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OPTIMIZED PHOTOVOLTAIC STAND-ALONE BATTERY CHARGING SYSTEM WITH MPPT FOR VARYING ILLUMINATION CONDITION

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ABSTRACT

In this paper the output voltage regulation in response to the perturbation of input voltage by means of varying insolation condition with reference to the perturb and observe maximum power point tracking algorithm was presented and a battery charging for stand-alone photovoltaic (PV) applications was presented for varying illumination condition. The essential work of modeling, control and regulation of output voltage for battery application due to varying input voltage by means of varying insolation condition was carried out. The buck converter was used as a power conditioner for battery charging application. The advantageous of the proposed method are: better exploitation of the available PV charger by means of a perturb and observe maximum power point tracking (MPPT) techniques employed in the control algorithm, increased battery lifetime due to higher level state of charge operation and the charging control process does not depends on accurate battery current measurements. Through this modeling and design the satisfactory performance of the converter in both transient and steady state conditions were obtained and presented.

INTRODUCTION

Photovoltaic (PV) generators are increasingly being used in many remote area applications. The stand-alone mode of energy generation from solar, consists of system, which are not connected to the grid i.e. off-grid applications. It is most effective especially in the remote places, where there is a scarce of electricity from the conventional sources. This stand-alone system have a solar array coupled with a power conditioning device such as power converter, which step downs the voltage to suit the load requirements such as home power, UPS charger, simple solar battery charger solar emergency lantern, solar pump, solar vehicle and a battery to store the solar energy harnessed during the day to consume it in the absence of solar energy. Rechargeable batteries are widely used in stand-alone pv systems to store the energy surplus and supply the load in case of low renewable energy production. The most common type used is lead-acid battery, because of its low cost, maintenance-free operation and high efficiency characteristics. Although the battery installation cost is relatively low compared to that of Photovoltaics, the lifetime cost of the battery is greatly increased because of its limited service time (Saucer *et al*., 1997). The expected battery lifetime is reduced if there is low PV energy availability for prolonged periods or improper charging control, both resulting in low battery state of charge (SOC) for long time periods. The overall system cost can be reduced by the use of proper battery charging/ discharging control techniques, which achieve high battery SOC, and consequently longer lifetime. In order to regulate the converter due to non linearity conventional controller like PI controller with Perturb and Observe algorithm is proposed and simulated. The tracking algorithm integrated with a solar PV system has been simulated with buck DC-DC converter for the application of battery charging in stand-alone PV system. The proposed PV charger system with buck DC-DC converter is shown in Fig.1.

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Mathmatical modeling of PV system

A solar cell model and the equivalent circuit with parameters of the PV cell are shown in Fig.2. PV cells are grouped in larger units called PV panels, which are further interconnected in a parallel-series configuration to form PV arrays (Ramaprabha *et al*., 2009). To simulate the array, cell model parameters are properly multiplied by number of cells. The model, takes into account the variation of the photoelectric current, when the radiation and the temperature changes, and also the variation of the diode saturation current when the temperature changes. In this, the current generator I_L represents the generated photoelectric current while the diode (D) and the resistance Rs, which takes into account the internal electrical losses, model the photovoltaic module (Liu *et al*.,).

