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Modeling and a MPPT Method for Solar Cells

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Abstract: This study presents the construction of a model for PV panel and tracking the maximum power point using constant voltage control method. This model takes into account the series and parallel (shunt) resistances of the panel. The equivalent circuit and the basic equations of a PV cell panel in Standard Test Conditions (STC), as well as parameters extraction from the data sheet values are shown. Based on these equations, a PV panel model for Solarex MSX60, which is able to predict the panel behavior in different temperature and irradiance conditions is built. Photovoltaic module or solar module consists of many solar cells which are electrically connected and placed between glass and tedlar plate and framed by an aluminium frame. A solar module and number of other components (batteries, charge regulators, inverters, etc) form large photovoltaic systems. The model of a photovoltaic module consisting of 36 solar cells is presented in this study.

Key words: Modeling, Maximum Power Point Tracking (MPPT), Photovoltaic (PV), Voltage Based Maximum Power Point Tracking (VMPPT)

INTRODUCTION

Solar arrays are used in many terrestrial and space applications. For best utilization, the photovoltaic cells must be operated at the maximum power point. However the maximum power point varies with illumination, temperature, radiation and other ageing factors (Green, 1982).

Insolation level, cell temperature and array voltage set the limits at the maximum power available from PV array. The influence of all future parameters can be minimized accordingly. The limit imposed by insolation levels on the available PV power can be relieved by the use of solar path tracker, while the limit imposed by the cell temperature on the PV system may be relieved by improved thermal conductivity between PV cells and the environment. However, the insolation levels and the cell temperature determine only the best obtainable matching.

The array voltage determines the real matching. The mismatch can be improved by the use of a peak power point tracker converter to track the maximum power point in PV response range of the PV panel.

SOLAR CELL MODEL DEVELOPMENT

The theoretical models of the solar cell are derived from solid state physics theory. The starting point for the derivation of basic solar cell equation is pn junction.

The DC model of solar cell shown in Fig. 1 (Rauschenbach, 1980) can be written as:

$$I_L=I_{ph}-I_0\{\exp[e(V+I_LR_{se})/AKT]-1\}-V/R_{sh} \quad (1)$$

It can be re-written as follows:

$$I_L=I_{ph}-I_0\{\exp[K_0(V+I_LR_{se})]-1\}-V/R_{sh} \quad (2)$$

This equation can be solved to obtain V as

$$V = Rsh[I_{ph}-I_L- I_0\{\exp[e(V+I_LR_{se})/AKT]-1\}] \quad (3)$$

Where,

$$K_0 = e/AKT$$

The V-I and the P-V characteristics for the above shown model are obtained using the following equations in MATLAB.

$$i_l = I_{ph}/I_{sc} \quad (4)$$

$$i_0 = I_r/I_{sc} \quad (5)$$

$$r_s = [\log((i_l+i_0-1)/i_0)]/ \quad (6)$$

$$r_p=1/[i_l+i_0-(i_0*\exp(x))] \quad (7)$$

Where,

$$x = K_0*V_{oc}$$

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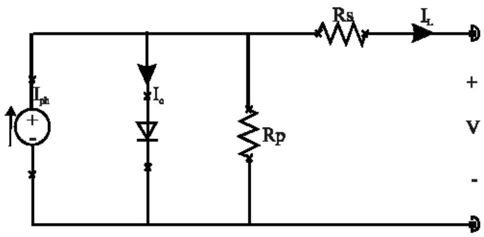

