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A Novel MPPT Control of a Photovoltaic System using an FLC Algorithm

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Abstract

This paper proposes a novel maximum power point tracking (MPPT) system using a fuzzy logic control (FLC) algorithm for robust in-environment changing. The power available at the output of a photovoltaic (PV) cell continues to change with radiation and temperature because a solar cell exhibits nonlinear current-voltage characteristics. Therefore, the maximum power point (MPP) of PV cells varies with radiation and temperature. The MPPT methods are used in PV systems to make full utilization of the PV array output power, which depends on radiation and temperature. The conventional MPPT control methods such as constant voltage (CV), perturbation and observation (PO) and incremental conductance (IC) have been studied but these methods are problematic in that they fail to take into account the changing environment. The proposed FLC controller is based on the fuzzy control algorithm and facilitates robust control with the environmental changes. Also, the PV systems applied FLC controller is modeled by PSIM and the response characteristics of the FLC method according to environmental variations are analyzed through comparison with the performance of conventional methods. The validity of this controller is shown through response results.

Key Words : Photovoltaic, MPPT, FLC

1. Introduction

Recently, interest in alternative energy has been increasing due to the rise of oil prices forced by peak fossil fuels and environment pollution caused by the indiscriminate use of these fossil fuels. Compared to traditional energy sources, solar energy is limitless and does not generate any pollution emission. The photovoltaic (PV) system is a generating system using the photoelectric effect, which changes light energy into electric energy. The performance of the PV system depends on both radiation and temperature. The methods for the improvement of PV systems are solar tracking method, MPPT control, improvement of solar cell performance, and a power conversion system[1-2].

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The output power of the PV system is always changing with the weather conditions such as solar radiation and temperature. Therefore, an MPPT control to extract maximum power from PV arrays becomes indispensable in PV systems. A large number of methods such as CV, PO and IC have been proposed for tracking the MPP [3-8]. However, the CV method can't track MPP when radiation changes, so the CV method is not generally used in the MPPT control. The PO has drawbacks such as slow tracking speed and oscillations at MPP and IC is requested high performance CPU [9-10].

There are many studies of MPPT methods using fuzzy control [11-12]. These methods include calculating the step size of the PO and IC method using fuzzy control[11] and other methods that gain the simple PI controller that is adjusted using fuzzy control[12]. These methods, however, are not the main controller of the fuzzy control and improvement in MPPT performance is limited.

To resolve these issues, this paper proposes a novel MPPT algorithm using FLC. The FLC algorithm can maintain robustness in regards to environmental change such as radiation and temperature. Also, it has little oscillation at the MPP. This paper analyzes and compares the performance of conventional methods and FLC. The validity of this proposed algorithm is shown using those results.

2. Solar Cell Model

Fig. 1 shows the equivalent circuit of a solar cell where the short current I_{sc} is equal to the photo current I_c . The open voltage of the solar cell is decided by the diode saturation current I_o and is expressed as follows [13].

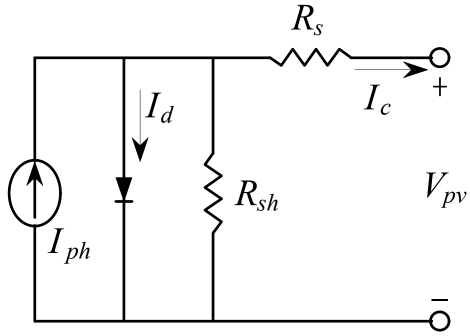


Fig. 1. Equivalent circuit of PV array

$$V_{oc} = \frac{kT}{q}\ln\left[\frac{I_c}{I_o}+1\right] \tag{1}$$

where V_{oc} is the open voltage, k is the Boltzmann constant, q is the electric charge, I_o is the diode saturation current and T is the operating temperature of the solar cell. In addition, a related equation for the short current and open voltage is expressed as follows.

$$I_{sc} = I_o\left[e^{(\frac{qV_{oc}}{kT})}\right] \tag{2}$$

The PV module is connected to a number of solar cells in series and parallel to get the desired voltage and current. In addition, the PV array is connected to a number of PV modules. An equation to obtain the current-voltage characteristic curve of the solar cell is expressed as follows.

