OPTIMISED MULTISOURCE EV CHARGING STATION WITH GRID VOLTAGE SAG CONTROL

PROJECT REPORT

submitted by

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the APJ Abdul Kalam Technological University
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of

Master of Technology
in
Electrical and Electronics Engineering
with specialisation in
Industrial Instrumentation and Control

Department of Electrical and Electronics Engineering

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DECLARATION

I undersigned hereby declare that the project report entitled "**Optimised Multisource EV Charging Station with Grid Voltage Sag Control**", 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 the supervision of *Dr. Muhammed Shanir P P*, Project Supervisor, Assistant Professor, Department of Electrical and Electronics Engineering, *Prof. Amal A*, Project Co-ordinator, 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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June, 2023

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CERTIFICATE

This is to certify that the project report entitled "**Optimised Multisource EV Charging Station with Voltage Sag Control**" submitted by **GIRI GOVIND S** , **(Reg. No. TKM21EEII07)** 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 him under our 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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GIRI GOVIND S

ABSTRACT

The voltage quality is the major issue in the distribution grid due to sudden load changes, electric motor starting, a fault occurring in the distribution grid, accidents in the power line, and energizing the transformers. The poor voltage quality directly affects the electric vehicle (EV) charging profile and battery life. A high-quality power supply is required for the proper functioning of the EV charging system. However, the voltage quality is one of the significant issues in the distribution grid. The proposed system is to reduce the impacts of voltage disturbance on EV batteries and charging systems by providing a dynamic voltage restorer (DVR) to enhance the voltage sag. It protects the EV batteries and charging system from the critical voltage sag levels.

A solar Photovoltaic (PV) array with backup battery energy storage (BES) and grid based EV charging station (CS) with voltage sag control is introduced to provide the uninterrupted charging in standalone, battery powered and grid connected mode. The charging station is mainly designed to work in solar PV array and a BES to charge the vehicle. The charging station automatically draws power from the grid due to the discharge of the storage battery and the lack of solar power. The goal is to ensure that the charging station has a constant and uninterrupted power supply. As a result, an automatic switching control is implemented. The controller will switch the energy source automatically based on the output parameters of the energy sources. As a result, the charging station ensures that the EV is charged continuously.

Contents

List of Tables

List of Figures

ABBREVIATIONS

EV	Electric vehicle
CS	Charging Station
PV	Photo Voltaic
BES	Battery Energy Storage
DC	Direct Current
INC	Incremental Conductance
MPPT	Maximum Power Point Tracking
SOC	State of charge
DCQC	Direct Current Quick Charging
DVR	Dynamic Voltage Restorer
PLL	Phase Locked Loop
LPF	Low Pass Filter
VCO	Voltage Control Oscillator

NOTATIONS

V	Voltage
I	Current
P	Power
L	Inductance
C	Capacitance
F_s	Switching Frequency
I_L	Load Current

Chapter 1

INTRODUCTION

1.1 GENERAL BACKGROUND

Electric vehicles (EVs) have come to be considered as one of the most commonly used transportation with zero emissions of gases. Three million EVs have already been introduced on the road due to their advantages, and by 2030, it is predicted that this number will reach 150 million [1]. Thus, a massive infrastructure of charging stations and a massive amount of electricity are needed for the planned plan's implementation. Only when the electrical energy needed for charging EVs is produced from renewable energy sources can EVs be considered sustainable. Therefore, using renewable energy sources to generate power can result in a reduction in emissions and other environmentally friendly advantages. The solar PV-based generation is the best among the several renewable energy sources now accessible, including solar PV arrays, wind energy, fuel cells, and hydro energy.

Thus, energy from renewable source charging stations are the best option for recharging electric vehicles; but, when they are integrated into the current charging system, an additional power conversion stage is introduced, increasing the system's complexity and power loss. Additionally, a unique controller is required for each conversion stage, and it must be integrated with the voltage control. As a result, it is crucial to create an integrated system with the ability to operate in several modes and functions, which requires unified control over all of the sources and close coordination between them.

EV charging stations rely on a stable power supply to charge the vehicle's battery. A voltage sag can disrupt the charging process, leading to interruptions or even complete cessation of charging. This can result in prolonged charging times or incomplete charging sessions. Voltage sags can impact the overall stability and reliability of the EV's electrical system. Sudden voltage drops can lead to unexpected behavior in electronic control systems, affecting safety-critical functions such as regenerative braking, traction control, or stability control [2]. This can compromise the safety of the vehicle and its occupants.

1.2 OBJECTIVES

- To Design a Dynamic Voltage Restorer (DVR) to reduce the voltage sag in the grid supply.

- To Design a reliable charging station with multiple energy sources with automatic changeover control.

- To study the analysis of PV array with different types of MPPT.

1.3 SCOPE

The renewable energy type of charging station are mainly considered for its optimization of charging cost, Size of the system, Charging schedule etc. The scope of an integrated energy source in a charging station revolves around the integration of renewable energy, energy independence, peak load management, cost savings, environmental benefits, and sustainability promotion. These features contribute to a more resilient, efficient, and environmentally friendly charging infrastructure for electric vehicles.

The scope of MPPT is essential for maximizing the energy yield and efficiency of PV systems, making it a crucial component in various applications such as residential solar installations, commercial and industrial rooftop systems, utility-scale solar farms, and off-grid systems.

A Dynamic Voltage Restorer (DVR) is a power quality device used to mitigate voltage sags, swells, and interruptions in electrical power systems. When it comes to EV charging stations, DVRs can play a significant role in maintaining stable and high-quality power supply during the charging process. The scope of the DVR extends to various industrial, commercial, and residential applications where voltage stability and power quality are critical.

1.4 THESIS OUTLINE

This work is to overcome the drawbacks of EV charging stations currently facing on the charging of EVs. Battery health is a crucial factor in the performance and longevity of electric vehicle (EV) batteries. Abnormal voltage conditions can significantly impact battery health and degrade its capacity, efficiency, and overall lifespan. This work is to minimize abnormal voltage conditions occurring in the grid supply by compensating with a dynamic voltage restorer to enhance battery longevity in electric vehicles. Normally stations with single power source are currently used in the charging stations. If the supply in the charging station fails, The charging of EVs is not reliable to the customers. So this work includes the multimode operation of energy sources in the charging station to provide an uninterrupted power supply in the charging of EVs. The report is organized in 6 chapters. Chapter 1 titled by Introduction includes general background, objective, scope and Thesis outline. Chapter 2 surveys the literature review done on the work. Chapter 3 titled by methodology used in the charging station. Chapter 4 includes the control methods. Chapter 5 shows the simulation model and test results. Chapter 6 is the conclusion of the proposed system.

Chapter 2

LITERATURE REVIEW

2.1 OVERVIEW

The development of a charging station powered by renewable energy has received a lot of attention. Cross-checking the behaviour of the grid-connected and islanded modes reveals that they are managed differently [1]. To regulate the mode of operation, there is no automatic mode switching offered. Therefore, without automatic mode switching and a change in the PV array's irradiance, electricity would be stopped and the EV won't be charged continuously. Zhang demonstrates the best placement of an EV charging station at a workplace with two charging options [3]. The premature life of a storage battery utilised with a commercial building-based solar PV array system has been studied by Kandasamy and Tseng [4]. For maximum solar PV array utilisation with little grid impact, Kineavy and M. Duffy have recommended using the on-site PV generated power (deployed on the commercial building) in cooperation with the EV charging station [5]. Saxena et al. have implemented a grid tied PV array system for EV and residential application [6]. Mouli et al. have utilized the solar power for charging of EVs using the high power bidirectional EV charger [7]. The designed charger, however, does not offer AC charging. The charger's current distortions in the grid current are not taken into account while it is being developed. The charger, however, is not intended to operate in the islanded mode. As a result, in the absence of a grid, it is unable to enable EV charging. A hybrid optimisation model has been discussed by Chaudhari et al. for managing the battery storage so that the operating costs of the charging station can be reduced and the solar PV array output is employed to the fullest extent possible [8]. The onsite deployment of the PV array-powered CS is also suited for the best service at the lowest cost while minimising the charge's impact on the grid. [9].

The electric vehicle (EV) charging system must have a high-quality power source in order to operate properly. However, one of the major problems with the distribution grid is the quality of the power. In order to improve the voltage quality, this article proposes a fault ride-through capability (FRTC) and examines the effects of voltage disturbance on EV batteries and charging systems [10]. A power quality issue is when voltage, current, or frequency in electrical equipment deviates from its ideal value. This includes a variety of disturbances in accordance with IEEE Standard 1159-2009. Voltage sag is one of the frequent issues with power quality [11]. Voltage sag, according to IEEE Standard, is a drop in voltage magnitude between 10% and 90% of the nominal voltage value, lasting 10 ms to 1 minute. The duration and magnitude of a voltage sag are two more categories [12]. The startup of a high induction motor on the customer's electric load and short circuit faults are just two examples of the many causes of voltage sag. Every 30 days, there is a voltage sag trend, with an average magnitude of 0.5 each sag [13]. An effective method for enhancing the voltage quality of delicate loads while making the best use of a dynamic voltage restorer (DVR)Traditional control methods mostly concentrate on the voltage compensation stage to lower the DVR's voltage rating or reduce the amount of energy storage device capacity needed [14]. Voltage sag, which is frequently affecting industrial power, is a phenomena that causes a temporary voltage drop from the nominal value. It obviously has a negative effect on industrial production. Installing an AC-AC converter that has been converted into a Dynamic Voltage Restorer (DVR) will solve this issue. In order to eliminate harmonic components and conserve battery power, this design employs an AC-AC converter [15].

2.2 STUDY ON CHARGING STATION INFRASTRUCTURE

EVs have been considered to be a key technology to cut down the massive greenhouse gas emissions from the transportation sector, and they are also expected to mitigate the fossil fuels scarcity problems [1]. The sales of EVs will reach 50 percentage of total sales of mobile vehicles by 2030.

The charging stations play an important role in providing charging services to EVs. Typically, there exist two different charging modes for conventional public chargers: i) AC Level II (charging power typically is 10-22 kW); and ii) Direct Current Quick Charging (DCQC) (charging power typically is 50-120 kW) is shown in Figure 2.1.

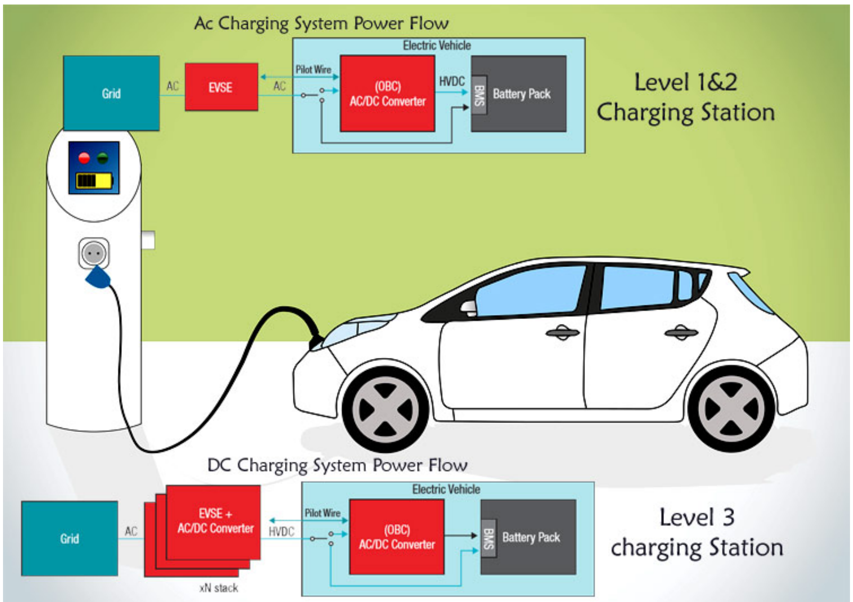

Figure 2.1: Schematic diagram of CS

Given the EV charging requirement, AC Level II has a longer charging duration while DCQC has a shorter charging duration, which may further reduce battery lifetime. Because of deployment cost concerns, both the number of charging stations and the number of chargers in charging stations are limited. How to use limited charging station resources to satisfy the various EV charging requirements has attracted attention, such as developing intelligent charging station architectures. To deal with the various EV charging requirements, the charging station can install two types of chargers, such as part of them with the AC Level II mode and part of them with the DCQC mode.

The selections of EV owners depend on several factors, i.e., service fee, charging duration, waiting time, etc . The charging station sholud also have the criterias like :

1. Compatibility: The charging station should support the charging standards and connector types compatible with your electric vehicle.

2. Sufficient Charging Power: The station should provide an adequate charging power level that suits your needs, whether it's fast charging for shorter stops or slower charging for longer stays.

3. Reliability: The charging station should be reliable, with a track record of minimal downtime and consistent performance.

