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ENERGY TRANSFER FROM THE PV PANEL TO BATTERY VIA BUCK-BOOST CONVERTER

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Abstract

This paper deals with the means of transferring energy from the input to the output. The buck boost converter is considered as a maximum power point tracker or power equilibrium device used between the photovoltaic solar system and the battery by supplying the desired power for the stand-alone system requirements. The system energy is assigned by SLP190S-24 High Efficiency Monocrystalline PV module based Perturb and Observe (P&O) MPPT algorithm with a selected lead acid battery bank of 24 Volts. In order to achieve this energy transfer with minor energy losses, Buck-Boost converter with the switching frequency of 25Khz is designed for charging the lead acid battery applied in standalone system. The MATLAB SIMULINK is used to validate the accuracy and effectiveness of the designed Buck-Boost converter simulation results. The result clings to the value of 99.72% for the combined Tracking and conversion efficiencies.

Keywords

Photovoltaic Solar Panel, Buck-Boost Converter, Perturb And Observe (P&O) Algorithm, Battery

1. Introduction

A suitable battery charge controller is mostly recommended for the stand-alone system application (Sree, et al, 2011). This project embedded the PV solar system as an energy supplier, the buck-boost converter as power matching or interface device between the pv solar source and the battery, the charge controller is used to ensure the power equilibrium from the PV system to the battery so as to transfer effectively the required power to the battery without overcharging mischief and (Sree, et al, 2011) precluding deep discharge and opposite current flow to the battery. The maximum power point tracking (MPPT) algorithm is used to fetch the PV solar power at its peak value at night or during insolation and temperature changing conditions. The standalone application with PV solar system connected to the load with and without MPPT technique presents energy efficiency of 97% and 31% respectively and having 30-40% more energy collection with MPPT technique based than without MPPT method (Taghvaee, et al, 2012). The renewable energy system and battery storage system are the two main components of stand-alone system. The PV solar system has high raw price and low output capacity; however, it is mostly the best choice for standalone applications due to its environment friendly and pollution absenteeism characteristics. The following features such as vast temperature operating range, insignificant self-discharge rate, extended service life span and minimum maintenance requirements (Enslin, et al, 1991) make lead acid battery most applicable for stand-alone energy storage system (Remli, et al, 2015). However, Lead acid battery can suffer from sulfation when the gassing voltage value is greater than its charging maximum voltage value and vis versa. The abrupt temperature increase, gassing, watering losses, plates corrosion are caused by the lower gassing value irrespective to its charging maximum voltage value and vis versa. The cost tradeoff of the battery lifetime to PV solar panel installation and the battery installation are higher and lower respectively (Koutroulis, et al, 2004). When comparing, the installation cost of the PV solar panel deems to be higher than that of the battery whereas the lifetime cost of the battery is in contrast higher than the installation cost of the PV solar panel due to its restricted operating time (Koutroulis, et al, 2004). Appropriately charging and discharging of the battery tend to a prolong battery lifetime and high state of charge (SOC). (Taghvaee, et al, 2012) DC-DC non-isolated converters state-of-the art studies states that buck boost converter is quite convenient for PV system applications because of its ability to achieve a finest system operation with affordable cost and high efficiency regardless of the applied load. The standalone system commonly resembles to the following structure.

