Design and Modeling of Standalone Solar Photovoltaic Charging System

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ABSTRACT
Standalone Photovoltaic (PV) system requires a proper battery charge controller. In this paper an efficient battery charge controller using Buck-Boost regulator with Maximum Power Point Tracking (MPPT) is presented. The voltage command is determined by both the PV panel maximum power point tracking (MPPT) control loop and the battery charging loop. Here the controller is designed so as to balance the power flow from PV panel to the battery and load such that the PV power is utilized effectively. The design and simulation using MATLAB is presented in this work.

Keywords
PV stand-alone system, Power balance control, SOC, SMF, MPPT, Battery Charger, MATLAB.

Nomenclature

I_{PV}, V_{PV}	-	Solar cell current and voltage
I_D, V_D	-	Diode current and voltage
I_{ph}	-	Light generated current
G	-	Irradiance
T	-	Temperature
N	-	Diode ideality factor
K	-	Boltzmann's constant
Q	-	Electron charge
I_r	-	Reverse saturation current
R_{sh}, R_{se}	-	Shunt and series resistance
V_t	-	Thermal voltage(= nkT/q)
M	-	Voltage gain ratio
V_B	-	Battery Voltage
δV, δI	-	Ripple voltage and current
L,C	-	Converter inductance and capacitance
T_s, f_s	-	Switching period & Frequency
D	-	Duty ratio
E_m	-	Open-circuit Voltage(EMF)in Volts
R_0	-	Resistance in Ohms
R_1	-	Main Branch Resistance in Ohms
R_2	-	Main Branch Resistance in Ohms
C_1	-	Main Branch Capacitance in Farads
V_{mref}	-	Reference Voltage
I_{b*}	-	Battery current command
V_{p*}	-	Voltage command
V_{bl*}	-	Battery lower limit voltage
V_{b*}	-	Batter floating stage voltage

1. INTRODUCTION
One of the most popular non conventional energy sources is the solar energy. Standalone PV system is the very popular way of utilizing solar energy. Photovoltaic panels are used to convert the solar energy into electrical energy. PV has nonlinear internal characteristics. The voltage-power characteristics of the PV panel is varied which depends upon insolation and temperature. Considering the high initial installation cost of the PV system, it is always necessary to operate PV at its Maximum Power Point (MPP). For this purpose dc-dc converter interface is required between PV and battery [1]-[3].Lead acid battery is commonly used because of its features such as wide operating temperature range, low self-discharge, long service life and maintenance free. The installation cost of the battery is low compared to PV panel .But the lifetime cost of the battery is high compare to the PV installation because of its limited service time. Battery life time is reduced if there is low PV energy availability for longer period or improper charging discharging. So the battery charging needs control for achieving high State of Charge (SOC) and longer battery life [4]-[5]**.** Hence proper controller for battery charging is an inevitable need for this hour. The main function of the battery charging controller in standalone PV system is to fully charge the battery without permitting overcharging while preventing reverse current flow at night and deep discharge under load conditions.

In this proposed system, the PV model, battery model and the battery charging system is implemented. A popular single diode model of PV is used in this work .A simple equivalent circuit model structure for lead-acid batteries are used to facilitate the battery model part of the system model[6]. The equivalent circuit empirically approximated the behaviour seen at the battery terminals. Buck-Boost converter interface is used hence it is more suitable for battery charging. The purpose of the buck-boost converter is used to control the power flow from the PV panel to battery and load which requires MPPT control algorithm to find out the peak power of the PV panel. Perturb and Observe algorithm (P and O) is used for MPP tracking [7]. The complete system is simulated using MATLAB-SIMULINK and the results are presented.

2. MODELING OF PHOTOVOLTAIC PANEL
The equivalent circuit of the PV cell is shown in Figure 1. PV cells are grouped in larger units called PV panels which are

further interconnected in a parallel-series configuration to form PV arrays [8].To simulate the array, cell model parameters are properly multiplied by number of cells.

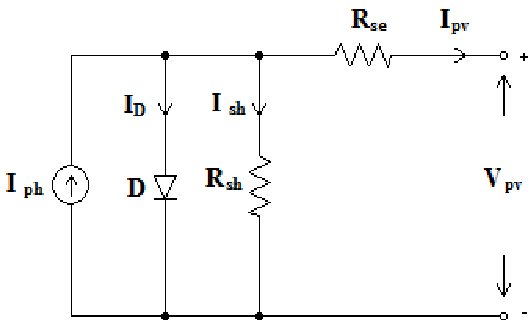

Figure 1. Equivalent circuit of SPV panel

The model equations are given from (1) to (4).