4. Availability: Sufficient availability of charging stations is crucial to ensure you can find an open charging spot when needed, especially in high-demand areas.

5. Convenient Location: Charging stations should be conveniently located along your regular routes, in places like parking lots, shopping centers, or rest areas, to facilitate easy access and charging during your daily activities.

6. User-Friendly Interface: The charging station should have a user-friendly interface, clear instructions, and easy payment options for a seamless charging experience.

EV owners are price sensitive, we analyze the relationship between the service dropping rate and the service rate of the charging station and then design an optimal pricing scheme to guide and coordinate the charging processes of EVs, such that the number of EVs that leave the charging station without being charged can be minimized and the operation efficiency of the charging station can be improved.

2.3 STUDY ON SOLAR PANEL

Solar panels (also known as "PV panels") are used to convert light from the sun, which is composed of particles of energy called "photons", into electricity that can be used to power electrical loads. Solar panels collect clean renewable energy in the form of sunlight and convert that light into electricity which can then be used to provide power for electrical loads. Solar panels are comprised of several individual solar cells which are themselves composed of layers of silicon, phosphorous (which provides the negative charge), and boron (which provides the positive charge). Solar panels absorb the photons and in doing so initiate an electric current. The resulting energy generated from photons striking the surface of the solar panel allows electrons to be knocked out of their atomic orbits and released into the electric field generated by the solar cells which then pull these free electrons into a directional current. This entire process is known as the Photovoltaic Effect.

Every model of solar panel has unique performance characteristics which can be graphically represented in a chart. The graph is called an “I-V curve”, and it refers to the module’s output relationship between current (I) and voltage (V) under prevailing conditions of sunlight and temperature. From Ohm’s Law, Power = Voltage x Current, the result of reduced voltage is reduced power output. The ideal position on any V-I curve Figure 2.2. we can collect the most power from the module.

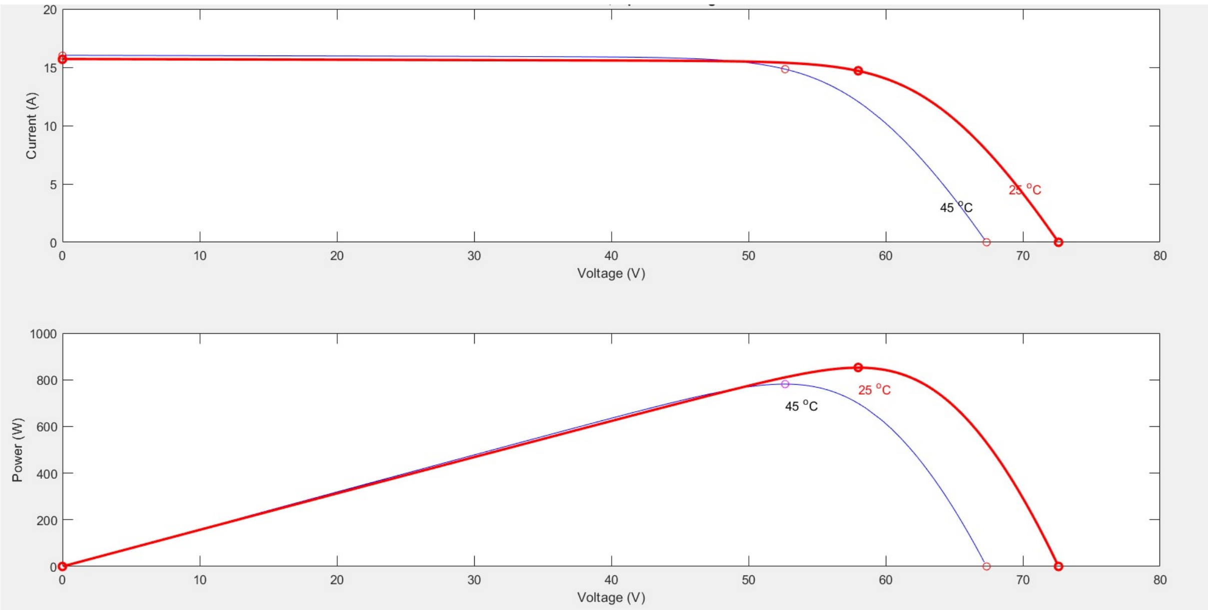

Figure 2.2: P-V and V-I characteristics of PV module

2.4 STUDY ON MPPT ALGORITHM

Maximum power point tracking (MPPT) is an algorithm implemented in photovoltaic (PV) inverters to continuously adjust the impedance seen by the solar array to keep the PV system operating at, or close to, the peak power point of the PV panel under varying conditions, like changing solar irradiance, temperature, and load.

Engineers developing solar inverters implement MPPT algorithms to maximize the power generated by PV systems. The algorithms control the voltage to ensure that the system operates at "maximum power point" (or peak voltage) on the power voltage curve. MPPT algorithms are typically used in the controller designs for PV systems. The algorithms account for factors such as variable irradiance (sunlight) and temperature to ensure that the PV system generates maximum power at all times. The most common MPPT algorithms are:

2.4.1 Perturbation and observation (P&O)

This algorithm perturbs the operating voltage to ensure maximum power. While there are several advanced and more optimized variants of this algorithm.

A drawback of P&O is that, at steady state, the operating point oscillates around the MPP giving rise to the waste of some amount of available energy [16]; moreover, it is well known that the

PO algorithm can be confused during those time intervals characterized by rapidly changing atmospheric conditions.

2.4.2 Multistep Perturbation and observation (MS P&O)

This algorithm increases or decreases the voltage until the maximum power point (MPP) is reached. Unlike with the PO algorithm, the voltage remains constant once MPP is reached.

The tracking speed, deviation in tracking and the accuracy of duty cycle value are taken into account while selecting the duty cycle values. The algorithm selects the step value depends upon the slope of the Voltage-Power curve. The slope value is considered as "error". The algorithm stops the perturbation and continue to use the duty cycle of previous step [17]. So the response of proposed MPPT algorithm is fast and effective corresponding the changes occur in the temperature.

2.4.3 Incremental conductance multistep MPPT

Multistep Incremental Conductance MPPT is an extension of the basic Incremental Conductance algorithm. Instead of perturbing the voltage in a single step, it uses multiple smaller steps. This allows for finer control and more precise tracking of the MPP, especially when the system operates near or in rapidly changing irradiance conditions. The advantage of the Incremental Conductance MPPT algorithm, including the multistep approach, is its ability to quickly track and maintain the MPP, maximizing the energy harvesting efficiency of PV systems [18]. However, it's important to note that the performance of MPPT algorithms can still be influenced by factors such as system design, parameter tuning, and response time.

2.5 STUDY ON LIFE OF SOLAR BATTERY

Off-grid Photovoltaic (PV) system along with battery storage is very effective solution for electrification in remote areas. However, battery capacity selection is the most challenging task in system designing. In this study, an off-grid PV system along with battery storage is designed. A battery is typically said to be at the end of its useful life when it fails to meet around 60% of its nominal storage capacity. The battery may still be able function at lower percentages, but it likely will not provide enough charge to meet your requirements.

Analysing loss of life of EV batteries used as storage energy system for solar PV system is essential to understand the impact on the drivability and the life time of EVs [3]. The more you cycle the battery, the shorter its lifespan.There are two primary types of solar batteries available on the market today: Lithium-Ion (Li-ion) and Lead Acid. A lead acid battery is typically the battery of choice for off-grid solar and storage systems, and can be found in both flooded (liquid electrolyte) or sealed AGM (Absorbed Glass Mat) styles. Lead acid batteries are less expensive than lithium ion batteries but have lower cycle lives before it reaches its estimated useful life.

2.6 STUDY ON LIFE OF EV BATTERY

The lifespan of an electric vehicle (EV) battery can vary based on several factors, including battery chemistry, usage patterns, environmental conditions, and charging practices. While it is challenging to provide an exact figure for the loss of life of an EV battery, The following criteria to be considered:

1. Battery Degradation: Over time, all lithium-ion batteries, which are commonly used in EVs, experience some level of degradation. Battery degradation is a natural process that leads to a gradual loss of capacity and performance. The rate of degradation depends on factors such as the battery's chemistry, temperature, depth of discharge, and charging patterns.

2. Depth of Discharge: Deep discharges (i.e., fully draining the battery) can accelerate battery degradation. It is generally recommended to avoid regularly depleting the battery to its lowest capacity and instead maintain a moderate state of charge between approximately 20% and 80%.

3. Charging Habits: Frequent use of fast charging, particularly high-power fast charging stations, can impact the battery's longevity. Charging at a slower rate, such as using Level 2 AC chargers, is generally less stressful on the battery and can help minimize degradation.

4. Temperature: Extreme temperatures, both hot and cold, can affect battery performance and lifespan. High temperatures can accelerate degradation, while very low temperatures can reduce the battery's efficiency and capacity temporarily. It is important to park or store the vehicle in a moderate temperature range whenever possible.

5. Battery Management Systems: Most EVs have sophisticated battery management systems (BMS) that actively monitor and control the battery's operating conditions. These systems

help optimize charging and discharging processes, balance individual cell voltages, and protect against overcharging or over-discharging, all of which contribute to prolonging battery life.

2.7 STUDY BASED ON BIDIRECTIONAL CONVERTER

A bidirectional DC-DC converter is a power electronic device that can transfer energy bidirectionally between two DC sources [19]. It can convert the voltage level of a DC power supply to match the requirements of a load or transfer energy back to the source. The working principle of a bidirectional DC-DC converter depends on the specific topology used, but the basic operation involves two main stages: the forward stage and the reverse stage.

1. Forward Stage: In the forward stage, the bidirectional converter operates as a buck or boost converter, depending on the voltage levels of the input and output sources. The forward stage is responsible for transferring power from the input source to the output load. Here's how it works:

Buck Mode: If the output voltage needs to be lower than the input voltage, the converter operates in the buck mode. It uses a power switch (typically a MOSFET) and an inductor to store and transfer energy. The switch is controlled using a pulse width modulation (PWM) signal. When the switch is on, energy is stored in the inductor, and when the switch is off, the inductor releases energy to the output. This process reduces the voltage and increases the current to match the load requirements.

Boost Mode: If the output voltage needs to be higher than the input voltage, the converter operates in the boost mode. Similar to the buck mode, it uses a power switch and an inductor, but the energy flow is reversed. When the switch is on, energy is stored in the inductor, and when the switch is off, the inductor releases energy to the output, resulting in an increased voltage and reduced current.

2. Reverse Stage: The reverse stage allows bidirectional power flow, enabling energy transfer back to the input source. This stage is achieved by using additional power switches and control mechanisms. It operates based on the concept of regenerative energy transfer. When the load produces excess energy or operates in a regenerative mode, the converter can transfer that energy back to the input source rather than dissipating it. The bidirectional DC-DC converter often incorporates control and feedback systems to maintain the desired voltage levels and reg-

ulate the power flow direction. These control systems monitor the input and output voltages, currents, and other parameters to ensure proper operation and prevent voltage/current spikes or instabilities.

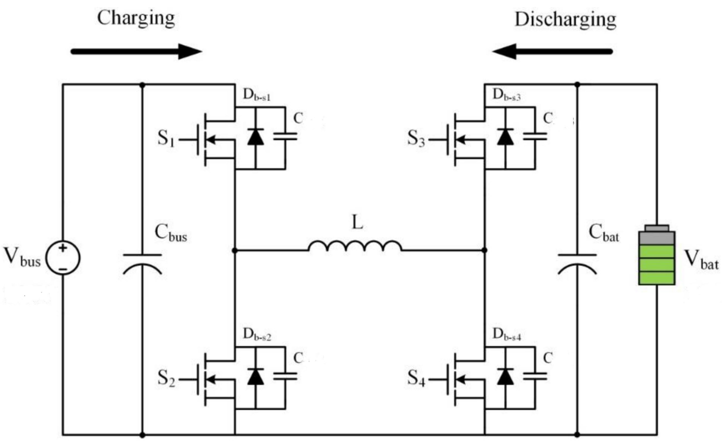

Figure 2.3: Bidirectional DC-DC Converter

Overall, the bidirectional DC-DC converter provides a flexible solution for power transfer between DC sources, allowing energy to be efficiently shared or balanced in various applications such as hybrid vehicles, renewable energy systems, energy storage systems, and more.

Charging electric vehicles (EVs) from photovoltaic panels (PV) provides a sustainable future for transportation.The EV port is designed to be isolated and bidirectional, so that both charging and vehicle-to-Grid (V2G) can be implemented [6]. As PV and EV are both DC by nature, the converter uses a central DC-link to exchange power between the EV and PV, thereby increasing efficiency. The use of silicon carbide devices and powdered alloy core inductors enables high switching frequency and power density. The closed-loop control allows four different power flows from PV to EV, EV to grid, grid to EV and PV to grid. Hence the converter operates as a PV inverter, a bidirectional EV charger and a combination of both. It has three times the power density and higher partial and peak load efficiency when compared to existing solutions.

