بسم الله الرحمن الرحيم

Electric Vehicle Charge Station

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الملخص

محطة شحن للسيارات الكهربائية

أصبحَ التوجه الى استخدام التنقل الكهربائي أكثر من أيِ وقتٍ مضى في قطاع النقل بسبب تضرر البيئة لارتفاع نسبة ثاني اكسيد الكربون في الجو نتيجة استعمال السيارات التي تعمل بواسطة محركات الاحتراق الداخلي ومن أهم هذه الطرق الصديقة للبيئة للتنقل هي السيارات الكهربائية . والسيارات الكهربائية تعملُ في المقام الأول بواسطة محرك كهربائي يتم تغذيتة بواسطة مصدر طاقة قابل لِأعادة الشحن وهي البطاريات حيث يعادُ شحنُها باستخدام شاحن كهربائي خاص .

في هذا المشروع سيتم دراسة السيارات الكهربائية ومكوناتها ووظيفة كل مُكون وكذلك التقنات المستخدمة فيها و البطاريات بأنواعها ونظام إدارة البطارية وتقنية شحن السيارات الكهربائية ومستويات الشحن وانماط الشحن وأنظمة الشحن حسب المعايير والمقاييس العالمية المعتَمدة.وأيضا سَيتم عرض أهم التِقَنيات الحديثة حول أجهزة شحن السيارات الكهربائية,وبالتالي من خلال هذه الدراسة بالإمكان أخذ الصورة العامة وفهم أنظمة شحن السيارات الكهربائية .

الهدف النهائي للمشروع هو تصميم نموذج لِمحطة شحن للمَركبات الكهربائية حسب المواصفات والمعايّر العالمية المعتمدة بأستخدام برنامج (MATLAB).

Abstract

Electric Vehicle Charge Station

The trend towards using electric mobility has become more than ever in the transportation sector due to the environmental damage and the high level of carbon dioxide in the atmosphere as a result of the use of cars that are powered by internal combustion engines. Electric cars are primarily powered by an electric motor that is fed by a rechargeable power source which is the batteries where they are recharged using a special electric charger.

In this project, the electric vehicle and their components, the function of each component will be studied, as will the technologies used and the batteries of all kinds, Batteries, Battery Management System, the charging technologies of electric vehicles, related standards, charging levels, charging modes and Charging Schemes are described. Also, EV charging sockets are explained clearly. The whole issue about chargers is presented for commercial EV manufacturers. Consequently, the big picture of the electric vehicle charging system could be easily seen in this project.

The main aim of this project is the design and implementation of an electric vehicle charge station with the international protocols and standards for electric vehicles using MATLAB.

الإهداء

إلى من هم أشرف منا جميعا ... الشهداء و الأسرى

إلى التي علمتني درساً بالعقيدة ودرساً أخر في حب الوطن بضربة يد عندما رأتني أَرسم بالنقل واجبي البيتي رسم خارطة فلسطين و أنا بالسادسة من عمري ... إلى أمي.

إلى نبع العطاء الذي لا ينضب... أبي.

إلى بانية الجيل الواعد ... للغراء جامعتي ...جامعة بوليتكنك فلسطين .

إلى كلية الهندسة.

إلى دائرة الهندسة الكهربائية ...بطاقمها الأداري و التدريسي.

إلى المشرف على البحث الدكتور الفاضل ...فؤاد الزرو.

إلى أهلي و عشيرتي و أصدقائي و زملائي و زميلاتي.

إليكم جميعاً أهدي عملي المتواضع هذا.

فريق العمل

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Finally, we would like to thank our university for the help and support provided in its facilities for the past five years, and for our electrical engineering department for the large effort had been spent during our study to reinforce us with all knowledge needed.

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Abbreviations

EV	Electric Vehicle
ICE	Internal Combustion Engine
BEV	Battery Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
HEV	Hybrid Electric Vehicles
FCEV	Fuel cell electric vehicles
BMS	Battery Management System
DoD	Depth of Discharge
EVSE	Electric Vehicle Supply Equipment's
RES	Renewable Energy Sources
IEC	International Electrotechnical Commission
SAE	Society for Automotive Engineers
SoC	State of Charge
SoH	State of Health
V2G	Vehicle to Grid
V2H	Vehicle to Home
V2V	Vehicle to Vehicle
AC	Alternative Current
DC	Direct Current
CO2	Carbon Dioxide

LI-ION	Lithium ion
PalEV	Palestine electric vehicle company
CHAdeMO	Charge de Move
THD	Total Harmonic Distortion
kWh	Kilowatt-hour
Wh	Watt-hours
km/h	Kilometers per hour
ZEVs	Zero-Emissions Vehicles
TBD	To Be Defined
PV	Photovoltaics

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Chapter One

Introduction

1. Introduction

1.1 Overview

Electric Vehicles (EVs) are a promising technology for drastically reducing the environmental burden of road transport. More than a decade ago and also more recently, they were advocated by various actors as an important element in reducing CO2 emissions of particularly passenger cars and light commercial vehicles as well as emissions of pollutants and noise.

It is expected that 500 million electric vehicles will be on the roads by 2030. The technology and infrastructure for the charging of electric vehicles will be the key enabler for this mobility transition. EV charging facilities will be required at homes, workplaces, shops, recreational locations and along highways. The EV charging power has to be provided by the distribution network at low cost, with minimal reinforcement and at maximum reliability [1].

Charging time reduction is one of the key goals in making electric vehicles user-friendly. In this context, fast DC charging offers an interesting opportunity. It allows for reducing charging time [1].

1.2 History of Electric Vehicles

In 1801, the steam-powered carriage was built, opening the era of horseless transportation. After thirty years of noise and dirtiness due to steam engines, the first battery-powered EV was built in 1834. Over fifty years later, the first gasoline-powered ICE vehicle was built in 1885. In 1899, the first-ever propulsion vehicle developed was an EV, which could run at a speed of over 100 km/h. This vehicle is presented in **(Figure 1.1)**. So, EVs are not new and already over 170 years old. With the drastic improvement in combustion engine technology, ICE vehicles showed much better performance and EVs were out of use from the 1930s to the 1950s [1].

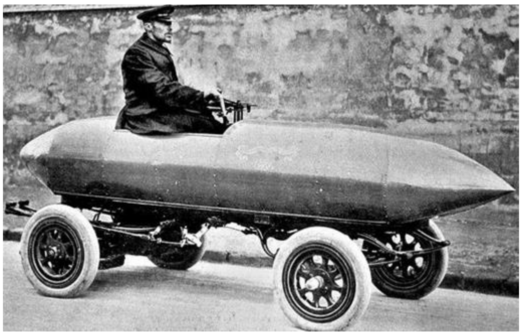

Figure 1.1 First Electric Vehicle

At the end of the 19th century, the automobile industry started to focus more on the ICE vehicle. In the late 1990s, Toyota sold its first hybrid car: the Prius. This marked a new era in the automotive sector. At the end of 2019, Tesla released the latest version of its fully electric vehicles Cybertruck with high specifications. This vehicle is presented in **(Figure 1.2)**

Figure 1.2 Electric Vehicle Cybertruck 2019

1.3 Motivation

Electric vehicles become much more popular and important day by day for many people and companies because they are more economical and less maintenance. Because of that, electrical charging stations of all kinds are installed and activated, especially the fast-charging stations in different Palestinian cities and regions, in addition to developing the appropriate infrastructure to establish and install these stations such as home chargers, or in the headquarters of companies, institutions and municipalities as fast-charging stations.

Recently, PalEV Company installed the first charging station in the Ramallah and Al-Bireh governorates, followed by a station in the city of Hebron, Nablus, and Bethlehem, to include the rest of the Palestinian cities and vital places.

1.4 Objectives

The aim of this project is design and implementation electric vehicle charge station with the international protocols and standards for electric vehicles, the objectives are:

1) Design of EV charging station.
2) Implementation Design on MATLAB.
3) Design protection type for EV charging station.

1.5 Literature Review

Future of Electric Vehicle Charging, This paper focuses on five technologies that will play a fundamental role in this regard: smart charging, vehicle-to-grid (V2G), charging of EVs from photovoltaic panels (PV), contactless charging and on-road charging of EVs. Smart charging of EVs is expected to enable larger penetration of EVs and renewable energy, lower the charging cost and offer better utilization of the grid infrastructure [2].

Modeling of an Electric Vehicle Charging Station for Fast DC Charging. The proposed model of an electric vehicle charging station is suitable for the fast DC charging of multiple electric vehicles. The station consists of a single grid-connected inverter with a DC bus where the electric vehicles are connected. The control of the individual electric vehicle charging processes is decentralized, while a separate central control deals with the power transfer from the AC grid to the DC bus [3].

Review of Charging Technologies for Commercial Electric Vehicles. In this paper, the different EV charging methods are presented. An electric vehicle can be charged with conductive or inductive charging method. Using the conductive method the battery is connected by a cable and plugged directly into an electricity provider. The inductive method, in contrast, works through electromagnetic transmission without any contact between the EV and the charging infrastructure.

The EV charging levels, modes, and types are examined in this study. The charging level describes the power level of a charging outlet. Charging mode describes the safety communication protocol between EV and charging stations. There are four different charging modes namely Mode 1, Mode 2, Mode 3 and Mode 4 [4].

2

Chapter Two

Electric Vehicles

2.1 Types of Electric Vehicles

2.2 Main Components in EV

2. Electric Vehicles

An electric vehicle (EV) is a vehicle equipped by an electric motor, instead of an internal combustion engine (ICE), and the motor is run using the power stored in the batteries. The batteries have to be charged frequently by plugging into the main supply.

EVs are known as zero-emissions vehicles (ZEVs) and are much environment-friendly than gasoline vehicles. As EVs have fewer moving parts, maintenance is also minimal. With no engine, there are no oil changes, tune-ups, or timing and there is no exhaust. EVs are also far more energy-efficient than gasoline engines and they are very quiet in operation [5].

2.1 Types of Electric Vehicles

An EV can be broadly categorized into two types: Battery electric vehicle (BEV) one that runs just on electricity and the hybrid electric vehicle (HEV) that combines the electric energy with any other source. And the types are:

1) Hybrid electric vehicles (HEVs).
2) Plug-in hybrid electric vehicles (PHEVs).
3) Battery electric vehicles (BEVs).