$$I_{PV} = I_{ph}(G,T) - I_D - \frac{V_d}{R_{sh}} \tag{1}$$

$$I_D = I_R(e^{\frac{V_d}{V_T}} - 1) \tag{2}$$

$$V_T = nKT/q \tag{3}$$

$$V_d = V_{PV} + I_{PV}R_{se} \tag{4}$$

The voltage-current and voltage-power characteristics at STC [G=1000 W/m^2,T=25^{0}C] are shown in Figure 2 which is obtained by simulating the equations (1) to (4) through MATLAB M-file coding

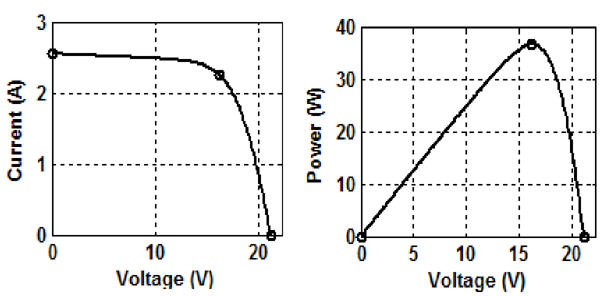

Figure 2. Simulated characteristics of SPV panel

SOLKAR SPV panels are available to compare the model parameters. The PV panel specifications are: I_{sc}=2.55A, V_{oc}=21.25, P_{max}=37.08W, V_{max}=16.54 and I_{max}=2.25A.

3. SIMULATION OF MPPT SYSTEM

3.1 Design of Power Circuit

The Buck-Boost converter interfaces PV panel and the load. The design equations of the Buck-Boost converter [9] are presented from (5) to (7).

The voltage ratio of the Buck-Boost Converter is given as,

$$M = \frac{-D}{1-D} V_T \tag{5}$$

The inductor and capacitor is designed based on the following equations to operate converter in Continuous Current Mode (CCM).

$$L = \frac{DV_{PV}}{f_s \Delta I} \tag{6}$$

$$C = \frac{DV_s}{f_s \Delta V} \tag{7}$$

The SIMULINK diagram of the buck-boost converter is shown in Figure 3.

The design parameters used in simulation are L=200µH, C=350µF and f_s=10 kHz.

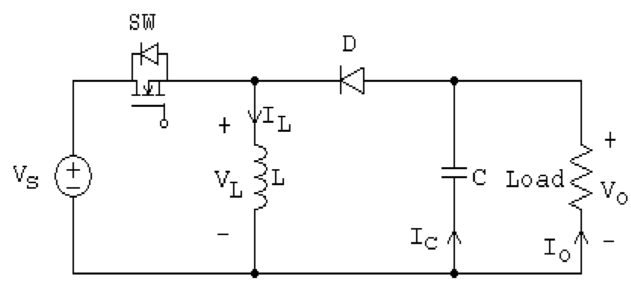

Figure 3. Schematic of Buck-Boost Converter

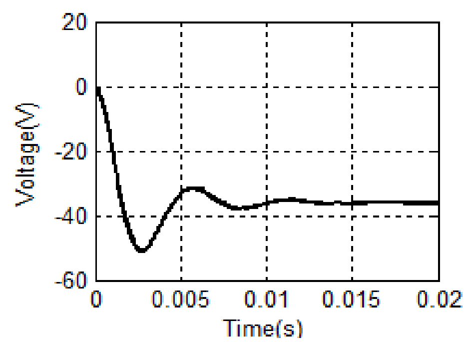

Figure 4. Output voltage of Buck-Boost Converter for duty ratio=0.70(Boost Mode)

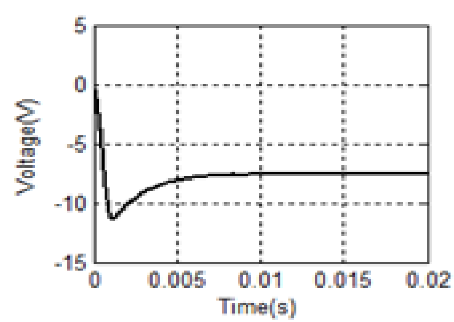

Figure 5. Output voltage of Buck-Boost Converter for duty ratio=0.30(Buck Mode)

Figure 4 and Figure 5 show the output voltage of the Buck-Boost Converter for various duty ratios. The mode of operation of converter depends on duty ratio.

3.2 Simulation of MPPT Algorithm

Perturb and Observe algorithm is used for MPP tracking. Perturb and observe algorithm has a simple feedback structure and fewer measured parameters. It operates by periodically perturbing (i.e. incrementing or decreasing) the array terminal voltage and comparing the PV output power with that of the previous perturbation cycle. If the perturbation leads to an increase (decrease) in array power, the subsequent perturbation is made in the same (opposite) direction. In this manner, the peak power tracker continuously seeks the peak power condition. Moreover, in rapidly changing atmospheric conditions, the MPPT takes considerable time to track the MPP. Figure 7 shows the flow chart of the Perturb and Observe Algorithm [7].