The bidirectional, isolated DC/DC converter for the EV is composed of four interleaved flyback converters. MOSFETs and anti-parallel diodes are used on both sides of the transformer for bidirectional operation.

2.8 STUDY ON GRID CONNECTED CHARGING STATION

A grid-connected EV charging station refers to an electric vehicle charging infrastructure that is directly connected to the electrical grid. It allows electric vehicles to be charged by drawing power from the grid, providing convenient and efficient charging options for EV owners. A grid-connected charging station requires a reliable and sufficient power supply from the electrical grid. The charging station should be designed to handle the expected power demand, considering the number of EVs being charged simultaneously. The charging station energy management method that decreases load demand as well as load variations on the main distribution grid. The growing popularity of electric vehicles (EVs) and hybrid EVs necessitates the installation of more charging stations. The increased number of charging stations raises the power demand to a high level. This places an additional strain on the main supporting grid. Most notably, it increases load oscillations on the primary distribution grid .

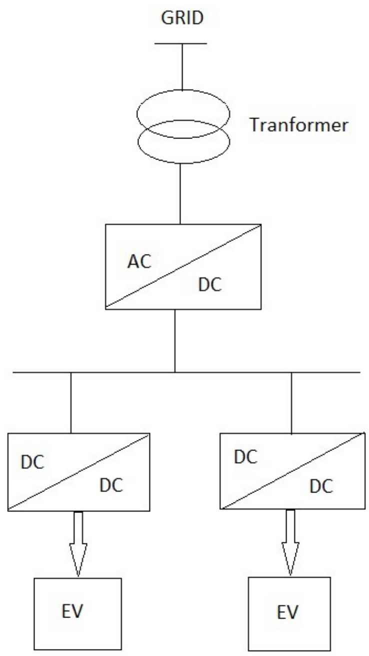

Figure 2.4: Schematic diagram of Grid connected charging station

The schematic diagram of proposed fast EV charging station is shown in Figure 2.4. As shown, the given architecture uses only one AC-DC Grid Tied converter to realize a DC bus, connecting the charging EVs through DC-DC converters. The DC bus makes it possible to connect Renewable Energy Sources (RESs) generation systems directly through a simple DC-DC converter. It is estimated that DC bus architecture reduces the overall conversion losses from about 32% to less than 10% when compared with the AC bus architecture.

2.9 STUDY ON VOLTAGE SAG IN GRID

Voltage sag is the most common power quality issue in the distribution system. A transient drop in voltage levels on the electrical grid is referred to as a voltage sag or dip as shown in Figure 2.5. It is characterised by an abrupt change in the load or disruptions in the power system, which often result in a considerable drop in voltage magnitude for a brief period. When there is a significant reduction in the voltage level during the charging process drop in voltage can have various causes and can impact the charging efficiency and performance.

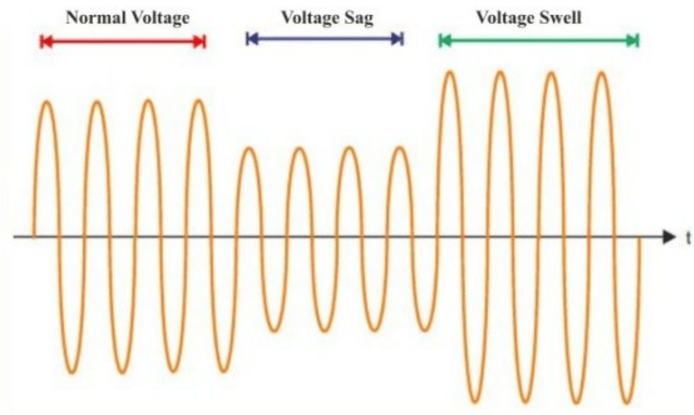

Figure 2.5: An Illustration of Voltage sag and Voltage swell.

It causes sensitive equipment such as medical equipments, PLCs, and electric vehicle (EV) charging stations to malfunction. Voltage sag influences the charge submission procedure for the car being charged in the event of EV charging. The following are some typical voltage sag sources and effects: Causes of Voltage Sag:

1. Faults or Short Circuits: A short circuit or fault in the power system can cause a sudden and significant increase in current, leading to voltage sags.

2. Starting Large Motors: When large induction motors start, they draw a high inrush current, causing a voltage sag.

3. Faulty Equipment Operation: Malfunctioning or faulty equipment, such as transformers or capacitor banks, can introduce voltage sags when they experience internal faults.

4. Lightning Strikes: Lightning strikes on power lines or nearby equipment can induce voltage sags.

2.10 STUDY ON DYNAMIC VOLTAGE RESTORER

A Dynamic Voltage Restorer (DVR) is a power electronic device used to mitigate voltage sags or dips in electrical power systems. It dynamically injects voltage into the system to compensate for the sag and restore the voltage at the point of connection. Here's an overview of the working principle of a DVR:

1. Sensing and Detection: The DVR continuously monitors the voltage waveform at its point of connection to the power system. It uses voltage sensors to detect voltage sags or dips below a predefined threshold. These sensors provide input to the control system of the DVR.

2. Voltage Sag Detection Algorithm: The control system of the DVR employs a voltage sag detection algorithm to analyze the incoming voltage waveform and determine the magnitude and duration of the sag. This information is crucial for generating the compensating voltage.

3. Energy Storage: The DVR utilizes energy storage devices, typically capacitors or batteries, to provide the necessary power during voltage sag compensation. The energy storage is charged and maintained at an appropriate voltage level to enable rapid response during a sag event.

4. Voltage Generation and Injection: When a voltage sag is detected, the control system of the DVR triggers the power electronics components to inject a compensating voltage into the system. The compensating voltage waveform is typically a series of voltage pulses generated by the DVR.

5. Voltage Pulse Generation: To generate the compensating voltage pulses, the DVR uses a combination of power electronic switches, such as insulated-gate bipolar transistors (IGBTs), and high-frequency pulse width modulation (PWM) techniques. The switches are controlled by the control system to regulate the voltage magnitude, frequency, and phase of the injected pulses.

6. Voltage Restoration: The compensating voltage pulses generated by the DVR are injected in series with the power system voltage at the point of connection. The injected pulses add up

with the sagging voltage, compensating for the voltage dip and restoring the voltage waveform to its nominal level.

7. Control and Coordination: The control system of the DVR continuously monitors the voltage at the point of connection and adjusts the compensating voltage pulses to maintain the desired voltage level. It coordinates with the power system to ensure seamless operation and avoid any interaction or disturbance between the DVR and the grid.

By injecting the compensating voltage, the DVR effectively mitigates voltage sags and provides a stable and continuous supply voltage to the loads connected downstream. This helps to protect sensitive equipment from malfunctions or interruptions caused by voltage sags and ensures the reliable operation of the power system.

2.11 SUMMARY

The current scenario of EV charging stations is witnessing significant growth and development in many regions worldwide. The adoption of electric vehicles has been increasing steadily, driven by environmental concerns, government incentives, and improvements in EV technology. This chapter discussed about the study and importance of renewable energy integration, energy storage systems, smart grid integration and voltage sag the previous works related to the working of solar panel, selection of batteries, charging stations with multiple energy sources and working of bidirectional dc dc converter. It also deals with the optimization and reliability of the charging station.

Chapter 3

METHODOLOGY

This chapter discusses about the block diagram of the proposed Charging station.

3.1 BLOCK DIAGRAM OF THE PROPOSED CHARGING STATION

The basic structure of the charging station is shown in figure 3.1, It consist of a solar PV array, battery energy storage and grid supply to charge the EV.

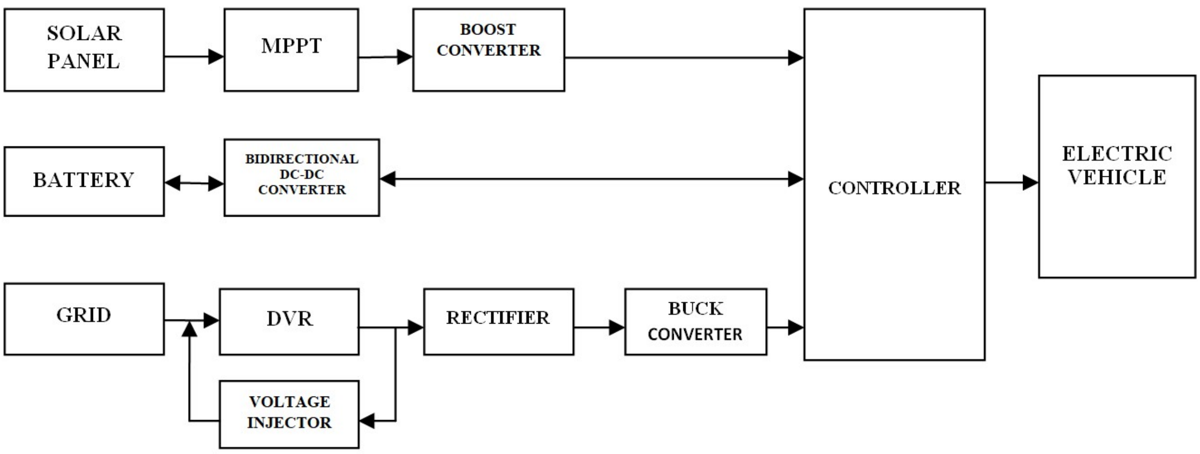

Figure 3.1: Block Diagram Of Charging Station

A solar panel with MPPT (Maximum Power Point Tracking) is connected through a boost converter and a battery energy storage with bidirectional DC-DC converter and a grid supply with DVR system is connected in the charging station. The grid is used as a backup source even if the solar energy and battery energy are failed to deliver power to the charging station. The alternating current from the grid is converted into DC signal with the help of a full bridge rectifier and then converted into the required voltage level through a buck down converter. As the system is entirely a constant DC supply system the charging station does not require any synchronizing circuits. An AND gate logic control switch is used for controlled connection and disconnection of each energy sources into the charging station depending on the source parameters.

Primarily the CS delivers power from the solar array. At the same time the battery is also charged through the bidirectional dc-dc converter. In the absence of solar power the CS is switched to battery mode. If these two sources fails, the CS will switched to Grid supply. The Dynamic Voltage Restorer system consist of a AC-AC converter. The controller detects the voltage sag by comparing the reference voltage and sag level voltage. The change in voltage sag level determines the switching of injection voltage to the grid supply. So whenever a voltage sag is occurred in the grid supply, The DVR injects voltage to the grid supply. These injection voltage will helps to maintain the voltage level constant in the charging station.

3.2 DESIGN OF PV MODULE

Solar panels contain photovoltaic cells, which are constructed of semiconductors (such as silicon) and convert sunlight into electricity. When light strikes the cells, electrons are separated from their atoms and travel through the cell, causing electricity to be generated.At the top of the atmosphere, the quantity of energy striking the planet from the sun is around 1,370W/m2 (watts per square metre). This is the irradiation of the sun. The value at the earth's surface varies around the world, but on a clear day, the maximum observed at sea level is roughly 1,000W/m2. The loss is caused by some of the sunlight's energy being absorbed by the atmosphere on its journey down.

The amount of electrical output a solar panel can give for the amount of solar radiation falling on it per metre square is referred to as its efficiency. The temperature of the solar panels has a significant impact on their output. The temperature of the solar panels is determined by the ambient temperature and the temperature coefficient of the panels.

The temperature coefficient describes the rate at which power declines with each degree increase in temperature. The solar panels' temperature coefficient ranges between 0 and 0.5%. The higher the power output, the closer the value is to 0. The temperature of the solar panels is also affected by their installation. All of the solar panels have a temperature rating of 25°C . However, the temperature outside might rise much higher. The equivalent circuit for simplified model of PV cell is shown in Figue 3.2. It consists of a current source I_{pv}, diode(D), and series resistor R_s connected.

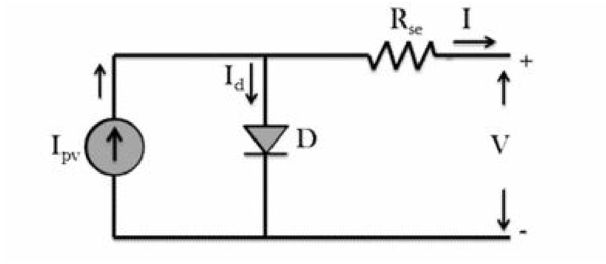

Figure 3.2: Equivalent Circuit of PV Cell

The equation for output current is as follows [20]

$$I = I_{pv} - I_d \tag{3.1}$$

Equation 3.1 can re-written as

$$I = I_{pv} - I_s \left\{ \exp\left(\frac{q}{AkT_cN_s} V + IR_{se} \right) - 1 \right\} \tag{3.2}$$

where,

$$I_{pv} = [I_{sc} + K_l (T_c - T_r)] \cdot G \tag{3.3}$$

$$I_s = I_{rs} \left(\frac{T_c}{T_r} \right)^3 \exp\left[\frac{qE_g}{A_k} \left(\frac{1}{T_c} - \frac{1}{T_r} \right) \right] \tag{3.4}$$

$$I_{rs} = \frac{I_{sc}}{\exp\left(\frac{q}{AkT_{c(n)}N_s} V_{oc} \right) - 1} \tag{3.5}$$

The output current (I) equation 3.2 is derived by applying Kirchhoffs law in the equivalent circuit.The general model of the PV cell has a parallel resistor R_p in the circuit which is connected across the diode. The value of parallel resistance is very high and thus it is generally neglected in modeling the PV cell. Modeling and simulation of PV module using simple blocks is presented in[21]. This model is very primitive, and the user has to change to parameters inside the blocks of the model in order to analyze different PV modules. Therefore, the possibilities of error in feeding the data are high.