$$I_{ph} = I_{sc}S_N + I_t(T_c - T_r) \tag{3}$$

$$I_d = I_o\left[e^{\frac{q(V_{pv}+I_cR_s)}{AkT}} - 1\right] \tag{4}$$

$$I_o = I_{or}\left[\frac{T_c}{T_r}\right]^3 e^{\frac{qE_g}{Bk}\left(\frac{1}{T_r}-\frac{1}{T_c}\right)} \tag{5}$$

$$I_c = I_{ph} - I_d - \frac{V_{pv} + I_c R_s}{R_{sh}} \qquad (6)$$

where I_{ph} is the Photo-current, S_N is the radiation per area, I_t is the short current temperature coefficient, I_d is the diode current, R_s is the series resistance, R_{sh} is the parallel resistance, T_c is the temperature of solar cell$[K]$, T_r is the command temperature of the solar cell$[K]$, A, B are the manufacture constants, I_{or} is the reverse saturation current and E_g is the energy band gap.

Fig. 2 shows a PSIM model of a PV array and can be used to calculate the theoretical maximum power point of PV generation through a PSIM simulation.

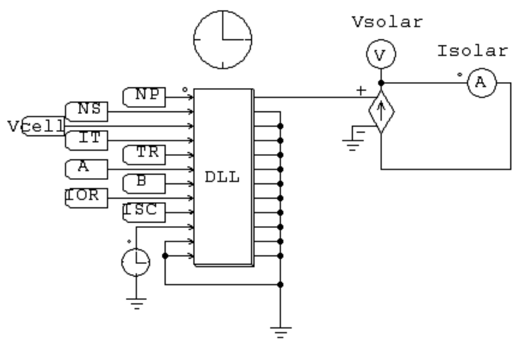


Fig. 2. PSIM model of solar cell array

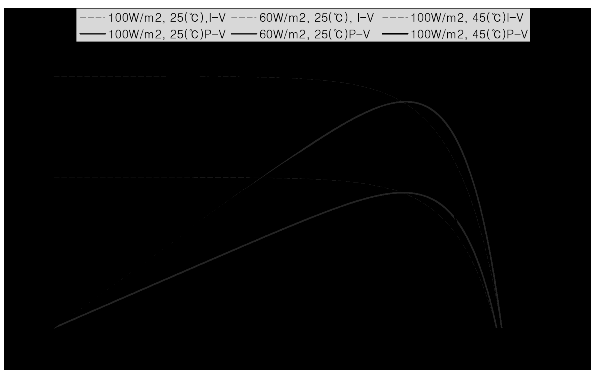


Fig. 3. Output characteristics of solar cell with radiation and temperature change

Fig 3 shows the V-I characteristic curve of the solar cell array with the solar radiation and temperature change.

3. Traditional Mppt algorithm

3.1 PO control method

The PO control method is widely used because it has a simple feedback structure. It operates by incrementing and reducing the PV voltage periodically. This control method operates by the flowchart as follows in Fig. 4.

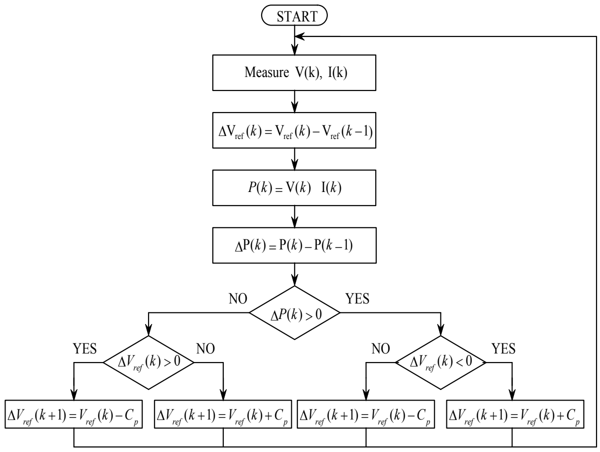


Fig. 4. Flowchart of PO MPPT Method

This is based on the following criterion. If the operating voltage of the PV array is disturbed in a given direction and if the power drawn from the PV array increases, this means that the operating point has moved toward the MPP and, therefore, the operating voltage must be further disturbed in the same direction. Otherwise, if the power drawn from the PV array decreases, the operating point has moved away from the MPP and, therefore, the direction of the operating voltage perturbation must be reversed.