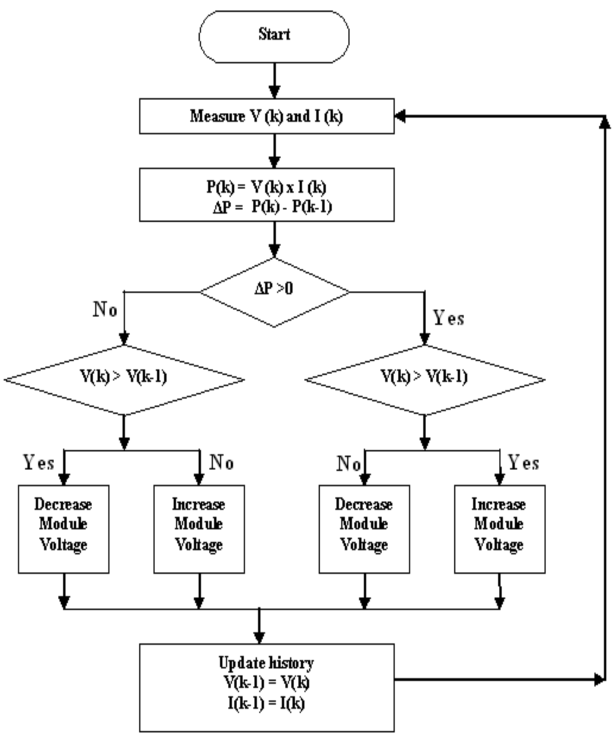

Figure 6. Flow Chart for Perturb and Observe Algorithm

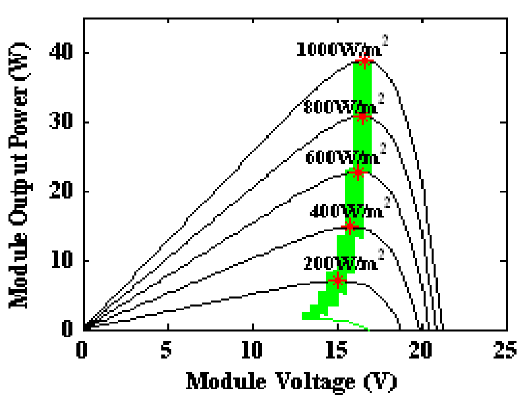

Figure 7. Simulation Output for Perturb and Observe Algorithm

From Figure 7, it is inferred that the P and O algorithm tracks MPP for various insolations. For various insolations, the PV output power and converter output power is listed in Table 1.

Table 1.SPV module and converter output power for various Insolation

S.No.	Insolation (W/m^2)	SPV output power (W)	Converter output (W)
1	1000	37.08	36.02
2	700	22.26	20.03
3	500	11.8	10.37
4	300	4.46	3.71
5	100	0.6	0.47

4. MODELING AND SIMULATION OF BATTERY

For battery modeling the parameters of Sealed Maintenance Free (SMF) available in the lab.

The Battery Parameter specifications:

Battery type: Exide (SMF)

Nominal Voltage: 12 V

Standby use: 13.6 V~ 13.8V

Cycle use: 14.6V~14.8V

Maximum initial current: 20A

Nominal capacity: 100Ah

The equivalent circuit is based on nonlinear equations [6]. The equivalent circuit consisted of two main parts: a main branch which approximated the battery dynamics under most conditions, and a parasitic branch which accounted for the battery behaviour at the end of a charge. The equivalent circuit of the battery is shown in Figure 8.

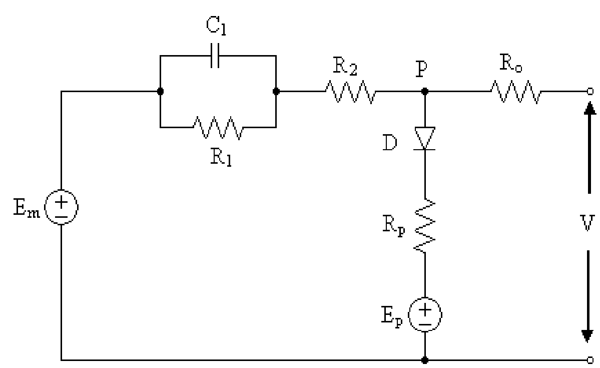

Figure 8. Equivalent Circuit of the Lead acid Battery

The value of E_m, C_1, R_1, R_2, R_0 are determined from the equations (8)-(12) with the given parameters.

$$E_m = E_{mo} - K_E(273+\theta)(1-SOC) \qquad (8)$$

$$R_o = R_{oo}[1 + A_o(1-SOC)] \qquad (9)$$

$$R_1 = R_{1o}\ln(DOC) \qquad (10)$$

$$C_1 = \tau_1 / R_1 \qquad (11)$$

$$R_2 = R_{2o}\frac{\exp[A_{21}(1-SOC)]}{1+\exp(A_{22}I_m / I^*)} \qquad (12)$$

The simulated output voltage of the battery for Maximum PV output current I_m=2.25A and Temperature =25 ^{0} C is shown in Figure 9.