Fig. 1: DC model of solar cell

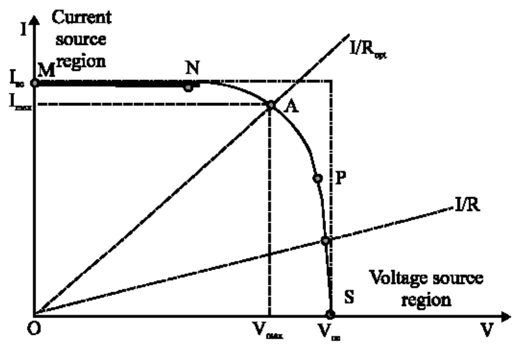

Fig. 2: I-V Characteristic of solar module

Thus we have,

$$R_{sh}=V_{oc}*r_p/I_{sc} \quad (8)$$

$$R_{se}=V_{oc}*r_s/I_{sc}\ldots \quad (9)$$

By substituting the values of R_{sh} and R_{se} and other constants from datasheet values, we get the values of voltage and current. The V-I and the P-V, model characteristics for the PV model will be as shown in Fig. 2 and 3.

MAXIMUM POWER POINT TRACKING TECHNIQUE

Constant Voltage (CV) MPP tracking algorithm: This method (Trishan and Patrick, 2007) is based on the observation that MPP voltage (Vmp) has almost a linear relation with open-circuit voltage (Voc) of the PV panel.

$$Vmp = Mv*Voc \quad (10)$$

Where Mv, called the voltage factor is equal to 0.71 for the silicon panel and has different values for different solar panels ranging from 71-86%.

The PV panel is locked at the reference voltage given by Eq. 10. The open-circuit voltage required to determine the MPP voltage can be measured by disconnecting load from the PV panel after regular intervals. The measured values of Voc and Mv are stored and used for the determination of PV panel Voltage (V). To operate the panel at MPP, the actual PV panel voltage V, is compared with the reference voltage Vref, which corresponds to the MPP voltage Vmp. The error signal is processed to make V = Vref. The error signal is used to change the duty cycle of a dc-dc converter, interfaced between the PV panel and the load, so as to make the PV panel voltage equal to the MPP voltage as shown in Fig. 4.

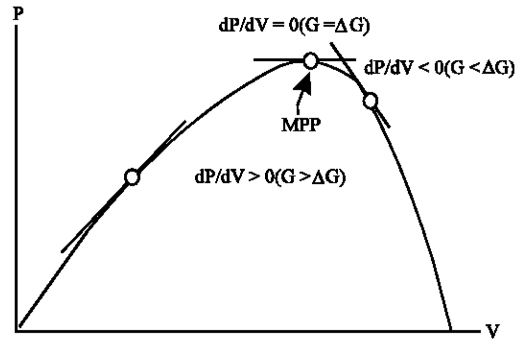

Fig. 3: The P-V curve

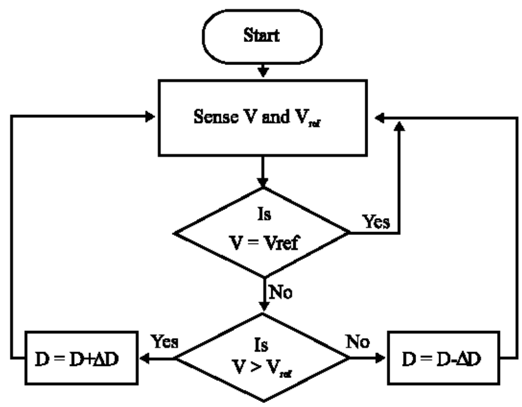

Fig. 4: Flow chart for constant voltage algorithm

Simulation of Constant Voltage (CV) MPPT algorithm: The PV panel is formed by the combination of many PV cells connected in series and parallel to provide the desired output voltage and current. The PV panel exhibits a nonlinear insolation dependent V-I characteristic, mathematically expressed for the solar cell array consisting of N_s cells in series and N_p cells in parallel as shown in Eq. 11

$$I = N_p I_{ph} - N_p I_s[\exp(q(V + IR_s)/mkTN_s) - 1] \quad (11)$$

Equation 11 can be rewritten in terms of array voltage as:

$$V = (N_s mkT/q)\log((N_p I_{ph} - I + N_p I_s)/N_p I_s) - (IR_s N_s/N_p) \quad (12)$$

