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Design and Simulation of a Solar Parking System to meet all Energy needs of 10 Electric Cars

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***Abstract*—Electric vehicles are a growing segment of the green transport industry and are helping reduce the carbon footprint of the global transport sector. However, EV adoption is slow due to the lack of charging infrastructure throughout the Newfoundland. We propose the design and control of a solar PV parking system that also serves as a charging station for 10 electric vehicles. The main source of power for our system would be solar PV and a battery bank for the storage of excess energy to be used during off-daylight hours. The sizing, design, and feasibility analysis of the system were performed in HOMER Pro. After that, the major components of the system were modeled in Simulink including PV, Battery, inverter, Load, and Controller. The solar charge controller utilized in our design used a DC-DC buck-boost converter running on the Perturbation and Observation (P&O) Algorithm. The system design details and simulation results are included in the paper.**

Keywords—solar parking, renewable energy, EV charging station, battery storage, control

I. INTRODUCTION

The alarming situation of global warming and climate change has been a cause for concern for a while now. The industrialization of the world has seen a steep increase with the increase in population of Earth. The use of fossil fuels to meet human energy needs as well as the widespread use of gas-powered vehicles as a mode of transportation has been one of the biggest contributor to the deteriorating climate landscape.

According to a study carried out by EPA, a good 63% of the United States’ current electricity needs are being met by the burning of fossil fuels, mostly coal and natural gas. Electricity production accounts for 26.9% of greenhouse gas emissions as of 2018 [1]. Similarly, the greenhouse gas emissions from transportation account for another 28% of the total U.S. greenhouse gas emission, making it the largest contributor of GHG emissions in U.S [2]. Unfortunately, the situation in many other countries around the world is no different and in most cases worse than that of U.S.

To counter this alarming issue of global warming and climate change, a lot of new projects are being undertaken, which include the replacement of fossil fuel electricity generation plants by renewable energy plants and the use of battery powered electric vehicles instead of internal combustion engines. However, there are many challenges that stand in the way of the successful execution of these projects.

II. LITERATURE REVIEW

Given the alarming situation of global warming that we are in, the adoption of electric vehicles as a common mode of transportation has been ongoing for the past few years. This means that a number of projects and research studies have been undertaken to design and optimize charging stations that take electricity from Grid, PV or other resources.

We looked at a number of similar studies and projects that have been undertaken to develop a better understanding of what is at stake when designing a solar powered EV charger. A feasibility study carried out by Dutch researchers speaks about the solar energy potential at workplaces in Netherlands, enough to charge the battery powered electric vehicles under the use of workplace employees. The project presents two different mechanisms of 1. Charging the electric vehicles on weekdays only and 2. Charging electric vehicles all 7 days of the week. The optimal storage size required to bring down the grid dependency by 25% is also evaluated [3].

Another similar study undertaken by researchers at Aligarh Muslim University campus building makes the use of the campus parking as a means to erect a solar PV system in order to charge a small battery powered electric vehicle with a 10kWh lithium-ion battery pack [4].

The following study gives a comprehensive review on solar powered electric vehicle charging systems and lists down the industry best practices to be kept in mind while designing a solar PV powered charger [5]. Another similar project shows the implementation of a grid-integrated PV battery system for both electric vehicle charging and residential applications [6].

We will also refer to the bibliographical review carried out by Mohammad Saad Alam et al. on the electric vehicles standards while designing an EV Charger [7].

III. CURRENT RESEARCH

A. *Research Problem*

While the renewable energy generation and distribution projects face a wide variety of challenges. There is really only one major issue that hinders the worldwide adoption of electric vehicles apart from a huge gap in demand and supply of EVs, and it is the lack of charging infrastructure in cities and on roads across the world. There is a popular term in the electric vehicle community known as “range anxiety”, which refers to the fear of running out of electricity while driving an electric vehicle due to a lack of EV charging stations.

B. *Proposed Solution*

In order to counter this issue, we are going to propose the design of a simple yet economical solar parking system, which makes the use of solar energy as a source to generate electricity and produces enough electricity to fulfil the power needs of 10 electric vehicles. The project will be designed using products that are easily available commercially, making it easy to implement this project in the real world.

C. *Scope of Work*

The location we have chosen in order to install our solar PV parking project is in St. John’s, NL, Canada. The solar panels would be mounted on a shed like structure in the parking lot next to the International Office at Memorial University of Newfoundland, St. John’s NL. The storage scheme being utilized in this system are rechargeable batteries. The nominal power at which both the wall chargers would be rated as well as the vehicle would charge is 7.7 kW. The hours of operation of the charger would be 8.8 hours (9 hours). The current project being designed would be able to charge 10 vehicles in a day. The parking would be a shed type structure made up of carbon steel.