A drawback of the PO MPPT method is that, at steady state, the operating point oscillates around the MPP, giving rise to the waste of some amount of available energy.

3.2 IC control method

The IC MPPT method is called the impedance comparison method or the increment conductance method. This method tracks the MPP by comparing the conductance of the solar cell array output with increment conductance. When compared with the PO control method, this method added the algorithm in which the fluctuation range of voltage is '0' considering the temperature change and can be said to be an improved control algorithm. Particularly, there is the method being effective in the rapidly changing solar radiation and the output power of the solar cell array is stable in case of reaching MPP. The IC control method for improving the PO control method measures the voltage and current and calculates the slope of the power versus voltage. After the reference numeral of a slope is determined and is tracked, the MPP along with the reference voltage is increased or decreased. This is a good control method for rapidly-changing solar radiation; it operates by the flowchart as follows in Fig. 5.

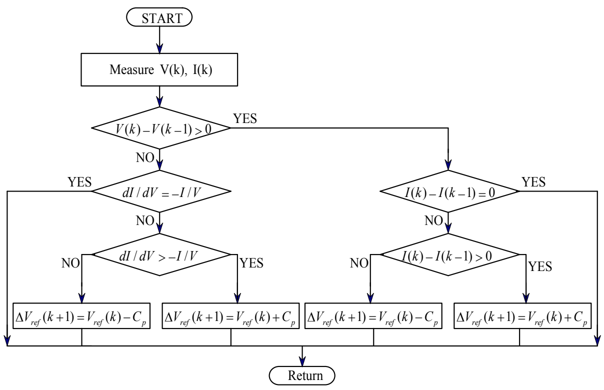


Fig. 5. Flowchart of IC MPPT Method

Since MPP is the case where $\frac{dP}{dV}=0$ becomes, as follows.

$$IdV + VdI = 0 \tag{7}$$

$$\frac{V}{I} = -\frac{dV}{dI} \tag{8}$$

In the maximum power curve about MPP, the left of MPP gets the increase of the output power and the right of MPP shows the reduction of the output power. It is as follows if it shows with the solar cell current and voltage.

$$\frac{dP}{dV} = \frac{dIV}{dV} = I\frac{dV}{dV} + V\frac{dI}{dV} = I + V\frac{dI}{dV} \tag{9}$$

The equation below satisfying the MPP condition ($V = V_{mp}$) can be obtained.

$$\frac{dI}{dV} = -\frac{I}{V} \tag{10}$$

The MPPT performance of the IC control method is excellent in a rapidly changing environment. One disadvantage, however, is that a high effectiveness CPU is needed due to many computational complexities, which increases system unit cost.

4. FLC mppt method

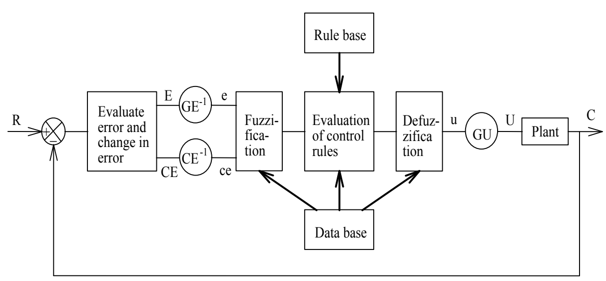


Fig. 6. Base structure of a fuzzy controller system

Fig. 6 shows base structure of a fuzzy controller system.

