Cumhuriyet Üniversitesi Fen Fakültesi
Fen Bilimleri Dergisi (CFD), Cilt:36, No: 6 Özel Sayı (2015)
ISSN: 1300-1949

Cumhuriyet University Faculty of Science
Science Journal (CSJ), Vol. 36, No: 6 Special Issue (2015)
ISSN: 1300-1949

Investigation of Boost Converter to Track Maximum Power Point in order to Control Voltage and Power in Photovoltaic Cell

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Received: 24.04.2015; Accepted: 09.07.2015

Abstract. In this paper, utilization of a boost converter to control photovoltaic power using Maximum Power Point Tracking (MPPT) control mechanism is presented. First the photovoltaic module is analyzed using SIMULINK software. The main aim of the project is to use boost converter along with a Maximum Power Point Tracking control mechanism. The MPPT method is responsible for extracting maximum possible power from the photovoltaic cell and feed to the load via the boost converter which steps up the voltage to required magnitude. Perturb & observe method is the selected approach for MPPT mechanism. The algorithm is conducted in m files of MATLAB and utilized for simulation. Both the boost converter and the solar cell are modeled using Sim power Systems blocks.

Keywords: Photovoltaic (PV) system, boost converter, maximum power point tracking (MPPT), Perturb and bserve method

I. INTRODUCTION

AS the costs of fossil fuels and their environmental concerns rise, due to shortage of fossil fuels and environmental problems caused by conventional power generation, renewable energy, especially solar energy, has become very popular. Solar-electric-energy demand has grown consistently by 20%-25% per annum over the past 20 years [1], and the growth is mostly in grid-connected applications. With the extraordinary market growth in grid-connected PV systems, there is increasing interests in grid-connected PV configurations the demand for innovation in renewable energy grows. solar photovoltaic (PV) energy has seen a rapid growth in the last few years, resulting in the PV panel prices decrease, the cost of the power electronics required to extract the maximum power of the PV panels and to interface the PV system to the grid is becoming a larger part of the overall system cost [1]. Much attention has, therefore, been given to the development of power electronics that enable a cost reduction of the overall system. In addition, much research is focused on increasing the efficiency of the power processing stage, as well as on improving the power yield of the overall system [2], [3]. Many PV installations suffer from current mismatch between different panels, due to nonuniform shading of the array, dirt accumulation, or manufacturing variability. Ensuring uniform illumination is particularly challenging in residential PV applications, where large current mismatch can be present due to external objects that cause shading [2], [3].

Solar energy is abundantly available that has made it possible to harvest it and utilize it properly. Solar energy can be a standalone generating unit or can be a grid connected generating unit depending on the availability of a grid nearby. Thus it can be used to power rural areas where the availability of grids is

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Special Issue: International Conference on Non-Linear System & Optimization in Computer & Electrical Engineering

very low. Another advantage of using solar energy is the portable operation whenever wherever necessary[4].

In order to tackle the present energy crisis one has to develop an efficient manner in which power has to be extracted from the incoming solar radiation. The power conversion mechanisms have been greatly reduced in size in the past few years. The development in power electronics and material science has helped engineers to come up very small but powerful systems to withstand the high power demand. But the disadvantage of these systems is the increased power density. Trend has set in for the use of multi-input converter units that can effectively handle the voltage fluctuations. But due to high production cost and the low efficiency of these systems they can hardly compete in the competitive markets as a prime power generation source[5], [6].

The constant increase in the development of the solar cells manufacturing technology would definitely make the use of these technologies possible on a wider basis than what the scenario is presently. The use of the newest power control mechanisms called the Maximum Power Point Tracking (MPPT) algorithms has led to the increase in the efficiency of operation of the solar modules and thus is effective in the field of utilization of renewable sources of energy [7], [8], [9].

II. SYSTEM DESCRIPTION

A. PV Characteristics

A solar cell is the building block of a solar panel. A photovoltaic module is formed by connecting many solar cells in series and parallel. Considering only a single solar cell; it can be modeled by utilizing a current source, a diode and two resistors. This model is known as a single diode model of solar cell. Two diode models are also available but only single diode model is considered here [1], [2], [9] and [10].

