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Modelling and Simulation of Solar Photovoltaic array for Battery charging Application using Matlab-Simulink

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Abstract

This paper presents a model of solar photovoltaic array for charging a battery in Matlab/simulink. This model is used to extract the parameters of a solar module under continuous irradiation. An array of PV modules created and tested for continuous solar insolation. The output from this array system is provided as input to the Boost converter to produce a regulated output of 24V. Regulated output from the converter is used for charging a battery which can be used for powering any application. The entire model is simulated and verified for its suitability to implement in real time and the resulting outputs are presented here. This model can be used as a basic for prototype hardware construction in real time.

Keywords: Solar PV Array, Boost Converter, Battery, insolation, Matlab, Simulink.

Introduction

The Renewable energy sources are becoming popular nowadays in the field of energy generation to meet the energy demand. Among the different sources available, solar energy is considered as the best source of energy as it does not produce any pollution. The solar module uses the principle of photovoltaic which directly converts the incoming light radiation into electricity. This is mainly used for power generation because of its modular in nature which can be easily modified for any level of requirement. It remains functioning for a long period without requiring major maintenance. The drawbacks of the system are high capital cost and need for many storage devices to store the energy

A model for solar PV cell has been created to extract the physical parameters as a function of temperature and solar radiation and experimental validation also done [1]. The internal parameters of solar PV cell such as ideality factor, series and shunt resistance are extracted using a method which is represented in block diagram simulink model [2]. Simulation of Matlab based Solar PV module with MPPT using incremental conductance for various insolation levels has been tested in [3]. A mathematical model of solar PV module has been developed, I-V and P-V characteristics of PV with 60 W and 64W are simulated and verified with data sheet value [4].An accurate two diode model representation of PV cell has been developed using Matlab / simulink and the effect of series and shunt resistance has been observed [5].A generalized PV model which is including solar PV cell, PV module and array has been created with Matlab/Simulink and been verified with a commercial PV module [6].In this paper a Matlab/ Simulink based solar PV model is developed and the output parameters are determined. Then a PV array is developed for required level of output value using the tested PV module. The output from PV array is given to the DC-DC boost converter for regulating the output voltage to 24V. Then the regulated output voltage is provided as input for charging the battery.

Model of Solar Photovoltaic Module

A solar PV cell produces an output voltage of around 0.6V. To increase the voltage level, many cells are connected in series to form a PV module. This module in turn can be either connected in series or shunt to improve the voltage or current level respectively. The solar cell used for designing a module has the following characteristics shown in table 1. The interconnection of 20 solar cells in series is shown in figure 2 forms a PV module. To determine the output parameters such as current, voltage and power of the solar module, a test set up is developed here which is shown in figure 1. This test model consists of a voltage sensor and current sensor for sensing the output voltage and current from PV module. The input is continuous solar radiation of 1000 W/m^2. To convert the constant data to solar irradiation a Simulink-Physical signal converter is used at the input side. Similarly a Physical signal to simulink converter is used at the output side to change the physical signal to computational data. The output of the sensors is given to

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a multiplier to find the output power. A solver block is used to carry out continuous simulation and computation.

Table 1. Parameters of a Solar Cell

Parameters	Values
Short circuit current (I_{SC})	4.34 A
Open circuit voltage (V_{OC})	0.6 V
Solar Irradiation (I_{rr})	1000 W/m^2
Quality Factor (N)	1.5
Series Resistance	10 Ω