IV. RESOURCE DATA COLLECTION

A. *Location*

The location that we have chosen is a parking lot next to the International Office at Memorial University of Newfoundland, St. John’s NL.

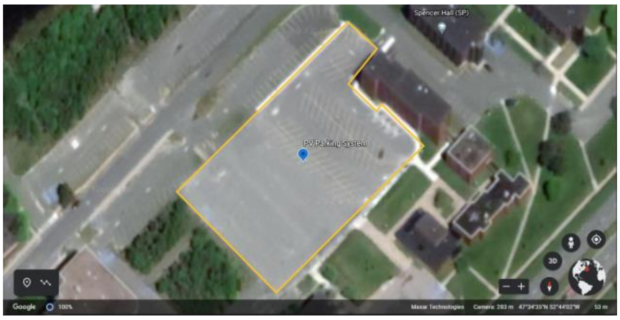
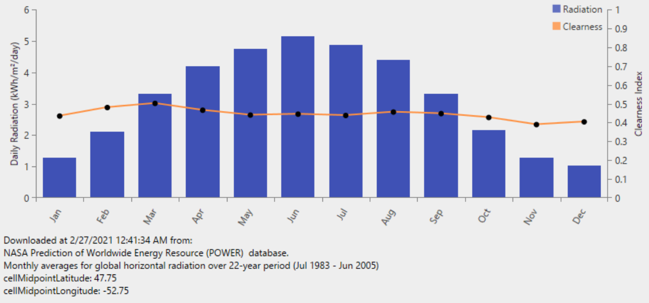


Figure 1: Locaton for PV Parking System

B. *Solar Potential*

The solar potential at our chosen site is as following;



Downloaded at 2/27/2021 12:41:34 AM from:
NASA Prediction of Worldwide Energy Resource (POWER) database.
Monthly averages for global horizontal radiation over 22-year period (Jul 1983 - Jun 2005)
cellMidpointLatitude: 47.75
cellMidpointLongitude: -52.75

Figure 2: Monthly Average Solar Global Horizontal Irradiance Data

The values are as given below in Table 1;

Table 1: Monthly Solar Global Horizontal Irradiance Data

Month	**Clearness Index**	**Daily Radiation ($kWh/m^2/day$)**
Jan	0.434	1.280
Feb	0.479	2.110
Mar	0.501	3.310
Apr	0.465	4.180
May	0.439	4.740
Jun	0.444	5.140
Jul	0.437	4.880
Aug	0.455	4.390
Sep	0.447	3.310
Oct	0.426	2.150
Nov	0.389	1.270
Dec	0.403	1.020

C. *Vehicle Chosen*

While there is a wide variety of fully electric battery powered vehicles present in the market as of today, we decided to go with the all-famous Tesla Model 3, which is one of the best-selling electric car in the world. Being widely adopted, Tesla Model 3 has plenty of after-market support in Canada or anywhere around the world. Tesla Model 3 comes in a number of different trims each with different battery packs and electric motors in them. The model we have chosen to go with is called Tesla Model 3 Standard Range Plus and is the base model of the Tesla Model 3 lineup.

Figure 3: Tesla Model 3

The technical specifications of the car are as follows;

Table 2: Technical Specifications of Tesla Model 3

Pricing	
MSRP	CA$54,610
Powertrain	
Engine	Electric (rear, center)
Power	283 hp (211 kW)
Hybrid / Electric	
Battery type	Lithium-ion (Li-ion)
Energy	50.0 kWh
Voltage	360 V
Charging times	• 120V: N/A • 240V: 8.5 h • 400V: 0.8 h
• **Fuel efficiency / Autonomy**	
Electric autonomy	402 km
CO_2 emissions	0 g/km

Model 3 has onboard charger which is rated at 7.7 kW at 32 A.

D. *Solar Panels*

For this project, we have chosen solar panels from Canadian Solar based on the local availability of panels, record testing and performance of the manufacturer.

The ratings for the chosen panel are as follows:

- Model: Canadian Solar MaxPower CS6U-340M
- Voltage: (1500 V)

- Cell efficiency: 20.0%
- Low Irradiance Performance: 96.5%
- IP67 Junction box for long-term weather endurance.
- Heavy snow load: 5400 Pa.
- Wind load: 2400 Pa.

