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Option : **Power**

Title:

Design of EV Charging Station Based on a Multisource System

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Abstract

This report aims to create a battery charging system for electric vehicles (EVs) that incorporates several energy sources, such as a photovoltaic (PV) array, a backup battery, and the electrical grid. The objective is to create a charging station that can reliably produce a steady power output under a range of supply and environmental circumstances.

The research begins with applying Maximum Power Point Tracking (MPPT), a technique essential for maximizing the energy harnessed from solar panels. This is followed by an exploration of Direct Power Control (DPC) for AC to DC conversion, which is crucial for maintaining power quality and stability. Additionally, the study delves into the cascade control of EV and station batteries to ensure seamless energy management across the system for different scenarios depending on the power state of the sources, and all implementations have been done using Matlab Simulink.

Dedication

I warmly dedicate this humble work to my beloved parents, my dear siblings, all of my family, friends, and teachers for their continuous care and support.

Ticherafi Fouad.

I sincerely dedicate this humble work to my cherished parents, my entire family, friends, and teachers, whose unwavering care and support have been a constant source of strength.

Teber Amine.

Acknowledgements

Praise to Allah Almighty who guided us through this blessed journey and gave us strength to be able to achieve this much and strive this far.

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His assistance and valuable support have been crucial for the making of this project, and his remarks paved a way for us through challenging times, and for this we are deeply grateful.

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List of Abreviations

AC : Alternating current

BEV : Battery Electric Vehicles

BJTs : Bipolar Junction Transistors

BMS : battery management systems

D : Duty Cycle Ratio

DC : Direct Current

DCFC : Direct Current Fast Charging

DER : Distributed energy resource

DPC : Direct Power Control

DPM : Deficient power mode

DTC : Direct Torque Control

ECM : Equivalent circuit model

EPM : Excessive power mode

EV : Electric Vehicle

EVSE : Electric vehicle supply equipment

FCEV : Fuel Cell Electric Vehicle

FETs : Field Effect Transistors

FF : Fill Factor

FPM : Floating power mode

GTOs : Gate Turn-off Thyristors

HEV : Hybrid Electric Vehicle

IGBTs : Insulated Gate Bipolar Transistors

KOH : Potassium hydroxide

kW : Kilowatt

kWh : Kilowatthour

LIBs : lithium-ion batteries

Li-ion : Lithium-ion

MOSFETs : Metal Oxide Semiconductor Field Effect Transistors

MPP : Maximum Power Point

MPPT : Maximum Power Point Tracking

NiCad : Nickel–cadmium

NiMH : Nickel–metal hydride

PO : Perturb and Observe

PHEV : Plug-in Hybrid Electric Vehicle

PV : Photovoltaic

SCRs : Silicon-controlled Rectifiers

SOC : State of charge

SOH : State of Health

V : Volt

V2G : Vehicle to grid

W : Watts

Genenral Introduction

Global warming is a pressing issue demanding action. The world is starting to retaliate by shifting towards renewable energy sources such as solar and wind energy and also using electric vehicles to reduce emissions. Cooperation between nations is crucial to curb greenhouse gas production and mitigate the effects of global warming. By transitioning to a cleaner future the planet can be protected for the next generations.

Electric vehicles (EVs) are used to combat climate change. EVs produce zero emissions, and pairing them with renewable energy sources such as solar or wind energy keeps the system clean. Many governments are backing this transition with policies incentivizing EV purchases and developing renewable energy infrastructure.

EV charging stations powered by renewable energy are a great weapon against global warming. They address both the emissions from traditional vehicles and the reliance on fossil fuels for electricity. This creates a cycle: more EVs drive demand for clean energy, making it cheaper and more accessible, attracting even more EVs.

This report investigates the development of an EV battery charging system that integrates multiple energy sources, including photovoltaic (PV) panels, a backup battery, and the electrical grid. The aim is to devise and execute a charging station that can reliably produce a constant power output, independent of fluctuating environmental and supply circumstances. The suggested solution seeks to improve the dependability of EV charging infrastructure and guarantee continuous charging availability by utilizing the complementing qualities of these various energy sources.

This research intends to optimize an energy management system to provide a constant and reliable power supply for EV charging stations.

Chapter 1 overviews EV charging stations, discussing their components and categories. It covers the different types and classes of EVs, levels of chargers, and connector types. It also examines battery technologies, charging methods, and capacity, highlighting their impact on station performance. Finally, it compares the pros and cons of various battery types.

Chapter 2 details the design and modeling of the system's components, providing a comprehensive overview of the architectural framework and the specific elements that constitute the system. It also introduces the overall system architecture, explaining how various components interact with one another to achieve the desired functionality.

Chapter 3 explores vital control mechanisms for our EV charging station's efficient operation and energy management. It covers Maximum Power Point Tracking (MPPT) for optimizing solar panel energy, Direct Power Control (DPC) for maintaining power quality, cascade control for EV and station batteries, and energy management strategies for balancing demand and improving efficiency.

Chapter 4 concentrates on assessing the performance of the EV battery charging system using diverse simulation scenarios. These scenarios aim to gauge the system's functionality and efficiency across different operating conditions to ensure optimal performance in all cases.

In summary, this report covers an overview of EV charging stations, detailing components, EV types, charger levels, standardization importance, battery technologies, and charging methods. It delves into system design and modeling, explaining the architectural framework and component interaction. Control mechanisms like MPPT, DPC, cascade control, and energy management for efficient operation are explored. Lastly, system performance is assessed through diverse simulation scenarios to ensure optimal functionality and efficiency across varying operating conditions.

Chapter 1

Generalities

1.1 Introduction

This chapter explores the complexities of EV charging stations, offering a thorough outline of their parts and categories. We begin by exploring the various types and classes of EVs, as these distinctions influence the design and requirements of charging infrastructure. Following this, we examine the different levels of EV chargers, from slow to rapid charging options, essential for meeting diverse consumer needs. The discussion continues with an in-depth look at charger connector types, highlighting the importance of standardization for compatibility across different EV models and charging stations. Battery technologies and charging methods are then scrutinized to understand their impact on the efficiency and speed of charging processes. Additionally, we explore the capacity of batteries, which plays a significant role in determining charging duration and station performance. Lastly, we contrast the benefits and drawbacks of different battery types, offering information on how these differences may affect the layout and functionality of charging stations.

1.2 Electric Vehicles (EVs):

Environmental challenges have always made it a necessity for technological advancement to diverge into a certain way; For this particular reason and with the rising awareness of the need to prevent greenhouse gases from causing any more harm on the climate and the general health and the severe regulations related to this issue that came along, most vehicle manufacturers are drifting from the traditional fossil fuel driven vehicles that emit various pollutants which represents 16% of global emissions, into a cleaner alternative: Electric Vehicles. EVs due to their many advantages are showing an exponential sales growth, and are expected to become even more popular in the future if their prices become more economical, especially in Europe, the United States, and China who dominated the market in the past few years[1].

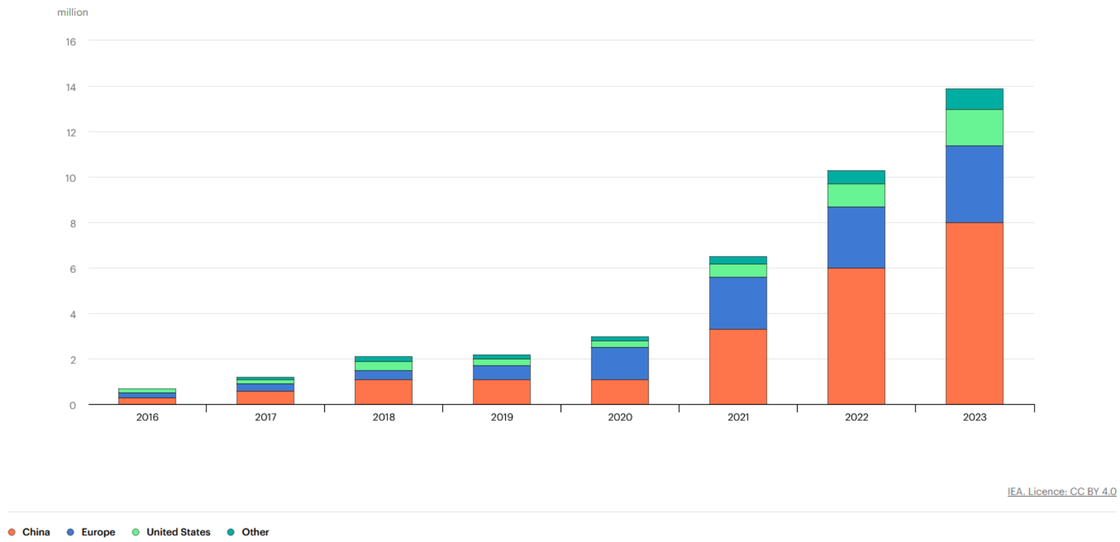

Figure 1.1: EV Sales over time [1]

1.2.1 EV Classes

EVs are classified into different classes and accordingly their emission rate varies, we can thus distinguish these types of EVs:

a)Fuel Cell Electric Vehicle (FCEV)

In this particular type, electricity is generated within the vehicle using pure hydrogen gas thanks to the fuel cell technology. The electrochemical reaction is considered clean and only emits water vapor and heat, and is relatively less noisy compared to conventional vehicles; however, this EV has limitations, and carrying a hydrogen tank can be dangerous due to the explosive nature of this substance[2].

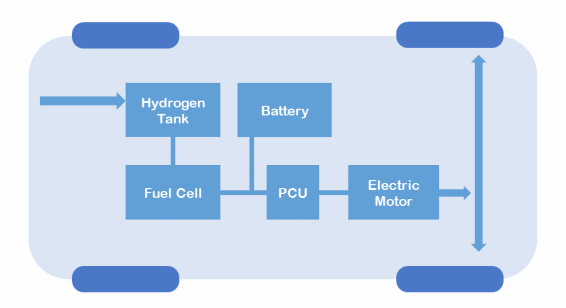

Figure 1.2: Fuel Cell Electric Vehicle

b)Hybrid Electric Vehicle (HEV)

They contain both a battery and an internal combustion engine. Though the existence of the battery reduces emissions, it is still significantly high compared to other EVs, since the hybrid EV depends mainly on the gas/fuel engine and the battery cannot be recharged externally but is self-charged using regenerative breaking, and this limits the use of the battery[3].

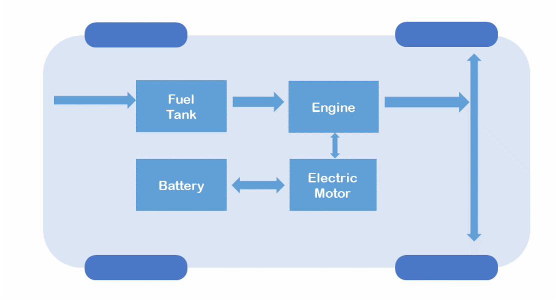

Figure 1.3: Hybrid Electric Vehicle

c)Plug-in Hybrid Electric Vehicle (PHEV)

They're similar to HEV but they're considered more efficient because the battery pack within the vehicle can be charged from an external electric power source and not solely depend on the on-board charging, this allows an all-electric driving mode and an easy swift change to fuel engine if the battery is drained[3].

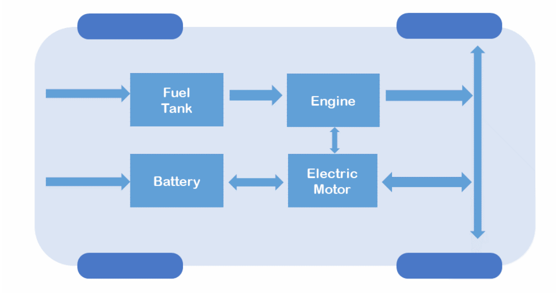

Figure 1.4: Plug-in Hybrid Electric Vehicle

d)Battery Electric Vehicles (BEV)

Also referred to as an all-electric vehicle, it's powered only by the rechargeable battery packs stored in it, and no other additional source. It's as pure as an EV can be, and it's more efficient than both HEV and PHEV, with no pollutant discharges to the nature. The batteries, which will be discussed in a later section can be charged externally from charging station that are becoming more accessible, or chargers that can be installed in houses[3].

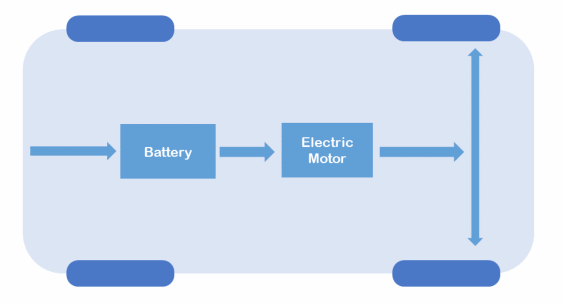

Figure 1.5: Battery Electric Vehicles

1.3 EV Chargers levels:

EV charging is available in three levels, level 1 and 2 AC charging, and level 3 Direct Current Fast Charging (DCFC). Each level delivers a different level of power and thus a different charging time and speed.

1.3.1 AC level 1

A standard 120-volt household outlet is used for level 1 charging. All PHEVs and BEVs can be charged on Level 1 by connecting the charging plug to a wall socket, these EVs make use of their on-board charger to convert the AC into DC. It's important to note that the slowest method for charging an EV is Level 1, it delivers between 1 to 1.4 KW and increases range by 3 to 5 miles (4.8 to 8 Km) per hour. So, to charge a 60 KWh EV it would take up 30 to 40 hours, this doesn't suit all EV owners, especially those who tend to drive for long distances find level 2 charger a better option[4].

1.3.2 AC level 2

It's considered the most common type of charging, like level 1 it depends on an on-board charger to do the AC to DC conversion, however for this level a 230/240 V outlet is needed, and an up to 22KW of power is delivered. Level 2 charging is much faster than that of level 1, comparing with this latter it takes only 2.5 to 4.5 hours to charge a 60 KWh EV and the range per hour of charging added is somewhat between 12 to 80 miles (19.3 to 128.7 Km). For this reason, many BEV owners tend to install a level 2 EVSE at their households, and it is also installed in different public places for public use[4].

1.3.3 DCFC level 3

DC fast charging is the quickest and least time-consuming charging method, it takes direct current directly from the source to charge the EV battery, and bypasses the on-board conversion which usually limits the current flowing into the vehicle. It can charge a 60 KWh EV in less than an hour, by delivering power from about 24 KW up to 300 KW. Level 3 chargers are considered more as public chargers and can be found along highways or in specific charging stations, this type of charging is the one that interests us most and our study will be focused on it[4].

1.3.4 Chargers Connector Types

The connector types vary from region to region and between DC and AC as represented in the following figure:

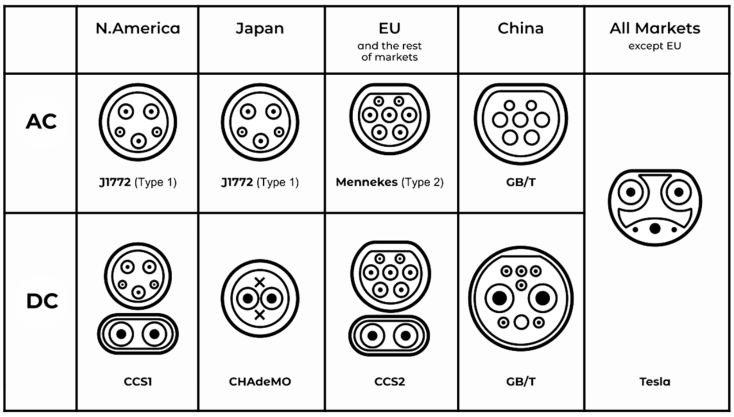

Figure 1.6: Chargers Connector Types [5]

1.4 Battery Technologies

A battery consists of a minimum of two electrochemical cells joined together. It converts chemical energy into electrical energy. Each battery cell consists of a positive cathode and a negative anode, both connected to an electrolyte. The chemical reaction between the electrolyte and terminals generates power. Rechargeable batteries can reverse the chemical reaction by reversing the current flow, allowing them to be recharged. The choice of materials and their types for the cathodes and electrolytes determines the battery's specifications. Several types of batteries suitable for electric vehicles (EVs) are available, which are discussed below.

1.4.1 Lead/Acid

The lead-acid battery was invented in 1859 by the French physicist Gaston Planté, and stands as the pioneering rechargeable battery type in history. Although its energy density is comparatively lower than its modern counterparts, lead-acid batteries boast the capability to deliver robust surge currents. These qualities, coupled with their affordability, render them a favored choice for powering motor vehicles, particularly for meeting the high current demands of starter motors. These batteries are also one of the most established classes of battery utilized in battery electric vehicles[6].

However, lead-acid batteries are plagued by limitations such as relatively short cycle lifespan, usually less than 500 deep cycles, and overall lifespan due to ”double sulfation” in the discharged state, as well as prolonged charging times. Despite advancements in newer battery technologies, their widespread usage persists due to their cost-effectiveness[7].

