Management of Electric Energy in Stand-alone Off-grid Solar PV System

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Abstract:*The stand-alone solar photovoltaic system has different kinds like on-grid and off-grid. This paper deals with the analysis, design and control of electric energy with different load profiles in off-grid stand-alone solar photovoltaic systems. The management of electric energy varies according to various load profiles. In here, the loads are considered as only DC loads. This paper shows three different dc load profiles. The goal of the management is to show and control the loads according to the load profiles and observe the outputs in MATLAB/Simulink. The simulation of the system has been developed in MATLAB/Simulink. Here, a simple stand-alone solar photovoltaic model has been used which carries PV module, charge controller, management strategy, battery, loads and a monitoring box to monitor the load profiles. This work introduces the procedure of how to control with different load profiles and what are the outputs. Finally, experimental results and related figures are shown to verify the effectiveness of the proposed energy management strategy.*

Keywords: *Stand-alone System, Management, Solar cell, MPPT, Energy, PV.*

Introduction

Due to environmental greenhouse gasses and global warming issues, sources of Renewable energy are considered alternative sources to conventional energy sources like fossil fuel. Solar, wind, hydro, geothermal are the renewable sources that got attention from different audiences in the world. Scientists are all working with these sources of energy to get the best out of them. Among them, Solar energy got attention and did a huge improvement in the efficiency and also at the same time its cost reduce a lot. Solar panels named photovoltaic (PV) systems use sunlight and convert it directly into electricity.

Using a small PV power system that can enable homeowners to get some part of the electricity what they needed for daily use of the house. It is possible to put the system on the rooftop of the house. Now a day it is possible to get the total electricity demand from the rooftop PV

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system. It is possible to build a PV system with a battery backup system that can ensure the power for the home for day and night.

Stand-alone PV systems are becoming popular nowadays. This system can work without the support of the electric utility grid. It can supply DC and also AC (Inverter) current on basis of specific loads. There several types of systems are invented for the stand-alone PV system. Like, for the stand-alone system we can use a PV array, wind, or PV hybrid system. In this work, we are going to show about the PV array especially. The SPV power system is known as a remote area power supply system.

A stand-alone system consists of different components. This part of the article is going to describe them. Here is a simple block model for stand-alone PV (SPV) systems:

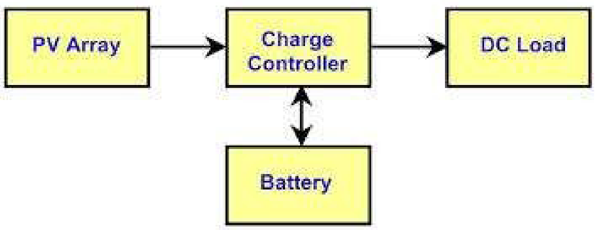

Figure 1: Simple Diagram for Stand-alone PV (SPV) system.

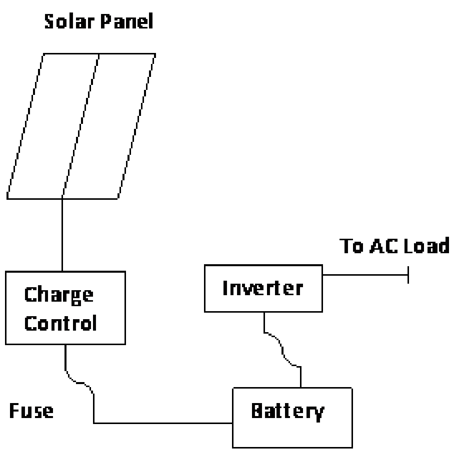

Figure 2: SPV system with battery bank powers the AC load.

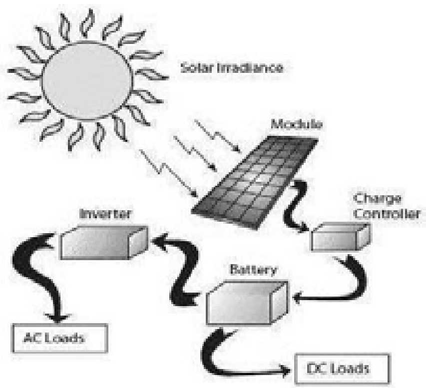

Figure 3: Diagram of a SPV system.