2.1.1 Hybrid electric vehicles (HEVs).

Hybrid electric vehicles (HEVs) incorporate more than one propulsive power source to energize the vehicle. They have the ability to optimize the propulsive energy of the vehicle by effectively utilizing dual power sources and achieve higher mileage and reduce greenhouse gas emissions [5].

HEVs are integrated with an internal combustion engine (IC engine) and electric machines, which are energized by the onboard electric battery, ultra-capacitor, or a combination of both.

The common configuration is a battery coupled with the ICE or fuel cell. The series architecture, as shown on the **(Figure 2.1)** consists of using the ICE directly coupled to an electric motor. The electric propulsion system provides higher acceleration performance at low speed, which cannot be achieved in conventional vehicles due to the various mechanical constraints of the IC engine. Owing to the increased number of propulsive components and complexity, the power management and control system in the HEVs plays a vital role in maximizing its overall energy efficiency and achieving higher operating performance, while significantly reducing emissions. The key features and the primary difference between hybrid and conventional vehicles are listed in **Table 2.1**.

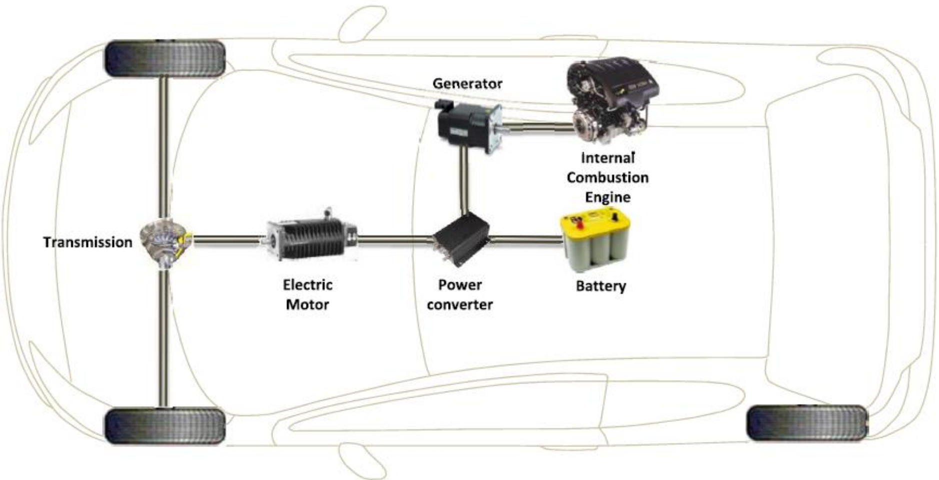

Figure 2.1 Hybrid electric vehicles (HEVs).

Table 2.1 Comparison between conventional and Hybrid electric vehicles

Features/Requirements	Conventional vehicles	Hybrid electric vehicles
powertrain	IC engine	IC engine +EM
Energy source	Gasoline	Gasoline + battery
Energy container	Fuel tank	Fuel tank + battery
Transmission system	Mechanically and hydraulically actuated transmission system	Electrically ,mechanically and hydraulically actuated transmission system
Emissions	Higher emissions during operation	Lower emission during operation
Operational energy Efficiency	Low energy efficiency during Stop-and-go(city)driving condition	Higher energy efficiency during stop-to-go (city) Driving condition
Technology	Matured technology	Growing technology
Cost	Inexpensive	Expensive
Maintenance	Relatively easier	Complex due the involvement of multiple systems
Energy recovery system	No energy-recovering capability during braking	Energy-recovering capability during braking

2.1.2 Plug-in hybrid electric vehicles (PHEVs).

PHEV is a category of hybrid vehicles. It is similar to the HEV in that it has double motorization, an ICE and battery pack, shown in **(Figure 2.2)**. PHEVs are identified as HEVs that have battery storage capabilities, which allow its recharging from an external charger and not its braking system. This gives it the ability to function for a minimum of 20 kilometers while in electric mode. These types of vehicles can operate on fossil fuels energy and electricity, or both; consequently, leading to vast advantages inclusive of less oil dependency, enhanced fuel economization, raised the efficiency of power and reduced environmental obstruction [5].

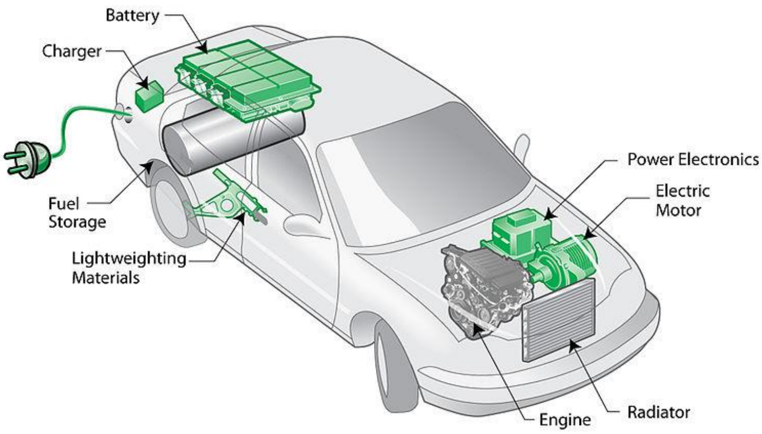

Figure 2.2 Plug-in hybrid electric vehicles (PHEVs).

2.1.3 Battery electric vehicles (BEVs).

Energy is normally produced by plug-in rechargeable battery-packs and sometimes capacitors or flywheels. The manner of charging is the same as PHEVs. The fundamental systems in BEVs consist of the electric motor, the battery-pack and power controller, which can be seen in **(Figure 2.3)**. Nowadays a BEV can function by way of BLDC or PMSM and in some cases AC electric machines [5].

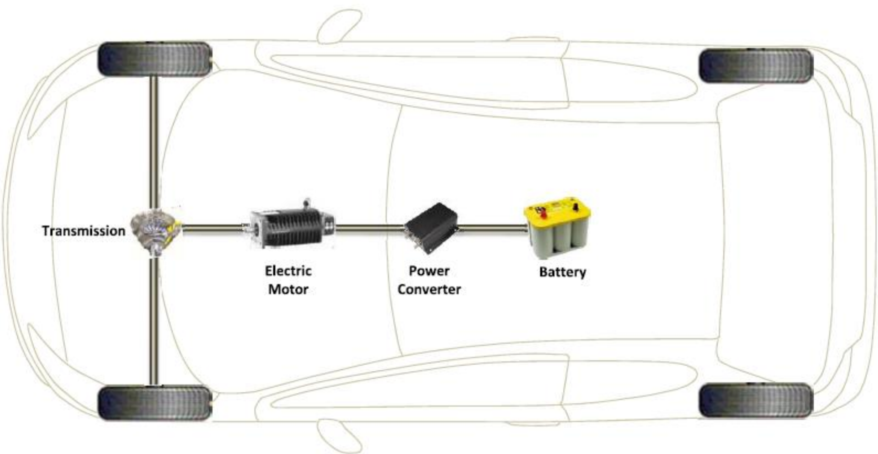

Figure 2.3 Battery electric vehicles (BEVs).

In 2017, the common EV BMW I3 model 2017, and Nissan leaf model 2017 presented in **(Figure 2.5)** with vehicle characteristics in **Table 2.2**.

Table 2.2 Characteristics of BMW I3 & Nissan Leaf EV

	BMW i3 model 2017	**Nissan leaf model 2017**
Battery	Li-ion	Li-ion
Range	114 Miles	107 Miles
High-voltage battery	353 Volts	360 Volts
Battery capacity	33 kWh	30 kWh
Battery charging time	4.5 hours	6 hours
Electric motor	Synchronous electric motor	Synchronous electric motor
Maximum power	125 kW	80 kW
Maximum torque	250 Nm	254 Nm
Maximum speed	150 km/h	144 km/h

Figure 2.4 BMW i3 & Nissan leaf EV’s Model 2017

2.2 Main Components In EV

2.2.1 Electrical motor

The motor is the main component of an EV. It is very important to select the proper type of motor with a suitable rating. An electric motor is a machine that converts electrical power to mechanical power. They work as an interaction between the winding currents and magnetic field of the motor to produce a rotational force. The electric motor can be powered either by an alternating current (AC) sources such as inverters or by a direct current (DC) source such as batteries or rectifiers [6].

There are a number of motors available for an electric vehicle: DC motors, Induction motor, DC brushless motor, permanent magnetic synchronous motor and Switched reluctance motor.

2.2.1.1 DC Motors

It is a classic motor and has been used in motor control for a long time. All the power involved in electromechanical conversion is transferred to the rotor through stationary brushes which are in rubbing contact with the copper segments of the commutator. It requires certain maintenance and has a shorter lifetime. However, it is suitable for low power applications. It has found applications in electric wheel-chair, transporter, and micro-car. Today, most of the golf-carts are using DC motors. The power level is less than 4kW [6].

2.2.1.2 Induction Motor

It is a very popular AC motors. It also has a large market share in variable speed drive application such as air-conditioning, elevator or escalator. Many of the higher power electric vehicles, for more than 5kW, uses induction motor. Usually a vector drive is used to provide torque and speed control [7].

2.2.1.3 DC brushless motor

The conventional DC motor is poor mechanically because of the low power winding, the field is stationary while the main high power winding rotates. The high power winding is put on the stationary side of the motor and the field excitation is on the rotor using a permanent magnet. The motor has a longer lifetime than the DC motor but is a few times more expensive. Most of the DC motor can be replaced by a brushless motor with a suitable driver. Presently, its applications find in low power EV [7].

2.2.1.4 Permanent magnetic synchronous motor

It is equivalent to an induction motor but the air-gap filed is produced by a permanent magnet. Permanent magnet motors are very efficient, but only in a very narrow rpm band, and quickly lose their efficiency in the varying speeds of normal driving.

2.2.2 DC/DC Converter

The DC/DC converter effectively replaces the alternator on an Internal Combustion Engine (ICE) car. Instead of taking energy from the rotation of the ICE motor to charge the 12V battery, it pulls power from the main High Voltage (HV) battery pack and converts it down to 12V. The 12V systems (headlights, stereo, seat heaters, etc.) use a lot of power and would quickly drain the on-board 12V battery if it were not charged while driving [6].

2.2.3 Regenerative Braking

Regenerative braking is unique to EVs and enables the vehicle's kinetic energy to be converted back to electrical energy during braking (deceleration or downhill running). The converted electrical energy is stored in energy storage devices such as batteries, ultra capacitors and ultrahigh-speed flywheels to extend the driving range by up to 10% [5].