Table 3.1: Specification of solar panel

SPECIFICATIONS	RATING
Peak power	248 W
Cells per module	60 No.s
Open circuit Voltage	38.4 V
Short circuit current	8.85 A
Voltage at MPP	30.7 V
Current at MPP	8.11 A
Parallel Strings	2
Series modules per Strings	2

3.3 INCREMENTAL CONDUCTANCE MULTISTEP MPPT

The Incremental Conductance Multistep Maximum Power Point Tracking (MPPT) algorithm is a method used in photovoltaic systems to maximize the power output from the solar panels. It is an improved version of the Incremental Conductance (IncCond) MPPT algorithm, which is widely used in solar PV systems.

The basic principle of the Incremental Conductance algorithm is to continuously track the maximum power point (MPP) of the solar panels by adjusting the operating voltage or current. The algorithm uses the instantaneous change in conductance (dI/dV) of the solar panel to determine whether the operating point is on the left or right of the MPP.

When the irradiance changes, the current and voltage will be affected accordingly. The Incremental Conductance algorithm suffers from a drawback called oscillation, where the algorithm may continually switch between two nearby points around the MPP without settling down to the exact MPP. This oscillation occurs when the solar panel's voltage and current are close to each other, making it difficult for the algorithm to determine the direction to adjust.

To overcome the oscillation issue, the Incremental Conductance Multistep algorithm adds additional steps to the original algorithm. Instead of making small voltage or current adjustments at each iteration, the multistep algorithm introduces larger voltage or current steps. These steps help the algorithm quickly move away from the vicinity of the MPP, reducing the chances of oscillation[22].

Here is a general outline of the Incremental Conductance Multistep MPPT algorithm:

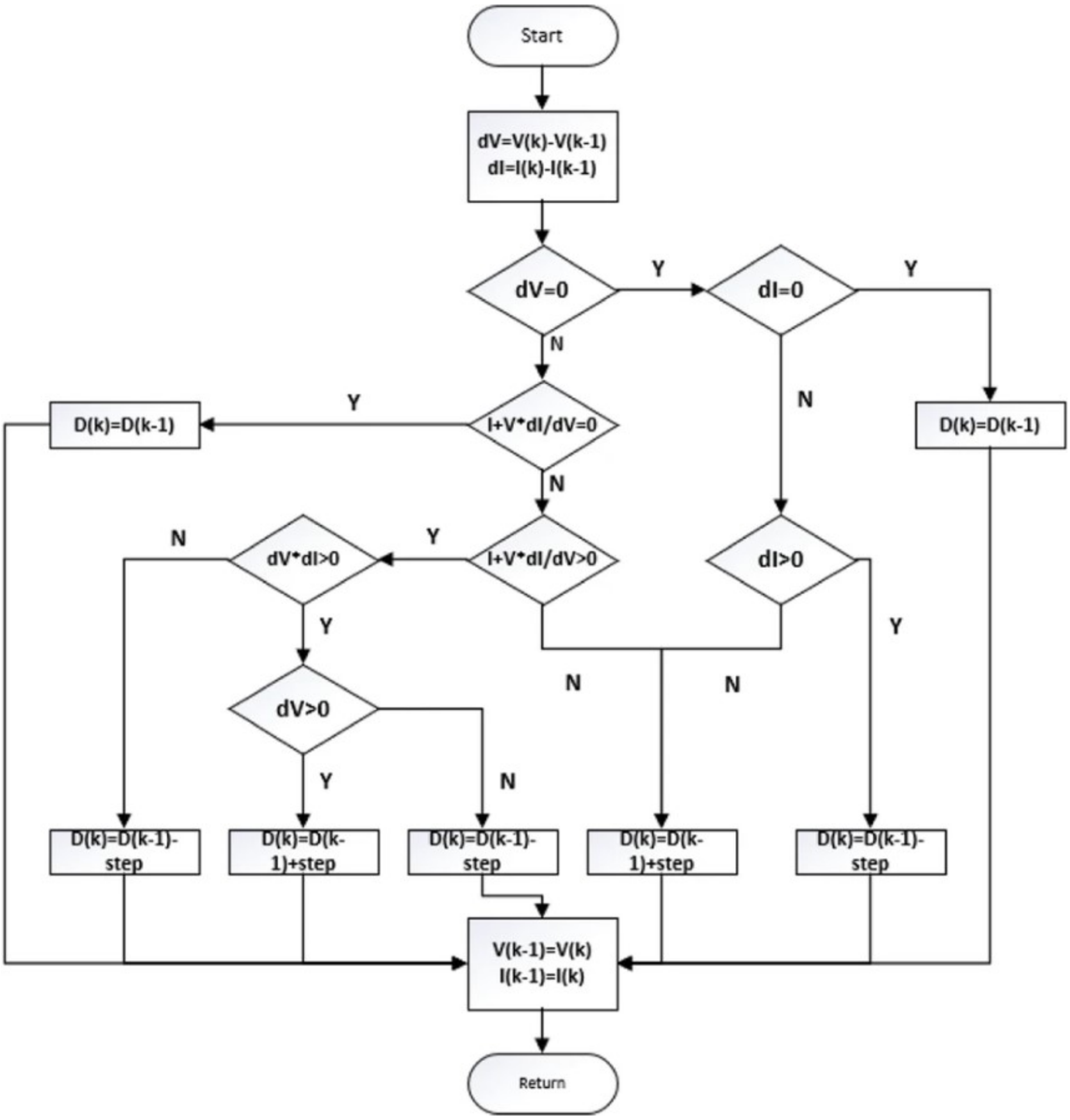

Figure 3.3: Flowchart of InC MPPT Algorithm

1. Measure the voltage and current of the solar panel.

2. Calculate the conductance (G) of the solar panel using the following formula: G = dI/dV = (I * dV/dt) / (V * dI/dt), where I is the current, V is the voltage, and dt is the sampling time.

3. Determine the direction to adjust the operating point:

If G > 0, the operating point is to the left of the MPP, so increase the voltage or decrease the current.

If G < 0, the operating point is to the right of the MPP, so decrease the voltage or increase the current.

4. Apply a voltage or current step to adjust the operating point. The step size depends on the proximity to the MPP and the desired speed of convergence.

5. Repeat steps 1-4 continuously to track the MPP as solar conditions change.

6. Monitor the power output of the solar panels and check if it is increasing or decreasing. If the power output decreases, the algorithm may have overshot the MPP. In such cases, reduce the step size for finer adjustments.

7. Periodically check for sudden changes in solar conditions (e.g., due to clouds) and adjust the step size accordingly for faster response.

The Incremental Conductance Multistep MPPT algorithm is known for its effectiveness in tracking the MPP under varying solar irradiance and temperature conditions. However, it is important to calibrate the algorithm parameters and fine-tune the step size to optimize its performance for a specific PV system and environmental conditions. From the figure 3.4 the following equations

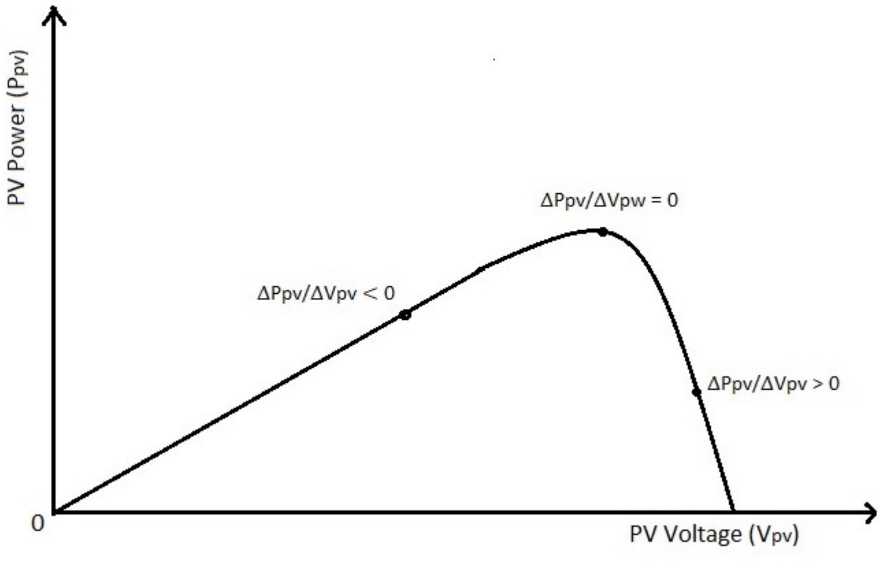

Figure 3.4: Voltage-Power Characteristics of PV Module

are derived

$$I_{pv} + V_{m\pi}\frac{\Delta I_{pv}}{\Delta V_{pw}} = 0 \text{ or } \frac{\Delta I_{w}}{\Delta V_{pv}} = 0 \text{ at the MPP [4]} \quad (3.6)$$

$$I_{pv} + V_{pv}\frac{\Delta I_{pv}}{\Delta V_{pv}} > 0 \text{ or } \frac{\Delta I_{pw}}{\Delta V_{pw}} > 0 \text{ at the left side of MPP} \quad (3.7)$$

$$I_{pv} + V_{pv}\frac{\Delta I_{pv}}{\Delta V_{pv}} < 0 \text{ or } \frac{\Delta I_{pw}}{\Delta V_{pw}} < 0 \text{ at the right side of MPP} \quad (3.8)$$

The InC MPPT works based on the change in the PV power M_{pv} and the PV voltage V_{pv} to compute MPP[22]. The IC algorithm shown in figure 3.5 was designed to control the duty cycle of Buck Boost converter and to ensure the MPPT work at its maximum efficiency. The system performance of IC algorithm was compared to widely used algorithm - Perturb and Observe (P&O) on a Simulink environment. From the simulation, the IC method shows a better performance and also has a lower oscillation.

The 2 phase Incremental Boost Converter (IBC) is made up by connecting two conventional converters in parallel. The current between inductor L_1 and L_2 are 180 degree out of phase. The input current ripple is very less since it is the average of inductor current. As the switches are operated with 180 degree phase shift between each other the input current ripple is cancelled with each, In theoretically the input current ripple is zero when the duty cycle (D) of the converter is 50%.

The converter circuit is designed for V_{in} = 60V, V_{out} = 96V, and I_o = 10.16A.

The important components of the circuit are inductors (L_l, L_2) and capacitor(C).

3.4 BOOST CONVERTER

A boost converter is one of the simplest types of switch mode converter is shown in Figure 3.5. As the name suggests, it takes an input dc voltage and boosts the voltage level. It it consists of an inductor, a semiconductor switch (MOSFET), a diode, and a capacitor.The key principle that drives the boost converter is the tendency of an inductor to resist changes in current by either increasing or decreasing the energy stored in the inductor magnetic field. In a boost converter, the output voltage is always higher than the input voltage. The control of this stage is composed of the MPPT and the PWM modulator that transfers the MPPT signal to gating pulses for the boost converter.

3.4.1 Working Principle

When the switch is closed (on-state), current flows through the inductor in the clockwise direction and the inductor stores some energy by generating a magnetic field. Polarity of the left side of the inductor is positive.

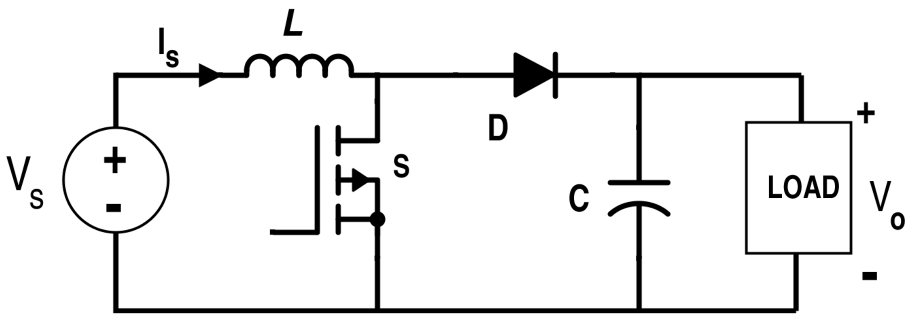

Figure 3.5: Boost Converter

When the switch is opened (off-state), current will be reduced as the impedance is higher. The magnetic field previously created will be reduced in energy to maintain the current towards the load. Thus the polarity will be reversed. As a result, two sources will be in series causing a higher voltage to charge the capacitor through the diode D.

