Maximum Power Point Tracker for PV Systems

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Abstract
The photovoltaic (PV) generator exhibits non-linear i-v characteristics and its maximum power point varies with solar insolation and temperature, thus this work deals with the design and laboratory implementation of a real time maximum power point tracker (MPPT) for photovoltaic system aiming to improve energy conversion efficiency. A MPPT algorithm is developed using PV array voltage and current informations and it is implemented by single chip 80C51 microcontroller to control the duty cycle of a boost converter with pulse width modulation (PWM). Experimental results show the performance of the designed MPPT.

Keywords: Photovoltaic system; Maximum power point tracker; Boost converter; Microcontroller

1. Introduction

Recently, the concern for environmental issue has been rising in the world such as global warming by exhausting carbon dioxide (CO_2) and breaking of ozone layer by freon gas. On December 1997, during the Kyoto Conference on Climate Change (COP3) it was agreed that by the year 2012 the developed countries would reduce at least 5% of the green house gases compared with year 1990 (Riza Muhida, et al., 2003).

Moreover, the global energy shortage, such as the Brazilian energy crisis (2001), and the need for sustainable energy systems enforces the development of power supply structures that are based mainly on renewable resources.

Photovoltaic (PV) generation is gaining increased importance as a renewable source due to advantages such as the absence of fuel cost, little maintenance and no noise and wear due to absence of moving parts. But there are still two principal barriers to the use of photovoltaic systems: the high installation cost and the low energy conversion efficiency.

A PV system is a non-linear power source, i.e. its output current/power depends on the terminal operating voltage. On the other hand, the maximum power generated by the system changes with solar radiation and temperature. Thus, to increase the ratio *output power/cost of installation* it is important a PV system to operate with maximum output power (MPP). This work deals with the design and laboratory implementation of a real time microcontrolled maximum power point tracker (MPPT) to obtain high energy conversion efficiency without increasing the installation costs. A simple MPPT algorithm that adjusts the solar array power with a digital control to track the MPP for the converter system is used in this paper to

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achieve the maximum power transfer and high efficiency for the photovoltaic conversion energy system.

This paper is divided in six sections, as follows: section 2 presents the solar array characteristrics, section 3 shows the maximum power point tracker and the topology used for implementation, section 4 discusses about the algorithm proposed to track the maximum power point and shows the experimental results to validate the performance of the proposed MPPT, conclusions are presented in section 5. The design of the DC/DC converter is presented in the appendix.

2. Solar array characteristics

The maximum power point of a solar module changes in accordance with changes in the solar irradiance and module temperature. The typical characteristic curves current *versus* voltage and power *versus* voltage of a solar cell at different levels of solar irradiation are illustrated in Fig. 1 and in Fig. 2, respectively.

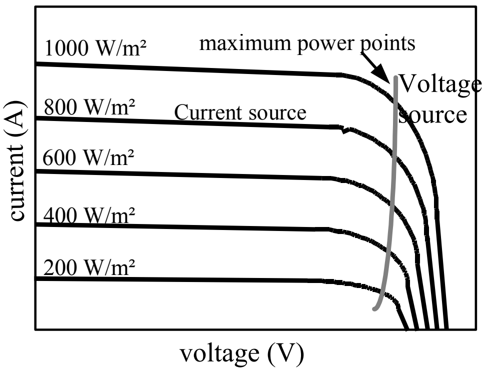

Fig.1 Typical I x V characteristics curves of a photovoltaic cell

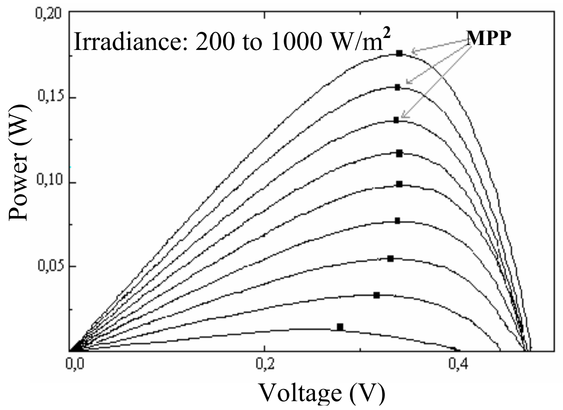

Fig. 2. P x V characteristics of a solar cell for different irradiance levels

Fig. 1 illustrates the operating characteristic of the solar array under several given solar insolations. It consists of two regions: one is the current source region, and the other is the voltage source region. In the voltage source region, the internal impedance of the solar array is low. That region is the right side of the current x voltage curve. The current source region, in which the internal impedance of the solar array is high, is at the left side of the current x voltage curve. The MPP of the solar array is located at the knee of the current x voltage curve. According to the maximum power transfer theory, the power delivered to the load is maximum when the source internal impedance matches the load impedance. Thus, the impedance seen from the converter input side (can be adjusted by PWM control signal) needs to match the internal impedance of the solar array if the system is required to operate at or near the MPP of the solar array. If the system operates on the voltage source region (namely low impedance region) of solar array characteristic curve, the solar array terminal voltage will collapse (C. Hua and J. Lin, 2003).

