A Maximum Power Point Tracking of PV System by Scaling Fuzzy Control

Yuen-Haw Chang and Chia-Yu Chang

Abstract—**A scaling fuzzy logic control (FLC) maximum power point tracking (MPPT) algorithm is suggested in this paper. The scaling FLC algorithm is modified from FLC algorithm to achieve MPPT in spite of single or 10 solar PV cells. Here, our solar system is composed of solar penal, boost dc/dc converter and MPPT controller, and then we use OrCAD Pspice for the system simulation. The simulated cases focus on the steady-state response, the dynamic response to the variation of the solar-cell current or load resistance. The simulated results are illustrated to show the efficacy of the proposed algorithm.**

Index Terms—**maximum power point tracking (MPPT), fuzzy logic control (FLC), photovoltaic (PV), boost DC-DC converter.**

I. INTRODUCTION

In recent years, the petroleum is getting more and more expensive. The people seek for new green energy, e.g. wind energy, water energy, solar energy, etc… Solar energy is a clean, maintenance-free, and an abundant resource of nature, so it is suitable to be a green energy source. But, there are still some drawbacks as follow: the install cost of solar panels is high, and the conversion efficiency is still lower. The solar system uses the solar module as a source of electrical power supply. Each solar module has an optimal operating point, called the maximum power point (MPP) which changes with its own characteristic as well as cell temperature and sunlight. In other words, the current/voltage curves of photovoltaic (PV) solar-cell module are affected with the sunlight illumination and cell temperature. So, it is not easy to keep the MPP operating when the curve of power versus voltage (P-V) is varying. To overcome this problem, many MPPT algorithms were suggested for tracking the MPP of solar module [1, 4]. Then, one of the well known algorithms for MPPT is Perturb and observe (P&O) algorithm. This P&O algorithm has the advantages of low cost and simple circuit. However, its tracking response is slower because it often results in the swing tracking around the MPP. Thus, perhaps it makes some power loss. Here, a scaling fuzzy logic control algorithm is suggested for MPPT, and modified by fuzzy logic control algorithm [2, 5]. The main goal is to use 25 scaling fuzzy rules and pulse-width-modulation control (PWM) not only for the reduction of the tracking time of

MPPT, but also for the enhancement of the tracking regulation for the different number of solar cell in parallel [3], sunlight or loading variation. Finally, our overall solar system is designed by combining scaling fuzzy logic, and simulated by using OrCAD Pspice for the cases of steady-state response, dynamic response to the variation of solar-cell current or load (RL). These simulation results are illustrated to show the efficacy of the proposed scheme.

II. MPPT IN STAND-ALONE SOLAR SYSTEMS

A. Solar Cell Model

In general, the equivalent models of solar cell have three types as shown in Fig. 1. Fig. 1(a) shows an ideal model with one current source and diode just. Going a step further, Fig. 1(b) has an extra small resistor to simulate the line loss. And then, Fig. 1(c) has a big internal resistor to realize the solar cell's power loss. In this paper, we choose the module of Fig. 1(b) for the simulation later.

B. MPPT Circuit Frame

Fig. 2 shows the overall circuit frame of MPPT PV system. Our system includes three parts: solar panel, DC-DC converter and MPPT controller. The solar panel we used is a low-power photovoltaic cell with open voltage Voc=3.25V and rated current I_{rated} =100mA. The boost DC-DC converter is adopted in this paper because it is a low-cost and high-efficiency converter. The MPPT controller is shown in the lower half of Fig. 2. According to voltage V_{PV} and current I_{PV} of solar cell in Fig. 2, the duty cycle D will be determined via scaling fuzzy logic and PWM blocks in order to realize MPPT.