3.4.2 Boost Converter Design

$$V_{in} = 60V$$
$$V_{out} = 96V$$
$$f_s = 20KHz$$
$$Power = 1KW$$

1. Capacitor selection

$$C = \frac{I_0 * D}{f_s * V_c} = 203.3\mu F \tag{3.9}$$

2. Inductor selection

$$L = \frac{V_{\text{in}} * D}{f_S * I_L} = 225\mu H \tag{3.10}$$

$$\text{Duty ratio } = 1 - \frac{V_{in}}{V_0} = 0.375 \tag{3.11}$$

Table 3.2: Specification of boost converter

SPECIFICATIONS	RATING
Input voltage	60V
Output voltage	96V
Output power	1000W
Switching frequency	20 KHz
Capacitor	203.3 μF
Inductor	225μH
Load	9.21 Ω

3.4.3 Bidirectional Converter Design

Design of Bidirectional Converter (boost mode).

$$V_{in} = 60V$$
$$V_{out} = 96V,$$
$$Frequency f_s = 20KHz,$$
$$Power = 1KW$$

1. Inductor selection

$$L = \frac{V_{\text{in}} * D}{f_S * I_L} = 225\mu H \tag{3.12}$$

$$P = \frac{V^2}{R} \tag{3.13}$$

Design of Bidirectional Converter (buck mode).

$$\begin{aligned} V_{in} &= 96V, \\ V_{out} &= 67.2V, \\ Frequency f_s &= 20KHz, \\ Power &= 1KW \end{aligned} \tag{3.14}$$

1. Inductor selection

$$L = \frac{V_{\text{in}} * D}{f_S * I_L} = 182\mu H \tag{3.15}$$

Table 3.3: Specification of buck converter

SPECIFICATIONS	RATING
Input voltage	96V
Output voltage	67.2V
Switching frequency	20 KHz
Inductor	$182\mu H$

3.5 BATTERY SELECTION

The best battery for solar installation is a lithium ion battery.They are able to hold more energy in a small amount of space, discharge most of their stored energy, and they have high efficiencies. Also, because these are the most common, many solar companies will be able to install a lithium ion solar battery both accurately and safely.Lithium ion batteries are maintenance free batteries.They also have a higher battery energy density, meaning they can hold more energy in a smaller space than a lead acid battery.

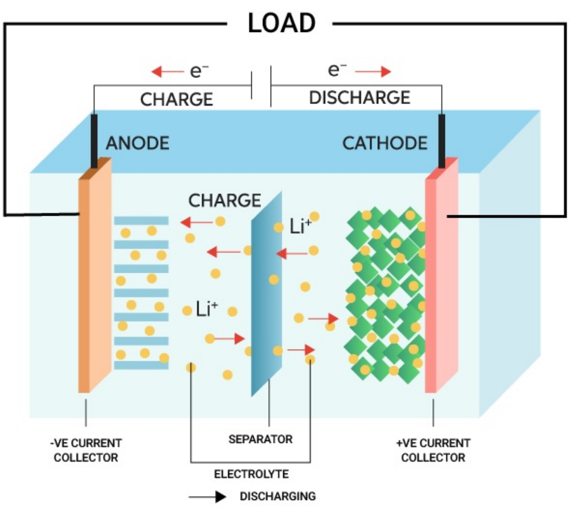

Figure 3.6: Components of Lithium-ion Battery

Lithium ion batteries have a longer life cycle, or lifespan, as well - most have a guaranteed warranty of at least 10 years. This longer lifespan has to do with lithium ion batteries having a higher depth of discharge, so you can use more of the energy stored within the battery before it has to be recharged.

The fig 3.6 shows the components of a Li-ion battery. It consist of an Anode and cathode which stores the lithium and the electrolyte carries positively charged lithium ions from the anode to the cathode and vice versa through the separator. When the battery is discharging and providing an electric current, the anode releases lithium ions to the cathode, generating a flow of electrons from one side to the other. When plugging in the device, the opposite happens: Lithium ions are released by the cathode and received by the anode.

3.6 INTERLEAVED BIDIRECTIONAL DC-DC CONVERTER

An interleaved bidirectional DC-DC converter is a power electronic circuit designed to transfer energy bi-directionally between two DC power sources is shown in Figure 3.7. It is commonly used in applications such as energy storage systems, electric vehicles, and renewable energy systems. This converter allows efficient power transfer in both directions while reducing voltage ripple and current stress on components. This type of converter nowadays is mainly used in electric vehicles. It is also called a Half-Bridge DC-DC converter. When the Buck and the boost converters are connected in antiparallel across each other with the resulting circuit is primarily having the same structure as the basic Boost and Buck structure but with the combined feature of bidirectional power flow is called Bi directional DC-DC converter.

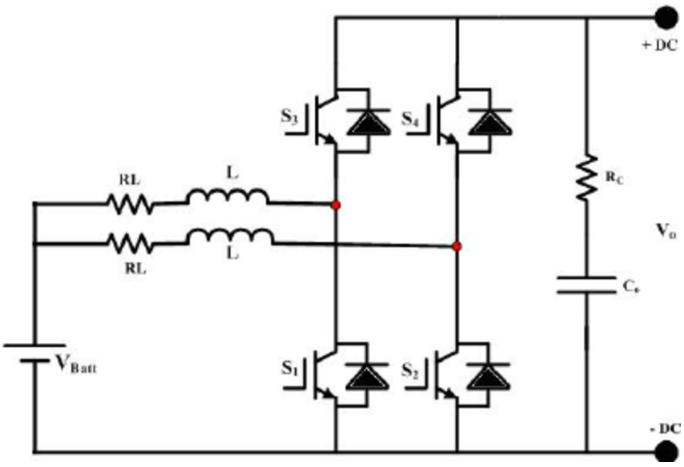

Figure 3.7: Bidirectional DC-DC converter

3.6.1 Working Principle

The DC/DC converter used in this paper consists of two power modules connected in parallel as shown in Figure 3.7. Drive signals of the two modules are shifted by 180° to ensure interleaving of inductor currents over a switching period. The power rating of the used switches is reduced due to sharing the battery current between converter modules. There are two modes of operation of the bidirectional DC/DC converter.

3.6.2 Mode of Operation

1. Charging/Boosting Mode: In the charging or boosting mode, power flows from the input source to the output source. The switches in each module are synchronized such that only one module conducts at a time, while the others remain off. This interleaved operation helps reduce voltage ripple and current stress. The control circuitry monitors the input and output voltages and adjusts the duty cycle of the switching signals to regulate the output voltage at the desired level.

2. Discharging/Bucking Mode: In the discharging or bucking mode, power flows from the output source to the input source. Similar to the charging mode, the control circuitry ensures interleaved operation, with only one module conducting at a time. The control circuitry monitors the input and output voltages and adjusts the duty cycle of the switching signals to regulate the output voltage and control the power flow from the output to the input source.

3.7 DYNAMIC VOLTAGE RESTORER

In the context of a Dynamic Voltage Restorer (DVR) [23], a Phase-Locked Loop (PLL) is used to synchronize the device's output voltage with the utility grid's voltage. The PLL in a DVR helps to maintain accurate voltage injection and ensures effective voltage restoration is shown in Figure 3.8. Here's a simplified explanation of how a PLL is used in a DVR:

1. Grid Voltage Monitoring: The DVR continuously monitors the voltage of the utility grid to detect any disturbances or voltage sags.

2. Voltage Reference: The DVR has a reference voltage that represents the desired output voltage. This reference voltage is typically set to the nominal voltage level of the grid.

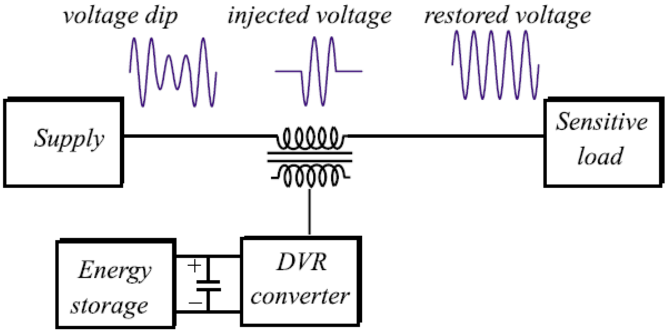

Figure 3.8: Block diagram of DVR

3. Phase Detector: The phase detector in the PLL compares the phase of the grid voltage with the phase of the reference voltage. It determines the phase difference between the two signals.

4. Voltage-Controlled Oscillator (VCO): The VCO generates an oscillating signal whose frequency is proportional to the phase difference detected by the phase detector. The VCO output is used as the output voltage of the DVR.

5. Voltage Injection: Based on the phase difference between the grid voltage and the reference voltage, the DVR injects a compensating voltage into the grid to mitigate voltage sags or disturbances. The VCO output voltage is used as a control signal to generate the compensating voltage.

6. Phase Locking: The PLL continuously adjusts the frequency and phase of the VCO to minimize the phase difference between the grid voltage and the reference voltage. This process is known as phase locking. The PLL ensures that the output voltage of the DVR is synchronized with the grid voltage, providing effective voltage restoration.

The use of a PLL in a DVR helps to achieve accurate and synchronized voltage restoration. By continuously monitoring the grid voltage and adjusting the output voltage accordingly, the DVR can inject the necessary compensating voltage to mitigate voltage sags and maintain stable and reliable power supply to connected loads.

3.7.1 Block Diagram and Working of PLL

The Figure 3.9 represents the block diagram of a PLL circuit. The operation of a PLL can be summarized in the following steps:

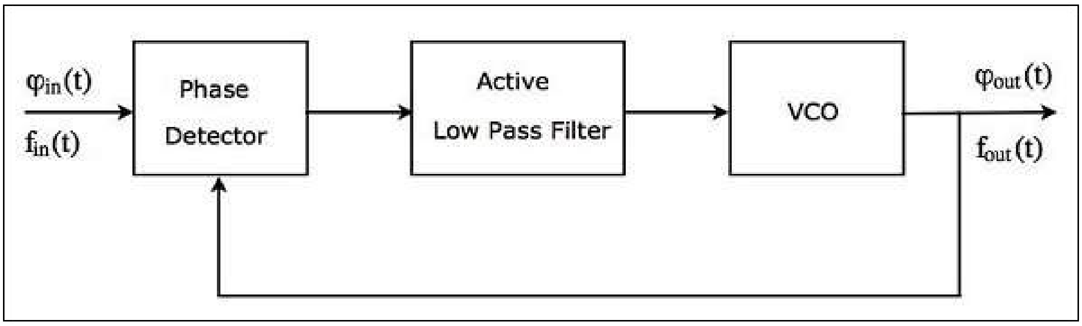

Figure 3.9: Block diagram of PLL

1. The input signal is compared with the feedback signal in the phase detector, generating an error signal.

2. The error signal is filtered by the low-pass filter to remove high-frequency components, resulting in a control voltage.

3. The control voltage is applied to the VCO, which generates an output signal with a frequency proportional to the control voltage.

4. The output signal is fed back to the phase detector, completing the feedback loop.

As the PLL operates, the feedback loop adjusts the VCO's frequency to minimize the phase difference between the input and output signals [24]. Once locked, the output signal of the PLL will have a fixed phase relationship with the input signal.

3.8 SUMMARY

The methodology used in EV charging stations involves a structured approach to designing, implementing, and managing the charging infrastructure to provide efficient and reliable electric vehicle charging services. This chapter deals with methodology used for the design of EV charging station with voltage sag control. Designed a DVR, solar array, boost converter, MPPT, bidirectional DC-DC converter and grid power. The next chapter deals with the control method for switching each energy sources depending the source parameters and control method of DVR for voltage sag control in grid supply.

Chapter 4

CONTROL METHODS

4.1 CONTROL OF CS IN ISLANDED MODE

The islanded control of the CS ensures the stable operation in solar mode. So primarily the charging station delivers power from the solar array. The DC charging and the solar PV generation can be managed by the storage battery without much modification in the control. The MPPT provides the maximum power to the charging station by tracking the maximum power point from the solar array.

On day time the charging station delivers power from the solar array for charging EVs is shown in Figure 4.1. The storage battery is charged by solar energy through the inlerleaved bidirectional dc-dc converter in charging/buck mode and discharges when the availibility of power from the PV is not sufficient.

