Proceedings of the International MultiConference of Engineers and Computer Scientists 2013 Vol II,
IMECS 2013, March 13 - 15, 2013, Hong Kong

# Microprocessor based Fuzzy MPPT for PV-AC Module DCM-flyback Inverter

Poom Konghuayrob and Somyot Kaitwanidvilai

***Abstract*— This paper proposes a maximum power point tracking using fuzzy based perturb and observe (P&O) algorithm for a photovoltaic (PV) system (an AC module). In AC module flyback inverter, modulation index (Δma) are adopted as a control variable to track the maximum power point (MPP) of PV array. In the conventional technique, step size of modulation index (Δma) is adopted in the simple P&O technique; Although this technique is easy to be implemented but there is some problems regarding large oscillation around the MPP and slow tracking when improper step size is selected. The proposed technique, fuzzy based P&O technique, is adopted to provide non-equal step size of Δma. The proposed fuzzy system was programmed on microcontroller which is a low cost processing device. Experimental result confirms that the proposed system can effectively track the power from PV system, and is better than the conventional technique.**

***Index Terms*—AC-module, fuzzy MPPT, flyback inverter, discontinuous mode.**

## I. INTRODUCTION

NOWADAYS, interest in an AC module in photovoltaic energy has grown to solve the problem of environment crisis. Photovoltaic (PV) systems have been developed to overcome the problem of energy crisis. Solar energy generators are extensively adopted to generate the electrical power from solar irradiation. In this approach, solar power is converted into electric power by photovoltaic (PV) array. The output of the PV panels depends on surrounding weather conditions those are sun irradiance level and temperature [1-3]. Several circuits and control schemes for photovoltaic power generation systems were applied and studied. Generally, a PV system consists of PV array and PV power conditioner that can be divided into two categories, first is dc–dc converter to control the dc voltage and second is inverter to generate ac power [4].

In this paper, a flyback inverter with center-tapped secondary winding is adopted for implementing the proposed technique, fuzzy based P&O algorithm. The design of this circuit was presented in the references [5]–[7]; the features of flyback inverter are summarized here as follows. No dc–dc converter is required and the flyback inverter can directly convert the specified dc power to ac power. The main circuit configuration is simple and the number of power semiconductor switches used is less than that of the other circuits. This research work adopts the fuzzy maximum power point tracking (MPPT) technique to utilize the power from PV array.

Modulation index (flyback inverter) and duty-cycle (DC-DC converter) are key parameters for tracking MPP of solar array [8]. Although general P&O technique can be simply adopted for the tracking purpose, the selection of appropriate step size of modulation index (Δma) or duty cycle is not easy. If the step size is too high, the oscillation around the maximum power point (MPP) will be large. On the contrary, results of tracking will be slow if the step size is low. To overcome this problem, this paper proposes the fuzzy based P&O algorithm to adjust the appropriate Δma to achieve both fast tracking and low MPP power oscillation. The inputs of the proposed fuzzy logic are the magnitudes of the change of power (ΔP) and the change of PV voltage (ΔV) which are used to estimate the appropriate Δma. The system was programmed on microcontroller; thus, the cost of controller are reduced when compared to DSP or personal computer. The experimental results show that the proposed technique can perform efficient power tracking in various irradiance conditions.

## II. FLYBACK INVERTER WITH CENTER-TAPPED SECONDARY WINDING

### *A. Operation of DCM-flyback inverter with center-tapped secondary winding*

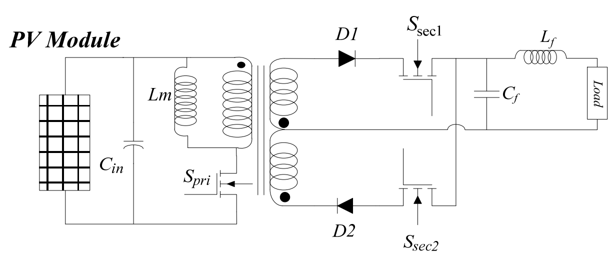



Fig. 1. Circuit configuration of grid connected flyback inverter with center-tapped secondary winding.

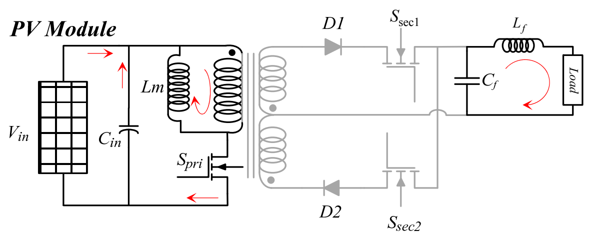
The main circuit of DCM-flyback inverter for a prototyped PV power conditioner is shown in Fig. 1. PV module is utilized as the input source of this inverter. A

Manuscript received Febuary, 2013; This work was supported in part by the King Mongkut's Institute of Technology Ladkrabang Research Fund.