2.2.4 Speed Controller

The speed controller is crucial to the efficiency and smooth operation of the electric car. Speed controllers are rated according to the voltage and amperage ranges. Pulse width modulation (PWM) DC motor controllers work by "pulsing" the current delivered to the motor. Just like a piston water pump, the individual pulses are smoothed to produce a continuous flow. They are usually air-cooled or water-cooled.

3

Chapter Three

Batteries in EV

3.1 Batteries

3.2 Battery Management System

3.3 Charging Technologies

3. Batteries in EV

3.1 Batteries

The battery is a storage device consisting of one or more electrochemical cells joined together. The battery converts stored chemical energy into electric energy. A single battery cell is made of a negative electrode and a positive electrode which are connected by an electrolyte. The kind of material used for the electrodes and electrolyte determines the battery specifications. The chemical reaction between the electrodes and electrolyte generates DC electricity. Rechargeable batteries can reverse the chemical reaction by reversing the current in this way the battery can be recharged [11].

3.1.1 Some Technical Terms Related to Batteries

Several terms are used while discussing the characteristics of batteries. These are important in determining which battery should be used for a particular application. Below is a short description of these characteristics [8-11].

Specific energy or gravimetric energy density: Specific energy is an important factor in determining range. Specific energy is the total amount of energy in Watt-hours (Wh) that the battery can store per kilogram of its mass for a specified rate of discharge.

Energy density or volumetric energy density: Energy density refers to the amount of energy a battery has to its size. Energy density is the total amount of energy (in Wh) a battery can store per liter of its volume for a specified rate of discharge. Batteries that have high energy density are smaller in size.

Specific Power or Power Density: Specific power or power density is an important factor for determining acceleration. Specific power is the maximum number of Watts per kilogram (W/kg) a battery delivers at a specified depth of discharge. Specific power is highest when the battery is fully charged. As the battery is discharged, the specific power decreases and acceleration also decreases. Specific power is usually measured at 80% depth of discharge.

Life Cycle: Cycle life is the measure of the total number of times a battery can be discharged and charged during its life. When the battery can no longer hold a charge over 80%, its cycle life is considered to be finished.

Battery Cost: Cost is expressed in currency units, per kilowatt-hour (kWh) [10].

3.1.2 Battery technologies

Today, there are several types of battery technology. The major differences between those technologies are the materials that constitute both electrodes. Some offer more advantages than others and the same goes for the disadvantages. Table 3.1 depicts some of the characteristics of several types of battery technology. If examined closely, Li-ion battery is superior in many aspects compared to others [11-13].

Table 3.1 Characteristics of several types of battery technology

System	Voltage (V)	Specific Energy (Wh.kg^{-1})	Energy density (Wh.L^{-1})	Advantages	Disadvantages
lead-Acid	2	30-40	60-75	• Cheaper • Widely available	• Heavy • limited cycle life
nickel–cadmium Ni-Cd	1.2	20-60	20-150	• Reliable • good low temperature behaviour	• Heavily toxic material • High cell self-discharge rate
Nickel–metal hydride Ni-MH	1.2	50-80	90-300	• High energy density • Environmental friendly	• Higher internal resistance • self- discharge
lithium-ion Li-ion	3-4.2	100-160	160-315	• High specific energy • low self- discharge • 20%<SOC<90%	• Expensive • requires safety electronics

Li-ion battery possesses higher energy densities per mass and volume than other types of batteries as shown also in **(Figure 3.1)** besides; Li-ion technology provides higher voltages than nickel-based systems for example. However, the energy cost of this Li-ion technology is the highest compared to others. Nevertheless, Li-ion batteries have gained a significant amount of popularity among the transportation manufacturers, as transport applications require high energy density, long cycle life, safety, reliability; the cost and weight are also very important.

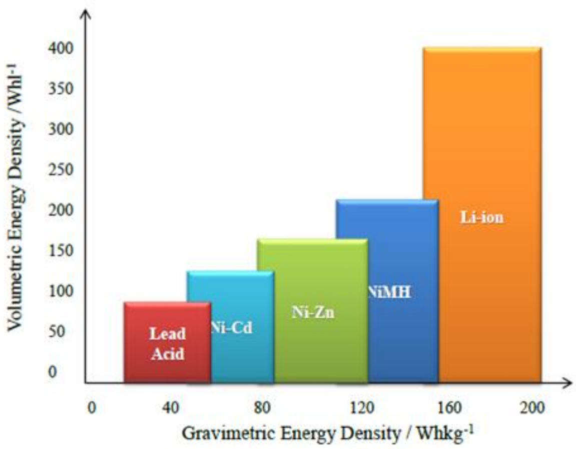

Figure 3.1 Comparison of varied electrical storage technologies

It is obvious that the Li-ion batteries have suitable performances (high energy density, high power density, high discharge rate) for this application and as well as for portable vehicle (i.e. electric vehicle etc...). For individual electric vehicle for example, the Li-ion battery seems to be unquestionable due to the required high specific energy. Li-ion batteries have energy density approximately three to seven times higher when compared to other technologies. They allows manufacturer to build electric vehicles with acceptable performance in term of range, speed and acceleration [15].

Now, the cost of Li-ion batteries is one of the most important issues for transportation applications. The high cost is mainly attributed to the materials which constitute the batteries; positive electrode material represents 40-50% of the overall battery cost, and negative about (20-30) % .Apart from the safety issues of Li-ion batteries, one of the main setbacks of an electric vehicle is the recharging time of the battery packs. The charging procedures require suitable hardware and fast-charging protocols for monitoring the battery cells and also shorten the overall charging time of the vehicles [12].

3.2 Battery Management System

The basic task of the Battery Management System is to ensure that optimum use is made of the energy inside the battery powering the portable product and that the risk of damage inflicted upon the battery is minimized. This is achieved by monitoring and controlling the battery’s charging and discharging process. Li-ion battery has become the most widely used chargeable battery because of its advantages, such as higher voltage level, higher energy density, no memory effects and no pollution to the environment.

Li-ion battery packs of multi cells in series or parallel provide a high-voltage power supply; have become more and more useful in many applications an example hybrid electric vehicle, electrical vehicle electro motors, photovoltaic systems, etc. For more powerful voltage, the cell number is increased and the voltage rises as well. Battery management for battery packs composed of multi cells is quite different from single-cell applications, and thus challenges arise.

The information of each battery must be acquired and processed to ensure the safe operation of every single cell and improve the performance of the whole battery pack. Estimation on the state of charge (SOC) and monitoring the battery characteristics have always been important parts in battery management research. A high-performance battery management system (BMS) is able to allow the cell work in the best performance. BMS can improve the battery's performance and extend its working life through real-time battery state monitoring and battery SOC estimation [16].

The BMS system has a function to monitor the batteries, to protect, estimate the battery state, to maximize their performance. BMS system should do the following task: prevent the voltage of any cell from exceeding a limit, by stopping the charging current for example. This is the safety issue for all Li-ion cells. Prevent the cell for increasing temperature by stopping the current directly and requesting cooling. The exceeding temperature can bring the batteries to the thermal runaway process [14].

Keep from drooping of cell voltage below the limit. Limited the charging and discharging current. BMS can balance the battery to maximize its capacity [17].

The BMS may provide different functions to control a cell, module or a complete pack.

1) Charge and Discharge Voltage control.
2) Control of the Charge and the Discharge Current.
3) Monitoring of the SOC.
4) Monitoring of the SOH.
5) Monitoring of State of Function (SOF).
6) Monitoring and Control of the Temperature.

3.2.1 Voltage control

The BMS monitors the cell voltage and controls the charge and discharge current in such a manner that this voltage remains in the recommended limits. In this way the battery overcharge or over-discharge are prevented [18].

The Constant Voltage (CV), the battery is charged at a constant voltage, while the charging current of the battery varies through the charging process. The current intensity can be high during the initial stage when the battery begins to charge. This intensity decreases to zero until the battery is fully charged. Constant Voltage is not available for most residential and parking infrastructures, as it requires very high power in the early stage of charging. Such voltages could induce operational risks.

3.2.2 Current control

The charge and discharge of Li-ion cells with currents higher than the recommended ones leads to rapid degradation in terms of energy storage capacity and power delivery. The higher currents increase the cell internal temperature from one hand and exert additional stress on the active materials from the other. A main function of the BMS is to control the magnitude of the charge and discharge (if possible) current and thus providing the longest possible time of battery exploitation [18].

Constant Current (CC), this method controls the charging voltage applied to the battery so as to maintain a constant current. This induces a linear increase of the SOC of the battery. In this case, it is a combination of parameters such as an increment on the temperature, or of the voltage, or simply after a defined period of time that the BMS determines that a charge is completed.

3.2.3 Constant Current - Constant voltage (CC-CV)

This is a combination of the two methods previously described and it is the most widely used method for charging Li-ion batteries. Three steps are identified during a charging process as it is illustrated in **(Figure 3.2)**. During the first step, the battery is pre-charged at a low constant current, normally around 0.1 C rate units. At the second step, the charging current is maintained constant until a certain threshold is reached by the SOC, this normally happens when the voltage of the cell reaches the battery terminal voltage VBAT. At this point, the third step begins, the voltage being kept constant (CV), until the current exponentially decays and reaches typically one-tenth of the fast charge current IEND. Approximately 70% of the total charge is delivered during the CC step and the rest is completed during the CV step.

