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A Novel Intelligent Fuzzy Controller for MPPT in Grid-connected Photovoltaic Systems

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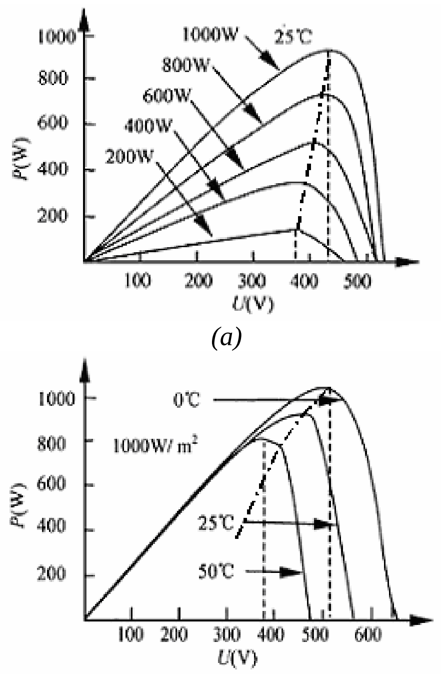
Abstract: - This paper presents a novel intelligent fuzzy logic controller for maximum power point tracking (MPPT) in grid-connected photovoltaic systems. The main advantages of this approach are that the intelligent fuzzy inference algorithm expressed with equation is simple to be implemented on MCU chip and needs no memory space to save fuzzy rules, and that optimizing factor in the fuzzy inference equation can adjust fuzzy rules on-line automatically to improve system control effect, which provides the system with an intelligent characteristic. The simulation and experiment results showed the attractive features of the presented intelligent fuzzy controller such as simplicity, fast response, good dynamic performance and that it can increase output power extracted from photovoltaic arrays. The availability and adjustability of this novel fuzzy controller is confirmed by experiments using PV arrays, boost converter and single phase grid-connected inverter.

Key-Words: - MPPT, fuzzy, PV systems, grid-connected

1 Introduction

With the development of industry and the decrease of oil and coal, more and more countries are paying great attention to green energy such as wind, solar energy and so on. Although solar energy is abundant and free of cost, the high initial investment on photovoltaic systems and non-linearity of photovoltaic array output characteristic counteract its wide commercialization. How to decrease the whole cost of photovoltaic systems and improve their output performance, which is the most important problem on spreading photovoltaic application.

The photovoltaic array has an optimum operating point to generate the maximum power with certain insolation level at certain temperature, showed as in Fig.1. To draw maximum power from photovoltaic array, maximum power point tracking controller is required in a stand-alone or grid-connected photovoltaic system. However, the output characteristic of photovoltaic cell is nonlinear, and the generating power varies with solar insolation level and cell temperature. Therefore, it is not easy to track the maximum power point of the photovoltaic cell quickly and effectively in the real application. To solve this problem, many tracking control strategies have been proposed such as perturb and observe, incremental conductance, parasitic capacitance, constant voltage, neural network and fuzzy logic control[1]. These strategies have some disadvantages such as high cost, difficult operating, complexity and non-stability. In recent years, some fuzzy controllers



(a)

(b)

Fig.1 Photovoltaic array characteristics
(a) Maximum power varies with different insolation at normal temperature(at 25℃)
(b)Maximum power varies with different cell temperature at the same insolation (1000W/m^2)

have been presented to track maximum power point, which require no mathematical model and is easy to real control system[2][3]. However, these fuzzy rules that were constructed based on some expert knowledge and the operation experiences are rude and not enough to provide satisfied control effect. The solar insolation level varies with time and season. It is hard to get quick and efficient tracking performance in transient conditions with traditional fuzzy logic controller. Therefore, the fuzzy rules should be adjusted on-line at realtime to conform to operation environment change.

There are some features for maximum power point tracking controller: simpleness, low cost, quick tracking performance, and smaller output power fluctuation.To meet these requirements, this paper presents a new intelligent fuzzy logic controller for maximum power point tracking in a grid-connected photovoltaic system. Different from the traditional fuzzy controller, its fuzzy inference algorithm can be expressed with a expression with an intelligent optimizing factor. Therefore its control output can be get from simple computing rather than looking up the fuzzy rules table. It is easy and quick to operate at real condition and need no memory space for fuzzy rules for this novel intelligent fuzzy controller. Moreover, optimizing factor can improve system control effect by adjusting parameters of fuzzy inference expression automatically on-line.