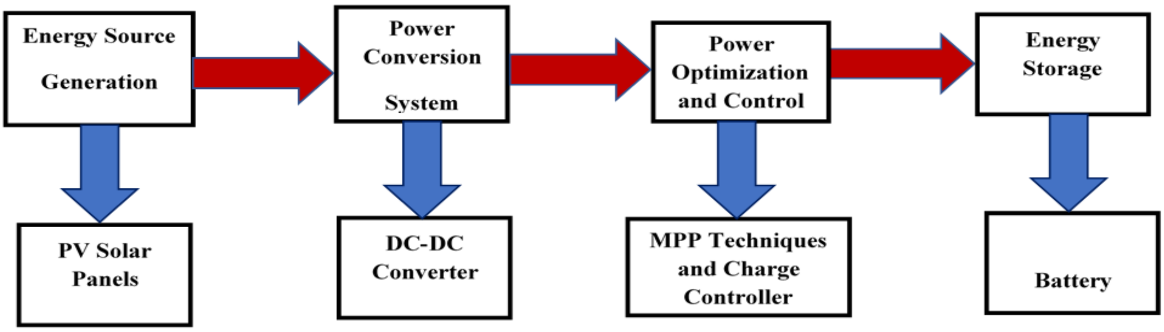


Figure 1: *Energy Transfer and Conversion System Configuration*

2. PV Solar Cell Model

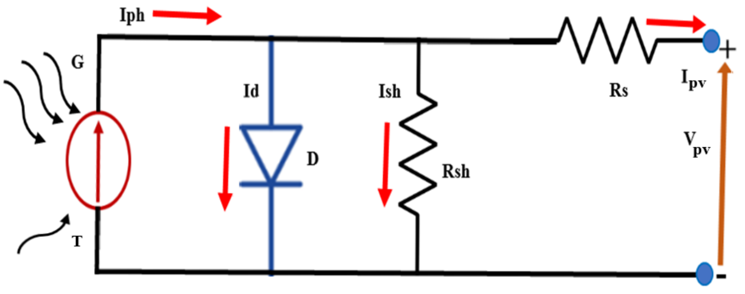


Figure 2: *Photovoltaic Cell Equivalent Circuit Model*

$$I = I_{ph} - I_d\left(exp\left[\frac{q(V+IR_S)}{KTA}\right] - 1\right) - \frac{(V+IR_S)}{R_{RH}} \qquad (1)$$

Here are different equations of the PV solar V-I characteristic. The photovoltaic solar cell output current expression with some variables and constants such as:

I_{ph}: The Light generated current or photocurrent(A)

I_d: Diode reverse saturation current(A)

K: The constant of Boltzmann (1.3810^{-23} J/K)

Rsh: solar cell shunt resistance (Ω)

A: The ideality factor of a single solar cell.

V: The voltage imposed on the diode or thermal voltage (V)

q: The charge of electron (1.60210^{-19} C)

Rs: solar cell series resistance (Ω)

T: Cell temperature(K)

2.1 PV Solar Cell I-V and P-V Characteristics

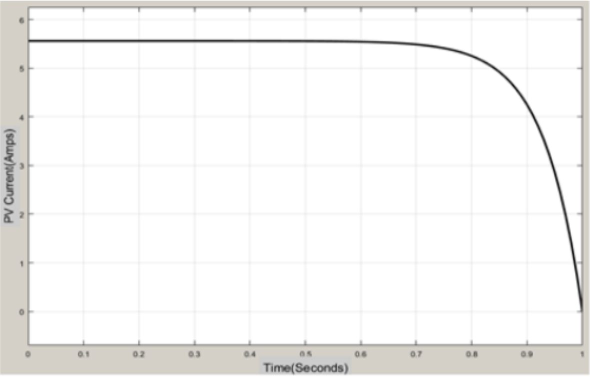


Figure 3: *IV based Time Curve*

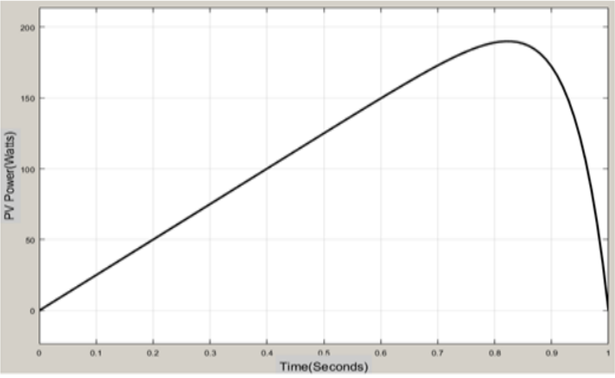


Figure 4: *PV based Time Curve*

Figures 3 and 4 are respectively the selected PV solar panel current and voltage (IV), power and voltage (PV) characteristics curves simulated in 1 second which are commensurate to the values given in the table 2.

3. Power Conversion System

3.1 Buck Boost Converter

In a photovoltaic solar system, the Buck-Boost converter acts as impedance matching device between the PV solar panel and the load. Besides it communicates with the microcontroller and adjusts the duty cycle value accordingly. Buck-Boost converter is convenient to use for maximum power tracking purposes: it works in Buck mode when the resistance load is lesser than the internal resistance of PV array at MPP, and the opposite is true for the Boost mode operation (Byamakesh Nayak, et al, 2017).

