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Simulation of Regulated Power Supply for Solar Photo-Voltaic Model

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Abstract

This paper presents the simulation of regulated DC voltage source. The DC source main supply is solar PV model which produce unstable output voltage. The model is done such that the input parameters are the light and the temperature and the output is the unstable voltage. The output current is important parameter to achieve accurate output voltage, that current is measured and fed to the input of the model to be used for equation evaluation. Voltage regulation is needed to make the generated voltage usable. A simple buck converter with PID controller used to regulate the output voltage. SIMULINK is used to simulate the overall system. Simulation result is given to verify the operation of the model.

Keywords: Photovoltaic of KD205GX-LPU Model, Buck Converter,Voltage Regulation, PID Controller and MATLAB Simulation

Introduction

Renewable energy sources are getting day after day more attention in the world. Among them, the photovoltaic (PV) panels, which offer many advantages such as requiring a little maintenance, do not pollute the environment. On the other hand, renewable energy sources, such as solar energy systems, attract more attention because they provide a greater opportunity for generating electricity.

There are many factors that affect the efficiency of solar cells, such as temperature, insolation, sunlight spectral characteristics, dirt, and shadow and so on. Insolation changes on panel's solar cells are caused by rapid climate changes such as cloudy weather and a rise in ambient temperature, which can reduce the output power of PV. In other words, the producing energy of a PV cell is related to its operational and environmental conditions [1,2]. The PV systems often consist of PV generator (cell, module, array), storage devices of energy (like batteries), and power conditioning elements.

Actually, one of the advantages of using photovoltaic systems (PV) is not to put any kind of emissions to nature. As is well known, that photovoltaic system (PV) produces DC electricity when the sunlight fall on it directly. So that DC power can be transferred to AC power using an inverter to run the local loads [3]. In other words, some electronic converters are used to get electricity from the PV cells. The device used in this research for the purpose of voltage regulation is a buck converter. As well as to control the flow of energy in the system, including the highest point of maximum power tracking (MPP). Buck converter is characterized by a high efficiency Step-Down (DC / DC) converter switch. This converter uses a transistor witch, typically a MOSFET, to pulse the modulation width of the voltage into an inductor. Rectangular pulses of voltage into an inductor result in a triangular current waveform.

The aim of this paper is to produce a PV model based on Shockley diode equation. The PV model is used as a part of regulated power supply. Buck converter is used in the regulator with PID controller for voltage regulation. That means, a PV model can be utilized in any simulation studies such as solar power systems.

Solar Cell Modelling

Basically, there are two kinds of PV model like single-diode model and double-diode model. The type was used in this paper is single-diode model, look to the Figure 1 below.

Ideal Photovoltaic Cell

The equivalent circuit of the ideal photovoltaic cell is shown in Figure1. The basic equation from the theory of semiconductors [4] that mathematically describes the I-V characteristic of the ideal photovoltaic cell is:

$I = I_{pv,cell} - I_{o,cell}\left[e^{(qV/aKT)} - 1\right]$(1)

Where $I_{pv,cell}$ is the current generated by the incident light (it is directly proportional to the Sun irradiation), Id is the Shockley diode equation, $I_{o,cell}$ is the reverse saturation or leakage current of the diode, q is the electron charge (1.60217646 ·10−19C), K is the Boltzmann constant (1.3806503 · 10−23J/K), T (Kelvin) is the temperature of the p-n junction, and (a) is the diode ideality constant.

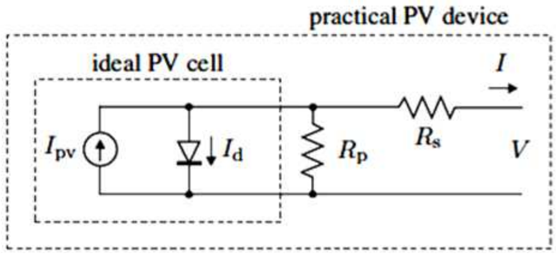

Figure 1: Photovoltaic cell of Single-diode model.

Photovoltaic Cell Modelling

The basic equation (1) of the elementary photovoltaic cell does not represent the I-V characteristic of a practical photovoltaic cell. Practical cells are composed of several connected photovoltaic cells and the observation of the characteristics at the terminals of the photovoltaic cell requires the inclusion of additional parameters as shown in Figure 2.

