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An improved PO and immune MPPT method for PV generating system under partially shaded conditions

Abstract*. The maximum power point tracking (MPPT) for photovoltaic (PV) generating system study on the tracking method at partial shading is very important to improve the output efficiency of costly PV, the objective is to improve the respond speed and extract maximum power under different weather and partial shading conditions. The output characteristics of PV system get more complex than same irradiation because of the continually changing of atmospheric conditions and frequently partially shaded in actual woke state. The nonlinear and multiple local peaks characteristics of PV system at partial shading are considered by using perturbation and observation (PO) method to gain the actual global peak of PV system, and the conventional PO method is improved by using the perturb Pulse-Width Modulation (PWM) method at ideal irradiation and partial shading, and then the artificial immune theory is used to accelerate the response speed and robustness. The proposed improved PO and immune method has an excellent dynamic performance and small oscillation as compared to the traditional PO method under partially shaded conditions.*

Streszczenie. *W artykule opisano algorytm śledzenia maksymalnego punktu pracy (MPPT) dla system paneli fotowoltaicznych, w warunkach częściowego zacienienia. W celu wyznaczenia punktu globalnego MPPT, zastosowano metodę perturbacji i obserwacji (PO). Metoda PO została ulepszona poprzez zastosowanie zmodyfikowanej modulacji PWM przy braku nasłonecznienia i częściowym zacienieniu. W celu zwiększenia dynamiki i odporności algorytmu wykorzystano teorię sztucznej odporności. Proponowana metoda gwarantuje bardzo dobrą efektywność.* ***(Ulepszona metoda PW oraz odporny algorytm MPPT dla systemu paneli fotowoltaicznych w warunkach częściowego zacienienia).***

Keywords: Photovoltaic; Maximum Power Point Tracking; Partially Shaded; Artificial Immune.
Słowa kluczowe: fotowoltaika, MPPT, częściowe zacienienie, sztuczna odporność;

Introduction

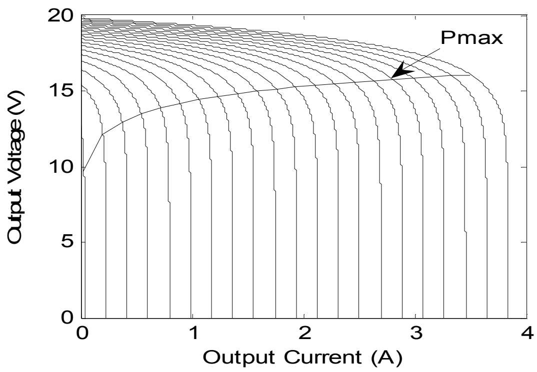
The production of electric power need abundant fossil resource by means of billions of tons oil and gas and coal are consumed in order to supply enough power for the development of modern industrial society. The amount of polluted gases and greenhouse gases emission is more than billions of tons per year. At present, more and more countries regarded the application of renewable and innovative energy in order to overcome the pollution and energy shortage in foresee future and realize the sustainable development of society and country. The demand of clean and renewable energy has increased consistently in past ten years, and the developmental velocity is rapid in the whole world, such as wind energy, photovoltaic (PV) and tidal energy etc. Among a variety of renewable energy sources available, photovoltaic appears to be a major contender on account of its abundance, easy availability, and pollution-free operation [1]. The total installed amount of PV in the whole world is more than 8.6GW till 2010, and billions of dollars have been invested in PV industry, and more and more electric energy is produced by using PV. Studies on PV generate systems are actively being promoted in order to mitigate environmental issues such as the green house effect and air pollution [2-3]. However, there are various issues exist in the actual work course of PV, such as maximum power point tracking (MPPT), partially shaded, grid integration and power quality and so on. Furthermore, the PV generating system requires expensive initial investments. For example, the PV price is about 4 dollars per watt at present and the electric power price per kilowatt-hour is about 0.8 dollar, the costly price can not be accepted by the ordinary people. In order to decrease the cost of PV generating system, it is important to have an efficient MPPT algorithm in order to extract as much energy as possible from a PV system.