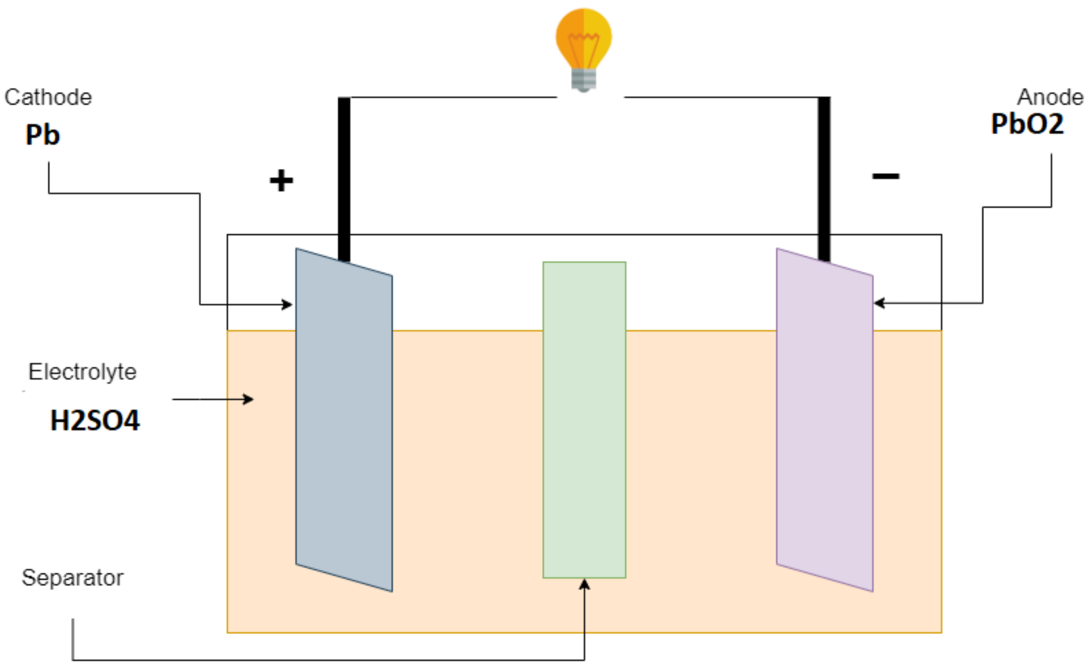

Figure 1.7: Lead/Acid Battery[7]

1.4.2 Nickel Metal Hydride

This battery shares similarities with the Nickel-Cadmium battery, utilizing nickel-hydroxide as the positive electrode and KOH as electrolyte. However, it replaces cadmium in the negative electrode with hydrogen gas, requiring a pressure vessel to contain the gas. Primarily used in low-orbit satellites, nickel-hydrogen batteries undergo frequent charging and discharging cycles during each orbit around the Earth, necessitating a battery with an extended cycle life, which nickel-hydrogen cells provide, often lasting tens of thousands of cycles[8].

Another approach to hydrogen storage involves intermetallic compounds known as metal-hydrides. Certain metals possess space within their atomic structures to incorporate hydrogen atoms. Electrochemical methods can induce the ingress and egress of hydrogen within the metal lattice. Consequently, the nickel-metal-hydride battery emerges as a variant of the nickel-hydrogen battery, employing a novel, low-pressure technique for hydrogen storage. However, due to the susceptibility of metal-hydrides to corrosion upon exposure to KOH, they fall short in longevity compared to nickel-hydrogen batteries

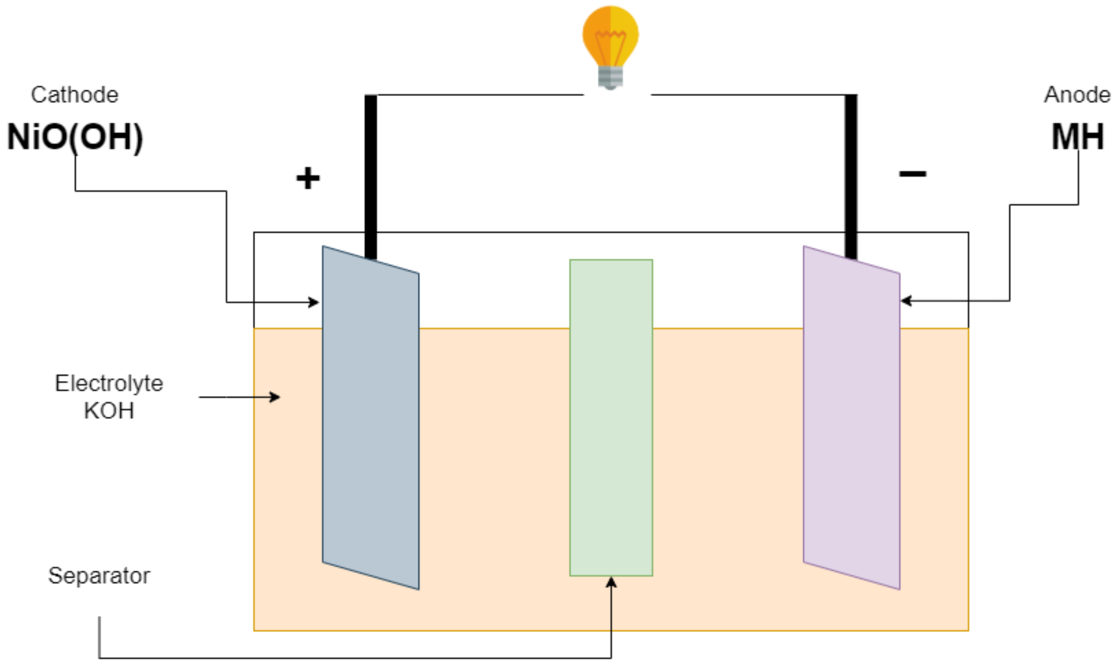

Figure 1.8: Nickel Metal Hydride Battery[8]

1.4.3 Lithium-Ion

These types of batteries are the most dependable and prevailing innovation in the field of batteries for EVs. The lithium-ion (Li-ion) battery stands as the prevailing commercial variant of rechargeable batteries, finding extensive application in portable electronics and electrically powered transportation systems. Unlike its predecessor, the lead-acid battery, which persists in automotive applications for starting internal combustion engines, the foundational research for Li-ion batteries was laid out in the 1970s, with the first commercial Li-ion cell entering the market in 1991[9].

During the discharge cycle, lithium atoms within the anode undergo ionization, separating from their electrons. These lithium ions then traverse the electrolyte, moving towards the cathode, where they reunite with electrons, achieving electrical neutrality. Facilitated by micro-permeable separators between the anode and cathode, the small size of lithium ions enables their mobility[9].

Li-ion batteries can incorporate various materials for electrodes. Among the most prevalent combinations are lithium cobalt oxide (for the cathode) and graphite (for the anode), commonly employed in commercial portable electronic devices like cellphones and laptops. Additionally, other cathode materials such as lithium manganese oxide (used in hybrid electric and electric automobiles) and lithium iron phosphate find application. Typically, Li-ion batteries employ ether, a class of organic compounds, as the electrolyte[9].

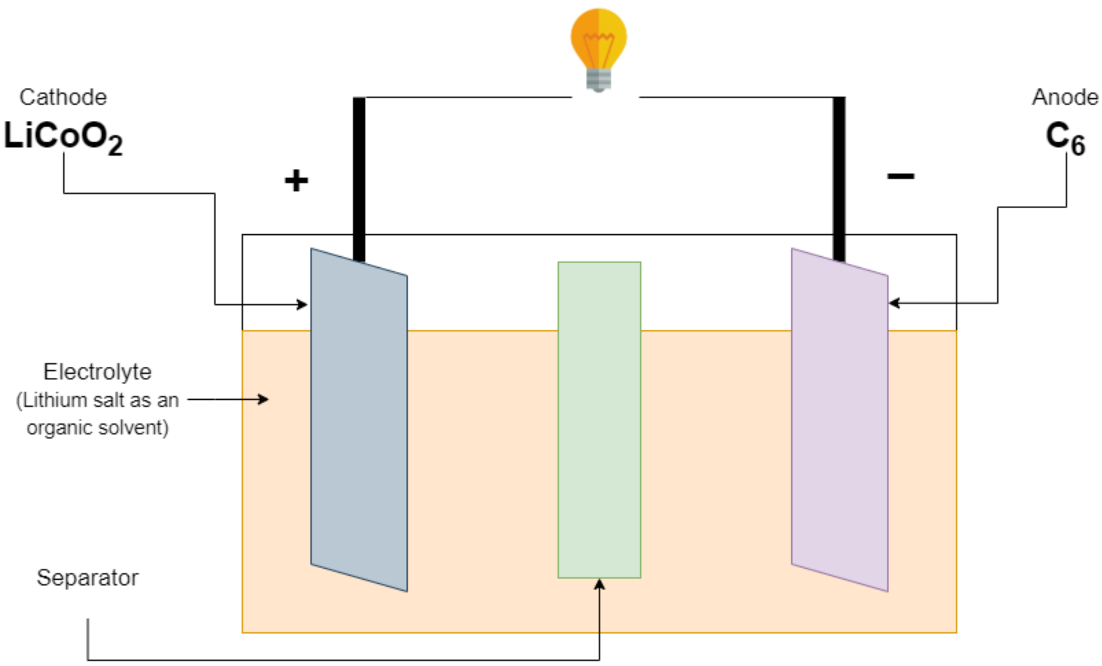

Figure 1.9: Lithium-Ion Battery[7]

1.4.4 Ultra Capacitors

Ultracapacitors represent a distinct type of capacitor engineered with a significant surface area for its conductive plate, called an electrode, and a minimal distance between them. Unlike traditional capacitors that employ solid and dry dielectric materials like Teflon, ultracapacitors utilize a liquid or wet electrolyte between their electrodes, resembling more of an electrochemical device akin to an electrolytic capacitor[10].

Despite being categorized as an electrochemical device, ultracapacitors do not involve chemical reactions in the storage of electrical energy. Instead, they function primarily as electrostatic devices, storing energy as an electric field between their two conducting electrodes[10].

Ultracapacitors excel as energy storage solutions due to their exceptionally high capacitance values, reaching hundreds of farads. This is attributed to the minute distance between their plates and the extensive surface area of their electrodes, facilitating the formation of a layer of electrolytic ions on the electrode surfaces, thereby creating a double layer. This unique construction effectively establishes two capacitors, one at each carbon electrode, earning ultracapacitors the alternate designation of "double layer capacitor," basically two capacitors in series[10].

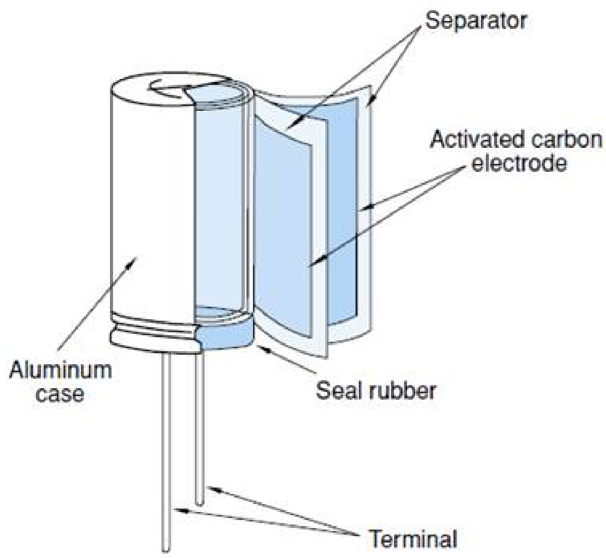

Figure 1.10: Ultra Capacitor Battery[10]

1.4.5 Battery Charging Methods

Battery charging methods vary depending on the type of battery, application, and desired charging speed. Here are some common methods:

Trickle Charging: This method administers an extremely low and steady current to uphold a fully charged status in batteries. It works well in standby batteries, especially those found in backup power supply or emergency systems. Its ability to maintain batteries at their best without running the risk of overcharging is its main advantage. However, because of its innately poor charging rate, it's not ideal for scenarios demanding quick charging.

Pulse Charging: This method of charging replenishes the battery by using sporadic bursts of current instead of a steady flow. Its flexibility enables use with several battery types, including lead-acid and lithium-ion models. The method offers advantages such as diminished heat accumulation and prolonged battery lifespan. Nonetheless, its implementation necessitates more intricate and typically pricier chargers, which is a notable drawback.

Taper Charging: This method involves a gradual decrease in charging current as the battery voltage rises. Because of its ease of use and efficiency with lead-acid batteries, it is frequently used with these kinds of batteries. While simple, it might not fully charge all battery varieties and might not charge as quickly as alternative charging ways.

Inductive Charging: This technology harnesses electromagnetic fields to transfer energy without the need for physical connectors, making it prevalent in wireless charging devices for phones, electric toothbrushes, and certain electric vehicles. Convenience is its main benefit as it does away with the headache of managing cords. However, it's typically less effective and charges at a slower rate than cable charging.

Fast Charging: This charging method employs a higher current or voltage to rapidly charge batteries, a practice prevalent in modern smartphones and electric vehicles. Its main advantage is that it greatly shortens charging times and improves user comfort. There are disadvantages, too. If the increased current or voltage levels are not properly controlled, they may result in increased heat generation and a reduction in battery lifespan.

Constant Voltage (CV) Charging: The charger operates by delivering a steady voltage while the charging current gradually diminishes as the battery replenishes its energy. It is mostly used with lead-acid and lithium-ion batteries and is simple but effective, especially when the batteries need a constant charging voltage. The risk of overcharging, meanwhile, is a disadvantage if oversight is inadequate[11].

Constant Current (CC) Charging: The charger functions by providing a consistent current flow while the voltage escalates throughout the battery's charging process. It is mostly used for nickel-metal hydride (NiMH) and nickel-cadmium (NiCd) batteries, ensuring a consistent and predictable charging rate. However, this approach carries a danger of overheating in the absence of sufficient control systems[11].

CC-CV (Constant Current - Constant Voltage) Charging: This charging method integrates both constant current and constant voltage approaches. It starts with a phase of constant current and changes to a phase of constant voltage when a voltage threshold is reached. It is a popular choice for lithium-ion batteries in consumer electronics since it balances quick charging with security measures.

However, compared to simpler approaches, its implementation requires a more complex charging circuit[11].

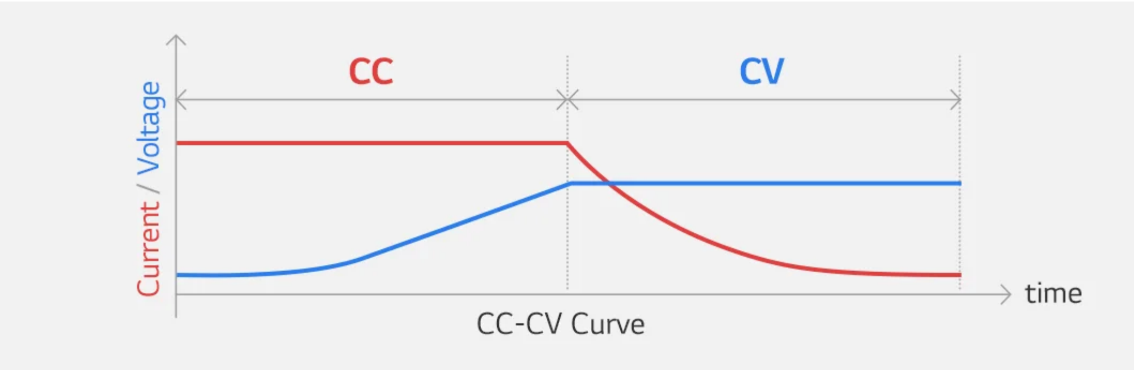

Figure 1.11: CC-CV Charging[12]

Dual Loop Classical Cascaded Charging: The goal of classical cascade charging is to maximize battery charging by segmenting the process into multiple phases, or cascades, each with distinct voltage and current configurations. This technique guarantees a more controlled and effective charging procedure. Dual-loop control systems improve on this strategy by controlling the charging through two feedback loops. While the outer loop regulates the voltage and keeps it within safe bounds to safeguard the battery, the inner loop controls the current and makes sure the battery is charged at the proper rate. When combined, these techniques guarantee a secure and effective charging procedure.

1.4.6 Capacity of Batteries

Table 1.1: Capacity of Batteries

Types of batteries	Capacity Range
Lead-Acid	15 kWh to 30 kWh.
Nickel Metal Hydride	1.5 kWh to 5 kWh.
Lithium-Ion	Entry-level EVs: Around 40 kWh to 60 kWh. Mid-range EVs: Around 60 kWh to 80 kWh. Premium EVs: Around 80 kWh to 100 kWh. Luxury EVs: Can go beyond 100 kWh.
Ultra Capacitors	Capacitance is typically measured in farads (F) rather than kilowatt-hours (kWh), but they typically have lower energy density compared to other batteries. Equivalent to around 6kWh.

1.4.7 Advantages and Disadvantages of Each Battery Type

a) Lithium-ion

Advantages

High Energy Density: Because of their high energy density, Li-ion batteries have the capacity to store a significant quantity of energy despite their small size. They are ideal for EVs because of this feature[13].

Long Life: Li-ion batteries have a longer lifespan than other rechargeables such as nickel-metal hydride (NiMH). They don't lose capacity even after being charged and discharged hundreds of times[13].

Low Self-Discharge: Because Li-ion batteries have a low self-discharge rate, they may hold a charge for a long time. They are therefore ideally suited for use in infrequently used equipment like safety gear or backup batteries[13].

Fast Charging: Li-ion batteries can be charged quickly with the aid of fast charging technology. They are therefore a great option for usage in fast-charging gadgets[13].

Disadvantages

Cost: Compared to other rechargeable batteries like NiMH, Li-ion batteries are more expensive. The primary cause of this is the high cost of the materials utilized in their production[13].

Safety Concerns: If Li-ion batteries are not used or charged correctly, they might overheat, catch fire, or explode. They need to be handled with care and kept in the proper storage environment[13].

Capacity Loss over Time: Li-ion batteries have a tendency to lose capacity over time, particularly if they are frequently charged and discharged or exposed to high temperatures[13].

Disposal: Li-ion batteries need special handling and disposal techniques; they cannot be thrown out with conventional rubbish. Due to that, recycling them is more challenging than it is for other battery kinds[13].

b) Nickel-metal hydride batteries

Advantages

Environmentally friendly: NiMH batteries prevent waste from ending up in landfills due to their extended lifespan and reusability[13].

High energy density: They work well in portable electronics and are therefore preferred over NiCad batteries due to their superior energy density[13].

Low self-discharge rate: Compared to other batteries, they may hold their charge for longer because of their low self-discharge rate[13].

No "memory effect": NiMH batteries do not suffer from the "memory effect" that can occur in NiCad batteries[13].

Cost-effective: In general, NiMH batteries are less expensive than lithium-ion batteries[13].

Disadvantages

Low power density: NiMH batteries are unable to deliver power as quickly as lithium-ion batteries due to their lower power density[13].