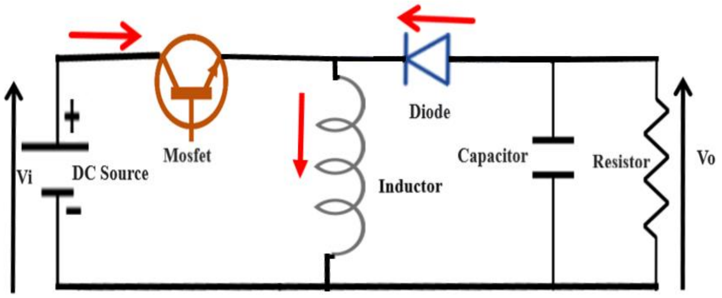


Figure 5: *Basic Circuit of Buck-Boost Converter*

3.2 Continuous Conduction Mode (CCM) Operation Principle of Buck Converter

When the main switch is closed, and the diode switch is open, the inductor voltage remains equal to the input voltage ($V_L = V_{in}$) while the load is supplied by residual energy store in the capacitor.

When the main is released to open position and the diode closed at this time, the inductor current supplied directly the load where its voltage is equal to opposite value of the load or output voltage.

$(V_L = -V_0)$ (figure 7).

3.3 Inductor Minimum, Maximum and Peak to Peak Ripple Current Calculation

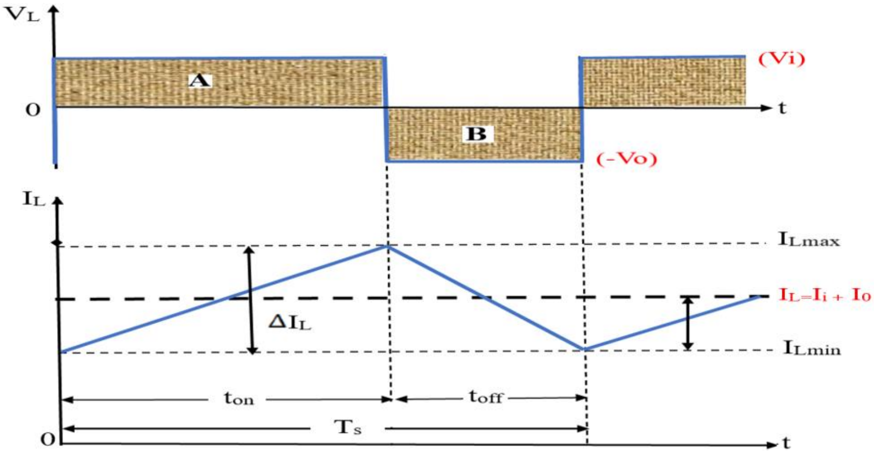


Figure 6: *Inductor Voltage and Current Wave in Continuous Conduction Mode (CCM)*

At $0 < T < t_{on}$, the main switch closed, and diode switch opened,

$$V_L = V_{in} \rightleftharpoons V_L = L\frac{di_{L(t)}}{dt} = V_{in} \quad (45)$$

The peak to peak ripple inductor current is expressed as:

$$\Delta I_L\ (ON) = \frac{V_{in}}{L}\delta T \quad (46)$$

At $t_{on} < T < t_{off}$, the main switch opened, and diode switch closed,

$$V_L = -V_0 \rightleftharpoons V_L = L\frac{di_{L(t)}}{dt} = -V_0 \quad (47)$$

The peak to peak ripple inductor current becomes:

$$\Delta I_L\ (OFF) = \frac{-V_0\ (1-\delta)}{L}T \quad (48)$$

In steady state condition, summation of the ON peak to peak ripple inductor current and the OFF peak to peak ripple inductor current is equal to zero.

$$\Delta I_L\ (ON) + \Delta I_L\ (OFF) = 0 \rightleftharpoons \Delta I_L\ (ON) = \Delta I_L\ (OFF) = \Delta I_L \quad (49)$$

$$\frac{V_{in}}{L}\delta T = \frac{-V_0\ (1-\delta)}{L}T \quad (50)$$

Therefore; the output average voltage can be deduced from (50) and expressed as:

$$V_0 = \frac{-\delta \quad V_{in}}{(1-\delta)} \qquad (51)$$

From (49) and by substituting (51) in (48), the total peak to peak ripple inductor current is:

$$\Delta I_L = \frac{\delta \quad V_{in}}{f_p \, L} \qquad (52)$$

The minimum inductor value required for the Buck-Boost converter to operate in continuous conduction condition is:

$$I_{Lcrit} = \frac{(1-\delta)^2}{2f_p} R \qquad (53)$$

The Conventional Buck-Boost Converter is simple in design with fewer components, but it requires input and output filters. It has both Buck and Boost operating functions; however, its output voltage is upset, unsuitable for the battery application. As matter of solution, it is required transformer which adds the printed circuit board (PCB) space and increases the implementation cost.