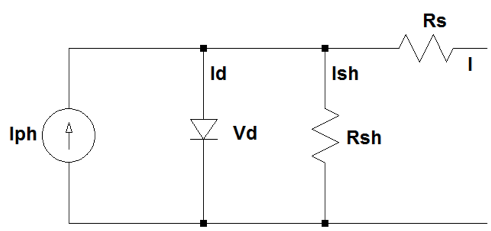

Fig 1. Single diode model of a solar cell

The characteristic equation for a photovoltaic cell is given by [1], [2], [9] and [10].

$$I = Ilg - \ Ios * \left[\exp\left\{q * \frac{V + I * Rs}{A * K * T}\right\} - 1\right] - \frac{V + I * Rs}{Rsh} \qquad (1)$$

Where,

$$Ios = Ior * \left(\frac{T}{Tr}\right)^3 * \left[\exp\left\{ q * Ego * \frac{\frac{1}{Tr} - \frac{1}{T}}{A * k} \right\}\right] \qquad (2)$$

$$Ilg = \{Iscr + Ki * (T - 25)\} * lambda \qquad (3)$$

I & V : Cell output current and voltage;
Ios : Cell reverse saturation current;
T : Cell temperature in Celsius;
K : Boltzmann's constant, $1.38 * 10^{-19}$ J/K;

q : Electron charge, $1.6*10^{-23}$ C;
Ki : Short circuit current temperature coefficient at Iscr;
Lambda : Solar irradiation in W/m^2;
Iscr : Short circuit current at 25 degree Celsius;
Ilg : Light-generated current;
Ego : Band gap for silicon;
A : Ideality factor;
Tr : Reference temperature;
Ior : Cell saturation current at Tr;
Rsh : Shunt resistance;
Rs : Series resistance;

The characteristic equation of a solar module is dependent on the number of cells in parallel and number of cells in series. It is observed from experimental results that the current variation is less dependent on the shunt resistance and is more dependent on the series resistance [11].

$$I = Np * Ilg - Np * Ios * \left[exp\left\{ q * \frac{\frac{V}{Ns} + I * \frac{Rs}{Np}}{A * k * T} \right\} - 1 \right] - \frac{V * \left(\frac{Np}{Ns}\right) + I * R}{Rsh} \qquad (4)$$

The I-V and P-V curves for a solar cell are given in the following figure. It can be seen that the cell operates as a constant current source at low values of operating voltages and a constant voltage source at low values of operating current.

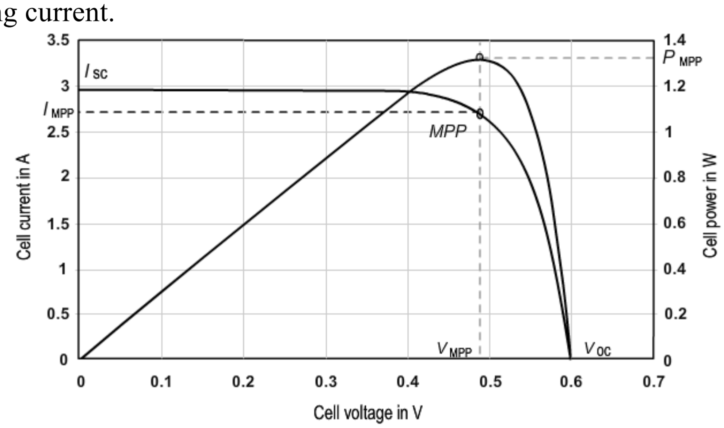

Figure 2. P-V I-V curve of a solar cell at given temperature and solar irradiation

Too Details of the current-input PV module model as shown below:

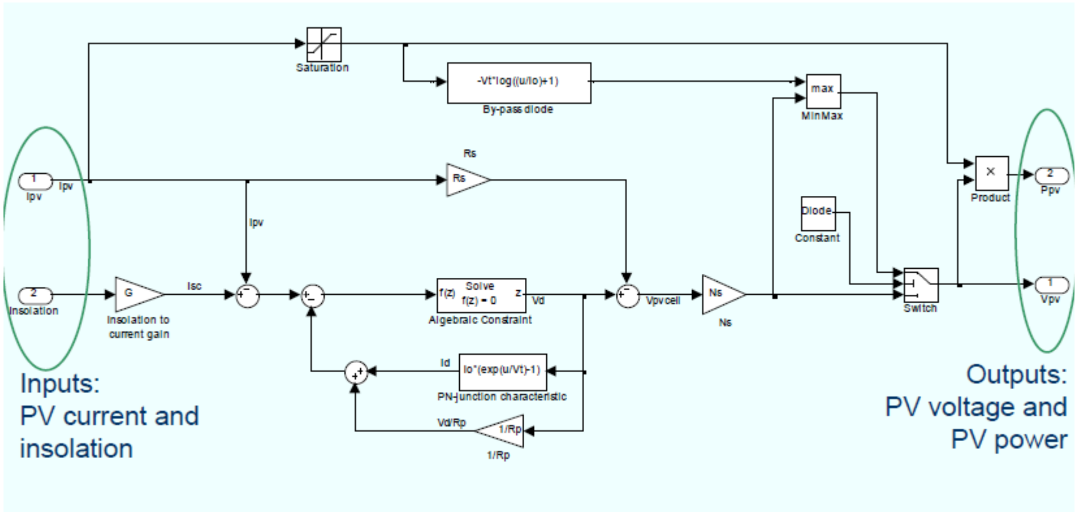

Figure 3. Current-input PV module model

B. EFFECT OF VARIATION OF SOLAR IRRADIATION

The P-V and I-V curves of a solar cell are highly dependent on the solar irradiation values. The solar irradiation as a result of the environmental changes keeps on fluctuating, but control mechanisms are available that can track this change and can alter the working of the solar cell to meet the required load demands. Higher is the solar irradiation, higher would be the solar input to the solar cell and hence power magnitude would increase for the same voltage value. With increase in the solar irradiation the open circuit voltage increases. This is due to the fact that, when more sunlight incidents on to the solar cell, the electrons are supplied with higher excitation energy, thereby increasing the electron mobility and thus more power is generated [11].

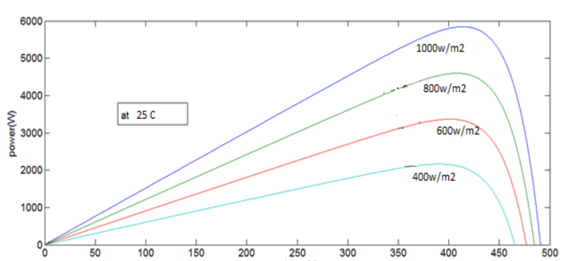

Figure 4. Variation of P-V curve with solar irradiation

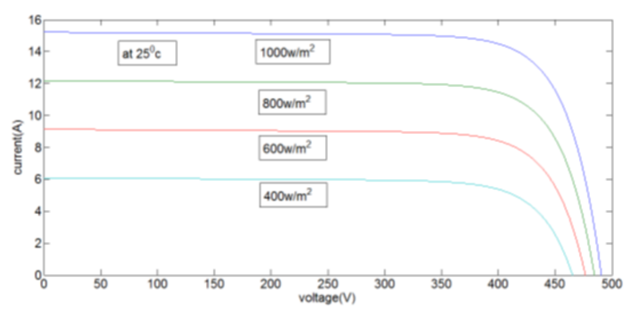

Figure 5. Variation of I-V curve with solar irradiation

C. BOOST CONVERTER

Boost converter steps up the input voltage magnitude to a required output voltage magnitude without the use of a transformer. The main components of a boost converter are an inductor, a diode and a high frequency switch. These in a co-ordinated manner supply power to the load at a voltage greater than the input voltage magnitude. The control strategy lies in the manipulation of the duty cycle of the switch which causes the voltage change [11] and [12].

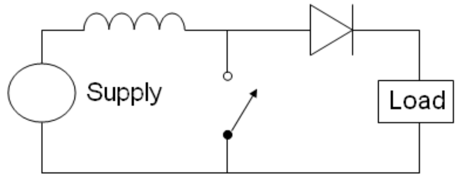

Figure 6. A boost converter.

C.1. MODES OF OPERATION

There are two modes of operation of a boost converter. Those are based on the closing and opening of the switch. The first mode is when the switch is closed; this is known as the charging mode of operation. The second mode is when the switch is open; this is known as the discharging mode of operation [12].

