Input Characteristic Impedance Technique of Power Converters Circuits Applied to the Maximum Power Point Tracker of Photovoltaic Panels

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***Abstract*—In this paper a maximum power point tracker (MPPT) method for photovoltaic (PV) panels using the input characteristic impedance (ICI) of power circuits is presented. The proposed MPPT algorithm employs just a single voltage sensor. Although the input impedance theoretically depends on its load resistance, it is shown that using the proposed algorithm the maximum available PV power is obtained without previous knowledge of the load resistance value. This technique can be applied to any dc-dc power converter circuit, mainly to the basic dc-dc converters as: Buck, Boost, Buck-Boost, Cúk, SEPIC, and Zeta. To validate the proposal method the Zeta power converter circuit was chosen.**

Keywords—power converter circuits; maximum power point tracker; PV panels; input characteristic impedance; Zeta converter.

I. Introduction

The photovoltaic (PV) system can be divided easily in three parts, comprising of PV panel, energy converter and load. The PV panel generates electric energy in a dc form and its characteristic curve, current versus voltage (I-V) varies according to the incident solar irradiance and the temperature, i.e., the power generated depends on these parameters, where the solar irradiance affects the current and the temperature affects the voltage.

The power converters are used to modify the PV panel energy source in an appropriate energy to be consumed by the load. In addition, power converters are used as Maximum Power Point Tracking (MPPT), since PV panels still have low efficiency, it is important to extract the maximum PV power available.

Several MPPT techniques have been studied and compared in the literature [1, 2, 3, 4]. Most require one or more of the following sensors: voltage sensor, current sensor, temperature sensor, solar irradiance sensor. Some are expensive and complex which sometimes are not worth the energy tracked.

This paper introduces a MPPT control algorithm called Input Characteristic Impedance (ICI) method, which uses only a single voltage sensor. It is based on the maximum power transfer theorem where the Input Characteristic Impedance of the DC-DC power converter circuit is modified to reach the Maximum Power Point (MPP) of the PV panel.

The MPPT algorithm calculates the power variation making the partial derivative of power in relation to voltage and Input Characteristic Impedance of the dc-dc power converter circuit. This technique can be applied to any dc-dc converter like: Buck, Boost, Buck-Boost, Cúk, SEPIC, and Zeta. To validate the new proposal the Zeta converter operating in Continuous Conduction Mode (CCM) was chosen. It will be shown, that the speed and accuracy to reach the MPP depends only on the variation of the power converter duty cycle.

II. Electrical Model of the PV Panel

The electrical modeling of the PV panel is represented as a voltage source E_{pv} in series with a dynamic resistance R_s. The model is shown in Fig. 1.

The resistance R_s is responsible for losses and it has a dynamic behavior, because its value changes for each operation region of the PV panel. E_{pv} is the internally generated voltage in the PV panel, and V_{pv} is the delivered voltage to the load.

III. Modeling of the DC-DC Power Converter Circuit

Fig. 2 exhibits an ideal lossless dc-dc power converter circuit, operating in Continuous Conduction Mode, with a fixed duty-cycle (D) and in steady state. Thus, $P_{in} = P_{out}$.

The dc-dc power converter circuit presents the relations between output voltages (V_o) and input voltage (V_{in}), and the relation between output current (I_o) and input current (I_{in}) given in (1) dependent only on the function of the duty-cycle (D). The input characteristic impedance is defined in (2) and using (1) in (2), achieve (3).

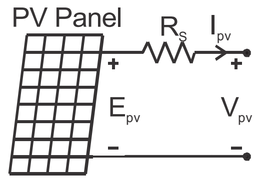

Fig. 1. PV panel as voltage source.

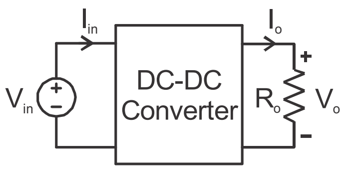

Fig. 2. DC-DC power converter circuit.

$$\frac{V_o}{V_{in}} = f(D) \qquad \frac{I_o}{I_{in}} = \frac{1}{f(D)} \tag{1}$$

$$Z_{in} = \frac{V_{in}}{I_{in}} \qquad Z_o = \frac{V_o}{I_o} \tag{2}$$

$$Z_{in} = \frac{1}{f(D)^2} Z_o \tag{3}$$

The impedance Z_{in} depends on the duty-cycle D and Z_o [4], where Z_o is firstly represented by a simple resistance R_o.