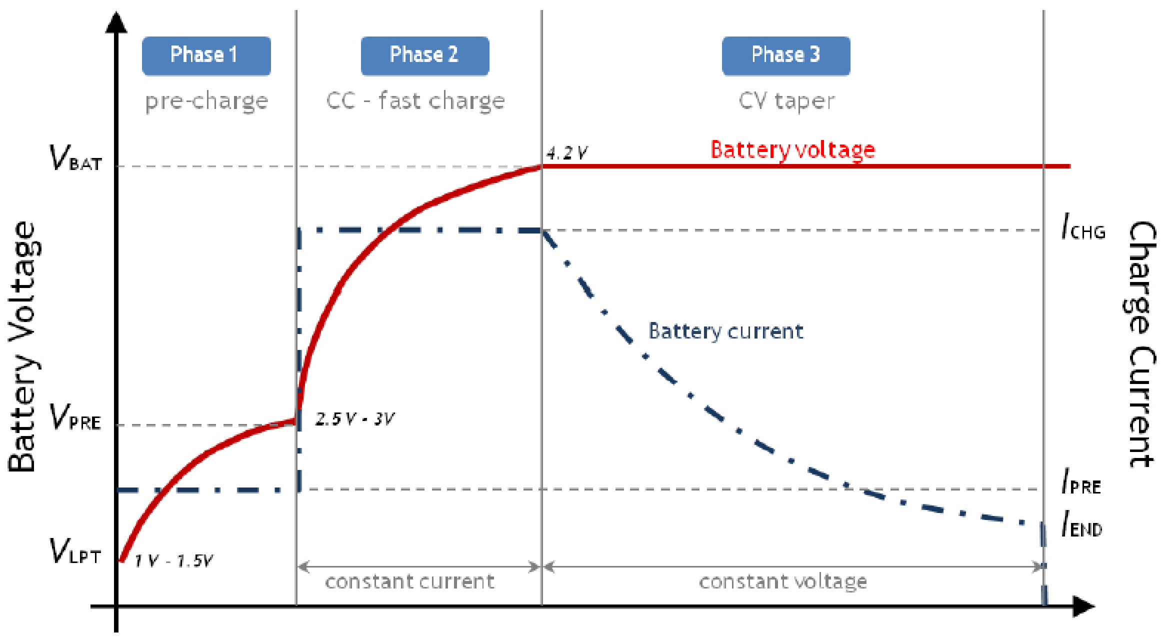

Figure 3.2 Constant Current - Constant voltage (CC-CV)

3.2.4 State of Charge (SOC)

The SOC (state of charge) is the percentage ratio between residual discharge capacity (C_{res}) and discharge capacity obtained after complete recharge (C_F, full capacity) :

$$\mathbf{SOC_{discharge} = \frac{C_F - Cres}{CF} . 100} \qquad \text{Equation 3-1}$$

When a completely discharged the battery is recharged SOC is expressed by the ratio between the injected charge (Q_{ch}) and C_F :

$$\mathbf{SOC_{charge} = \frac{Q_{ch}}{CF} . 100} \qquad \text{Equation 3-2}$$

Often, instead of SOC, the remaining charge in the cell is expressed by the Depth of Discharge (DOD), i.e. how much of the total available battery capacity is used during the discharge :

$$\mathbf{DOD = 100\% - SOC} \qquad \text{Equation 3-3}$$

Using the above definitions, the State of Charge can be estimated and monitored by the so-called Ah integration or Ah balancing. In this method, the current through the cell I (t), positive during the Charge and negative during the discharge is continuously integrated and the SOC is calculated by the following formula :

$$\mathbf{SOC_{(t)} = soc_{initial} + \frac{100}{CF} \int_0^t I(t)dt} \qquad \text{Equation 3-4}$$

In order to have precise SOC estimation in time, the BMS should be provided by an initial value $SOC_{initial}$. Typically such a value is available after complete recharge ($SOC_{initial}$ = 100%), complete discharge ($SOC_{initial}$ = 0%) or by some complementary method of SOC estimation [19].

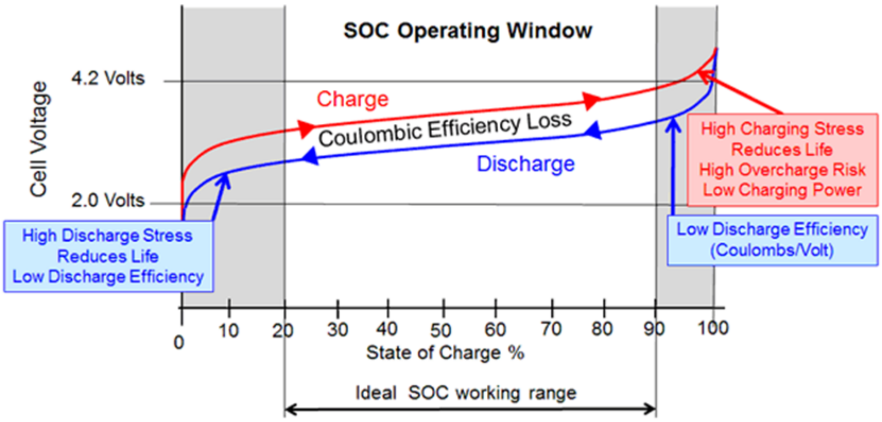

Figure 3.3 Evaluation of SOC for Battery cell protection

As shown in **(Figure 3.3)** demonstrates the risk factors during overcharged and undercharged conditions of a cell beyond the SOC standard level. The safe operation, i.e., charging and discharging, of a rechargeable battery cell within the ideal working range of the state of charge (SOC), i.e., 20% - 90%, can be accomplished by using a battery management system (BMS) [20].

3.2.5 State of Health (SOH)

On the other hand, the state of health (SOH) of a battery which is an indication of wear and tear on a battery is related to the capacity decrease of the battery. It is obtained by calculating the ratio between the actual discharge capacity and the initial discharge capacity of the battery [21]:

$$\mathbf{SOH} = \frac{\mathbf{Q_{discharge,act}}}{\mathbf{Q_{discharge,init}}} \quad \text{Equation 3-5}$$

Where $Q_{discharge,\,\mathrm{act}}$ is the actual discharge capacity of the battery cell (Ah) and $Q_{discharge,\,init}$ the initial discharge capacity of the battery (Ah) measured in the standard discharge condition [21, 29].

3.2.6 Thermal management

During the battery charge and discharge a certain amount of electric energy is transformed into Joule heat throughout the battery internal and charge transfer resistance. The result is an increase in battery temperature. Additionally, the battery can be subjected to heating from the nearby power electronics (chargers, inverters, converters, etc…) or to cooling in the case of outdoor applications. For most of the available Li-ion technologies, the longest cycle life is achieved in the temperature range 15-35°C. The thermal management aims to keep the battery temperature as close as possible to this recommended temperature range. The battery cooling is achieved in different ways depending on the severity of the application: passive cooling using a specifically engineered pack, casing design for low power applications, air fan cooling for moderate power applications or liquid cooling circuits for high power applications [14].

Most of the Li-ion systems exhibit relatively low-temperature stability points – typically between 75 and 90°C depending on the particular technology. A main function of the thermal management (and the battery management too) is to prevent reaching this threshold. Else way in the pack, the thermal runaway starts and it may lead to fire, explosion, and toxic gas hazards [14].

3.3 Charging Technologies

Electric mobility becomes a trending issue than ever in the transportation sector. EV receives electricity by plugging into the grid and stores it in batteries. EV Charger is an electrical device that converts alternating current energy to regulated direct current for replenishing the energy of an energy storage device (i.e. battery). The energy storage device namely battery is the heart of an electric vehicle. Therefore, the battery charger plays a very important role in electric vehicle technology. Electric vehicle battery chargers divided into two types: on-board type (in the electric vehicle) and off-board type (at a fixed location) [19].

In this chapter, the charging technologies in electric vehicles, related standards, charging levels and charging modes are described. Also, EV charging sockets are explained clearly. The whole issue about chargers is presented for EV manufacturers. Consequently, the big picture of the electric vehicle charging system could be easily seen in this chapter [21].

There are 3 functions that must be performed to allow the charging of the EV battery from an electric supply network. The two of them are electrical functions and another one is mechanical function. The first electrical function is the rectification process and the second one is controlling and regulation of supply voltage according to battery charge acceptance characteristics. The mechanical function is the connecting of the EV to the EVSE and this process is performed by the user [18-121].

The block diagram of EV charging system is given below on (**Figure 3.4**). Main parts of this system are charger control unit, charging cable and vehicle control unit [18].

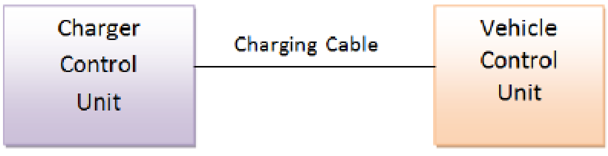

Figure 3.4 Descriptive block for electric vehicle charger

3.3.1 The Different EV Charging Methods

Generally, there are three main ways of charging: conductive charging, inductive charging and by changing the battery. Using the conductive method the battery is connected by a cable and plugged directly into an electricity provider. The inductive method, in contrast, works through electromagnetic transmission without any contact between the EV and the charging infrastructure. The charging spot is equipped with wires which carry an alternating current, during which the EV is at the right place. The alternating current creates an electromagnetic field, which affects the receiver (also consisting of wires) in the EV in a way that a current is induced and charges the battery [22].

3.3.1.1 Inductive Chargers

Inductive charging, also known as Wireless Power Transfer (WPT), is a new way of recharging without the need for cables, as shown in **(Figure 3.5).** Inductive charging uses an electromagnetic field to transfer energy between two objects. This is usually done with a charging station. Energy is sent through an inductive coupling to an electrical device, which can then use that energy to charge batteries or run the device [20].

Induction chargers use an induction coil to create an alternating electromagnetic field from within a charging base, and a second induction coil in the portable device takes power from the electromagnetic field and converts it back into electric current to charge the battery. The two induction coils in proximity combine to form an electrical transformer. Greater distances between sender and receiver coils can be achieved when the inductive charging system uses resonant inductive coupling. Recent improvements to this resonant system include using a movable transmission coil and the use of other materials for the receiver coil made of silver-plated copper or sometimes aluminum to minimize weight and decrease resistance due to the skin effect [20, 32].

