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A New Photovoltaic Charge Controller Using Dc-Dc Converter

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Abstract

In this paper, we present a novel maximum power point tracking method for a photovoltaic system consisting of a photovoltaic panel with a power electronic converter; the whole is feeding a battery. This maximum power point depends on the temperature and irradiation conditions. A robust control using a PI regulator is used to track this maximum power point. Photovoltaic or in short term PV is one of the renewable energy resources that recently has become broader in nowadays technology. The demand or future work is looking for high efficiency, more reliable and economical price PV charge controller which is come in portable size has become very popular in PV system. In general, PV system consists of a PV array, charge controller, rechargeable battery and dc load.

Introduction

Photovoltaic or in short term PV is one of the renewable energy resources that recently has become broader in nowadays technology. PV has many benefits especially in environmental, economic and social. In general, a PV system consists of a PV array which converts sunlight to direct-current electricity, a control system which regulates battery charging and operation of the load, energy storage in the form of secondary batteries and loads or appliances. A charge controller is one of functional and reliable major components in PV systems. A good, solid and reliable PV charge controller is a key component of any PV battery charging system to achieve low cost and the benefit that user can get from it. The main function of a charge controller in a PV system is to regulate the voltage and current from PV solar panels into a rechargeable battery. The minimum function of a PV charge controller is to disconnect the array when the battery is fully charged and keep the battery fully charged without damage. A charge controller is important to prevent battery overcharging, excessive discharging, reverse current flow at night and to protect the life of the batteries in a PV system. A power electronics circuit is used in a PV charge controller to get highest efficiency, availability and reliability. The use of power electronics circuits such as various dc to dc converters topologies like buck converter, boost converter, buck boost converter and others converter topology as power conditioning circuitry to provide a desired current to charge battery effectively.

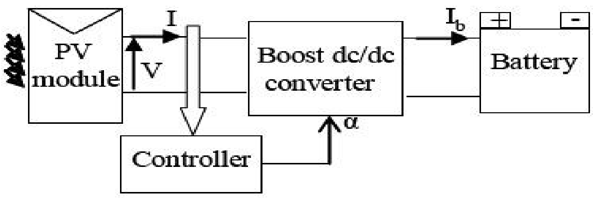


Figure 1: Block diagram of proposed system

Keywords: *Photovoltaic panel, boost dc/dc converter, PI regulator, Maximum Power Point Tracking.*

Nomenclature
MPPT maximum power point tracking, PV photovoltaic panel, MPP maximum power point

2. Theoretical study

2.1. Optimal operating

The equivalent circuit of a PV module is shown in figure 2. The PV module considered in this paper is the SM55. It has 36 series connected monocrystalline cells. The relationship between the panel output voltage V and current I is given by-

$$I = I_{sol} - I_{os}\left\{\exp\left[\frac{q}{\gamma kT}(V + R_s I)\right] - 1\right\} - \frac{V + R_s I}{R_{sh}} \quad (1)$$

Where:

$$I_{os} = I_{or}\left(\frac{T}{T_r}\right)^3 \exp\left[\frac{qE_{GO}}{\beta k}\left(\frac{1}{T_r} - \frac{1}{T}\right)\right] \quad (2)$$

$$I_{sol} = [I_{SC} + K_I(T - 298.18)]\frac{\lambda}{1000} \quad (3)$$

I, V, Ios, T, k, q, KI, Isc, λ, Isol, EGO, γ(=β), Tr, Ior, Rsh, and Rs are respectively, cell output current and voltage, cell reverse saturation current, cell temperature in Kelvin, degree Boltzmann's constant (1.381e-23 J/K), electronic charge (1.602e-19 C), short-circuit current at 25 °C and 1000 W/m2, short-circuit current temperature coefficient at Isc (KI =0.0004 A/K), solar irradiation in W/m2, lightgenerated current, band gap for silicon (=1.12 eV), ideality factor (=1.740), reference temperature (=298.18 K), cell saturation current at Tr, shunt resistance and series resistance. The output power of PV panel is *P =VI*, at optimal point, we have:

$$\frac{\partial P}{\partial V} = I + V\frac{\partial I}{\partial V} = 0 \Rightarrow \frac{\partial I}{\partial V} = -\frac{I}{V}$$
$$\Rightarrow I = (V - R_s I)\left\{I_{os}A\exp[A(V + R_s I)] + \frac{1}{R_{sh}}\right\} \quad (4)$$

Where: $A = \frac{q}{\gamma kTN_{cell}}$ and N_{cell} is the number of series cells in the module.