In this MPPT technique the model of the dc-dc power converter circuit is represented by its Input Characteristic Impedance, shown in Fig. 3, because the PV panel sees it like an impedance.

IV. Connection Between PV Panel and DC-DC Power Converter Circuit

Making use of the models described above, in Fig. 1 and Fig. 3, arrives to Fig. 4.

By applying a voltage divider in the circuit given in Fig. 4 we obtain the V_{pv}, as given in (4), and replacing the definitions of Z_{in} given in (3), the PV panel output voltage is given in (5).

$$V_{pv} = \frac{Z_{in}}{Z_{in} + R_s} E_{pv} \tag{4}$$

$$V_{pv} = \frac{R_o}{R_o + f(D)^2 R_s} E_{pv} \tag{5}$$

In the equation (5) for a given condition of solar incident irradiance and panel temperature, the internal voltage E_{pv} and the resistance R_s of the PV panel have a fixed value, and if the load R_o is constant, the input voltage of the converter V_{pv} depends only on the duty-cycle (D).

The insight of this method is based on the Maximum Transfer Power theorem, where the impedance Z_{in} has to have the same value of R_s to extract the maximum power available from PV panel to certain conditions of temperature and irradiance. The R_s and E_{pv} change all the time, because they depend on weather conditions, and to have the impedance Z_{in} equal to R_s it is only necessary to adjust de duty-cycle D.

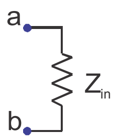

Fig. 3. Input characteristic impedance.

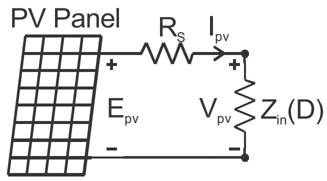

Fig. 4. PV panel connected to the Input Characteristic Impedance of the dc-dc power converter circuit.

V. MPPT Analysis

Equation (6) is employed to evaluate the power delivered by the PV panel to the dc-dc power converter circuit. It depends on the voltage V_{pv} and the impedance Z_{in}. Thus, applying the partial derivative to the power with respect to V_{pv} and Z_{in} into (6) leads to (7).

$$P = \frac{V_{pv}^2}{Z_{in}} \tag{6}$$

$$dP = \frac{2V_{pv}}{Z_{in}} dV_{pv} - \frac{V_{pv}^2}{Z_{in}^2} dZ_{in} \tag{7}$$

In (7) the variation of the Input Characteristic Impedance Z_{in} and the voltage V_{pv} of the dc-dc power converter circuit depend on the duty-cycle D.

Major MPPT techniques employ the relation between the power variation by voltage variation [5]. Thus, (7) can be rewritten as (8).

$$\frac{dP}{dV_{pv}} = \frac{2V_{pv_k}}{Z_{in_k}} - \frac{V_{pv_k}^2}{Z_{in_k}^2} \frac{dZ_{in}}{dV_{pv}} \tag{8}$$

To implement (8) in a microcontroller, an Euler method is used to discretely compute the derivative. It is employed as shown in the following approaches. The differential equations are given in (9).

$$\begin{cases} dV_{pv} = \Delta V_{pv(k)} = V_{pv(k)} - V_{pv(k-1)} \\ dZ_{in} = \Delta Z_{in(k)} = Z_{in(k)} - Z_{in(k-1)} \end{cases} \tag{9}$$

where (k) is a sampling instant index of the calculation step of the variables.

Through Fig. 5, it is noted that the maximum power point (MPP) is reached when (10) is satisfied. Then, equating to zero the right side of (8), and after mathematical simplification, (11) is obtained.

$$\frac{dP}{dV_{pv}} = \frac{\Delta P}{\Delta V_{pv}} = 0 \tag{10}$$

$$\frac{2\Delta V_{pv}}{V_{pv(k)}} = \frac{\Delta Z_{in}^*}{Z_{in(k)}^*} \tag{11}$$

