

**A SOLAR/BATTERY POWERED STEP-UP DC-DC
CONVERTER FOR EV CHARGING APPLICATION
WITH AUTOMATED MODE SELECTION**

A PROJECT REPORT

submitted by

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to

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in partial fulfillment of the requirements for the award of the Degree

of

Master of Technology

in

Electrical and Electronics Engineering

with specialisation in

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DECLARATION

I undersigned hereby declare that the project report entitled "**A Solar/Battery Powered Step-up DC-DC Converter for EV Charging Application with Automated Mode Selection**", submitted for partial fulfillment of the requirements for the award of degree of Master of Technology in Electrical and Electronics Engineering with specialisation in Industrial Instrumentation and Control, of the APJ Abdul Kalam Technological University, Kerala is a bonafide work done by me under supervision of *Dr. Muhammed Shanir P P*, Assistant Professor, Department of Electrical and Electronics Engineering. This submission represents my ideas in my own words and where ideas or words of others have been included, I have adequately and accurately cited and referenced the original sources. I also declare that I have adhered to ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the institute and/or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been obtained. This report has not been previously formed the basis for the award of any degree, diploma or similar title of any other University.

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CERTIFICATE

This is to certify that the report entitled " **A Solar/Battery Powered Step-up DC-DC Converter for EV Charging Application with Automated Mode Selection**" submitted by **JESNA N**, (Reg. No. **TKM20EEII11**) of fourth semester to the APJ Abdul Kalam Technological University in partial fulfillment of the requirements for the award of the Degree of Master of Technology in Electrical and Electronics Engineering with specialisation in Industrial Instrumentation and Control, is a bonafide record of the project work done by her under my guidance and supervision. This report in any form has not been submitted to any other University or Institute for any purpose.

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Abstract

The concept of electric vehicles (EV) has made a huge impact in the field of transportation. However, EV charging is by no means simple, effective, or economical. There is a lot of possibility and control in charging electric vehicles with renewable energy sources like solar energy. For the current situation, a solar power and energy storage system (ESS) with an effective converter topology are combined to design an electric vehicle charging system. The proposed step-up DC-DC converter utilised solar power efficiently and effectively by operating in five different modes. Also proposes an automated system for mode selection of the converter based on the availability of input sources. In EV charging applications, when there is excess solar energy is available in the Photo Voltaic (PV) panel and EV battery reaches its maximum value of State Of Charge (SOC), ESS is provided and charged through a bi-directional DC-DC converter. The power from PV modules changes on account of the changes in ecological conditions and this influence differences in maximum power points (MPP). The Maximum Power Point Tracking (MPPT) controllers are used to determine the MPP of the PV output and regulate the operating point of the converter. The performance comparison of different MPPT algorithms such as Perturb and Observe (P&O), Variable Step Size Perturb and Observe (VSS P&O), and Look-up Table (LT) are used to track the MPP in PV based system. SPV (Solar Photo Voltaic) system with suggested converter topology is developed and simulated in MATLAB/Simulink.

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Abbreviations

ESS	Energy Storage System
EV	Electric Vehicle
LT	Look-up Table
MIC	Multi Input Converter
MPPT	Maximum Power Point Tracking
PO	Perturb and Observe
SOC	State Of Charge
VSSPO	Single Ended Primary Inductor Converter
SPV	Solar Photo Voltaic
VSSPO	Variable Step Size Perturb and Observe

Notations

f_s	Switching frequency, KHz
V_c	Capacitor voltage, V
V_L	Inductor voltage, V

Chapter 1

INTRODUCTION

1.1 General Background

Electric vehicles (EVs) are recognized as a clean mode of transportation because of its smooth operation, absence of fuel costs, and lack of pollution. At the same time, excessive use of electricity to charge electric vehicles is a major concern to the future. In addition, Electric vehicle charging has been unreliable due to lack of convenient charging outlets and a lengthy charging process. So a truly sustainable way to charge EVs is to use electricity from renewable energy [1] like solar photovoltaic (PV) panels or wind turbine. Solar has great potential to generate the electricity from PV panel. The charging of EVs from PV panels would be a great solution and also a sustainable step toward the environment. Solar photo voltaic system is most commonly used, the only concern is about its intermittent nature. ie, The output of PV arrays/modules changes due to varying temperature or irradiation level. To overcome this, multiple renewable and non-renewable energy sources are integrated to form hybrid energy system which supply power to common load through a bi directional dc dc converter. The combination of different energy sources have greater applications in EVs. For the integration of energy sources, a suitable power electronic circuit is necessary [2].

In recent years, lots of multi input converters (MICs) have been proposed for various applications [3]. With different conventional converters such as buck/boost, Single-ended primary-inductor converter (Sepic), CUK etc. different multi input converters are designed and it can be applied in various systems. By using MICs, it is possible to integrate these renewable energy

sources all over the nature [4]. Different types of MICs are reported in earlier literatures[5] [6] [7] [8] . For EV applications, there are various converter configurations have been proposed to increase the performance of E-vehicles [9]. Multi input DC converter configuration approached by various researchers to combine different sources like battery (as dc source), fuel cell, solar PV as hybrid energy [10]. However, the proposed two input DC- DC converters is required to store and recover the energy from battery.

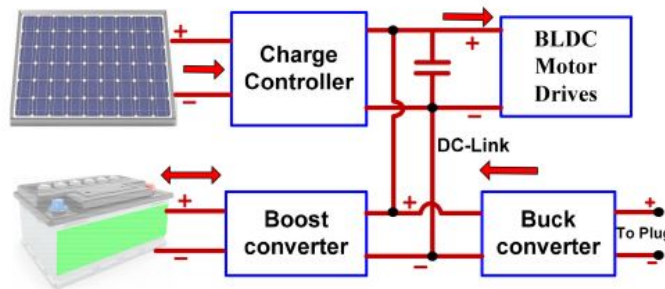


Figure 1.1: Solar powered vehicle with conventional configuration

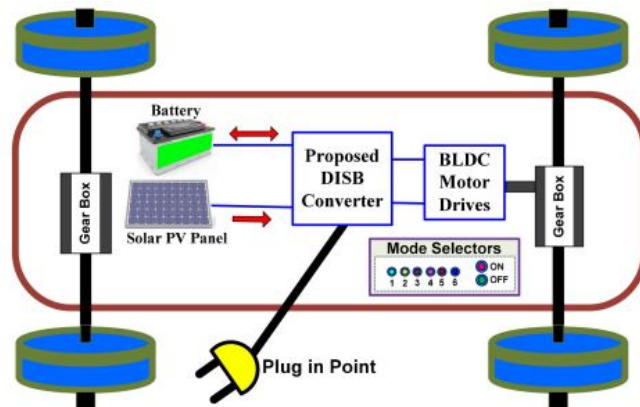


Figure 1.2: Solar powered vehicle with proposed configuration

The typical converter topology depicted in Figure 1.1. For each of the five operational modes, two independent converters are needed. However, in the suggested converter, a single-stage converter is needed to carry out the same functions because of the common buck-boost cell in Fig. 1.2. In comparison to conventional converter topology, it decreases the number of conduction devices and component count for each working mode.

In commercial E vehicles, the solar PV charges the EV battery through separate charge controller and these battery drive the vehicles. If the state of charge of battery value is optimally

reached, the excess power from solar PV panel is wasted. In order to overcome this problem, the paper suggests a step-up DC-DC converter with a back-up battery for the effective utilization of solar power. These converters are used to exchange the power in bidirectional way as per the requirement, and they can be worked in both buck and boost modes with improved dynamic response for productive transportation [11]. For the effective utilization of power proposed converter works in five different modes of operation. An automated system is introduced in the work for mode selection of the converter based on the availability of input source. By this, each mode will be automatically selected and the selection is based on the controlling of the switches in each mode.

The work is mainly focusing on solar powered operating automobiles. But the power from PV modules changes on account of the changes in ecological conditions and this influence differences in maximum power points [12]. In order to consider the constraint, P&O and VSS P&O and Look up Table power tracking algorithms are used to track the maximum power point. When compared to other methods, the perturb and observe (PO) algorithm is preferred because its simplicity. In comparison to the traditional fixed step size method, the VSS P&O can significantly increase MPPT speed and efficiency. These tracking methods differ from one another in terms of input parameters, tracking speed, and effectiveness [13]. Another simple offline solution for MPP tracking is the Look-Up Table (LT), which uses the previously computed data stored in the RAM [14]. Compare these methods in the solar PV systems in order to achieve maximum power and a constant power generation. Also compare the output power values of the system without using MPPT and with MPPT.

1.2 Thesis Objective

The main objective of the thesis are,

- To design a step-up DC-DC converter for the optimal utilization of solar power of EV charging applications.
- To design an automated system for the mode selection of the proposed converter based on the availability of input sources.

- Implement Perturb and Observe (PO), Variable step size P&O (VSS PO) and Look-up Table (LT) power tracking algorithms for the optimal usage of solar power.

1.3 Organization of Thesis

The report is organised as follows :

- Chapter 2 is the literature review where the background study of the system and methodology is done.
- Chapter 3 will discuss about the converter topology.
- Chapter 4 constitute the design of the system.
- Chapter 5 will discuss about the PV system in MPPT and also about the various methods using in MPPT to track the maximum power point.
- Results obtained from simulation of the system using MATLAB/SIMULINK is explained in chapter 6.
- Chapter 7 are the conclusions of the work.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

This chapter mostly discusses a review of the literature on solar-powered electric vehicle charging. In this part, the thesis-related works are examined.

2.2 Electric Vehicle

The categories broadly describe electric vehicles: Vehicles that are hybrid electric vehicles (HEV)[8] and Battery-powered vehicles (BEV)[9]. There are different ways of charging for electric vehicles[10], and they can usually be charged at homes or public outlets. They are rapid charging from specialised charging stations, fast charging from private or public outlets used in homes.



Figure 2.1: Electric car

2.3 Solar Powered Electric Vehicle

Researchers think that now is the ideal time to switch from combustion engines to renewable sources because of rising environmental awareness and shifting climate patterns. Numerous studies have been done to enhance the efficiency of solar-powered electric vehicles. Liu et al. [11] Present a unique idea about electric vehicles and sustainable energy. They are mostly concerned with solar and wind power, with various works in three areas: (i) work on the interaction between electricity generation and renewable energy works in order to cut energy prices; (ii) enhance energy efficiency; and (iii) propose reductions.



Figure 2.2: Solar Electric car

In the paper [12] describes cell plate of electric vehicles has a relatively low transition rate, which is an advantage, efficiency (i.e). Due to the high degree of movement of the Solar Car's office setting, the highest-point tracking algorithm regularly varies by 14 percent in the desire for additional transformation. The best traceability method involves keeping track of the constant observations, disturbances, and voltages, as well as the behaviour at the moment. In addition, the most widely used power point tracking method is the same.

The effort mostly involves solar-powered electric vehicle charging. Review all of the prior research that has been done on solar and electric vehicles. Several scholars have explored the creation of hybrid charging stations for electric cars. [13] Solar energy and grid electricity are used to power the charging station. The demands, limitations, and risk assessment of the infrastructure for charging EVs are also covered [6]. If the SCS can meet the current demand for EVs, it will become well-known. [14]. The charging circuit for the OFF Board is kept inside the charging station, and it is charged using DC, both of which have pros and cons [15]. Solar-

powered EV charging can be difficult.