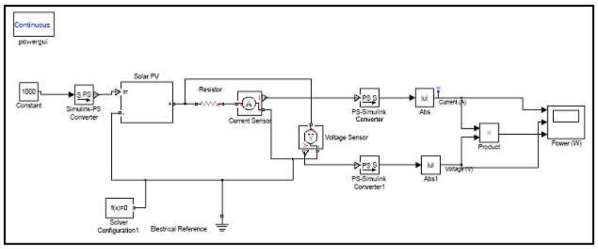


Figure 1. Model of Solar PV module to test output parameters

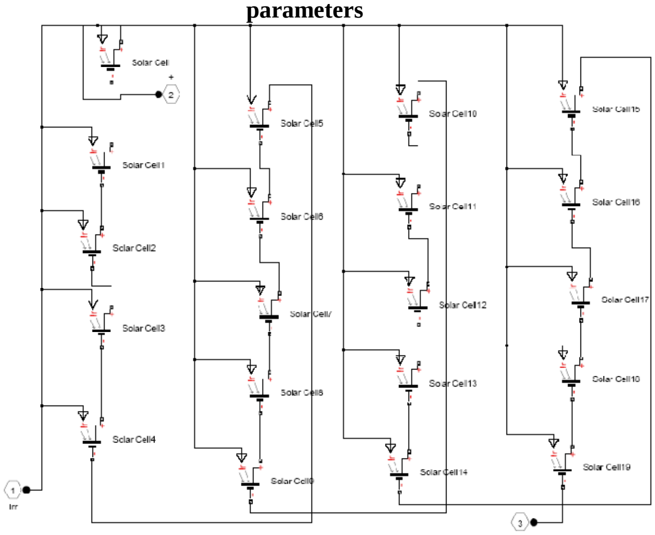


Figure 2. Model of Internal architecture of a Solar PV module

Model of Solar Photovoltaic Array

The PV module tested above is used for construction of solar array. Here 6 PV modules are connected in parallel to enhance the current level of the array. This PV array model is irradiated with continuous solar radiation of 1000 W/m^2. Using a solver configuration, the output parameters are determined. The entire PV array model for determination of output parameters is shown in figure 3.

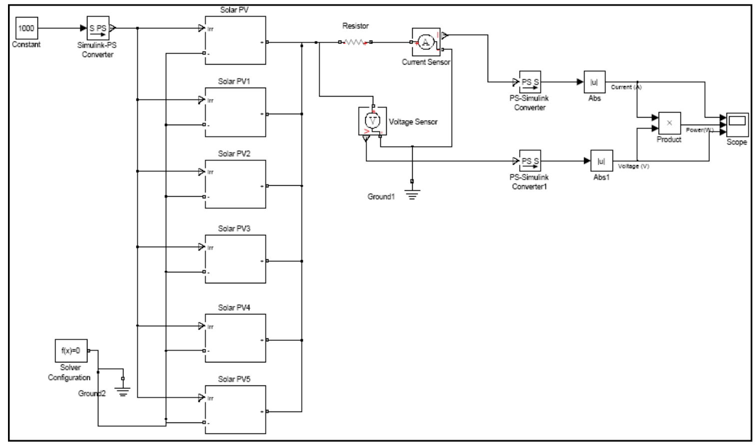


Figure 3. Model of Solar PV Array to test output parameters

Model of DC-DC Boost Converter

The output of the PV array is connected to the input of DC-DC boost converter. The boost converter is a power electronics circuit which is used to convert dc voltage at lower level to another dc voltage at higher level. They generally perform the conversion by applying a dc voltage across an inductor for a period of time which causes current to flow through it and store energy magnetically, then switching this voltage off and causing the stored energy to be transferred to the voltage output in a controlled manner. The output voltage is regulated by adjusting the ratio of on/off time of the pulse generator. The *Pulse-width modulation* (PWM) signal allows control and regulation of the total output voltage. Since the output of solar array is variable dc voltage, a boost converter is required to produce constant regulated high dc voltage. In this project, a boost converter is designed to step up 12V to constant 24V output at 50% duty cycle of PWM signal with switching frequency of 20 kHz.

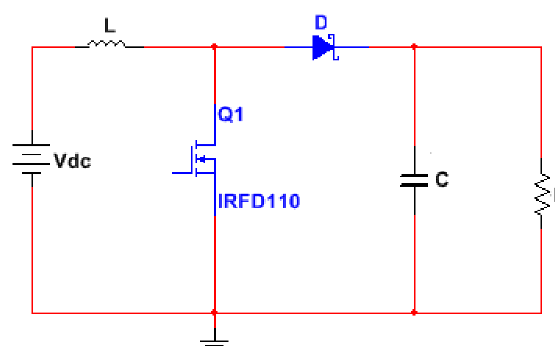


Figure 4. Circuit diagram of Boost converter

The dc-dc boost converter shown in figure 4 is operated in two modes.

Mode-1: When the MOSFET switch is in ON state (closed), the whole circuit will be divided into two loops one at the output side and another at the input side. The closed loop at input consisting of inductor gets charged by the current flowing through the loop during this period. This current will increase linearly till the time the switch is in closed condition. In the same time interval, inductor voltage is also high as it is not delivered to any load but to itself. Diode is off during this mode. The equivalent circuit representation of mode 1 is shown in figure 5.