The conventional Buck-Boost DC-DC converter encapsulates the following:

1. Advantages

The advantage of Buck and Boost converter based on step up or down the output voltage respect to the input Voltage.

- Output voltage can be either greater or smaller than input voltage.
- Ensures the MPP Tracking by adjusting continuously the input/output voltage ratio.
- Relatively lower cost due to low number of components to be used.

2. Disadvantages

- Output voltage inversion not desirable for battery application
- Switch is not connected to ground which required additional PWM level shifter by adding cost and circuit complexity.
- Pulsed output current increases output voltage ripple.
- Pulsed input current requires input filter.

4. Power Optimization and Control

4.1 Perturb and Observe MPPT Algorithm

Perturb and observe algorithm can be of constant step or variable step type. It is one of the most used tracking techniques. The perturb and observe method of MPP tracking technique is based on controlling constantly the voltage by increasing the voltage with respect to increase in power. When the power starts to decrease after noticing the point over leads the maximum power point, as a result, the algorithm will compensatively decrease the voltage as well and the process hangs around in reiterating until the maximum point is reached (figure 8). The approximate oscillation of the algorithm parameters around the maximum tracking point makes this method less efficient in the situation where bad climate such as irradiance and temperature variation occurred. In this case, determining whether the maximum power point is reached or not, seems very obscure and sometimes the algorithm may restate the step variation in wrong direction due to changing of the irradiation. However, P&O is vastly known and common used maximum power point technique due to its ease of design.

