MPPT Scheme for Small Scale Photovoltaic Systems using dSPACE

Abrez Mondal
Department of Electrical and Computer Engineering
North Dakota State University
Fargo, ND 58108
e-mail: Abrez.Mondal@my.ndsu.edu

Subbaraya Yuvarajan
Department of Electrical and Computer Engineering
North Dakota State University
Fargo, ND 58108
e-mail: Subbaraya.Yuvarajan@ndsu.edu

Abstract— **This paper presents a maximum power point tracking (MPPT) scheme for a small photovoltaic (PV) system. The algorithm for the proposed scheme has been formulated using the mathematical equations which describe the non-linear characteristics of a PV panel under different levels of insolation and temperature. The scheme uses only the open circuit voltage and short circuit current of the PV panel. The control strategy developed is simple and is implemented in Simulink using dSPACE. The scheme particularly suits small PV systems and is tested on a small PV panel illuminated by a sun-simulator assembly. The power-versus-voltage characteristics for the panel have been shown at different levels of insolation along with the tracked maximum power.**

Keywords- PV Panel; Maximum Power Point Tracking; Short-Circuit Current; Open-Circuit Voltage; dc-dc converter

I. INTRODUCTION

Solar or photovoltaic (PV) energy has gained increased attention as a prominent renewable energy source. The progress made in semiconductor technology has helped immensely in designing efficient solar panels which are used in power applications. Solar energy is considered as one of the primary renewable energy sources because it is abundant, pollution free and recyclable but the high initial costs involved in the installation of PV systems has so far hindered its extensive usage. Moreover, the non-linear characteristics of the PV panels call for the implementation of complex control algorithms. The electrical power derived from PV panels is greatly affected by the prevailing atmospheric conditions such as illumination level and temperature. The maximum power (MPP) of the panel increases with insolation and decreases with ambient temperature. Many harvesting schemes for maximum power point tracking (MPPT) are based on a perturbation and observation (P&O) technique [1], [2]. But the main disadvantage of the P&O approach is that it leads to lot of oscillations. Some approximate methods also exist which use the linearity between current at MPP and the short-circuit current [3].

This paper develops a control scheme for implementing the MPPT equation which is derived from the open-circuit voltage and the short-circuit current of a solar panel [4]. The power circuit uses a pulse width modulated (PWM) DC/DC buck-boost converter between the solar panel and the load. The MPPT is realized by sensing the short-circuit current and the open-circuit voltage and adjusting the duty-cycle of the buck-boost converter and hence the converter output current such that the MPPT equation holds. The control algorithm is modeled using Simulink and the PWM pulses for the DC/DC converter are generated using dSPACE [5].The proposed method focuses on the delivery of maximum power under all environmental conditions and eliminates complex control circuitry for the MPP tracker resulting in an efficient and inexpensive PV system.

II. MATHEMATICAL ANALYSIS

The approximate expression for the output current I_{PV} of a PV panel at any operating point is given by [2]

$$I_{PV} = I_{sc} - I_s exp(KV_{PV}) \qquad (1)$$

where V_{PV} is the voltage across the PV panel, I_{SC} is the short-circuit current, I_S is the dark saturation current and K is a constant that depends on the panel temperature and arrangement of cells in the panel.

The power output of the PV panel is given by

$$P_{PV} = V_{PV}\, I_{PV.} \qquad (2)$$

Combining (1) and (2),

$$KP_{PV} = I_{PV}\, ln\, [(I_{SC} - I_{PV})/I_s]. \qquad (3)$$

For obtaining the value of current (I_{MP}) at MPP, (3) is differentiated with respect to I_{PV} and equated to zero giving

$$I_{MP} = (I_{SC} - I_{MP})\, ln\, [(I_{SC} - I_{MP})/I_s]. \qquad (4)$$

The dark saturation current of the PV panel can be expressed as

$$I_S = I_{or}\, (T/T_r)^3 exp[(qE_{go}\, /Bk)(1/T_r\, - 1/T)] \qquad (5)$$

where I_{or} is the cell's reverse saturation current at a reference temperature T_r (=298K), T is the cell temperature in Kelvin, E_{go} is the band gap for Silicon in eV, q is the electron charge, B is ideality factor and k is Boltzmann's constant.