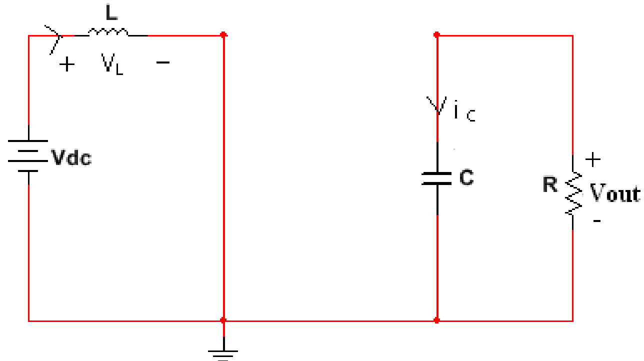


Figure 5. Equivalent Circuit of Mode 1

Mode-2: When the switch is in OFF state (Open), there will be a closed loop consisting of power source, inductor and RC load. The energy stored in the inductor during ON state is discharged to the RC load circuit through the diode. Thus inductor current is reducing linearly, charging the capacitor at the load side. The equivalent circuit for mode 2 is shown in figure 6.

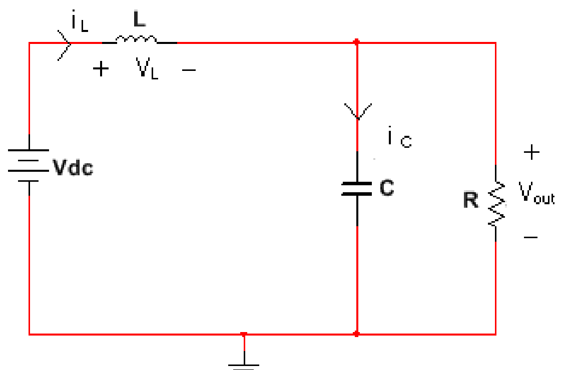


Figure 6. Equivalent Circuit of Mode 2

Thus for closed switch time inductor gets charged and capacitor is delivering the required power to the load, and for the opened switch time inductor will discharge supplying the full power to load and charging capacitor simultaneously. The model of boost converter done in matlab is shown in figure 7.

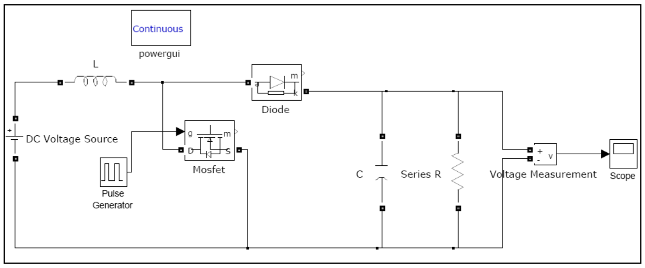


Figure 7. Model of DC-DC Boost Converter

Model of Battery Circuit

PV panels only provide power during the daylight hours and many applications require energy when the sun is set, hence a battery is often needed to store energy. A real battery has an internal resistance and is often modeled with an equivalent circuit consisting of an ideal battery of voltage V_B in series with some internal resistance R_i. During the charge cycle, the applied voltage needs to be greater than the battery voltage and during discharge cycle; the output voltage is less than V_B.

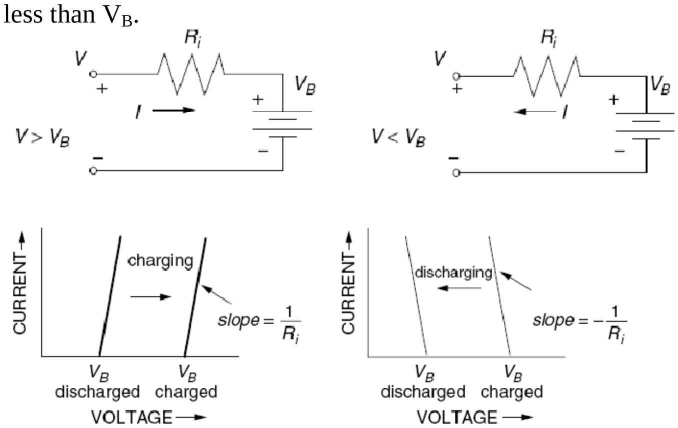


Figure 8. Equivalent circuit of battery and I-V characteristic graph.