Temperature sensitivity: If they are not charged and discharged correctly, they may experience voltage depression and become more susceptible to high temperatures[13].

Limited lifespan: NiMH batteries can deteriorate over time and have a limited lifespan, particularly if they are not properly maintained[13].

Greater charging duration: In contrast to alternative batteries, they often require more time to charge than lithium-ion batteries[13].

Reduced voltage output: Compared to other rechargeable batteries, NiMH batteries have a lower voltage output[13].

c) Lead-Acid Batteries

Advantages

Affordable Solution: Lead-acid batteries are cost-effective due to the abundant materials and established production methods[13].

Efficient Energy: Lead-acid batteries have a high power-to-weight ratio, providing substantial power output relative to their size[13].

High-Current Capability: These batteries excel in high-current discharge applications like electric vehicles and UPS systems[13].

Convenient Recharging: Lead-acid batteries are easily rechargeable with standard equipment, extending their lifespan[13].

Sustainable Materials: Lead-acid batteries are highly recyclable, with materials used in various industries. This recycling efficiency supports environmental sustainability and resource conservation[13].

Disadvantages

Heavy and Bulky: Lead-acid batteries are heavier and bulkier than many other rechargeable types. This makes them less ideal for portable or space-constrained applications[13].

Regular Maintenance: They require regular maintenance, such as checking electrolyte levels and adding distilled water[13].

Charging Sensitivity: Lead-acid batteries can be damaged by overcharging or undercharging. Such issues can significantly shorten their lifespan and efficiency[13].

Hazardous Materials: Containing lead and sulfuric acid, these batteries need special handling and disposal[13].

Limited Cycle Life: Lead-acid batteries have a shorter cycle life compared to some other rechargeable types. This limits their long-term use and necessitates more frequent replacements[13].

d) Ultra Capacitors

Advantages

Rapid Charging: Ultra capacitors can be charged very quickly, often in seconds or minutes. This makes them ideal for applications that require rapid energy replenishment.

Long Lifespan: Compared to traditional batteries, ultra capacitors have a significantly longer lifespan[14].

High Power Density: They provide high power density, enabling them to deliver intense bursts of energy. This is particularly useful in applications such as regenerative braking in vehicles and power backup systems[14].

Wide Temperature Range: They operate efficiently over a wide temperature range, from extreme cold to high heat[14].

Low Maintenance: Ultra capacitors require little to no maintenance throughout their lifespan. This reduces the need for regular checks and servicing compared to other energy storage solutions[14].

Environmentally Friendly: Ultra capacitors are generally more environmentally friendly than traditional batteries. They do not contain hazardous materials and are easier to recycle[14].

Disadvantages

Lower Energy Density: Ultra capacitors have a lower energy density compared to batteries. They store less energy, which limits their use in applications that require long-term energy storage[14].

Higher Cost: The initial cost of ultra capacitors is higher than that of conventional batteries[14].

Voltage Balance: Maintaining voltage balance in ultra capacitor banks can be challenging. They require additional circuitry to ensure an even distribution of voltage across cells[14].

Self-Discharge: Compared to other batteries they have a higher self-discharge rate. They lose stored energy relatively quickly[14].

Safety Concerns: Ultra capacitors can release stored energy rapidly, which may pose safety risks if not properly managed. Proper design and safety mechanisms are required to mitigate potential hazards[14].

1.5 Conclusion

In conclusion, this chapter has comprehensively examined EVs' various components and classifications and their charging infrastructure. Understanding the different EV types and classes is essential for designing effective charging solutions that cater to diverse vehicle specifications. The exploration of charger levels and connector types has emphasized the importance of standardizing and diversifying charging options to meet the varying needs of EV users. Insights into battery technologies and charging methods have highlighted the advancements and challenges in ensuring efficient and rapid energy replenishment. The discussion on battery capacity has further emphasized its critical role in determining charging station performance and user satisfaction. By comparing the advantages and disadvantages of different battery types, we have gained a nuanced perspective on the trade-offs in selecting suitable technologies for vehicles and charging stations.

Chapter 2

System Description

2.1 Introduction

As previously mentioned, our study proposes a system that provides DC fast charging to the EV battery, which is powered by both a utility grid and a photovoltaic system, in addition to a station battery to overcome changes in the environment and operating conditions or the absence of the previous sources. This hybrid system ensures a flexible and ideal charging scheme, that harvests solar energy and integrates it with the power of the grid, making the charging station more reliable and available at all times. Realizing such a system requires compatibility in power, hence the utilization of different power converters is indispensable to achieve this goal and to maintain a constant level of voltage at the DC link. The proposed design for the charging station is shown in figure 2.1; in this chapter we will focus on the design and modeling of its different parts, while the control schemes and strategies will be discussed in a later chapter.

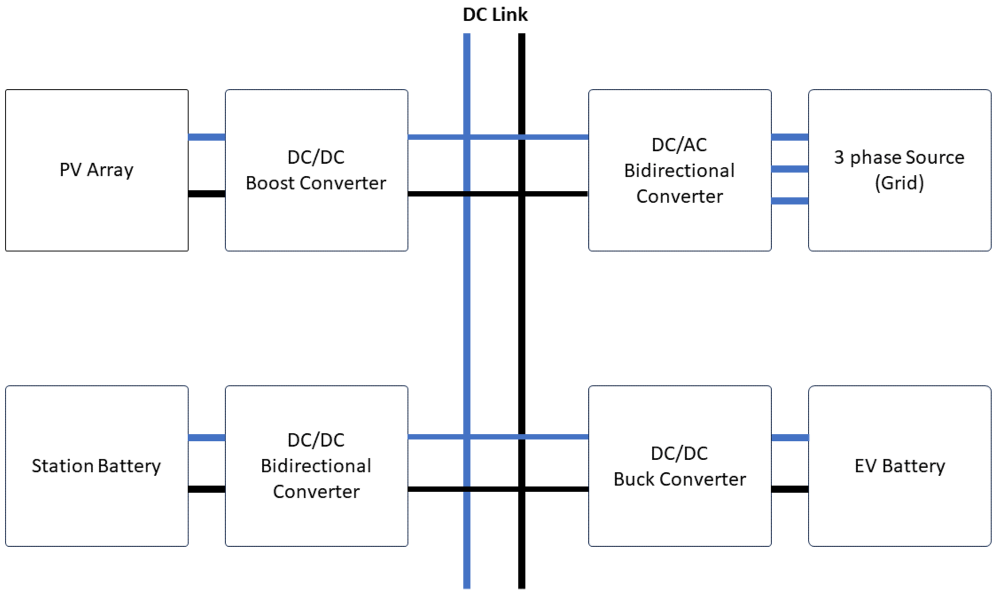

Figure 2.1: Diagram of the Proposed Charging Station

2.2 Smart Grids

Smart grids introduce an enhanced technology in electrical networks that allows them to control and manage the flow of power more efficiently and with a higher reliability. This aspiring power grid uses digital communication and real-time monitoring to achieve an automated energy system with a two-way flow of both electricity and information [15]. The bidirectional flow of energy creates a room for integrating renewable energy sources, which improves the stability and sustainability of the grid, as it also allows the integration of EVs in V2G mode as a distributed energy source. In our application, when no vehicle is charging, the solar panels will act as a distributed energy resource (DER) and supply power to the grid in case of high demand, to reduce the strain over the power generation units. This proves the usefulness and adeptness of smart grids over traditional ones and how soon they will outperform them.

2.3 PV Array

With the use of photovoltaic (PV) modules, the light emitted from the sun can be converted straight into electricity without the need of a heat engine or other dynamic machinery. Since photovoltaic equipment does not have any moving components, it does not require much maintenance and lasts for considerable periods of time, as they should last about 25 years [16]. In addition to this, they operate silently and produce power without releasing any greenhouse or other emissions into the atmosphere. In a PV system, the output voltages and currents can be controlled with ease because they depend on the number of panels connected, meaning that additional panels may be added with ease to boost output. PV systems can be connected to grid, set up as stand-alone, and can be also put to work in a hybrid system with different other sources of energy.

2.3.1 Solar cells operation and types

A solar cell is basically made of 3 main parts: an anti-reflection coating that is put above the cell to increase the amount of light absorbed by the PV cell, the metal grids that improve the cell's ability to collect current from both its front and rear and the active photovoltaic material which is usually silicon-based, where negatively doped atoms of this semiconductor (n-type) are joined with others positively doped (p-type) creating a PN junction.

In the semiconductor layer, there is a continuous creation of electron/hole pairs, whenever photons are absorbed, since their energy will excite the valence electrons to leave their positions if it is higher than the band gap of the semiconductor. The p-n junction's electric field will result in the splitting of charges if these pairs are close enough to it; making the electrons displace to the n-type side and holes to the p-type side. Now with the condition that solar radiance is available; if a load is connected, an electric current will start flowing through it, and this describes the

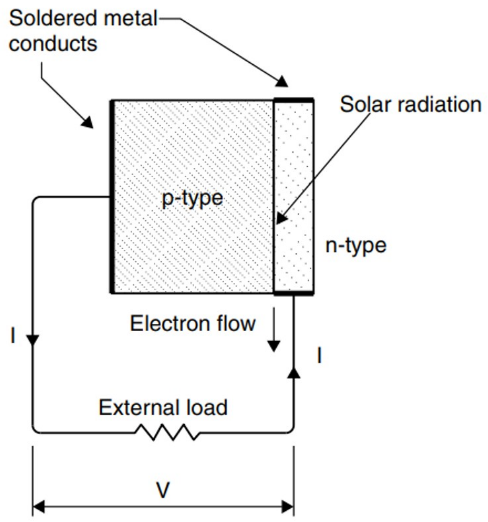

Figure 2.2: Photovoltaic effect [17]

photovoltaic effect in the solar cell[17].

PV cells vary into different types according to their atomic structure composition used in their manufacturing technologies, and we can distinguish from them the following main types [18]:

1- Mono-crystalline silicon cells: These cells require a sophisticated production process since the silicon in them has a single lattice with no flaws or impurities. Their efficiency is high compared to other types and it is about 15%.

2- Multi-crystalline silicon cells: Compared to single crystalline, this has a little lower conversion efficiency, but it also costs less to manufacture. The average efficiency is about 12%.

3- Amorphous silicon: a thin homogeneous layer of silicon atoms is the basis of these cells, which are also called thin-film PV cells, their average efficiency is about 6%.

Another type that is considered to be fairly new is the nano-PV, it's flexible and inexpensive compared to the traditional PV cells since it's based on flexible and printable polymer substrates coated with nano-components that conduct electricity.

2.3.2 Single diode equivalent circuit model

For representing a solar cell, an electrical equivalent model referred to as the single diode model is often used [19]. This model is composed of a current source, a series resistance, a diode with a shunt resistance as illustrated in the following figure:

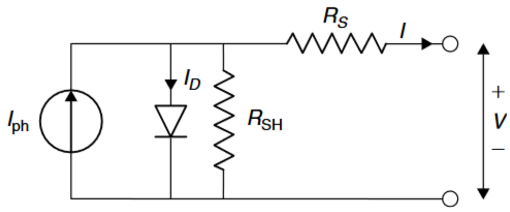

Figure 2.3: Single diode model of solar cells [17]

From the figure one can see that the output current would be the result of the difference between I_{ph} the photocurrent and the diode current I_D and the shunt current I_{SH} as given in the following governing equation:

$$I = I_{ph} - I_D - I_{SH} = I_{ph} - I_0 \left\{ exp\left[\frac{e(V + IR_S)}{kT_C}\right] - 1 \right\} - \frac{V + IR_S}{R_{SH}} \tag{2.1}$$

Taking into account the large difference between the series resistance and the shunt resistance, the previous equation can be reduced to:

$$I = I_{ph} - I_0 \left[exp\left(\frac{eV}{kT_C}\right) - 1 \right] \tag{2.2}$$

Where:

k = Boltzmann's constant.

T_C = Temperature of the cell (K).

e = Electron charge (Coulomb).

V = Voltage across the cell (V).

I_0 = Saturation current (A).

The governing equation allows to draw the current versus voltage characteristics curve, from which we can distinguish different features of the solar cell such as the I_{SC}, V_{OC}, and M_{pp}.

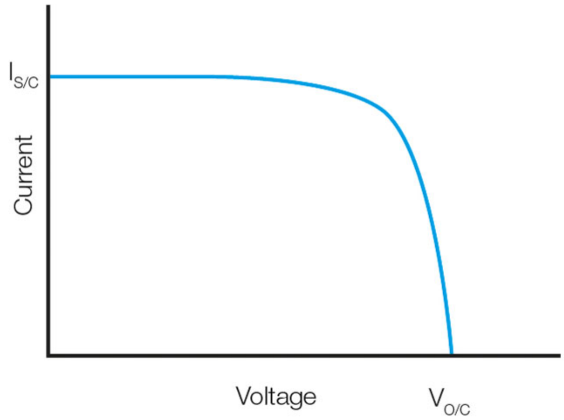

Figure 2.4: IV curve of a solar cell

2.3.3 Solar cells configurations and their characteristics

A single solar cell can not power any device by itself since its output voltage varies from 0.5V to 0.6V, that is why they are often grouped to produce more voltage. Solar cells can be connected in series or in parallel and encased in a single package forming what we call a PV module, which usually consists of 32, 36, 48, 60, 72, and 96 cells, there are ones with a higher number of cells but not as much used. We can in turn connect these modules in series or in parallel forming PV Panels and PV arrays.

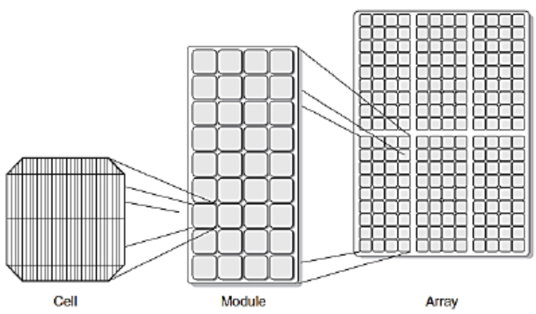

Figure 2.5: PV cells configuration [20]

As previously mentioned, if we seek to increase the voltage of the module, we need to connect cells in series (V_{out}=V_1+V_2+V_3+...).
Alternatively, if we wish to increase the current, we need to connect cells in parallel (I_{out}=I_1+I_2+I_3+...).

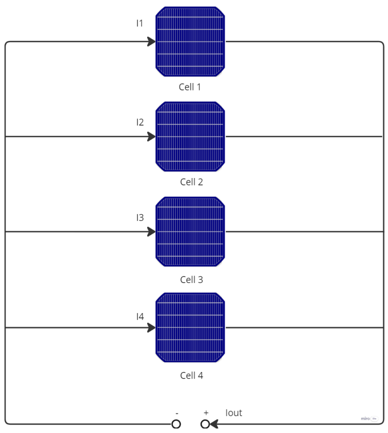

Figure 2.6: Cells Connected in Parallel

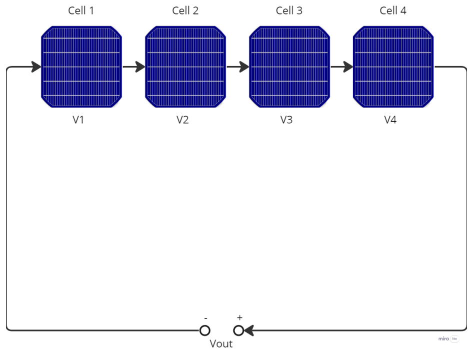

Figure 2.7: Cells Connected in Series

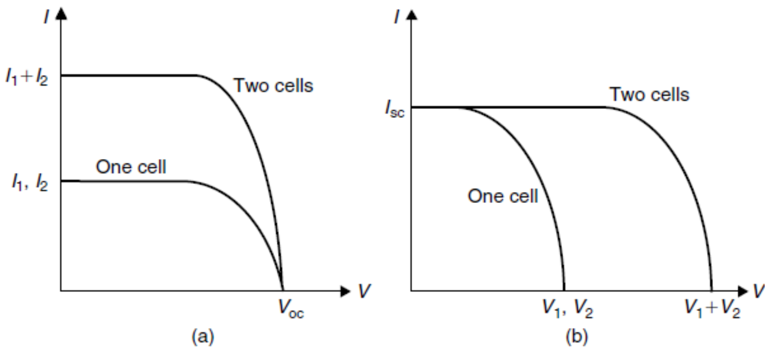

Figure 2.8: (a) Parallel and (b) series connection of two identical solar cells [17]

Taking the voltages and currents at different working points, allows us to draw the I-V characteristics curves. Multiplying those two quantities gives us the power curve, which can be drawn on the same axis, from this curve we can distinguish a specific point at which the current and voltage are at maximum, this point is called the maximum power point (MPP). We can also see the current at short circuit I_{sc}, and the voltage at open circuit V_{oc}.

The fill factor (FF) is another quantity that is frequently used to describe the

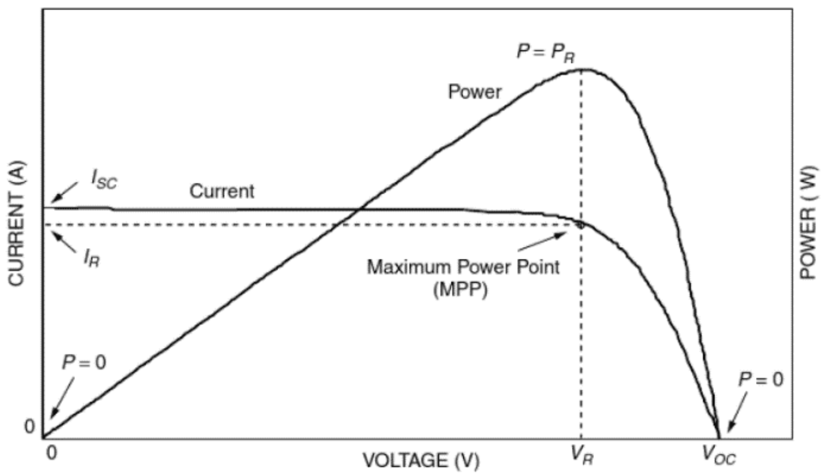

Figure 2.9: IV & PV Characteristic curves [21]

performance of a module, for good cells it should be greater than 0.7. FF is the ratio of the maximum power to the product of I_{sc} and V_{oc}:

$$FF = \frac{P_R}{I_{sc} * V_{oc}} \tag{2.3}$$

Another crucial characteristic is the efficiency η, that has a direct relation with the cost of the PV module, scientists are continuously trying to improve it, and get high efficiencies for a low cost of production. It can be calculated by dividing the output power at the mpp of the PV cell on the input power of the sunlight (P_{sun}):

$$\eta = \frac{P_R}{P_{sun}} \tag{2.4}$$

2.4 Power Electronics

Power electronics in electrical engineering is used in home electronics all types of equipment to control high voltages and currents. It processes power supplies and generates regulated power using control mechanisms and power semiconductor switches. In several industries, especially transportation, where motor control is essential, it is vital for consistent electricity. Power electronics emphasizes efficiency and precise control and connects with electrical motors, control systems, semiconductor physics, and other fields.[22].