C. Solar Cell Characteristic

Each solar module has its own characteristic and unique I-V curve. General speaking, the I-V curve is shown in Fig. 3.
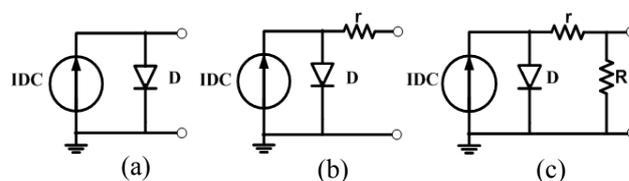
Fig.1 Solar cell model
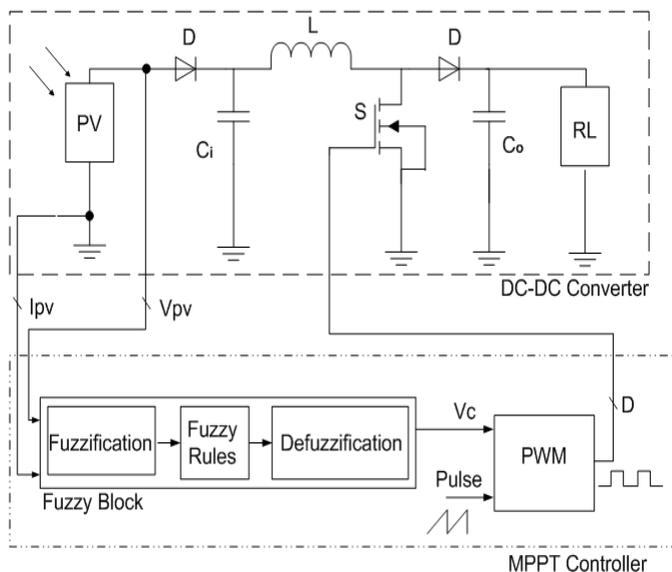
Fig.2 MPPT PV system frame
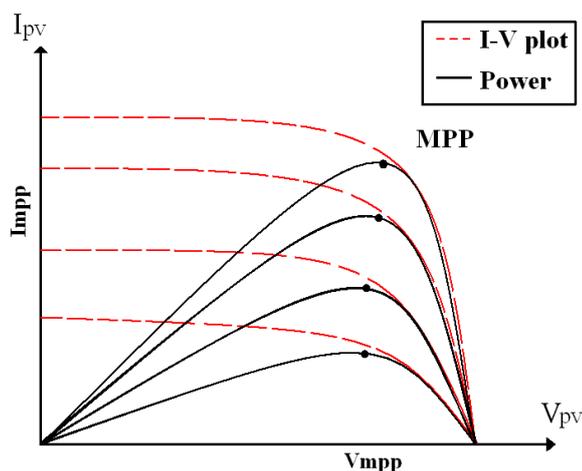
Fig.3 P-V Characteristic curve of solar cell

Fig.4 Membership function (a) input $I_{PV}(k)$; (b) input $V_{PV}(k)$; (c) duty cycle

D. DC-DC Converter

The non-isolated boost DC-DC converter is widely used in stand alone PV system because it is simple, low-cost, and high-efficiency. In general, the conversion efficiency is reading 90%. So, the boost is suitable for simple stand alone system. Here we adopted this converter are our regulator [1].

E. MPPT Controller

Fuzzy logic has the advantages to face the imprecise and uncertainty. And this kind of fuzzy logic control can be easily made by digital microcontroller unit (MCU). So, our MPPT controller will be realized based on this fuzzy logic idea here, and it contains three units as: (i) fuzzification, (ii) fuzzy rules, and (iii) defuzzification described as follows.