Battery is an electrochemical device that converts chemical energy into electrical energy. The most commonly used battery is the lead acid battery because of its low cost and simple charging process. The cell in a lead acid battery consists of lead electrodes in an electrolyte of aqueous sulphuric acid. The anode is made up of lead and cathode is lead oxide. Inside the cell, the oxidation and reduction reaction takes place for discharging and charging. The regulated output from the boost converter is fed to the battery circuit for storing energy. Here two lead acid batteries are used in series for storing the charge. Each battery has the following characteristics shown in table 2. The complete model for testing the battery characteristics is shown in figure 8.The discharge characteristics of the battery is shown in figure 9.

Table 2. Parameters of a Lead acid Battery

Parameters	Values
Nominal voltage	12 V
Rated Capacity	6.5 Ah
Initial state of charge (SOC)	100 %
Nominal discharge current	1.3 A

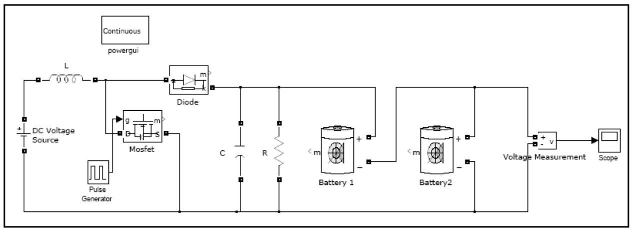


Figure 9. Model of Battery Circuit

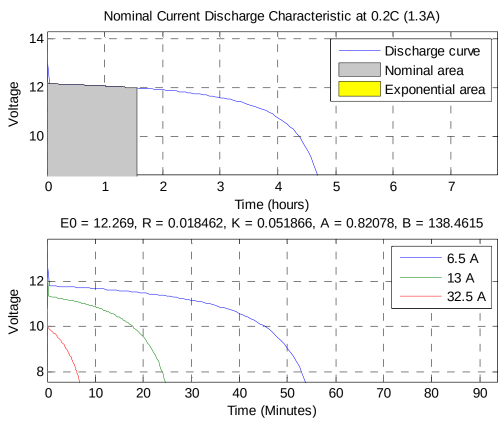


Figure 10. Discharge characteristics of lead acid battery

Result and Analysis

The simulink model of solar PV module shown in figure 1 is simulated and observed output waveforms are shown in figure 11. It produces an output voltage of 11.8 V, current of 1.2 A and power of 14 W for a continuous irradiation of 1000 W/m^2. Simulink model of solar PV array is then simulated and the output waveforms are shown in figure 12. In this case, the output values are 11.75 V, 11.75 A and 137 W. The output of solar PV array is fed to the boost converter and its regulated output is shown in figure 13. The ripple factor of the output voltage is calculated using the following formula;

Ripple factor (γ) = (V_{max} – V_{min}) / V_{avg}

From the graph,

γ = (23.56 – 23.28) / 23.42

γ = 0.0119.

Ripple factor of the boost converter output is equal to 1.195%. The voltage across the battery is shown in figure 13.