Power semiconductor devices are used in all these applications to switch the input voltages and currents to produce the desired outputs. To tolerate high voltages and currents, the design of fundamental semiconductor devices like diodes, field effect transistors (FETs), and bipolar junction transistors (BJTs) is modified. Thus, we have insulated gate bipolar transistors (IGBTs), gate turn-off thyristors (GTOs), power diodes, power metal oxide semiconductor field effect transistors (MOSFETs), power BJTs, and so on. The efficiency, power levels, required switching frequency, and input and output types all play a role in the device selection process. For example, the power handled in an EV powertrain is in the range of kW. Power MOSFETs, which can handle high voltages and switch at greater frequencies, are frequently employed in these kinds of applications. Silicon-controlled rectifiers, or SCRs, are employed in power transmission applications where the handled power is typically a few megawatts or less[22].

The block diagram of a typical power electronic system is shown in the figure below.

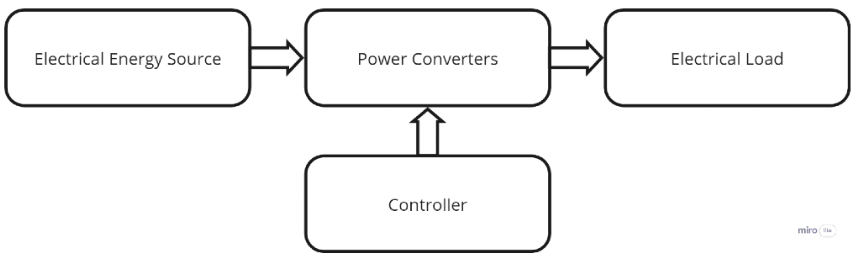

Figure 2.10: Typical Power Electronic System

2.4.1 DC/DC Converters

Boost Converter

The boost converter works on leveling up and increasing the voltage, it consists of a DC input voltage source, a boost inductor, a controlled switch, a diode, a filter capacitor, and a load as depicted in the figure:

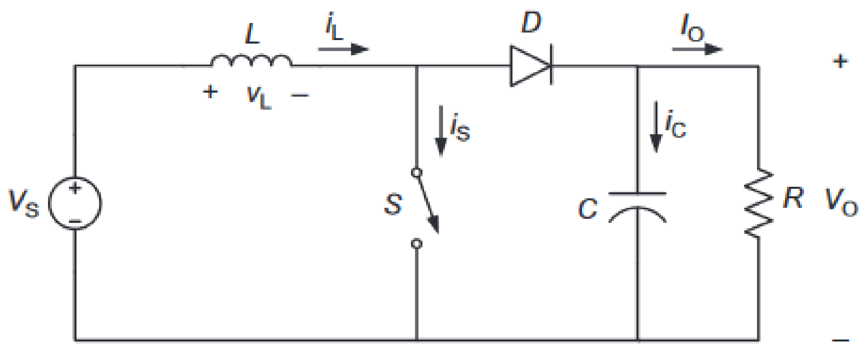

Figure 2.11: Boost Converter Diagram[23]

In our system, the boost converter is responsible for stepping up the output voltage of the photovoltaic array, and maintaining a maximum level of power thanks to the maximum power point tracking technique. The mathematical equation that describes the relation between the input and the output is as follows:

$$V_{out} = \frac{V_{in}}{(1-D)} \tag{2.5}$$

Buck Converter

Contrary to the boost converter, the buck converter is a DC/ DC converter that steps down or decreases the input voltage into a desired value at the output, and in our application we used it to step down the DC link voltage to meet the battery's intake. This system usually includes a DC input source, a filter inductor, a controlled switch, a capacitor, a diode, and a load at the output as shown in the following figure:

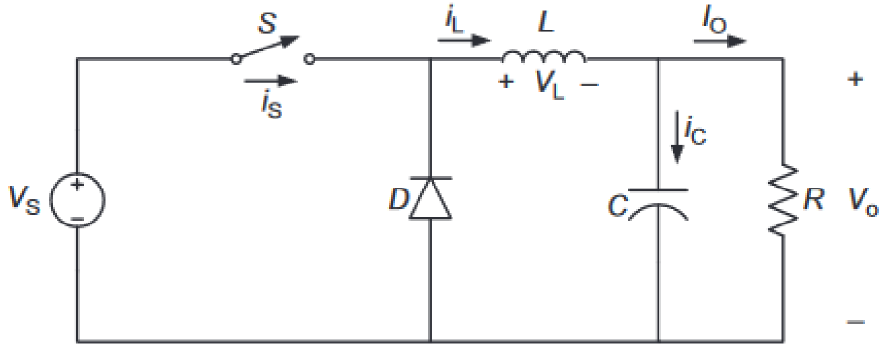

Figure 2.12: Buck Converter Diagram [23]

The timing of operation of the switch over the inverse of the switching frequency represents the duty ratio D, which has a linear relationship with the output described mathematically with the following equation:

$$V_{out} = V_{in} * D \tag{2.6}$$

Bidirectional Converter

The bidirectional converter allows a power flow from both directions, it acts as a boost converter in one direction and as a buck converter in the opposite direction, which makes the charging and discharging of the station battery possible in our application. This converter contains two capacitors, an inductor, and two identical switches.

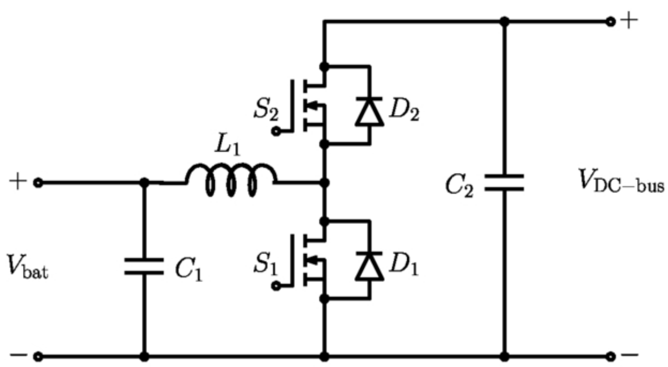

Figure 2.13: Bidirectional Converter Diagram

2.4.2 AC/DC Bidirectional Inverter

To ensure an exchange of power between the grid and our system, it is necessary to use a bidirectional Inverter. This latter will function as a rectifier in the forward path converting AC from the grid to DC and as an inverter in the backward path converting DC to three-phase AC. The bidirectional converter is a 3-phase bridge that consists of six IGBT switches, with each phase leg comprising an upper and lower IGBT.

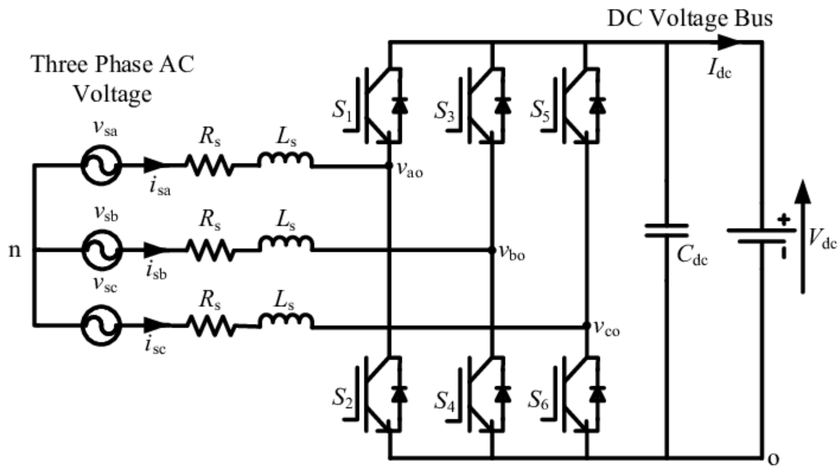

Figure 2.14: AC/DC Bidirectional Inverter Diagram [24]

Inverter Sizing

The size (in watts) should be determined based on the peak power demand of the charger. The formula for inverter sizing is:

Inverter Size (W)=Peak AC Load (W)×Inverter Over-sizing Factor

Where: Peak AC Load is the maximum power demand of the charger in watts.

The Inverter Over-sizing Factor is a safety margin (typically 1.25 to 1.3) accounting for efficiency losses and future load expansions. It's worth noting that while an inverter adds flexibility to power AC devices, it also introduces energy losses during the conversion process. Proper sizing and component selection are key considerations in maximizing system efficiency and longevity[25].

2.5 Batteries

2.5.1 Battery Parameters

Understanding these parameters helps in selecting the right battery for various applications and ensures optimal performance and longevity.

Capacity: The plates' chemistry and physical dimensions are primarily their area, though, for some chemistries, their thickness determines how much energy a cell can store. The amount of amps a battery can deliver in a specific number of hours is measured in ampere-hours (Ah).

Voltage: This is the potential difference between the battery's terminals. The battery's chemistry determines the nominal voltage, while the actual voltage can vary with the state of charge, temperature, and load.

Cycle life: This refers to the number of complete charge-discharge cycles a battery can undergo before its capacity drops below a specified percentage of its original capacity, in the neighborhood of 80%. This is typically between 500 and 1200 cycles.

Efficiency: The efficiency of a battery, as with anything, is output/input $\times$ 100%.

State of Charge (SOC): Is a crucial metric called it shows how fully charged a battery is right now in relation to its capacity. It is often stated as a percentage.

SOC is a vital data point since it gives users and battery management systems (BMS) important knowledge about how much energy is present in the battery. Since a battery's internal chemical processes are not easily visible, estimating the level of charge of a battery is complex. To estimate SOC, however, numerous techniques have been created. Starting with coulomb counting, which involves observing the current entering and leaving the battery and calculating the total accumulated or lost charges by gradually integrating this current. While this method calculates the SOC based on the change in charge relative to the battery's overall capacity, it suffers from cumulative errors over time due to efficiency losses and measurement tolerances. To enhance accuracy, Coulomb counting can be combined with Open Circuit Voltage (OCV) measurements. The OCV, which correlates with the battery's charge level, can periodically correct the errors in Coulomb counting, providing a more precise SOC estimation. However, accurate OCV readings require the battery to be at rest, which is often impractical since many systems need a continuous energy supply from the battery[26].

State of Health (SOH): State of Health (SOH) is a metric used to compare a battery's current status to that of a brand-new battery. SOH is expressed as a percentage, with 100% denoting a brand-new battery in perfect condition and lower numbers denoting aging and degeneration. For several reasons, it's crucial to understand a battery's SOH such as performance assessment, maintenance/replacement decisions, and safety. The condition of a battery can be impacted by a number of variables, including[26]:

1. Cycling.
2. Temperature Effects.
3. Depth of Discharge (DoD).
4. Overcharging.

5. Current Magnitude.

6. Storage Conditions.

2.5.2 Battery Modeling

Battery modeling refers to the process of creating mathematical or computational representations of the behavior and characteristics of batteries. These models are crucial for many applications, including portable electronics, electric vehicle design, battery management systems, and the integration of renewable energy sources. These days, lithium-ion batteries (LIBs) are widely used in EV applications because of their low self-discharging, charging, and energy density. Therefore, we have decided to utilize LIBs, here are a few LIB model-based techniques[27]:

$\mathbf{R_{int}}$ Equivalent circuit model (ECM): The R_{int} Equivalent circuit model (ECM), as shown in Figure 2.15, is a simple model for practical implementation but the output equation leads to uncertainties in state estimation. Equation 2.7 is the output voltage (V_L) is the sum of the open circuit voltage V_{OC} and internal resistance R_O, where V_{OC} and R_O are the functions of SOC, SOH, and temperature. The I_L is the load current which is positive during discharging and negative during charging of the cell[27].

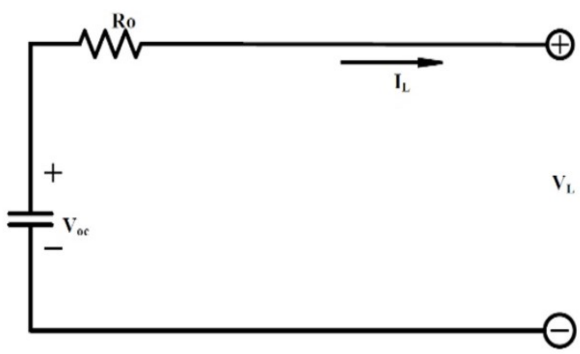

Figure 2.15: The R_{int} ECM[27]

$$V_L = V_{OC} - I_L R_O \tag{2.7}$$

Thevenin ECM: Thevenin ECM is shown in Figure 2.16. It is an Improved model of R_{int} with a Parallel RC network in series. It is most used in practical applications but it has accuracy problems during the charging and discharging process. The internal resistance of this model includes R0 and R_{Th} namely called ohmic and polarization resistances respectively. The C_{Th} describes the transient response of the ECM. The behavior of the output voltage is shown in Equations 2.8 and 2.9[27].

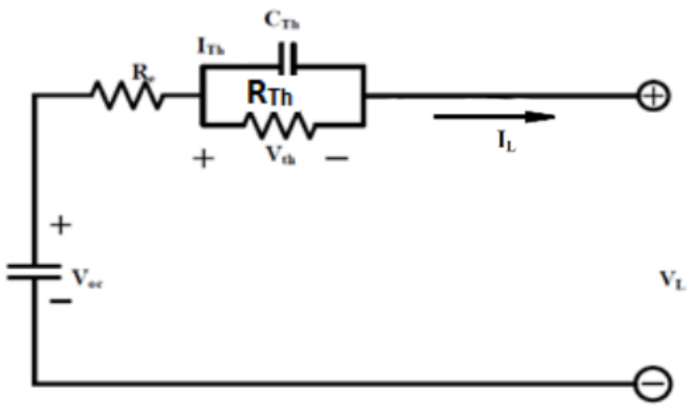

Figure 2.16: Thevenin ECM[27]

$$V_{\text{Th}} = -\frac{V_{\text{Th}}}{R_{\text{Th}} C_{\text{Th}}} + \frac{I_L}{C_{\text{Th}}} \tag{2.8}$$

$$V_L = V_{OC} - V_{Th} - I_L R_O \tag{2.9}$$

Dual polarization ECM: Dual polarization ECM is shown in Figure 2.17. It is an improved model of Thevenin's model. It is more accurate during charging and discharging. The output voltage equations are shown in Equations 2.10 to 2.12[27].

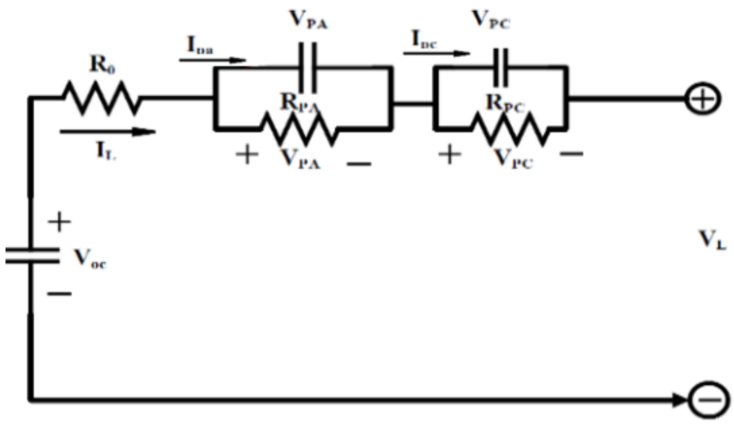

Figure 2.17: Dual polarization ECM[27]

$$V_{\text{pa}} = -\frac{V_{\text{pa}}}{R_{\text{pa}}C_{\text{pa}}} + \frac{I_L}{C_{\text{pa}}} \tag{2.10}$$

$$V_{\text{pc}} = -\frac{V_{\text{pc}}}{R_{\text{pc}}C_{\text{pc}}} + \frac{I_L}{C_{\text{pc}}} \tag{2.11}$$

$$V_L = V_{OC} - V_{pa} - V_{pc} - I_L R_0 \tag{2.12}$$

2.6 Conclusion

In summary, our study has successfully proposed and detailed a hybrid system for DC fast charging of EV batteries, which leverages the combined power of a utility grid, a PV system, and a station battery. This innovative approach addresses the challenges of varying environmental conditions and the potential unavailability of primary power sources. By integrating solar energy harvesting with grid power, our charging station design offers enhanced reliability and continuous availability. Throughout this chapter, we have meticulously designed and modeled the key components of the charging system, including smart grids, PV modules, power electronics, and batteries. Each part is critical in ensuring the system's efficiency and stability. Smart grids provide the intelligent management of power flows, PV modules capture renewable energy, power electronics facilitate the necessary power conversions, and batteries offer backup support. The effective interplay between these components, facilitated by advanced power converters, maintains a stable DC link voltage essential for consistent charging performance. Our comprehensive design approach ensures that the charging station can adapt to various operational scenarios, making it a robust solution for the future of EV infrastructure.