The FLC has two input values and input values $E(k)$; $CE(k)$ in sampling time k is defined as follows.

$$E(k) = \frac{V_{pv}(k) \cdot I_{pv}(k) - V_{pv}(k-1) \cdot I_{pv}(k-1)}{V_{pv}(k) - V_{pv}(k-1)} \quad (11)$$

$$CE(k) = E(k) - E(k-1) \quad (12)$$

The fuzzy linguistic value defines seven steps of positive big (PB), positive middle (PM), positive small (SM), zero (ZO), negative small (NS), negative middle (NM) and negative big (NB). Fig. 7 shows fuzzy membership function according to seven basic linguistic values for input and output value.

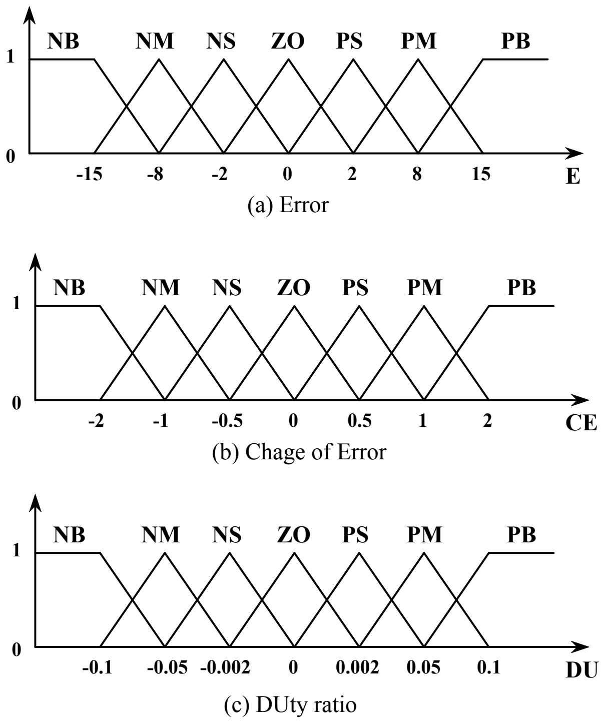


Fig. 7. The membership function for the E, CE and DU

Table 1 shows the fuzzy rule base. The factors of the matrix are error (E), change error (CE) and duty ratio variation (dD). For one example, the control rule in Table 1 is expressed as follows.

"IF E is PB and CE is ZO THEN DU is PB"

In other words, if slope in P-V characteristic curve is large, the variation of slope is small and output value increases. Also, the control rule is designed to become "0", the duty ratio, when E is zero.

Table 1. FLC rule base

E \ CE	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZO
NM	NB	NB	NM	NM	NS	ZO	PS
NS	NB	NM	NS	NS	ZO	PS	PM
ZO	NB	NM	NS	ZO	PS	PM	PB
PS	NM	NS	ZO	PS	PS	PM	PB
PM	NS	ZO	PS	PM	PM	PB	PB
PB	ZO	PS	PM	PB	PB	PB	PB

5. performance result of system

Fig. 8 shows the MPPT circuit using PSIM.

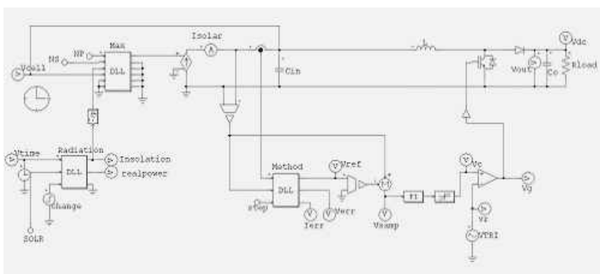


Fig. 8. PSIM circuit for MPPT control

To test performance, radiation changes 1,000w/㎡ at 0sec, 600w/㎡ at 0.4sec, 800w/㎡ at 0.6sec and 1,000w/㎡ at 0.8sec.

5.1 CV method

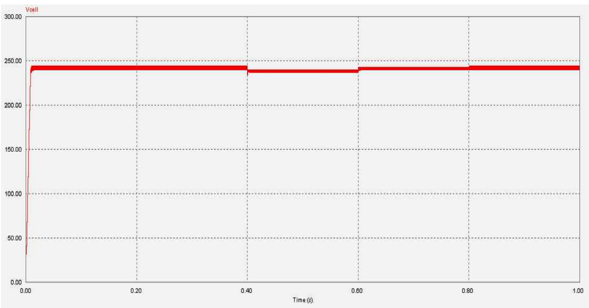
Fig. 9 shows the result of the CV method. Fig. 9 (a) is solar cell voltage, Fig. 9 (b) is solar cell current and Fig. 9 (c) is the power of the solar cell.