Theory:

In a photovoltaic system, there are several types of components being used as a PV array that is linked with charge controller and storage like battery and loads are connected altogether. The components are given below:

The solar cell is the primary component of a PV system. A module consists of many cells. A module with many cells can start to generate the minimum amount of workable power for a small system. Solar cells are made from semiconductors that convert sunlight to electricity directly. An electrical equivalent circuit for a solar cell is represented by a parallel combination of a current source, two exponential diodes, and a parallel resistor, Rp, that are connected in series with a resistance Rs. The output current I, is given by:

$$I = IL - Is1*(e^{((V+I*Rs)/(N*Vt))}-1) - Is2*(e^{((V+I*Rs)/(N2*Vt))}-1) - (V+I*Rs)/Rsh$$

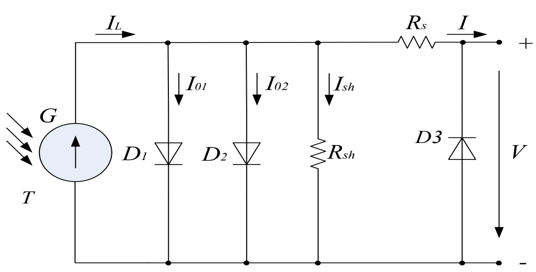

Figure 4: Double diode PV equivalent circuit diagram

Where,

Is1 and Is2 = Diode Saturation Current

N1 and N2 = Quality Factors (Diode emission coefficients)

IL = Solar generated current

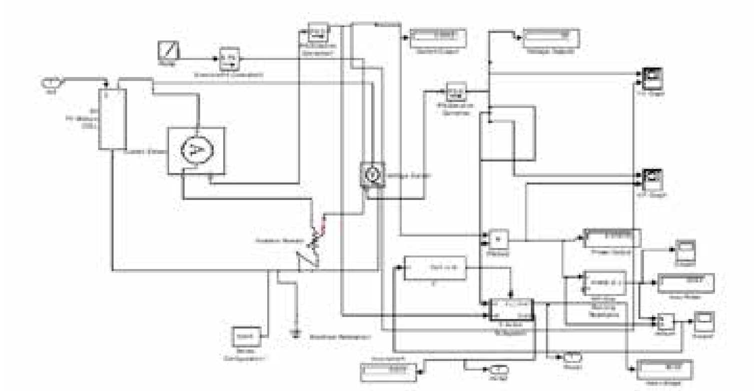

Figure 5: PV model in Simulink.

Solar cell's properties are given below:

Different Parameters	**Value**	**Unit**
Diode Saturation Current	1e-6	Ampere
Solar Generation Current	7.34	Ampere
Irradiance	1000	W/m^2
Ideality Factor	1.5	n/a
Series Resistance	0	Ohm
Parallel Resistance	Infinity	Ohm

In this work, we have used 60 solar cells. Each cell has 0.6 V and in total module voltage is 36 V.

The battery is a significant element of an SPV system, which needs a storage system that can have energy. During the daytime, excess energy is generated and stored in the battery. There are many types of batteries are available in the market but most people use lead-acid battery and for our work lead-acid battery used to simulate the scenario.

Figure 6: General image of a Lead-Acid Battery.

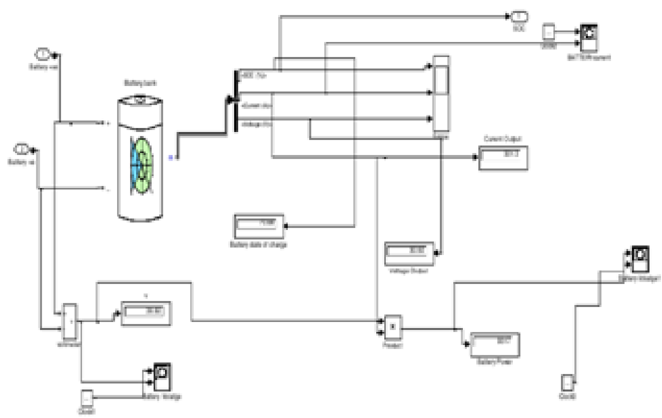

Figure 7: Simulink Diagram of a Battery.