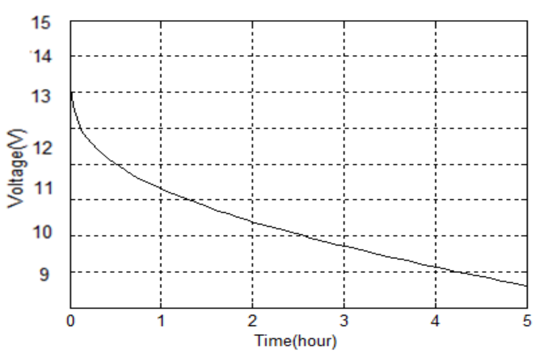

Figure 9. Output Voltage of the Battery

5. DEVELOPMENT OF CHARGE CONTROLLER

Figure 10 shows the block diagram of the proposed system with power balance and battery charging controllers. It consists of PV array, Buck-Boost converter, Battery charge controller, current controller and MPPT controller.

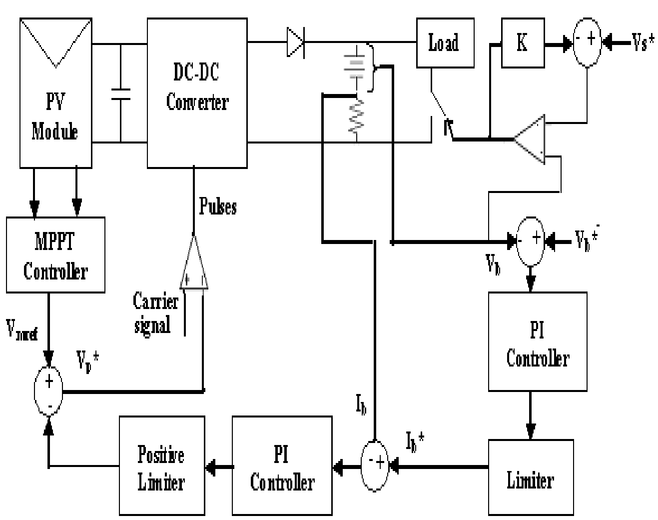

Figure 10. Block Diagram of Proposed system

The voltage command V_p* is generated by combining both the MPPT control and the Battery charging loop. The available PV power is greater than the load power with which the battery gets charged. If the available maximum PV power is less than the load power, the needed power will be supplied by the battery. But the charging current is still less than the preset value .At that instant the signal generated by the current controller will go positive and limited to be zero. It results that the voltage command (V_P^*) is determined completely by the MPPT controller. If the available peak power of the PV panel is greater than the battery charging and load requirement, the battery current will reach its command (I_b^*). The signal generated by the controller will go negative which will add to the voltage generated by the MPPT controller. Consequently, the PV panel will discard the MPPT because the voltage command is shifted to a higher level than the MPPT voltage. And finally, the generated PV power will balance the load and battery charging requirements [10]-14].

Figure 11 shows the charging and discharging current (~ 8.37 A) of the battery with both power and battery charge controllers which illustrates that the floating state of the battery is attained.

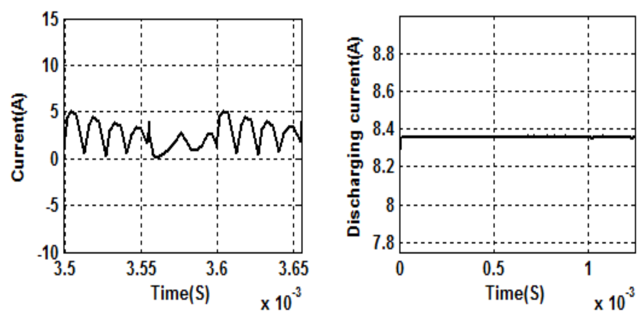

Figure 11 .Charging and discharging currents of the battery

6. CONCLUSION

Standalone PV system with efficient battery charging controller by proper design equations has been presented in this work. The system has been simulated using MATLAB and the effectiveness of the proposed controller has been highlighted by checking the charging and discharging currents of the battery. PI controller used in this work can be replaced by sliding mode controller to get improved control action.

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