5.2 IC method

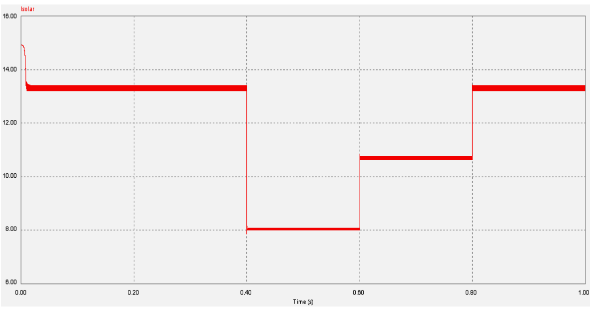
Fig. 10 shows the results of the IC method. Fig. 10 (a) is solar cell voltage, Fig. 10 (b) is solar cell current and Fig. 10 (c) is the power of the solar cell.

5.3 PO method

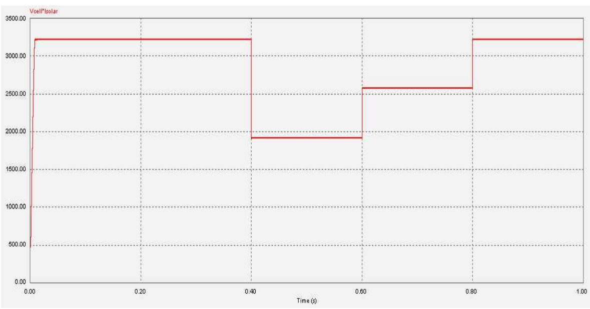
Fig. 11 shows the results of the PO method. Fig.



(a) Output voltage of solar cell

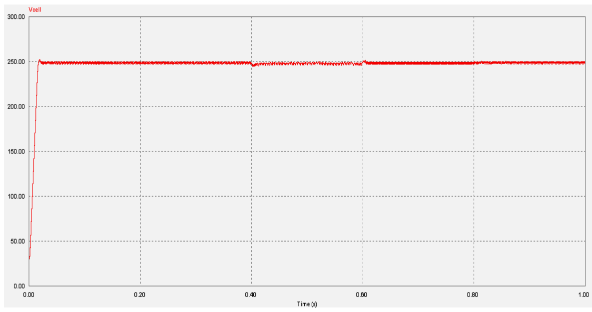


(b) Output current of solar cell

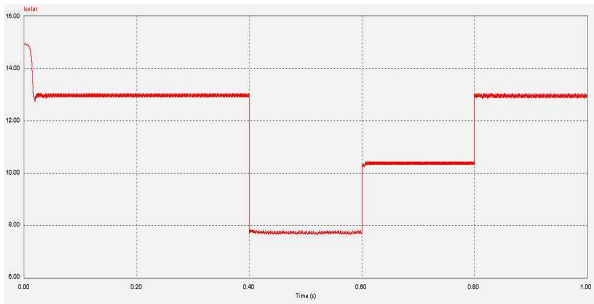


(c) Output power of solar cell

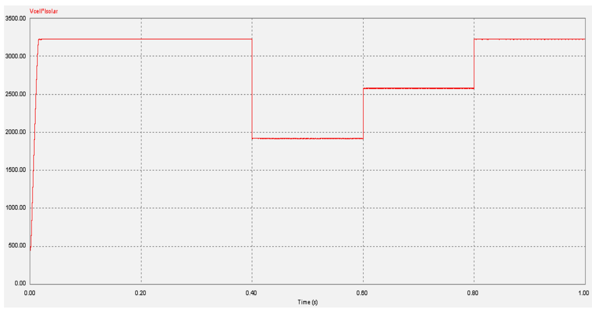
Fig. 9. The response results of CV method