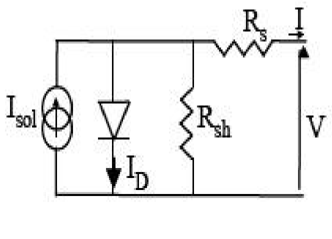


Figure 2: PV panel equivalent circuit

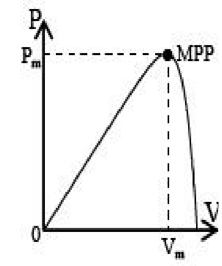


Figure 3: PV panel P-V characteristic

we have measured the shunt resistance Rsh and determined the constants in these equations using the manufacturer ratings under standard test conditions of the PV panel.

2.2. Boost converter study

Value L of the inductor required to ensure the converter operating in the continuous conduction mode (figure 5) is calculated such that the peak inductor current at maximum input power does not exceed the power switch current rating [15]. Hence, L is calculated as:

$$L \geq \frac{V_{om}(1 - \alpha_m)\alpha_m}{f_s|\Delta I_{Lm}|} \quad (5)$$

Where fs, αm, ΔILm, Vom and Iom are respectively, switching frequency, duty cycle at maximum converter input power, peak-to-peak ripple of the inductor current, maximum of dc component of the output voltage, and dc component of the output current at maximum output power. Taking into account that the ripple of the PV output current must be less than 2% of its mean value [15], the input capacitor value is given by:

$$C \geq \frac{I_{om}\alpha_m^2}{0.02(1 - \alpha_m)V_{inm}f_s} \quad (6)$$

Where Vinm is the PV module input voltage at the MPP. When the boost converter is used in PV applications, the input power, voltage and current change continuously with atmospheric conditions. Thus, the converter conduction mode could change since it depends on them. Also, the duty cycle α is changed continuously in order to track the maximum power point of the PV array. The choice of the converter switching frequency and the inductor value is a compromise between the converter efficiency, the cost, the power capability and the weight

2.3. Boost converter model

If the chopping frequency is sufficiently higher than the system characteristic frequencies, we can replace the converter with an equivalent continuous model (figure 6). We will consider, for that, the mean values, over the chopping period, of the electric quantities. The transistor had been replaced by a voltage source whose value equals its mean voltage. At the same, the diode had been replaced by a current source. Thus:

$$V_T = E(1 - \alpha) + R_b I_b \text{ and } I_b = (1 - \alpha)I_L \quad (7)$$

Where I_L is the mean value of inductance current.
We deduce from the continuous model equations:

$$C\frac{dV}{dt} = I - I_L \quad (8)$$

$$L\frac{dI_L}{dt} = V - (1 - \alpha)E - R_b I_b \quad (9)$$

At optimal operating point, we have:

$$\begin{cases} I_m = I_{Lm} \\ V_m = (1 - \alpha_m)E + R_b I_{bm} \\ I_{bm} = (1 - \alpha_m)I_{Lm} \end{cases} \quad (10)$$

Where Im, ILm, Ibm, Vm, αm are respectively the optimal
values of I, IL, Ib, V and α.

2.4. Small signal model and transfer function

After having put the converter "mean" equivalent circuit in equations, we can determine the transfer function of the system open loop for a small variation around a point also called an operating point.Thus we write

$$q = q_m + \Delta q$$

For each quantity q in the set

$$\{V, \alpha, I_L, I, I_b, I_{sol}, y\}$$

defining the operating point. Where:

$$y(t) = \frac{\partial P}{\partial V}(t). \text{ So,}$$

the system can shown by a functional diagram like that used in [16] for synthesizing the regulators. The system can be presented as follows:

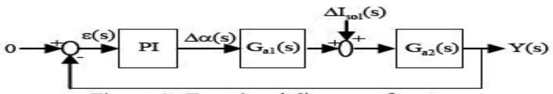


Figure 4: Functional diagram of system.