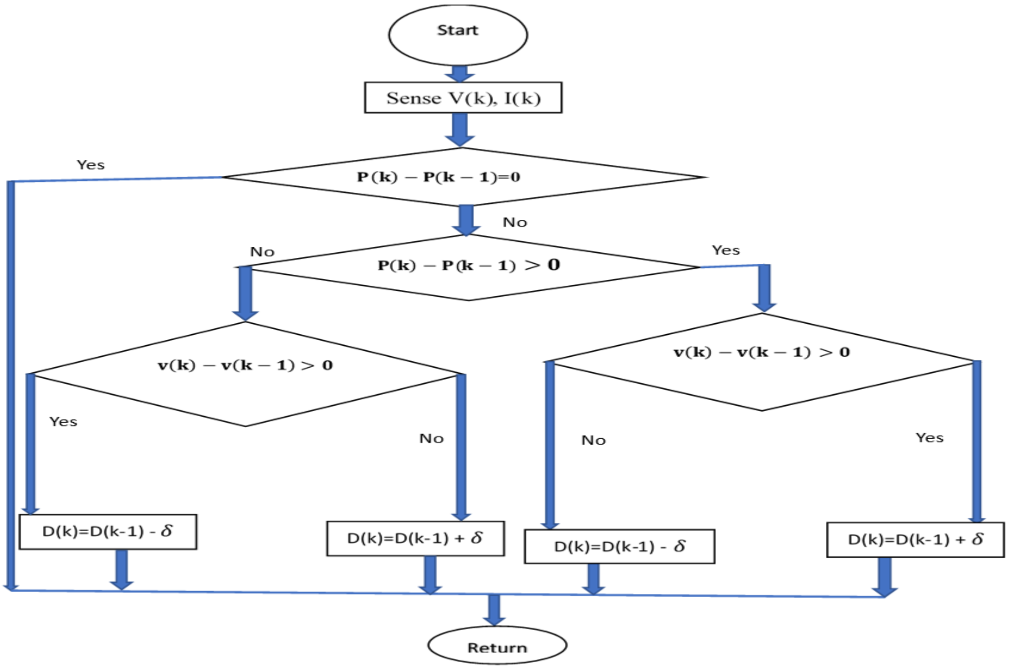


Figure 7: *Flowchart Algorithm of Perturb and Observe (P&O)*

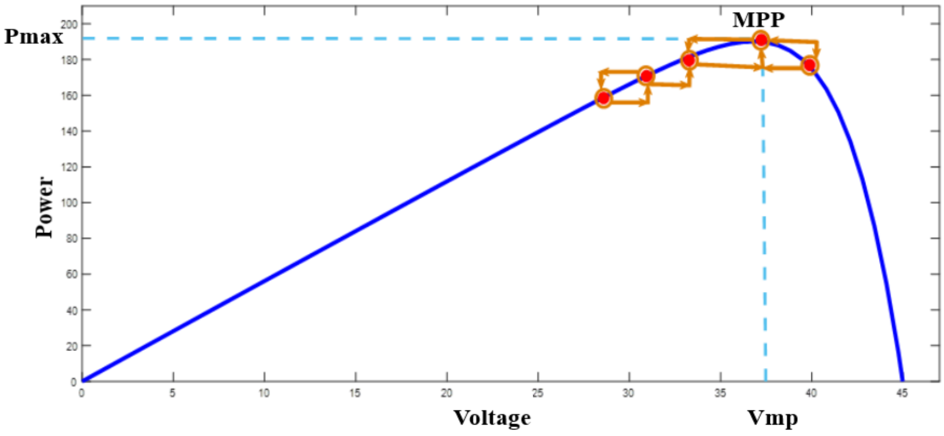


Figure 8: *Perturb and Observe(P&O) P-V curve MPP Tracking at Constant Temperature and Irradiance Conditions*

5. Energy Storage System

5.1 Lead Acid Battery

As one of the ancient rechargeable battery, lead acid battery was invented by French physicist Gaston Planté in 1859 (Daniel, et al, 2017). Thereafter, a technique of achieving its manufacturing was implemented in 1880 by Camille Faure. Lead acid battery is a vital and key part in the renewable energy systems (Armstrong, et al, 2008). Lead acid battery is commonly used in stand-alone photovoltaic solar applications. The valve regulated lead acid battery (VRLA) is the most famous battery used due its cheapest cost and abundance (Moubayed, 2008). Since 1980 lead acid Battery has been commercially utilized as source of energy (Hannan, et al, 2017). The common Valve Regulated Lead acid (VRLA) batteries type are absorbed glass material(AGM) and GEL abtteries, GEL battery is a gelatinous mass without leakage and made of gel-state electrolyte (Hannan, et al, 2017).

Table 1: *Lead Acid Battery Types Characteristics (Doris, et al, 2000) & (Smart Grid IEEE*)

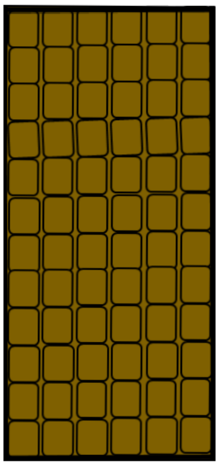
Lead Acid	Efficiency	Advantages	Disadvantages	Applications
VRLA AGM GEL	70-90%	-Less expensive -Developed Technology -High Efficiency	-Limited cycling capability for most standard types -Low energy density -Hazardous to environment	-Power and Energy applications -Some off-grid and microgrid applications

The table 1 summarises the characteristics features of lead battery based on its efficiency range, pros, cons and use for the selection requirements.

6. Proposed System Parameters and Simulation Model

In this section, PV solar panel, Buck Boost converter and the Battery parameters are given respectively in the tables below in order to facilitate their parameters calculation and simulink modeling.

Table 2: *SLP190S-24 High Efficiency Monocrystalline PV Module Specification*



PV panel solar designation	SLP190S-24
Product code	190022401D
Maximum power(pmax)	190W
Voltage at Pmax (Vmp)	36.8V
Current at Pmax (Imp)	5.16A
Open-circuit voltage (Voc)	45.0V
Short-circuit current (Isc)	5.56A
Ideal factor (A)	1.5
Series Resistor (Rs)	0.162 Ohm
Shunt Resistor (Rsh)	466 Ohm
Diode Reverse Current (Id)	2.1067e-14 A
Photon Current (Iph)	5.3424

The table 2 shows the selected PV solar module specification and input power , voltage , current and other main parameters such as open circuit voltage and short circuit current values for the system output requirements.