(a) Output voltage of solar cell



(b) Output current of solar cell



(c) Output power of solar cell

Fig. 10. The response results of the IC method

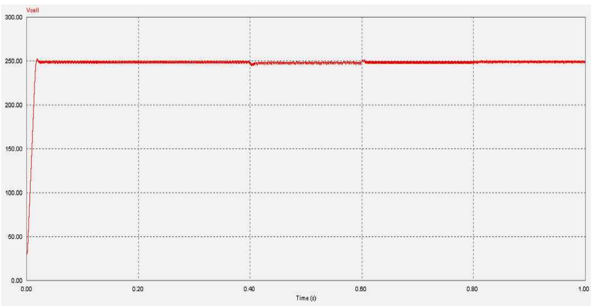
11 (a) is solar cell voltage, Fig. 11 (b) is solar cell current and Fig. 11 (c) is the power of the solar cell.

5.4 FLC method proposed in this paper

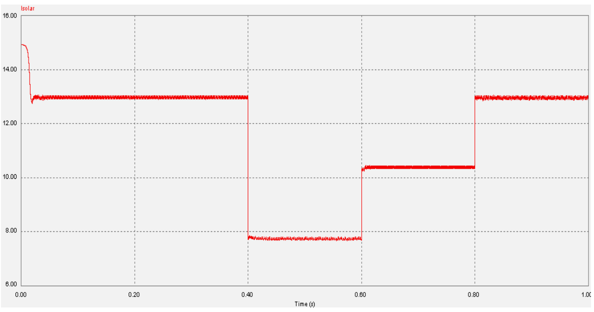
Fig. 12 shows the results of the FLC method proposed in this paper. Fig. 12 (a) is solar cell voltage, Fig. 12 (b) is solar cell current and Fig. 12 (c) is the power of the solar cell.

5.5 Comparison of response results

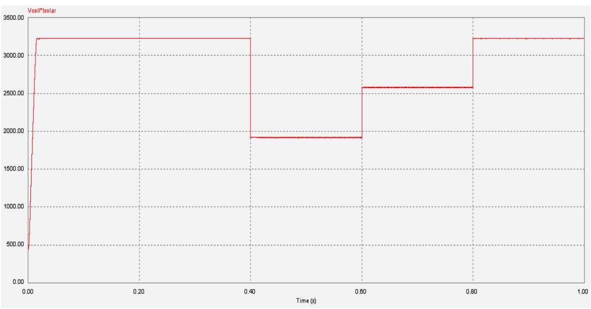
Fig. 13 shows expansion of maximum power error. Fig. 13 (a) is CV method, Fig. 13 (b) is PO method and Fig. 13 (c) is the FLC method proposed in this paper. The peak to peak of the CV method in Fig. 13 (a) vibrates at 8.482W (-0.258W~8.244W), the PO method vibrates at 2.694W (-0.829W~1.865W) and the FLC method vibrates at 0.446W (0.259W~0.446W). The maximum power error of the FLC