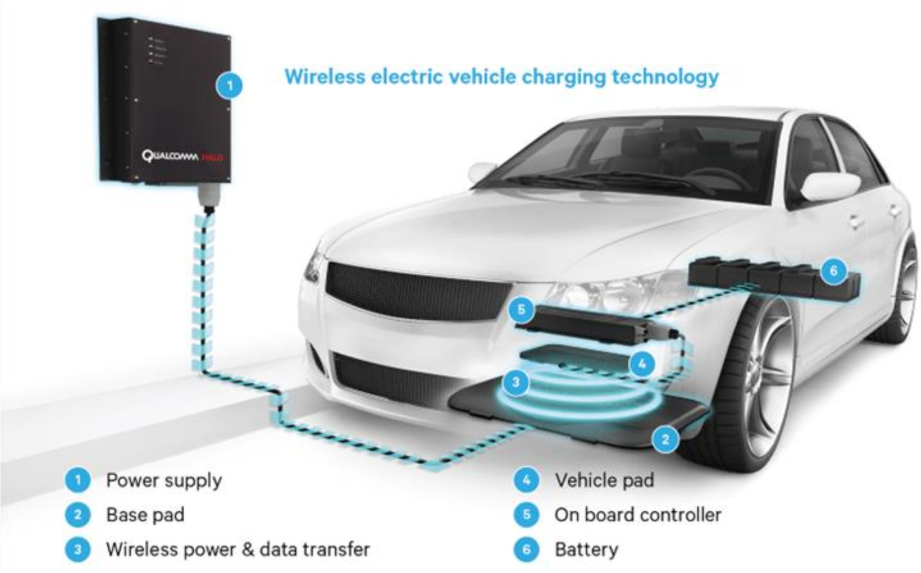

Figure 3.5 Wireless electric vehicle charging technology

Table 3.2 Advantages & Disadvantages of Inductive Charging

Advantages	Disadvantages
• Protected Connections away from (water/oxygen) • Durability • Increased convenience and aesthetic quality • No need for cables	• Slower Charging • More expensive

3.3.1.2 Conductive Charging

The conductive charging system uses direct contact between the EV connector and charge inlet. The cable can be fed from a standard electrical outlet or a charging station.

For historical reasons, AC charging was the first to be adopted and developed, as EVs were often charged from regular household sockets. Nevertheless, the maximum power was limited, which lead to long charging sessions and dangerous charging conditions for the final user. As a consequence, the automobile and electronics industry started to develop different plugs and sockets and a set of standards that could allow this inter-operability [31].

In recent years, standardization efforts for the EVSE have been intensified from different organizations such as the International Electrotechnical Commission (IEC) and the Society for Automotive Engineers (SAE) in the United States. In the United States, the SAE J1772 standard specifies the EV conductive charging requirements. Its European counterpart is the IEC 61851-1 standard. The term 'level' used by SAE and 'mode' used by IEC essentially means the same thing. Both standards define the operational and functional requirements for the charging infrastructure [32].

According to the IEC standard, there are 4 modes for charging EVs as described in Table 2. However, SAE standard defines 6 levels of EV charging as shown in Table 3 Some information in the table is still to be defined (TBD) by the standard [23].

Table 3.3 The IEC EV charging modes based on IEC 61851-1

Modes	Supply	Duration	Charger configuration	Example charger
Mode 1	AC	Slow	Standard household-type connector	1- or 3-phase plug
Mode 2	AC	Slow	Standard household-type socket-outlet with an in cable protection device	The Park and Charge
Mode 3	AC	Slow/Fast	Specific EV socket-outlet and plug with control and protection function permanently installed	SAE J1772
Mode 4	DC	Fast	External charger	CHAdeMO

From Table 3.4 Essentially 'Level 3' does not exist yet .and the charging standard everybody has been thinking of as Level 3 is either 'DC Level' 1or 'DC Level 2' [30] .

Table 3.4 Levels of EV charging according to SAE

Source	Level	Voltage	Phase	Max current	Max power (kW)	Time (h)
AC	Level 1	120	Single	16	1.9	6 - 24
	Level 2	240	1- or 3 -phase	80 (typical 40)	19.2	2 - 8
	Level 3	TBD	TBD	TBD	TBD	TBD
DC	Level 1	200-450	DC	<= 80	<= 19.2	~ 30 min
	Level 2	200-450	DC	200	90	~ 15 min
	Level 3	TBD	DC	TBD	TBD	TBD

3.3.2 The EV Charging Modes

The IEC defines four different charging modes according to the complexity of the system and the charging speed. A charging mode refers to the power level that rates a charger and its Connectors. It also specifies the safety and control features that guarantee the safety and efficiency of charging [24, 30].

1) Mode 1

It is the simplest and most direct connection between the grid and the vehicle, as shown in **(Figure 3.6).** It uses a standard non-dedicated socket outlet at 16 A for single or three-phase infrastructures. It provides basic charging capabilities for domestic use, limiting its power at 3.3 kW for a single-phase connection. However, this mode is currently prohibited in the U.S. due to the risk of overheating.

Figure 3.6 Mode 1 type connection

2) Mode 2

This is the default mode for new EVs in the U.S. and Japan, where the J1772 plug is used on the EV side. As in mode 1, a direct connection is established between the vehicle and the grid, as shown in **(Figure 3.7).** Unlike mode 1, mode 2 uses a charging cable including a protective device that consists of a control pilot pin. The control pin allows detecting possible current-leakage and indicates the maximum charge current that can be supported. In order to avoid any risks of overheating of the electrical installation, a power limit is considered. Meanwhile, current intensities of 16 A or 32 A are admissible in the charger.

Figure 3.7 Mode 2 type connection

3) Mode 3

This mode enables fast charging on an AC connection, which can go up to 55 kW. For that purpose, a dedicated EVSE is required for charge monitoring through a dedicated cable, as shown in **(Figure 3.8).** This mode is safer than modes 1 or 2, as it allows continuous communication between the vehicle and the charging station.

The pilot wire not only indicates the maximum charge level, but it confirms to the charging station that the connection is secured and that the vehicles are ready for charging. The pilot wire also confirms the interruption of the charge if a disconnection is detected.

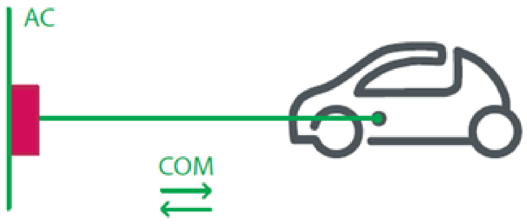

Figure 3.8 Mode 3 type connection

4) Mode 4

An indirect connection between the vehicle and the grid through an external charger is performed. For monitoring the charging process, mode 4 as shown in **(Figure 3.9).** Requires a bidirectional communication over the pilot of a dedicated wire. This mode enables fast charging using DC and higher voltages that would enable long-distance travel since the charging time is considerably reduced. The maximum current specified is 400 A. This mode is therefore preferred by dedicated charging stations due to its installation requirements and safety issues [24].

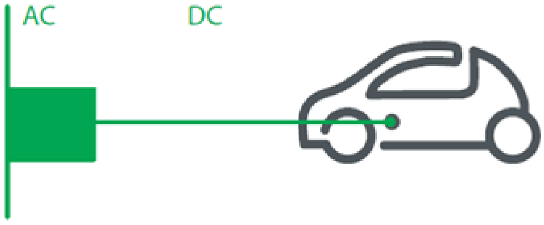

Figure 3.9 Mode 4 type connection

3.3.3 Charging Connectors

The IEC standard defines plugs, socket outlets, vehicle connectors, and vehicle inlets. The plug type refers to the specifications needed for the design and manufacturing of the plug with which an EV connects to the charging equipment [26, 31].

3.3.3.1 AC charger connectors

Three plug designs are officially recognized for AC charging. These designs are designated as Type 1, Type 2, and Type 3, as shown below in **(Figure 3.10).** By the IEC standard, the terms "sockets" and "plugs" are used for the supply-side. The terms "vehicle inlet" and "vehicle connector" are used for the vehicle-side.

The first connector standards were only suited for low power levels, as EVs were mainly connected to regular household sockets. However, as the new generation of EVs requires higher power levels for faster charging, several improvements have been achieved on the design of plugs and connectors. In practice, the sockets and plugs have been developed before any standard has been defined. We describe in this section the types of connectors available today on the market [30-31].

1) Type 1: The Yazaki connector

This connector was approved by the SAE as the new J1772 connector standard which enables Charging at 120 V or 200 V. It consists of two power pins, one ground pin and two additional pins for safety and communication features. It is defined as a vehicle-side connector which requires a corresponding inlet. This connector is primarily used at charging stations which have fixed cables, as part of the infrastructure. Its vehicle inlet and connector were developed by the Japanese manufacturer of power network equipment Yazaki from where it gets its name. It was primarily embraced at the American and Japanese EV market.

This connector was approved by the SAE as the new J1772 connector standard which enables Charging at 120 V or 200 V. It consists of two power pins, one ground pin and two additional pins for safety and communication features. It is defined as a vehicle-side connector which requires a corresponding inlet. This connector is primarily used at charging stations which have fixed cables, as part of the infrastructure. Its vehicle inlet and connector were developed by the Japanese manufacturer of power network equipment Yazaki from where it gets its name. It was primarily embraced at the American and Japanese EV market [31].

2) Type 2: The Mennekes connector

This plug is commonly referred as type 2 according to the IEC nomenclature as well as Mennekes plug. This name refers to the German manufacturer (Mennekes Ekectrotechnik) at the origin of the design of this plug. Due to the differences in the European power grids, such as the availability of three-phase power at households, the specifications of the Yazaki plug were considered insufficient. European manufacturers needed a plug which could handle semi-fast charging and three-phase power. These requirements are achieved by this new connector. It is used on loose cables which on the charger side can handle three-phase power connections while on the car side require a plug that matches the vehicle inlet. Type 2 plugs are rated for higher power levels that Type 1 plugs.

The Mennekes plug has been adopted by the Association of German Car makers in 2010. It has also been adopted in 2013 by the European Commission as the the European standard for AC Charging [30].

3) Type 3: the Scame connector

A group of French and Italian electrical equipment manufacturers, headed by the Scame Italian Company, rejected the Mennekes plug. Because of an electrotechnical safety issue. As a consequence, the electrical equipment manufacturers members of the EV Plug Alliance proposed their connector.

Figure 3.10 AC charger connectors types

3.3.3.2 DC Charger connector

The standardization of DC charging followed a different path from the standardization process of AC charging. For DC charging, the definition of a standard happened before the installation of any equipment. However, the early standard has been challenged by alternative proposals from a consortium of different firms [30].

1) CHAdeMO

In 2010, the Japanese power company TEPCO set up the Charge de Move (CHAdeMO) association, which includes different Japanese car manufacturers and electric utilities. Along with the Japan Automotive Research Institute, they designed a connector that can handle high voltages (300-600 V) and high current levels (up to 400 A). Due to the diameter of the copper wire of the cables to support such current intensities, it was decided to use a fixed cable on the supply side. On the vehicle side, CHAdeMO inlets have been progressively installed in Japanese vehicles. This massive implementation helped to position CHAdeMO as the DC fast charging standard. For this reason, the CHAdeMO design was recognized by the IEC standard. This standard needs, however, an exclusive vehicle inlet for DC charging.