6.1 Simulations Diagram and Results

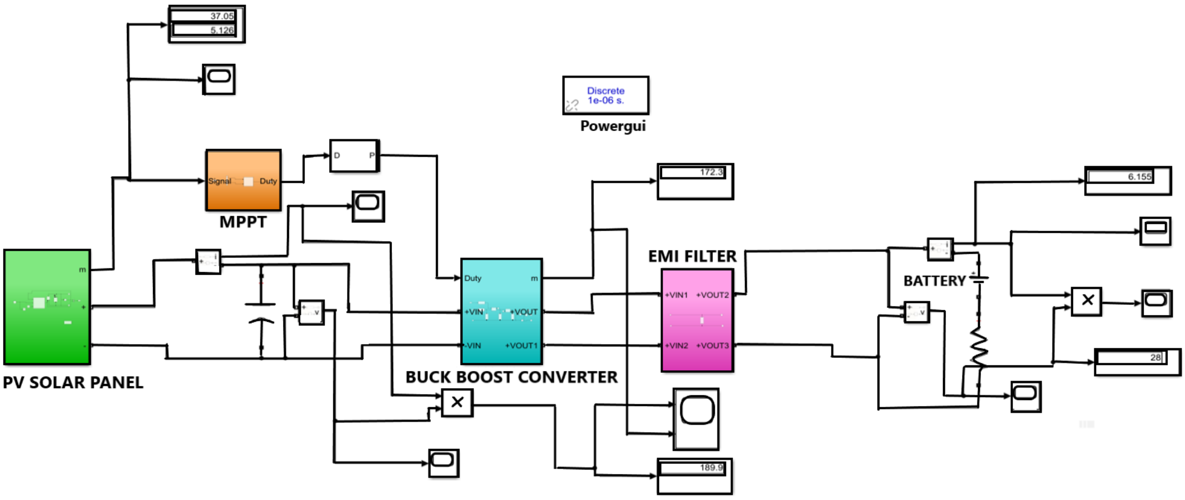


Figure 9: *Simulated Simulink System Diagram (SSD)*

The figure 9 above shows the view spectrum of the system. It encompasses PV solar panels (green block) as an energy source supplier, MPPT (orange block) as energy booster for bad weather conditions related solar insolation from the PV solar panel, Buck Boost conveter (bleue block) as energy converter which increases or decreases power level based on the output requirements, EMI filter (cyan block) used to prevent the electromagnetic interferences from occuring and the battery considered as a load in this diagram for energy storage purposes.

Table 3: *Tracking Efficiency Result*

Irradiance(W/m2)	Ppvmax (Watts).	PBB (Watts)	**Efficiency
1000	172.3	172.27	99.94%
800	135.6	135.38	99.84%
500	81.42	81.21	99.74%
		Eff=99.83%	

The table 3 describes the ratio of powers extracted from the Buck Boost converter(PBB) to the maximum power of the panel (Ppvmax) at specified insolation level which gives a tracking efficiency average value of 99.83%.

Table 4: *Conversion Efficiency Result*

Irradiance(W/m2)	Ppv-Ext (Watts)	PBat-out(Watts)	**Efficiency
1000	189.9	189.7	99.89%
800	149.8	149.78	99.99%
500	90.59	90.42	99.81%
		Eff=99.89%	

The table 4 analyses the measurement of the input powers extracted from the PV solar panel (Ppv-Ext) and output powers transmitted to the battery (PBat-out) from 1000W/m2, 800 W/m2 and 500 W/m2 irradiation level variations which results in a supreme conversion efficiency average value of 99.89%.

** The system efficiency is the product of the tracking efficiency and the conversion efficiency where the value is 99.72.