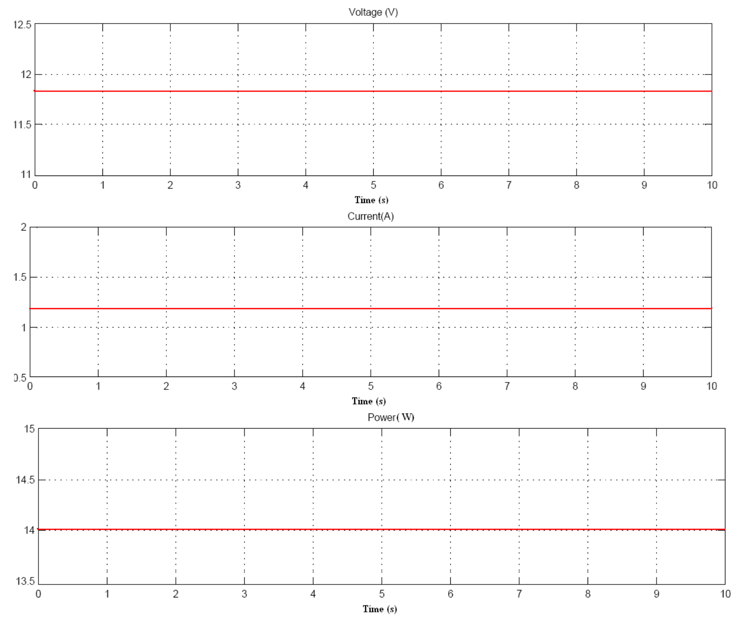


Figure 11. Output waveform of Solar PV module

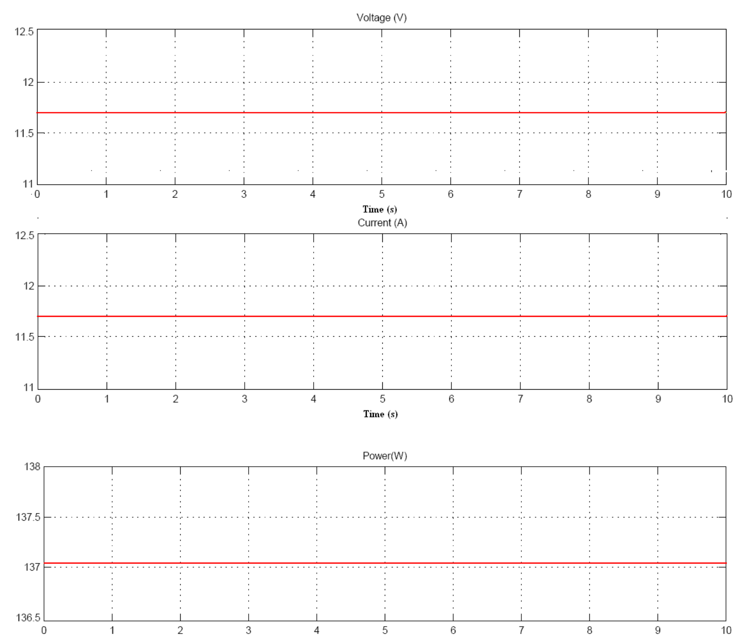


Figure 12. Output waveform of Solar PV array

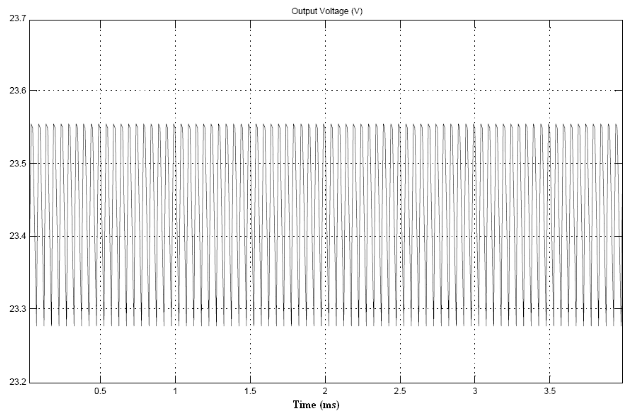
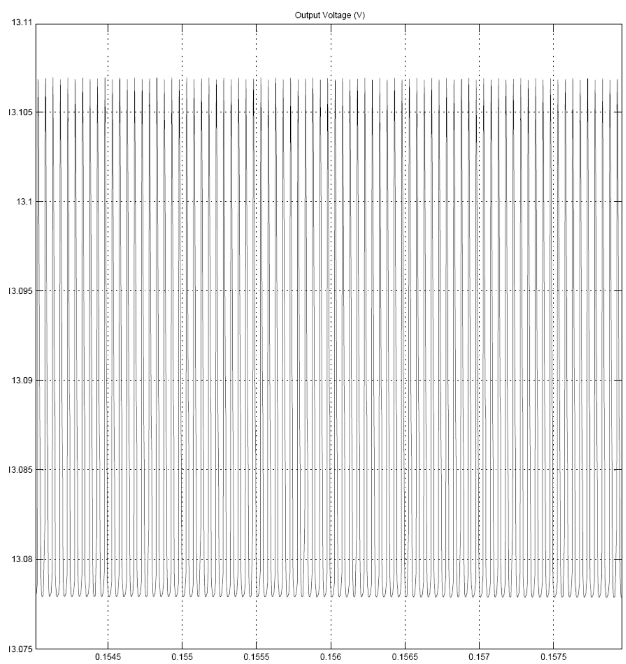


Figure 13. Output waveform of Boost converter



Time (s)

Figure 14. Voltage across Battery circuit

Conclusion

In this paper, a Matlab / simulink based Solar PV array has been modeled and is connected to the battery charging circuit through boost converter. At each stage the output parameters like, voltage, current and power has been determined. The boost converter produced a step up voltage of 24V from 11.75 V input from PV array. This regulated dc output has a ripple content of 1.19%. Two lead acid battery connected in series is used for storing the energy. The charging and discharging characteristics of the battery has been observed. This simulink model can be used as a preliminary test and it forms the base for making prototype hardware.

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