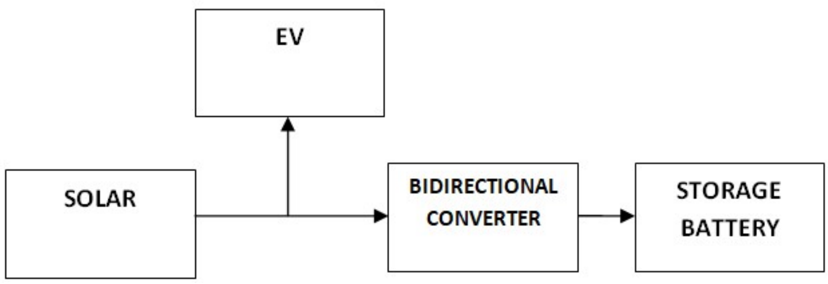

Figure 4.1: Charging Station in Solar mode

4.2 CONTROL OF CS IN BATTERY MODE

The change in irradiance and unavailability of sun light will affect the continuous supply in the charging station. A storage battery backup supply is provided for the constant supply in the charging station is shown in Figure 4.2. For the automatic switching control, Irradiance value is taken as the reference value.

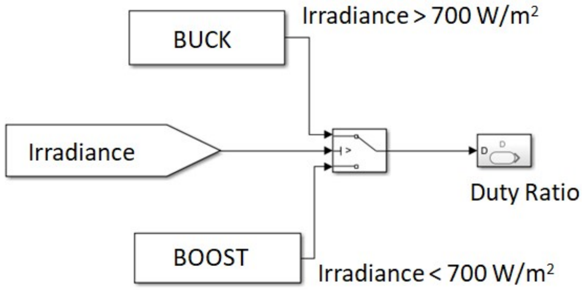

Figure 4.2: Charging Station in Battery mode

The switching is done by comparing the solar irradiance, when the irradiance is less than 700 w/m the control switch will be turned ON to battery mode. At this time the bidirectional converter will act as a boost converter, providing power to the charging station. When the irradiance is greater than 700 w/m the bidirectional converter will act as a buck converter

4.3 CONTROL OF CS IN GRID MODE

The change in irradiance and unavailability of sun light will affect the continuous supply in the charging station. A grid backup supply is provided for the constant supply in the charging station. For the automatic switching control we are using an AND gate logic control.

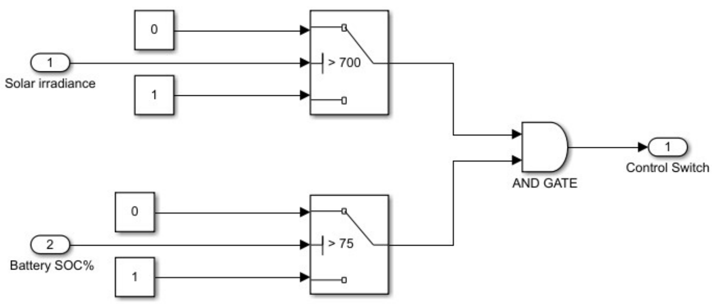

Figure 4.3: CS in Grid mode

The switching is done by comparing the solar irradiance and battery SOC level of less than 700 w/m and less than 75% respectively with an AND logic circuit is shown in figure 4.3. When the PV and Battery is not sufficient to supply power, The AND logic gives as output of high (logic 1) as shown in figure 4.3. The logic 1 will turn ON the control switch to the grid mode. At this time the battery will not be charged as a part of optimisation to reduce the running cost of the charging station.

4.4 CONTROL OF DVR IN GRID MODE

A Phase-Locked Loop (PLL) is used to synchronize the phase of an output signal with the phase of a reference signal. The DVR has a reference voltage that represents the desired output voltage which is a standard grid voltage of 230V. The PLL compares the phase of the grid voltage with reference voltage to determine the phase difference between the two signals.

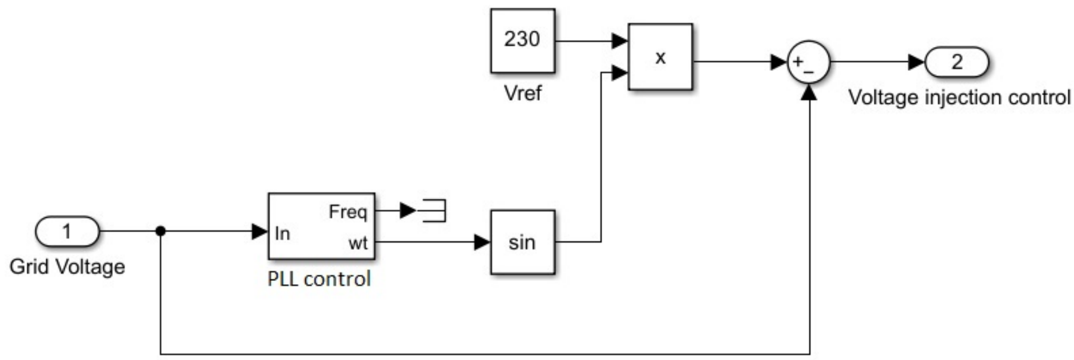

Figure 4.4: DVR control

Based on the phase difference between the two signals the DVR injects a compensating voltage (equation 4.1) into the grid to mitigate voltage sags is shown in Figure 4.4.

$$V_{injection} = V_{source} - V_{load} \tag{4.1}$$

PLL ensures that the output voltage of the DVR is synchronized with the grid voltage, providing effective voltage restoration.

4.5 SUMMARY

EV (Electric Vehicle) charging control refers to the management and regulation of the charging process for electric vehicles. It involves various technologies and strategies to optimize the charging process, improve grid stability. This chapter deals with the control strategies of EV charging station with voltage sag control and different mode of operation of different sources. Design of DVR for grid voltage sag control and design of controller for the changeover from one energy source to another is discussed in this chapter. The next chapter deals with the simulation results of charging station.

Chapter 5

SIMULATION MODEL AND RESULTS

This chapter deals with the MATLAB simulation model and results of the proposed charging station. The proposed CS simulation model is shown in Figure 5.1.

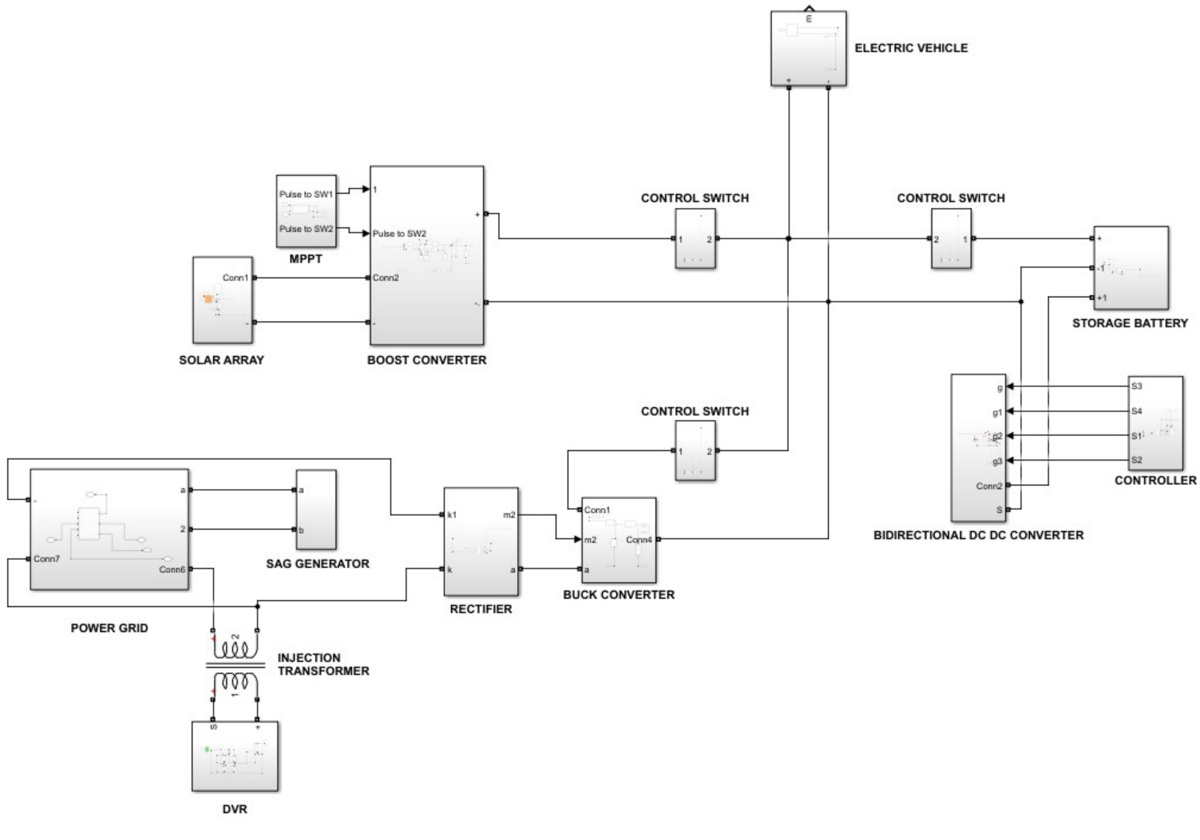

Figure 5.1: Simulation model of the charging station

The charging station includes three different enrgy sources of Solar, Battery storage system and Grid supply with voltage sag control. results of the charging station. The charging station performance is tested under three different conditions of the energy sources.

5.1 SIMULATION RESULT OF DVR

The performane of DVR in matlab simulation is shown below. The simulated result shows that the voltage sag occurred in the grid supply is compensated with the injection voltage applied to the grid supply.

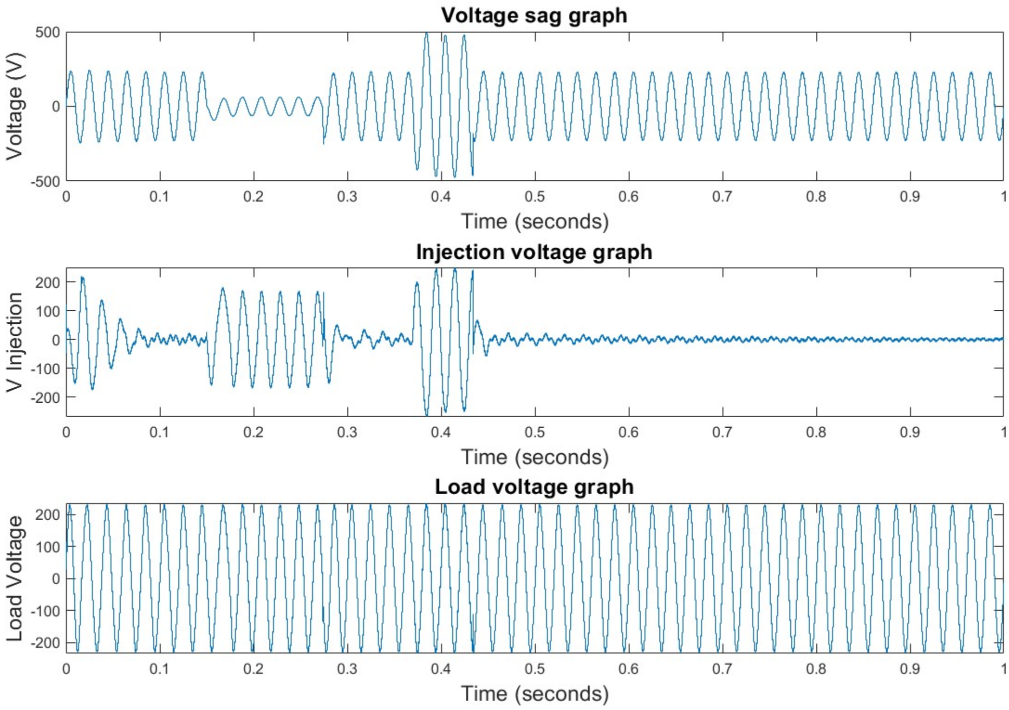

Figure 5.2: Performance of DVR in Grid supply

A Single phase voltage sag compensation is simulated for a duration of 0.18s to 0.28s with voltage sag and 0.38s to 0.42s with voltage swell is shown in figure 5.1. A 50% voltage sag of the normal value means the line voltage value is 110 V_{rms} during fault as shown in Figure 5.1. The load needs 110 V_{rms} additional supply. So, the converter only produces 120 V_{rms} , after passing through the coupling transformer it becomes 120 V_{rms}. Thus, the load voltage is constant at 230 V_{rms}.

5.2 PERFORMANCE OF SOLAR PANEL

The performance of solar panel in matlab simulation is shown below. The simulated result shows the output voltage of the solar panel with 1000 w/m irradiance and 25°C temperature produces an output voltage of 60V DC supply.