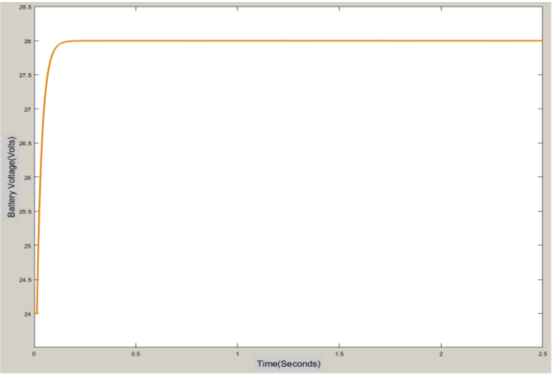


Figure 10: *The Battery Voltage Curve at STC*

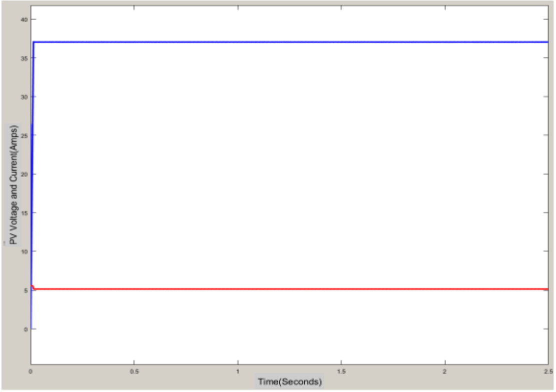


Figure 11: *PV Voltage (blue) and Current (red) curves at STC*

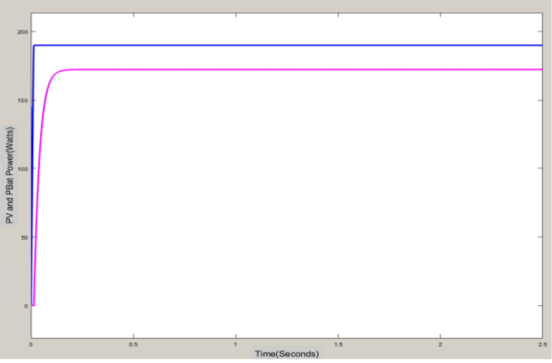


Figure 12: *PV Power (blue) and Load Power(cyan) Curves at STC*

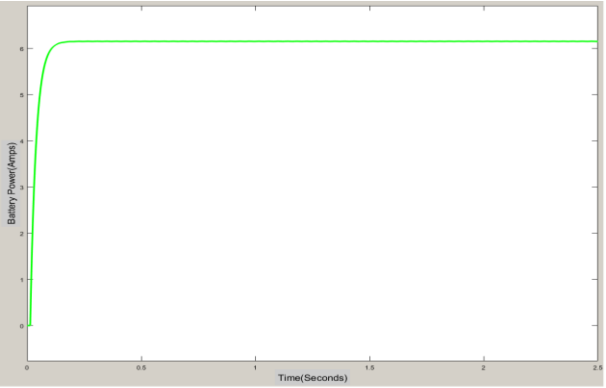


Figure 13: *The Battery Current Curve at STC*

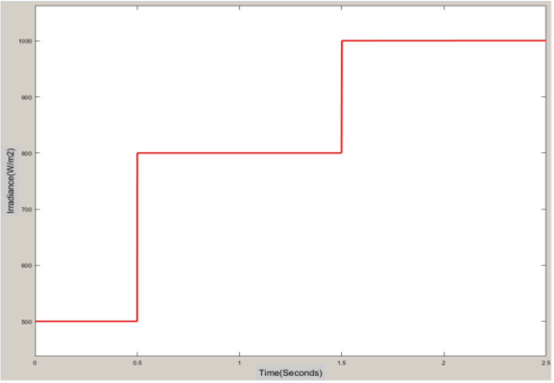


Figure 14: *The Curve at 1000, 800 and 500 W/m2 level of Irradiance*

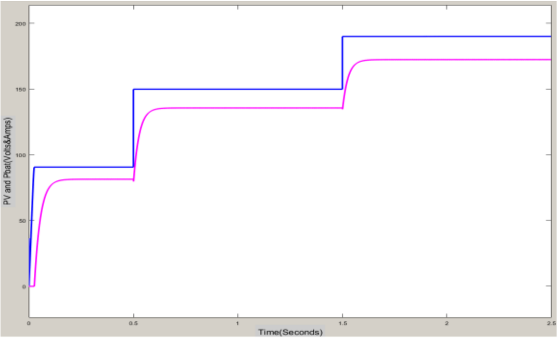


Figure 15: *PV Power (blue) and Load Power (cyan) Curves at 1000, 800and 500 W/m2 of Irradiance*