E. Storage

For our storage, we chose the Tesla Powerwall, which is a fully-integrated AC battery system for residential or light commercial use. The specs of the chosen storage system are given below

Energy Capacity

- 13.5 kWh
- 100% depth of discharge
- 90% round trip efficiency

Power

- 7kW peak / 5kW continuous

F. Wall Charger

Tesla Wall Connector is an efficient and convenient home charging solution that lets you plug your vehicle in overnight and start your day fully charged.

- Up to 44 miles (77 km) of range per hour of charge
- Up to 11.5 kW / 48 amp output
- Wi-Fi connectivity (2.4 GHz 802.11 b/g/n)

V. STEADY STATE MODELING

A. System Sizing

We made the use of HOMER simulation software in order to model both the size of the system as well as the economics of it. Then out of the multiple solutions provided by HOMER, the most optimized solution was chosen. The system given in the figure below shows the following components;

1. Solar PV Array
2. Battery Bank
3. Electric Cars modeled as load
4. Converter.

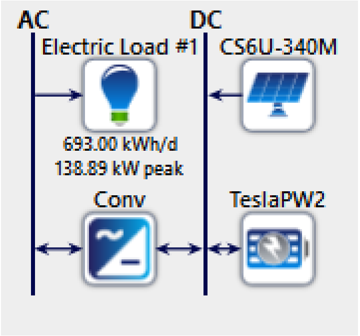


Figure 4: System Design in Homer

B. Load Requirement

Load requirement of the system is chosen by the no. of vehicles and the power each one of them requires to come to a full charge.

No. of Vehicles = 10

Power Rating = 7.7 kW

Time Taken by each vehicle to charge to 100% = 8.8 hours (9 hours)

Hourly Load = No. of vehicles*power rating*1 hour = 10*7.7*1 = 77 kWh

Daily Load = No. of Hours*Hourly Load = 9*77 = 693 kWh.

Peak Load = 77 kWh

Figure 5: Daily Load Profile

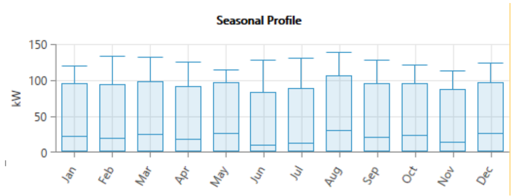


Figure 6: Seasonal Load Profile

C. Array Size

- CanadianSolar MaxPower CS6U-340M
- Efficiency (%): 17.49
- Capital Cost per panel: $279.50
- Replacement Cost per panel: $279.50
- O&M Cost per panel: $10.00

D. Battery Size

Tesla Power Wall 2.0. Powerwall is a battery that stores energy, detects outages and automatically becomes your energy source when the grid goes down.

- Nominal Voltage (V): 220
- Nominal Capacity (kWh): 13.2
- Nominal Capacity (Ah): 60
- Roundtrip Efficiency (%): 89
- Maximum Charge Current (A): 31.8
- Maximum Discharge Current (A): 31.8
- Capital Cost per battery: $6500
- Replacement Cost per battery: $6500

E. Optimum Solution

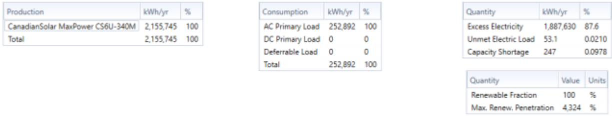
Based on the components chosen, HOMER simulation software gave us the following optimum solution;

Table 3: Possible Solution for our Given Project in the presence of the Grid

Architecture/CS6U-340M (kW)	1745.84375
Architecture/TeslaPW2	52
Cost/NPC ($)	1309774
Cost/COE ($)	0.4006328
Cost/Operating cost ($/yr)	37424.89
Cost/Initial capital ($)	825963.3
System/Ren Frac (%)	100
System/Total Fuel (L/yr)	0

CS6U-340M/Capital Cost ($)	487963.3
CS6U-340M/Production (kWh/yr)	2155745
TeslaPW2/Autonomy (hr)	23.77143
TeslaPW2/Annual Throughput (kWh/yr)	17259.96
TeslaPW2/Nominal Capacity (kWh)	686.4
TeslaPW2/Usable Nominal Capacity (kWh)	686.4
Architecture/CS6U-340M (kW)	1745.84375
Architecture/TeslaPW2	52
Cost/NPC ($)	1309774
Cost/COE ($)	0.4006328