The open-circuit voltage V_{OC} (T) at temperature T can be expressed as

$$V_{OC}\, (T) = V_{OC}\, (T_r) + \alpha(T - T_r) \qquad (6)$$

where $V_{OC}\, (T_r)$ is the open-circuit voltage at a reference

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temperature T_r and α is the temperature coefficient of V_{OC} .

The term $(T/T_r)^3$ in (5) can be approximated as 1 in the practical temperature range of the PV panel. With the above approximation, the resulting equation for tracking maximum power point becomes

$$I_{MP} = (I_{SC} - I_{MP})\left[\ln(I_{SC} - I_{MP}) + B_1 + \left(\frac{C_1}{V_{OC}(T) - A_1}\right)\right] \quad (7)$$

where, $A_1 = V_{OC}(T_r) - \alpha T_r$

$B_1 = -\,ln\,(I_{or}\,exp(qE_{go}/BkT_r))$

$C_1 = \alpha\, qE_{go}/Bk$.

III. PRACTICAL IMPLEMENTATION

Equation (7) has to be implemented in order to track the MPP of the solar panel. As can be observed from (7), the MPPT control circuit will force the PV system to operate at the optimal current I_{MP} so that the load will receive the maximum power from the PV panel. In order to track the MPP of the panel, both the short-circuit current and the open-circuit voltage of the panel have to be sensed. The parameters for the different blocks have been calculated using the data for the panel under test.

A. Power Circuit

The power circuit of the proposed scheme is shown in Fig.1. The output voltage of the panel is applied to the buck-boost converter made up of the MOSFET M, inductor L, capacitor L and diode D as shown in Fig. 1. Between the panel and the DC/DC converter a small resistance R_{se} is inserted for current measurement. Also, a potential divider assembly consisting of R_1 and R_2 is used for measuring the open-circuit voltage $V_{oc}(T)$. The buck-boost topology has been chosen to cater to different loads at different voltages. In Fig.1 the load shown is a resistor and the power converter operates in the buck mode. For applications such as charging batteries at higher voltage levels, boost action is required.

B. Control Scheme

The Simulink model of the control scheme is shown in Fig. 2. Equation (7) suggests that in order to implement the MPPT equation, the short-circuit current and the open-circuit voltage of the panel needs to be sensed at regular intervals of time. The current and voltage are sensed through the dSPACE blocks DS1104ADC_C5 and DS1104ADC_C6 respectively. Both the blocks are connected to the output ports of the dSPACE controller board CP1104. The same block DS1104ADC_C5 is used for sensing both the instantaneous current and the short-circuit current. The blocks "V_{oc} Measurement" and "I_{sc} Measurement" (Fig. 2) measure the values of V_{oc} and I_{sc} once in an interval of 800ms and hold the values until the the next measurement takes place.

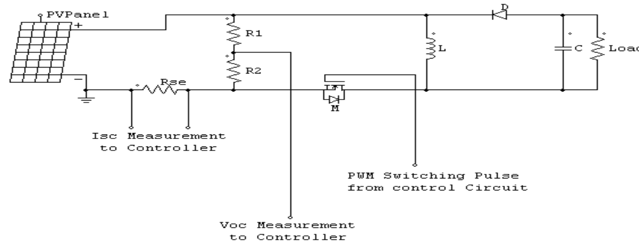

Fig. 1 Power Circuit of proposed scheme

The normal PWM pulses to the MOSFET M generated by the control scheme is stopped for a period of 2300μs in an interval of 800ms for measuring the values of V_{oc} and I_{sc}. The measuring period is divided into two separate durations within each cycle of 800ms. The first duration of 800μs is used for I_{sc} Measurement. A long pulse is applied to the MOSFET during this time so that the inductor current reaches its steady-state value and this current represents the short-circuit current. During the second duration of 1500μs of the measuring period, the pulses to the MOSFET are blocked and this condition represents the open-circuit state. The open-circuit voltage V_{oc}(T) is measured across R_2 using the potential divider arrangement. Sufficient time is allowed for the circuit to reach steady-state condition so that both V_{oc} and I_{sc} measurements are done correctly. In our case, the measuring period is only 2300μs in an interval of 800ms so that the PV power is unavailable for only 0.29% time. In the Simulink model, the two blocks "Short-circuit Pulse Generator" and "Open-circuit Pulse Generator" generate pulses of durations 800μs and 1500μs respectively once in