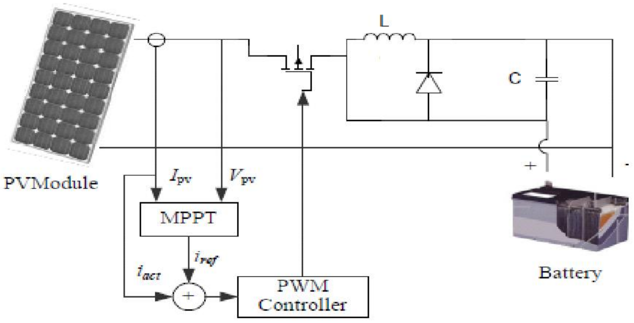


Figure 1.Circuit configuration of the proposed PV charger system

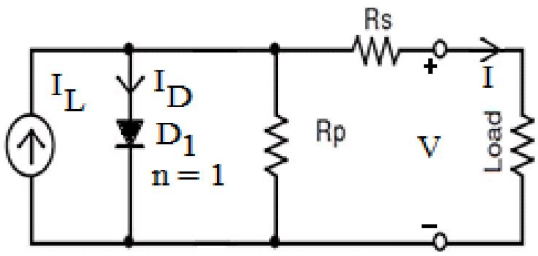


Figure 2. Equivalent circuit of photoelectric module

By applying the Kirchhoff law to the node of the circuit reported in Fig. 1, the current 'I' produced by the photovoltaic module is obtained as

$$I = I_L - I_D \qquad (1)$$

The I_D diode current is given by the Shockley equation:

$$I_D = I_o[\exp\left(\frac{q(V+IR_s)}{\gamma k T_c}\right) - 1] \qquad (2)$$

where - I_D is the diode current; I_L- is the photoelectric current related to a given condition of radiation and of temperature; V is the output voltage [V]; I_o is the saturation diode current [A]; γ is the form factor which represents an index of the cell failing; Rs is the series resistance of the cell [Ω]; q is the electric charge ($1.602*10^{-19}$C); k is the Boltzmann's constant ($1.381*10^{-23}$K); T_c is the module temperature [K].

By substituting (2) in (1), the following equation is obtained, which represents the I-V module characteristics curve under generic radiation and temperature conditions.

$$I = I_L - I_o[\exp\left(\frac{q(V+IR_s)}{\gamma k T_c}\right) - 1] \qquad (3)$$

The model proposed in (3) describes the working of a photovoltaic module under the hypothesis of knowing the values of γ, R_s, I_o and I_L. In order to take into account the variation of the diode saturation current and the photoelectric current when temperature and radiation change, with respect to standard conditions, the model is completed with the following equations:

$$I_o = I_{o,REF}\left(\frac{T_C}{T_{C,REF}}\right)^3 \exp\left[\left(\frac{qEg}{k\gamma}\right)\left(\frac{1}{T_{C,REF}} - \frac{1}{T_C}\right)\right] \qquad (4)$$

$$I_L = \left(\frac{G}{G_{REF}}\right)\left[I_{L,REF} + \mu_{ISC}(T_C - T_{C,REF})\right] \qquad (5)$$

where E_g is the energy gap of the material with whom the cell is made (for the silicon it is 1.12 eV); G is the radiation [W/m^2]; G_{REF} is the radiation under standard conditions [W/m^2] $I_{L,REF}$ is the photoelectric current under standard conditions [A]; $T_{C,REF}$ is the module temperature under standard conditions [K]; μ_{ISC} is the temperature coefficient of the short circuit current [A/K], given by the manufacturer according to CEI EN 60891 standard (Christopher *et al*., 2009).

Table 1. Standard Test Condition data

Electrical characteristics	
Cell	Poly-crystalline silicon
No of cells and connections	36 in series
Open circuit Voltage (V_{oc})	21.75 V
Short – circuit current (I_{sc})	4.75A
Maximum Power Voltage at Pmax, (V_{pm})	17.25 V
Maximum Power Current (I_{pm})	4.515 A
Maximum Power (P_{max})	77.88 W (+10%/-5%)
Module Efficiency (ηm)	13%
Series Fuse Rating	10 A
Type of output terminal	Junction Box
Temperature coefficient of I_{sc}	0.65e-3±0.015%/°C
Temperature coefficient of V_{oc}	-160±20mV%/°C
Temperature coefficient of Power	-0.5±0.05%/°C

The obtained equations allow representing the I-V characteristics curve of one photovoltaic module under generic temperature and radiation conditions, when the characteristic parameters under standard conditions are known as given in Table 1 (Alghuwainem, 1997; Akihiro, 2005). The voltage-current and voltage-power characteristics at STC [1000w/m^2, T=25° C] are shown in Fig. 3, which is obtained by simulating the equations from (1) to (5) through MATLAB M-file coding.