(i)Fuzzification: First, V_{PV} and I_{PV} of solar cell are combined with the previous V_{PV} and I_{PV} for the average computation as:

$$V_{pv}(k) = [V_{pv}(k-1) + V_{pv}(k-2)]/2 \qquad (1)$$

$$I_{pv}(k) = [I_{pv}(k-1) + I_{pv}(k-2)]/2 \qquad (2)$$

Such an average is used for the local trend estimation. With the help of the trend of V_{PV} and I_{PV}, the operation of MPPT can be achieved more easily. Next, these voltage and current values are scaled and normalized into -400~400 and -0.1~0.1, and through the membership function, the related fuzzy values (0~1) can be estimated for each fuzzy descriptor: NB, NS, ZO, PS, and PB (e.g. NB: negative and big, ZO: zero, and PS: positive small) as shown in Fig.4. Finally, by comparing all the values, V_{PV} and I_{PV} can be determined and assigned to some fuzzy descriptor (NB/NS/ZP/PS/PB) which possesses the biggest membership function value.

I_{pv} \ V_{pv}	NB	NS	ZO	PS	PB
NB	NB	NS	NS	ZO	ZO
NS	NS	ZO	ZO	ZO	PS
ZO	ZO	ZO	PS	PS	PS
PS	ZO	PS	PS	PS	PB
PB	PS	PS	PB	PB	PB

Fig.5 Fuzzy Rules

(ii) Fuzzy rules: The syntax "if-then" is always used for the expressions of fuzzy rules. Here for MPPT, we use 25 rules totally as follow:

If V_{PV} is NB and I_{PV} is NB, then D is NB.
If V_{PV} is NB and I_{PV} is NS, then D is NS.
If V_{PV} is NB and I_{PV} is ZO, then D is ZO.
If V_{PV} is NB and I_{PV} is PS, then D is ZO.
If V_{PV} is NB and I_{PV} is PB, then D is PS.
If V_{PV} is NS and I_{PV} is NB, then D is NS.
If V_{PV} is NS and I_{PV} is NS, then D is ZO.
If V_{PV} is NS and I_{PV} is ZO, then D is ZO.
If V_{PV} is NS and I_{PV} is PS, then D is PS.
If V_{PV} is NS and I_{PV} is PB, then D is PS.
If V_{PV} is ZO and I_{PV} is NB, then D is NS.
If V_{PV} is ZO and I_{PV} is NS, then D is ZO.
If V_{PV} is ZO and I_{PV} is ZO, then D is PS.
If V_{PV} is ZO and I_{PV} is PS, then D is PS.
If V_{PV} is ZO and I_{PV} is PB, then D is PB.
If V_{PV} is PS and I_{PV} is NB, then D is ZO.
If V_{PV} is PS and I_{PV} is NS, then D is ZO.
If V_{PV} is PS and I_{PV} is ZO, then D is PS.
If V_{PV} is PS and I_{PV} is PS, then D is PS.
If V_{PV} is PS and I_{PV} is PB, then D is PB.
If V_{PV} is PB and I_{PV} is NB, then D is ZO.
If V_{PV} is PB and I_{PV} is NS, then D is PS.
If V_{PV} is PB and I_{PV} is ZO, then D is PS.
If V_{PV} is PB and I_{PV} is PS, then D is PB.
If V_{PV} is PB and I_{PV} is PB, then D is PB.

For example, (1) when V_{PV} is PB and I_{PV} is NB, it means that V_{PV} is higher than the voltage around MPP with a small current I_{PV}, we directly assign the duty cycle D to be ZO for the medium-sized drive. By using such a medium D, it is enough to make the exceeded V_{PV} decreasing a little back to a suitable value. (2) When V_{PV} is ZO and I_{PV} is ZO, it means that V_{PV} and I_{PV} are at the medium values in the full range, i.e. V_{PV} is lower than the voltage on MPP. Then, we have to assign the duty cycle D to be PS for the medium-plus-sized drive. Fig.5 shows the 25 fuzzy rules to define the relationship between V_{PV}, I_{PV}, and D.