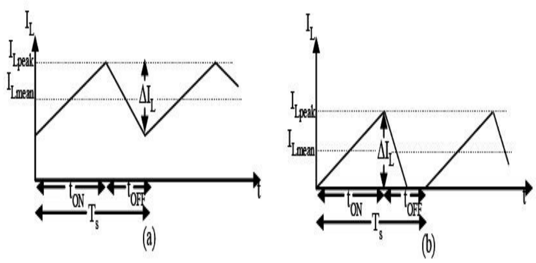


Figure 5: Boost converter waveforms (a) continuous conduction mode (b) discontinuous conduction mode

Where

$$G_{a1}(s) = K_{a1}\frac{1}{b_2 s^2 + b_1 s + 1}$$

$$G_{a2}(s) = K_{a2}\frac{b_2 s^2 + b_1 s + 1}{a_2 s^2 + a_1 s + 1}$$

With:

$$K_{a1} = \frac{(K_1 G - K_2)(E + R_b I_{Lm})(1 + R_s G_m)}{K_1 + K_2 R_b (1-\alpha_m)}$$

$$K_{a2} = \frac{K_1 + K_2 R_b (1-\alpha_m)}{(1 + R_s G_m)[1 + G R_b (1-\alpha_m)]}$$

And:

$$b_2 = \frac{K_1 LC}{K_1 + K_2 R_b (1-\alpha_m)}; \; b_1 = \frac{K_1 C R_b (1-\alpha_m) + K_2 L}{K_1 + K_2 R_b (1-\alpha_m)}$$

$$a_2 = \frac{LC}{1 + G R_b (1-\alpha_m)}; \; a_1 = \frac{C R_b (1-\alpha_m) + GL}{1 + G R_b (1-\alpha_m)}$$

$$K_1 = 1 + \frac{A R_s (R_s I_m - V_m)}{R_{dm}(1 + R_s G_m)}; \; K_2 = \frac{A (R_s I_m - V_m)}{R_{dm}(1 + R_s G_m)} - G$$

$$G = \frac{G_m}{1 + R_s G_m} \; ; \; G_m = \frac{1}{R_{dm}} + \frac{1}{R_{sh}};$$

$$R_{dm} = \frac{1}{I_{os} A \exp[A(V_m + R_s I_m)]}.$$

Ka1 and Ka2 are constants gain for a given temperature T and solar irradiation λ. Rdm and Gm are the optimal dynamic resistance and conductance of PV module. The values of Ka1, Ka2, K1, K2, b2, b1, a2, a1, G, Gm and Rdm can be easily determined if we have know the values of L, C, Rb, E, Im, Vm, αm and the parameter values of PV module. The transfer function of the open loop used to synthesizing a PI regulator is:

$$G_0(s) = G_{a1}(s) G_{a2}(s) = K_{a1} K_{a2} \frac{1}{a_2 s^2 + a_1 s + 1} \quad (13)$$

3. Simulation procedure

We have built our model by using Simulink Matlab. The bloc used for simulations is given by figure 7. In PV module block, equations (1-3) are used; and in block (converter + battery), equations (7-9) are used.

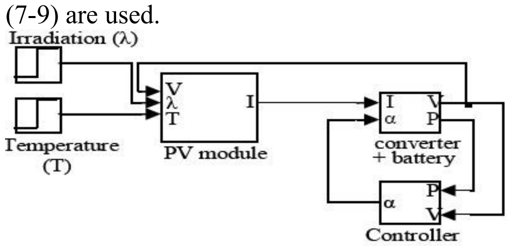


Figure 7: Bloc diagram for system

The proposed controller circuit that forces the system to
operate at its optimal operating point under variable temperature and irradiation conditions is shown in figure 8. Thus, for any temperature and solar irradiation level, the proposed controller circuit is obtained as follows:

- On one hand, we multiply the PV output signal current I by the PV output signal voltage V. We
obtain the PV output signal power P who is derived in order to obtain the signal.

- On the other hand, we derive the signal voltage V, who is inverted. Thus, the signal
  1/(dV/dt) is obtained.
  The product of 1/(dV/dt) and dP/dt gives the signal dP/dV which is compare dto zero.

The resulting difference signal (error signal) is used as an input signal of the PI regulator. This PI regulator is used to deliver a duty cycle signal to the dc/dc converter corresponding to the condition dP/dV=0

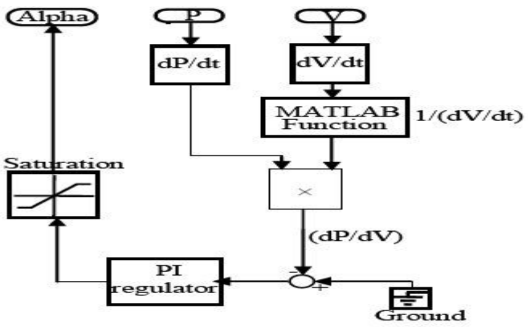


Figure 8: Controller circuit

4. Theoretical Results

4.1. PV module parameters

Measure of Rsh. The shunt resistance Rsh of PV module (Figure 2) is measured. This measure (Figure 9) is performed in dark room (Isol = 0) in laboratory (no wind) by ammeter and voltmeter. We have applied an external negative voltage to the PV panel (ID = 0).