Many MPPT algorithms and control methods of PV generating system have been described in the literature [2-4], i.e., the linearity method is a novel method in order to track the maximum power point which is proposed in literature [2-3], the proportionality factor of the prediction line is automatically corrected by using the hill-climbing method when the panel temperature of the solar arrays is changed. The incremental conductance (IC) method is proposed in the literature [4], which is based on the mathematical computation method to calculate the actual maximum power point (MPP) by using the voltage signals at that time, and IC method does not require any current sensing devices. The PO method is well known as the hill-climbing method which has been widely used due to its simple feedback structure and fewer measured parameters. The fuzzy methods are described in the literature [5] that focuses on the nonlinear characteristics of solar cell, which does need the accurate data of PV system and weather. Although, several MPPT methods have been proposed in above-mentioned literatures, but the power generate efficiency is relative low because of the amount of electric power generated by PV generating system is always changing with weather conditions. Particularly, the irradiation of PV is not always same at different weather due to the PV can be partially shaded by cloud and building and tree etc. The output characteristic of PV is very complicated to compare with the output at same irradiation, and there are many MPP which is called the local MPP. Certainly, there are only one actual MPP which is called the global MPP at the special weather. The output efficiency by using above MPPT control method is very low, and the essential reason is that the conventional method can judge the actual MPP among several local MPP. Many literatures are described to acquire the actual global MPP under partially shaded conditions. The output characteristic of PV under partially shaded conditions is described in literature [6], while literature [7] introduce a complicated MPPT control method to track MPP under partially shaded conditions, but the course is very difficult. Artificial neural network-polar coordinated fuzzy control method is presented to acquire MPP at partial shading in literature [8]. However, it is well known that the partially shaded changing is rapid with the movement of cloud and the shadow of tree and building which induce that the output efficiency fall by using above method. An easy and rapid MPPT method is necessary to acquire enough electric from PV system under partially shaded conditions. Furthermore, the output characteristics of PV system have the oscillation by using DC/DC circuit and PO method, the big oscillation affect the quality of electric power and the stability of power supply. So the oscillation should be eliminated to improve the power quality. The immune principle is proposed to improve the output characters of PV generating system in this paper, which have excellent dynamics performance and high response speed and robust at different work state [9-10].

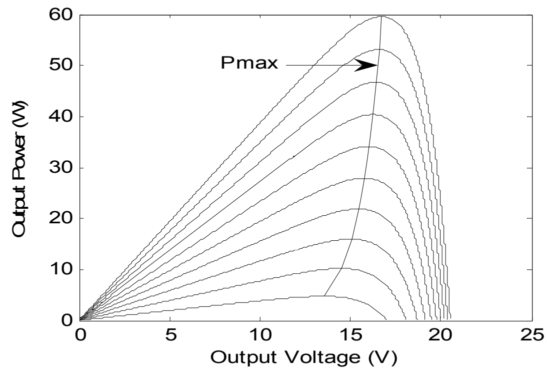
This paper proposes a novel method that is capable of tracking the MPP of PV generating system under partially shaded conditions. Based on an extensive study of same irradiation and partially shaded PV arrays, Section II describe certain critical output characteristic on the V–I and P–V curves of same irradiation and partially shaded arrays. Section III describes the proposed PO control method to track the MPPT, and the improved PO method is used to achieve a quick response for tracking the MPP. While section IV described the artificial immune principle and the block diagram of combined PO and immune control module. Sections V present the results of proposed improved PO and immune MPPT control method. The main conclusions are summarized in Section VI.

Principle analyzing and modeling of PV

The instantaneous output characteristic of PV depends on the operating temperature and irradiance with the changing of external weather conditions. And a variety of internal parameters affect the output characteristic of PV, i.e. Rs, Rsh, n, and Io. Furthermore, the PV output is affected by dynamic variation of load. Above factors induce that the actual MPPT course is very difficultly. Here, Rs is the intrinsic series resistance of the solar cell. Normally, the value of Rs is very small (in milliohm). Rsh is the equivalent shunt resistance of the solar array. Io is the reverse saturation current (in amperes), n is the diode factor,



(a)



(b)

Fig.1. Output characteristic of PV at uniform irradiation

Fig.1 (a) shows the V-I characteristics and $P\max$ curve of PV when the irradiation is changed from $50W/m^2$ to $1KW/m^2$ at temperature 25^oC. Fig. 1 (b) shows P−V characteristics and $P\max$ curve when the irradiation is changed from $100W/m^2$ to $1KW/m^2$ at temperature 45^oC. As shown in Fig.1, the only MPP exists in same irradiation, and the work conditions of PV generating system is a ideal conditions, and the MPPT method is easy to track and gain MPP at the time by using conventional PO or IC or Fuzzy method.