Chapter 3

System Control

3.1 Introduction

This chapter delves into the critical control mechanisms and strategies that ensure the smooth operation and energy management of these systems. We begin with Maximum Power Point Tracking (MPPT), a technique essential for maximizing the energy harnessed from solar panels. Following this, we explore Direct Power Control (DPC) for AC to DC conversion, which is crucial for maintaining power quality and stability. The discussion then advances to the cascade control of EV and station batteries. This section highlights the importance of precise control in enhancing battery longevity and performance. Finally, we address energy management strategies, focusing on the optimal allocation and utilization of energy resources to balance demand and improve the overall efficiency of the charging station. By examining these control systems and methodologies, this chapter aims to provide a comprehensive understanding of the key factors that contribute to the effective and efficient operation of our EV charging stations.

3.2 Maximum Power Point Tracking (MPPT)

In photovoltaic (PV) systems, such as solar panels, Maximum Power Point Tracking (MPPT) is a technique that maximizes the power output from the solar module or array. A solar panel's power production is contingent upon several elements, such as temperature, solar irradiance, and the electrical properties of the panel itself. The maximum power point (MPP), where the solar panel's power production is maximized, is the operating point that the MPPT system modifies to guarantee it works. The basic idea behind MPPT is to continuously adjust the electrical operating point of the solar panel to extract the maximum available power. This is typically done by a controller that adjusts the electrical operating conditions of the PV system to optimize the power output [28].

3.2.1 Perturb and Observe (P&O) Algorithm

The Perturb and Observe (P&O) algorithm is the most widely used MPPT technique. The P&O method and its corresponding formulas are explained in this straightforward manner:

Perturb: The controller slightly changes the operating point and observes the resulting change in power output.

Observe: The controller compares the new power output with the previous one to determine the direction in which the power increased.

Adjust: The controller continues to adjust the operating point in the direction that increases power until the maximum power point is reached.

P&O Algorithm Formulas

Instantaneous Power: P Instantaneous = V Instantaneous ×I instantaneous

Change in Power (ΔP): ΔP = P Instantaneous - P previous

Change in Voltage (ΔV): ΔV = V Instantaneous - V previous

Updating the Duty Cycle: Dnew = D Previous +/- ΔD Step

Where D represents the duty cycle and ΔD Step is a small step that increases or decreases the duty cycle depending on the sign of ΔP and ΔV (positive or negative) as shown in the following flowchart.

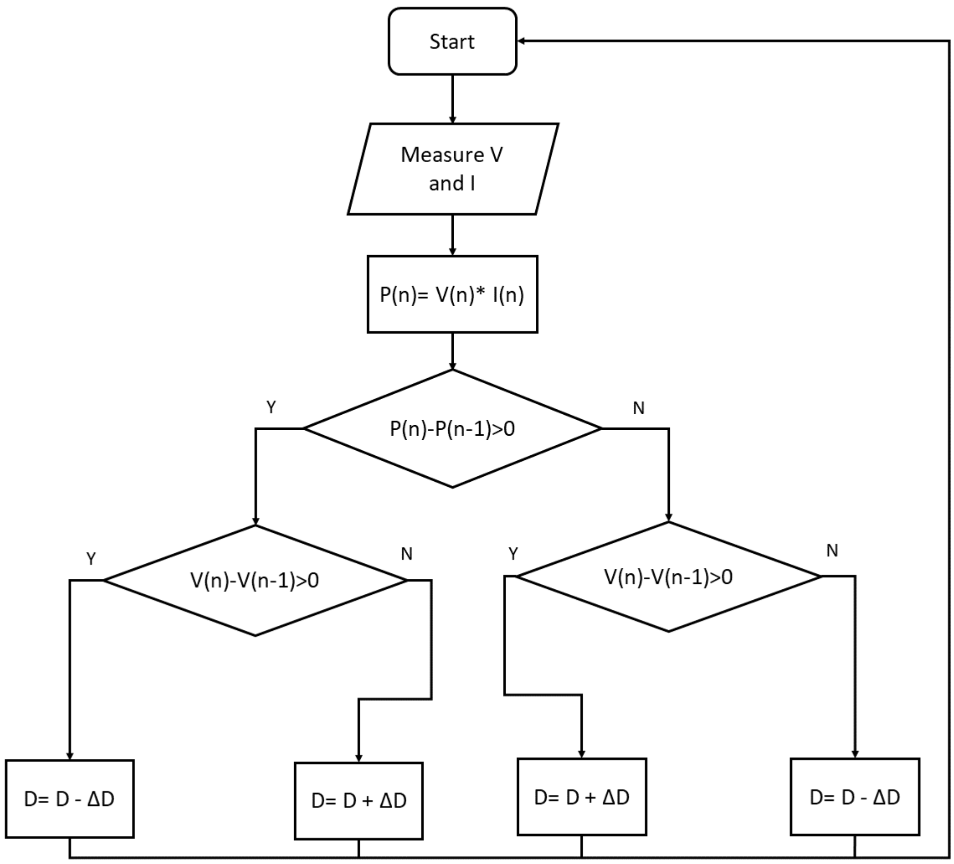

Figure 3.1: P&O Algorithm Flowchart

It's important to note that while P&O is a commonly used algorithm, there are other MPPT algorithms, such as Incremental Conductance, Fractional Open Circuit Voltage, and Perturb and Hold, each with its own advantages and disadvantages.

3.3 Direct Power Control AC to DC

Direct power control (DPC) operates on the principles of direct torque control in electrical machines. Its purpose is to manage active and reactive power control loops, much like how DTC controls the torque and flux of induction machines. In this DPC method, depicted in figure 3.2, a switching table plays a crucial role. This table takes inputs of the instantaneous error of active power, reactive power, and the voltage vector position, facilitating the selection of appropriate switching states for the converter [29].

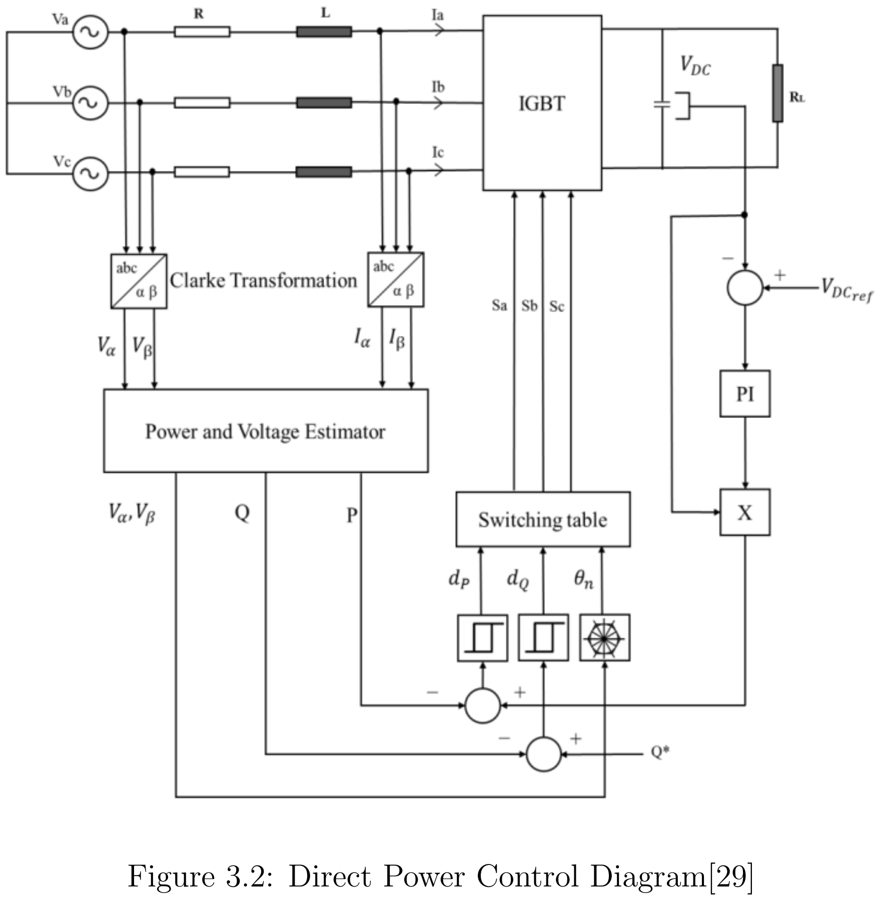

Figure 3.2: Direct Power Control Diagram[29]

In conventional DPC, four voltage sensors and three current sensors are employed to measure the three-phase AC input voltage, DC output voltage, and three-phase input currents[29]. These measurements are then processed through "abc-αβ" blocks utilizing the Clarke Transformation, converting them into corresponding αβ-reference frames. The transformation matrix to the stationary frame is used accordingly. The three-phase input components (xa, xb, xc) and two-phase components (xα, xβ) in the αβ-reference frame are then fed into another block to estimate instantaneous active power (Pinst) and reactive power (Qinst) as indicated in equations 3.2 and 3.3 respectively.

$$\begin{bmatrix} X_\alpha \\ X_\beta \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & \frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} X_a \\ X_b \\ X_c \end{bmatrix} \tag{3.1}$$

$$P_{inst} = \frac{3}{2}[V_\alpha I_\alpha + V_\beta I_\beta] \tag{3.2}$$

$$Q_{inst} = \frac{3}{2}[V_\beta I_\alpha - V_\alpha I_\beta] \tag{3.3}$$

Next, the estimated P_{inst} and Q_{inst} are inputted into a hysteresis comparator to derive active and reactive power errors (dP and dQ). The angle of the input voltage vector (θ_n) is determined by the voltage vector angle converter block. These inputs (θ_n, dP, and dQ) are then used to generate suitable switching states for the converter via the switching table. Finally, a PI controller is tuned appropriately to maintain the output voltage close to the reference DC voltage.

For active power controller:

$$P_{ref} - P < -hp, dP = 0 \tag{3.4}$$

$$P_{ref} - P > -hp, dP = 1 \tag{3.5}$$

For reactive power controller:

$$Q_{ref} - Q < -hq, dQ = 0 \tag{3.6}$$

$$Q_{ref} - Q > -hq, dQ = 1 \tag{3.7}$$

The phase of the input voltage vector in the αβ-frame is given by ϑ. The αβ plane is divided into six sectors as shown in Fig 3.3.

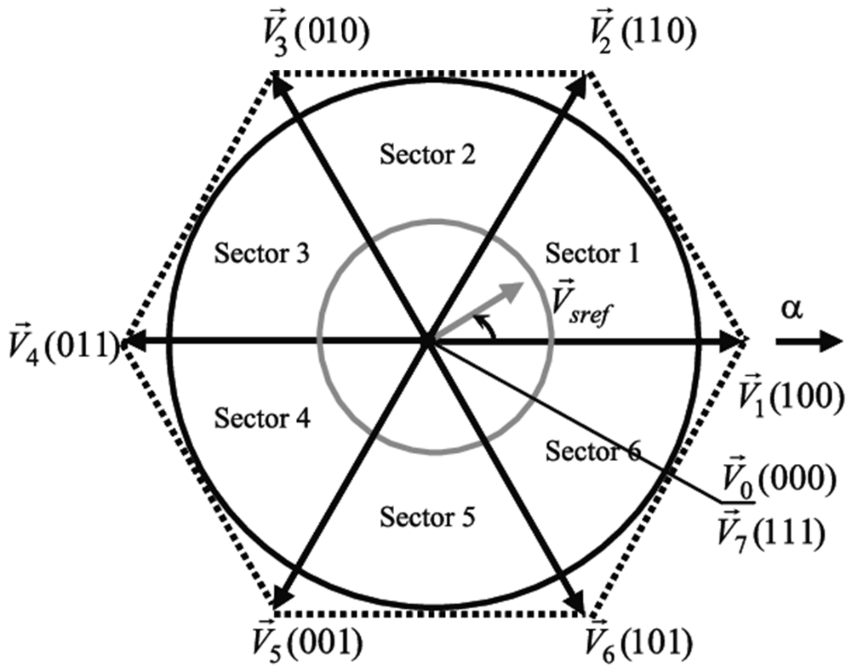

Figure 3.3: Sectors[30]

Table 3.1: Switching Table for Direct Power Control

dP	dQ	θ_1	θ_2	θ_3	θ_4	θ_5	θ_6
0	0	V_1	V_2	V_3	V_4	V_5	V_6
0	1	V_2	V_3	V_4	V_5	V_6	V_1
1	0	V_6	V_1	V_2	V_3	V_4	V_5
1	1	V_4	V_5	V_6	V_1	V_2	V_3

3.4 Cascade control of EV and Station batteries

3.4.1 EV battery control

For the EV battery, the power flows only in a single direction since we have only a charging mode; The buck converter switches are switched on/off using the classical cascade control. The outer loop ensures that the battery voltage stays within limits.

The reference Voltage is selected as the maximum Voltage of the battery, taking its error with the voltage of the battery and passing it through a PI controller gives the reference current Ib*. Next, the current Ib* is in turn subtracted from the actual battery current (Ib) and output is supplied to the battery controller to generate the duty ratio (D), the output of this inner loop is then converted to the gating pulses of the buck converter.

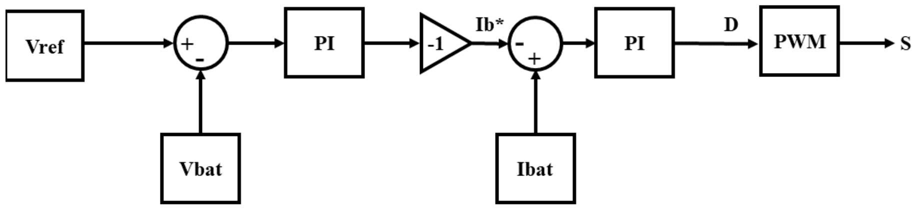

Figure 3.4: EV battery cascade control

3.4.2 Station battery control

The station battery can be either charged or discharged depending on its SOC, the control for charging mode is similar to the EV one; however, for discharging, a constant value of DC link voltage is assumed to maintain the DC-link voltage stable. The following figure describes the control method:

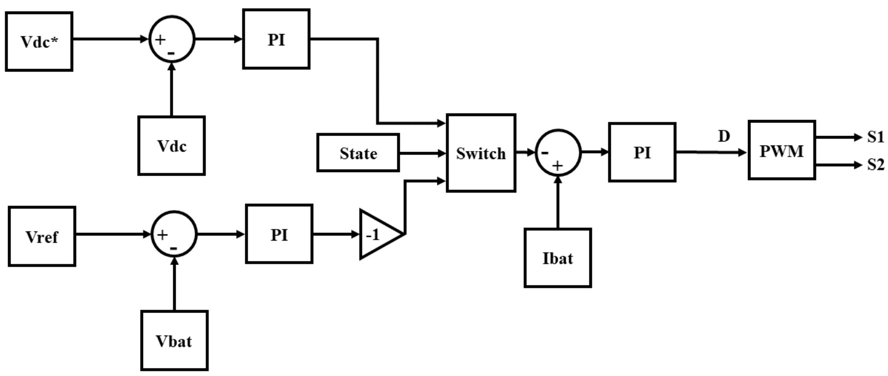

Figure 3.5: Station battery cascade control

3.5 Energy management

Depending on the state of the main power source which is the photovoltaic system, we can differentiate three power modes that describe the energy management scheme in our system:

Excessive power mode

In EPM the PV power exceeds the demand power, whether it be the power supplied to the EV battery alone, or in the case where the Station battery is also charging. The surplus energy is directed to the grid through the inverter.

Floating power mode

In FPM the demand is equal to the power generated from the PV. In this mode, there's no drawing or injecting of energy to the grid.

Deficient power mode

In DPM, the main source can not cover the demand and requires the intervention of the secondary sources. The station battery and the grid work together to compensate for the deficiency. In case the Station battery was in charging mode due to low SOC, the grid will cover also the power requirement of this latter.

This management scheme is depicted in the flowchart of the following figure:

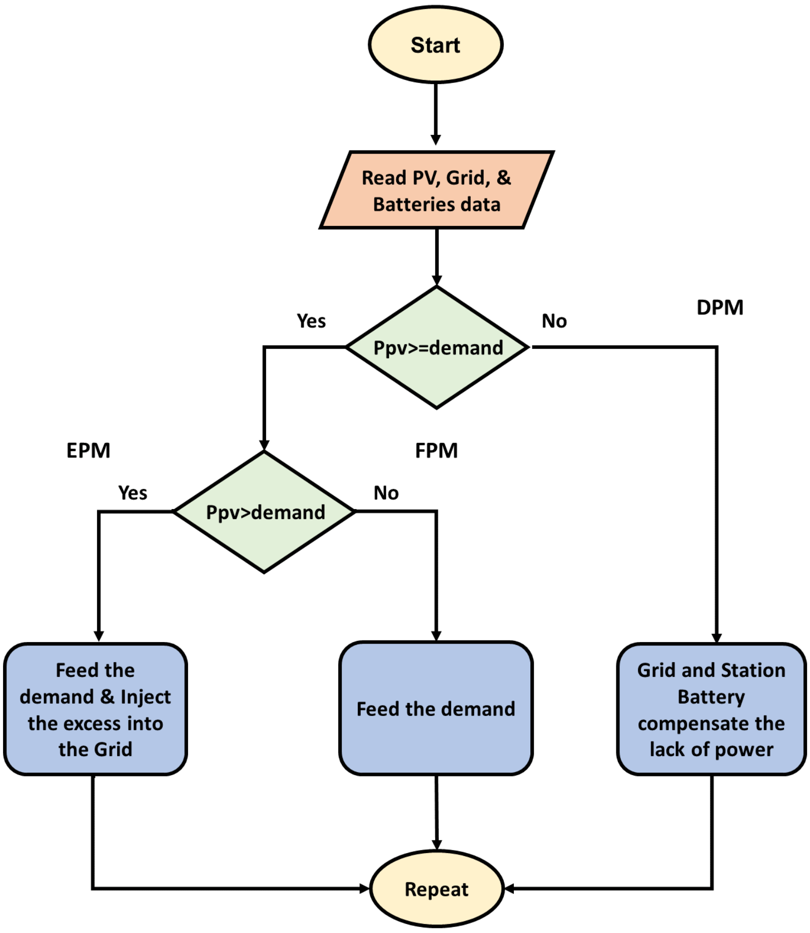

Figure 3.6: Flowchart of the proposed energy management

3.6 Summary and Conclusions

In summary, effective control systems are crucial for the performance and efficiency of EV charging stations. This chapter covered key strategies including MPPT for maximizing energy from renewable sources, DPC for maintaining power quality in AC to DC conversion, and cascade control for optimal coordination of EV and station batteries. Additionally, we discussed energy management strategies to balance demand and enhance efficiency. Implementing these control methodologies is essential for developing reliable and efficient EV charging infrastructure.