The property of used Lead-Acid battery is given below:

Parameters	Value	Unit
Nominal Voltage	36	Voltage
Rated Capacity	100	Ampere-Hour
Initial State-Of-Charge (%)	20	n/a
Maximum Capacity	104.1667	Ampere-Hour

Fully Charged Voltage (V)	9.1974	Voltage
Nominal Discharge Current	20	Ampere
Internal Resistance	0.0036	Ohm
Capacity (Nominal Voltage)	31.0278	Ampere-Hour
Exponential Zone [Voltage, Capacity]	[36.6513, 0.3333333]	[Voltage, Ampere-Hour]

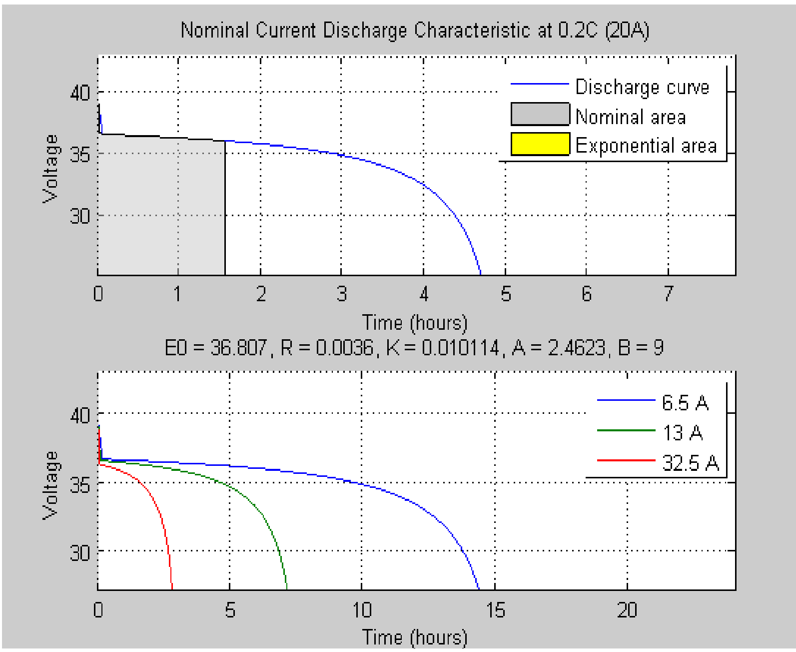

Figure 8: Nominal Current discharge characteristics.

Another important component in SPV is a change controller. It is also known as a voltage regulator, it regulates the output voltage of a PV module. During the operation period, a change controller is connected with the PV module and also connected with load and battery. When the load needs energy then change controller sends the energy from PV to load but if the generated energy is more than the demand energy then the change controller sends the excess energy to the battery system to store that. During night change controller provide energy to load from batteries.

Figure 9: An image of a charge Controller.

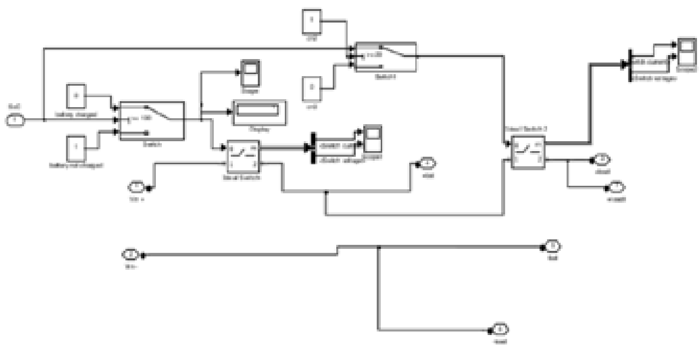

Figure 10: Simulink Model of the charge controller

It protects from over-discharged, protects from over load, and/or displays battery status and the flow of power. In this work, we have used two conditions according to the state of charge to control the system. The conditions are:

(1) The battery will be disconnected when the SOC will be equal to or more than 100 it means the battery will not be overcharged.