From Fig. 2, it is observed that each curve has a maximum power point (MPP), which is the optimal point for the efficient use of the solar array.

The main function of a MPPT is to adjust the panel output voltage to a value which the panel supplies the maximum energy to the load (A. M. Torres, 1998).

3. Maximum power point tracker

In this work, for implementation of maximum power point tracker, a dc/dc boost converter working in continuous conduction mode is used as the power-processing unit. Switch S is PWM controlled with switching frequency of 33kHz generated by control signal Sc. The power flow is controlled by adjusting the on/off duty ratio of the switch S. Fig. 3 shows the schematic of the DC/DC converter implemented.

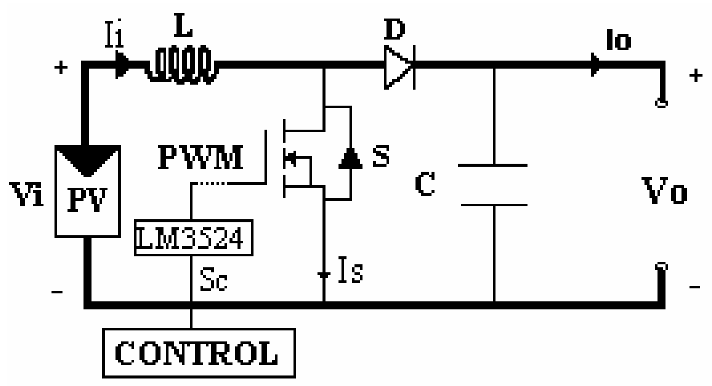

Fig. 3. Boost converter

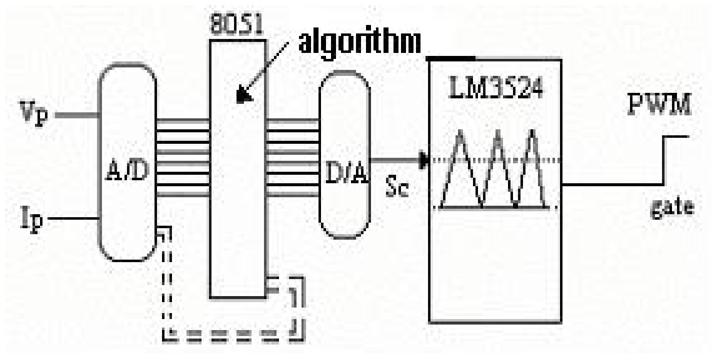

Fig. 4. Control circuit diagram

The MPPT control circuit is made up of a 80C51 microcontroller, a 8-bits analog-to-digital (A/D) converter and a 8-bits digital-to-analog (D/A) converter as shown in the Fig. 4. The control circuit compares the PV output power before and after a change in the duty ratio of the dc/dc converter control signal (Sc).

4. Control algorithm and experimental results

"To track, in real time, the maximum power point of the PV panel a simple algorithm based on perturbation and observation (P&O) method has been developed. The P&O method has been widely used because of its simple feedback structure and fewer measured parameters" (Chihchiang Hua and Chihming Shen, 1998).

Fig. 5 shows the flowchart of the implemented algorithm. By measuring the array voltage (V_P) and current (I_P) informations, the PV array output power is calculated and compared to the previous PV array output power. Initially on start up, the duty ratio is set to 0.1 and if the actual output power (P_A) is equal or bigger than previous measured output power (P_P), the control circuit increases the switch duty ratio. In case the actual power is smaller than previous measured power, the system decreases the duty ratio of the boost converter. Thus, the MPPT allows that the PV array to operate oscillating around the maximum power point.