Hawkins et al.[16] Analyze environmental research on battery-powered hybrid and electric cars (BEVs). 51 environmental risk evaluations of two vehicles—BEVs and HEVs—during their respective life cycles are offered for this reason. The writers take into account concerns including greenhouse gas emissions, production, generation, transmission, and distribution, as well as auto production, battery generation, and longevity.

Rahman et al.[17] presents a collection of Methods have been applied to address various issues pertaining to the infrastructure for PHEV and BEV charging. Additionally, diverse contexts are used to evaluate the various charging methods, such as residential garages, apartment buildings, and shopping malls. Some publications look at the different problems and potential opportunities that EV integration can bring to the smart grid because widespread use of EVs has detrimental effects on the current power grid[18].

As has previously shown, the vast majority of studies pertaining to electrically processed cars were generally: I. how electricity charges affect power demand; II. how electricity from renewable resources is used in the charging process; However, the current state of the electric vehicle business as well as the key properties of batteries, their methods, and the charging process are covered in this paper[19]. We compare the many standards established by these standards and show the various charging techniques, particularly the adapters used. We also talk about the difficulties that Evs encounter as well as the areas of study that we think need more attention.

Numerous research projects have been carried out to enhance the efficiency of solar-powered automobiles. Every major study of solar electric vehicles is discussed in over review document. By taking into account the review above, the investigation of the newest solar electric vehicles would be simple to operate.

2.4 Summary

All significant solar electric vehicle research is addressed in this chapter. It would be straightforward to undertake research in the developing domains of solar electric vehicles in light of the analysis that is offered above.

Chapter 3

CONVERTER CONFIGURATION AND OPERATING MODES

3.1 Introduction

This section will examine the converter configuration employed in the system as well as the operational principles and different operating modes of the converter. Also, the main circuit of the system will be covered in this chapter.

3.2 Bi-directional DC-DC Converter

A bidirectional converter can manage power flow in both directions, unlike a normal buck-boost converter that can only regulate power flow in one direction. The device used to step-up or step-down the voltage level with the capacity to move power either forward or backward is known as a bidirectional dc-dc converter. By adopting an unique switching technique and phase-shifted control strategy, bidirectional dc to dc converters can control the flow of power in both directions between two dc sources and a load. As a result, any extra energy created can be stored in batteries or a storage device. A bidirectional switch and a diode can transform a regular dc-dc converter into a bidirectional converter. The output of a renewable energy system fluctuates owing to changes in weather conditions, hence a bidirectional dc to dc converter is employed as a crucial device to interface storage devices between source and load in a renewable

energy system for continuous flow of power.

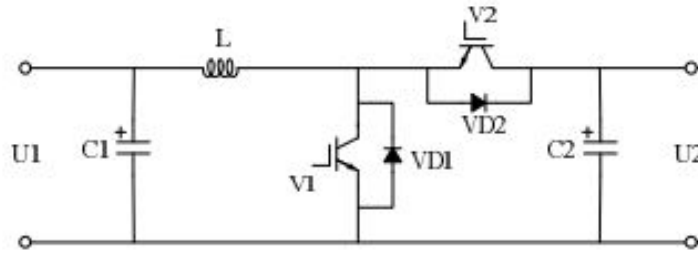


Figure 3.1: Bidirectional buck-boost converter topology

DC-DC converters that operate in both directions serve as power flow regulators for the DC bus voltage. The production of wind turbines and solar power systems varies due to the shifting environmental conditions. Due to the significant output swings, these energy systems are not dependable to provide power as a stand-alone system, hence they are constantly coupled with energy storage devices like batteries and super capacitors. These energy storage systems serve as a backup in case of system breakdown and when the energy system's output changes owing to weather conditions. They store excess energy during periods of low load demand. As a result, in order to enable power flow in both the forward and backward directions, bidirectional dc-dc converters are required. Bidirectional converters are also used in electric vehicles to transfer power from the battery to the motor.

Boost mode converters are the converters of choice for most electrical power circuit designers. Boost converter is a straightforward converter that is used to increase the DC voltage from a lower level. Because the output voltage is almost usually higher than the source voltage. DC-DC boost converters are used in grid connected applications to step up the module voltage, and The output voltage of the boost converter depends on the duty cycle of the control switch. So, the output voltage can be varied by varying the ON time of the switch. In this circuit, the power stage can function in one of two ways: one is boost converter in continuous conduction mode and the other is discontinuous conduction mode. High-power boost converters are typically made to work in CCM, while low-power boosts work in DCM. This is due to the fact that CCM permits circuits to have lower peak currents overall, which often leads to lower circuit losses.

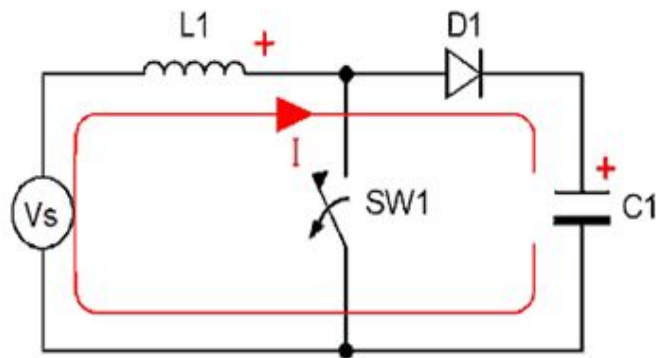


Figure 3.2: Boost Converter Continuous Conduction Mode

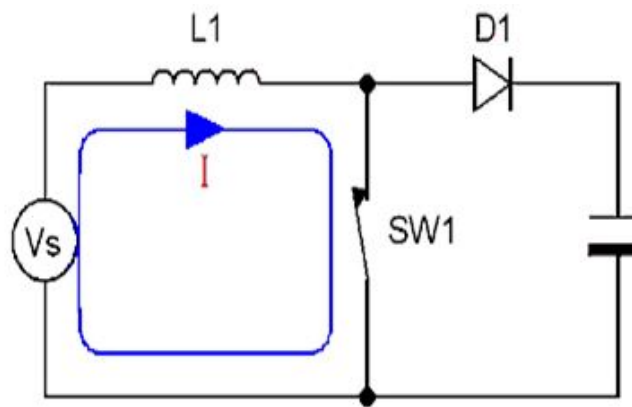


Figure 3.3: Boost Converter discontinuous Conduction Mode

Buck converters is a voltage regulators that step down current or convert it. The switch turns on and lets current flow to the output capacitor, charging it up. Since the voltage across the capacitor cannot rise instantly, and since the inductor limits the charging current, the voltage across the cap during the switching cycle is not the full voltage of the power source. Now the switch closes an inductor generates a voltage across it because an inductor's current cannot abruptly shift. When the switch is off, this voltage is permitted to power the load through the diode and charge the capacitor, maintaining the output current throughout the switching cycle. Comparing switching converters (such as buck converters) to linear regulators, which are more straightforward circuits that lower voltages by dissipating power as heat but do not step up output current. When specifying an inductor for buck, the first item to determine is the minimum inductance. It is done by taking the inductor ripple current into account, the switch ON/OFF switch times, voltage drop across the rectification (or rectified) device, and the maximum input voltage.

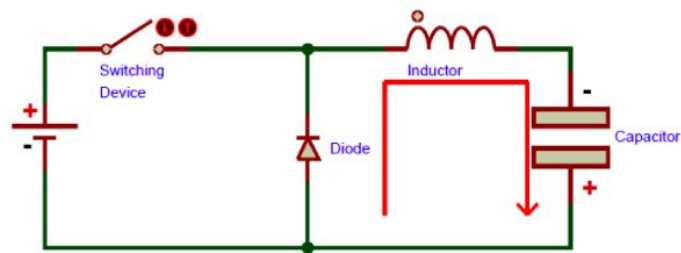


Figure 3.4: Buck Converter circuit

3.3 Block Diagram of the System

A power electronics device known as a DC-DC converter accepts a DC input voltage and also outputs a DC voltage. A DC to DC converter's output voltage may be higher than its input voltage or vice versa. The power supply needed by the loads is matched using the converter output voltages. As power conditioning units, DC-DC converter circuits are used between the PV source and the load. Most often, DC-DC Boost converters are used. The boost converter has a significant degree of ripple in both its input current and output voltage. The boost converters are interconnected in order to reduce input current ripple and increase output current.

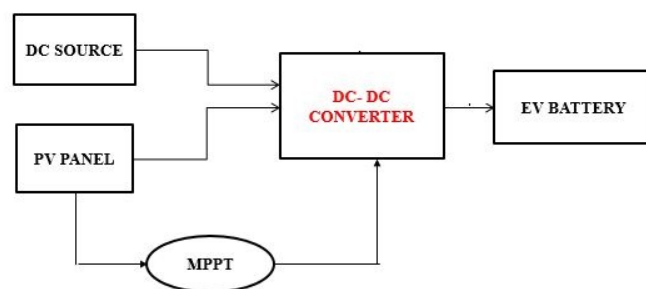


Figure 3.5: Basic block diagram of the proposed system

A two- input single output high performance DC -DC converter is used here for the productive combination of two different sources. The basic block diagram of the suggested converter for E vehicle application is shown in Fig 3.5. The input sources are realized using a solar PV and a battery. Here, two inputs are used one is the battery as dc source, this battery is act as the backup battery and the second input source is solar PV. This input source is connected to the DC-DC converter here introduced two input single output high step up DC-DC converter. For

the effective use of solar power converter operates in five different modes and the out is given to the EV battery as the load. Basically, the output power of PV panel will varying due to the changes in ecological conditions. That is the PV having non-linear characteristics. In order to consider this constraints, MPPT controllers are used to track the point at which the power is maximum. For that several algorithms are available to track maximum power point (MPP) at varying weather conditions.

3.4 Operational Principle and Analysis

The suggested converter can be operated in both buck and boost modes to perform five operating modes. They are;

1. First mode of operation (PV charged mode).

During the condition, if irradiation is available and the battery SOC is greater than 80%. The power is generated from the solar photovoltaic (source V1) and is given to the motor and the automobile speed is controlled by the switch S2. In this mode proposed converter is operates in boost mode.

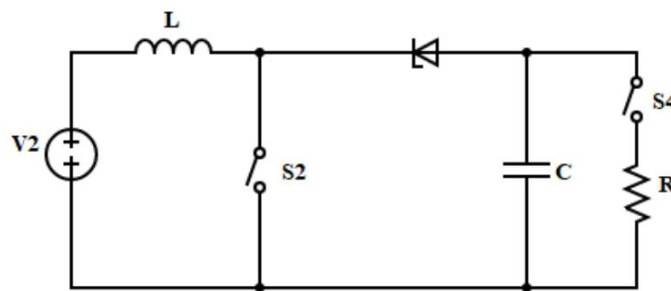


Figure 3.6: Equivalent circuit diagram of First mode of operation

2. Second mode of operation (Battery charged mode)

In this mode switch S1 is continuously ON. When the solar irradiation is not available, the battery (source V2) generates the power to the motor. It is similar to the operation of mode1. In this mode the proposed converter operates in boost mode.

