

Efficiency Model Of DC/DC PWM Converter Photovoltaic Applications

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This paper presents a DC/DC PWM converter for photovoltaic application. Firstly, a simulation solarex MSX60 PV module current-voltage and power-voltage characteristics at various lights and temperature levels have been presented. Next, the ratio between the load voltage and the open circuit voltage of a PV panel at maximum power point is nearly constant for different lights levels and this property is utilized in designing a simple maximum power point tracking controller. Finally, a model of a boost DC/DC PWM converter is constructed taking into account the conduction losses, the switching losses, the diode power loss, the gate drive loss and the capacitive switching losses, for both the continuous conduction model (CCM) and discontinuous conduction mode (DCM) are presented. The simulation results are carried out using Matlab/Simulink.

1. INTRODUCTION

Solar energy is one the most effective, less expensive, harmless and less environmental pollution effect of renewable energy sources. The utilization of solar energy can be categorized in two ways: solar heating/cooling and solar electricity. This energy can be converted into electrical energy through implementation of photovoltaic array. Recently, photovoltaic (PV) systems application is well recognised and widely used in electric power technologies [1]. Unfortunately, PV system has its own drawbacks, which are mainly due to high cost of manufacturing silicon solar panels and the low conversion efficiency. With the newer techniques of manufacturing crystalline panels and efficient power converter design, it's possible to make the PV project cost-effective.

A PV system is a non-linear power source, its output current/power depends on the terminal operating voltage on the other hand, the maximum power generated by the system changes with lights and temperature levels [2-4]. The maximum power point tracking (MPPT) method is simple and is based on the relationship that exist between the load voltage and the open-circuit voltage of PV panel at maximum power point is nearly constant for different lights levels, it's known as constant voltage method.

The DC/DC boost PWM power converter systems are widely used to obtain a voltage higher than the source one. During the design step, the efficiency of such converter can be accurately predicted only if the main dissipation sources are considered. Over the last two decades various approaches to modelling DC/DC PWM converter for CCM and DCM have been developed, in reference [5] only the conduction losses were analysed and the ripple of the inductor current was neglected, while in reference [6] switching losses were ignored. Moreover, a method for including parasitic components has been considered in reference [7], but, unfortunately, capacitive switching losses, as well as, gate drive loss, were ignored.

This paper presents, Firstly, modelling and simulation, which begin with the solar cell characteristics simulation in various light and temperature levels. Next, the simulation MPP technique using constant voltage method

and finally, a thorough efficiency analysis of boost DC/DC PWM converter is carried out. In particular, relationship that take into account the conduction losses, the switching losses, the diode power loss, the gate drive loss and the capacitive switching losses, for both the continuous conduction mode (CCM) and discontinuous conduction mode (DCM) are given.

2. SOLAR ARRAY MODEL

To investigate current-voltage characteristics of PV array and maximum power point location for certain parameter variation, the solarex MSX60, a typical 60W PV module, was chosen for modelling. The module has $N_s=36$ series connected polycrystalline cells. The circuit diagram for solar cell is shown in fig.1 [1]. The output of the current source is directly proportional to the light falling on the cell which is known as photocurrent.

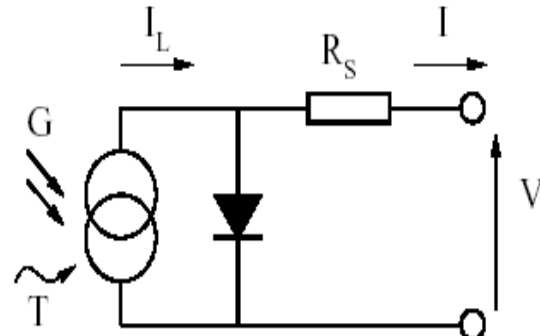


Figure 1: The circuit diagram of the PV model.