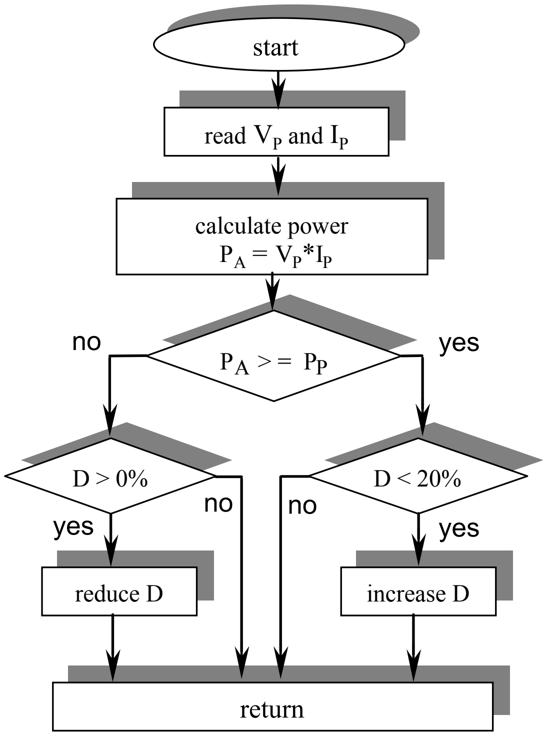

Fig. 5 Control algorithm flowchart

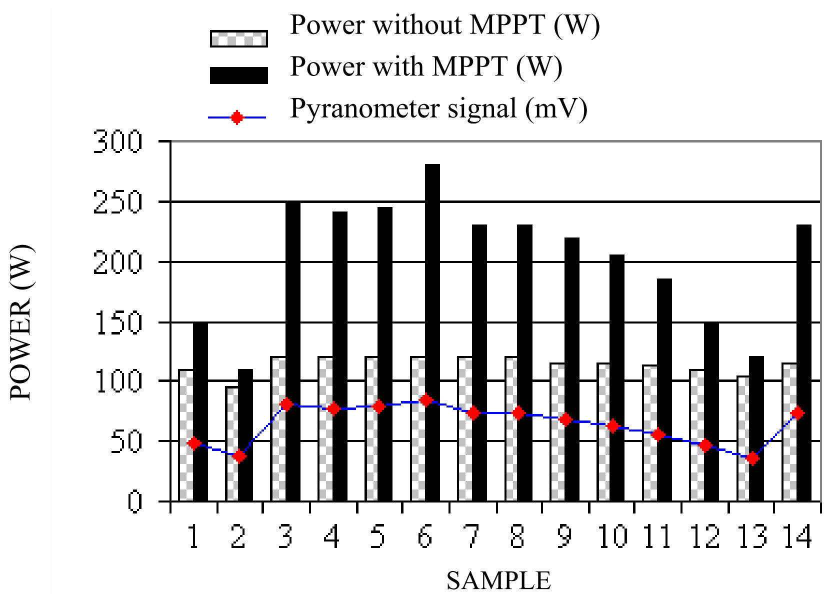

Fig. 6. Experimental results

A laboratory setup has been implemented in order to verify the performance of the maximum power point tracker here proposed. Two sets of experiments have been mounted.

Both of them are composed by seven series connected PV modules and mounted side by side. One is connected directly to a resistive load, and the other one is connected to a similar resistive load, but with the MPPT installed between the modules output and the load. During a specific day fourteen measurements were made. These measurements were the power dissipation at the load. Fig. 6 shows the results of the collected data. The experimental setup with the MPPT has provided more energy to the load. The MPPT has increased the PV panel capacity of energy supply to this load around 45%.

5. Conclusions

This work presented the design and laboratory implementation of a microcontrolled maximum power point tracker to allow, according to solar irradiance, the transfer of maximum energy generated by photovoltaic panel to the load. The main goal of this work is to increase the efficiency in comparison to systems that have not a MPPT, and thus to reduce the size and the cost of the PV panel. It consists of a DC/DC boost converter controlled by a single chip microcontroller that executes a perturbation and observation algorithm. The use of a microcontroller allows easy system modification, if additional renewable energy sources (e.g., more PV array) are used. The method has an advantage of unnecessarily knowing the solar array characteristics, thus it can be applied to all types of solar modules. Another advantages is that the system eliminates the reference cell used in other systems. It has been presented experimental results to show the performance of the designed MPPT.

Acknowledgment

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6. Appendix

DC/ DC converter design

The DC/DC boost converter has been designed according to characteristics described below:

- array A: 7 photovoltaic modules in series
- array B: 7 photovoltaic modules in series
- mounted panel: array A in parallel with array B
- DC/DC converter input voltage (V_I): 91 to 105 V
- DC/DC converter output voltage (V_O): 106 V
- swicthing frequency (*fs*): 33kHz
- panel peak power: 742 W_P (1000 W/m^2; 25^{0}C; AM 1.5)
- maximum output voltage ripple (ΔV_C): 5 %
- maximum input current ripple (ΔI): 20%

- continuous conduction mode

Below, are shown the basic equations necessary DC/DC boost converter design (Barbi, Ivo, and Martins, Denizar Cruz ,2000).

$$\frac{V_O}{V_i} = \frac{1}{(1-D)} \tag{1}$$

$$\Delta I = \frac{V_i \cdot D}{fs \cdot L} \tag{2}$$

$$\Delta V_C = \frac{I_0 \cdot D}{fs \cdot C} \tag{3}$$

For the specifications given and using Eq. (1), results:

$$0 \le D \le 0{,}41$$

Using Eq. (2), the inductance is determined:

$$\mathrm{L} = 238\ \mu H$$

With Eq. (3), the output capacitor is calculated:

$$\mathrm{C} = 5.64\ \mu F$$

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