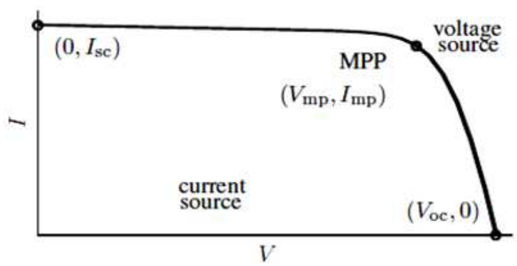

Figure 2:Photovoltaic cell of I-V Characteristic.

The fowling equation describes the practical photovoltaic cell parameters:

$$I = I_{pv,cell} - I_{o,cell}\left\{\exp\left[\frac{V+R_sI}{aV_t}\right] - 1\right\} - \left\{\frac{V+R_sI}{R_p}\right\} \quad (2)$$

Where:

- $I_{pv,cell}$ and $I_{o,cell}$ are the photovoltaic and saturation currents of the array
- $V_t = N_s\frac{KT}{q}$ is the thermal voltage of the array with Ns cells connected in series.

In equation. (2) Rs is the equivalent series resistance of the array and Rp is the equivalent parallel resistance. This equation originates the I-V curve seen in Figure 2, where three remarkable points are highlighted: short circuit (0, Isc), maximum power point (Vmp, Imp), and open-circuit (Voc, 0).

For simplicity, equation (2) describes the single-diode model presented in Figure1. This model offers a good compromise between simplicity and accuracy [5] and has been used by several authors in previous works, sometimes with simplifications but always with the basic structure composed of a current source and a parallel diode [6–10].

Datasheets of photovoltaic arrays often provide the following information: the nominal open-circuit voltage Voc,n, the nominal short-circuit current Isc,n, the voltage at the maximum power point Vmp, the current at the maximum power point Imp, the open-circuit voltage/temperature coefficient KV , the short-circuit current/temperature coefficient KI , and the maximum experimental peak output power Pmax,e. This information is always provided with reference to the nominal or standard test conditions (STC) of temperature and solar irradiation. The I-V characteristic of the photovoltaic device shown in Figure 2 depends on the internal characteristics of the device (Rs, Rp) and on external influences such as irradiation level and temperature. The light-generated current of the photovoltaic cell depends linearly on the solar irradiation and is also influenced by the temperature according to the following equation [11,12]:

$$I_{pv} = \left(I_{pv,n} + K_I\Delta_T\right)\frac{G}{G_n} \quad (3)$$

Where $I_{pv,n}$ is the light-generated current at the nominal condition (usually 25 ◦C and 1000W/m2), T = T – Tn (being T and Tn the actual and nominal temperatures K), G(W/m2) is the irradiation on the device surface, and Gn is the nominal irradiation. In addition, to improve the photovoltaic model which described in the previous section [13], look equation (4).

$$I_o = \left(I_{sc,n} + K_I\Delta_T\right) / \left\{\left[\frac{V_{oc,n} + K_V\Delta_T}{aV_t}\right] - 1\right\} \quad (4)$$

Where:

- $I_{sc,n}$ is the nominal short-circuit current .
- $V_{oc,n}$ is the nominal open-circuit voltage.
- K_I is the short-circuit current/temperature coefficient.
- K_V is the open-circuit voltage/temperature coefficient
- V_t is the thermal voltage of the array.
- Δ_T is T = T – Tn (being T and Tn the actual and nominal temperatures K).

Implementation of Proposed PV Model

SIMULINK is an environment for multi-domain simulation and Model-Based Design for dynamic and embedded systems. It provides an interactive graphical environment and a customizable set of block libraries that allow design, simulate, implement, and test a variety of time-varying systems, including communications, and controls. SIMULINK is used to implement the solar PV model.The model is formed using the above equations (2), (3) and (4) using MATLAB/SIMULINK. The forming of the equations is shown in Figure 3. The result of the model will be a value which needs to be converted to electrical parameter. Controlled voltage source is used to convert the generated value to proportional voltage as shown in Figure 4. The output voltage of the system shown in Figure4 is unregulated.