Chapter 4

Simulation Results

4.1 Introduction

This chapter focuses on evaluating the performance of the EV battery charging system through different simulation scenarios. These scenarios aim to assess the system's functionality and efficiency under various operating conditions, ensuring optimal performance in every possible case. The simulations were conducted within MATLAB/Simulink simulation environment.

4.2 System parameters

The system is composed of different components that required a well organized interconnection in order to ensure compatibility and stability in the system. These components consisting of a renewable energy source, grid, energy storage system, and power electronics converters, as well as their control blocks were modelled in Simulink.

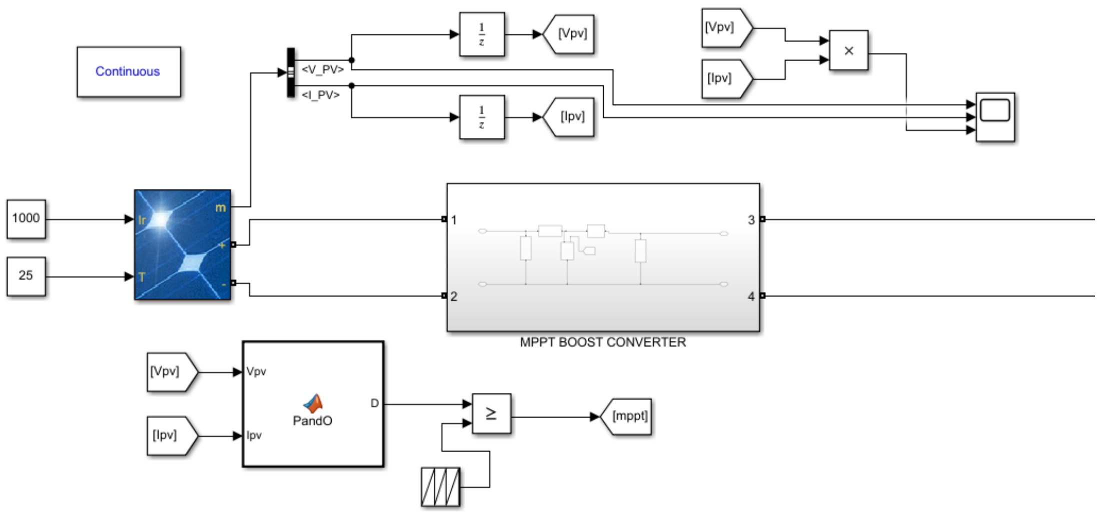

Figure 4.1: PV system and Boost converter model

The model of the photovoltaic system illusrated in figure 4.1 incorporates a solar array of 8 series modules and 6 parallel strings, accumulating approximately 15kW of Power as shown in the characteristics curves in figure 4.2 :

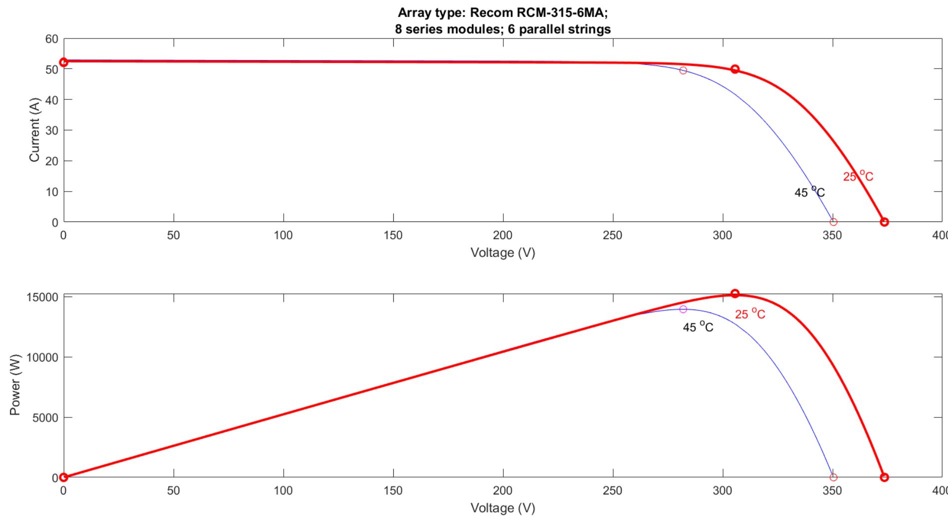

Figure 4.2: PV system characteristics curves

The boost converter increases the output voltage of the PV to meet the DC link reference voltage which was chosen to be 600V. In a similar manner, the voltage coming out of the grid which is a 400V (RMS) and 50 Hz in frequency is converted to DC thanks to a direct power controlled three phase inverter modelled as depicted in the following figure:

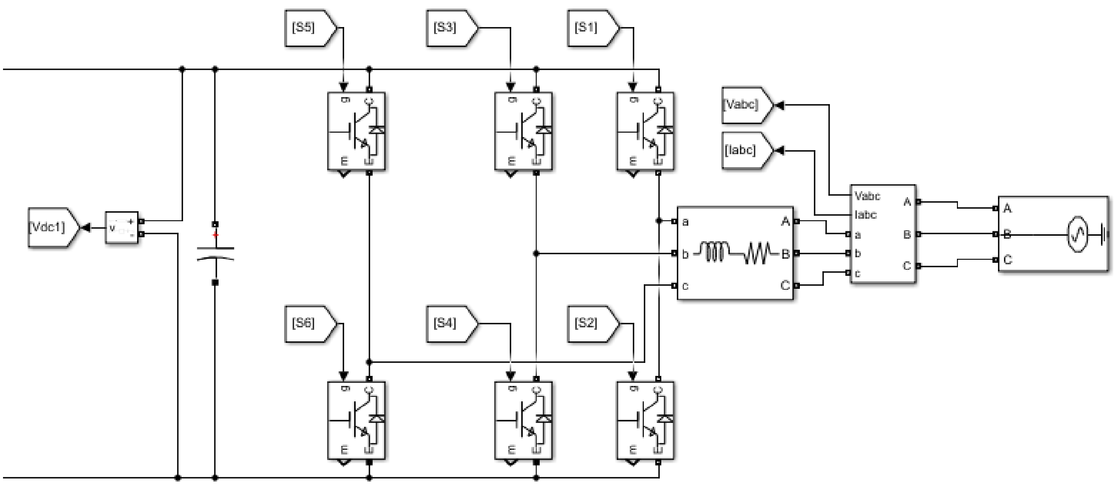

Figure 4.3: Grid and three phase inverter model

The DPC used for controlling the three phase inverter switches is modelled as the following:

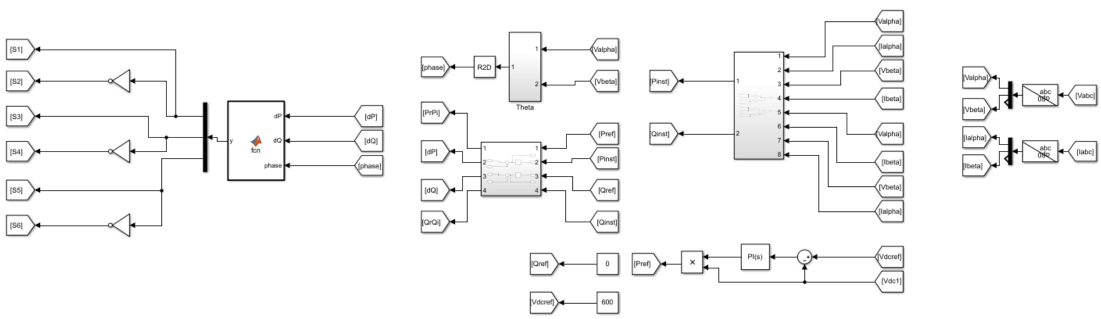

Figure 4.4: Grid and three phase inverter model

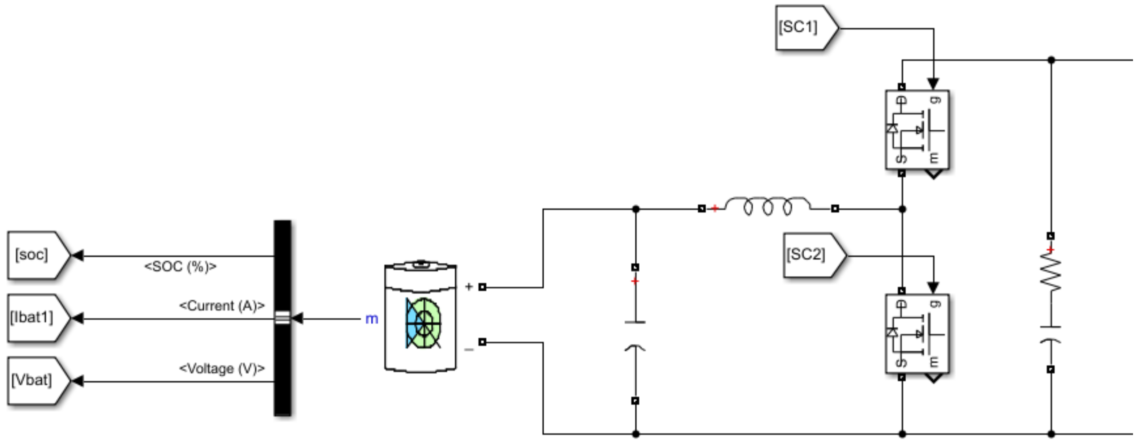

Figure 4.5: Station battery and bidirectional converter model

The station battery that can be seen in fig 4.5 is a lithium ion battery of 300 V and a capacity of 50 Ah. The capacity may be somewhat small compared to real values but that is for the purpose of reducing the long simulation time. The control scheme for the charging and discharging of this battery is depicted in figure 4.6.

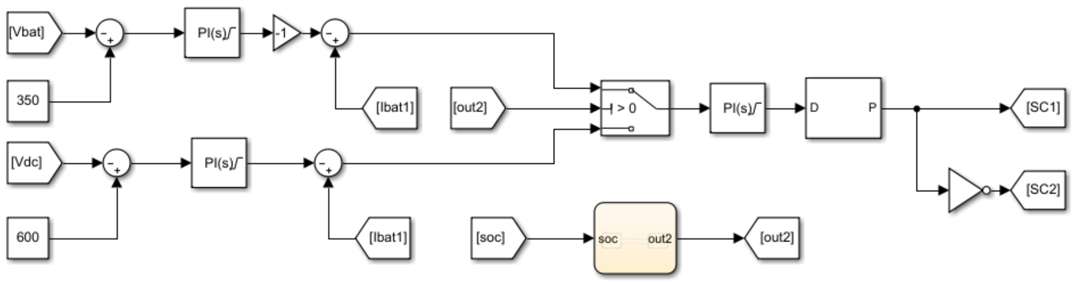

Figure 4.6: Modeling of station battery control system

Implementing both charging and discharging will help us later carry out different simulation scenarios to test the strengths and vulnerabilities of the system.

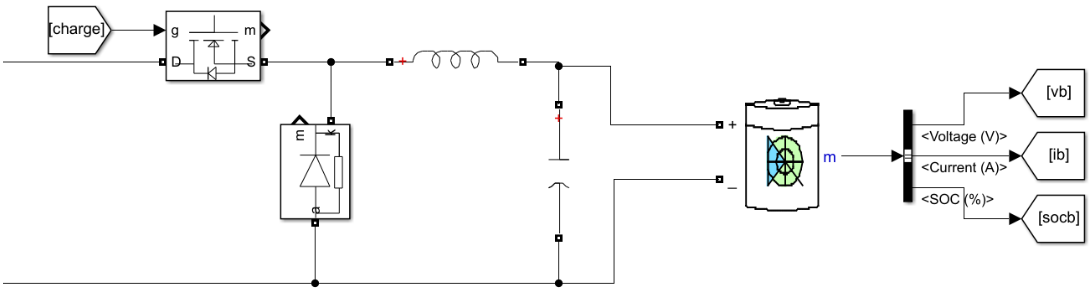

Figure 4.7: Buck converter and EV battery model

The EV battery parameters are identical to the station battery parameters for the sake of simplicity, and its control scheme is illustrated in the following figure:

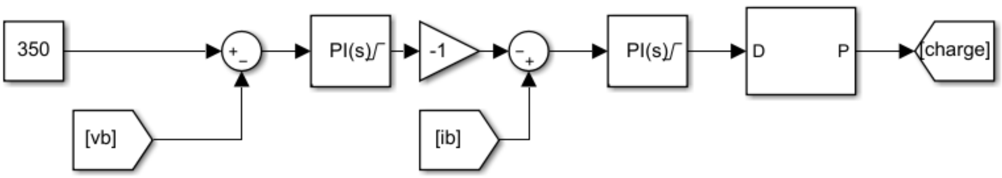

Figure 4.8: Modeling of EV battery control system

4.3 Simulation of different scenarios

With the varying states of the system sources, due to changes in environmental conditions or unexpected fluctuations of power, our system requires robustness and flexibility to give a reliable charging option for EVs. For this particular reason, it is necessary to test it under different scenarios and study its behavior during each one of them.

4.3.1 First scenario

The irradiance is set to 1000 which gives us PV Power at its highest value of about 15kW, and the state of charge of the station battery is set at 30%, thus both batteries are in charging mode.

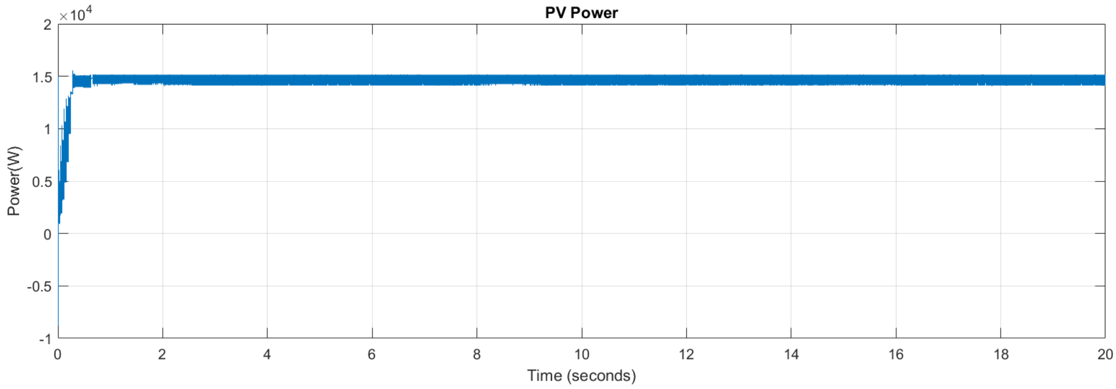

Figure 4.9: PV Power at 15kW

Figure 4.10 shows that the DC link voltage stabilizes after 1 second around the reference value 600V.

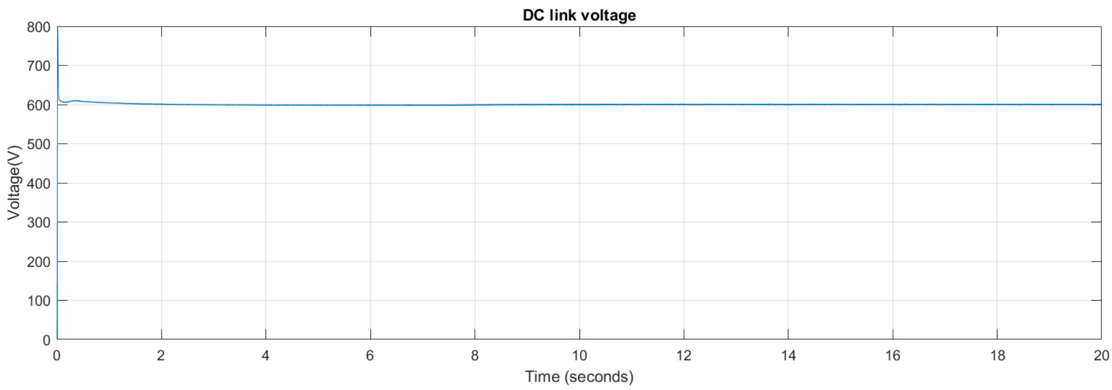

Figure 4.10: First scenario DC link voltage

One can see in figure 4.11 that the power of the grid stabilizes at 0 at second 8, and the system is in floating power mode. The power from the PV is solely used in charging the batteries. Before second 8, the grid power was negative which suggests an injection of power into the grid, this is due to the slow response of the station battery that wasn't charging at its full potential.