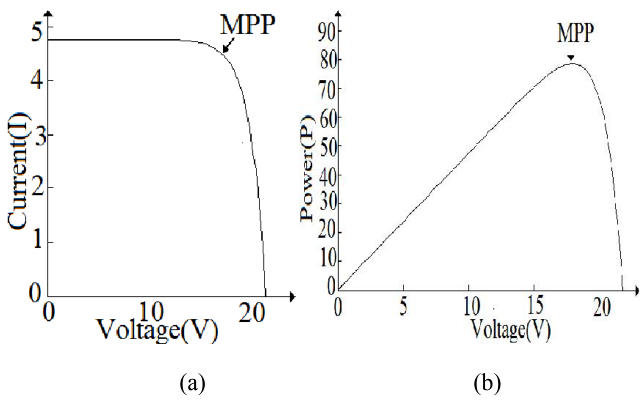


Figure 3. PV array simulated curves (a) I-V curve (25°C) and (b) P-V curve(1000w/m^2)

Simulation of Stand-Alone Photovoltaic System in matlab-simulink environment

Design of Power Circuit

The PV module design specifications for the proposed buck converter are given in table 2.

Table 2. Comparison of data

	P_{max}	V_{max}	I_{max}
Manufacturer Data	80	21.6	5.16
Simulation	78.51	21.65	4.75
Experimental	70	18.83	3.69

The buck converter interfaced with PV panel in open loop condition is shown in fig.4. The design equations of the Buck converter (Muhammad and Rashid, 2001) are presented from (6) to (9).

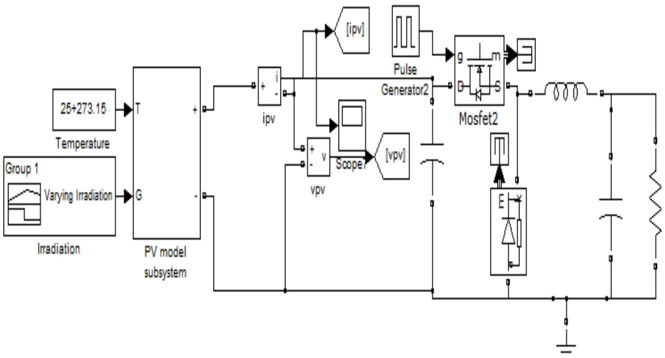


Figure 4. Circuit diagram of buck converter with PV module Without regulator circuit

The voltage ratio of the buck converter is given as,

$$M = \frac{V_o}{V_{in}} = D \qquad (6)$$

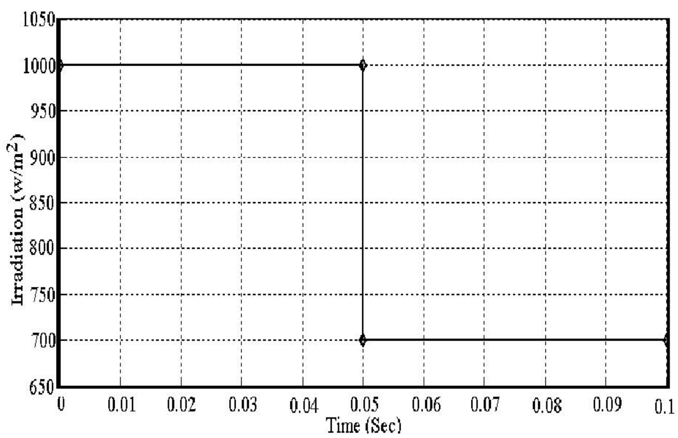
The inductor and capacitor is designed based the following equations to operate converter in continuous current mode (CCM).

$$L = \frac{(1-D)*R}{2*f} \qquad (8)$$

$$C = \frac{(1-D)*V_o}{8*V_r*L*f^2} \qquad (9)$$

Where – D is the duty ratio, R is the load resistance, f is the switching frequency and $\frac{V_o}{V_r}$ is the ripple factor. The design parameters used in simulation are L=7.6825µH, C=53.693µF and f = 100 KHz.