F. Array Power Output



Production	kWh/yr	%
CanadianSolar MaxPower CS6U-340M	2,155,745	100
Total	2,155,745	100

Consumption	kWh/yr	%
AC Primary Load	252,892	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	252,892	100

Quantity	kWh/yr	%
Excess Electricity	1,887,630	87.6
Unmet Electric Load	53.1	0.0210
Capacity Shortage	247	0.0978

Quantity	Value	Units
Renewable Fraction	100	%
Max. Renew. Penetration	4,324	%

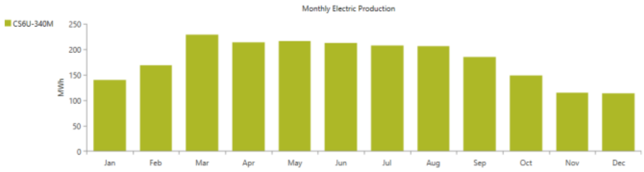


Figure 7: Monthly Electric Production

G. Excess Energy

After the calculations done by the HOMER simulation software, the excess electricity being generated is as following. This energy can be used to both increase the battery backup by a few more days or could be used for loads like street lighting.

Table 4: Excess Energy in the System

Quantity	**kWh/yr**	**%**
Excess Electricity	1,887,630	87.6
Unmet Electric Load	53.1	0.0210
Capacity Shortage	247	0.0978

VI. SYSTEM DYNAMIC MODELING

After this, we designed a simulation of the system in Simulink MATLAB and observed the dynamic behavior of the system.

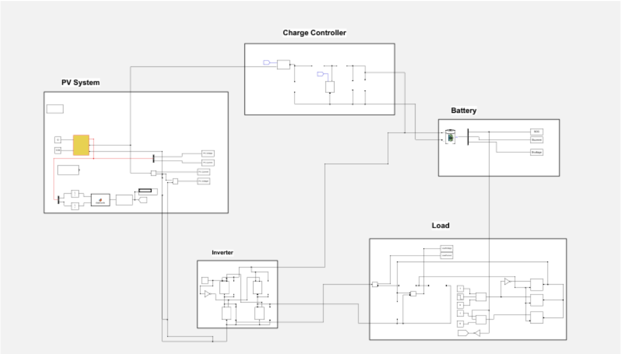


Figure 8: Modelled System in MATLAB

Now if we take a look at the PV part of the system it consists of the following;

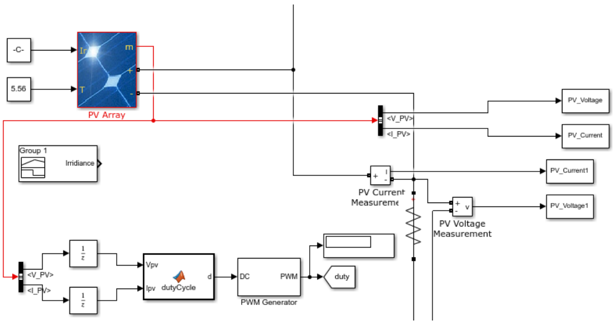


Figure 9: PV Model

The battery model is as follows;

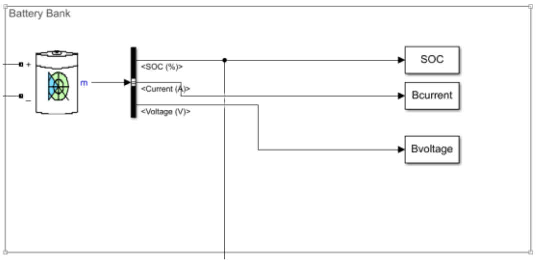


Figure 10: Battery Model

The inverter model is as follows;

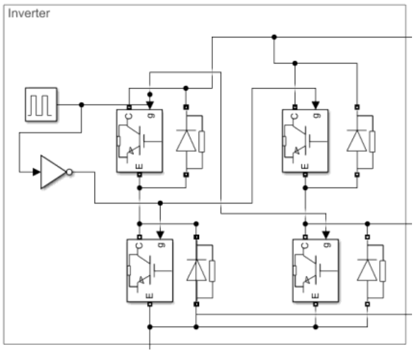


Figure 11: Inverter Model

Finally, the load of the system looks like following;

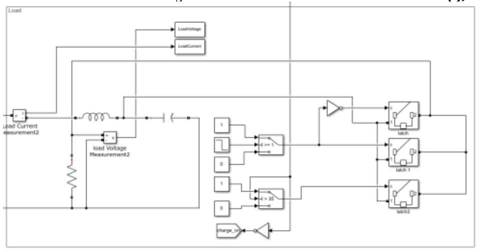


Figure 12: Load Model

VII. SYSTEM CONTROL DESIGN

A. Charge Controller

A solar charge controller is mostly used to manage the power going in and out of the battery bank from the solar array. By controlling this flow of power, a charge controller helps ensure that deep cycle batteries are not overcharged at daytime and power does not run in reverse direction into the solar panels at night time. The charge controller used in our system is a DC-2-DC buck boost converter.