2 Intelligent Fuzzy Control Algorithm

The most important part of a fuzzy controller is the inference engine that decides fuzzy controllers' effectivity and availability. Generally, there are three traditional fuzzy logic control algorithms that are fuzzy inference based on rules, table and expressions respectively[4] [5]. And traditional fuzzy inference based on expressions is developed from that based on table. The domain of control output can be get directly from the domains of error E and error change EC according to the following equation(1):

$$U = INT[(E + EC)/2] \tag{1}$$

where the domains of error E and error change EC can be expressed with integers:

$$\{E\} = \{EC\} = \{-N, -N+1, \cdots, -1, 0, 1, \cdots, N\} \tag{2}$$

Traditional fuzzy logic control requires the expert knowledge of the process operation for fuzzy inference rules setting. Fuzzy logic control with fixed rules is inadequate in application where the operating conditions change in a wide range and the available expert knowledge is not reliable. The weights of both input variables in equation(1) are fixed on 0.5. To improve the control effectivity and adaptability, an optimizing factor α is introduced into equation(1) . Therefore an intelligent fuzzy logic control algorithm is proposed in this paper, expressed in equation(3).

$$\begin{cases} U = INT[\alpha E + (1-\alpha)EC] \\ \qquad \alpha \in [0,1] \end{cases} \tag{3}$$

Adjusting optimizing factor α will change the weights of error E and error change EC in determining the control output U .Compared with the traditionall fuzzy control algorithm, the proposed one has such merits as[4]:

(a) Simple calculating and easy control with PC.
(b) Swift output response and quick tracking.
(c) No need of memory space for fuzzy rules or table.
(d) High control precision and good adjustability.

3 MPPT Using Intelligent Fuzzy Controller

3.1 The System Scheme

In order to explain the feasibility of maximum power point tracking using the proposed intelligent fuzzy controller, the grid-connected photovoltaic system is constructed with boost $DC-DC$ and single phase $DC-AC$ as shown in Fig.2.

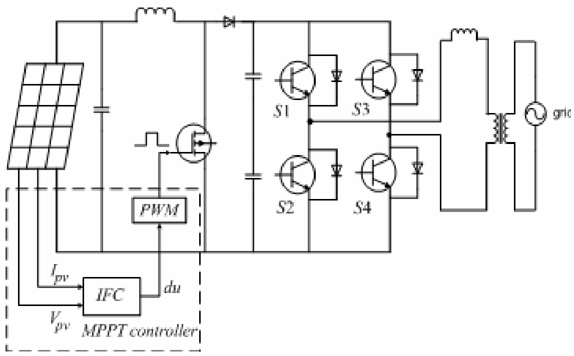


Fig.2 The frame of grid-connected PV system

The controller's output takes an action on PWM who generate pulse to control MOSFET switch. The maximum power point can be tracked by varying the duty factor u of MOSFET in the boost converter.

3.2 Maximum Power Point Tracking Using Intelligent Fuzzy Controller

To track and extract maximum power from the PV arrays for a given solar insolation level at some cell temperature, a novel intelligent fuzzy logic controller is presented based on the above proposed algorithm, as shown in Fig.3.

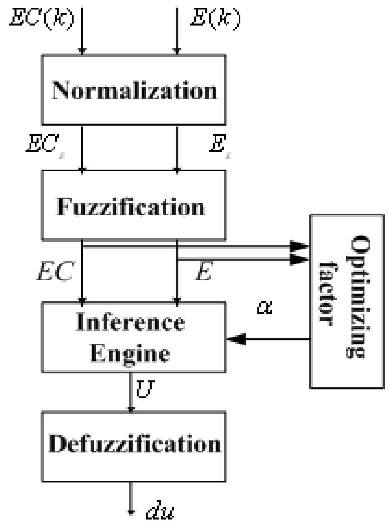


Fig.3 The frame of intelligent fuzzy logic controller

3.2.1 Fuzzification

The error E and error change EC can be calculated from the following equations(4) and (5):

$$E(k) = \frac{P_{ph}(k) - P_{ph}(k-1)}{i_{ph}(k) - i_{ph}(k-1)} \qquad (4)$$

$$EC(k) = E(k) - E(k-1) \qquad (5)$$

where $P_{ph}(k)$ and $i_{ph}(k)$ are the power and current of the PV array, respectively. Therefore, $E(k)$ is zero at the maximum power point of a PV array. To simplify the control operation, the values of error E and error change EC can be normalized with the following equation(6):

$$X_s = \begin{cases} -1, X < -X^* \\ X/X^*, |X| < X^* \\ 1, X > X^* \end{cases} \qquad (6)$$

where $X^* = X_{\max}$,so the domains of error E and error change EC will be $[-1,1]$. Then the membership functions expressed with triangular function can be shown in the Fig.4.