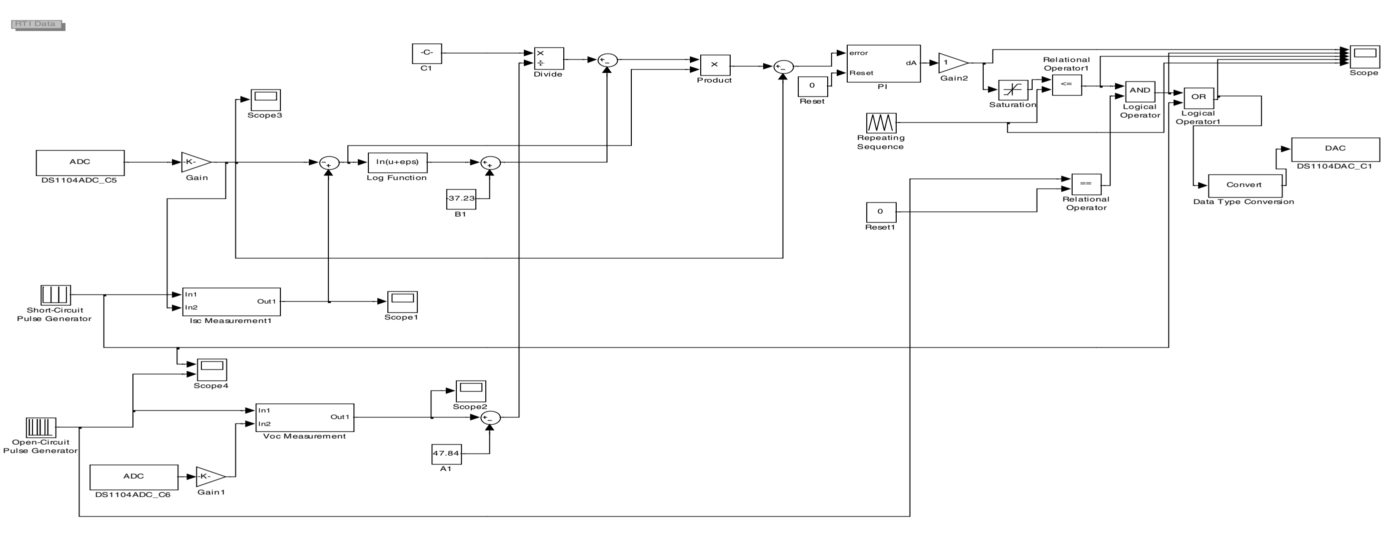

Fig. 2 Simulink Model of Control Scheme

each 800ms. The pulses of "Short-circuit Pulse Generator" are fed as the on-time pulse for "I_{sc} Measurement" block for recording the short-circuit current (Fig. 2). The "I_{sc} Measurement" subsystem of Simulink model has been shown in Fig. 3. There are two inputs to the subsystem. The first input (In 1) is the output of "Short-circuit Pulse Generator" and the second input (In 2) is the value of current through the measuring resistance R_{se}. The block "Switch Case Action Subsystem I" collects the value of In 2 until the pulse (In 1) is high and gives the last stored value of In 2 as output of "I_{sc} Measurement" subsystem once the pulse (In 1) goes low. The "V_{oc} Measurement" subsystem is exactly the same as the "I_{sc} Measurement" subsystem. The on-time pulse for "V_{oc} Measurement" block generated by the "Open-circuit Pulse Generator" serves as In 1, and In 2 is the voltage measured across R_2.