Fig.2 shows that the output P-V characteristic of PV under partially shaded conditions, which is different to compare with the ideal situation. For example, the output power has the only MPP under the uniform irradiation conditions. Certainly, the optimal output voltage and output current is unique at this moment. At the same time, PV array has steady internal parameters at same irradiation. As shown in Fig.2, the MPP and the optimal output voltage and optimal current are not unique at partial shading. There are two MPP as can be seen from Fig.2, and these MPP are called local MPP. And, there are only MPP is the actual MPP of PV system at the time, and the actual MPP is called global MPP. And the optimal output voltage and current is unique according with the unique actual MPP. How to find the unique global MPP from some local MPP is the essential question during MPPT course at partial shading.

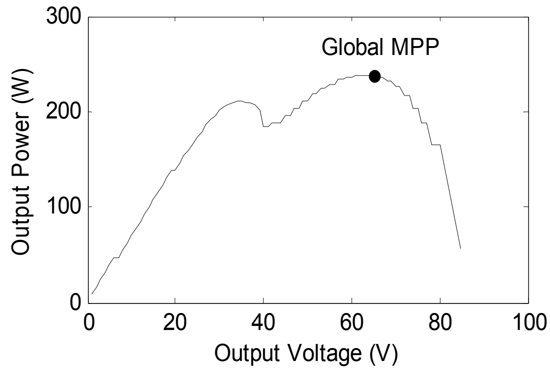


Fig.2. Output characteristic of PV at partial shading

Proposed MPPT Control Method

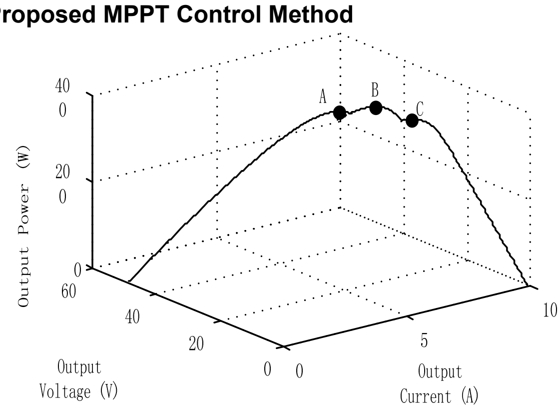


Fig.3. P-I-V output characteristic of PV at partial shading

A DC/DC circuit is necessary to buck or boost the output voltage, and Boost circuit is used to acquire the MPP in this paper. Certainly, the conventional PO method has been described in many literatures which can track the MPP at ideal weather and no partial shading. The elementary principle is that the PWM is changed in fixed-step or vary-step to increase the output power. A novel improved PO MPPT method is described in this section, firstly, the conventional PO method is used to gain a MPP, and the MPP should be judged whether or not the global MPP. For example, the MPP is A point by using PO method as shown in Fig.3 at the time, then in order to estimated A point whether or not the global MPP, the output PWM of A point by using PO method should add a perturb, and the perturbation range is $\pm$30% of PWM_A due to the local MPP is adjacent each other in a small scope. The perturbation step is 0.5% of PWM_A. When PWM changes from 0.7 times of PWM_A to 1.3 times of PWM_A, and there does not exist a larger power point than the A point, in that way the A point is the global MPP and actual MPP at the time, and the optimal PWM_A should be kept. Or else, the larger point is regarded as the new MPP, and the PWM is adjusted to the new PWM', then the new perturbation step is defined as 0.5% of PWM' and the perturbation range is defined as ±30% of PWM', and the perturbation course is continued until the actual global MPP is gained, and the PWM perturbation is stopped, and the optimal PWM is saved. When shading conditions changing cause a rapid output power changing, the program is recalled. The MPPT of PV generating system under partially shaded conditions is easy to achieve by using the proposed improved PO method.