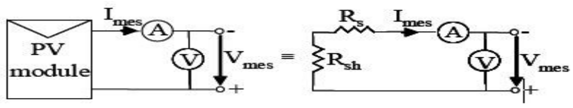


Figure 9: Measure of R_{sh} of PV panel.

The measures of Vmes and Imes must be done quickly (no overheating of photocell). The mean value of (Vmes/Imes) gives Rsh =6500Ω. Rs is considered negligible in front of Rsh.

Determination other PV module parameters

The manufacturer rated values of the SM55 PV module considered in this paper under standard test conditions (irradiation λ = 1kW/m2, A.M. = 1.5 solar spectrum and cell temperature T = 25 °C) are: open-circuit voltage Voc=21.7v, short-circuit current Isc = 3.45 A, maximum power current Im = 3.15 A, maximum power voltage Vm = 17.4 V and maximum power Pm = 55 W. Using these electrical characteristics, the constants Ior, γ (= β) and Rs in equations (1) and (2), obtained by programming on Matlab Software are 4.842 µA, 1.740 and 0.1124 Ω respectively.

4.2. PI regulator and converter parameters.

The PI controller gain and the integral time constant obtained by frequency synthesis using Bode method are respectively KP =0.01 and Ti (=1/Ki) = 1.8 ms. From equation (5), the boost inductance can be chosen as is L = 1mH. From equation (6), the input capacitance can be chosen as C = 4.7µF. The battery voltage and resistance utilized in this paper are respectively E = 24V and Rb = 0.65Ω. Fifty kilohertz switching frequency is adopted.

4.3. Optimal Values at MPP.

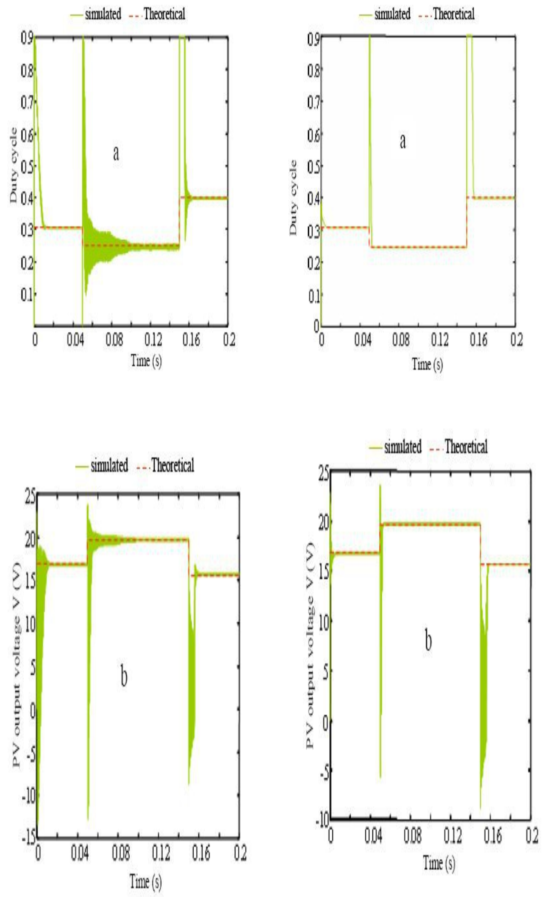
For different values of irradiance λ and temperature T, the computation of the theoretical optimum quantities V_m, P_m and α_m of P, V and α are assembled in table 1

	V_m (V)	P_m (W)	α_m
λ = 100 W/m² and T = 270.18 K	16.77	5.270	0.3069
λ = 1000 W/m2 and T = 270.18 K	19.64	62.73	0.2468
λ = 1000 W/m2 and T = 320.18 K	15.65	48.61	0.3984
λ = 100 W/m2 and T = 320.18 K	12.30	3.714	0.4912

Table 1. Quantities V_m, P_m and α_m for different values of λ and T.