C.2. Charging Mode

In this mode of operation; the switch is closed and the inductor is charged by the source through the switch. The charging current is exponential in nature but for simplicity is assumed to be linearly varying [11]. The diode restricts the flow of current from the source to the load and the demand of the load is met by the discharging of the capacitor.

C.3. Discharging Mode

In this mode of operation; the switch is open and the diode is forward biased [11]. The inductor now discharges and together with the source charges the capacitor and meets the load demands. The load current variation is very small and in many cases is assumed constant throughout the operation.

C.4. WAVEFORMS

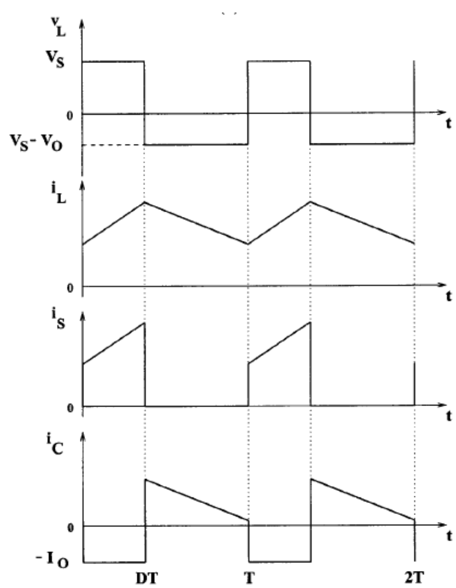

Figure 7. Waveforms of boost converter

III. PROPOSED MPPT ALGORITHM

A. METHODS FOR MPPT

There are many methods used for maximum power point tracking a few are listed below:

- Perturb and Observe method
- Incremental Conductance method
- Parasitic Capacitance method
- Constant Voltage method
- Constant Current method

B. PERTURB AND OBSERVE METHOD

This method is the most common. In this method very less number of sensors are utilized. The operating voltage is sampled and the algorithm changes the operating voltage in the required direction and samplesdP/dV. If dP/dV is positive, then the algorithm increases the voltage value towards the MPP until $dP/dV$is negative. This iteration is continued until the algorithm finally reaches the MPP. This algorithm is not suitable when the variation in the solar irradiation is high. The voltage never actually reaches an exact value but perturbs around the maximum power point (MPP) [18], [19].

C. FLOW CHART OF MPPT ALGORITHMS

One of the most widely used method for maximum power point racking are studied here. The method are

Perturb & Observe Method.

The flow charts for the method are shown below.

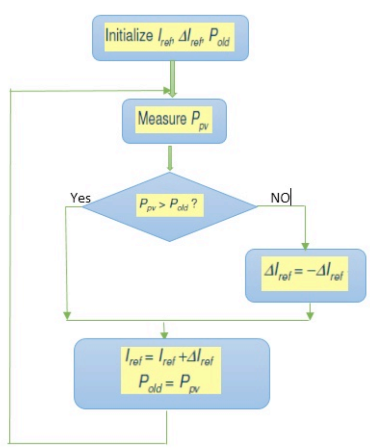

Figure 8. Flow chart of perturb & observe

This algorithm are implemented using the Embedded MATLAB function of Simulink, where the codes written inside the function block are utilized to vary certain signals with respect to the input signals.

IV. SIMULATION RESULTS AND DISCUSSION

The simulation of a solar cell's and boost converter was done using MATLAB and SIMULINK. The PV's and boost converter from the simulation and MPP traking controller are shown below.