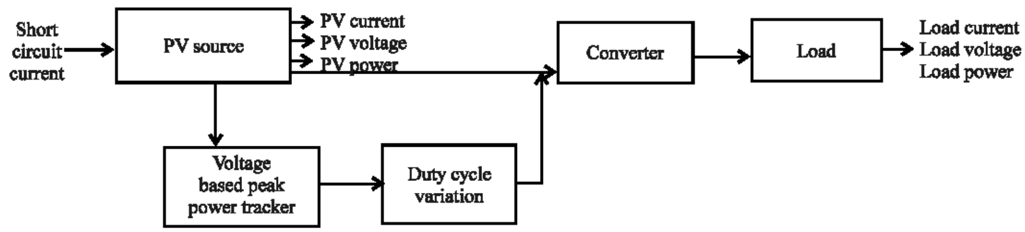

Fig. 5: Block diagram for constant voltage method

Where,

q : Electric charge.
m : Diode ideality factor.
k : Boltzmann's constant.
T : Absolute temperature.
R_s : Cell series resistance.
I_{ph} : Photo Current.
I_s : Cell reverse saturation current.
N_p : Number of parallel strings.
N_s : Number of series cells.

I and V are the panel current and voltage, respectively.

To determine the operating point corresponding to maximum power, Eq. 12 is used in simulation. In the proposed MPPT, shown in Fig. 4 for the solar cell equivalent circuit, a block called PV source is created which simulates the nonlinear V-I characteristics of solar panel as per the Eq. 12, employing the cell short circuit current (I_{sc}) as a measure of insolation level. A delay function is introduced to limit the fast current response of the controlled voltage source and to improve the convergence of solution. The voltage-based PPT equivalent block computes cell open-circuit voltage using $I_{no\text{-}load}$ and Eq. 12, compares it with the PV output voltage using (10) and calculates the firing commands for the Duty cycle variation block. The pulse width modulated output is used to drive the MOSFET of a step-down dc-dc converter. The duty cycle of the converter changes till the PV panel voltage becomes equal to the MPP voltage. For the simulation of the MPPT system a step down converter model is developed in simulink using power systems block set (Chomsuwan *et al.*, 2002).

The block diagram for the above discussed CV method is shown in Fig. 5 and is implemented in MATLAB Simulink environment.

RESULTS AND DISCUSSION

The solar cell has been modeled considering both the series as well as the shunt resistance and its I-V characteristics and P-V characteristics are obtained as