5. Simulation results

In order to demonstrate the effectiveness of the proposed method, some simulations have been carried out. Simulations were achieved with Matlab Simulink. The simulations studies were made to illustrate the response of the proposed method to rapid temperature and solar irradiance change. For this purpose, the irradiance λ and the temperature T, which are initially 100W/m2 and 270.18 K, are switched, at 0.05s and 0.15s, to 1000 W/m2 and 320.18 K respectively [Figures 10 and 10bis (a), (b) and (c)] and vice versa [Figures 11 and 11bis (a), (b) and (c)], i.e., the solar irradiance changes from 1000 W/m2 to 100 W/m2 at 0.05s and the temperature changes from 320.18 K to 270.18 K at 0.15s. [Figures 10(a), (b) and (c)] and [Figures 11(a), (b) and (c)] give the simulation results for values of Kp and TI of regulator PI obtained by Matlab programming. After adjust of TI (=0.01ms) we have obtained the [Figures 10bis (a), (b) and (c)] and [Figures 11bis (a), (b) and (c)]. Figures 10(a), 10 bis (a), 11(a) and 11bis (a) give the variation of duty cycle, figures 10(b), 10bis(b), 11(b) and 11bis (b) give the variation of the output voltage of PV panel and the figures 10(c), 10bis(c), 11(c) and 11bis(c) give the variation of instantaneous PV power for a step change of temperature and irradiance. It is shown that, the PI controller brings the system into the maximum power point after some oscillations and the steady state is then reached. At the steady state, it is shown that the average values of voltage, instantaneous power of the PV and duty cycle of a boost DC/DC converter are very close to theirs optimal values Vm, Pm and αm obtained by Matlab programming. So, the relative errors for different average values varied between 0.05% and 0.13%. The simulations of the MPPT show that the system is stable. The oscillations about the computed optimal operating point are due to the switching action of the dc-dc converter. The transients between operating points are natural for a dynamic system which is controlled by a PI type controller.



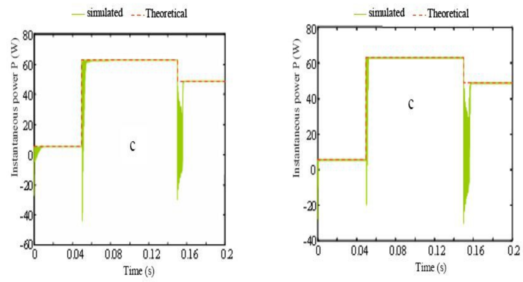


Figure 10: Variation before adjust of T_L of (a) duty cycle, (b) PV output voltage, and (c) instantaneous PV power for a step change on irradiation λ and temperature T from 100 W/m² to 1000 W/m² and 270.18 K to 320 K respectively.

Figure 10 bis: Variation after adjust of T_L of (a) duty cycle, (b) PV output voltage, and (c) instantaneous PV power for a step change on irradiation λ and temperature T from 100 W/m² to 1000 W/m² and 270.18 K to 320 K respectively.

Conclusion

The output power delivered by a PV module can be maximized using MPPT control system. It consists of a power conditioner to interface the PV output to the load, and a control unit, which drives the power conditioner for extracting the maximum power from a PV array. In this paper, a MPPT system has been proposed and tested by simulations in Matlab Software. It follows the irradiance and the temperature level change rapidly and tracks the MPPT. The PI regulator used to control the boost DC/DC converter is synthesized by frequency synthesis using Bode method. For that, we have developed a transfer function of global model using a small signal method. Simulations show that the regulation is robust against disturbances.

For a given temperature T and solar irradiance λ, we have calculated the corresponding optimal values α_m, V_m and P_m. The optimal values obtained by programming coincide with ones obtained by simulation. The simulation gives good results. Our proposed MPPT's charge controller is easier and cheaper to build.

7. References

[1] V. Salas, M.J. Manzanas, A. Lazaro, A. Barrado, and E. Olias, "Analysis of control strategies for solar regulators Industrial Electronics ISIE 2002, Proceedings of the 2002 IEEE International, Vol. 3, 26-29 May, pp. 936-941, 2002

[2] D.Hohm, M.E. Ropp, "Comparative study of maximum power point tracking algorithms", Proceedings Photovoltaic, Res. Appl., 11, 47-62, 2003.

[3] J.H.R. Enslin, D.B. Snyman, Combined low-cost, "high-efficiency inverter, peak power tracker and regulator for PV applications", IEEE Trans. Power Electr. 6, pp. 73-82, 1991

[4] M. Salhi, and R. El-Bachtiri, "Optimal operating point tracking of photovoltaic system Supplying a battery", Actes des Premières Journées de Télécommunications d'Electronique et Electrotechnique (PJTEE'06), 25-26 Mai, Oujda Maroc, pp. 85-87, 2006

[5] Min Chen, and Gabriel A. Rincon-Mora, "Accurate Electrical Battery Model capable of Predicting Runtime and I-V Performance", IEEE Transactions on Energy Conversion, vol,. 21, N° 2, pp. 504-511, June, 2006.