3.2.2 Intelligent Fuzzy Inference

The control output can be generated by simple calculating according to the equation (3), different from the traditional fuzzy logic controller, which usually by looking up the fuzzy rules table. Apparently, it can get the control output quickly and need no memory space for the fuzzy rules table. Moreover, this proposed inference algorithm can produce more abundant control info than others do. There would be a whole set of effective control rules for any value of optimizing factor α . One example is shown in Fig.5 with its control output surface.

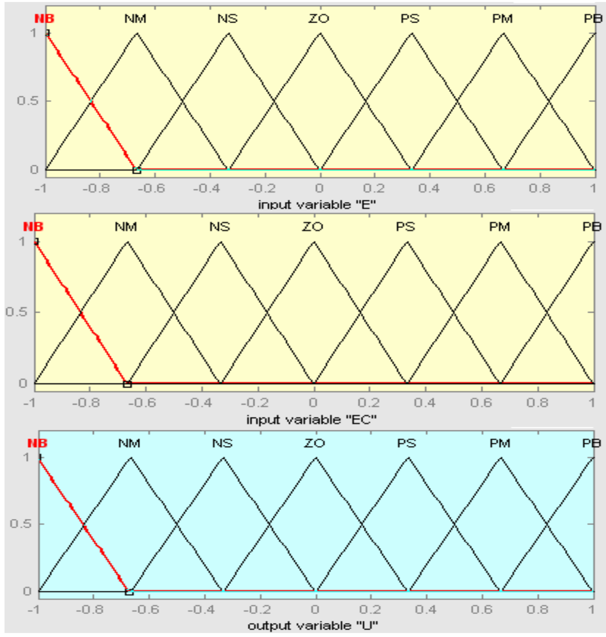


Fig.4 Fuzzy control membership function

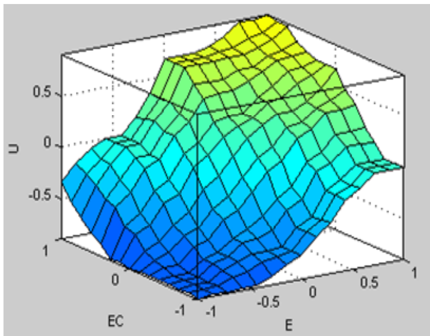


Fig.5 The control output surface for one example

3.2.3 Defuzzification

The output of this fuzzy controller is a fuzzy subset of control. To get a nonfuzzy value of control, a defuzzfication stage is necessary. Defuzzification for this system can be performed by height method. The nonfuzzy value of control output can be gained with the height method simply and quickly. The height defuzzification method can be done with the following equation(7):

$$du = \frac{\sum_{k=1}^{m} u^k \omega_k}{\sum_{k=1}^{m} \omega_k} \qquad (7)$$

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With the output of controller, pulse generated from PWM can switch MOSFET to change the duty factor u of the boost $DC-DC$. Then the PV array output voltage can be adjusted to track the maximum power point.

3.2.4 Optimizing the Fuzzy Control Rules On-line

One of the most important merits of the proposed controller is that it can optimize the fuzzy inference rules on-line according to the operation condition to improve the system performance. As we know, when the system is far away from the maximum power point(MPP), a swift adjusting would be expected. However, when the system operates in the vicinity of MPP, stabilizing output power and avoiding over-tuning would be more valuable. Therefore, the following equation(8) is presented to optimize the fuzzy rules on-line:

$$\alpha = \alpha_0 + (1-\alpha_0)\frac{|E|}{N} \qquad (8)$$

where $\alpha \in [\alpha_0, 1]$, α_0 can be set as 0.3 and N can be set as 3 here. When $|E| = |E|_{\max}$, then $\alpha = 1$, error E in equation (3) has the largest weight, and error can be eliminated in the quickest way. On the other hand, when $\alpha = \alpha_0$, α is the smallest value(0.3) and error change EC has the largest weight(0.7), which prevent the system from over-tuning and stabilize the output power. Here this controller represents an intelligent characteristic that can estimate and adjust the weights of error E and error change EC in the course of determining the control output.