B. *Buck-Boost Converter*

The main reason a buck-boost converter is used in a system is to receive an input DC voltage but output a different value of that voltage. This is done either by lowering or boosting the voltage of the system as required. A buck-boost converter is designed by combining the functionality of both buck converter and boost converter. Following is the model of buck-boost converter used in our system;

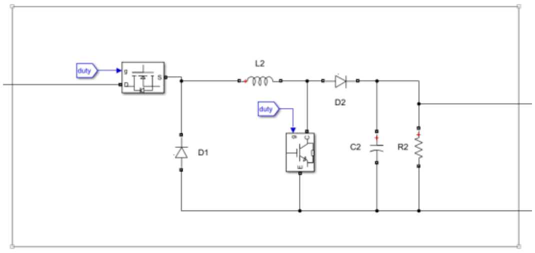


Figure 13: Buck-boost Converter

In figure 22, the duty cycle was generated by using the following circuit;

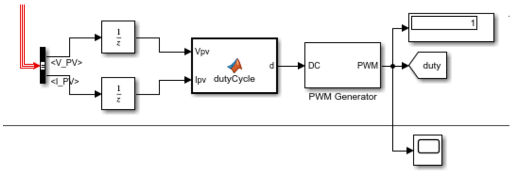


Figure 14: Duty Cycle Generator

C. *Perturbation and Observation (P&O) Algorithm*

The algorithm used in the MATLAB block is Perturbation and Observation (P&O) algorithm. This algorithm works by perturbing the operating point of our system thus causing the terminal voltage of the PV array to fluctuate around the MPP voltage. It then measures the current and voltage to make the decision or increasing or decreasing the duty cycle. Given below is the algorithm diagram for P&O method;

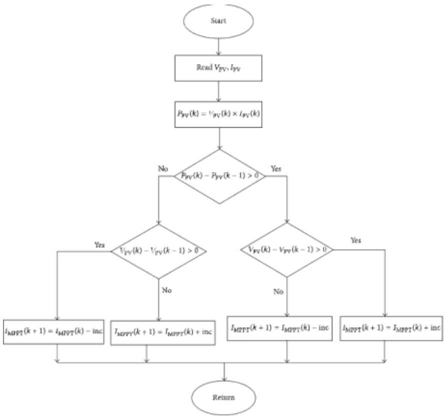


Figure 15: P&O Algorithm

The following code was used in the MATLAB function to generate the duty cycle signal through Perturbation and Observation (P&O) algorithm.

```
function d = dutyCycle(Vpv, Ipv)
%# code gen
persistent Vpre Ppre dpre
if isempty(dpre)
Vpre = 10;
Ppre = 20;
dpre = 0.3;
end


Ppv = Vpv*Ipv;
DeltaD = 0.01;
if  (Ppv == Ppre)
    d = dpre;
else
    if(Ppv > Ppre)
        if(Vpv > Vpre)
            d= dpre + DeltaD;
        else
            d = dpre - DeltaD;
        end
    else
        if(Vpv > Vpre)
            d = dpre - DeltaD;
        else
            d = dpre + DeltaD;
        end
    end
end
Vpre = Vpv;
Ppre = Ppv;
dpre = d;
```

D. *Control Logic*

The technique used in this system is very much similar to hill climb method as we measure the values of power and voltage on the power vs. voltage graph and determine the location of the system to find out if it is on the LHS or RHS of the graph shown in figure below.

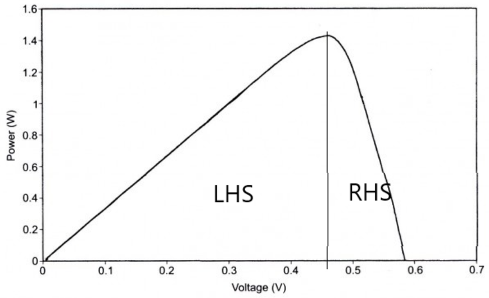


Figure 16: Power vs Voltage Diagram for PV

So there are four basic situations in this system;

1. When power is increasing and voltage is increasing
2. When power is decreasing and voltage is decreasing
3. When power is increasing but voltage is decreasing
4. When power is decreasing but the voltage is increasing

In the first two situations, the system is on the LHS of the graph and thus the duty cycle needs to be increased while in the second two situations, the system is on the RHS of the graph and thus the duty cycle needs to be decreased.