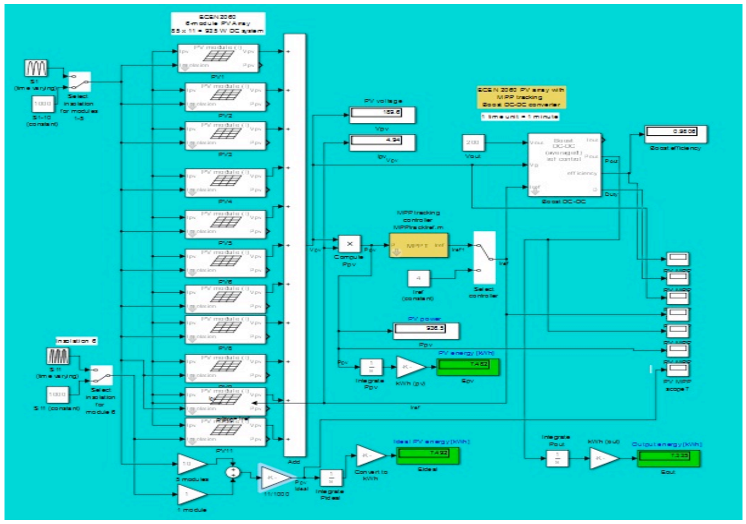

Figure 9. Simulation model (pv_boost_mpp_Iref)

A. CHARACTERISTICS OF A SOLAR CELL

The parameters were obtained for a generalized solar cell. The plot is similar to the theoretically known plot of the solar cell voltage and current. The peak power is denoted by a circle in the plot. the solar output voltage is (51.7V) in this case. The This plot gives the solar output power against the solar output voltage. This clearly abides by the theoretical plot that was shown previously. The maximum power point is marked with a small circle. The initial part of the plot from 0 V to the maximum power point voltage is a steady slope curve but after the maximum power point the curve is a steeply falling curve[14]-[17].

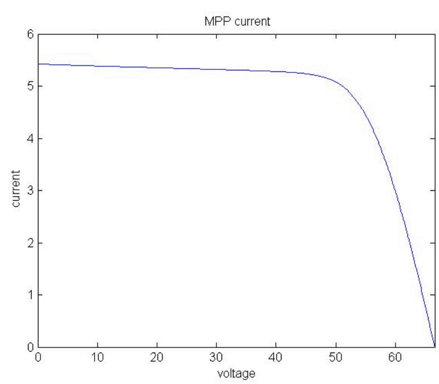

Figure 10. I-V characteristics of a solar cell

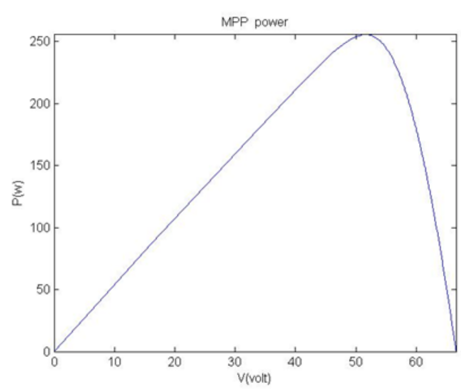

Figure 11. P-V characteristics of a solar cell

B. SIMULATION RESULTS OF THE CONVERTER MODEL

The simulations were carried out in Simulink and the various voltages, currents and power plots were obtained.