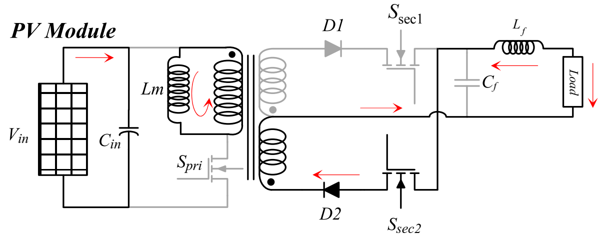
Somyot Kaitwanidvilai is with the Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Thailand. (corresponding author to provide phone: 883-906-6567; e-mail: drsomyotk@ gmail.com).

Poom Konghuayrob is with the Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Thailand. (e-mail: poom.konghuayrob@gmail.com).

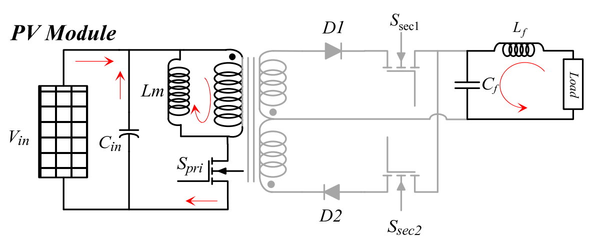
flyback inverter consists of one decoupling capacitor, one center-tapped secondary winding transformer, three semiconductor switches, two power diodes and LC output filter. The primary switch $S_{pri}$ operates with high switching frequency, secondary switches $S_{sec1}$ and $S_{sec2}$ operate with 50 Hz like as line frequency. The capacitor (*C1*) is used to reduce ripple component of input power because nearly constant input voltage and current is needed for MPPT algorithm. The flyback transformer performs energy flow from dc to ac side and provides isolation between the PV array and ac line for protection. The primary winding is connected to the PV array and the MOSFET *Sp*, where the switch $S_{pri}$ is driven by pulse-width modulated gate pulses generated by triangle compared with absolute sine. Both of AC semiconductor switches composed of the IGBTs $S_{sec1}$, $S_{sec2}$ and the diodes $D_1$,$D_2$ in series connection as shown in Fig. 3, connected to each terminal of the secondary winding of the flyback transformer. The active switches $S_{sec1}$ and $S_{sec2}$ are turned on or off on each of half line cycle to generate positive or negative output current according to the polarity of the sinusoidal waveform.



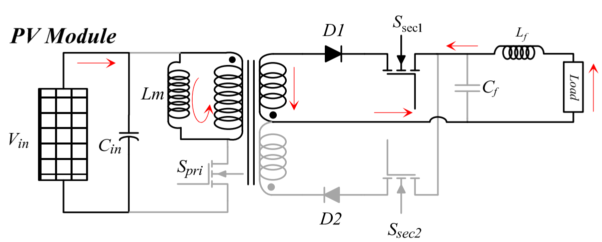

Mode I




Mode II




Mode III




Mode IV

Fig. 2. Circuit configuration and operation modes of flyback inverter.

The circuit of flyback inverter and the switching sequences (mode) are shown in Fig. 2. Mode I is defined for the situation where switch $S_{pri}$ is conducted and all other switches are off, and the stored energy in $C_f$ is discharged to the AC load or grid with the synchronized polarity and phase. Mode II is defined for the duration where IGBT $S_{sec1}$ is conducted with all the rest in off, implying the stored energy in $L_m$ releases to the AC utility grid and giving the positive polarity. Mode III and IV, the primary switch $S_{pri}$ alternately operates at high switching frequency during the negative half cycle. The thorough analysis of the DCM flyback inverter is described in [9]. The transferred power is expressed by the following equation [9]:

$$P_{PV} = \frac{1}{4} V_{dc}^2 g_L d_p^2 \quad (1)$$

where
$$g_L = \frac{1}{L_1 f_s} \quad (2)$$

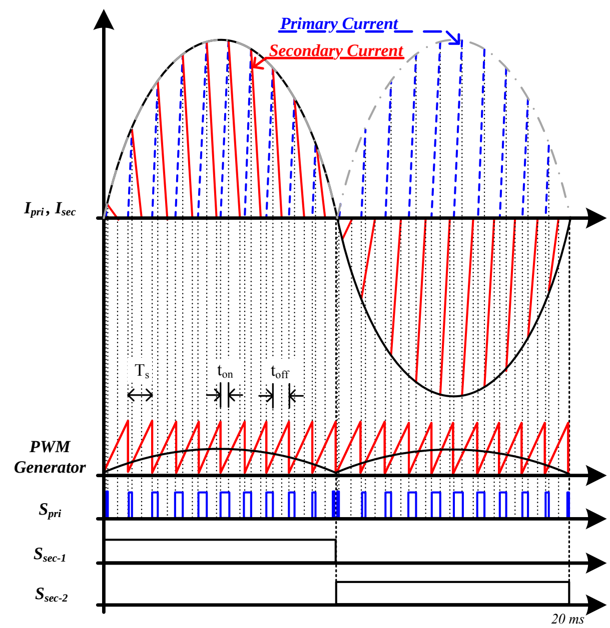



Fig. 3. Current waveform and switching sequence diagram

## III. Proposed Fuzzy Based P&O Algorithm

Fuzzy logic is easy to use because it does not require accurately mathematical model. Besides, fuzzy is able to work properly even without the precise knowledge of system and is more robust compared to the conventional non-linear controller [10]. The operation of fuzzy logic control can be classified into main basic elements, namely fuzzification, rule base inference engine and defuzzification.

ISBN: 978-988-19252-6-8
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

The operation of the proposed fuzzy logic control is shown in the flow chart in Fig. 4. Solar PV system consists of a PV panel, a flyback inverter, fuzzy based P&O MPPT control unit and load which are shown in Fig.1. The power from PV panel is delivered to the load through the flyback inverter. The change of output voltage ($\Delta V_{pri}$) and the change of power ($\Delta P_{pri}$) from the PV panel are adopted as the inputs of the fuzzy based MPPT control unit for MPP tracking. Fuzzy logic is used to determine the step size of perturbed modulation index. In the other words, the proposed fuzzy logic P&O MPPT will decide the new operating voltage for PV panel by adjusting the step size of modulation index (Δma) on the flyback inverter.

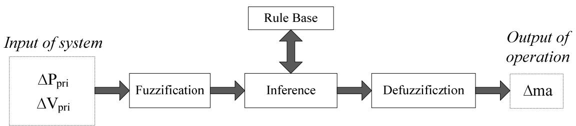



Fig. 4. Operation of fuzzy logic based P&O MPPT control

In this paper, fuzzification is the process of converting ($\Delta V_{pri}$) and ($\Delta P_{pri}$) from PV array, which are the inputs of fuzzy system, into linguistic fuzzy sets using fuzzy membership function with six fuzzy sets: NB (negative big), NM (negative medium), NS (negative small), PS (positive small), PM (positive medium), and PB (positive big). Fig. 6 shows the input membership functions of this proposed technique. 5 fuzzy sets of output membership are VB (Very Big), B (Big), M (Medium), S (small), VS (very small).

TABLE I
RULES OF FUZZY BASED P&O SYSTEM

| Change of voltage ($\Delta V_{pri}$) | Change of power ($\Delta P_{pri}$) NB | NM | NS | PS | PM | PB |
|---|---|---|---|---|---|---|
| **NB** | VS | S | M | M | S | VS |
| **NM** | B | VS | S | S | VS | B |
| **NS** | VB | B | VS | VS | B | VB |
| **PS** | VB | B | VS | VS | B | VB |
| **PM** | B | VS | S | S | VS | B |
| **PB** | VS | S | M | M | S | VS |

TABLE II
DESCRIPTION OF WEIGHT VALUES

| Rule No | Value of membership function | Δma weight ($W_k$) |
|---|---|---|
| 1 | VB | $6\times10^{-2}$ |
| 2 | B | $4\times10^{-2}$ |
| 3 | M | $3\times10^{-2}$ |
| 4 | S | $2\times10^{-2}$ |
| 5 | VS | $1\times10^{-2}$ |