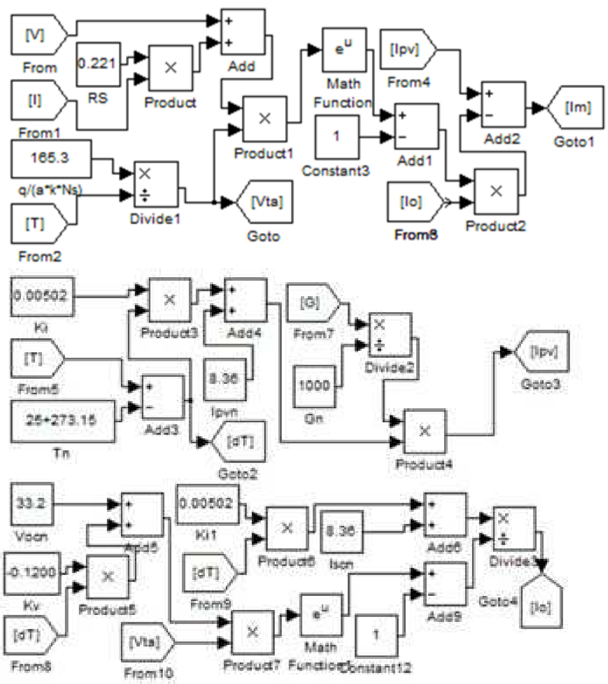

Figure 3: MATLAB/ Simulink of photovoltaic mathematical model.

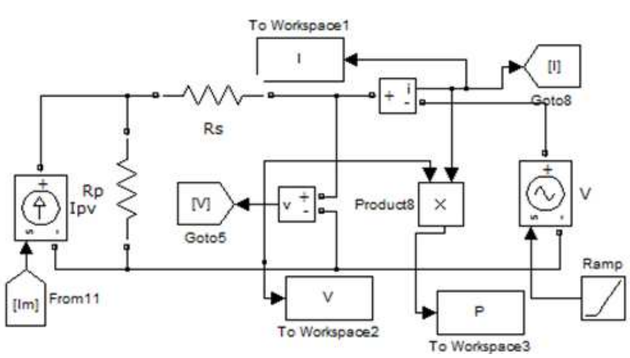

Figure 4: SIMULINK PV model.

Buck Converter Model

There are three types of switching mode DC/DC converters, buck, boost, and buck-boost. The buck mode is used in this article to regulate output voltage. A DC/DC converter forms an integral part of a PV system. Without DC/DC converter no system is designed.

Circuit Description

The basic DC/DC converter uses a pair of switches, usually one controlled (e.g. MOSFET) and one uncontrolled (i.e. diode), to achieve unidirectional power flow from input to output. One capacitor and one inductor are used in the converter to store and transfer energy from input to output. They also filter or smooth voltage and current. The buck converter circuit diagram is shown in Figure5.The DC/DC converters can have two distinct modes of operation:Continuous conduction mode (CCM) and discontinuous conduction mode (DCM). In practice, a converter may operate in both modes, which have significantly different characteristics. Therefore, a converter and its control should be designed based on both modes of operation.

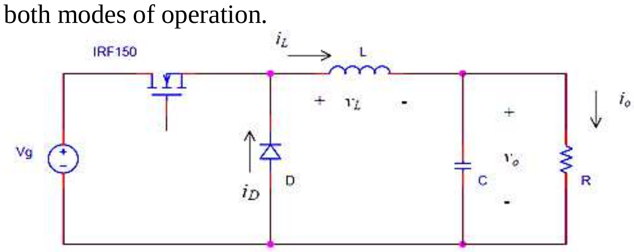

Figure5:Circuit diagram of buck converter.

Circuit Operation

When the switch is on, as shown in Figure6, for a time duration DT, the switch conducts the inductor current and the diode becomes reverse biased. This results in a positive voltage $V_L = V_g - V_o$ across the inductor. This voltage causes a linear increase in the inductor current IL. When the switch is turned off, as shown in Figure7. I_L continues to flow because of the inductive energy storage. This current now flows through the diode, and $V_L = -V_o$ for a time duration (1-D) T until the switch is turned on again, as shown in Figure8.

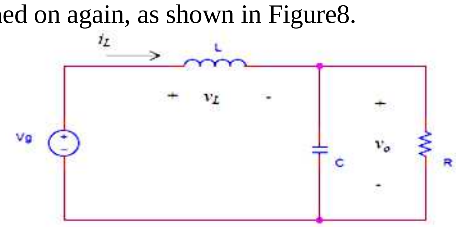

Figure6: Switch on for a time duration DT.

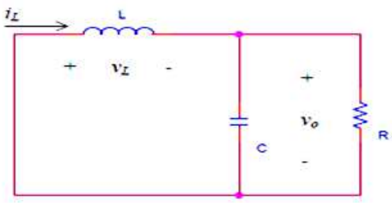

Figure 7: Switch off for a time duration (1-D) T.

