in Fig. 7. It shows that the track time mainly fluctuates between 50-260 m sec. It met the system requirements. The immune response time of few individual

Table 1: Output power at T = 25°, S = 1500, 1200, 850 W m^{-2}
Mean value of 10 times (25°)

S (W m^{-2})	Vm (V)	Im (A)	Pm (W)	Time (m sec)
850	22.84	3.24	74.02	125.12
1200	20.18	4.54	91.54	232.50
1500	19.45	6.34	123.23	214.38

was long in Figure 7 but it was consistent with the requirements of the law of statistics. The average response time remained a good level of about 230 m sec.

CONCLUSION

This study presents an effective Improved Clonal Selection Algorithm (ICSA) to implement maximum power point tracking control scheme for PV. The algorithm which introducing reasonable clonal selection rate, clonal proliferation rate, mutation rate can effectively improve the convergence speed and avoid prematurity. The simulation results show that: When temperature or light intensity conditions change, the system can quickly tracking the maximum output power. The algorithm has strong robustness, real-time and effectiveness characteristics.

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