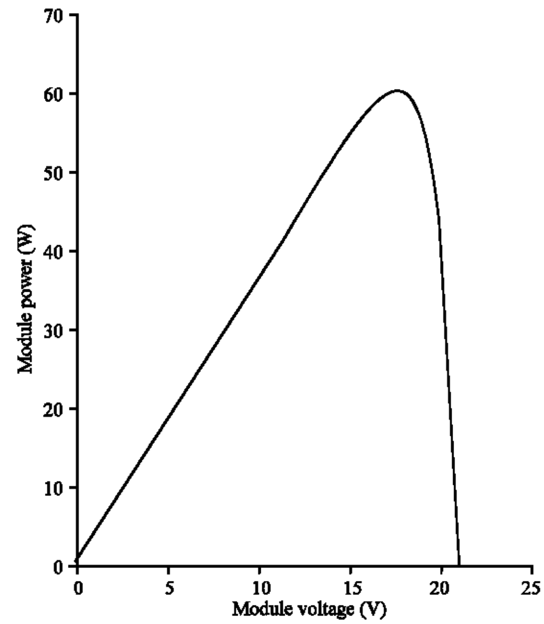

Fig. 6: Power voltage charateristics

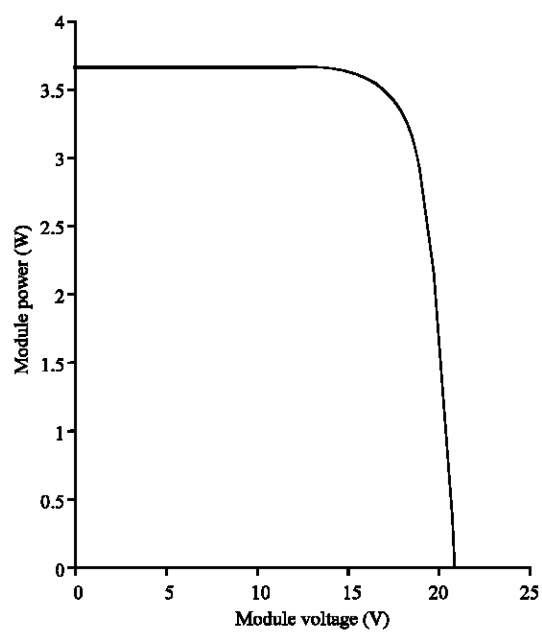

Fig. 7: Current voltage charateristics

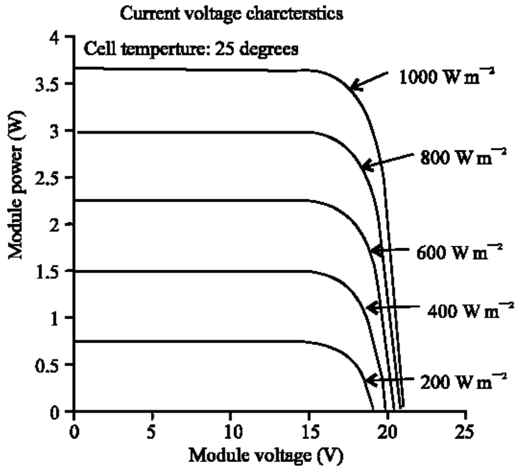

Fig. 8: I-V Characteristic of solar panel MSX-60 with varying irradiance

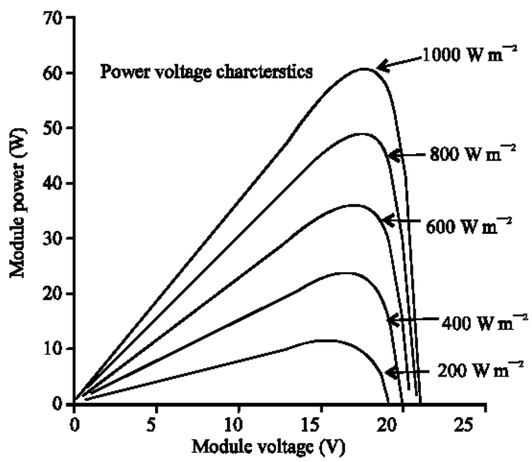

Fig. 9: P-V Characteristic of solar panel with varying irradiance

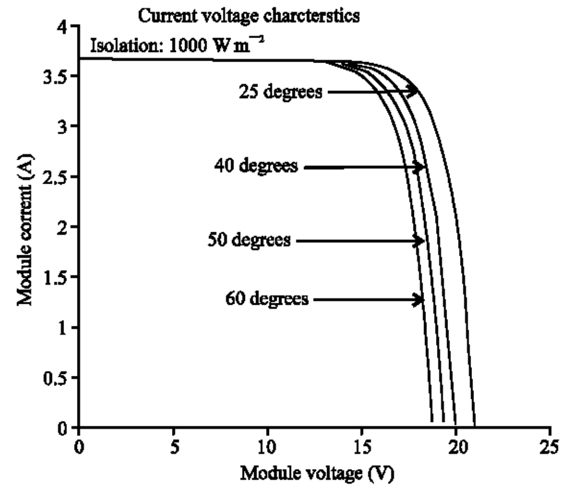

Fig. 10: I-V Characteristic of solar panel MSX-60 with varying temperature

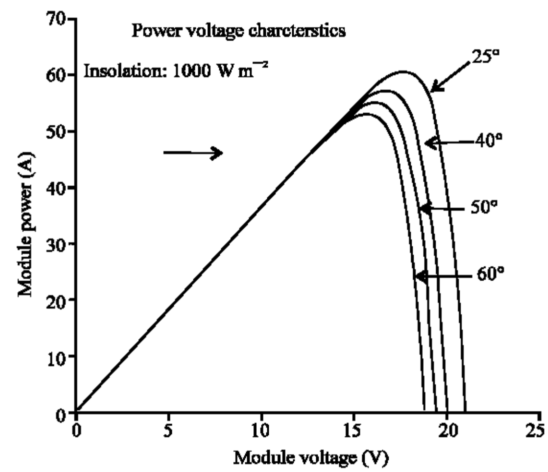

Fig. 11: P-V Characteristic of solar panel MSX-60 with varying temperature

shown in Fig. 6-13 by considering the varying temperature and the varying irradiance conditions separately and also by considering the variations in these two conditions simultaneously. The modeling for the PV panel equations described in this study is done using MALTAB programming. The values of various required parameters for the modeling of Solarex MSX60 panel are obtained from the manufacture's data sheet values as shown in Table 1 (www.solarex.com).