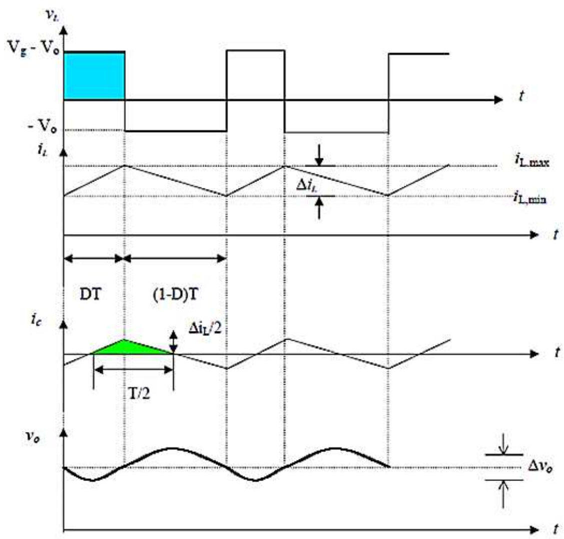

Figure 8: Switching waveforms.

Analytical expression for Vo/Vg , Δi_L ,and Δv_o

Assumptions made about the operation of the converter are as shown down:

- The circuit is operating in the steady state.
- The circuit is operating in the CCM.
- The capacitor is large enough to assume a constant output voltage.
- The components are ideal.

By equating the integral of the inductor voltage over one time period to zero yields.

$\int_0^T V_L\,dt = \int_0^{t_{on}} V_L\,dt + \int_0^{t_{off}} V_L\,dt = 0$ (5)

$= (V_g - V_o)DT + (-V_o)(1-D)T = 0$ (6)

$V_o = DV_g$ or $V_o/V_g = D$ (7)

Assuming a lossless circuit. $P_g = P_0$

Therefore;

$V_g I_g = V_o I_o$ (8)

$I_o/I_g = V_g/V_o = 1/D$ (9)

For a buck converter, it is obvious that: $I_L = I_o$

$\Delta i_L = \frac{1}{D}\int_0^{DT} V_L\,dt$ (10)

$= \frac{1}{L}$ [shaded area under waveform V_L (Area A)] (11)

$= \frac{1}{L}\{(V_g - V_o)DT\}$ (12)

From Δi_L we can obtain $i_{L,min}$ and $i_{L,max}$

$i_{L,min} = I_L - \frac{\Delta i_L}{2}\ \&\ i_{L,max} = I_L + \frac{\Delta i_L}{2}$ (13)

To obtain the average an inductor current, we can use the relationship:

$I_L = I_o = V_o/R$ (14)

The peak-peak output voltage ripple,ΔV_o. From the information of the capacitor currenti_c, we can obtain ΔV_o.

$\Delta V_o = \Delta V_c = \frac{1}{C}\int i_c\,dt$ (15)

$= \frac{1}{C}$ [shaded area under waveform i_c]

$= \frac{1}{C}\frac{1}{2}\frac{T}{2}\frac{\Delta i_L}{2}$

Therefore;

$\Delta v_o = \frac{\Delta i_L}{8} * f * C$ (16)

Photovoltaic Parameters of Multicrystal Type

The Multicrystal KD205GX-LPU module was chosen for modeling; it has 54 series connected Multicrystal cells. The key specifications are shown in table (1). MATLAB program is used to modulate the full system circuit diagram, as shown in Figure13 below. The model parameters are used by the equations listed on the previous sections. The program calculates the current I, using typical electrical parameters of the module such as (Isc, Voc), Irradiation (G), and Temperature (T).

Table1: Typical electricalparameters of kd205gx-lpu module under standard test conditions

Maximum Power (Pmax)	205W(+5w/- 0w)
Maximum Power Voltage (Vmp)	26.6 V
Maximum Power Current (Imp)	7.71 A
Open Circuit Voltage (Voc)	33.2 V
Short Circuit Current (Isc)	8.36 A
Max System Voltage	600 V
Temperature Coefficient of Voc	-1.20 e-1 V/◦C
Temperature Coefficient of Isc	5.02 e-3 A/◦C

The resistance (Rs=0.221Ω), ideality diode a=1.3, and the resistance (Rp=415.405Ω) are considered in the model.