(a) Output voltage of solar cell

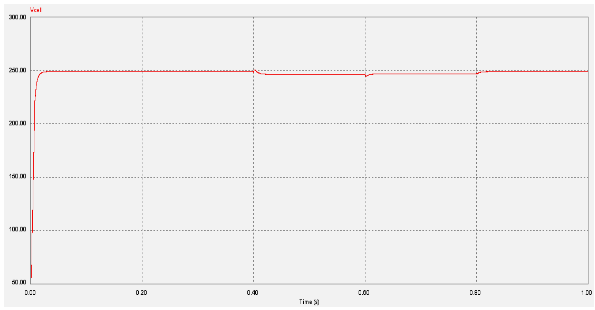


(b) Output current of solar cell

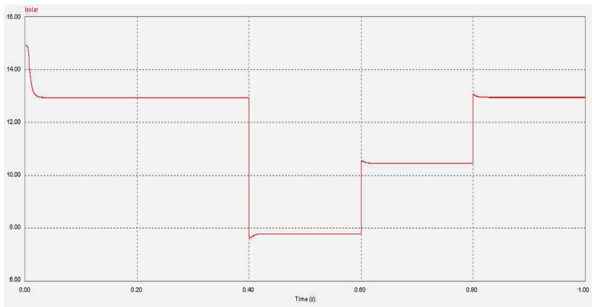


(c) Output power of solar cell

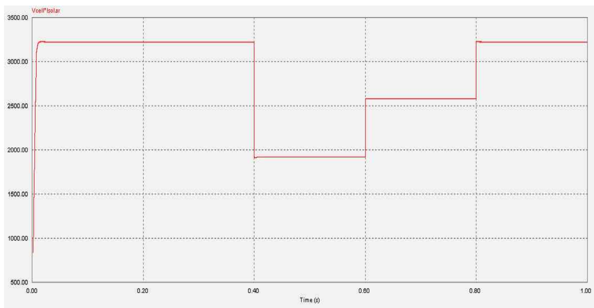
Fig. 11. The response results of the PO method



(a) Output voltage of solar cell

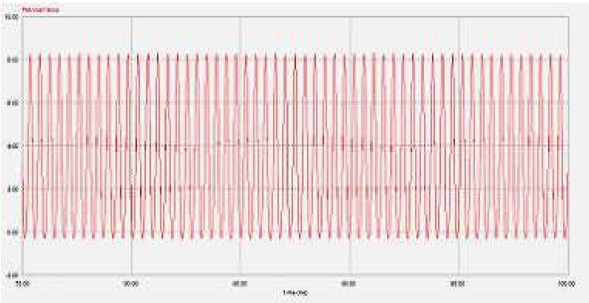


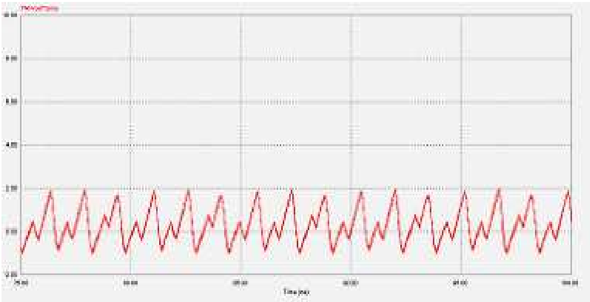
(b) Output current of solar cell



(c) Output power of solar cell

Fig. 12. The response results of FLC method


(a) CV control method


(b) PO control method

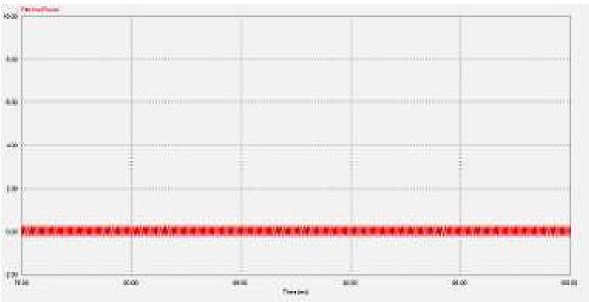

(c) NFC control method

Fig. 13. Maximum power error enlargement with MPPT control method

method proposed in this paper is the smallest of the CV, PO and FLC methods.

6. Conclusion

This paper proposes a novel MPPT control for a PV drive in solar car using the FLC. The maximum power point of the solar cell is changed according to radiation and temperature. Therefore, the PV system is a must-use MPPT control for increasing power and efficiency. The conventional methods (CV, PO, IC) has the weakness that it fails to find the maximum power point tracking with changes in the environment.

This paper proposes an FLC controller robustness that responds to environmental change. The FLC controller proposed in this paper is compared with traditional MPPT methods such as CV, PO, and IC. It has error at steady-state smaller than traditional MPPT methods. As a result, power loss is reduced. Therefore the validity of FLC controller algorithm proposed in this paper is shown.

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Biography

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He received his Ph.D. in Electrical Control Engineering at Sunchon National University. His research interests include fuzzy control, neural networks, motor control and photovoltaic power generation. His current research focuses on maximum power point tracking control for PV generation.

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