For the above modeled Solar cell, the maximum power point tracking is done with the Constant Voltage method using simulation in MATLAB and the corresponding Power, Voltage and Current characteristic curves are obtained as shown in Fig. 14-16.

The solar module selected is the Solarex MSX-60 solar cell. The solar module is able to output a maximum

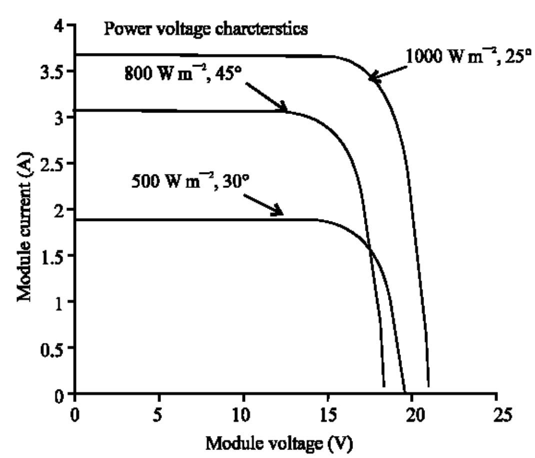

Fig. 12: I-V Characteristic of solar panel MSX-60 with varying temperature and irradiance

Table 1: The key specifications of the Solarex MSX-60 PV panel

	Data sheet values	
At temperature	T	25°C
Open circuit voltage	V_{oc}	21.0V
Short circuit current	I_{sc}	3.74A
Peak power voltage	V_m	17.1V
Peak power current	I_m	3.5A
Maximum power	P_m	59.9W

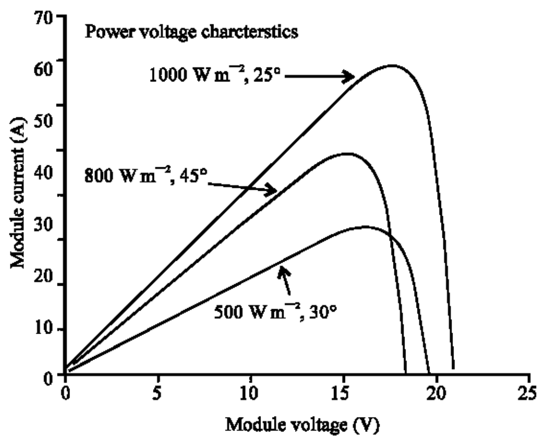

Fig. 13: P-V Characteristic of solar panel MSX-60 with varying temperature and irradiance