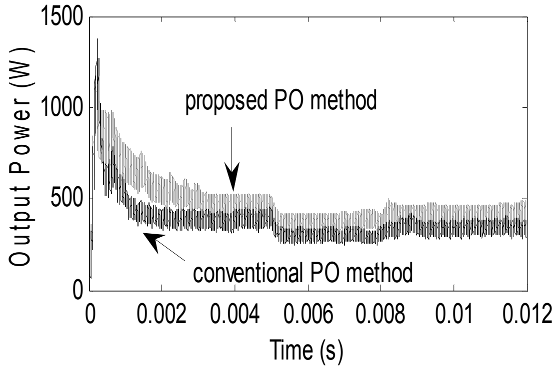


Fig.4. Output characteristic curves at partial shading

As shown in Fig.4, the proposed method have better output characteristic, and the output efficiency and sensitivity and response speed of improved method are higher than the conventional method. However, the output power oscillation does not be eliminated by using proposed PO method. It is well known that big voltage oscillation decreases the quality and stability of electric power, which can induce the damage of domestic appliance and reject of industrial product. So the voltage oscillation must be eliminated or reduced. The open voltage and short circuit of PV generating system in the paper are 20V and 35A, respectively. The maximum output power of PV system is about 500W. The load is resistance.

Proposed Immune PO method

Death of biological population would be inevitable without a strongly biological immune system. The immune system would response when the foreign microbes or antigen invade organism body in order to reproduce and survive under evil nature conditions. The T-cell (is called the self identification) and B cells (is called the non-self identification) are used in immune feedback response principle (IFRP), which are combined with other cells to eliminate invaded antigen. Billions of antibodies is generated to fastest kill invaded antigen, it is called positive feedback response. But the overfull antibodies may harm the self cells, certainly, the concentration of antibodies must be strictly controlled, which is called the negative feedback. Each B cell can kill similar non-self cells or antigen because there is a similar sign between antibody and invaded antigen. Normally, T cells is divided into three categories: T helper cells (T_H), killer T cells (T_k) and suppressor T cells (Ts). T_H cells can activate B cells, T_k cells can kill invaders antigen, Ts cells can restrain the excessive reproductions of T_H and T_k cells, and prevent the injury of self-cells.

The concentration of B-cell is suppressed or activated by the interaction between Ts and T_H. The connection between B cells and T cells can be represented as (1), which described the kth B-cell concentration. The kth T_H-cell and Ts-cell can be expressed by using (2), and ε is the kth antibody concentration, and $f(\bullet)$ is a non-linear function associated with the concentration of B-cell. K_1 is activated factor of T_H, and K_2 is the suppressed factor of Ts, and d is the immune delay. So the kth B-cell concentration can be derived as (5).

(1) $$B(k) = T_h(k) - Ts(k)$$

(2) $$\begin{cases} T_h(k) = K_1\varepsilon(k) \\ Ts(k) = K_2 f(\Delta B(k-d))\varepsilon(k) \end{cases}$$

(3) $$\Delta B(k-d) = B(k-d) - B(k-d-1)$$

(4) $$f(\bullet) = f[1-\exp(\Delta B(k-d))^2/\alpha$$

(5) $$B(k) = K_1[1 - K_2/K_1 \cdot f(\bullet)]\varepsilon(k)$$

(6) $$U(k) = K_1[1 - \lambda \cdot K_2/K_1 \cdot f(\bullet)]\varepsilon(k)$$

The robust characteristic of IFRP can be used to improve the anti-jamming capability and response speed of nonlinear system, which has been described in literature [9-10]. Normally, the kth concentration of antigen or antibody may correspond to kth sample time of control system. And the kth B-cell concentration corresponds with the sample output $U(k)$ of control system. The kth antibody concentration $\varepsilon(k)$ corresponds with the kth sample error between the given value and output value. So the (5) is represented as (6). Here λ shows the different immune stage, when $\lambda=-1$, which express that the immune response located in the immune initial stage of IRFP and the antigen concentration is high, which corresponds to the initial stage of control system, the maximum deviation and error of given value and output value are big, and B cells are activated by T_H cells. When $\lambda=0$, which express that the immune response located in the immune end stage, and the control system is steady and the maximum deviation and error are about null, B cells are suppressed by Ts cells. Or else, the output curve of control system is in oscillation and it shows that the immune response is located in the immune mid-late stage, and B cells are slightly activated by T_H cells, and the maximum deviation is more than 3%-5% of given value, and error is not null, and $\lambda=1$ at this time.