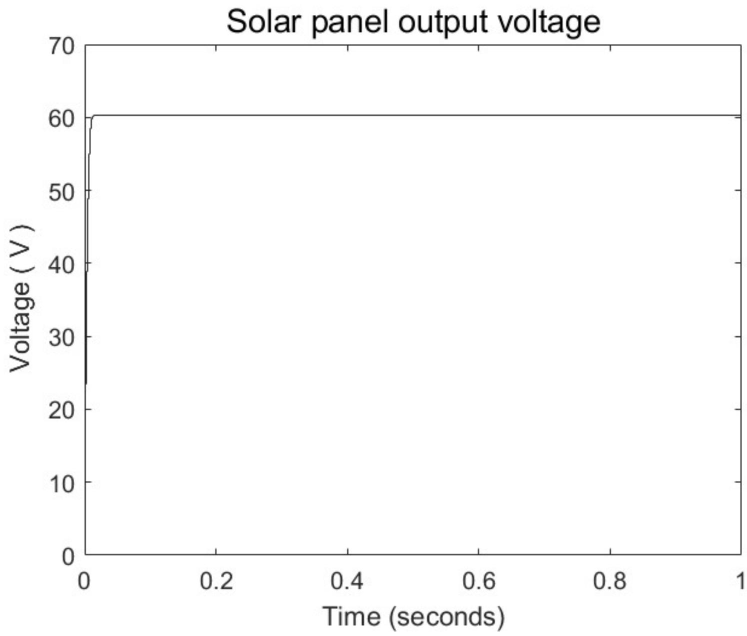

Figure 5.3: Output voltage of solar panel

The figure 5.2 shows the output voltage of solar panel with 60V output. The designed solar panel is having a load capacity of 1KW. As the panel is under default set parameters there output will be a pure DC supply. The change in irradiance leads to fluctuations in the DC signal. The figure 5.3 shows the output power of solar panel with a load capacity of 1000 Watts

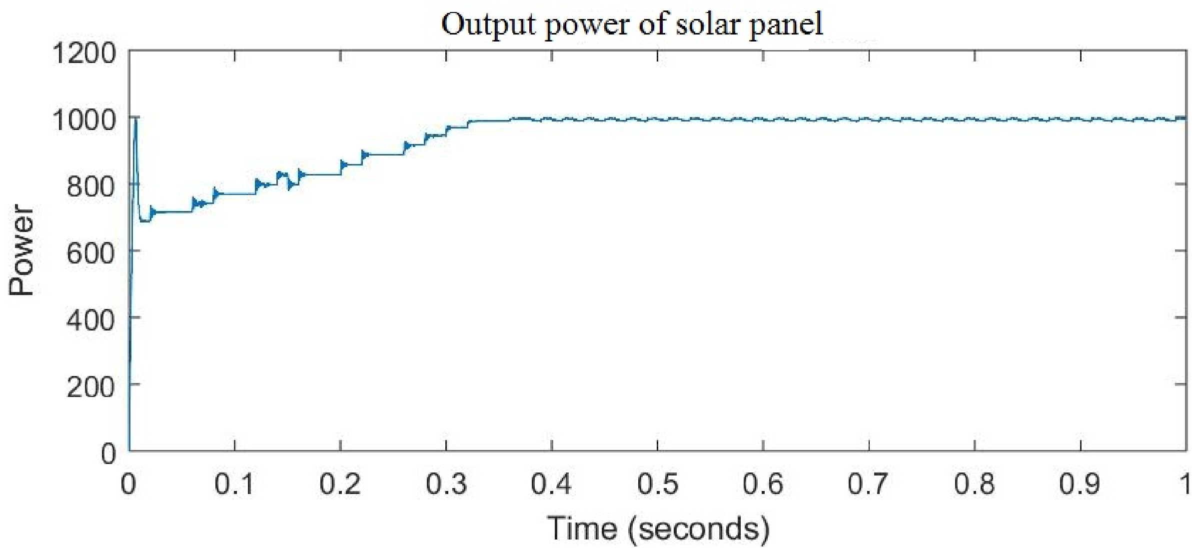

Figure 5.4: Output power of solar panel

output. The power of a solar cell is the product of the voltage across the solar cell times the current through the solar cell.

5.3 DUTY RATIO COMPARISON OF MPPT's

In this work, Three types of MPPT are used for the performance analysis. The main duty of an MPPT controller is to ensure that the solar panel operates at its MPP as much as possible. By extracting the maximum available power from the panel, the MPPT controller increases the overall energy efficiency of the solar power system and maximizes the amount of electricity generated.

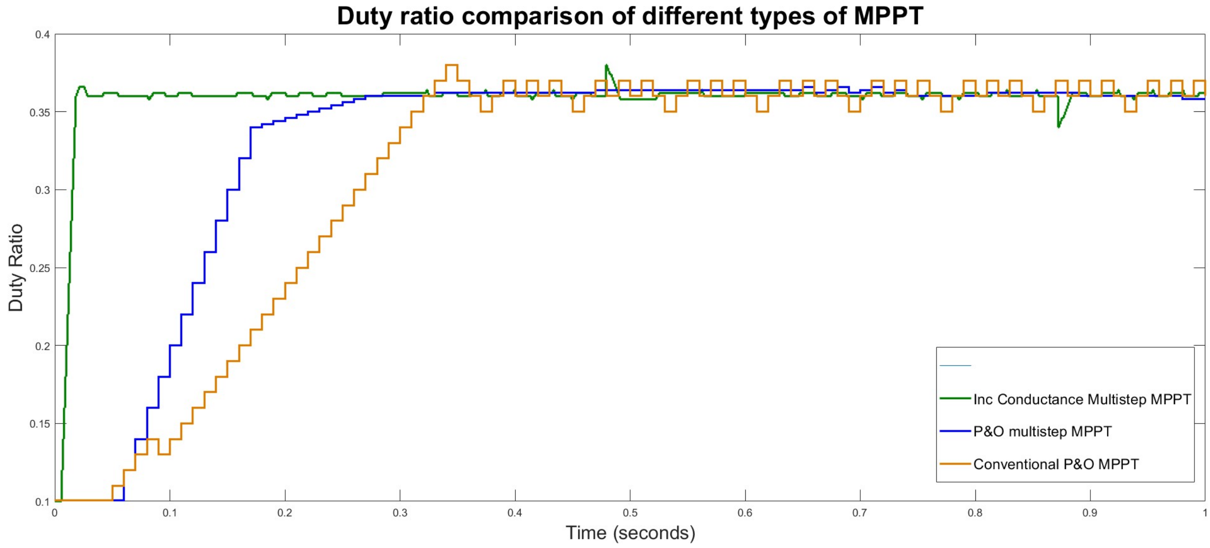

Figure 5.5: Duty Ratio Camparison of a) Inc Conductance Multistep b) P&O multistep c) Conventional P&O

The figure 5.3 shows the duty Ratio Camparison of (i) Inc Conductance Multistep MPPT (ii) P&O multistep MPPT (iii) Conventional P&O MPPT. The simulation results represent the time required to achieve the MPP for each MPPT algorithms.

The Conventional P&O MPPT takes 0.32s to track the MPP from the solar panel. The P&O algorithm tends to oscillate around the MPP, especially under rapidly changing irradiance conditions or when the panel is partially shaded. These oscillations can lead to power losses and reduce the overall efficiency of the system. The P&O multistep MPPT takes 0.17s to track the MPP from the solar panel. Comparing with the Conventional P&O MPPT, The P&O multistep is providing a better performance with less step size for the power tracking.

Compairing with Conventional P&O MPPT and P&O multistep MPPT, The Inc Conductance multistep MPPT takes only 0.02s to track the MPP from the solar panel. Comparing with the

Conventional P&O and P&O multistep MPPT, The Inc Conductance multistep MPPT is more precise in adjustments of duty cycle, allowing to track the maximum power faster.

5.4 PERFORMANCE OF MPPT

In this work, Three types of MPPT are used for the performance analysis. The main duty of an MPPT controller is to ensure that the solar panel operates at its MPP as much as possible. By extracting the maximum available power from the panel, the MPPT controller increases the overall energy efficiency of the solar power system and maximizes the amount of electricity generated.

Table 5.1: Comparison of MPPT

MPPT	Avg Voltage	Ripple	Efficiency	Avg Power (W)
Conventional P&O	96.41	1.5%	93%	958
P&O Multistep	95.10	0.95%	99%	972
Inc Cond Multistep	94.68	0.93%	97%	986

The output performance of different types of MPPT is shown in Table 5.1. The table shows the comparison of average voltage, ripple factor, efficiency and average power.

The output performance graph of a) Conventional P&O b) P&O multistep c) Inc Conductance Multistep is shown in Figure 5.6. From the graph we can conclude that Inc Conductance Multistep MPPT is very fast in tracking maximum power point with a better output power.

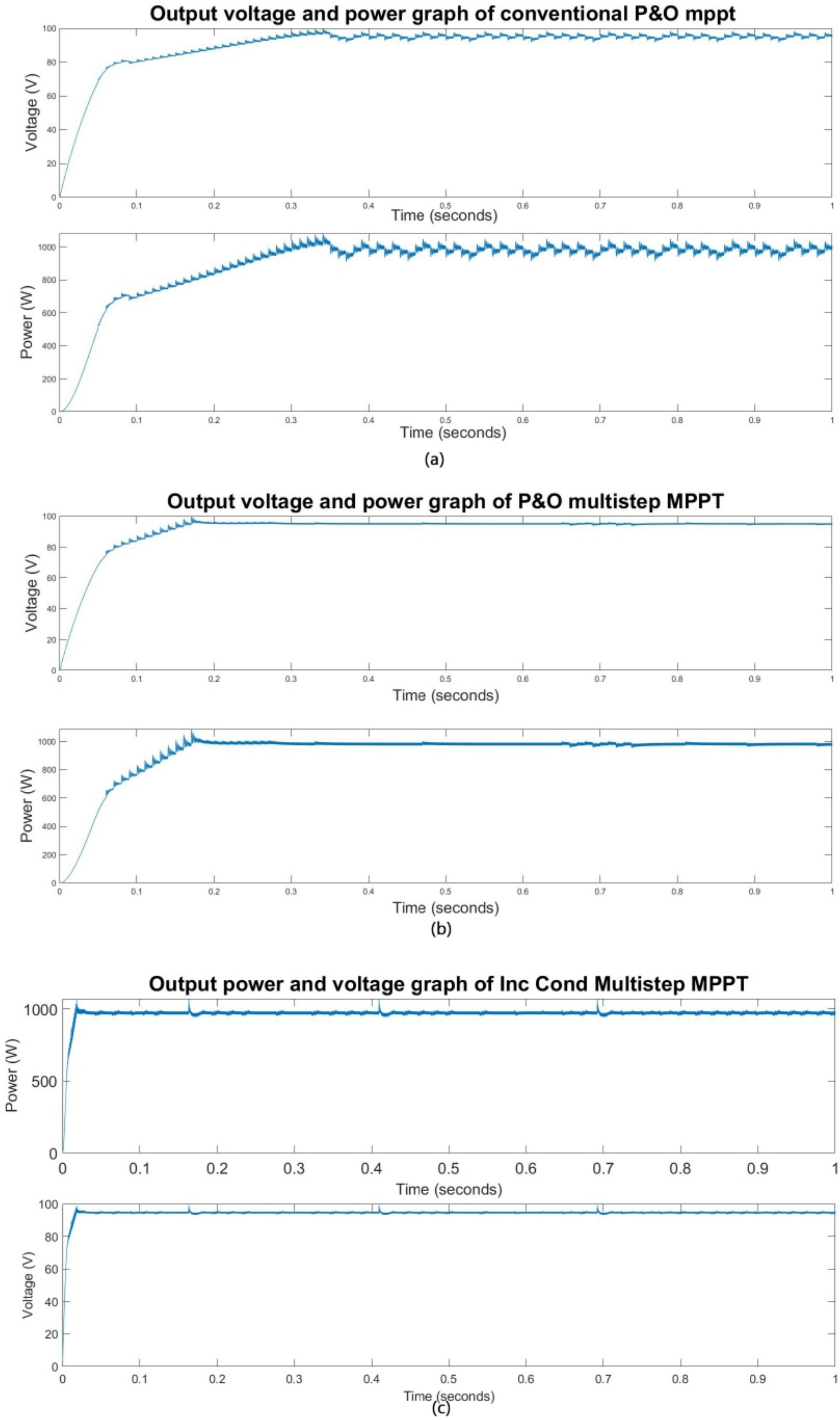

Figure 5.6: Performance of a) Conventional P&O b) P&O multistep c) Inc Conductance Multistep

5.5 STORAGE BATTERY OUTPUT CHARACTERISTICS

The output performance of storage battery used in the charging station is shown in figure 6.5.