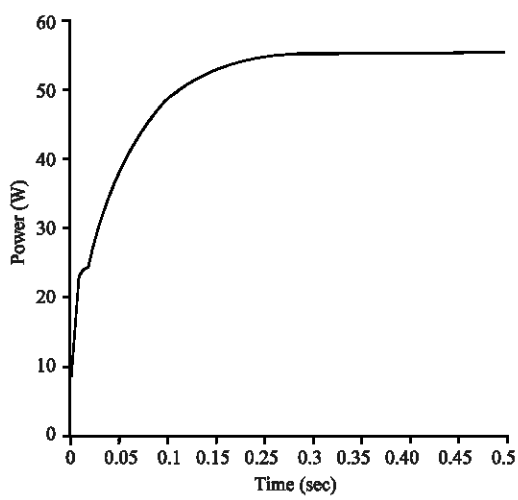

Fig. 14: Power characteristic curve with CV algorithm

power of 59.91W. The specifications of the solar module supplied by the manufacturer's data sheet are as shown in Table 1.

This method is very simple to implement, but it is not accurate. A problem with this method is that the available energy is wasted when the load is disconnected from the PV array; also the MPP is not always tracked at 71% of the array's open circuit voltage. There is substantial power wastage, as it does not take into account the effects of changes in solar

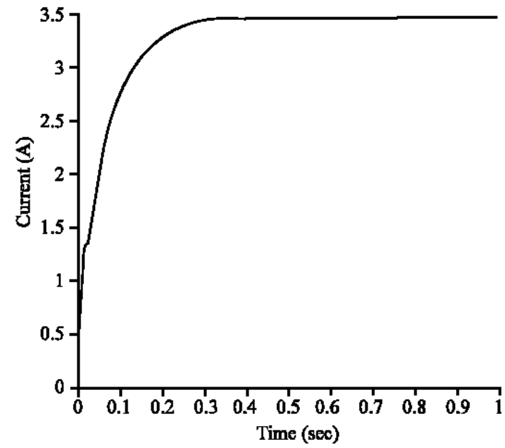

Fig. 15: Current characteristic curve with CV algorithm

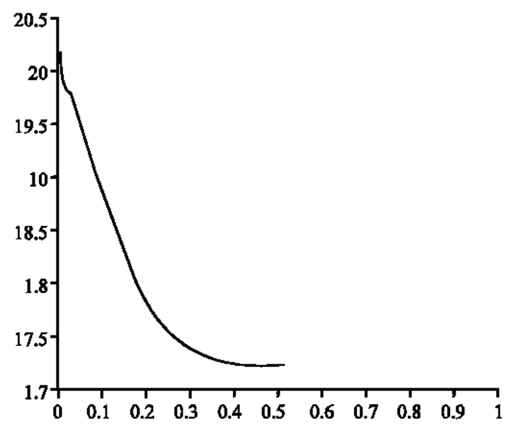

Fig. 16: Voltage characteristic curve with CV algorithm

insolation and temperature. The maximum power point tracking controller proposed in this study is very simple. So, this control algorithm can also be implemented on single chip micro processor.

CONCLUSION

Based on the results presented, the following conclusions may be stated:

- The linear voltage function is a more accurate approximation of the actual non linear PV Curve.
- The CV method is simple and easy to implement.
- PV loads, which require low voltage and high current output (eg. Battery and low resistance load) are best matched with VMPPT system which results in simple hardware and results in better over all performance (efficiency, cost and noise).
- This technique has less circuit losses.

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NOMENCLATURE

- e : Electronic charge.
- k : Boltzmann's constant.
- T : Absolute temperature.
- R_s : Cell series resistance.
- R_{sh} (R_p) : Cell shunt resistance.
- V : Cell terminal voltage.
- I_{ph} : Photo Current.
- I_o : Cell reverse saturation current.
- A : Curve fitting constant (1-5).
- I_L : Current through the load.

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