The equation that represents I-V characteristics of PV array can be derived,

$$I = I_L - I_0(e^{q(V+IR_s)/nk} - 1) \quad (1)$$

$$I_L = I_L(T_1)(1 + k_0(T - T_1)) \quad (2)$$

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$$I_L(T_1) = \frac{G}{G_{nom}} I_{sc}(T_1) \quad (3)$$

$$k_0 = \frac{(I_{sc}(T_2) - I_{sc}(T_1))}{(T_2 - T_1)} \quad (4)$$

$$I_0 = I_0(T_1) \cdot \left(\frac{T}{T_1}\right)^{3/n} \cdot e^{-qV_g/nk \cdot (\frac{1}{T} - \frac{1}{T_1})} \quad (5)$$

$$I_0(T_1) = \frac{I_{sc}(T_1)}{(e^{qV_{oc}(T_1)/nkT_1} - 1)} \quad (6)$$

$$R_s = -dV / dI_{V_{oc}} - 1 / X_V \quad (7)$$

$$X_V = I_0(T_1) \cdot q / nkT_1 \cdot e^{qV_{oc}(T_1)/nkT_1} - 1 \quad (8)$$

Where the suffix ‘nom’ refers to rated lights at standard test condition given by: $G=1000\text{w/m}^2$, $T_1=25^\circ\text{C}$ and A.M 1.5 while $I_{sc}=3.8\text{A}$ and $V_{oc}=21.06/\text{Ns}$.

V_g : Bandgap of the semiconductor (V),
 k : Boltzmann constant ($1.38 \cdot 10^{-23}\text{J/K}$),
 G : Solar irradiance W/m^2 ,
 n : Ideality factor of the PV module,
 q : Magnitude of the electron charge ($1.6 \cdot 10^{-19}\text{C}$),
 R_s : Series resistance of the PV module (Ω),
 T : PV module temperature (K),
 V_{oc} : Open-circuit voltage (V),
 I_{sc} : Short circuit current (A),
 I_L : Photocurrent (A),
 I_0 : Diode saturation current (A).

3. CONSTANT VOLTAGE METHOD

The basis for the constant voltage algorithm is the observation from I-V curves, that the ratio of the array’s maximum power voltage, V_{op} , to its open circuit voltage, V_{oc} , is approximately constant.

$$\frac{V_{op}}{V_{oc}} = K < 1 \quad (9)$$

It’s difficult to choose the optimal value of the constant K. The literature reports success with K values ranging from 73 to 80% [4]. This method is suitable for location having small variations in environmental conditions.

The main function of a MPPT is to adjust the panel output voltage to a value which supplies maximum energy to the load.

4. ANALYSIS OF DC/DC PWM CONVERTER

The conventional schematic of a boost DC/DC PWM converter is shown in figure 2, the circuit consists of a control block, a switch (MN), a diode (D_1), inductor (L), a filter capacitor (C) and a load resistance (R). Input side of the converter is connected to the PV system.

An expression relating the input and output voltage can be obtained in CCM, using fundamental circuit equation:

$$M = \frac{V_o}{V_i} = \frac{1}{1-D} \quad (10)$$

Where D is defined as the duty cycle of the switch, which is the ratio of ‘on’ time to the switching period ($T_s=1/f_s$) [9-10].

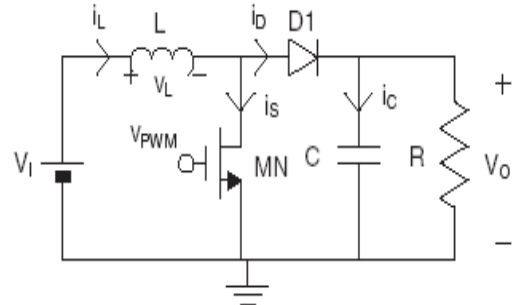


Figure 2: DC/DC boost converter topology.

The analysis of the boost DC/DC converter is based on the following assumptions:

- Transistor MN is modelled as a linear resistance, R_{DSN} .
- The diode is modelled as a series combination of a constant voltage, V_D , and a linear resistance, R_D .
- The inductor and capacitor have the equivalent series resistances, R_L and R_C .
- Power losses in the control circuit are neglected.

Hence, the equivalent circuit of the DC/DC PWM converter taking into account the losses is shown in figure 3.

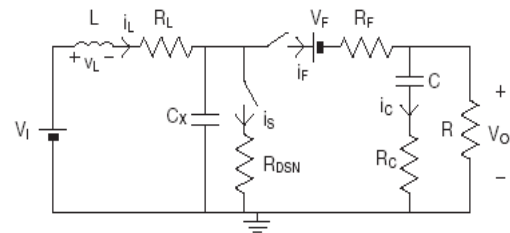


Figure 3: DC/DC PWM boost converter equivalent circuit.