3. Third mode of operation (Vehicle off at day time)

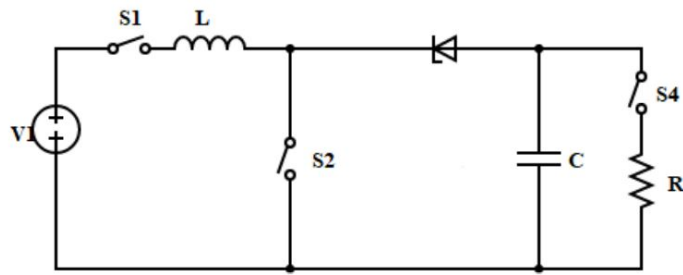


Figure 3.7: Equivalent circuit diagram of second mode of operation

Basic boost operation happens in this mode. Here the vehicle is not in operation, if SOC is less than 80 percent the energy from SPV (solar PV) is used to drive the vehicle and excess is released to (source V1) as back up battery. When SOC is greater than 80 percent it releases the power to the external battery.

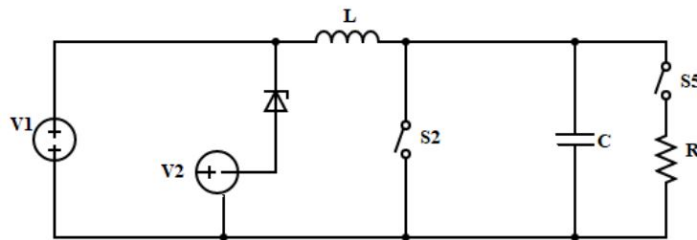


Figure 3.8: Equivalent circuit diagram of Third mode of operation

4. Fourth mode of operation (Vehicle off at night time)

In this mode, the battery is charged by external source (external battery). The power to charge the battery is controlled by switch S3.

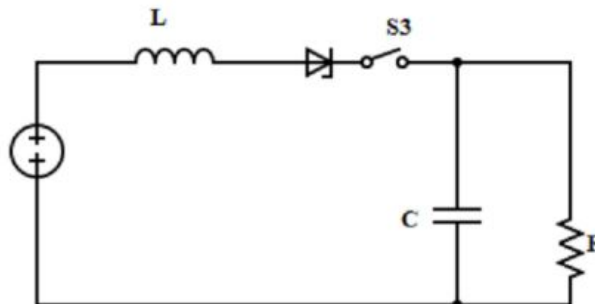


Figure 3.9: Equivalent circuit diagram of fourth mode of operation

5.Fifth mode of operation((High performance mode)

In this high speed operation mode, the proposed converter drives the vehicle from both battery and SPV sources. The combined energy from V1 and V2 sources has been released to the load. Here also basic boost operation is happened in the converter.

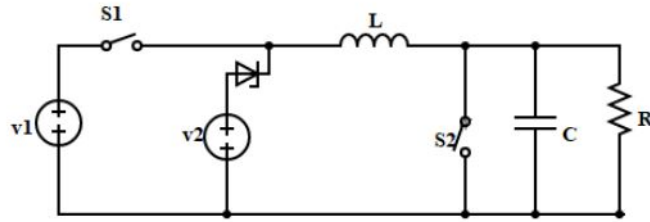


Figure 3.10: Equivalent circuit diagram of fifth mode of operation

In the Figures 3.6-3.10 shows the basic equivalent circuit diagram of the proposed converter in various mode of operations. Fig.3.6 shows the equivalent circuit diagram of the PV charged mode. The operation is similar to a boost converter. Fig.3.7 shows the equivalent circuit diagram of the Battery charged mode. Here also the operation is similar to a boost converter. Fig.3.8 shows the equivalent circuit diagram of the third mode of operation (vehicle off at day time). The proposed converter operates in boost mode. Fig.3.9 shows the equivalent circuit diagram of the fourth mode of operation (vehicle off at night time). The proposed converter operates in buck mode. Fig.3.10 shows the equivalent circuit diagram of the fifth mode of operation (high performance mode). The proposed converter operates in boost mode.

Table 3.1: Active Switches in Various Modes

Modes	S1	S2	S3	S4	S5	S6
First mode of operation		P		1		
Second mode of operation	1	P		1		
Third mode of operation(SOC<80%)		P		1		
Third mode of operation(SOC>80%)		P		1		
Fourth mode of operation			P	1		
Fifth mode of operation		P	P			1

3.5 Design of system parameters

By analysis, the main circuit is selected and designed the parameters of the component in the circuit. One inductor is all that is required for the bidirectional Buck/boost.

Additionally, we have gained some expertise in the Buck/Boost DC/DC converter. So, for the photovoltaic power system's energy storage system, we opt for the bidirectional Buck/Boost DC/DC converter. In fig.4.1 its topology is depicted.

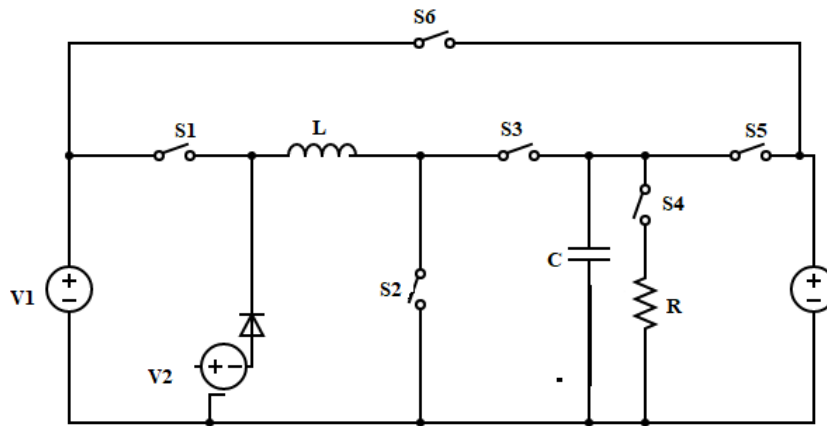


Figure 3.11: Basic Equivalent circuit diagram of the system

Inductor (L), Diode (D), Capacitor (C), Load Resistor (RL), and the Control Switch make up the DC-DC boost converter circuit . These parts are coupled with the input voltage source (Vin) in a manner that steps up the voltage in Boost Converter.

Selection of inductor and capacitor: The inductor for the bidirectional DC-DC converter is designed taking into account the current ripple and the operating mode of the circuit. The voltage ripple should be less than 1 percent in accordance with the design specifications. We can get,

- Design of converter based on given parameters,

$$Capacitor, C = \frac{D_2 V_2 (1 - D_2)}{8 f_s^2 L \Delta V_C} \tag{3.1}$$

$$\text{Inductor, } L = V_L \frac{\Delta t}{\Delta i} \quad (3.2)$$

$$\text{Load Resistance, } R = \frac{V^2}{P} \quad (3.3)$$

Table 3.2: Design of converter based on given parameters

Sl. No.	Parameters	Specifications
1	Source 1(Battery)	110V
2	Source 2(PV)	72V
3	Switching frequency	20KHz
4	Power	2KW
5	Output Voltage	250V

Table 3.1 and 3.2 shows the specifications of components of the system and designed parameters respectively.

Table 3.3: Designed Parameters of the System

Sl. No.	Parameters	Specifications
1	Capacitor	470microFarad
2	Inductance	3mH
3	Resistance(Load)	31.5ohms

3.6 Summary

In this part, the suggested converter topology for the system is detailed, along with a description of the block diagram. There is additional discussion of the converter's principle and its several modes of operation. The primary circuit and the planned component parameters were covered in this chapter.

Chapter 4

MAXIMUM POWER POINT TRACKING

4.1 Introduction

In addition to describing several power tracking algorithms utilised in the PV system, this chapter provides a study on the maximum power point tracking in the PV system.

4.2 PV system with MPPT

The standalone PV power system consists of a load, a DC-DC converter, and a PV module or array. The MPPT controller regulates how the DCDC converter works. Figure 5.1 depicts a standalone PV power system with an MPPT controller. The PV module/array, DC-DC converter, control circuit, and load are all components of the system.

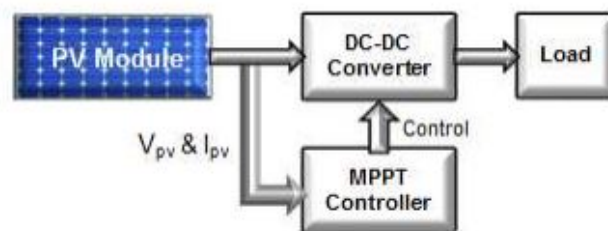


Figure 4.1: Standalone PV system with MPPT controller

The non-linear features of the PV modules/arrays mean that their output power will fluctuate in response to changes in temperature or solar radiation. Figure 5.2 and 5.3 depicts the PV module's voltage-current characteristics curve for various temperature levels. As the irradiation level rises, the module current I_{pv} does as well, and vice versa. But despite changes in irradiation level, the module voltage V_{pv} is remained essentially constant.

The voltage-current characteristics for different types of the temperature. While there aren't many variations in the module current I_{pv} in this situation, the module voltage V_{pv} is falling as the temperature rises and vice versa. As a result, the module voltage V_{pv} varies in relation to changes in temperature level and the module current I_{pv} varies in relation to variations in radiation level.

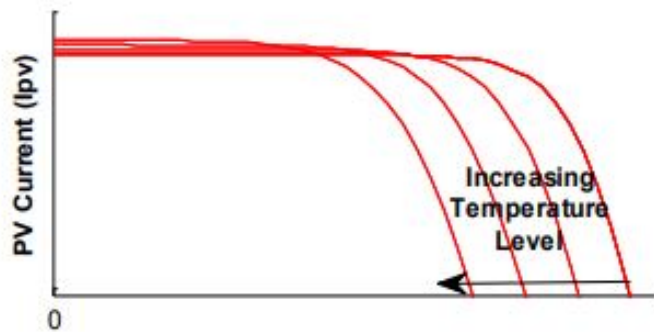


Figure 4.2: Voltage-current characteristics of PV at different temperature level

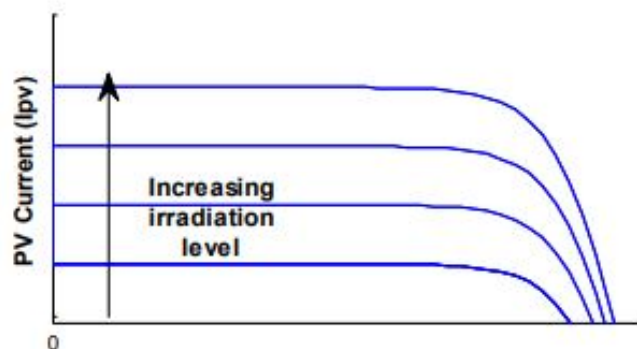


Figure 4.3: Voltage-current characteristics of PV at different irradiation level

Fig.5.4 shows the voltage-power characteristics of a PV module under various circumstances. When the temperature or/and irradiation levels fluctuate, the PV module's maximum output

power changes as well. When the temperature rose, the maximum power point, where the irradiation is constant in these situations, changed from T1 to T2. Similar to this, due to an increase in irradiation level where the temperature remains constant, the maximum power point has changed from G2 to G1. To achieve the highest power, the working point of the converter to circuit must be modified to align the load resistance with the PV source. The converter circuits were to be controlled by a variety of MPPT algorithms.