They make the solution for the current I, equation (1) a non-lineal problem, that be solved using numerical methods.Iterative solution of Rs and Rp is used in this program to find their values [13].

Results and Discussion

The parameters that determine the operation of a solar cellreflected in their characteristic curves, I-V and P-V. For the calculation of two families of curves, as shown in Figures 9 and 10, the temperature stayed constant at 25 ºC varying the irradiance (400, 600, 800 and 1000 W/m2) generating a type of curves. Figures 11 and 12 show the irradiance is maintained constant at 1000 W/m^2 changing the temperature (25, 50 and 75 ºC).

Figure9 shows PV voltage against PV current plot. The current curves depend on the irradiation changing. On the other hand, voltage is going to maintain almost constant and it is not going to vary much, although increases irradiation.

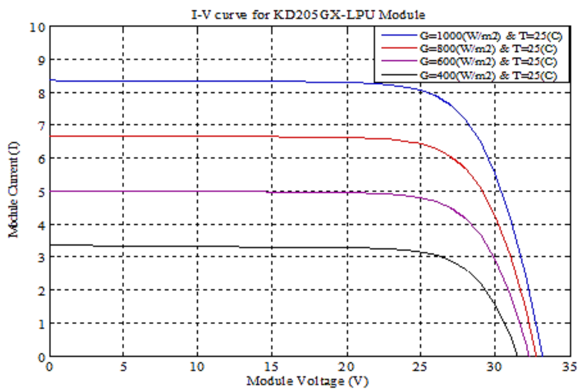

Figure 9: I-V Curve for KD205GX-LPU Module with G = 400, 600, 800, and 1000 & T=25.

The efficiency of the solar cells falls when temperature increases, as shown in Figure10, due to the decrease of the open circuit voltage.

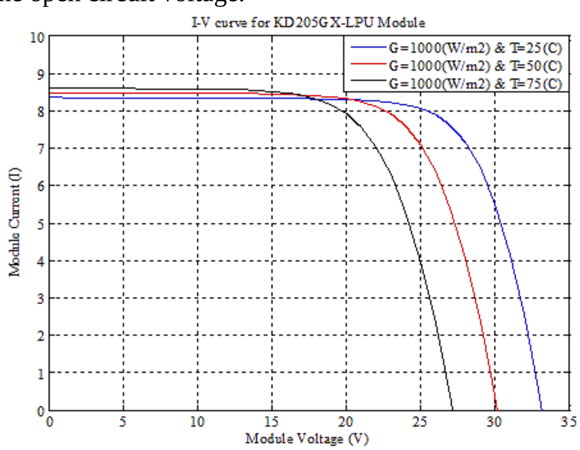

Figure 10: I-V Curve for KD205GX-LPU Module with G=1000,and T= (25, 50, and 75).

In this case, the influence of the temperature on the voltage can be seen in Figure 11. The greater temperature, the smaller voltage. Also, the power decreases with the increase of temperature.

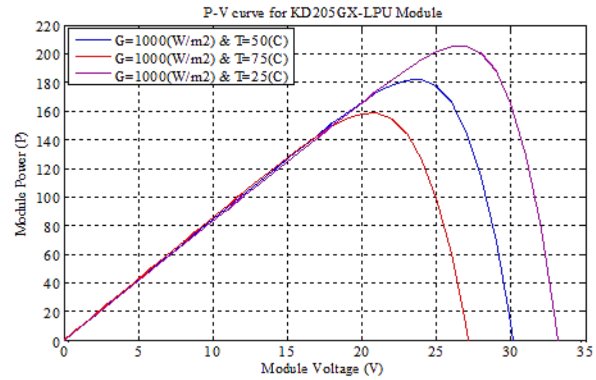

Figure 11: P-V Curve for KD205GX-LPU Module with G=1000 and T= (25, 50, and 75).

The influence of the Irradiation variation, at constant temperature, as shown in Figure 12.That means, the higher irradiation, the major MPP will be obtained in the photovoltaic module.