Where: $$Z_{in(k)}^* = \frac{1}{f(D)^2} \tag{12}$$

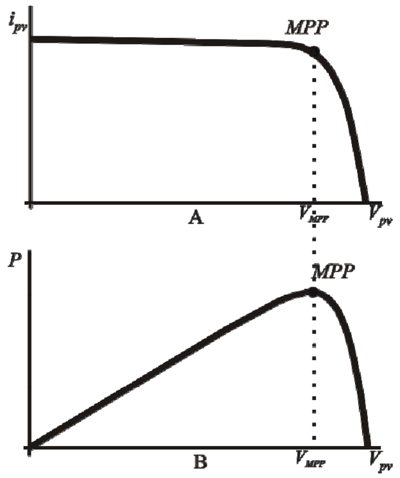

Fig. 5. Typical PV panels curve. (A) current i_{pv} versus voltage V_{pv}; (B) power P versus voltage V_{pv}.

and
$$\Delta Z_{in}^{*} = \frac{1}{f(D_k)^2} - \frac{1}{f(D_{k-1})^2} \tag{13}$$

Equation (12) gives the Input Characteristic Impedance (ICI) at sampling index k or $k - 1$, and this only depends on the duty-cycle D. This feature shows that with the ICI technique the MPP is achieved with no knowledge from the load resistance value R_o. Therefore, it is only required measure the dc-dc power converter circuit input voltage to have all argument necessary to satisfy (8), and the duty-cycle value is to compute to each step, leading the maximum power to the load at all time.

VI. Zeta Dc-Dc Power Converter Circuit

The dc-dc power converters circuits that can sweep the entire (I-V) plan of the PV panels are: Buck-Boost, Cúk, SEPIC and Zeta, because they have the function $f(D) = D$□$(1 – D)$ [3]. Zeta converter circuit, operating in a continuous conduction mode, was chosen to verify the Input Characteristic Impedance technique.

An isolated Zeta dc-dc power converter circuit with rated power of 1400 W and switching frequency of 50 kHz, shown in Fig. 6, was built to be submitted a sequence of different test in many conditions of temperature, solar irradiance and load.

VII. Experimental Results

The experimental results were acquired using a photovoltaic power module emulator MAGNA-POWER ELECTRONIC XR600-9.9. It was configured to emulate an array of PV modules connected in series. The PV module emulated was the solar module Kyocera KC200GT which its characteristics are depicted in Table I.

A. Condition of the test 1

- Irradiance: 500 W/m^2 to 1000 W/m^2;
- Temperature: 40 ^{o}C;
- Load: 110 Ω.

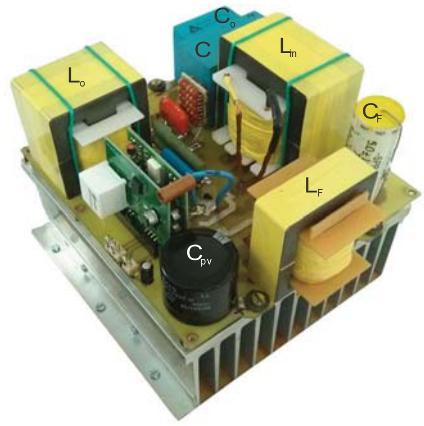

Fig. 6. Zeta dc-dc power converter circuit.

TABLE I. PV Panel Characteristics

Solar PV power module Kyocera KC200GT	
Rated Power (P_{max})	200 W
Open Circuit Voltage (V_{oc})	32.9 V
Short Circuit Current (Isc)	8.21 A
Voltage at MPP (V_{mp})	26.3 V
Current at MPP (I_{mp})	7.61 A
Temperature Coefficient of Isc	0.00318 A/^{o}C
Temperature Coefficient of V_{mp}	- 0.140 V/^{o}C
Irradiance = 1000 W/m^2 and of Temperature = 25^{o}C	

The first test, demonstrated in Fig. 7, consists of an abrupt increase irradiance step from 500 W/m^2 to 1000 W/m^2 after the PV system reached the MPP.

The MPP curves are overlapped with the curves generated when the duty-cycle vary the follow range $0.2 < D < 0.8$.

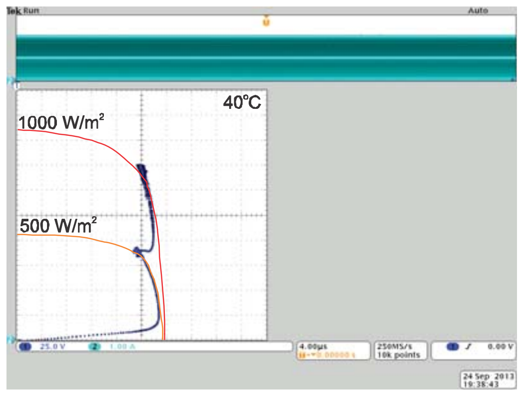

Fig. 7. Increased irradiance step.