VIII. RESULTS

Upon the simulation of the system, following results were obtained;

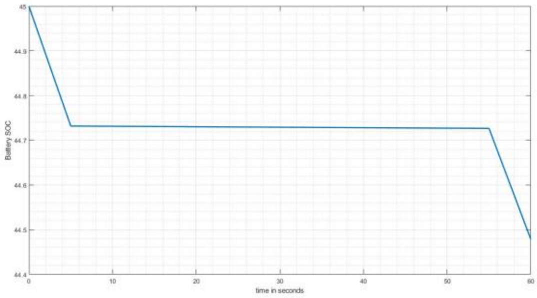


Figure 17: Battery SOC during charging and discharging cycle

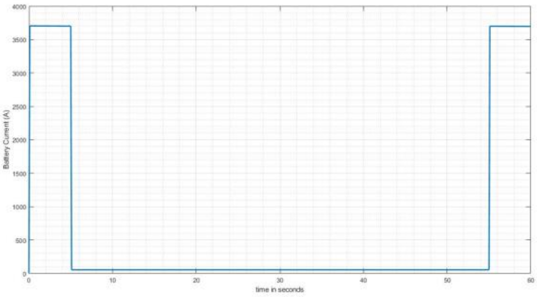


Figure 18: Battery Current during charging and discharging cycle

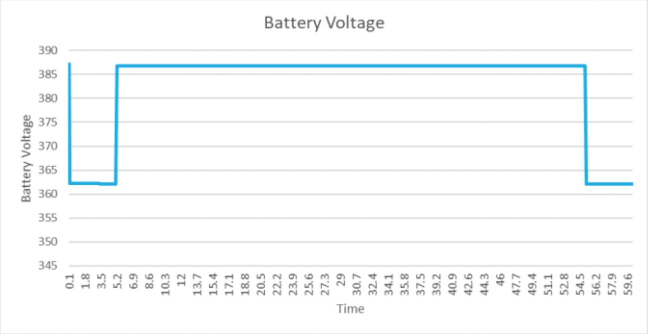


Figure 19: Battery Voltage during charging and discharging cycle

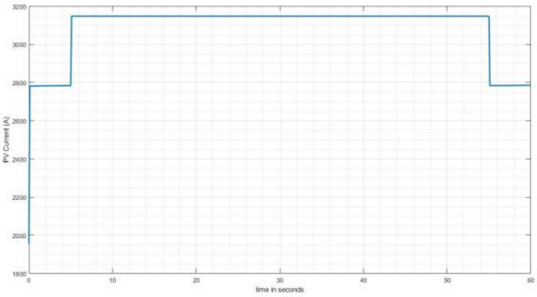


Figure 20: PV System Ouput Current

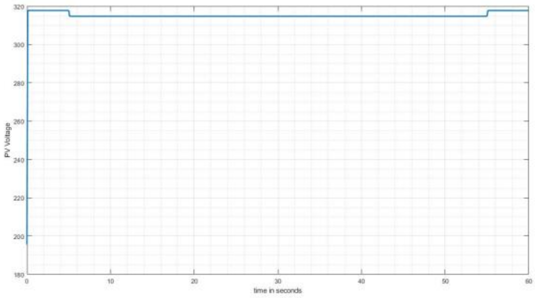


Figure 21: PV System Output Voltage

IX. DISCUSSION

As it can be seen through our results, our PV generation follows what is known as a bell-shape/bell-curve behavior. This is due to the sunlight behavior which is zero in the beginning and end of the day and slowly increases during the daytime. This PV generation affects the behavior of our entire system as PV is our main source of energy.

As seen in figure 26, 27, and 28, during the peak sunlight hours when there is ample electricity being generated, the battery voltage is at its highest. The state of charge of battery shows a constant behavior and similarly no current is flowing through the batteries.

However, this behavior changes in the begging and end of the day when there is no sunlight and ultimately no Power generation through PV. At this time, the state of charge of the battery can be seen depleting and the current is at its highest. This behavior is typical of any solar PV powered system with a battery backup.

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