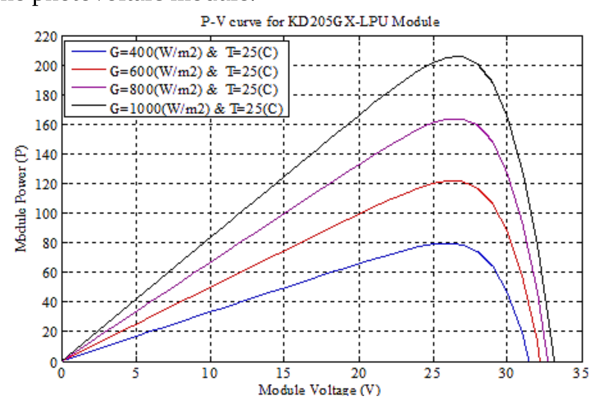

Figure 12: P-V Curve for KD205GX-LPU Module with T=25,and G=(400, 600, 800, and 1000).

Finally, buck converter as a regulator voltage. the converter output voltage V(t) is a function of the switch duty cycle D, a PID control system is used that varies the duty cycle to adjust the output voltage to follow a given reference Vr =50 v. Figure 13describes the PV model and a simple converter feedback system. The output voltage is sensed using a measurement voltage source and compared with an accurate dc reference voltage Vr. The resulting error signal is passed through a PID compensation network. The PID voltage produces a switched voltage waveform that controls the gate of the power MOSFET. The duty cycle D of this waveform is proportional to the PID voltage. If this control system is well designed, then the duty cycle is automatically adjusted such that the converter output voltage follows the reference voltage Vr, and is essentially independent of variations in load current. Figure 14 and 15 shows the results for unregulated and regulated voltages respectively.

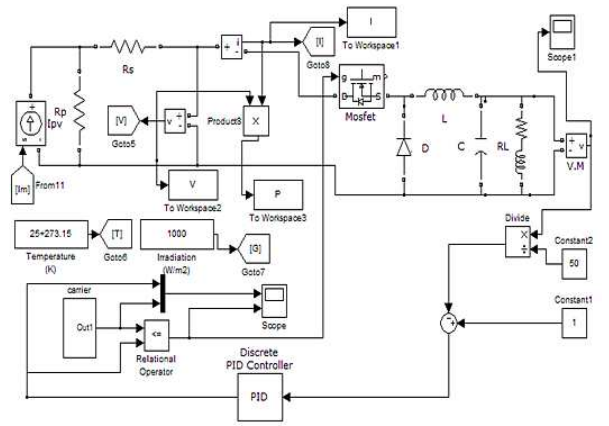

Figure 13: Full system circuit diagram.

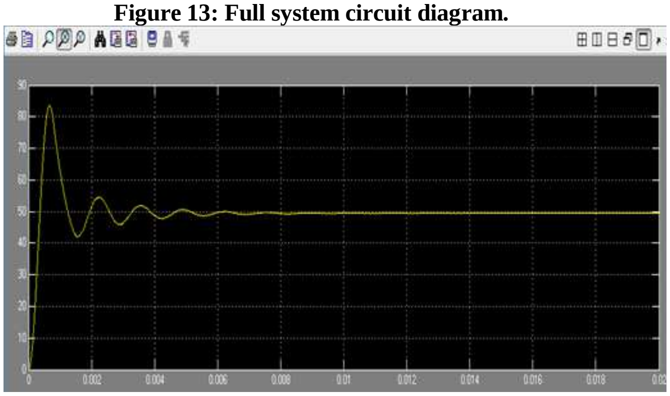

Figure 14: Output voltage without PID.

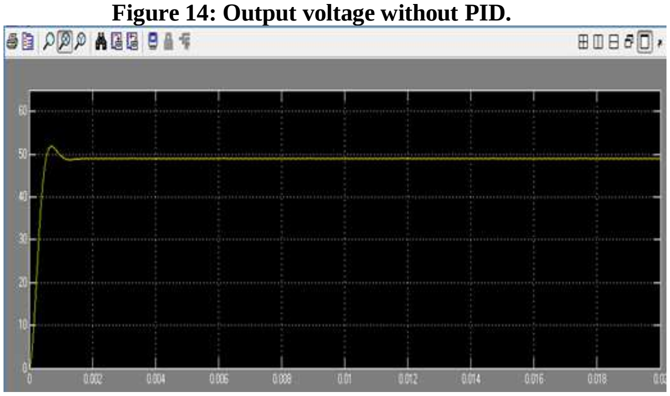

Figure 15: Output voltage with PID.

Conclusions

A Solar PV Model for Regulated Power Supply using PID Controller has been presented in this paper. The PV model generates unsuitable DC voltage proportional to the sun light and the temperature. The generated characteristic shows the validity of the model. The output voltage is regulated using the buck converter with a PID controller. The regulated output voltage makes the generated voltage usable.

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