This can be considered as a drawback since it will always be necessary to have a separate inlet for AC charging, as shown in **(Figure 3.11).**

Figure 3.11 CHAdeMO DC Charger connector

2) Combo or Combined Charging System (CCS)

Announced in 2012, the Combo connector consists of a combination of AC and DC connectors, as shown in **(Figure 3.12).** It prescribes fixed cables on the charging station. The Combo connector has been proposed by German car manufacturers. It considers two variants. The first variant is a combination of the Yazaki AC design with additional pins for DC charging. The second variant considers the Mannekes design. The European Commission defined the Combined Charging System (CCS) connector as the DC charging standard in Europe from 2014. However, it will take some time to replace the CHAdeMO stations previously deployed, leaving at least two DC connector standards in Europe in the years to come [31].

Figure 3.12 Combo DC Charger connector

3.3.4 Charging Schemes

The flow of energy between the EV and the EVSE can be in both directions depending on the needs of the vehicles or the grid. Vehicle to Grid (V2G) and Vehicle to Vehicle (V2V) schemes are still under continuous improvement and study by research teams around the globe [21-22].

1) Grid-to-Vehicle (G2V)

When an EV is being charged, it's called G2V (Grid to Vehicle). The vehicle is connected to the grid and the charge rate is controlled by the grid, either locally or remotely. Controlling the charge of the vehicles by the grid enables better management of the grid infrastructure and the possibility to take advantage of low-cost energy during low activity periods.

2) Vehicle to Grid (V2G)

This method allows vehicles to feed power back directly to the grid, as shown in **(Figure 3.13).** In order to perform such an operation, a constant communication between the grid and the vehicle in both ways is necessary. This technology has been tested for providing different ancillary services to the grid, such as frequency control, energy balance and to ease the integration of renewable energies into the grid when they are available.

In this case, EVs are not only able to vary charging power, but also to inject power back into the grid, which can be beneficial for the utilities and the grid.

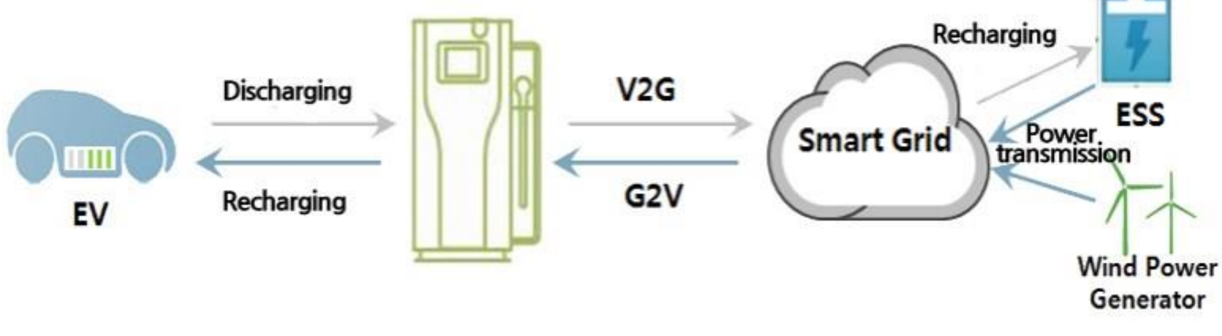

Figure 3.13 Vehicle to Grid (V2G)

3) Vehicle to Home (V2H)

A variant of V2G known as Vehicle to Home (V2H) consists in injecting power from the batteries of EVs to the household. Such an operation is particularly useful when the price of electricity delivered by the grid is at the highest. V2H can also be considered as a backup energy source in case of a natural disaster (an earthquake for instance) imposing a disconnection of the homes from the grid. Despite the current research status on V2G, its deployment in the electric network is not expected to be widespread soon without the proper economic model.

4) Vehicle-to-Vehicle (V2V)

This method allows to exchange energy between two vehicles connected to the same charging station. This scheme helps to significantly reduce the impact of the charging process on the electric grid during the day. Additionally, it could help EV users to buy energy directly from other EVs connected to the charging station instead of buying it directly from the grid. Added to the technical aspects that should be solved, the V2V business model should be investigated into more details before considering its effective implementation.

4

Chapter Four

Charging Station

4.1 Design of Charging Station

4.1.1 AC/DC Converter

4.1.2 DC/DC Converters

4.1.3 EV battery

4.2 Case Study

4.2.1 AC/DC Converter

4.2.2 DC/DC Interleaved Buck Converters

4.2.3 Protection

4.2.4 Battery Charger Control

4.2.5 Modelling Of Lithium-Ion Batteries

4. Charging Station

4.1 Design of Charging Station

The charge station is one of the most important parts of the energy source subsystem, as shown in **(Figure 4.1).** It provides all energy necessary for propulsion and the auxiliary devices to EV. The charger allows the battery to be charged from the electricity grid. From the technological perspective, the charger is AC/DC power electronic converter. While charging its operation is fully controlled or supported by the BMS. The AC voltage is transformed into a DC voltage that suits the battery parameters. The charger operation is constrained by the safety requirements of the battery used in the EV [26-27].

Figure 4.1 Electric Vehicle Charge Station

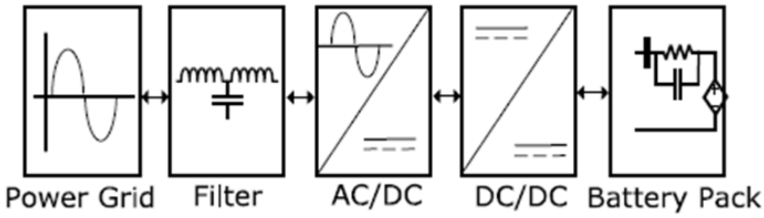

Figure 4.2 Energy Conversion Process

4.1.1 AC/DC Converter

Rectifiers have evolved to a mature state. There have been many rectifier topologies since the evolution of diodes and thyristors. Uncontrolled or line-commutated rectifiers usually consist of diodes. Most diode rectifiers have fixed frequency input AC voltages, fixed DC output voltage. Controlled rectifiers or Phase-control rectifiers have control on switching devices and usually consist of thyristors where the thyristors act as a switch and have two states: ON state and OFF state (i.e. achieved by providing suitable gate trigger pulse). In the case of diode rectifiers, load current flows when diodes conduct and in the case of phase rectifiers, the load current flows when the thyristors conduct. **(Figure 4.3)** shows an attempt to classify the rectifiers based on their operational control.

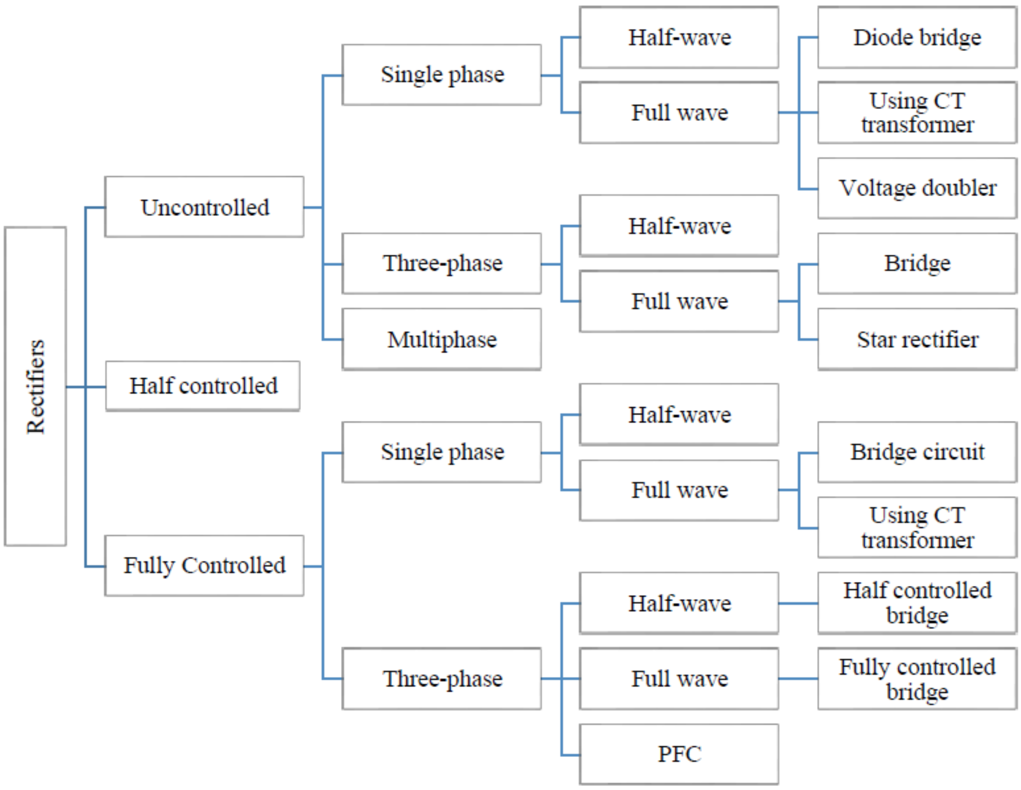

Figure 4.3 Rectifier Classification

4.1.2 DC/DC Converters

DC-DC converters designed for charger of EVs are divided into two groups, which are isolated and Non-isolated; the subgroups divide into two groups, which are unidirectional and bi-directional DC-DC converter [29, 32]. **(Figure 4.4)** shows Converter Topologies.

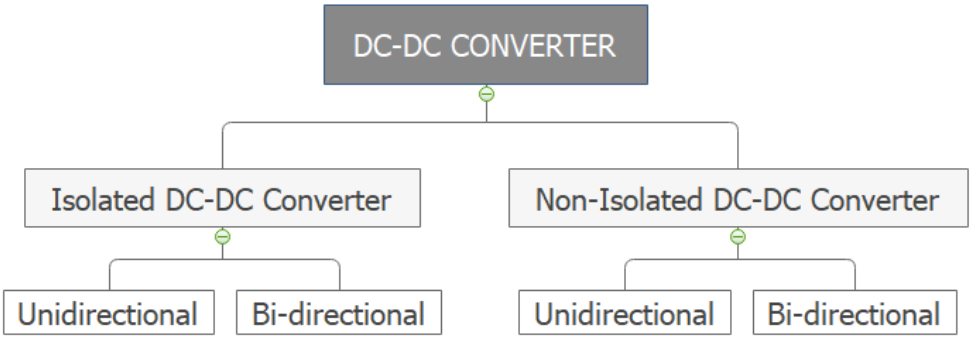

Figure 4.4 DC-DC Converter Topologies

4.1.1.1 Non-isolated DC-DC Converter

The main advantages of non-isolated converters are that they have low cost, low active component number, high efficiency. But they are used for low power desired system and the big disadvantage is that in the electrical connection between source and loads no protection for any high electrical voltage current, etc. occurs on the input side [29].