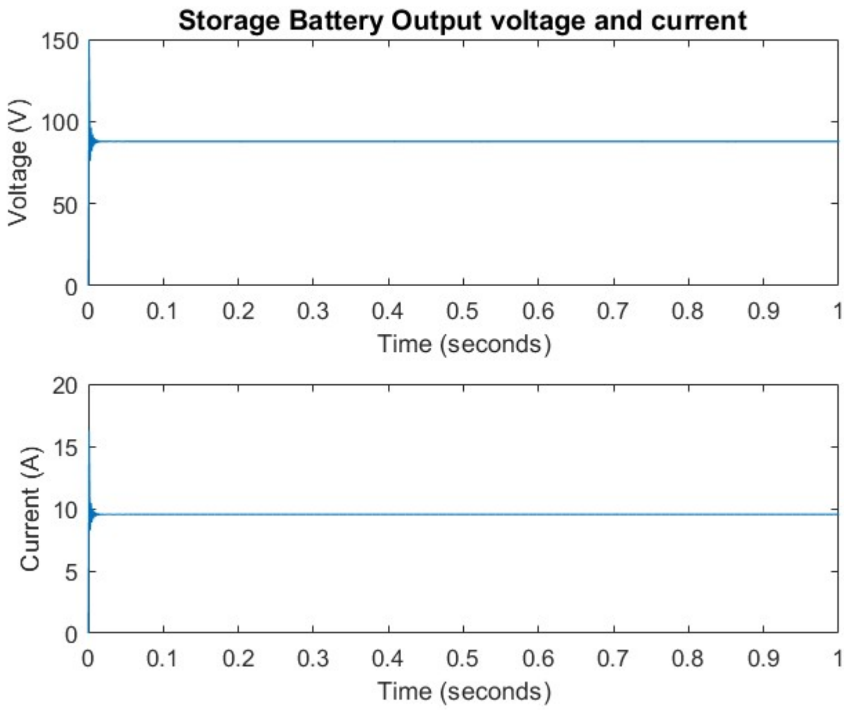

Figure 5.7: Storage Battery Votage and Current graph

The battery is providing the required voltage of 96V with 10A of discharging current. The battery is designed to deliver 1KW power in the charging station.

5.6 GRID OUTPUT CHARACTERISTICS

The charging station is designed to deliver DC supply. So the grid supply of AC should be converted into DC supply. This DC voltage is then converted into the required charging voltage.The grid supply of 230V AC is converted into 230V DC through a full bridge rectifier. This 230V is the converted into 96V DC with a buck down converter.The output characteristics is shown in Figure 6.7.

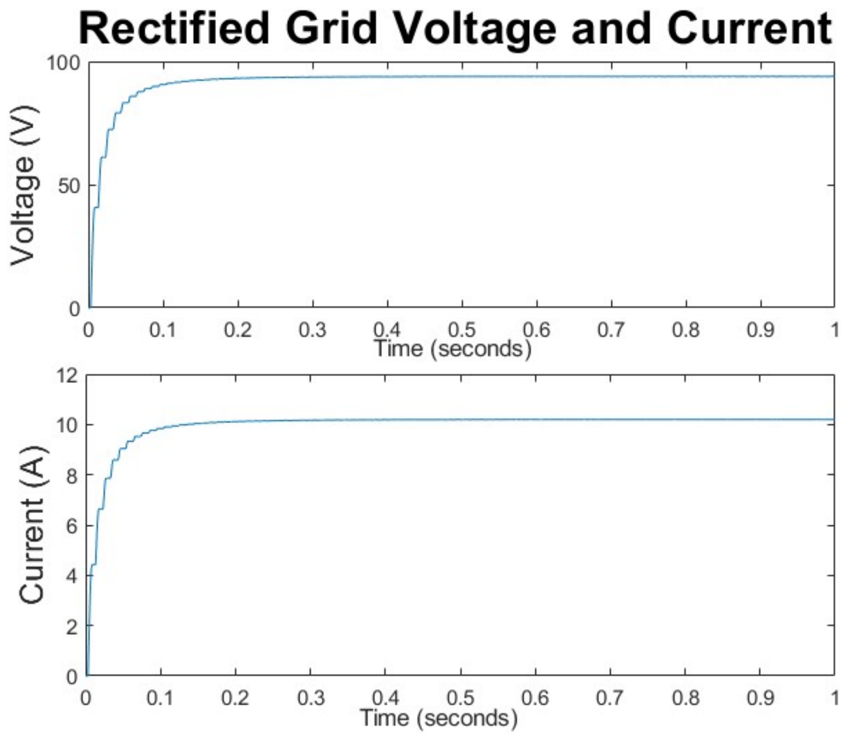

Figure 5.8: Grid Votage and Current graph

5.7 STORAGE BATTERY SOC CURVE

The state of charge (SOC) is a measurement of the amount of energy available in a battery at a specific point in time expressed as a percentage. The SOC provides the user with information of how much longer the battery can perform before it needs to be charged or replaced. Understanding the state of charge is important because understanding the remaining capacity of a batter can help make a control strategy.

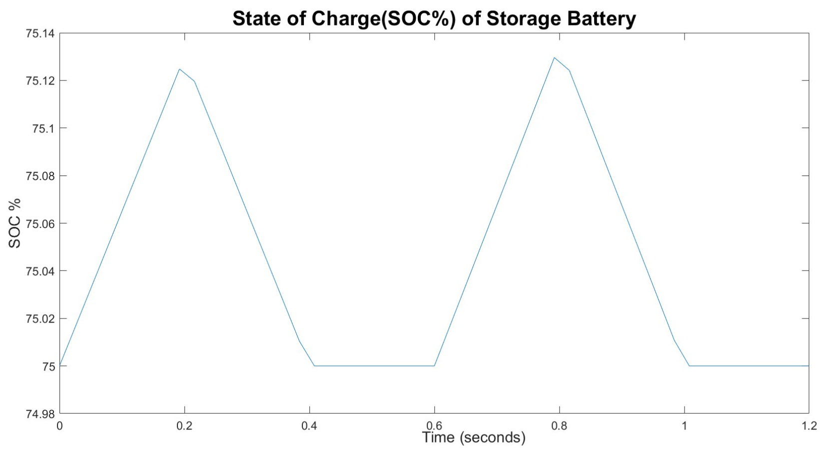

Figure 5.9: Storage Battery charging and discharging curve

Figure 6.8 shows that, When the station is in PV mode the battery is charging from 75% to 75.12%. When the solar irradiance reaches bellow 700W/m, The station will be switched to Storage battery. The graph represents the discharging of battery from 75.12% to 75%. The SOC value of 75% is the set point value of battery to switch the load into grid supply.

5.8 PERFORMANCE OF CHARGING STATION

The Simulation result of different modes of operation in the charging station under various transient conditions is shown in Figure 6.9. The charging station opreate satisfactorily under different conditions occuring due to irradiance and battery SOC.

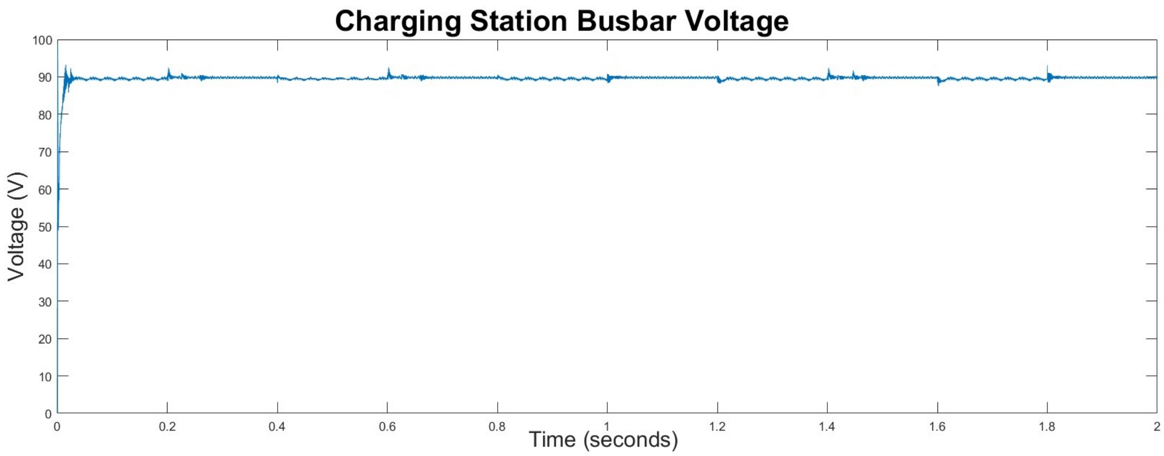

Figure 5.10: Output voltage of CS in different modes of operation

Primarily the CS deliver power from the solar array. From the grah, At 0 to 0.2s the CS is in solar mode. When the irradiance level is less than 700 W/m, The CS is switched to battery mode at 0.2s to 0.4s. When the battery exceeds the discharhing voltage level which has already given in the logic gate condition, It will switch into the Grid supply. At 0.4s to 0.6s the CS is in grid supply provided with DVR system to compensate the voltage sags. When the solar irradiance is enough to deliver power to the EV, The CS will be switched to solar mode. So the switching of each stage will be done automatically in the charging station to provide sustainable and reliable charging solution for EVs.

The CS performance under different conditions verifies the power balance capability and power quality of the charging. Since the charging station operates in many modes depending upon the power generation, the steady state results are discussed for three cases, (i) islanded mode: EV charging using solar PV array. (ii) Battery connected charging. (iii) Grid connected charging with DVR control.

5.9 EV BATTERY PERFORMANCE

The matlab simulation performane of EV in the charging station is shown in Figure 6.10. The simulated result shows that the EV connected to the proposed charging station is getting charged under different conditions as discussed above.

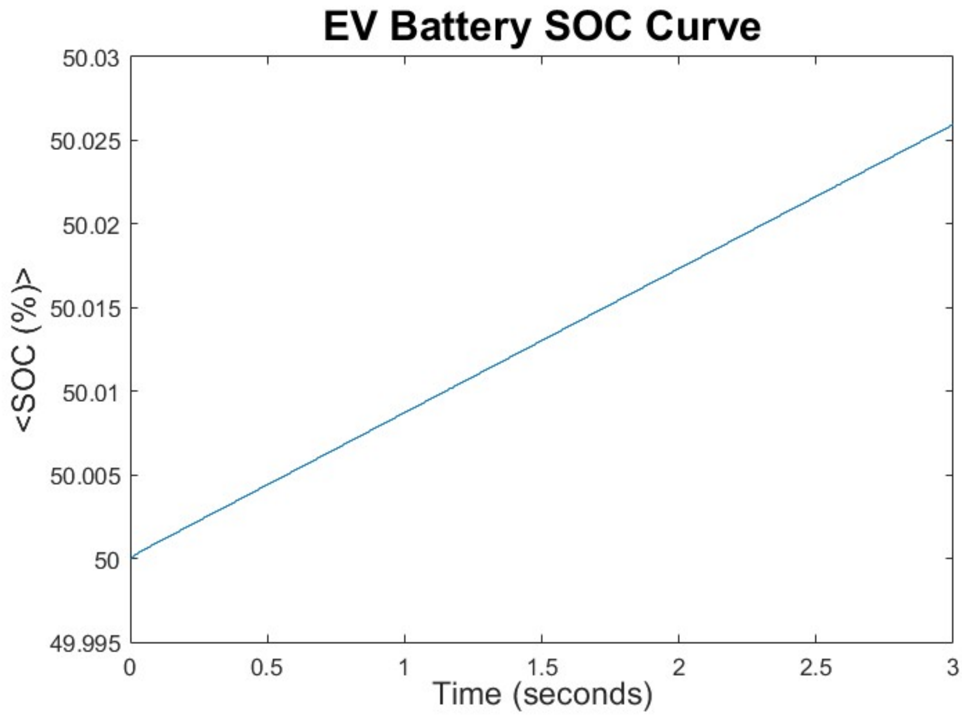

Figure 5.11: Performance of EV in proposed CS

An EV having 50% SOC is connected in the charging station is shown in Figure 6.10. The EV battery gets charged from 50% SOC to 50.026% SOC in 3 seconds. An uninterrupted and efficient charging system is provided in the charging station.

Chapter 6

CONCLUSION

The design of PV array, storage battery and grid supply with voltage sag control has been analysed for the EV charging station. The performance of different types of MPPT's are analysed. Voltage Sag in the grid supply is compensated. The presented results have verified the multi-mode operating capability of the CS using different modes of energy sources. Test results have also verified the satisfactory operation of charging station under different steady state condition caused by the change in the solar irradiance level, change in the Battery SOC level and voltage sag compensation. The charging station provides a good quality of power in the charging station. It can be concluded that this charging station with automatic changeover have the capability to utilize the various energy sources very efficiently and provides the constant and cost effective charging to the EV.

6.1 FUTURE SCOPE

The future scope of the project includes the addition of other renewable energy sources like wind, tidal etc. In remote areas, a diesel generator can also be used for a uninterrupted supply in the charging station. The voltage conversion can be done through a single DC-DC converters instead of using different converters for different energy sources. The Charging station can also deliver power to the nearest homes and buildings.

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