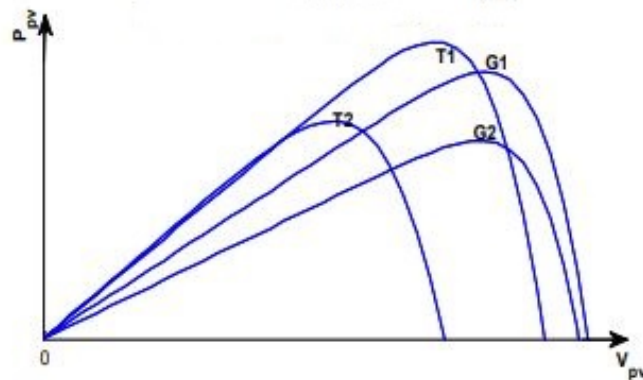


Figure 4.4: Voltage-Power characteristics of PV under various conditions

Several algorithms are available to track maximum power point at varying weather conditions. In this work, discussed about the three different power tracking algorithms

- Perturb and Observe(PO) MPPT algorithm
- Variable step size Perturb and Observe (VSS PO algorithm
- Look-up Table Method

4.3 Perturb and Observe MPPT Algorithm

P&O algorithm is the simplest algorithm than others and it is easy to implement. The P&O MPPT algorithm changes the perturbation in a regular interval based on the output of the previous state. In PO if a minor perturbation is introduced, output power is periodically measured and compared with the previous power.

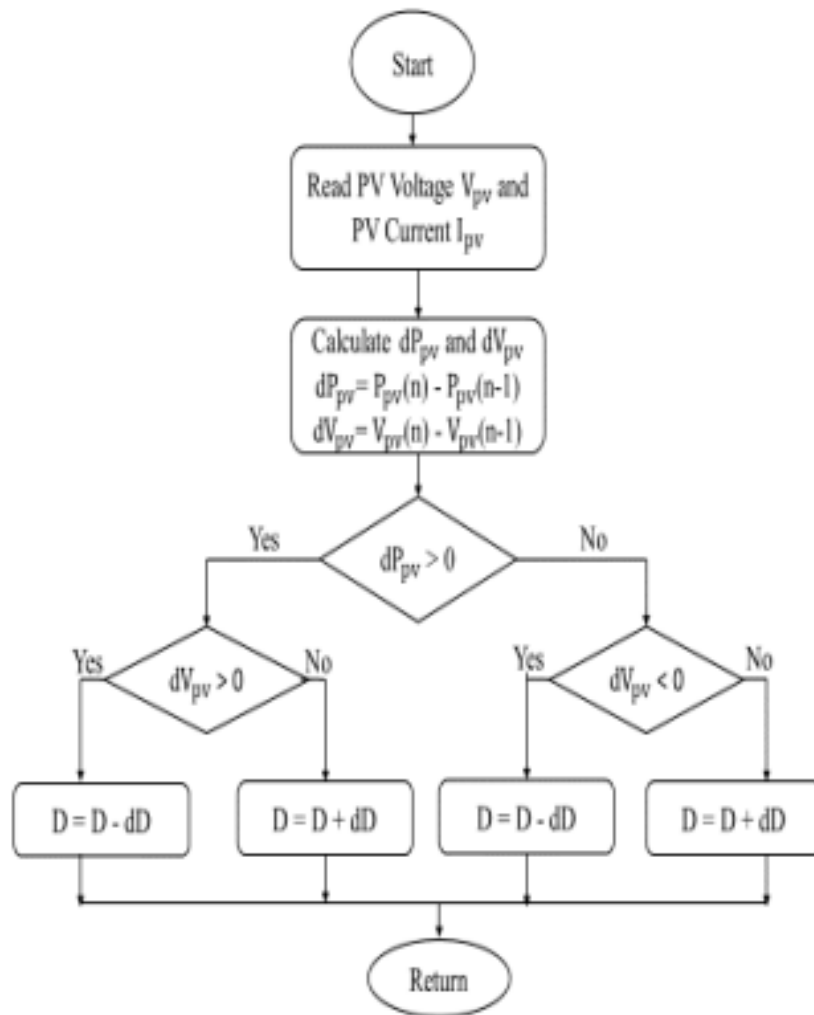


Figure 4.5: The flow chart of P&O Algorithm

The operation of P&O MPPT algorithm can be simply described as,

- (a) The power is increased; if the preceding state's perturbation was positive, the power rise is continued in that direction.
- (b) When the prior state was perturbed positively, the power is reduced and the current perturbation should be in the opposite direction.
- (c) The power is increased when the preceding state's perturbation was negative, and the perturbation is then continued in the same direction.
- (d) The power is reduced; if the prior state had experienced a negative perturbation, the current perturbation should go in the opposite direction.

This algorithm is not appropriate for fast varying atmospheric conditions due to slow tracking. To overcome the limitations of P&O algorithm, introduce a modified PO as Variable step size P&O algorithm, which enhances the tracking speed and also reduces the fluctuations. The flow chart of P&O MPPT algorithm is shown in figure 5.5.

4.4 Variable Step Size P&O MPPT Algorithm

Obtaining the PV panel's instantaneous voltage and current values, perturbing the operating voltage, and then calculating the instantaneous power and comparing it to the prior power are all steps in the stable step size P&O algorithm. The operating voltage changes depending on the duty cycle until the MPP is reached. Small step sizes result in higher steady state error and slower convergence times, whereas big step sizes result in faster convergence times but increased steady state error. The variable step size P&O algorithm was created to address this issue.

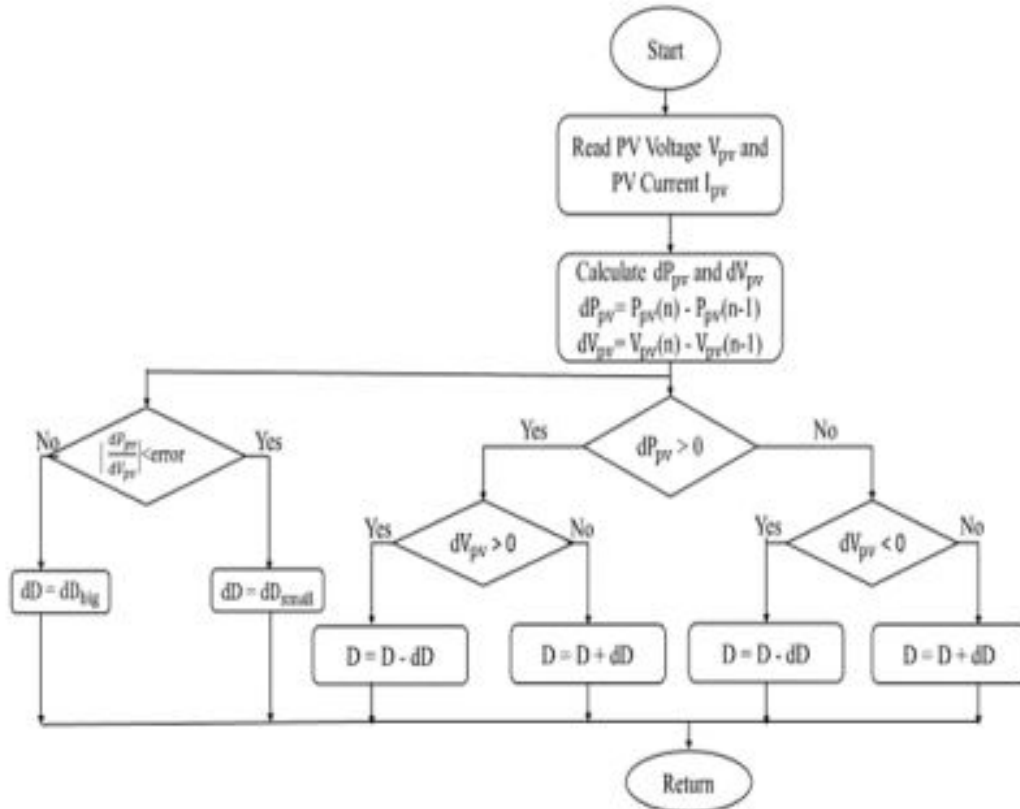


Figure 4.6: The flow chart of VSS PO algorithm

In the VSS P&O algorithm, an error is first taken into consideration, after which it is paired with a change in power via a change in voltage, and a step is then provided based on this error value. The algorithm outputs a big step value when the operating point is far from the maximum power point and a small step value when the operating point is close to the MPP. By taking into account the slope of the P-V curve, Fig. 5.6 depicts the flowchart of the variable step size P&O algorithm. At the MPP, it is zero, the slope is on the right side of the MPP, and the slope is on the left side of the MPP.

4.5 Look-Up Table Method

A straightforward offline MPPT technique called a look-up table (LT) retrieves the necessary values directly from the data kept in static memory. The key advantage of LT over other MPPT algorithms is that it requires less computing time and the memory-based pre-calculated data has a boundary. In spite of changing temperature and radiation levels, the Look-Up Table responds quickly and accurately to MPP. Therefore, there are no variations around the MPP. P&O based system Look-up Table generates constant output power in comparison to P&O and VSS P&O based system. Consequently, the effectiveness of the entire system is increased.

4.6 Summary

This chapter described the study about maximum power point tracking in the PV system and discussed about various power tracking algorithms used in the PV system.

Chapter 5

RESULTS AND DISCUSSIONS

5.1 Introduction

Verifies the effectiveness of the automated system through the results of five operating modes of the converter, and compared the outcomes of several MPPT techniques for monitoring the maximum power point in the PV-based system.

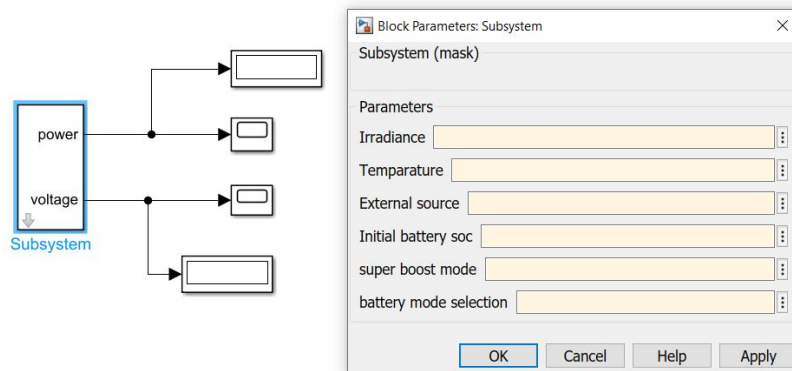


Figure 5.1: Simulink model of the proposed system with a mask dialogue box

Fig 5.1 shows the simulation model of the proposed system developed in the MATLAB. In the first three modes, the power has been controlled by changing the duty ratio of switch S2. In PV charged mode, the source voltage is less than battery charged mode (second mode of operation). So, the duty ratio of S2 is higher than battery charged mode. At day time if the vehicle is off and the SOC>80%, the duty ratio has been fixed according to the solar irradiation.