(iii) Defuzzification: Defuzzification is for the aggregation of the D from all rules, i.e. the duty cycles from 25 rules must be computed and combined for a specified value. Here, we adopt the center of area (COA) defuzzification method as [2]:

$$Vc = \frac{\sum_{j=1}^{25} D_j(w_j) \cdot w_j}{\sum_{j=1}^{25} D_j(w_j)} \tag{3}$$

where D_j is the duty cycle values for the j-th rule, and w_j is the weighted factor of the j-th rule. The w_j is bigger, the j-th rule affects more at this moment.

III. EXAMPLE OF MPPT BY SCALING FUZZY CONTROL

The MPPT PV system is shown in Fig.2 for testing the feasibility of the proposed method. A DC-DC converter is involved as the power stage between the PV array and load to use the duty-cycle adjustment for MPPT. In this paper, we use OrCAD Pspice to simulate the entire circuit. In the simulation, we consider the parallel connection of 1~10 solar cells as a single cell. The solar model has the rated value: 3.25V and 100mA with a little series resistor. The solar voltage of MPP is usually at 70%~82% of the open circuit voltage, and the solar current at MPP is close to about 86% of the rated current. According to reference [3], we can calculate the minimum/ maximum MPP of the solar module as follow:

$$P_{min} = 0.7V_{OC} \times 0.86 \ I_{rated} \tag{4}$$
$$P_{man} = 0.82V_{OC} \times 0.86 \ I_{rated} \tag{5}$$

Based on (3) and (4), the minimum value of MPP is estimated bout 194.79mW, and the maximum is about 229.19mW. Next, the MPPT system by using scaling fuzzy control will be simulated for the cases: (i) steady-state response, (ii) dynamic response to the variation of $I_{PV,}$ and (iii) dynamic response to the variation of RL.