The boost converter has two operating mode, characterized by the current waveform of the inductor. These modes referred to as continuous conduction mode or discontinuous conduction mode.

4.1. Continuous conduction mode

The conduction loss in the inductor is

$$P_{R_L} = R_L \cdot I_{L,rms}^2 \quad (11)$$

Where $I_{L,rms}$, the root mean squared current through the inductor which can be evaluated by,

$$I_{L,rms} = [(M \cdot I_0)^2 + \frac{\Delta I_L^2}{12}]^{1/2} \quad (12)$$

I_0 is the output current through the load and ΔI_L the ripple of the inductor current, given by,

$$\Delta I_L = \frac{V_0 \cdot (M - 1)}{L \cdot f_s \cdot M^2} \quad (13)$$

The power loss in the capacitor due to its equivalent series resistance, R_C

$$P_{R_C} = \frac{R_C}{M} I_L^2 - R_C I_0^2 \quad (14)$$

The diode power loss is

$$P_D = V_D I_0 + \frac{R_D}{M} I_L^2 \quad (15)$$

The power loss in the transistor, MN, depends on four dissipation sources. The first is the conduction loss, P_s , in the resistance R_{DSN} , which is calculated by

$$P_s = R_{DSN} \frac{M - 1}{M} \cdot I_L^2 \quad (16)$$

If the switching frequency is low enough so that the others losses as the switching loss, the gate drive loss and capacitive switching loss are neglected. Under this assumption, the approximate efficiency, η_{CCM} , can be evaluated as

$$\eta_{CCM} = \left\{ 1 + \frac{V_D}{V_0} - R_C \frac{I_0}{V_0} + \frac{I_0}{V_0} [R_L + R_{DSN} + \frac{V_i}{V_0} (R_D + R_C - R_{DSN})] \cdot \left[\left(\frac{V_0}{V_i} \right)^2 + \frac{(V_0 - V_i)^2 \cdot V_1^2}{12(L \cdot f_s \cdot I_0 \cdot V_0)^2} \right] \right\}^{-1} \quad (17)$$

4.2. Discontinuous conduction mode

The same procedure used in the previous section can be applied to model the converter in the DCM. In particular, relationships (11) and (15)-(17) still hold, but the expression of the current $I_{L,rms}$ is given by,

$$I_{L,rms} = I_0 \cdot \left[\frac{8 \cdot M \cdot (M - 1) V_0}{9 \cdot L \cdot f_s I_0} \right]^{1/4} \quad (18)$$

Hence, the efficiency during the DCM is given as,

$$\eta_{DCM} = \left\{ 1 + \frac{V_D}{V_0} - R_C \frac{I_0}{V_0} + \frac{I_0}{V_0} [R_L + R_{DSN} + \frac{V_i}{V_0} (R_D + R_C - R_{DSN})] \cdot \left[\left(\frac{V_0}{V_i} \right)^2 + \frac{V_0}{V_i} \sqrt{\frac{8 \cdot (V_0 - V_i)}{9 \cdot L \cdot f_s I_0}} \right] \right\}^{-1} \quad (19)$$

5. RESULTS SIMULATION

The outputs current / power of the Matlab/ Simulink is shown for various lights levels (figure 4 and figure 5), and then for various temperatures (figure 6 and figure 7).

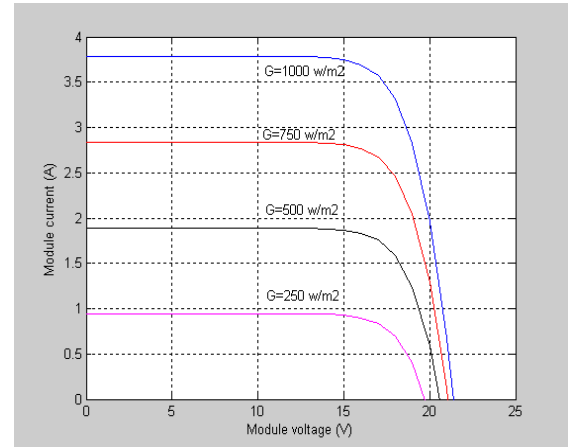


Figure 4: Typical V-I curves for various lights levels.