When the SOC < 80% the maximum power is given to the battery. When the vehicle is off at night, suggested converter operates in buck mode. The inductor stores the energy from the external battery, and this stored energy is given to the backup battery. At this mode, power has been controlled by the duty ratio of switch S3. By adjusting the duty ratios d1 and d2 the power has been controlled in the high performance mode

The dialogue box for subsystem mask is shown in the fig.5.1. As per the diagram, By opening the subsystem including the main circuit of the system. And applying the conditions of each modes on it. Hence, each mode will automatically selected and the selection is based on the controlling of switches on each modes.

5.2 First Mode of Operation

Figure 5.2, 5.3 and 5.4 shows the simulation results of first mode of operation (PV charged mode). Fig 5.2 depicts the wave form shows the status of switch, in which it is clear that the pulse is given on switch S2 and switch S4 is on and the other switches are in off conditions.

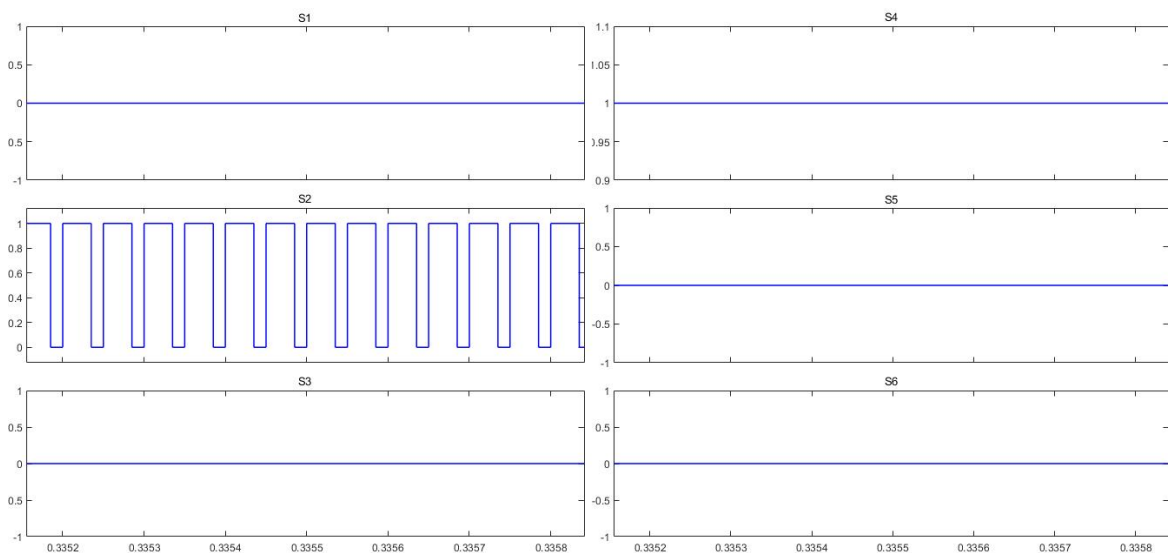


Figure 5.2: Simulated waveform of the switching of PV charged mode

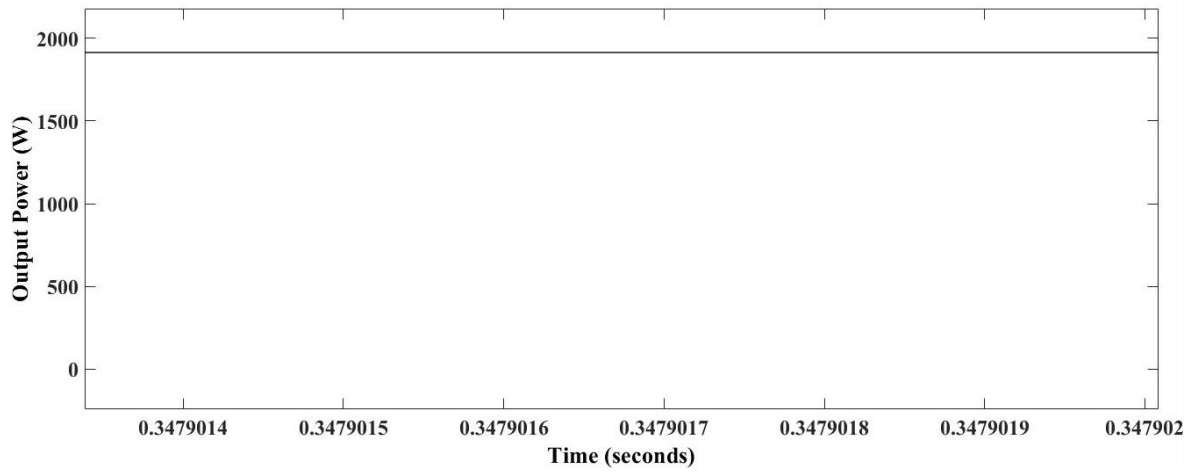


Figure 5.3: Simulated waveform of output power of PV charged mode

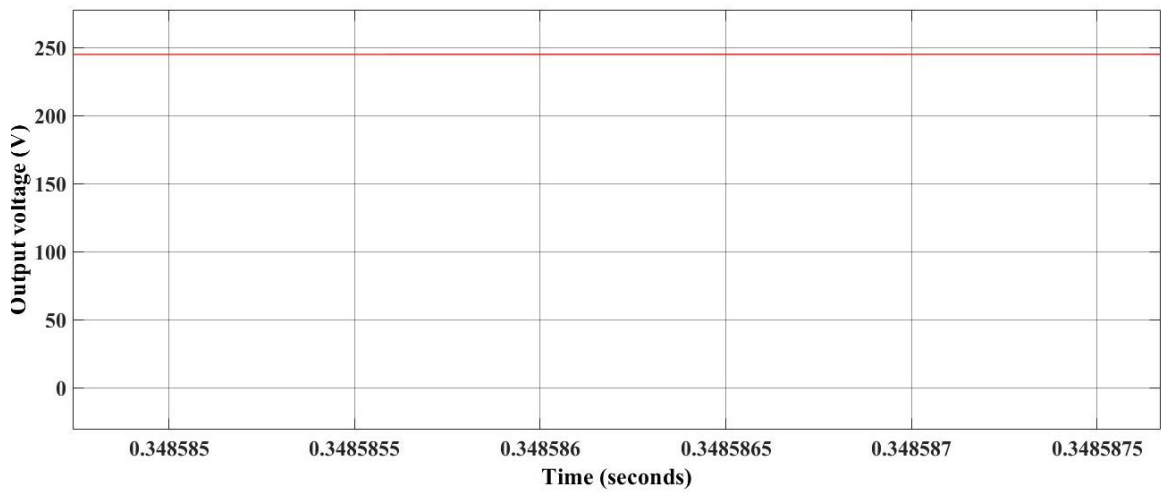


Figure 5.4: Simulated waveform of output voltage of PV charged mode

Fig 5.3 shows the output power in the specified mode of operation. Fig 6.4 shows the output voltage respectively.

5.3 Second Mode of Operation

In the battery-charged mode, the source V1 powers the load while the inductor current charges due to the duty cycle of S1 and degrades in the off state of S2.

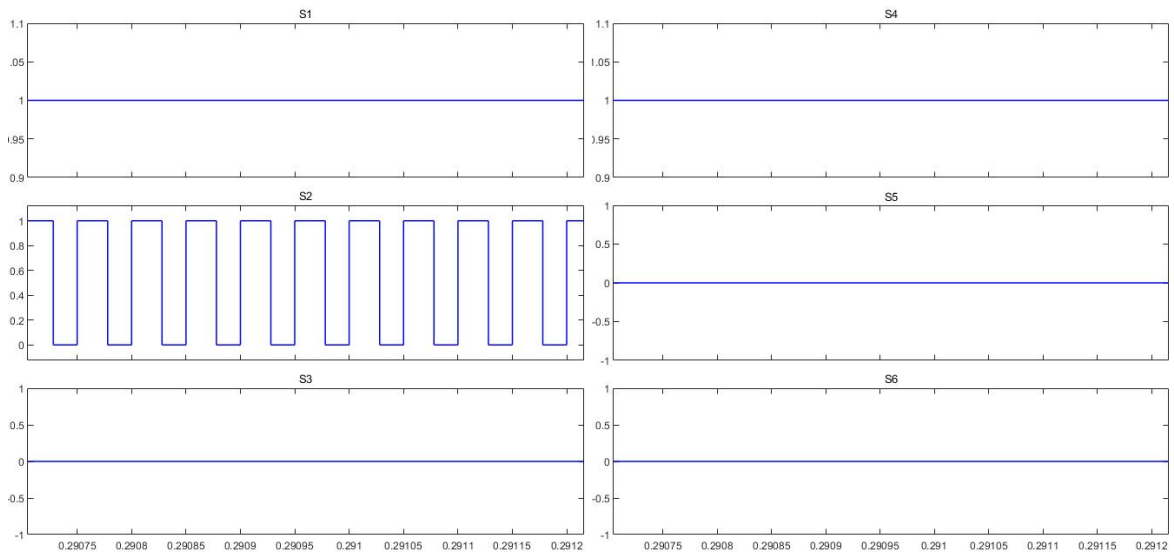


Figure 5.5: Simulated waveform of output power of Battery charged mode

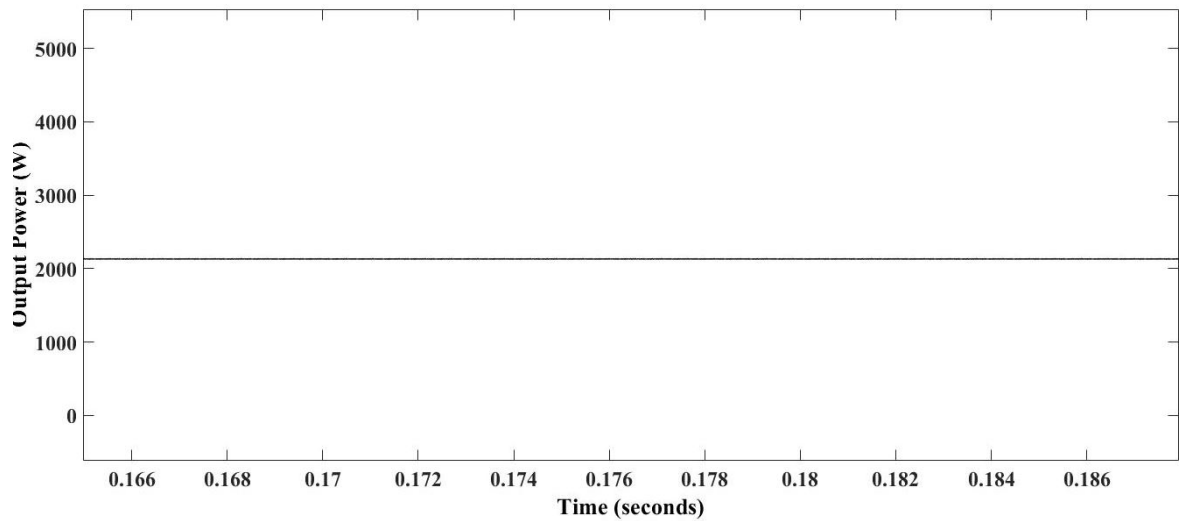


Figure 5.6: Simulated waveform of output power of Battery charged mode

Results of the simulation for the second mode of operation are shown in Figures 5.5, 5.6, and 5.7 (Battery charged mode). The waveform in Fig. 5.5 clearly reveals that the pulse is delivered on switch S2, switch S1, and switch S4 is on while the remaining switches are in off state. The output power in the given mode of operation is shown in Fig. 5.6. The output voltage is displayed in Fig. 5.7. Furthermore, this mode maintains a better battery life cycle since the current drawn from the source is ripple-free.