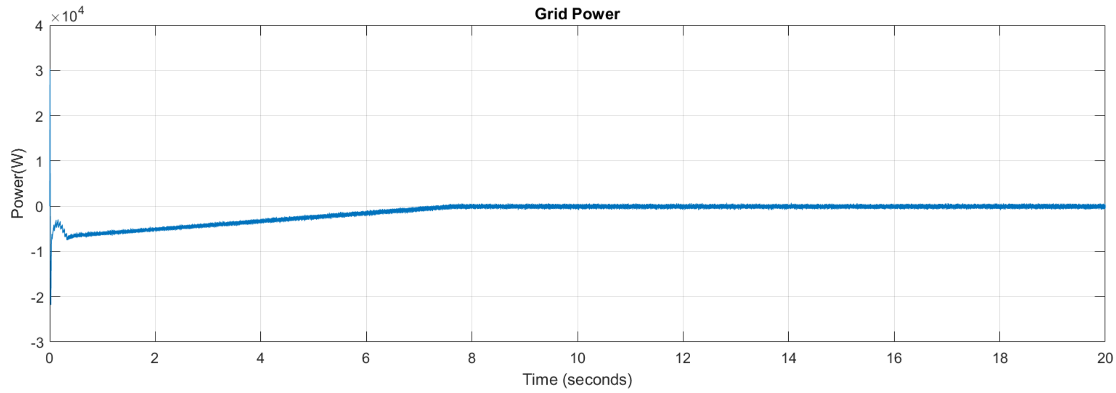

Figure 4.11: First scenario Grid Power

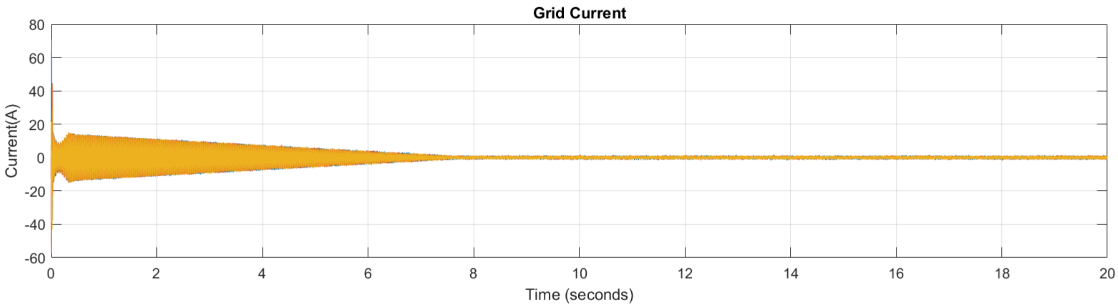

Figure 4.12: First scenario Grid current

Figure 4.12 shows how the current of the grid diminishes to 0 and no power flows through the grid for the reason mentioned before.

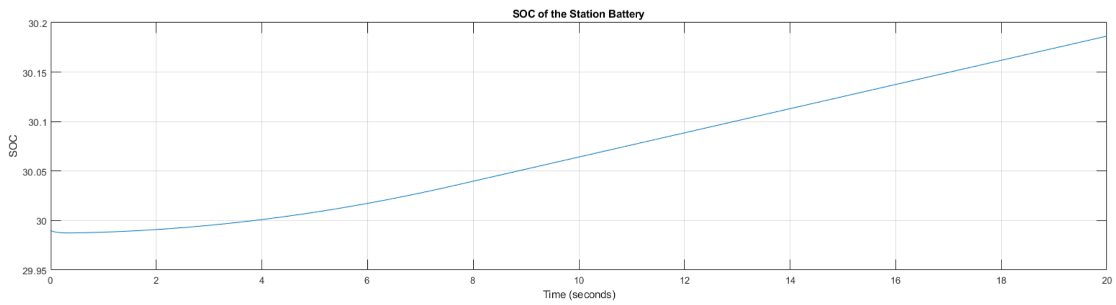

Figure 4.13: First scenario station battery SOC

It is apparent in figure 4.13 how the station battery undergoes sluggish charging at first, however the rate of charging rises, and the battery charges faster as it consumes enough power to render the demand equal to the PV output.

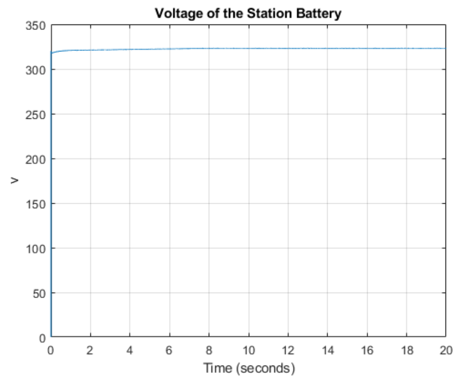

Figure 4.14: Voltage of the Station Battery

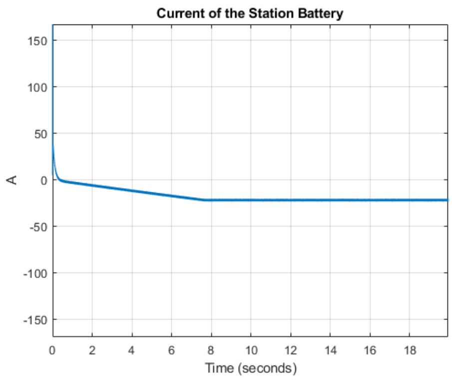

Figure 4.15: Current of the Station Battery

Figure 4.14 and 4.15 represent the voltage and current of the station battery, the battery voltage is at the value of 320 Volts, while the current is negative due to the charging process.

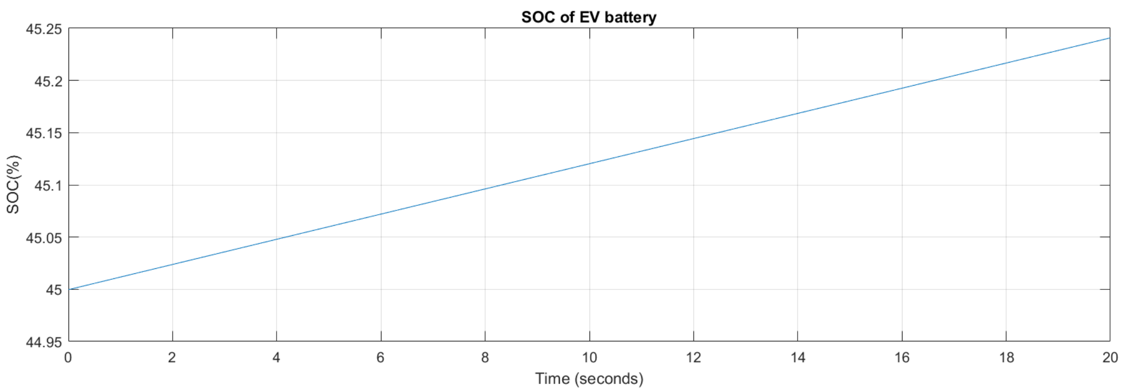

Figure 4.16: First scenario EV battery SOC

Figure 4.16 illustrates the battery SOC during charging. Thanks to the steady charging rate, one can easily calculate the time the battery approximately takes to change from 0% to a 100%, and it is about 2.22 hours.

Figure 4.17 and 4.18 represent the voltage and current of the EV battery, the battery voltage is at the value of 320 Volts, while the current is negative due to the charging process.

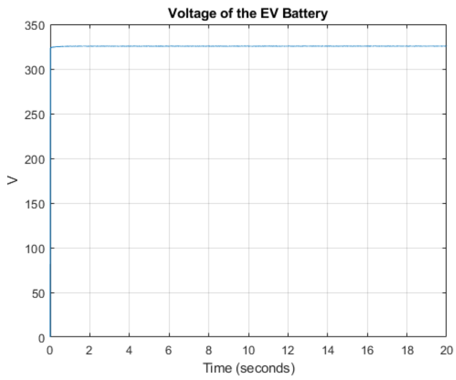

Figure 4.17: Voltage of the EV Battery

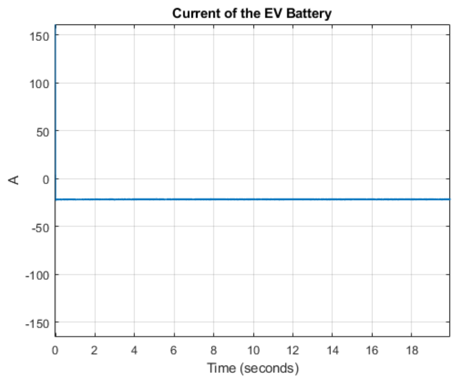

Figure 4.18: Current of the EV Battery

4.3.2 Second scenario

In this scenario, the PV power will gradually decrease due to the varying irradiance levels. These levels, which cycle through the values of 1000, 750, 500, and 250, are illustrated in Figure 4.19. Consequently, the power output will experience corresponding reduction, as shown in Figure 4.20.

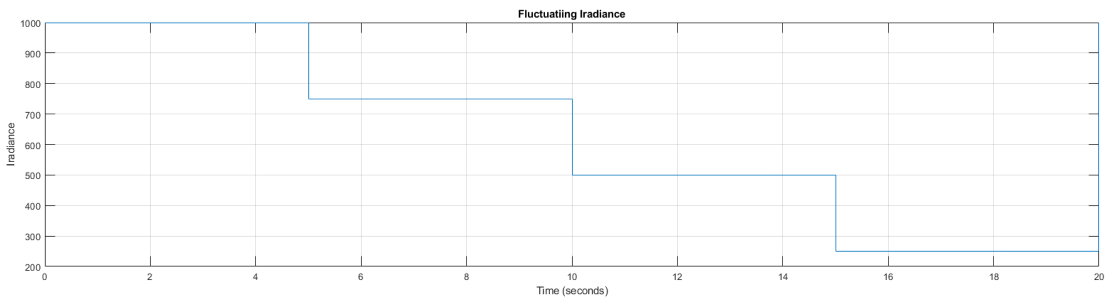

Figure 4.19: Varying Irradiance

In the figure 4.20 below, we can see that the power initially starts at 15 kW. As the irradiance decreases, the power correspondingly drops, showing a sharp dip each time there is a change in irradiance. These sharp dips occur only for a brief moment, after which the power output stabilizes until the next change in irradiance levels.

Figure 4.21 illustrates the DC link voltage, which remains stable at the reference voltage of 600V. Despite the overall stability, there are very slight dips in the voltage that occur each time there is a change in irradiance. These minor fluctuations are

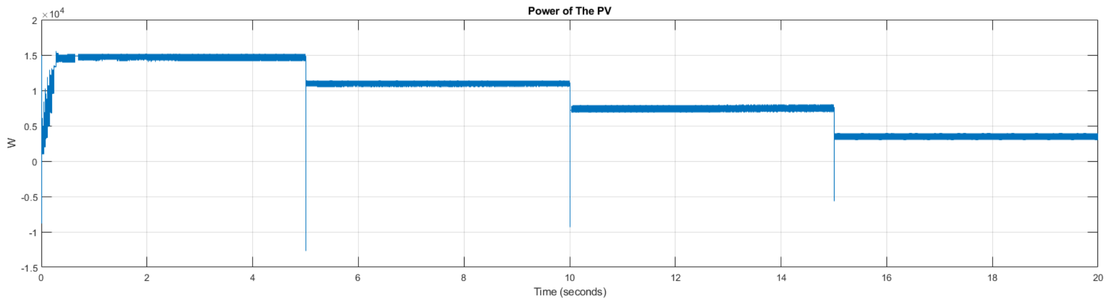

Figure 4.20: Decreasing PV Power

brief and do not significantly deviate from the reference voltage, ensuring that the DC link voltage is largely maintained at 600V throughout the varying irradiance conditions.

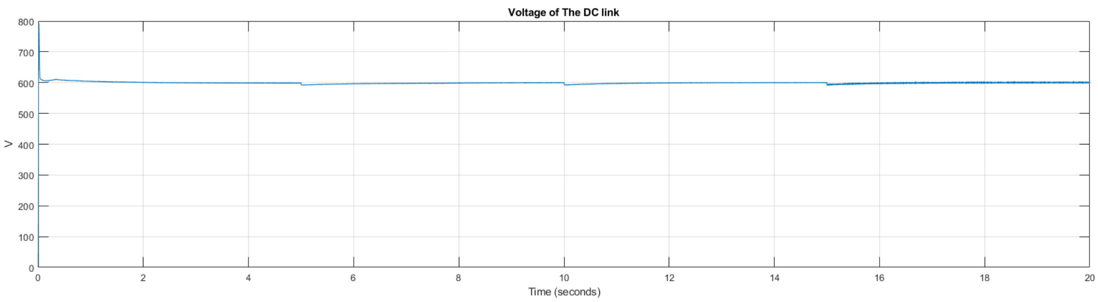

Figure 4.21: Second scenario DC Link Voltage

Figure 4.22 illustrates the changes in power coming from the grid. In the first 5 seconds, the power is negative, indicating an injection of power into the grid. However, during the next 5 seconds, the power turns positive due to a decrease in PV power caused by reduced irradiance. This indicates that the grid is compensating whenever the PV power is insufficient. This trend continues for the remaining 10 seconds of the simulation.

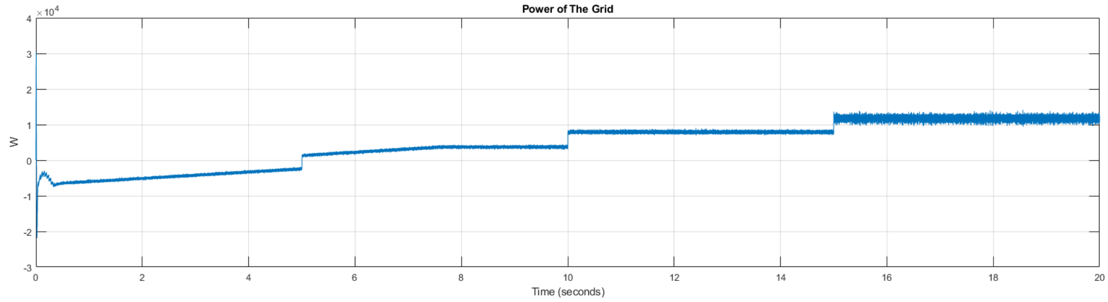

Figure 4.22: Second scenario Grid Power

The following figures show the grid current, which, contrary to the first scenario, kept increasing. This can be explained by the increase in grid power demand from the system.

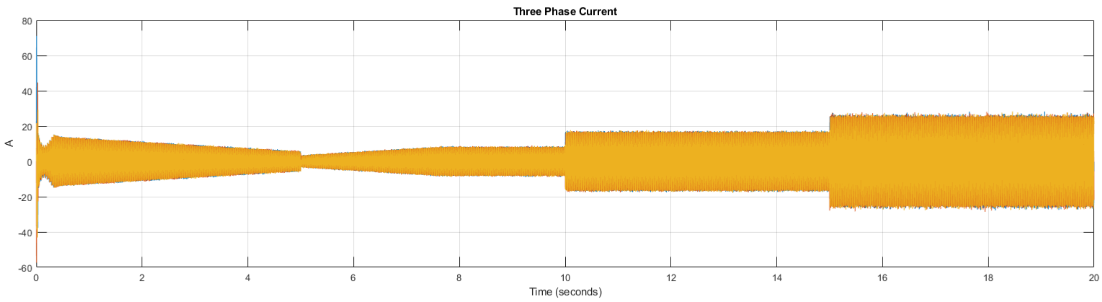

Figure 4.23: Second scenario Grid Current

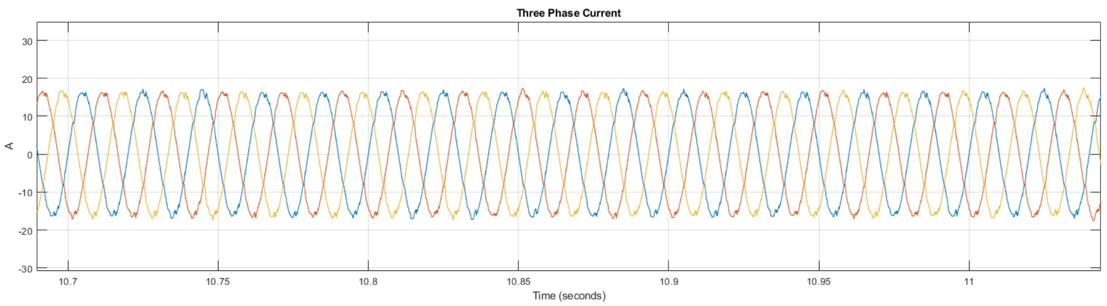

Figure 4.24: Second scenario close up of Grid Current

Figures 4.25 and 4.26 depict the state of charge of both the Station Battery and EV Battery, respectively. There were no changes observed from the first scenario. The charging rate of the EV was maintained throughout the simulation despite the continuous decrease in PV Power and that shows a flexibility in power sharing between the sources to compensate the demand.

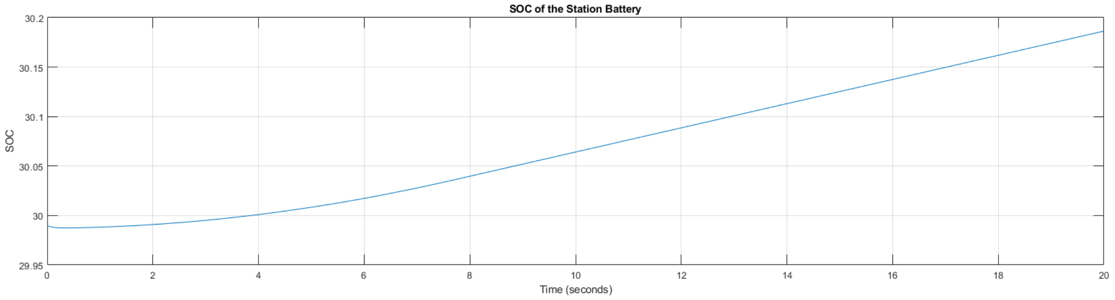

Figure 4.25: Second scenario station battery SOC

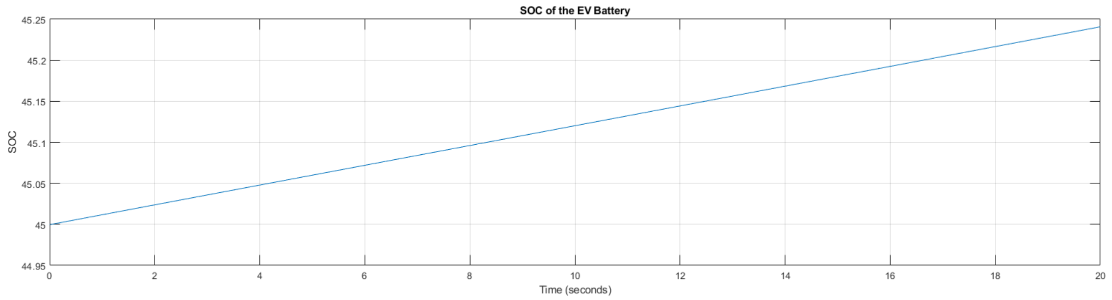

Figure 4.26: Second scenario EV battery SOC

4.3.3 Third scenario

In this scenario, we assumed the total absence of irradiance, in other words the power delivered by the PV is close to none. We set the SOC of the Station battery at 80%, for it to act as a secondary source and help in charging the EV.