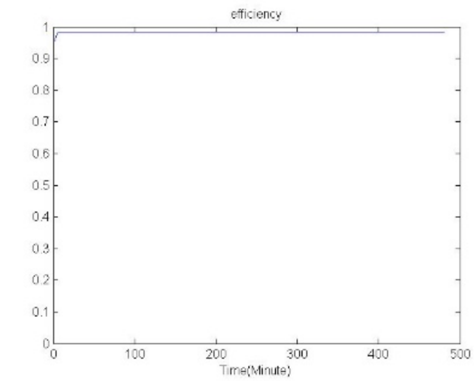

Figure 12. Efficiency for constant time

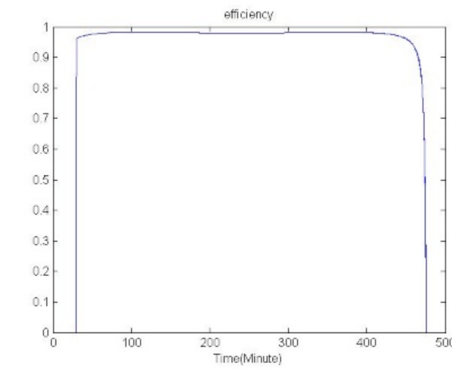

Figure 13. Efficiency for varying time

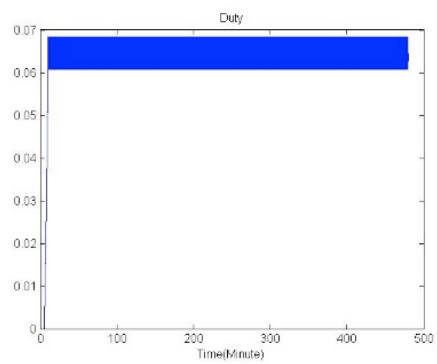

Figure 14. Duty for constant time

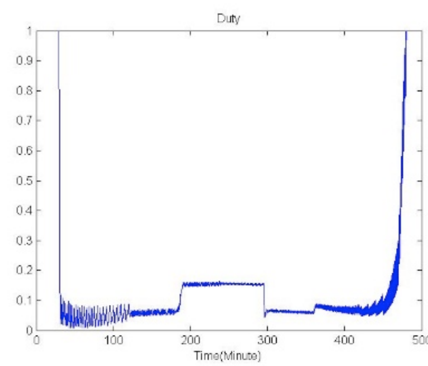

Figure 15. Duty for varying time

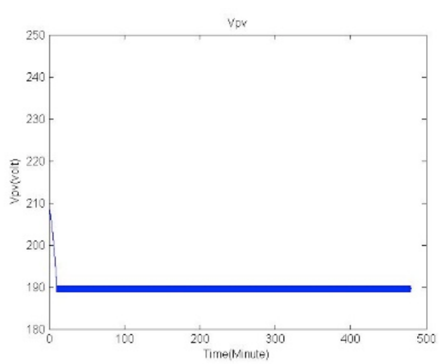

Figure 16. Vpv for constant time

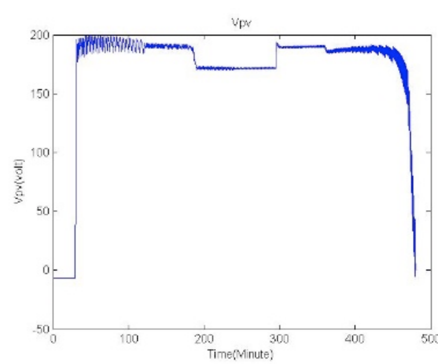

Figure 17. Vpv for varying time.

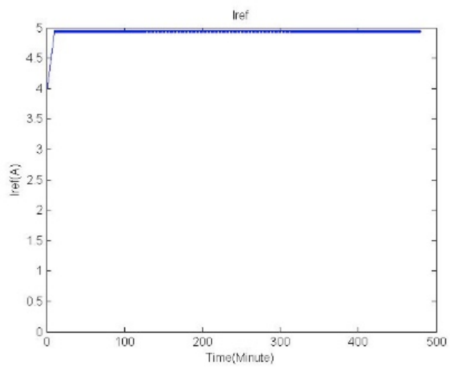

Figure 18. Iref for constant time

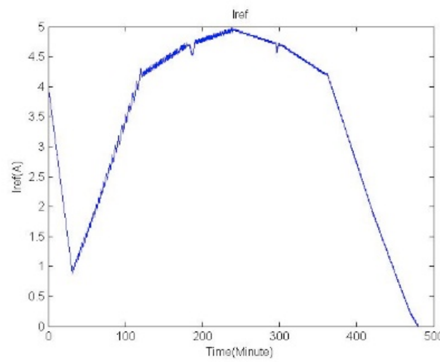

Figure 19. Iref for varying time

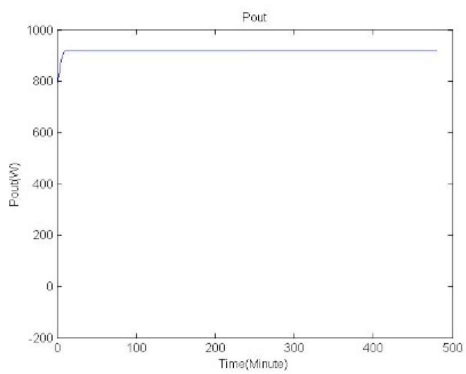

Figure 20. Pout for constant time.