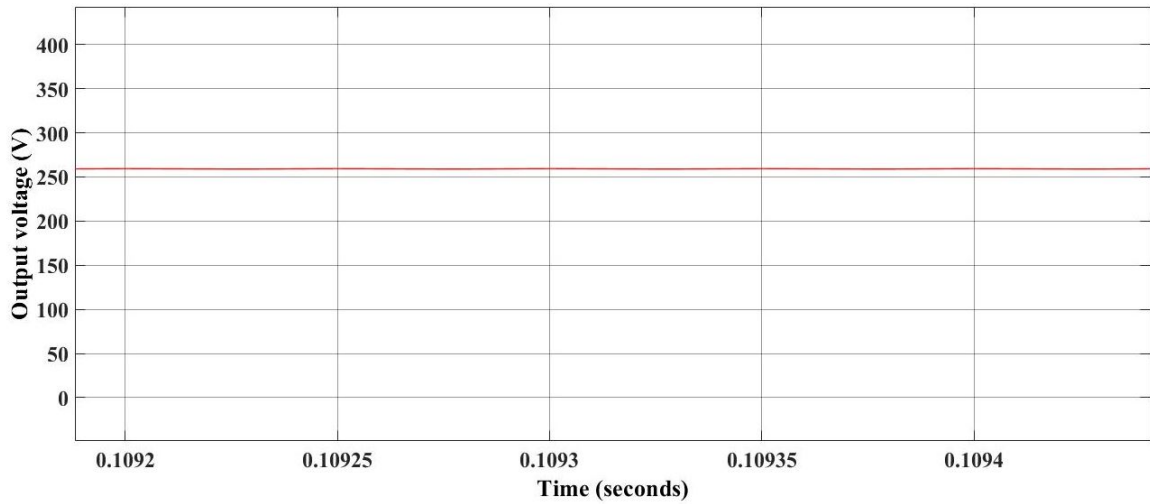


Figure 5.7: Simulated waveform of output voltage Battery charged mode

5.4 Third Mode of Operation

The simulation results for the third mode of operation are shown in Figures 5.8, 5.9, 5.10, and 5.11. Vehicles off at day time, if $SOC < 80\%$, the pulse is given on switch S2 and switch S5 is on, and when $SOC > 80\%$, the pulse is given on switch S2 and switch S5 is on. It is evident from the waveform in Figs. 5.8 and 5.9. The other switches S1, S3, S4 and S6 are also in the off position.

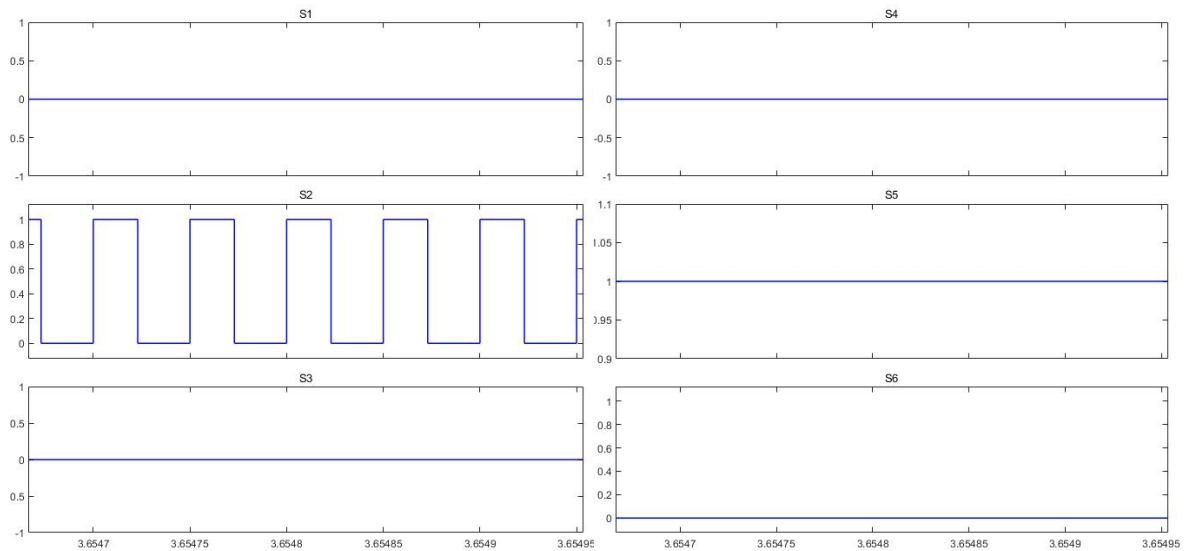


Figure 5.8: Simulated waveform of the switching at the vehicle off in day time (when $SOC < 80\%$ percent)

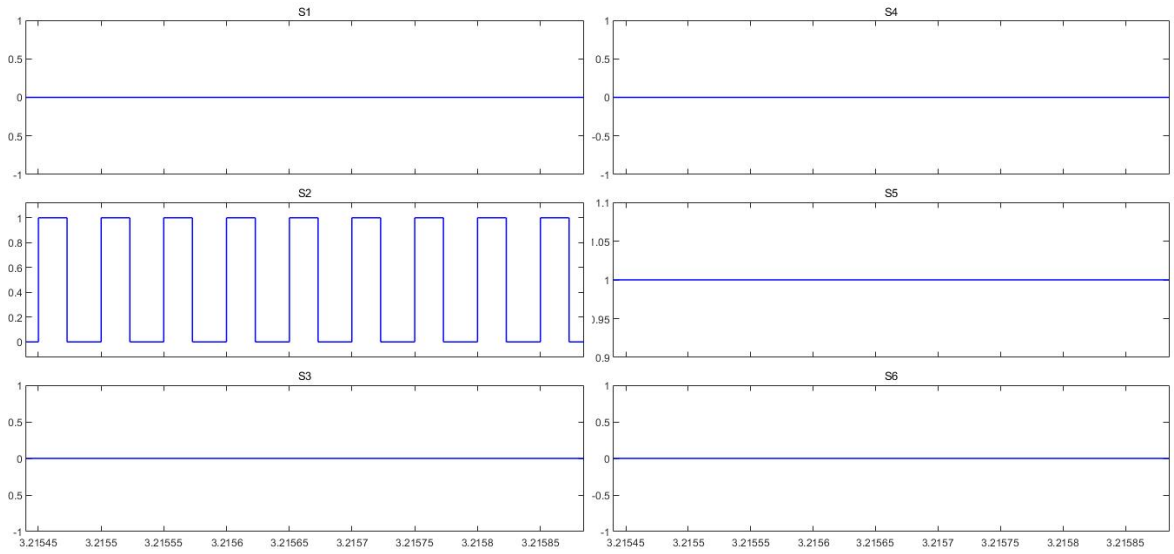


Figure 5.9: Simulated waveform of the switching at the vehicle off in day time (when SOC>80% percent)

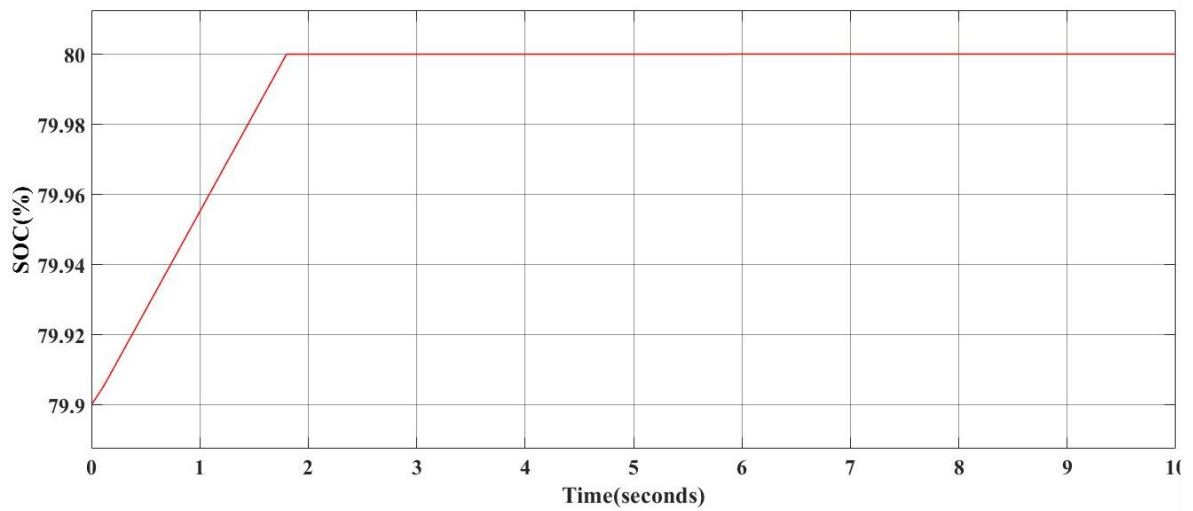


Figure 5.10: Backup battery status at the vehicle off in day time (when SOC<80% percent)

During this mode, there is no load (EV battery). Therefore, consider the charging status of the backup battery. Figure 6.10 illustrates that it will remain constant if SOC<80% and charges up to 80%. Solar PV provides power to the external source if SOC >80%.