1) Unidirectional DC-DC Converter

The voltage of many batteries for EVs ranges from 100-400 V, so the most popular dc-dc topology is a unidirectional buck converter in order to reduce the voltage from the DC-link to the voltage level of the battery. Unidirectional buck-boost converters are also used topology due to their capability to step-up and step-down the output voltage. In addition, the interleaving technique can be applied to these topologies [29]. **(Figure 4.5)** shows Non-isolated Unidirectional DC-DC Converter.

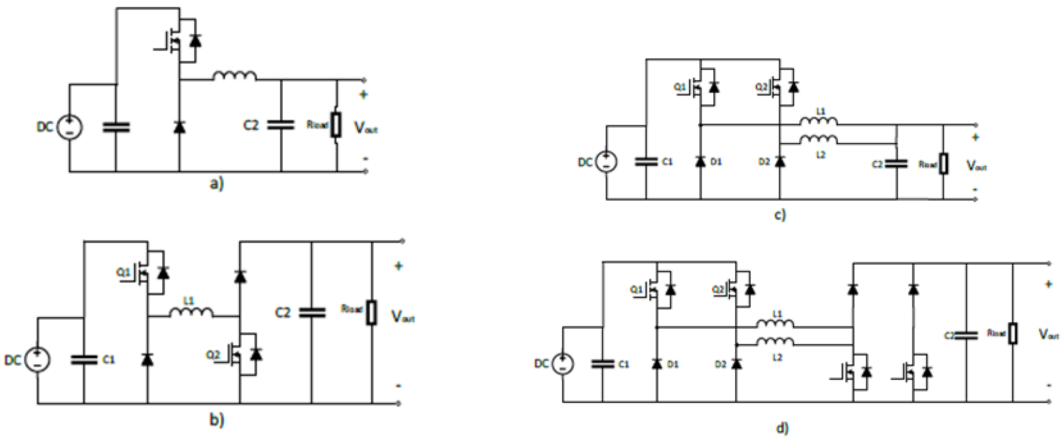

Figure 4.5 Unidirectional DC-DC converters (a) Buck Converter, (b) Interleaved Buck Converter, (c) Buck-boost Converter (d) Interleaved Buck-boost converter

2) Bi-directional DC-DC Converters

In vehicle-to-grid (V2G) systems, electric vehicles Energy storage systems are in interact with the grid by providing a large number of potential benefits. In V2G systems, bidirectional converters play a very important role. The features like being reliable, having efficiently conversion, cost-effective, safety, having lightweight, having a small size, producing low harmonics are crucial for bi-directional dc-dc converters to achieve V2G.

4.1.1.2 Isolated DC-DC Converter

The isolated DC-DC converters have large size, there are more active components compared to non-isolated converters, switching losses is higher, they have less efficiency in low power applications. But isolated dc-dc converters have higher efficiency at high power applications; the transformer provides protection between load and source, and also the turn ratio of transformer facilities regulating load voltage [29].

1) Unidirectional DC-DC Converter

Unidirectional DC-DC converters are used electric vehicle charge system in the grid to a vehicle the most popular topologies are given in (Fig.4.7). Flyback topology has a simple structure. It can be performed with a single switch. Also, this topology does not require an output inductor in addition to the transformer. **(Figure 4.6)** shows isolated Unidirectional DC-DC Converter.

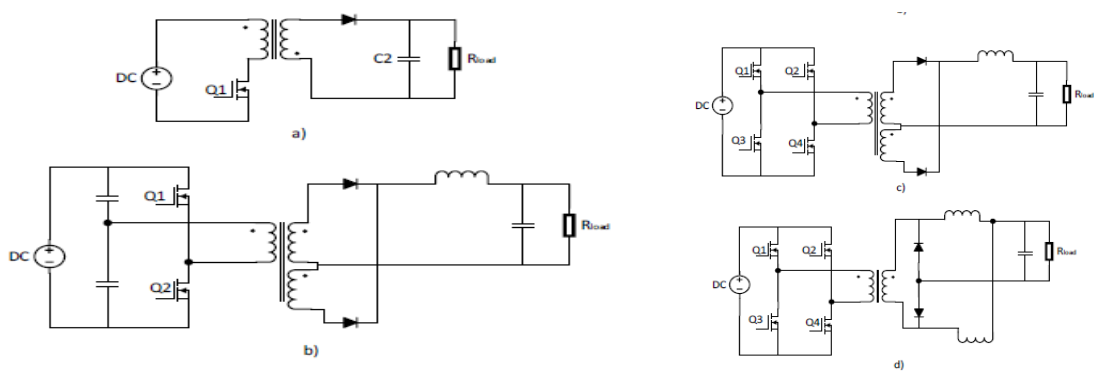

Figure 4.6 Unidirectional dc-dc Converter topologies (a) Fly back Converter (b) half-bridge (c) Full bridge (d) Full-Bridge phase shift (e) push-pull Converter

2) Bi-directional DC-DC Converters

The bi-directional dc-dc converters were designed to provide voltage and frequency regulation of absorbed excess electricity from vehicle to the grid, during high demand periods.

The bi-directional dc-dc converters allow two-directional power flow, in charging mode grid to vehicle (G2V) and in discharging mode vehicle to grid (V2G) [28-29].

The comparison of all DC-DC converter topologies is given in **Table 4.1**.

Table 4.1. The comparisons of DC DC converters

	Converter Types	Optimal Power demand	Efficiency	Number of component	Voltage stress	Cost
Unidirectional Non-Isolated DC DC Converters	Buck Converter	Low (<500 W)	medium	5	high	low
	Interleaved Buck	Low (<500 W)	high	8	low	medium
	Buck-Boost	Low (<1KW)	medium	7	medium	medium
	Interleaved Buck-boost	Low (<1KW)	high	12	low	high
Bi directional Non Isolated DC DC Converters	Buck-boost Converter	Low (<1KW)	medium	7	medium	medium
	Sepic converter	Low (<1KW)	medium	7	high	medium
	Cuk converter	Low (<1KW)	medium	6	high	medium
	Half bridge Converter	Low (<1KW)	high	5	medium	Low
Uni directional Isolated DC DC Converters	Flyback	Low (<500W)	high	4	high	low
	Half Bridge	Low (<1KW)	high	7	high	medium
	Full bridge	High (1KW<)	medium	9	medium	high
	Push pull	High (1KW<)	medium	8	high	high
	Full bridge phase shift	High (1KW<)	high	10	low	High
Bidirectional Isolated DC DC Converters	Half bridge	Low (<1KW)	medium	6	high	low
	Full bridge	High (1KW<)	medium	10	low	high

4.1.3 EV battery

Nowadays, run time-based models combined with Thevenin equivalent based models are the state of the art. In this work, such an approach is used. (Fig.4.8) shows the electric circuit configuration of the battery model. Here V_{oc} is the open-circuit voltage which is depending on the state of charge SOC, and the voltage-current characteristic is modeled by series resistance. The RC parallel circuit represents the transient response of the battery.

4.2 Case Study

The electric vehicle charging system is shown in the **(Figure 4.7)**. In this method three phase AC supply is given to the charging station. Charging station consist of fixed AC. From the charging station fixed AC supply applied to rectifier. Rectifier converts AC to DC and then DC supply is flow through the Interleaved Buck Converters the buck converter is used to step down the voltage from input to its output (load).here battery act as a load.

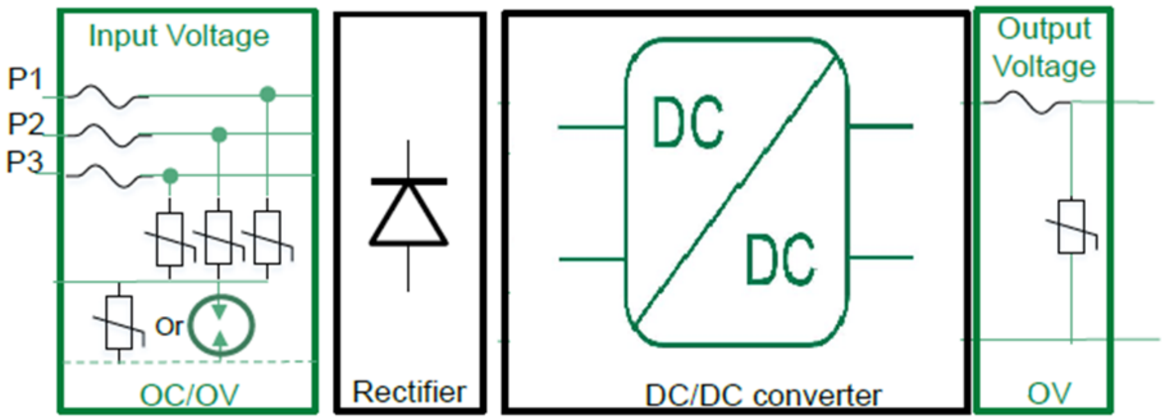

Figure 4.7 The electric vehicle charging system

4.2.1 AC/DC Converter

Full-wave Three-phase Rectification

Three-phase bridge rectifier is commonly used in high-power applications and it is shown in **(Figure 4.8)**. This is a full-wave three-phase uncontrolled bridge rectifier. Its circuit uses six diodes, two per phase in a similar fashion to the single-phase bridge rectifier. A 3-phase full-wave rectifier is obtained by using two half-wave rectifier circuits. The advantage here is that the circuit produces a lower ripple output than the half-wave 3-phase rectifier as it has a frequency of six times the input AC waveform , smooth output voltage waveform, no dc component introducing into input current of each phase, and high efficiency of power conversion [34].