The unregulated input and output results without MPPT algorithm for varying illumination condition are shown in fig. 6.



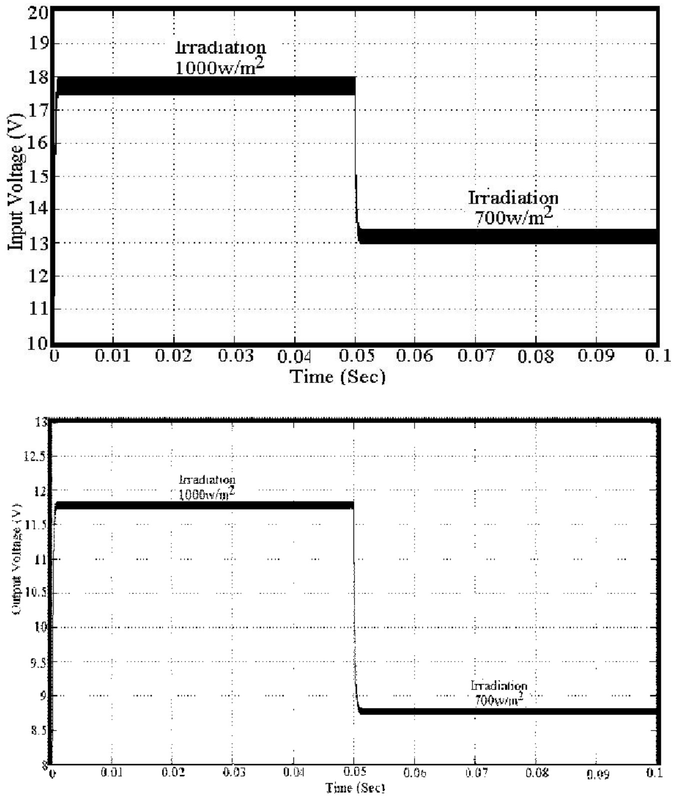


Fig.6. Simulation results depicting the change of insolation from 1000 to 700w/m^2, input voltage (Vin) and output voltage (Vo)

Closed loop simulation of Buck converter with perturb and observe MPPT algorithm

The block diagram of closed loop simulation circuit with MPPT algorithm is shown in fig.7. To regulate the output voltage Vo, the switching frequency of the PWM pulses are varied depends on error.

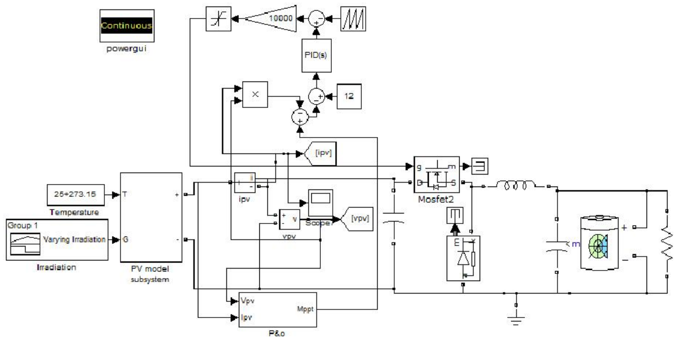


Figure 7. Circuit diagram of buck converter with PV module With regulator and MPPT circuit

Maximum Power Point Tracking

It is desirable to achieve Maximum Power Point output at minimum cost under various operating conditions. However, the Maximum Power Point varies with solar insolation. It is difficult to achieve an optimum matching that is valid for all insolation levels. Hence, in this paper an attempt is made to track the Maximum Power Point Tracking system with buck converter using Perturb and Observe method (Christopher *et al.*, 2009; Akihiro, 2005; Di Dio *et al.*, 2009; Durgadevi *et al.*, 2010). Perturb & Observe (P&O) algorithm, also known as the "hill climbing" method, is very popular and the most commonly used in practice because of its simplicity in algorithm and ease of implementation (Renji *et al*., 2000; Mohammad *et al*., 2002). The basic implemented circuit of the (P&O) algorithm is shown in Fig.8. In this algorithm the operating voltage of the PV module is perturbed by a small increment, and the resulting change of power, ΔP is observed. If the ΔP is positive, then it is supposed that it has moved the operating point closer to the MPP. Thus, further voltage perturbations in the same direction should move the operating point toward the MPP. If the ΔP is negative, the operating point has moved away from the MPP, and the direction of perturbation should be reversed to move back toward the MPP.