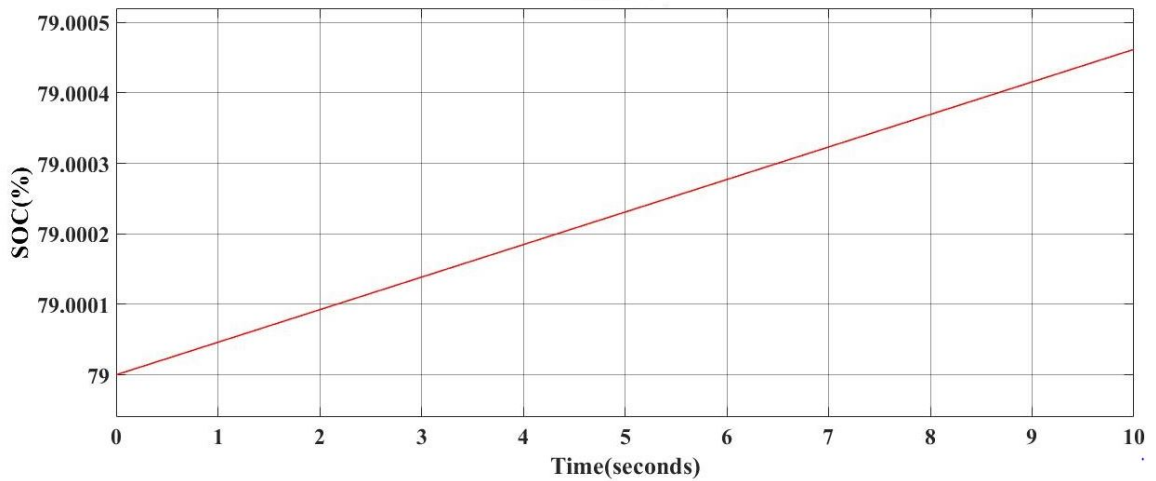


Figure 5.11: External battery status at the vehicle off in day time (When SOC>80% percent)

5.5 Fourth Mode of Operation

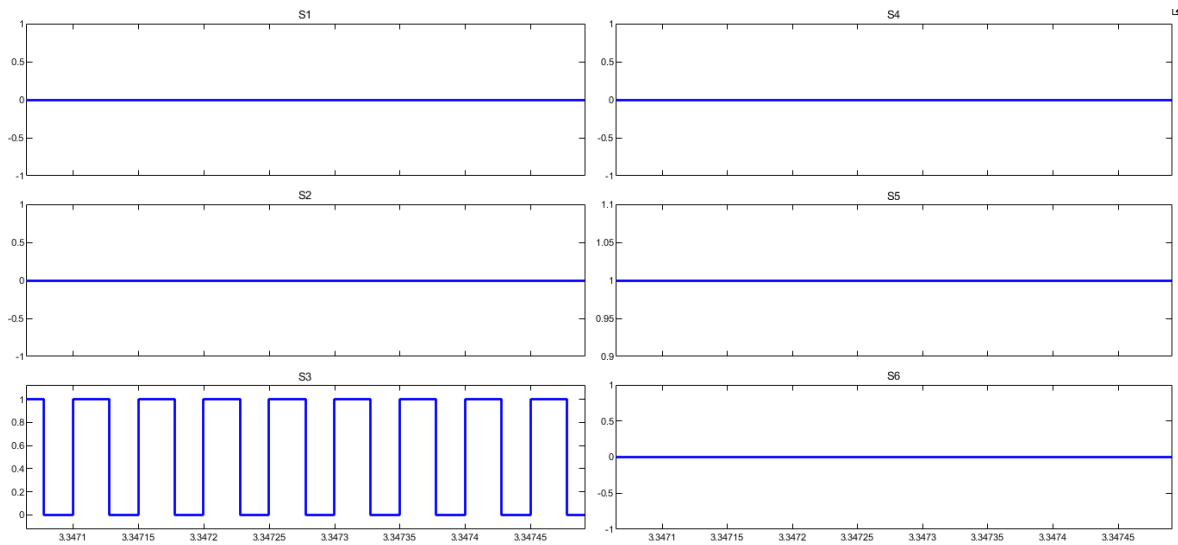


Figure 5.12: Simulated waveform of the switching at the vehicle off in night time

The simulation results of the fourth mode of operation are shown in Figures 6.12 and 6.13. (Vehicles off at night time). In Fig. 6.12, the waveform of a switch is shown, and it is obvious that switch S3 and switch S5 are receiving a pulse, while the other switches are in an off state. In this case, vehicle is off, that is there is no load (EV battery). So, consider the charging or discharging status of back up battery. It is clear that during night time when the vehicle is off the backup battery is charged by using the energy taken from the external battery..

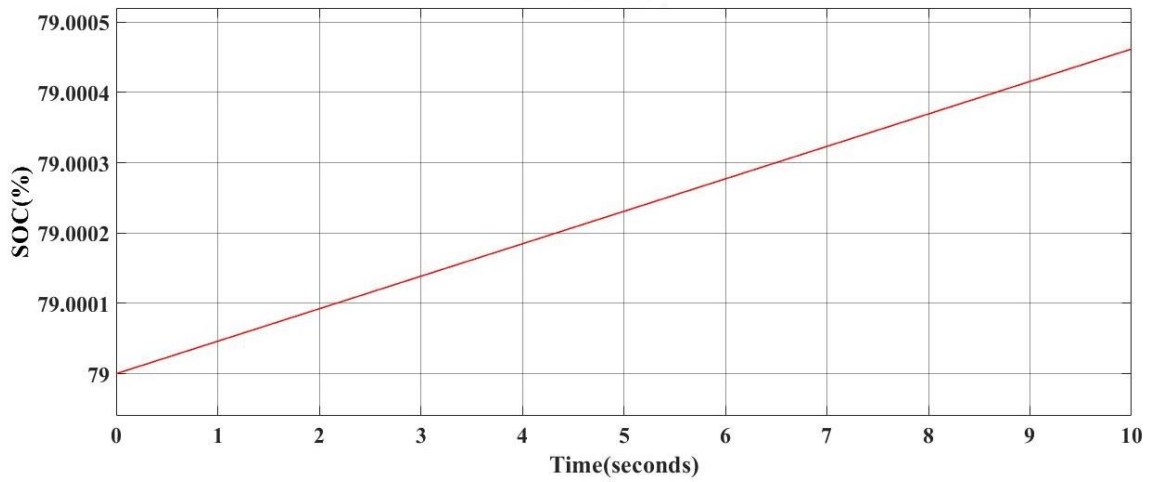


Figure 5.13: Back up battery status at the vehicle off in night time

5.6 Fifth Mode of Operation

To achieve high speed, power from both sources V1 and V2 is released to the load. The power has been controlled in this mode by adjusting $d1$ and $d2$. Due to these two control parameters of $d1$ and $d2$, wide range of power can be controlled in this mode.

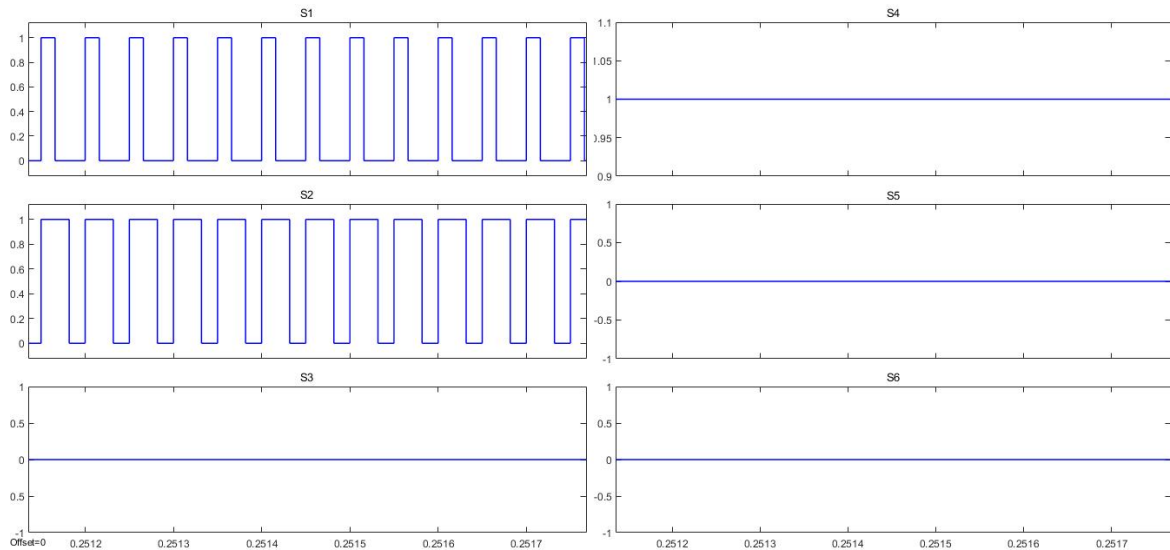


Figure 5.14: Simulated waveform of output power of PV high performance mode

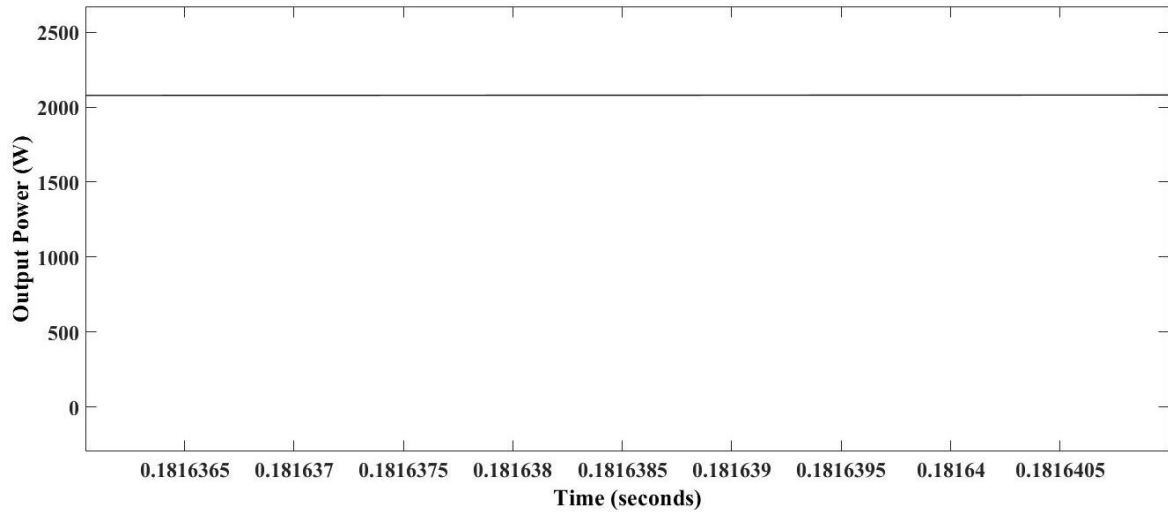


Figure 5.15: Simulated waveform of output power of high performance mode

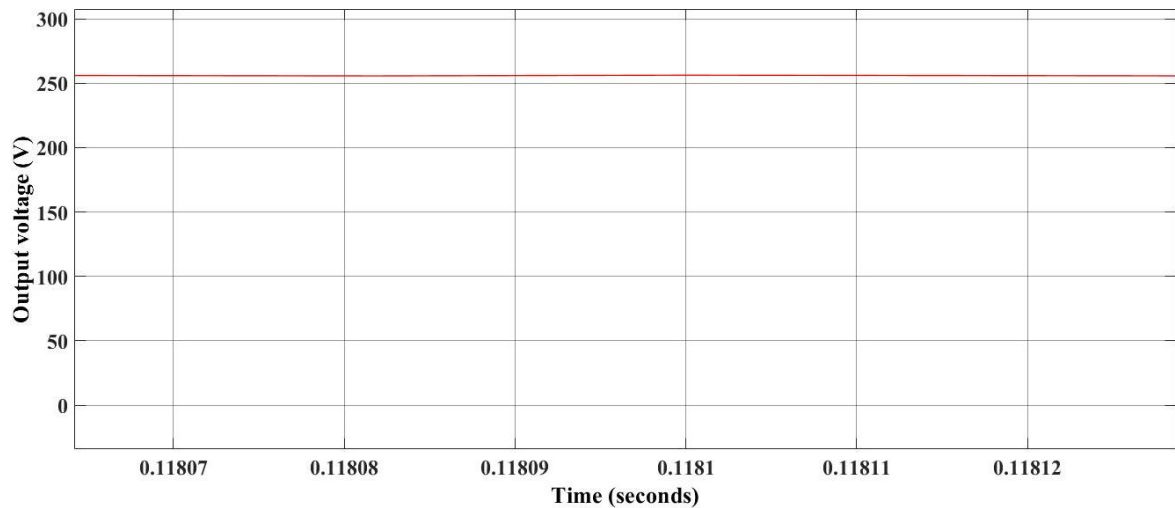


Figure 5.16: Simulated waveform of output voltage of high performance mode

Results from the simulation for the fifth mode of operation (High performance mode) are shown in figures 5.14, 5.15, and 5.16. Fig 5.14 depicts the waveform shows the status of switch, in which it is clear that the pulse is given on switch S1 and switch S2 and switch S5 is on and the other switches are in off conditions. Fig 5.15 shows the output power in the specified mode of operation. Fig 5.16 shows the output voltage. The proposed converter operates the EV at high speeds using both battery and solar PV power. One of the distinguishing characteristics of the suggested converter is this mode of operation. By changing d_1 and d_2 , the power has been adjusted in this mode. This is one of the unique feature of the proposed converter. Also, this mode maintains a better battery life cycle since the current drawn from the source is ripple-free.