B. Condition of the test 2

- Irradiance: 1000 W/m^2 to 500 W/m^2;

- Temperature: 40 °C;
- Load: 110 Ω.

The second test is exactly the opposite of the first one; it is depicted in Fig. 8 where after the PV system arrives to the MPP a step of 50% of irradiance is applied. When the system reached the smallest curve it continues on top until the new MPP.

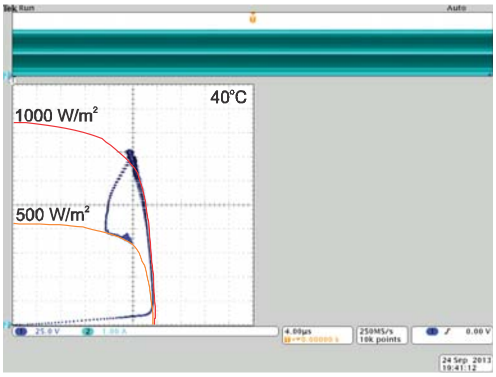

Fig. 8. Decreased irradiance step.

C. Condition of the test 3

- Irradiance: 1000 W/m^2;
- Temperature: 40 °C;
- Load: (55 Ω to 110 Ω) , and (110Ω to 55Ω).

In Fig. 9 the load step test is observed. It has two load steps, adding and removing 50% of the load. It is measuring the input voltage and current directly from PV panel, and the output voltage and current from the load.

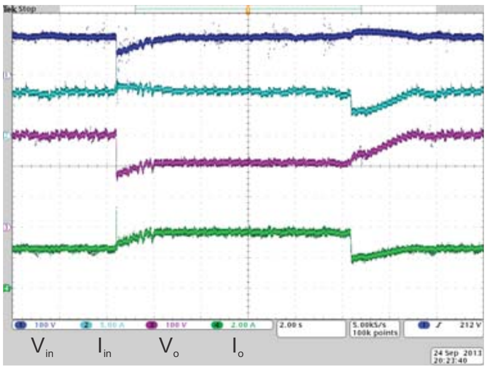

Fig. 9. Load step in time.

As soon after the Zeta power converter circuit puts the PV panel in a MPP, a step load is given. Firstly the load is increased, which means that the resistance is decreased. In the moment of the step, the input voltage falls and the input current grows. And as soon the ICI method detected that the PV panel is operating out of MPP, the algorithm calculates the new duty-cycle (D) to put the PV panel in the MPP again. This situation is representing by arrow 1 in Fig. 10. It is happens in anticlockwise.

Secondly, the load is removed, putting the system in original circumstance. In this case, the voltage input grows and the current input falls, and again the algorithm of the PV panel comes back to the MPP. The arrow 2 in Fig. 10 shows the direction of the trajectory, since the systems left the MPP until come back to it.

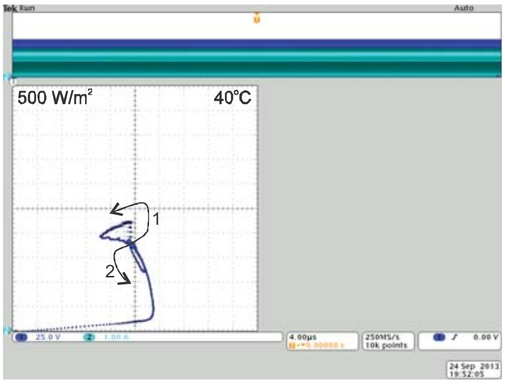

Fig. 10. Load step in (I-V) curve.

VIII. CONCLUSIONS

In this paper a new Maximum Power Point Tracking technique for photovoltaic systems employing just a single voltage sensor has been proposed. The MPPT is achieved by taking advantage of the steady state behavior Input Characteristic Impedance of the dc-dc power converter circuit, and the power derivative calculation based on such impedance. The Input Characteristic Impedance technique, called ICI method, does not use a current sensor, this potentially leads to less costs for such a PV system.

The Zeta converter circuit was chosen to validate the proposed technique. The extension to the others converters that have the same Input Characteristic Impedance such as: Cúk and Buck-Boot is straightforward. In spite of Buck and Boost converters do not sweeping the entire (IxV) plan of the PV panel, this technique can be applied to them. Experimental results validated the presented MPPT algorithm for several operating conditions.

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