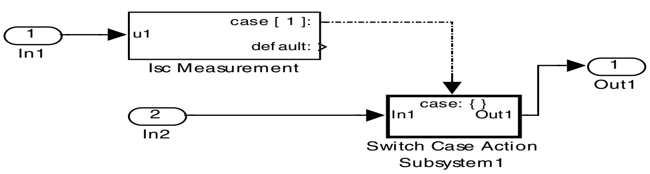

Fig. 3 "I_{sc} Measurement" block in Simulink

The inverse (complement) of the output of "Open-circuit Pulse Generator" block and the PWM pulses are first passed through a logic AND operation to ensure no pulses are fed to MOSFET M during open-circuit voltage measurement. The resulting signal is added (through logic OR operation) with output of "Short-circuit Pulse Generator" to apply a long pulse in order to measure short-circuit current. The resulting signal is the final gate signal to the MOSFET M which is sent out through the block DS1104DAC_C1.

IV. CALCULATIONS FOR PV PANEL

The proposed MPPT algorithm is implemented on a 15W PV panel. The maximum short-circuit current value of the panel is 1A. The panel is made of polycrystalline silicon for which the E_{go} value is 1.21eV. The reverse saturation current value for the panel at a reference temperature of 298K is given as 50μA. The temperature coefficient of V_{oc} for the panel is -80mV/K and the $V_{oc}(T_r)$ value at T_r= 298K is 24V for the chosen panel. A_1, B_1 and C_1 have been calculated as:

A_1= 47.84, B_1= -37.23 and C_1= -1123.72.

The power-versus-voltage characteristics of the solar panel under test are plotted for five different values of insolation level using MATLAB. The different insolation levels were obtained by varying the distance of the panel from the sun-simulator lamps (two 1kW lamps serving as the source of light). The level of insolation decreases with increasing distance of the panel from the light source while all other ambient conditions remain the same. The characteristics for the panel are shown in Fig. 4 in which the insolation level 1 is the highest and 5 is the lowest. The corresponding open-circuit voltage and short-circuit current values for the five levels are listed in Table I.

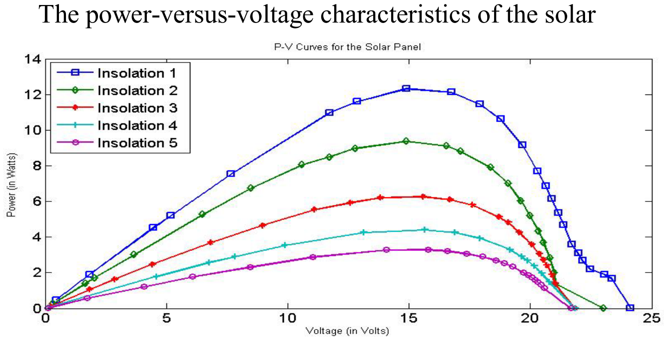

Fig. 4 Power-versus-voltage curves for the PV panel

TABLE I. PANEL CHARACTERISTICS

Insolation Level	Open-Circuit Voltage (in Volts)	Short-Circuit Current (in Amperes)
1	24.13	1.061
2	23.03	0.86
3	21.84	0.579
4	21.85	0.405
5	21.66	0.308

V. RESULTS

The proposed control scheme was implemented using dSPACE. The same five insolation levels used for plotting the panel characteristics were maintained for testing the MPPT scheme and the maximum power obtained from the panel at each insolation level during testing is compared with the actual value of maximum power at that level.

TABLE II. MAXIMUM POWER POINT VALUES

Insolation Level	Maximum Power from Characteristics (in Watts)	Maximum Power tracked by the Scheme (in Watts)
1	12.33	11.28
2	9.38	8.43
3	6.27	5.11
4	4.42	4.2
5	3.3	3.3

VI. CONCLUSION

In this paper, an approximate 'MPPT equation' is derived and a control scheme based on the equation is implemented using Simulink (MATLAB) and dSPACE and the results are compared with the actual values obtained from the panel characteristics. The minor discrepancies in the maximum power values can be due to the use of approximate MPPT equations instead of the actual ones.

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