4 Simulation and Experiment Results

This presented intelligent fuzzy logic controller can be simulated with MATLAB program[6]. The simulation results shown in Fig.6 are done with the following parameters:

Photovoltaic array peak power 50W, $V_{oc} = 20.5V$ and $I_{sc} = 3.05A$. All devices of boost converter and single phase inverter are assumed to be ideal.

The proposed intelligent fuzzy control algorithm is simple and has be implemented on the MCU chip of PIC16C5X. Experiments have been done using boost $DC-DC$, 500W single phase inverter and PV modules from Topsola. The main characteristics of a photovoltaic module are indicated below (1000W/m^{2}at 25℃):

Product type: TSM-50(734x651x40mm)
Open circuit voltage: 21.7V
Short circuit current: 3.4A
Maximum power voltage: 17.5V
Maximum power current: 3.05A
Peak power: 50W

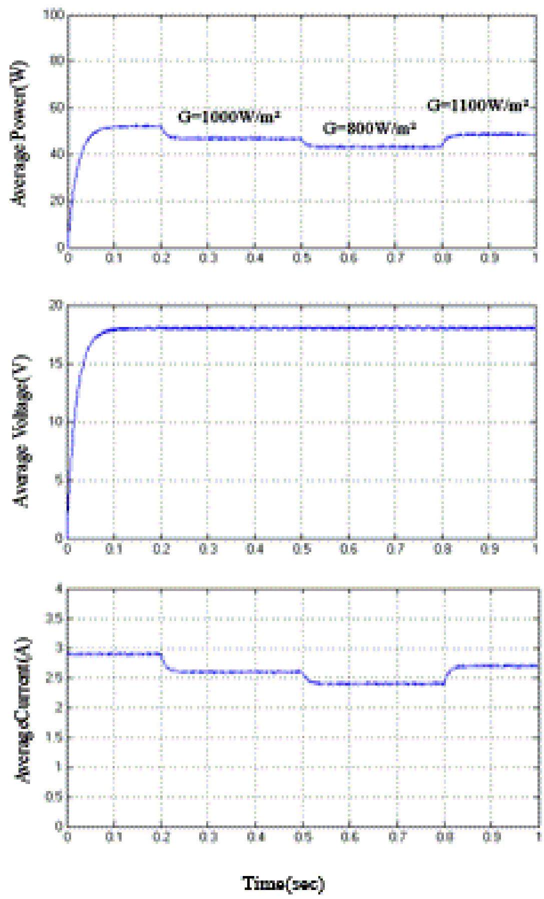

Fig.6 Simulation results depicting the change of Power, voltage and current of PV array vs time

Output power generated by the systems adopting the algorithms of intelligent fuzzy control, traditional fuzzy control and Perturb & Observe respectively is recorded at different times for a typical day in Oct. in Shanghai, China, shown in Fig.7.

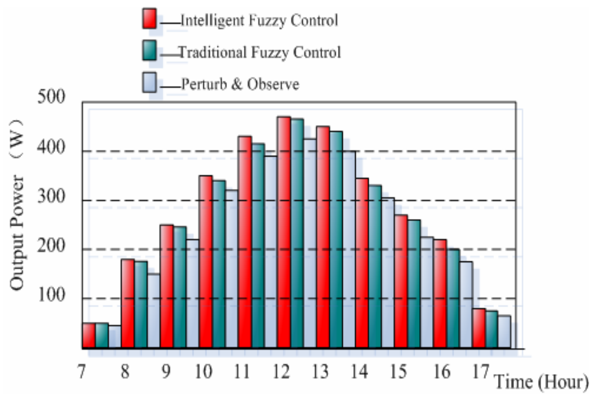

Fig.7 Output power generated by the systems adopting intelligent fuzzy controll, traditional fuzzy control and perturb & observe respectively for a typical day in Oct.

5 Conclusion

This paper has presented the intelligent fuzzy controller for maximum power point tracking in grid-connected photovoltaic system. The simulation shows that the proposed intelligent fuzzy control algorithm has the merits of simplicity, fast response, low over-tuning, high control precision, and easy implemention. In addition, the experiment results show that the PV system with this intelligent fuzzy controller has generated more power and held stable output, while its hardware cost is low. All these benefits will do good to the commercialization of photovoltaic system.

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