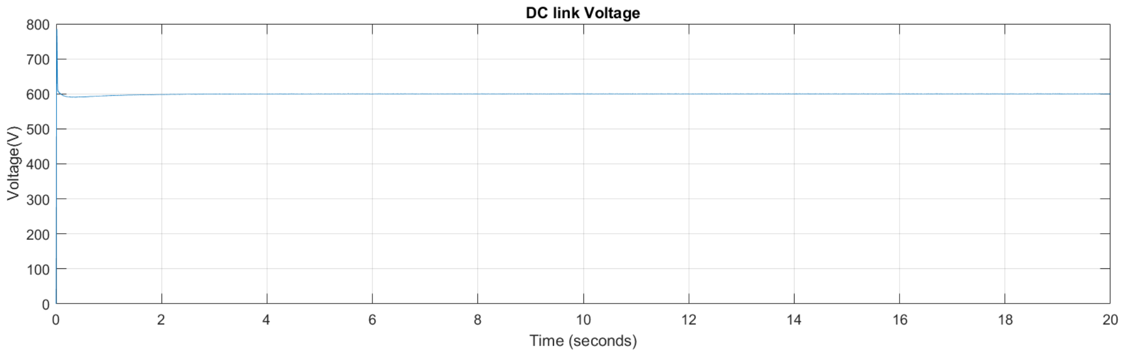

Figure 4.27: Third scenario DC link Voltage

Figure 4.27 shows that the DC link voltage was not affected or disturbed by the absence of PV power, as it is stable around its reference value.

It can be seen in figure 4.28 that the grid, in the absence of PV acted as a main

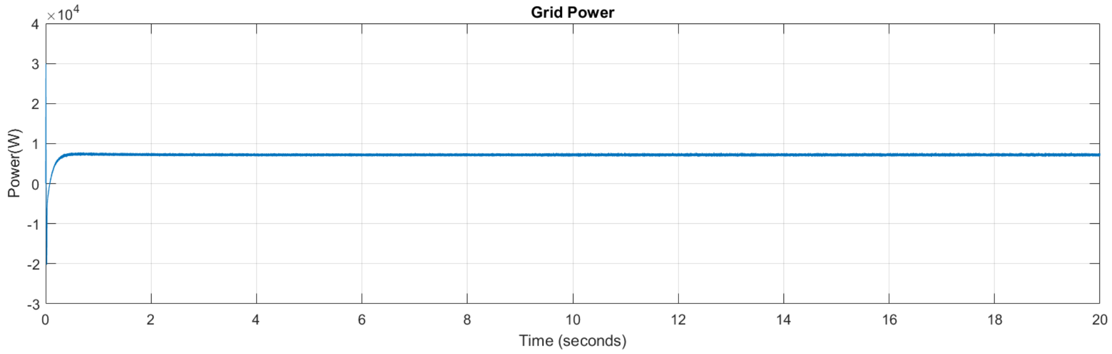

Figure 4.28: Third scenario Grid Power

source to our charging system, as it delivered about 7KW of power to ensure the charging of the EV battery.

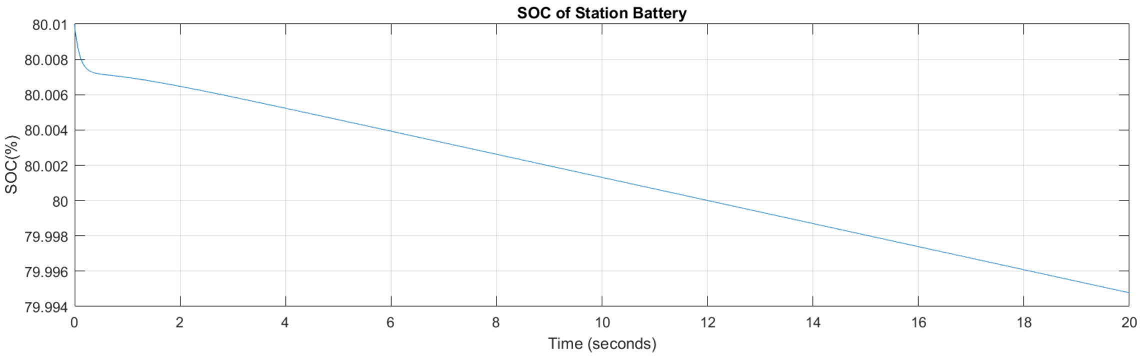

Figure 4.29: Third scenario station battery SOC

As figure 4.29 shows, the discharging of the station battery was very slow, which signifies a very little contribution to the charging of the EV. Nevertheless, this did not affect EV battery charging rate, which can be shown in figure 4.30:

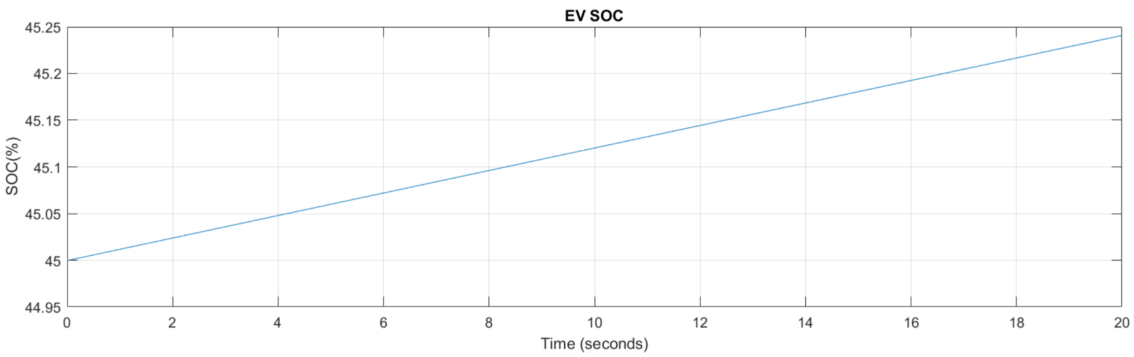

Figure 4.30: Third scenario EV battery SOC

4.3.4 Fourth scenario

As the effect of the station battery was not very obvious in previous scenarios, we limited in this one the output of the grid to simulate a shortage of power in high demand hours, and to ensure the robustness of our system. We kept the irradiance at the same level of the previous scenario to have the chance to record the behaviour of the station battery in such conditions.

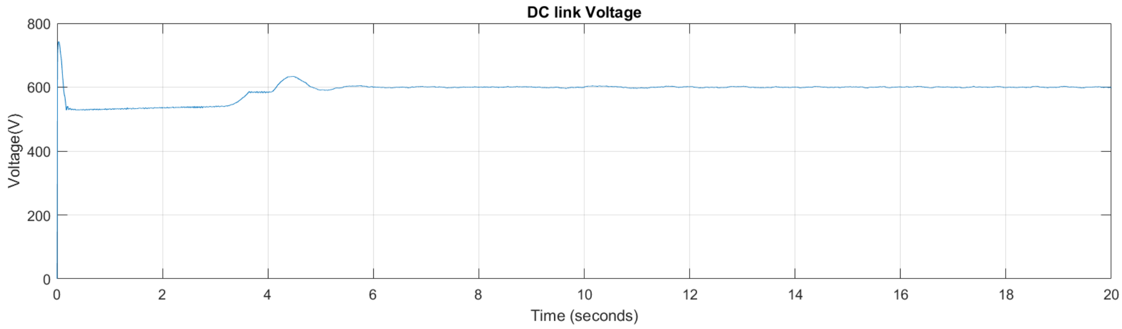

Figure 4.31: Fourth scenario DC Link Voltage

Figure 4.34 shows a fluctuation of voltage at the start of the simulation, before the DC link settled at its reference voltage at t= 6 s. This fluctuation might have been caused by the sharp decrease in grid power as shown in figure 4.32:

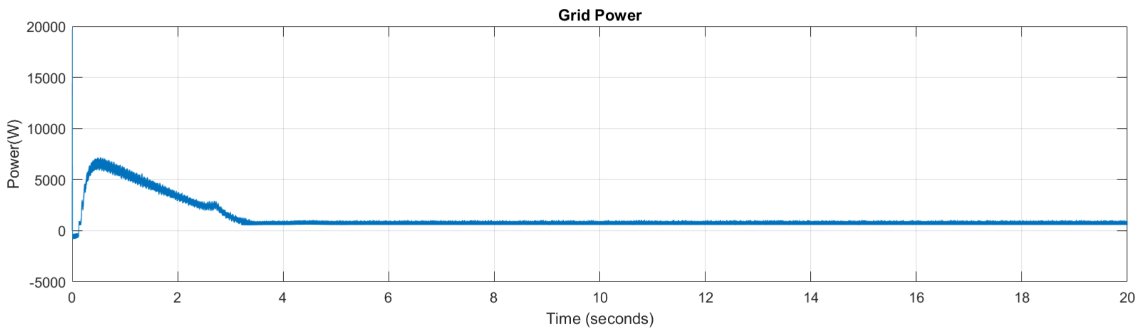

Figure 4.32: Fourth scenario Grid Power

This limitation of grid power was compensated by the station battery, which had a faster charging rate indicating a power flow from it to the EV battery. As can be shown in the following figures:

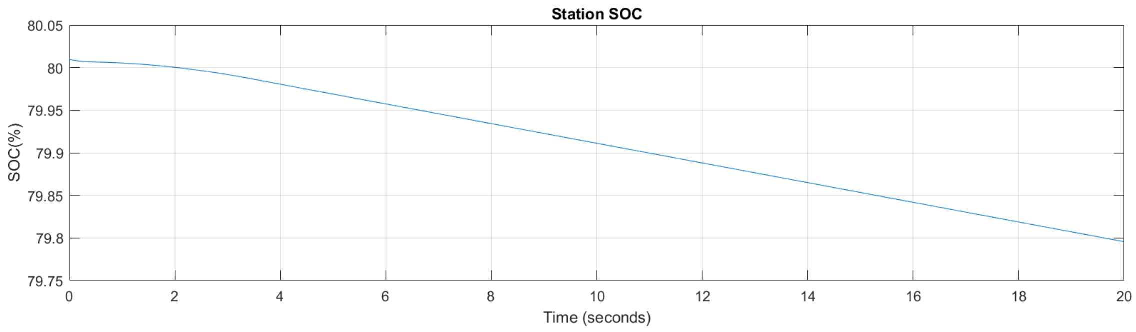

Figure 4.33: Fourth scenario station battery SOC

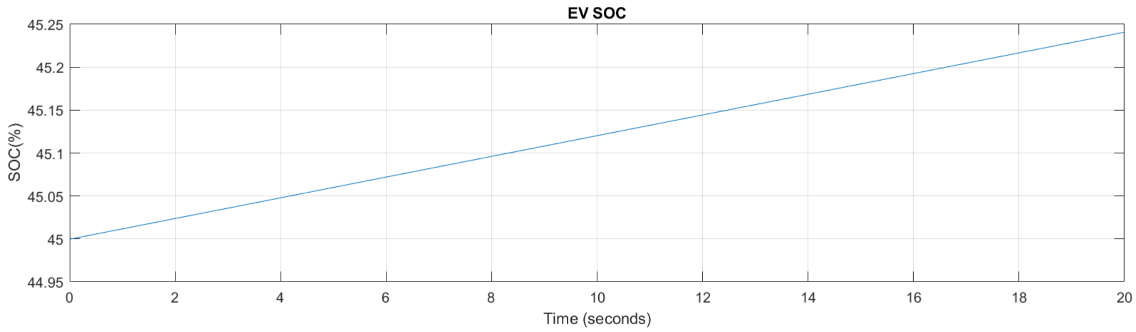

Figure 4.34: Fourth scenario EV battery SOC

4.3.5 Fifth scenario

In this scenario we assumed that both batteries are fully charged and we wanted to test the ability of the station in working as a distributed energy resource (DER). We set the PV Power at 15KW and observe the behaviour of the system.

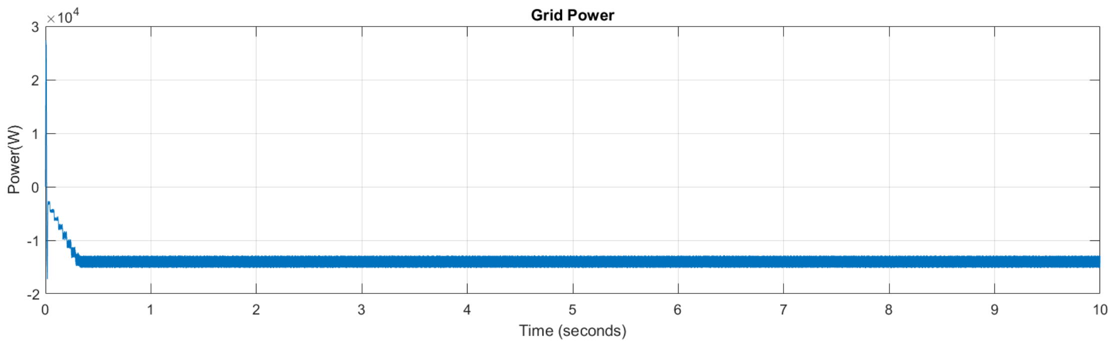

Figure 4.35: Fifth scenario Grid Power

As can be seen in figure 4.35, the power is negative and settling about the value of -15KW thus the output of the PV was injected directly to the grid. This proves the capability of the system to provide power to the grid whenever there's a need for it.

4.4 Conclusion

In this chapter, we have revealed the simulated model of our system and all of its components, and presented the results of the simulation under various scenarios. The scenarios emphasize on the different conditions that could affect on the performance of the system and allowed a thorough analysis of parameters such as PV power, DC link voltage, Grid Power and the behaviour of the batteries. The results of these simulations provided interesting insights about the reliability and flexibility of the system as well as its limitations.

Conclusion and Future Work

Conclusion

This report investigated the creation of a battery charging system for EVs that incorporates several energy sources, such as solar PV panels, a backup battery, and the electrical grid. The report aimed to develop a dependable charging station that could provide a consistent power output in a range of different scenarios.

The main conclusions show that, while operating in ideal conditions, the system functions great and the PV panels provide the required power. Through the complementary support of the grid and backup battery, the system was able to successfully sustain stable power output even in bad conditions. Although there were a few little issues with the system's operation, they had little effect on how it worked as a whole.

The successful implementation of such a system holds significant implications for the EV field. Widespread adoption of this integrated approach could enhance the reliability and efficiency of EV charging infrastructure, contributing to the advancement of the EV industry.

This study's findings highlight the benefits of combining various energy sources for EV charging stations. The results demonstrate how feasible it is to develop a strong and dependable charging system that makes use of renewable energy, benefiting both the environment and the growth of the EV market.

Future Work

For future work, there is always room for improvements, better control strategies can be used such as for maximum power point tracking where a more intelligent and optimized technique can be used, since the classical P&O is regarded as less efficient compared to other modern techniques.
- Another aspect that ought to be addressed is the power quality, where grid current should be analyzed and the total harmonic distortion should be determined, and the DPC can be improved also by using more developed techniques like model predictive control.
- Vehicle to grid mode can also be an interesting addition to the system as it enhances its efficiency and makes it a more reliable option.
- One other aspect that would upgrade the system is the integration of artificial intelligence in controlling the energy flow within the system as well as the communication between the station and the EV.
- Finally, a real time simulation and an experimental implementation would be a fine completion for the project.

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Appendix

PV Array

Figure 36 shows the characteristics of the PV array used in the charging station:

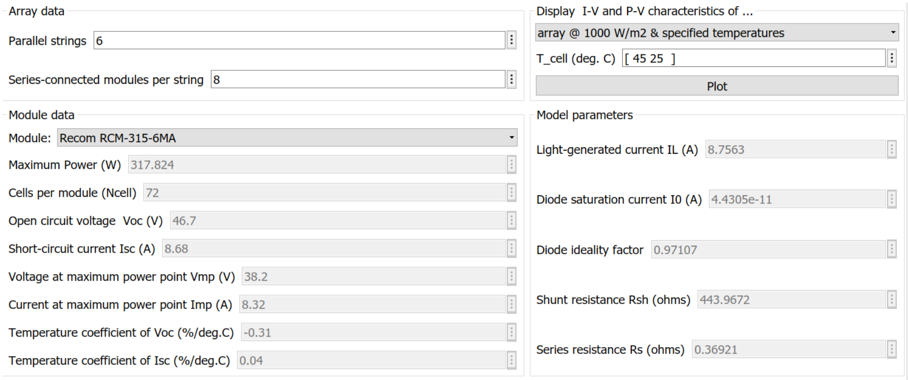

Figure 36: PV Characteristics

EV and Station Battery

Figure 37 shows the characteristics of the EV and station batteries used in the charging station:

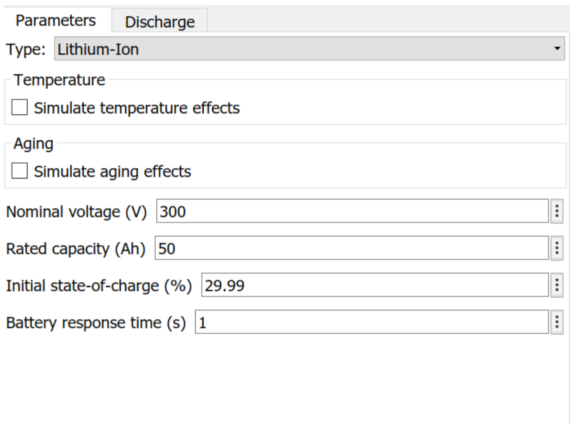

Figure 37: Battery Characteristics