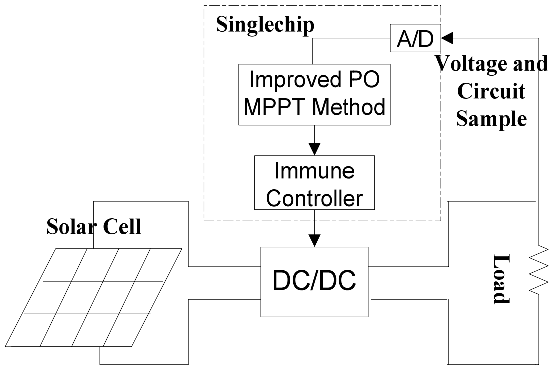


Fig.5. Control structure of the proposed method

The control structure of the novel improved PO and immune MPPT control method for PV generating system is shown in Fig5. The output of improved PO MPPT method is used in the input of immune controller, and then the output controls the duty cycle of PWM. The output of drive chip is used to control the switch of MOSFET of DC/DC circuit which corresponds with the PWM of single chip. Firstly, the IFRP is combined with conventional PO method in order to eliminate the oscillation during MPPT course. As shown in

Fig.6 (a), the output curve of proposed conventional PO and immune method (PCPOI) represented as black curve, and the PCPOI method decreases the output oscillation and improves the electric power quality at partial shading. Secondly, the IFRP is combined with the improved PO method, and the black output curve is shown in Fig.6 (b). The proposed improved PO and immune (PIPOI) MPPT method decreases the output power oscillation at partial shading which has an excellent response speed. Finally, the output curve of PIPOI method is compared with the output by using PCPOI method. The results show that the PIPOI has higher output efficiency and faster response speed, and the output liberation is small.

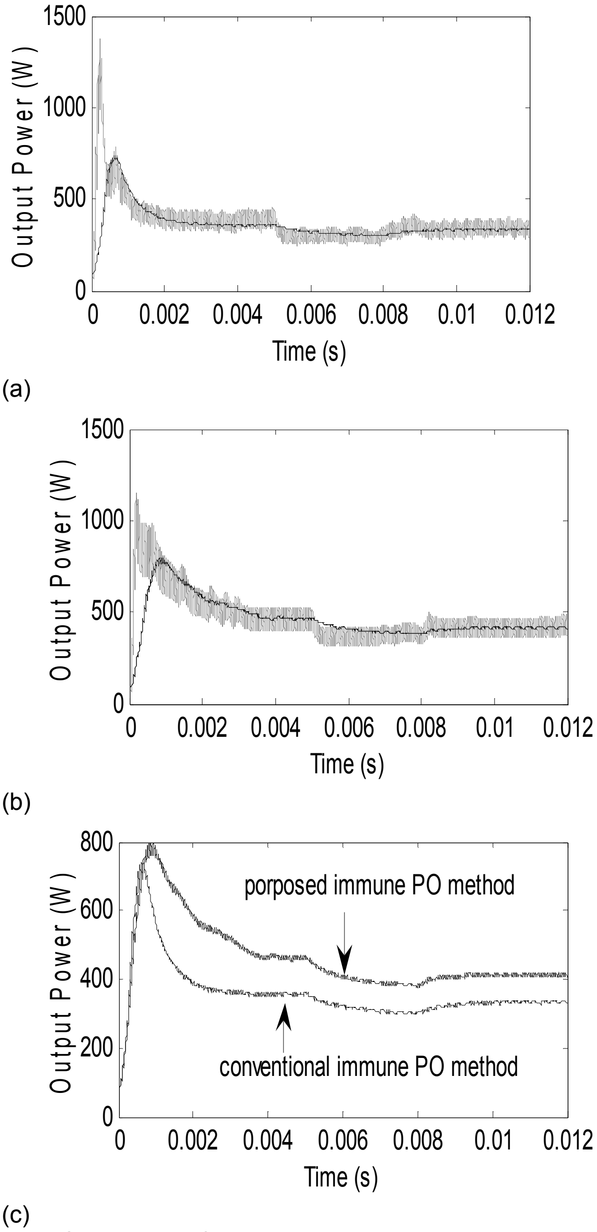


Fig.6. Output curve of PV generating system by using IFRP

Conclusion

A novel improved PO PWM MPPT method is proposed to acquire MPP of PV generating system at partial shading, which can improve the output efficiency under different partially shaded conditions. Then the immune feedback response principle is proposed to improve the output by using improved PO method. The results shows that the benefits of output character of PV generating system include high response speed and excellent dynamic output curve, and higher efficiency compare with conventional PO method.

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