(2) And, the battery will be connected always when the SOC will be equal to or more than 20 it means that the battery will never be low charged.

System Setup and Simulation:

An important part of this work is to make the controlling system. The controlling system is used between the charge controller and load profiles. In the management part, we have used three different kinds of load profiles so that we can get a clear idea about the SPV system. Here, we have used the switch to control the loads and it varies according to load profile. The management system for different load profiles is given below:

Load Profile 1:

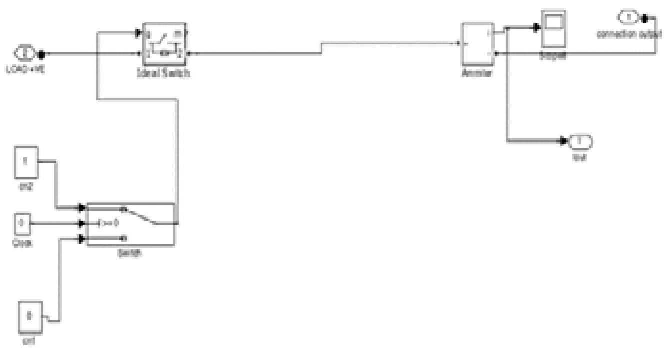

Figure 11: Simulink model of Load Profile Scenario 1.

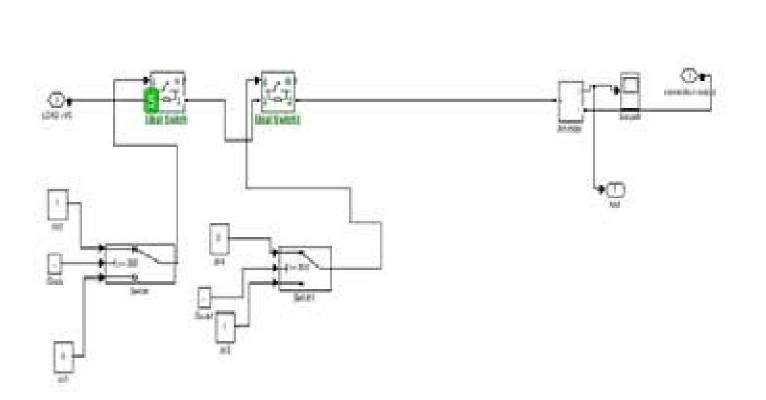

Figure 12: Simulink model of Load Profile Scenario 2 Part 1

Part 2:

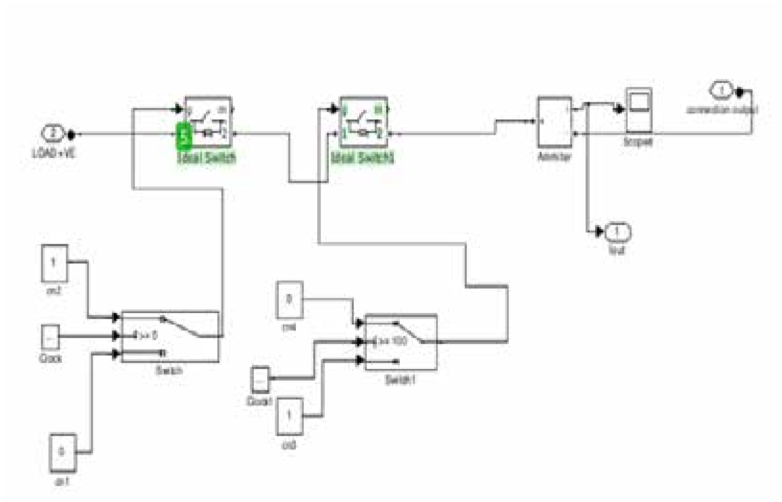

Figure 13: Simulink model of Load Profile Scenario 2 Part 2:

Load Profile 3:

Part 1

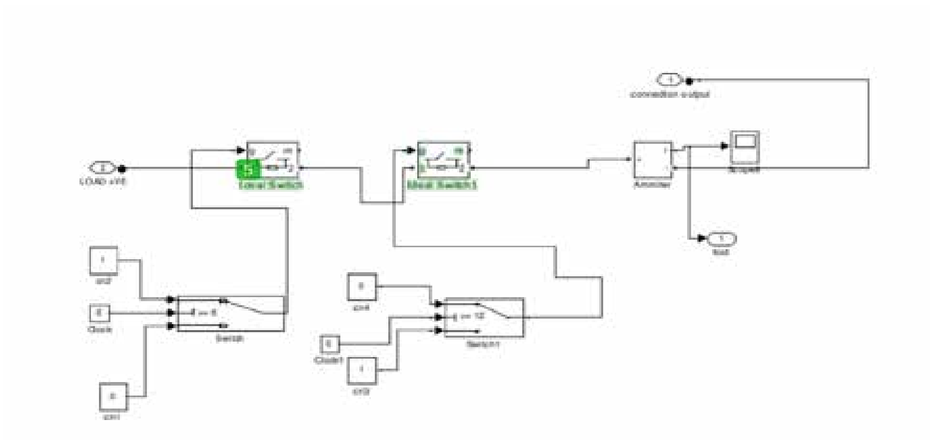

Figure 14: Simulink model of Load Profile Scenario 3 Part 1.

Part 2

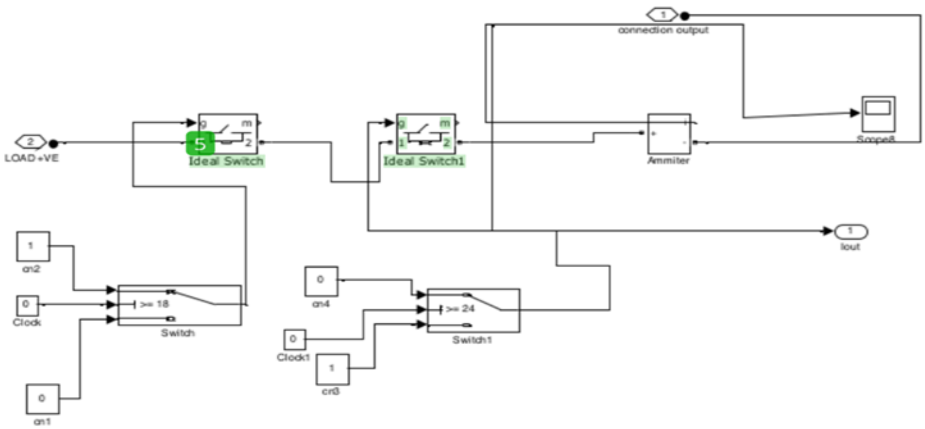

Figure 15: Simulink model of Load Profile Scenario 3 Part 2.

The entire Simulink figure is the control or management part of the program. It gives us a clear idea of how the program was being controlled.

In this work, the dc load is used and it is in series. The load has the same output current but a different output voltage. And, then the power has been calculated. The daily applications and power consumptions values are given below:

Applications	Power [W]	No. of hour [h]	Energy Consumption[WH]
Television	50	3	150
Computer	120	4	60
Lights (4)	400	4	1600
Freeze	100	8	800
Washing Machine	200	3	600
Dish Washer	30	2	60
Total			3270 [WH]

Results

In this work, the output from the different profiles of the load is analyzed the current versus voltage characteristics of the PV module. Here we have used a variable resistor so that it can have the appropriate value. Here is the graph of current versus voltage:

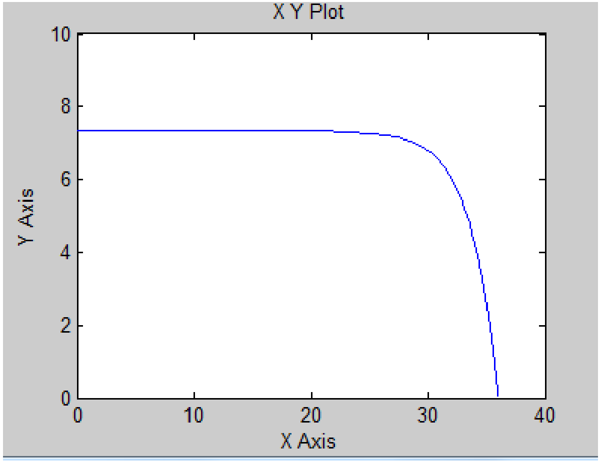

Figure 15: Voltage (V) vs. Current (I).

From here, we can see that there is a saturation point where the current and voltage is maximum, the point is named MPPT.

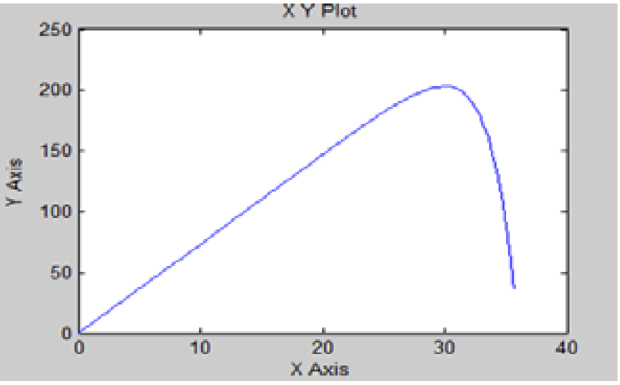

Figure 17: Voltage (V) vs. Power (W).

At the same time, we have found another graph it is a voltage versus power. From here we can see that the voltage and power increase up to a certain and again fall down. The figure is given below:

In this paper, we are going to manage the electricity control between charge controllers and loads. To get a clear idea about this work and to specify the different situations I have used three different load profiles with three different conditions. And, here I am going to describe it

LOAD PROFILE 1

In load profile 1, the purpose is to observe the output power or consumption of power in a certain time. And, in here, the load is on all the time so the output signal is constant all the time. For this work, time consumption was 5 minutes (1minute=60 s). Here is the output figure in Simulink:

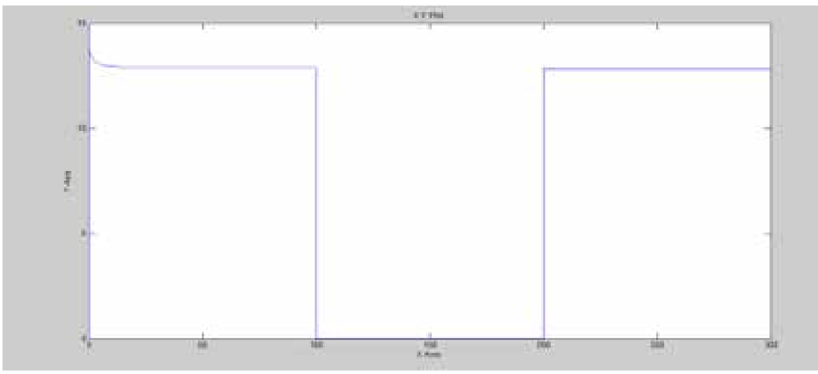

Figure 17: Output for Load profile 1.

Now, we will observe the open-circuit voltage, the current and the power output while the variation of battery SOC will take place.

State Of Charge (%)	Voc [v]	P [W]
30	30.66	12.60
60	30.77	12.69
100	30.92	12.81

From the table, we can see that, according to the increasing of the state of charge the Voc increases, and power output also increases.

LOAD PROFILE 2

In here, I have made the load on for certain time, and then put it off and then again on. So, here the overall load is on up to 100s, then off up to 200s and then again on from 200s. The output signal is given below.