(i)Firstly, the DC-DC boost converter is operated at the switching frequency of 60kHz, and all components are listed as follow: RL=50Ω, C_i=10000 μF, C_o=200 μF, L=100 μH, and MOSFET=IRF450. When a single solar cell is working, the MPPT system can be simulated to obtain the waveforms of V_{PV}, P_{PV}, P_{RL}, I_{PV} versus time as shown in Fig.6, where P_{PV} is the solar cell output power, and P_{RL} is the consumption power of RL. According to Fig.6, the final value of P_{PV} is reaching 220mW after 350ms. Obviously, the power value is really close to the MPP (229.19mW). Fig.7 shows P_{PV}, P_{RL}, I_{PV} versus V_{PV}, and clearly, the tracking performance of MPP can be realized. Next, when 10 solar cells are working in parallel, the MPPT system can be simulated to obtain the waveforms of V_{PV}, P_{PV}, P_{RL}, I_{PV} versus time as shown in Fig.8. The final value of P_{PV} is reaching 2.02W after 20ms. Obviously, the power value is really close to the MPP (2.29W). Fig.9 shows P_{PV}, P_{RL}, I_{PV} versus $V_{PV,}$ and clearly, the MPP tracking performance is realized. At the above descriptors, the MPPT can be achieved by the same scaling fuzzy control in spite of single cell or 10 solar cells.
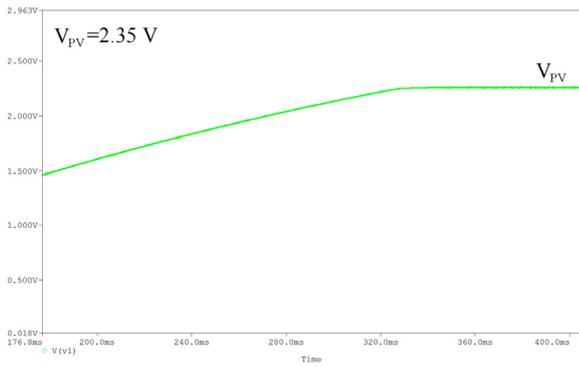
Fig.6 Waveform of V_{PV}, I_{PV}, P_{RL}, and P_{PV} when RL=50Ω when using a solar cell
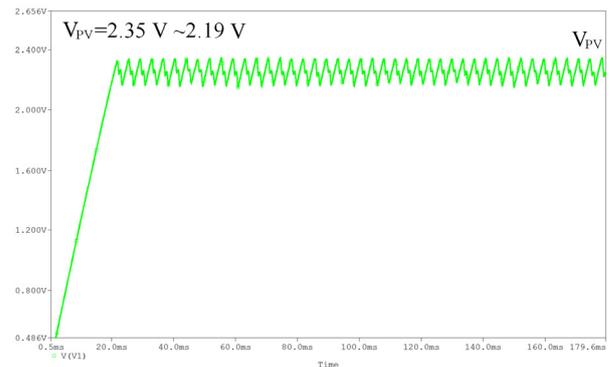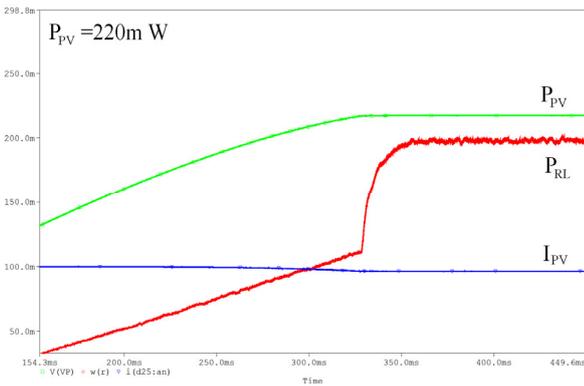
Fig.8 Waveform of V_{PV}, I_{PV}, P_{RL}, and P_{PV} when RL=50Ω when using 10 solar cells
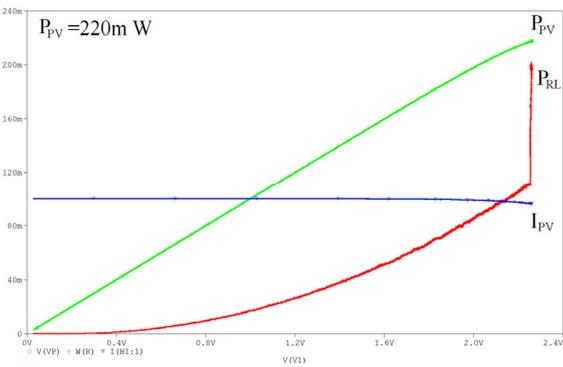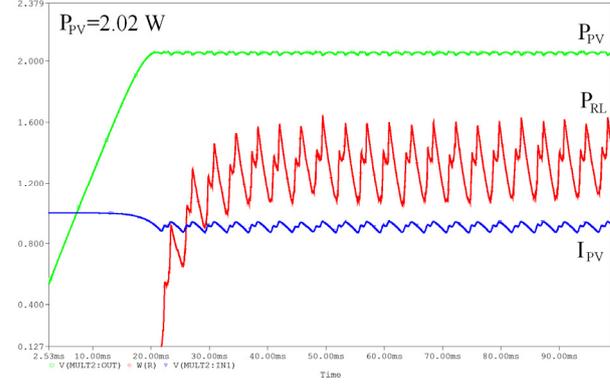
Fig.7 V-P Curve of P_{PV}, P_{RL}, and I_{PV} when RL=50Ω when using a solar cell
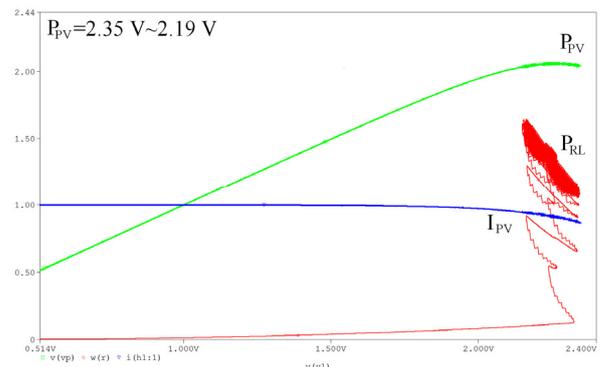
Fig.9 V-P Curve of P_{PV}, P_{RL}, and I_{PV} when RL=50Ω when using 10 solar cells