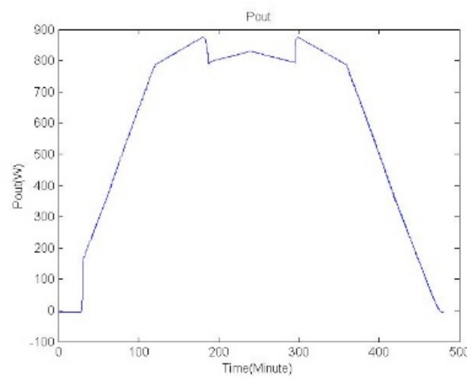

Figure 21. Pout for varying time.

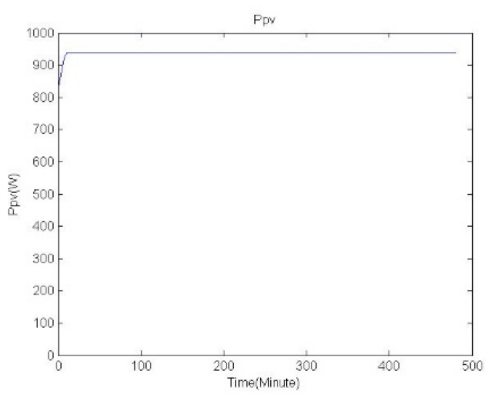

Figure 22. Ppv for varying time

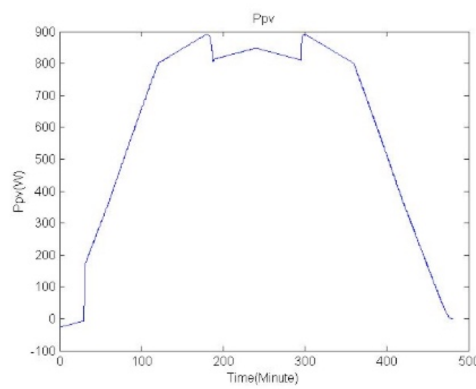

Figure 23. Ppv for varying time

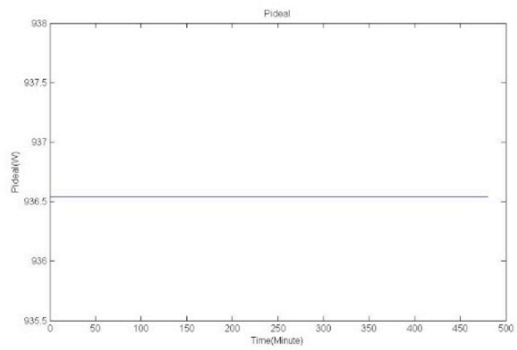

Figure 24. Pideal for constant time

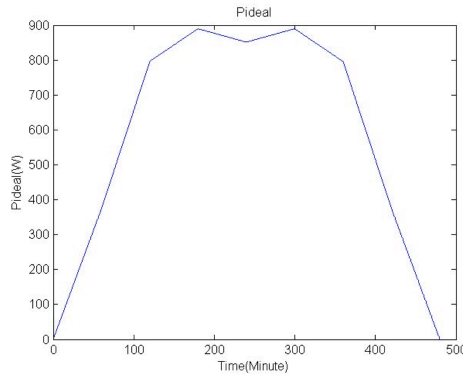

Figure 25. Pideal for varying time .

findMPP: MPP power = 927.4200 (w) , MPP voltage = 189.20 (v) , MPP current = 4.9500 (A)

V. CONCLUSION

When MPPT is used there is no need to input the duty cycle, the algorithm iterates and decides the duty cycle by itself. But if MPPT had not been used, then the user would have had to input the duty cycle to the system. When there is change in the solar irradiation the maximum power point changes and thus the required duty cycle for the operation of the model also changes. But if constant duty cycle is used then maximum power point cannot be tracked and thus the system is less efficient. The various waveforms were obtained by using the plot mechanism in MATLAB. There is a small loss of power from the solar panel side to the boost converter output side. This can attributed to the switching losses and the losses in the inductor and capacitor of the boost converter. This can be seen from the plots of the respective power curves.

APPENDIX

PV module characteristics [2]: Vm = 17.2V, Im = 4.95 A, Pm = 85 W, Voc = 22.2 V, Isc = 5.45 A, α = 0.05 %/K,

β = −0.36%/K, and NOCT =25 ◦C ± 2 ◦C.

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