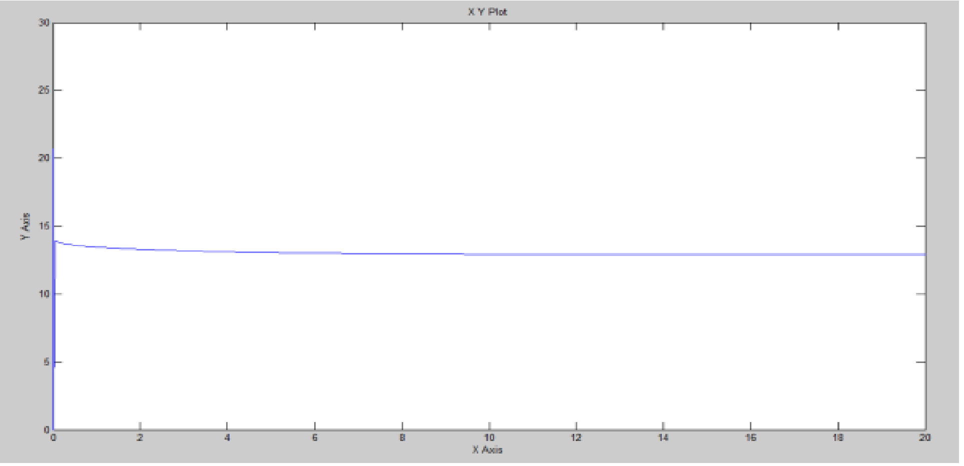

Figure 18: Power output Signal for load profile 2.

Now, we will observe the Voc, and power output of the load profile 2

State Of Charge (%)	Voc [v]	P[W]
30	31.15	13
60	30.77	12.69
100	30.92	12.81

From the table, we can see that according to the decrease of state of Charge the open-circuit voltage decreases and power output also.

LOAD PROFILE 3

In load profile 3, it is almost the opposite of load profile 2. In here, I observed that the loads are off from 0 to 100s, then on from 100 to 200s, then off for 200 to 250s, and from 250s to 300s is on and continuous. Here is the Simulink output is given below.

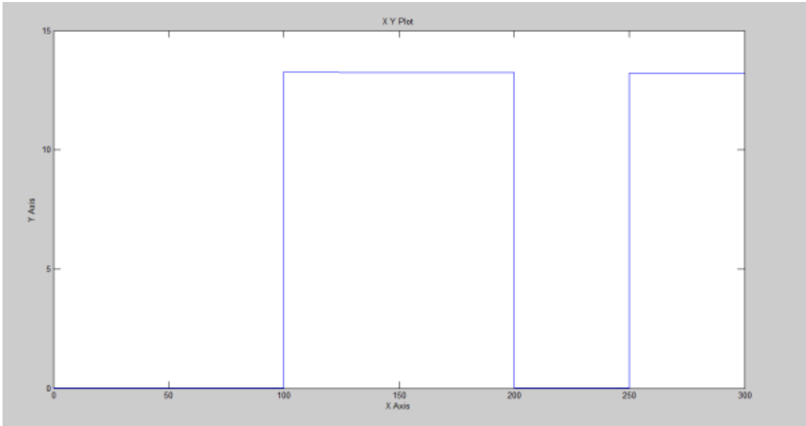

Figure 19: Power output Signal for load profile 3.

State Of Charge (%)	Voc [v]	P[W]
30	30.66	12.60
60	30.77	12.69
100	31.39	13.20

Conclusions

In this paper, it has been shown about the management of electricity and its control in a standalone solar photovoltaic system. And, it is discussed with three different load profiles with the same loads and output was also different. The work also discusses the total control and power management plan for the proposed solar energy system. The total simulation model is developed using the MATLAB/Simulink tool which is very close to the real scenario. All the simulation studies have been done to confirm the system performance under different scenarios using the MATLAB/Simulink. This work shows that it is possible to establish a stand-alone PV system for homes with a smart control management system with the storage system.

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