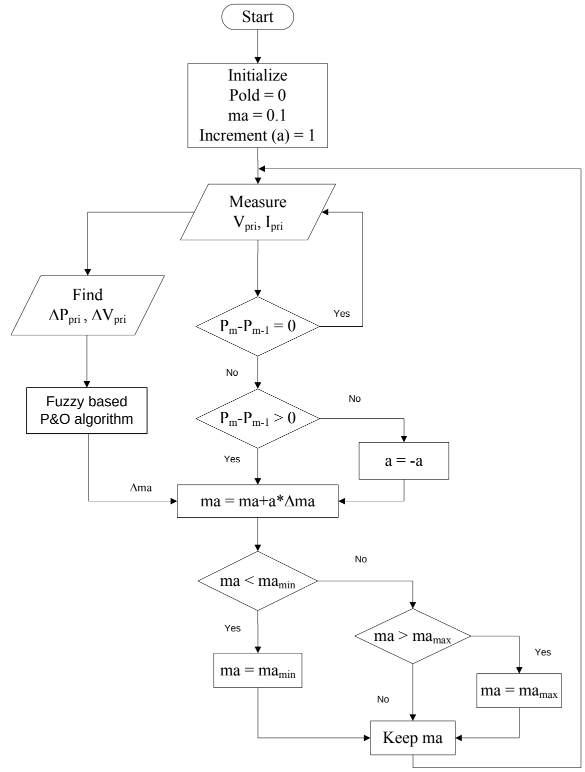



Fig. 5. Flow chart of the proposed fuzzy based perturb and observe (P&O) for MPPT of flyback inverter

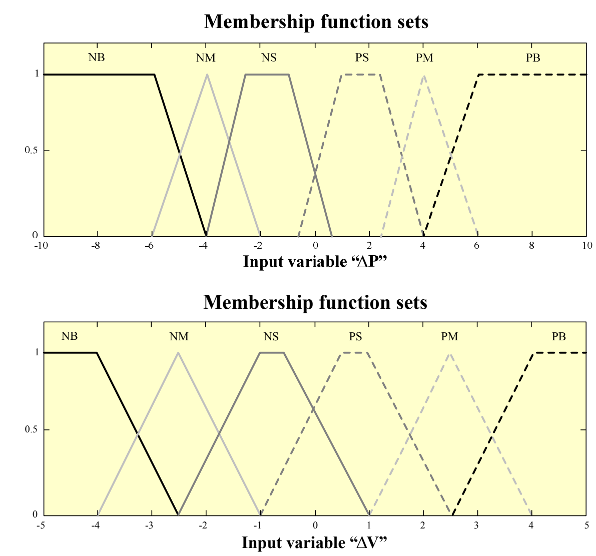



Fig. 6. Membership functions of the input variables ($\Delta V_{pri}$ and $\Delta P_{pri}$)

The fuzzy system rules can be designed as shown in Table I; rules and weights were specified by the knowledge of the expert. In this paper, the defuzzification method adopted in the proposed system is based on the concept of Sugeno's method which is the min-max composition. Defuzzification for Sugeno's system can be calculated by:

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ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

$$\Delta ma = \left( \sum_{k=1}^{m} u^k w_k \Big/ \sum_{k=1}^{m} w_k \right) \quad (3)$$

where $\Delta ma$ is the step size of modulation index. $u^k$ is the product of all membership values of rule no. $k$, and $w_k$ is the weight of rule no. $k$; $m$ is the number of rules. As seen in Fig. 5, $\Delta ma$ is used as the magnitude of change but the direction of change is specified by the concept of simple P&O. AC-module flyback inverter adopts the output of fuzzy system (the step size) to the P&O method to generate pulse width modulation (PWM) signal for controlling primary switch $S_{pri}$.

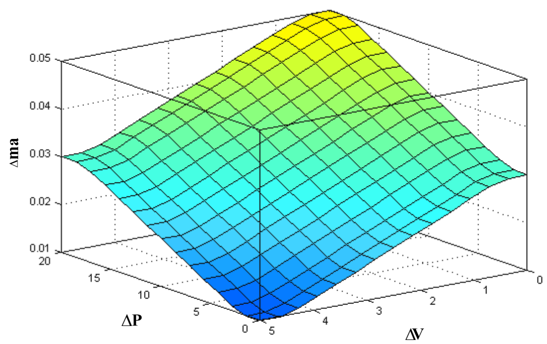



Fig. 7. Sugeno output surface (Δma)

## IV. Experimental Results

The effectiveness of flyback inverter and the proposed fuzzy system are verfied by simultaion with Matlab/Simulink and real experiment. Flyback inverter model in MATLAB is shown in Fig 8. The PV system adopted in this study is composed of 100W. PV panel and Fly back inverter with 30 kHz switching frequency.