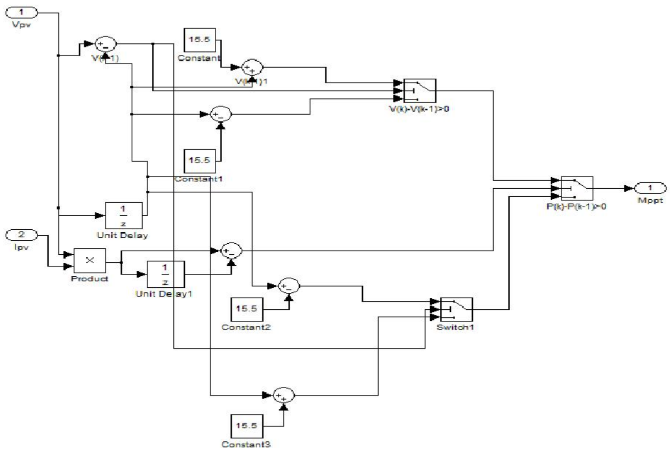
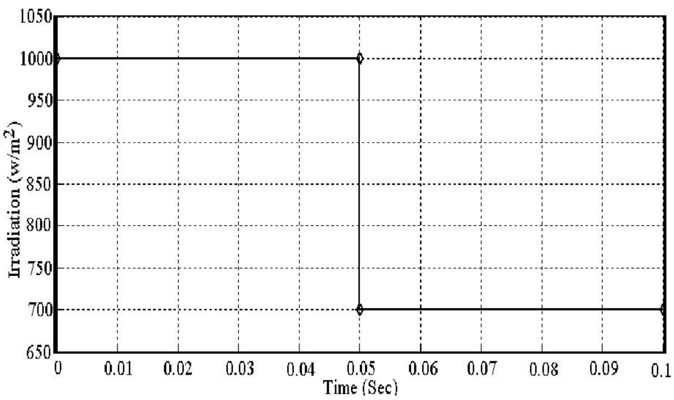
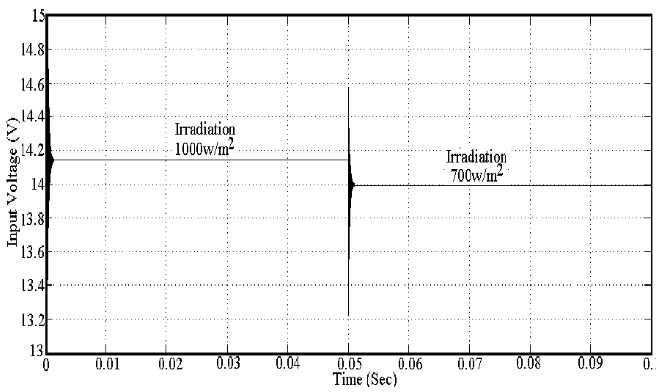


Fig.8. MPPT simulation in simulink environment

Closed loop simulation results

The regulated input and output results with MPPT algorithm for varying illumination condition are shown in fig. 9.





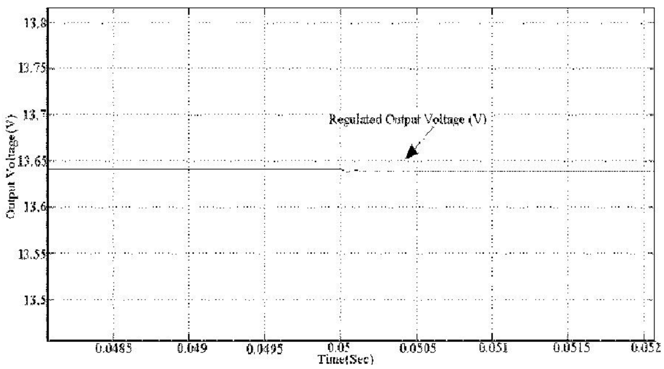


Fig.9. Simulation results depicting the change of insolation from 1000 to 700w/m^2, input voltage (Vin) and regulated output voltage (Vo).