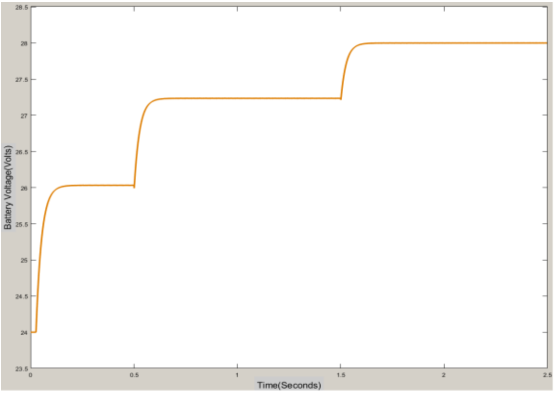


Figure 16: *The Battery Voltage Curve at 1000, 800 and 500 W/m2 of Irradiance*

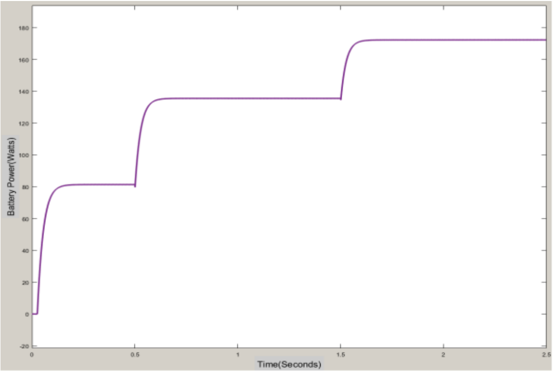


Figure 17: *The Load (Battery) Power Curve at 1000, 800 and 500 W/m2 of Irradiance*

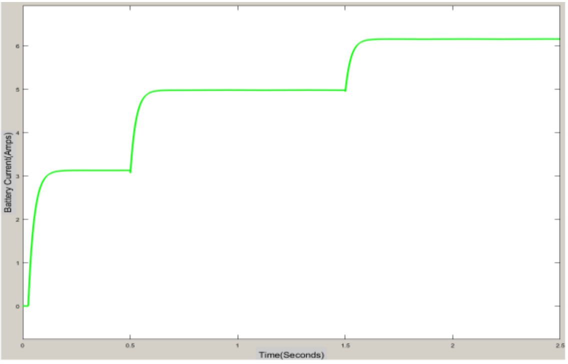


Figure 18: *The battery Current Curve at 1000, 800 and 500 W/m2 of Irradiance*

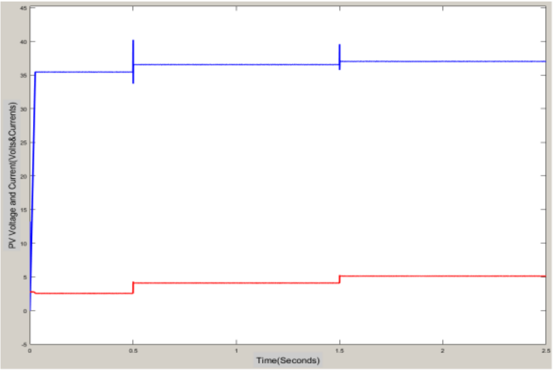


Figure 19: *PV voltage (blue) and Current (red Curves at 1000, 800 and 500 W/m2 of Irradiance*

From these above simulation curves, the figures 10, 11, 12 and 13 are simulated at standard irradiance level of 1000W/m2 where the results are steady and identique to the required values. The figure 14 represents different level of insolation taken to demonstrate the net effects of weather change conditions as compare to standard test conditions.The figures 15, 16, 17, 18 and 19 are the results of environement change conditions labelled in the figures 14 which truly affectes the output results for the various step of insolation levels.

7. Conclusion

The designed Buck Boost converter ensures impedance matching with effective output results. So as to achieve the required output power, the perturb and observe algorithm has been used with PWM frequency of 25 kHz to control the Buck Boost converter. The Simulation is undertaken in SIMULINK/MATLAB screen at a period of 2.5 seconds for all simulated curves. The Battery fully charge voltage is always constant and the system operation and effectiveness are not affected regardless of the battery internal resistance. The system is simulated under different varying insolation levels and at STC. The average efficiency for 500, 600, 800 and 1000 irradiance change were evaluated with value of 99.72% which relatively significant compare to 94% (Lipika, et al, 2014) and 94.4% (Deepak, et al, 2015).

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