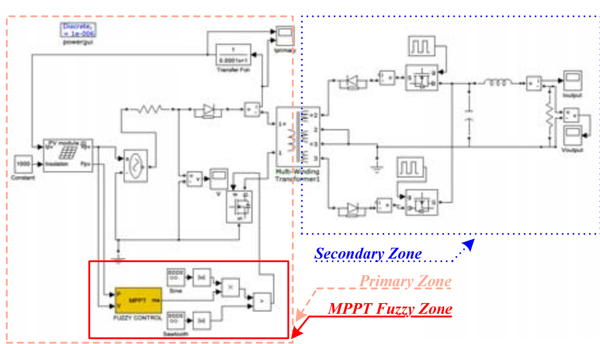
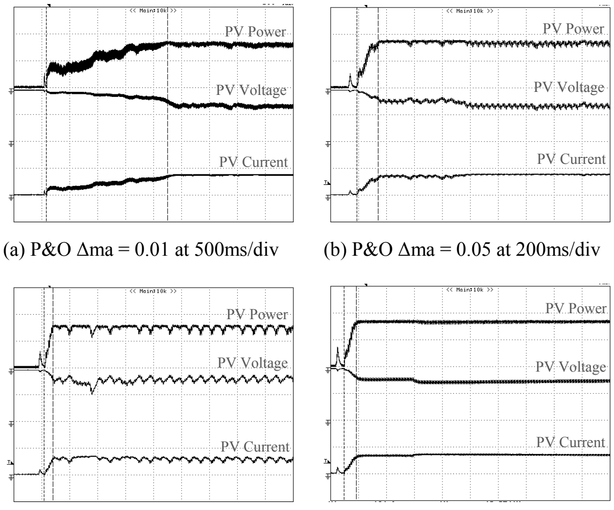



Fig. 8. Simulink model of fly back inverter

In order to show the effectiveness of the proposed fuzzy based P&O, both the proposed and the conventional P&O techniques were implemented on the MPPT. The results of comparision can be seen in Figs. 9 and 10. As seen in these figures, the proposed technique performs better performance in terms of fast tracking and low power oscillation at MPP.




(a) P&O Δma = 0.01 at 500ms/div (b) P&O Δma = 0.05 at 200ms/div

(c) P&O Δma = 0.1 at 200ms/div (d) Fuzzy based P&O at 200ms/div

Fig. 9. Real power, voltage and current of flyback inverter (a),(b) and (c) are experimental results of the conventional P&O (d) is the experimental result of the proposed fuzzy base P&O MPPT algorithm. (at irradiance level 450 W/m$^2$)

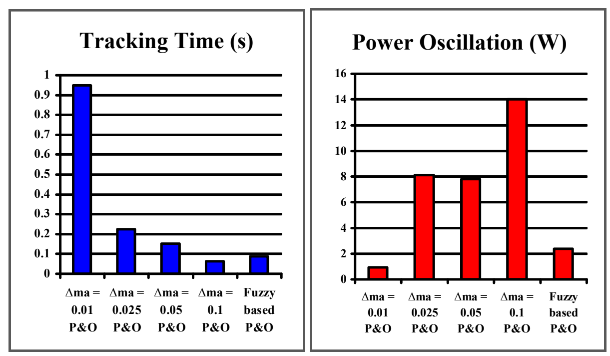



Fig. 10. The comparison results of the proposed and the conventional techniques

Figs. 9 (a), (b) and (c) show the results of power, voltage and current from the conventional MPPT algorithm when operted at irradiance level = 450 W/m$^2$. Fig. 9(d) shows the experimental results of the proposed fuzzy logic control based P&O algorithm. As seen in Fig. 9(c), high value of step size Δma results in fast tracking and high oscillation of power at MPP. In contrary, as shown in Fig. 9(a), low value of step size results in slow tracking and low oscillation of power at MPP. In Fig. 9(d), the results of tracking time and power oscillation concern that the proposed technique is better than the conventional technique in terms of lower power oscillation and faster tracking. Fig. 10 shows the bar graph of the results from Fig. 9.

## V. Conclusion

In this paper, flyback inverter with center taped secondary winding using fuzzy based P&O algorithm for AC module system has been proposed. The proposed MPPT technique is adopted to approximate the appropriate Δma for achieving good power oscillation and fast tracking. The experimental results confirm that the proposed MPPT performs better performance and effectiveness compared to the conventional P&O technique.

ISBN: 978-988-19252-6-8
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

### ACKNOWLEDGMENT

This work was supported by King Mongkut's Institute of Technology Ladkrabang Research Fund.

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