(ii) Secondly, the dynamic response to the variation of I_{PV} is discussed here. Since the strength of sunlight is varying with time, even when the cloud is coming, the light will change more, the current I_{PV} of solar cell should not be a fixed constant. Now, assume that I_{PV} is suddenly changing from 1A to 100mA at 150ms, and recovering from 100mA buck to 1A at 200ms. Then, the MPPT system is simulated to obtain the result waveforms as shown in Fig.10. Obviously, P_{PV} has a big change from 2.2W dropping to 219mW at 150ms, and then at 200ms, P_{PV} changes from 219mW back to 2.2W. So, by using the MPPT controller, the MPP still holds on in spite of the variation of I_{PV}. Fig. 11 shows the entire waveforms P_{PV} versus I_{PV} during the solar cell current variation.
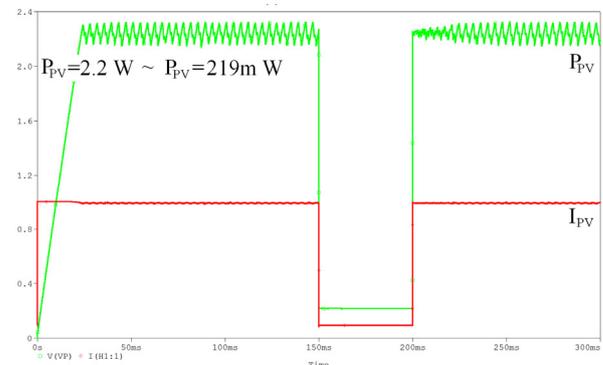
Fig.10 Waveform of P_{PV} when I_{PV}:1A to 100mA (RL=50Ω)
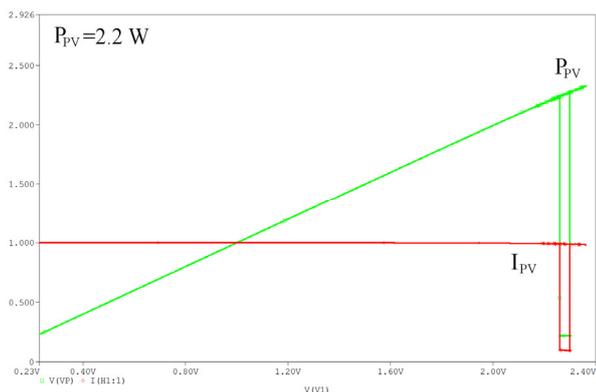
Fig.11 V-P Curve of P_{PV} when I_{PV}: 1A to 100mA (RL=50Ω)
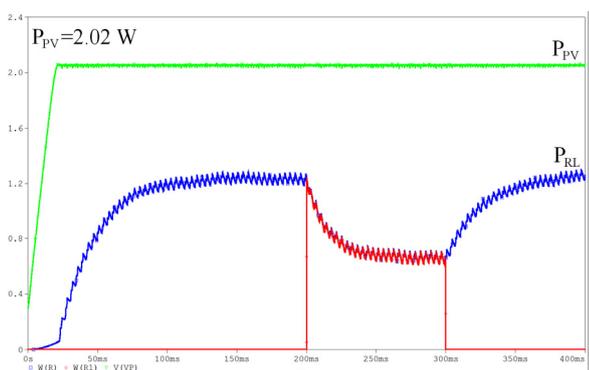
Fig.12 Waveform of P_{PV} when RL: 100Ω to 50Ω (I_{PV}=1A)
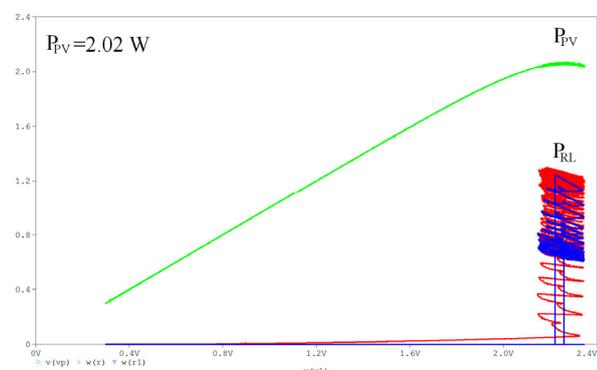
Fig.13 V-P Curve of P_{PV} when RL: 100Ω to 50Ω (I_{PV}=1A)