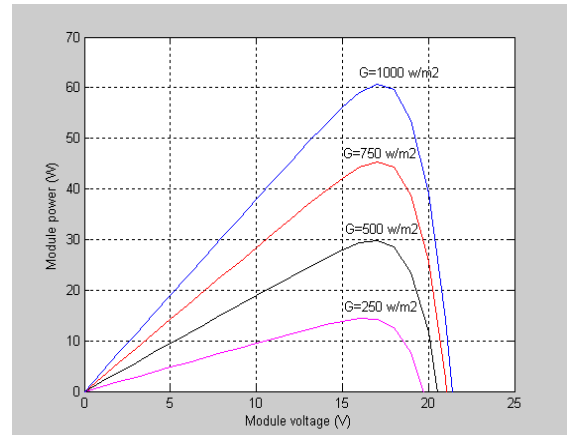


Figure 5: Typical V-P curves for various lights levels.

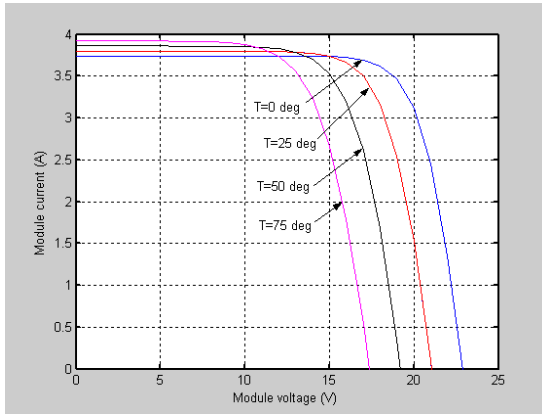


Figure 6: Typical V-I curves for various temperatures.

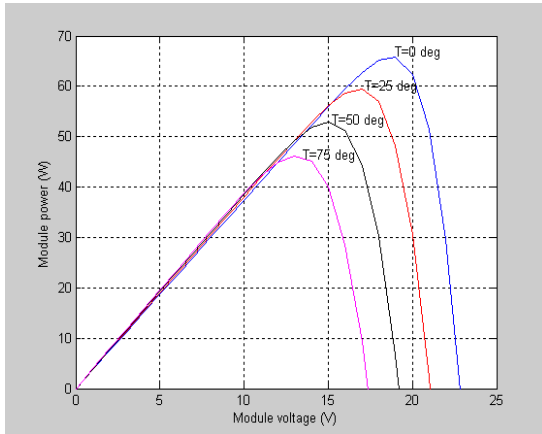


Figure 7: Typical V-P curves for various temperatures.

An estimate must be made of the unknown ideality factor, it takes a value between $1 < n < 2$, being near one at high current, rising towards two at low current, as seen in figure 8.

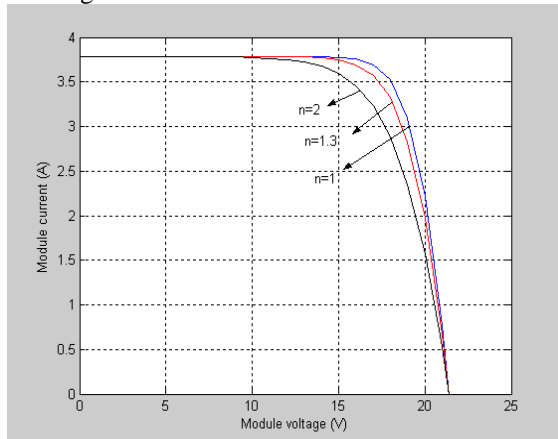


Figure 8: Typical V-I curves for various diode quality factor.

The series resistance of the panel has a large impact on the slope of V-I curve at $V=V_{oc}$, it calculate by differentiating equation (11), at $V=V_{oc}$, as seen in figure 9.

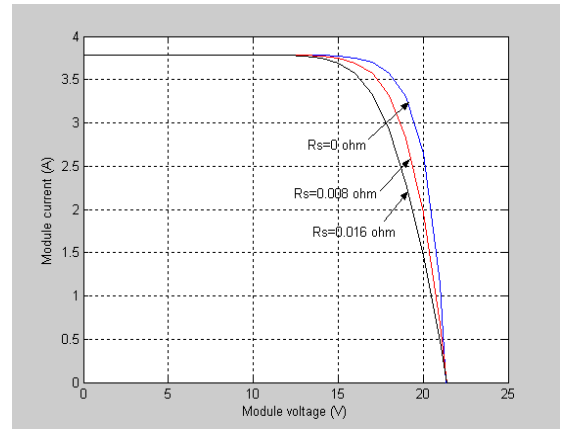


Figure 9: Typical V-I curves for various series resistances

In order to validate the previously developed, model of the boost DC/DC PWM converter was designed. Circuit parameters are reported in Table 1 [10].