5.7 Simulation Results(MPPT)

Consider the PV system, varying irradiation level is used for the simulation of the system. Fig 8 depicts the output power of VSS PO and LT MPPT algorithm.

Fig 6.17 shows the simulated waveform the duty cycle at constant temperature and varying irradiation of P&O, VSS P&O and LT methods of tracking maximum power point. From the graph it is clear that LT has constant duty ratio than P&O and VSS P&O.

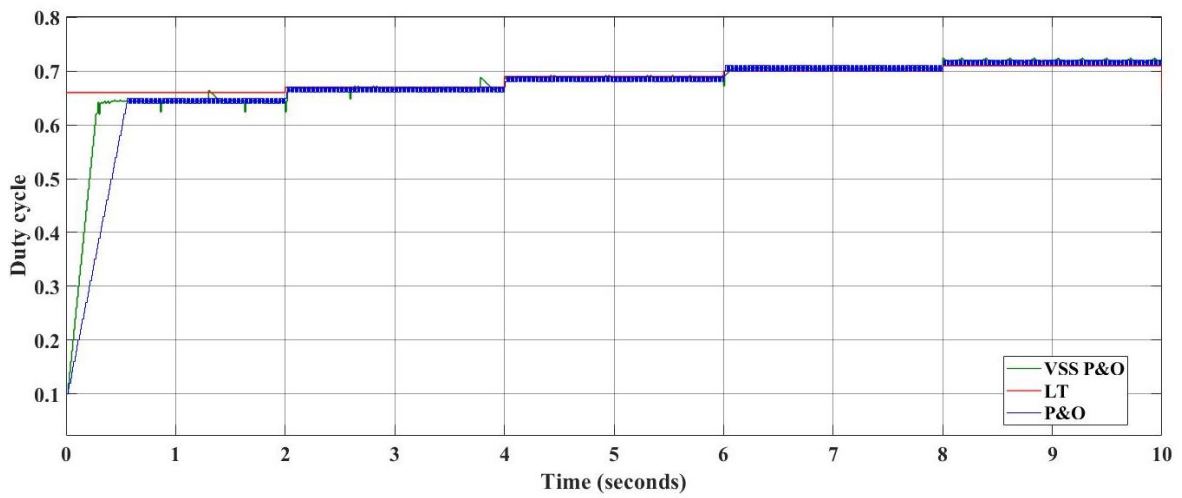


Figure 5.17: Duty ratio at constant temperature and varying irradiation of VSS P&O and LT

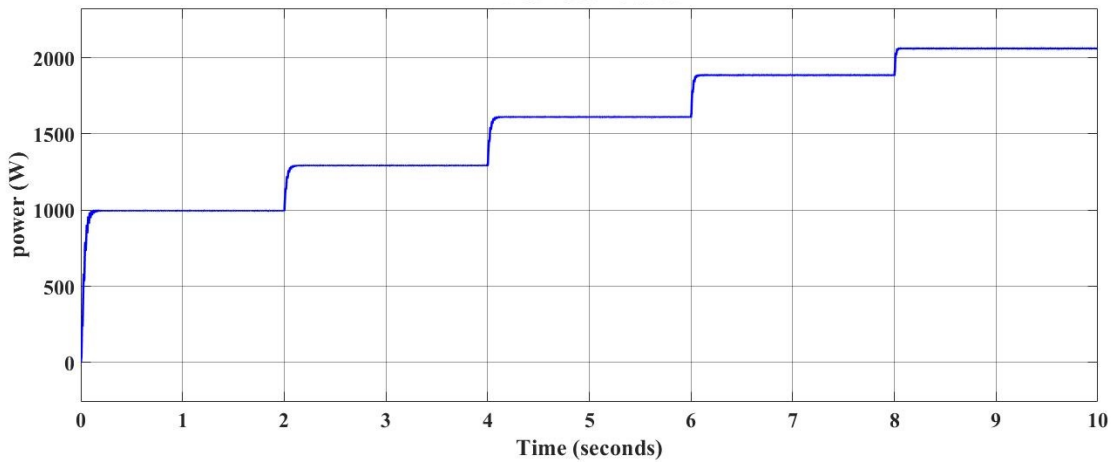


Figure 5.18: Power at constant temperature and varying irradiance without using MPPT

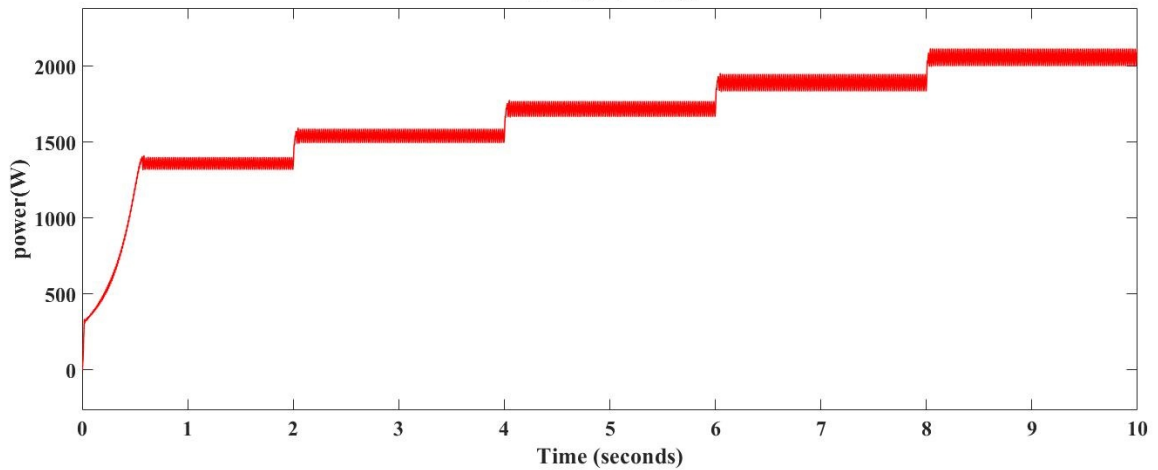


Figure 5.19: Power at constant temperature and varying irradiance of PO

From the above graphs (Fig 6.18-6.20), it is clear that output power is increases by using MPPT than without using MPPT. By using P&O, the output power ripples are more than other two methods (VSS P&O and Look- up Table). VSS P&O reduces the oscillations than P&O. But Look-up Table possess fast response than other two methods (P&O and VSS P&O). Moreover, there is no oscillations around MPP and make a constant power generation.

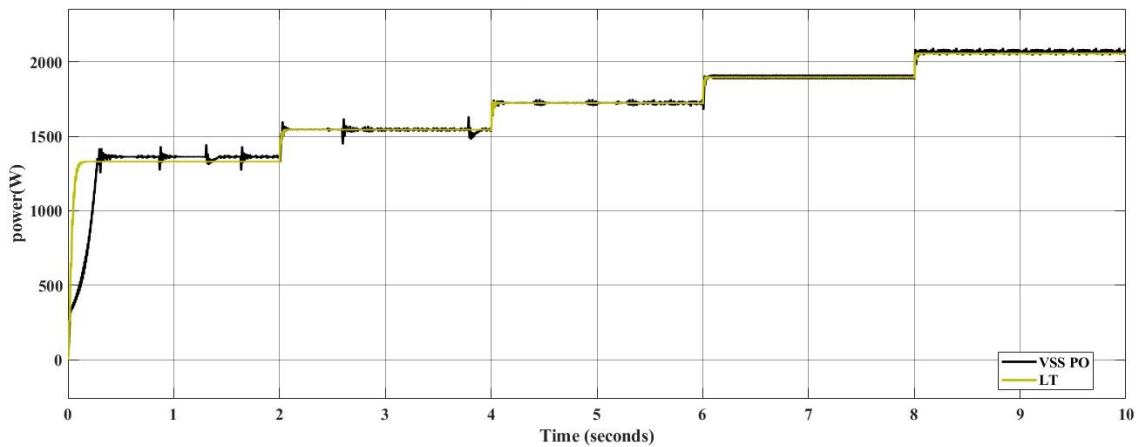


Figure 5.20: Power at constant temperature and varying irradiation of VSS PO and LT

5.8 Comparison Study

From the table it is clear that output power is increases by using MPPT. In this work three power tracking algorithms are used to track the MPP. By comparing with these three different power tracking algorithms Look up table is much better than others, because it possess fast response in varying temperature and irradiation. In LT method there is no oscillations in the output power. Therefore, ripples are very negligible than other two tracking methods. So make a constant power generation in the PV based system.

Table 5.1: Output Power obtained without using MPPT and With using MPPT

Irradiation W/m ²	Avg Power(W) (Without MPPT)	Avg. Power(W) (P&O)	Avg. Power(W) (VSS P&O)	Avg. Power(W) (LT)
800	1292.5	1536	1539	1544.5
900	1611	1718.5	1721	1723
1000	1885.5	1891	1898	1898.5
1100	2010	2048	2050	2055

Table 5.2: Power ripple of P&O, VSS P&O, LT

Irradiation W/m ²	Power Ripple (%) (P&O)	Power Ripple (%) (VSS P&O)	Power Ripple (%) (LT)
800	11.9	12.2	0.45
900	8.2	2.6	0.46
1000	2.58	1.58	0.47
1100	2.41	1.41	0.48

5.9 Summary

This chapter examined the efficiency of the automated system and came to the conclusion that the PV system's Look-up table (LT) approach produces better results than the other two tracking systems.

Chapter 6

CONCLUSION

The proposed system has a solar/battery powered step-up DC- DC converter to integrate the two different input sources such as solar PV and an ESS (as a battery). The proposed coverter operates in five different modes namely, PV charged mode, Battery charged mode, Vehicle off at dat time, Vehicle off at night time and high performance mode. These modes of the converter are automatically selected in the system based on the availability of input sources. The maximum utilization of solar energy is done by using MPPT controller. In the present work, 3 algorithms such as P&O, VSS P&O , and Look-up Table are used to track the maximum power point in the PV system. It is concluded that LT method is better to achieve maximum power and constant power generation over sudden varying temperature and irradiation than P&O and VSS P&O power tracking algorithms.

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