(iii) Finally, the dynamic response to the variation of P_{RL} is discussed here. Since the load is varying unexpectedly, e.g. connected with different load, the consumption power P_{RL} of RL should not be a fixed constant. Now, assume that RL is suddenly changing from 100Ω to 50Ω at 200ms, and recovering from 50Ω back to 100Ω at 300ms. For such the variation of RL, the MPPT system is simulated to obtain the result waveforms as shown in Fig. 12. Obviously, the MPPT system still holds on the power vale of 2.02W during the interval of RL (P_{RL}) variation (200ms~300ms). So, by using our MPPT controller, the system still holds on the MPPT in spite of the variation of P_{RL}. Fig. 13 shows the entire waveforms P_{PV} versus P_{RL} during the RL variation.

IV. CONCLUSION

A FLC-based MPPT algorithm is presented in this paper.
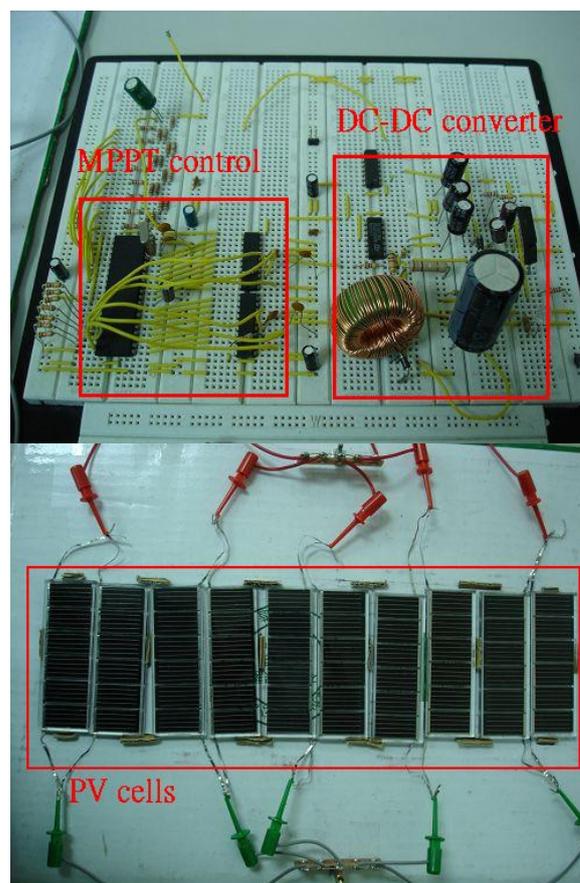
Fig.14 Hardware of MPPT PV System

The scaling FLC algorithm is modified from FLC algorithm, and based on this modified FLC algorithm, the MPPT controller is realized and tested for the good of MPPT no matter for single or 10 solar cells. In addition , since the sunlight strength varies or the unexpected RL variation occurs, the regulation capability of the MPPT controller has been also tested as above shown in the (ii) and (iii) of example. At present, we have implemented the hardware of scaling fuzzy logic control as shown the photo of Fig.14. Next, some more experimental results will be obtained and measured for the verification of our scaling fuzzy logic control.

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