Table 1: Circuit parameters.

Parameters	Value
L, R_L	$10 \mu H, 100 m\Omega$
C, R_C	$47 \mu F, 20 m\Omega$
V_D, R_D	$230 mV, 230 m\Omega$
R_{DSN}	$230 m\Omega$
f_s	$230 KHz$

The output voltage and the inductor current waveforms of the boost DC/DC PWM converter operated at CCM are depicted in figure 10 and figure 11. But, figure 12, shows the efficiency, evaluated by equations (17) and (19), versus output current, I_o , with input voltage, as parameter. When the high efficiency is the main goal, the DC/DC PWM converter must always operate in DCM.

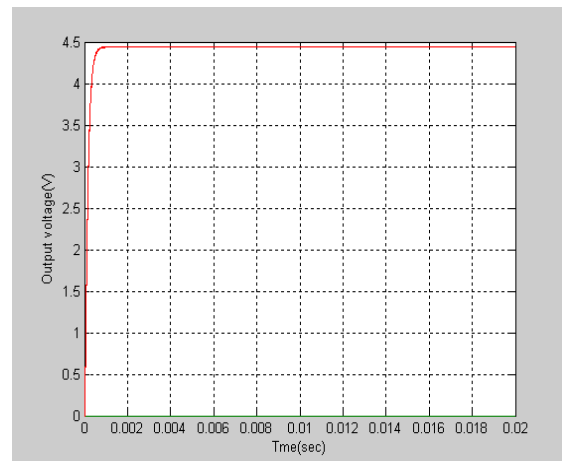


Figure 10: Output voltage of boost DC/DC PWM converter.

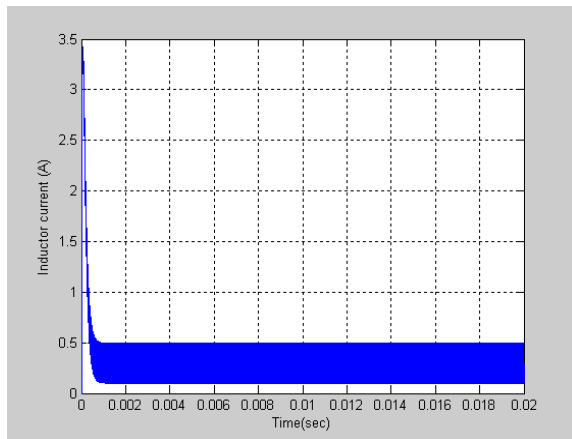


Figure 11: Inductor current of boost DC/DC PWM converter.

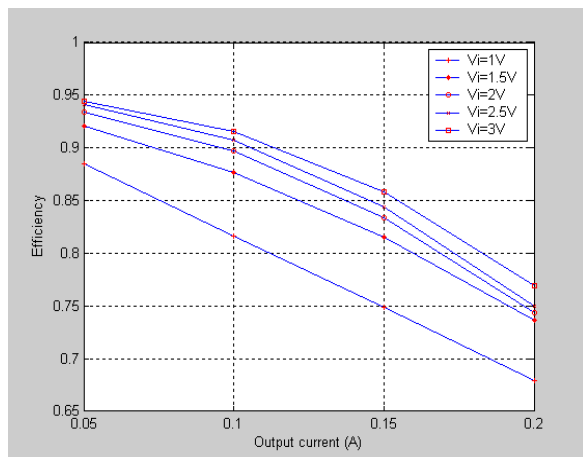


Figure 12: Efficiency of boost DC/DC PWM converter.

6. CONCLUSION

In this paper, an accurate PV module electrical model is presented and demonstrated for a typical 60W solar panel. A detailed efficiency analysis of a boost DC/DC PWM converter taking into account all the chief sources of dissipation, for both CCM and DCM are carried out. The proposed expressions can help designer for designing a PWM converter operated with the highest efficiency for a given applications.

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