Experimental set up

The experimental setup of the proposed photovoltaic system for the manufacturers specifications given table II is shown in fig.10. The experimental setup consists of solar PV panel, Battery and charge controller unit.

Battery

The lead-acid battery of 13.3V (±1) with 7.5Ah is used for the solar photovoltaic charging application. Fig.15. shows the input voltage to the buck converter from photovoltaic panel.

Solarimeter

The solarimeter is used as an insolation sensor.

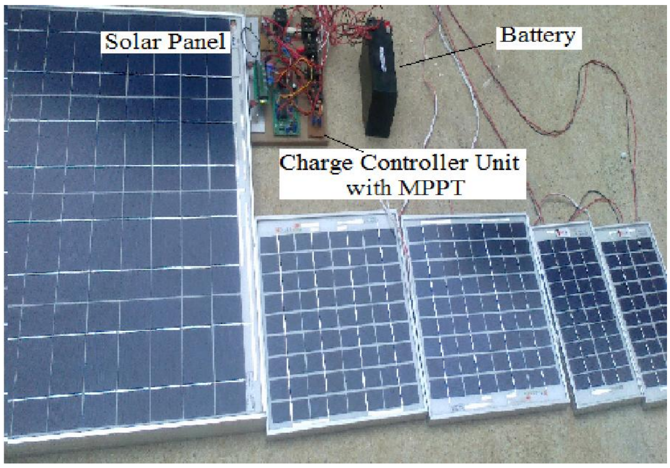


Fig.10. Photocopy of the Experimental setup

Experimental Results

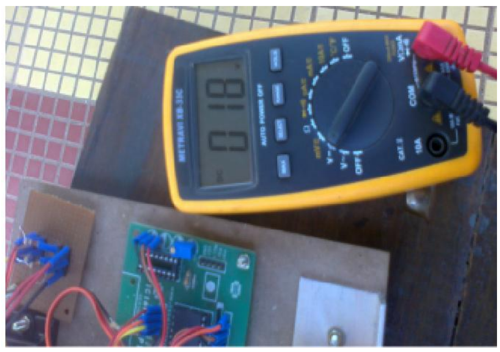


Fig.11. Photocopy of the Experimental setup showing output voltage (Vo) of 13 V and 12 V from the charge controller which charges the battery for the varying illumination 1000w/m^2 to 700w/m^2 irradiation

Conclusion

The photovoltaic model was modeled and validated in Matlab/Simulink environment. The results of simulation, manufacturer data were compared with the experimental data which was obtained through solar panel and these results were found to be almost close to each other. The simulations showed the effects of irradiance and temperature on the operating condition of the photovoltaic module. The simulation results showed that an increase in irradiance generally caused an increase in the modules output current while increase in operating temperature generally caused a drop in the module terminal voltage. In fact the results showed a linear relationship between the short circuit current and the irradiance level while there is a logarithmic relationship between the open circuit voltage and the operating temperature. The MPPT design was implemented and modeled in Matlab/Simulink environment. The simulation results of the MPPT showed that the tracker was able to maintain the operating point of the photovoltaic module at the maximum power point thereby improving the amount of energy successfully extracted from the module. The simulation results indicate that the significant amount of additional energy can be extracted from a photovoltaic array by using simple digital maximum power point trackers. The purpose of maximum power point tracking is to deliver the highest possible power for the battery charging application from the solar arrays. The output current of the PV generator is adjusted by the feedback loop whenever the insolation changes by changing the duty ration of the buck converter. Hence, efficient MPPT is designed and implemented for battery charging application. The same procedure can be used for other solar applications also.

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