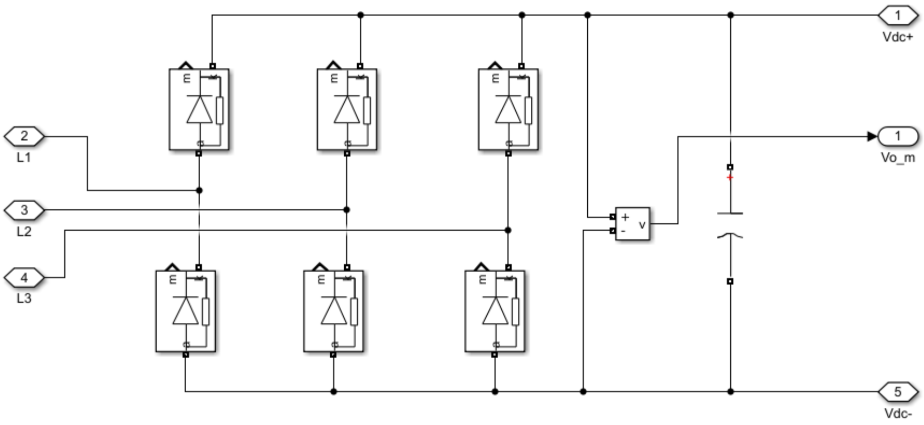

Figure 4.8 Three-phase rectifier

4.2.2 DC/DC Interleaved Buck Converters

The voltage of a common DC-bus structure usually is up to 600 V and higher than the battery voltage which is from 200 V to 450 V. For charging the batteries, a single-phase buck converter can be used. However, in high-current applications, the single-phase buck converter requires a large inductor to keep the inductor current ripples small. The large inductor increases the cost and size of the converter. Instead of using the large inductor, a multi-phase interleaved buck converter, as shown in **(Figure 4.9)**.

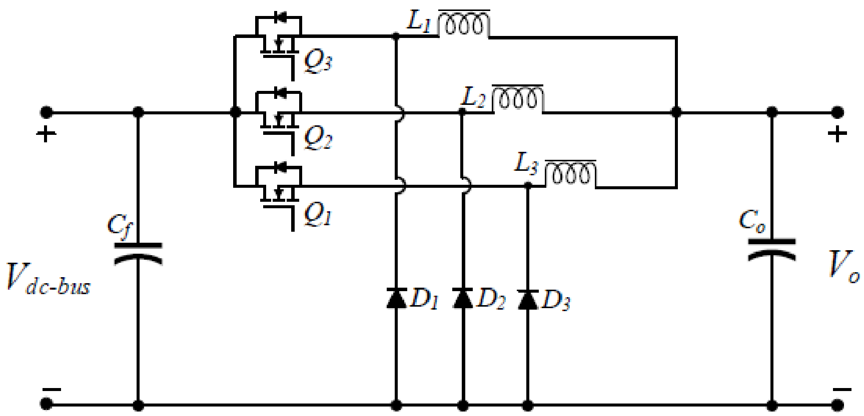

Figure 4.9 Three-phase interleaved Buck converter

A multi-phase buck regulator is a parallel set of buck power stages, as shown in **(Figure 4.10)**, each with its own inductor and set of power MOSFETs. Collectively, these components are called a phase. These phases are connected in parallel and share both input and output capacitors. This technique consists of phase-shifting 360°/*N* the control signals with the same switching frequency of *N* parallel converters [33].

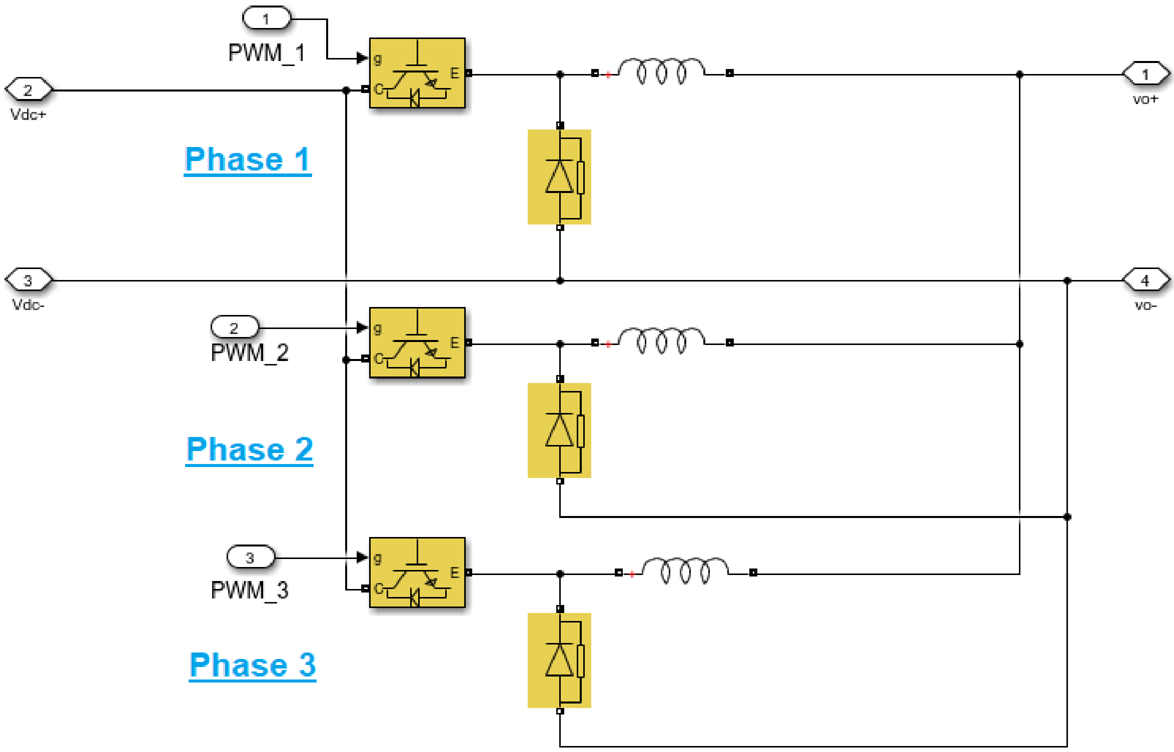

Figure 4.10 Multiphase Buck converter

The separate inductors of the multi-phase interleaved buck converter are used to enhance the efficiency of the converter. This converter shares currents between the multi-phase modules. If the number of phases is increased, the size of the inductor decreases as the number of phases is multiplied by the fundamental frequency of each inductor [34].

Advantages of interleaved Buck converter

Compared to single-phase buck regulators, multiphase converters offer several key performance advantages that make them the default choice for high-power, high-performance applications:

• Reduced input capacitance

• Reduced output capacitance

• Improved thermal performance and efficiency at high load currents

• Improved overshoot and undershoot during load transients

4.2.2.1 Design Equation

The following are design equations for the interleaved Buck converter.

Table 4.2 Multiphase Design Specifications

V_{in}	530 V	Input voltage
V_{out}	450 V	Output voltage
F_s	20 KHZ	Switching frequency
ΔI_L	5A	Inductor current ripple
N	3 phases	Number of phases
ΔV_{out}	5V	Output voltage ripple

4.2.2.1.1 Inductor

For this design, a switching frequency of 20 kHz is used to. Using the standard buck design equation for calculating inductance and a ripple current target of 5A, an inductance of 0.226 mH per phase is calculated using (Equation 4.1).

$$L = \frac{Vout * (1-D)}{Fs * \Delta IL * N} = \frac{450 * (1-\frac{450}{530})}{20K * 5 * 3} = \frac{0.679 * 10^{-3}}{3} = 0.226 * 10^{-3} \quad \text{Equation 4.1}$$

Where: D = VOUT / VIN

4.2.2.1.2 Input Capacitor

The function of the input capacitor is to filter the input current into the regulator – ideally it should appear as DC current for steady state load conditions

4.2.3 Protection

At present fault plays a major problem in a power system network and power application. EV charge stations is increasing year by year and therefore maintenance and protection of power system equipment's are very important for decreasing the cost and to increasing the life of the power system equipment's for reliable and uninterrupted operation. From the perspective of relay application, all this creates new engineering needs for improvements in understanding of new operating principles, determining proper way of using a given relay, calculating the settings, and finally, performing relay design and application testing [43].

Under normal condition, a power system operates under balanced conditions with all equipment's carrying normal load currents and the bus voltages within the prescribed limits. This condition can be disrupted due to a fault in the system. A fault in a circuit is a failure that interferes with the normal flow of current. A short circuit fault occurs when the insulation of the system fails resulting in low impedance path either between phases or phase(s) to ground. This causes excessively high currents to flow in the circuit, requiring the operation of protective equipment's to prevent damage to equipment's. The short circuit faults can be classified as:

1. Symmetrical faults
2. Unsymmetrical faults

1. Symmetrical Faults

In such types of faults, all the phases are short-circuited to each other and often to earth. Such fault is balanced in the sense that the systems remain symmetrical, or we can say the lines displaced by an equal angle (i.e. 120° in three phase line).

It is the most severe type of fault in volving largest current, but fortunately it occurs rarely. For this reason, balanced short- circuit calculation is performed to determine these large currents [36].

2. Unsymmetrical Faults

Unsymmetrical faults involve only one or two phases. In unsymmetrical faults the three phase lines become unbalanced. Such types of faults occur between line-to-ground or between lines. An unsymmetrical series fault is between phases or between phase-to-ground, whereas unsymmetrical shunt fault is an unbalanced in the line impedances. Shunt fault in the three phase system can be classified as;

- Single line-to-ground fault (LG).
- Line-to-line fault (LL).
- Double Line-to-ground fault (LLG).
- Three-phase short circuit fault (LLL).
- Three-phase-to-ground fault (LLLG).

The main protections that can be applied are under/over voltage, and over current on AC side, under/over voltage on DC side. The relays and other protection equipment are placed accordingly in modelled EVCS (Electric Vehicle Charge Station) depending on the possibility of occurrence of a fault.

4.2.3.1 Over-Current Relay

Electrical equipment and personnel when an electrical fault occurs. Protection relay is designed based on the basis of selectivity, reliability, speed and sensitivity [1]. One of protection relays used to protect the circuits in power system and EVCS is overcurrent relay [37].

Overcurrent relay is simple and widely used in protection strategy in distribution circuits, maintaining high degree of serviceability and security. The relay works on the basic principle that when current exceeds a threshold value or pickup value, it trips with or without time delay, tripping the associated circuit breakers. The overcurrent relays with fixed time delays are called as definite time overcurrent relay.

The definite time overcurrent relay measures the current and compares with the predefined threshold values, and after fixed time delay issues trip signal to the circuit breaker. **(Figure 4.11)** shows the overcurrent relay block modelled using MATLAB/Simulink. The relay model should be fed with input currents ‘Ia , Ib , Ic’, and the output terminal issues trip signal.

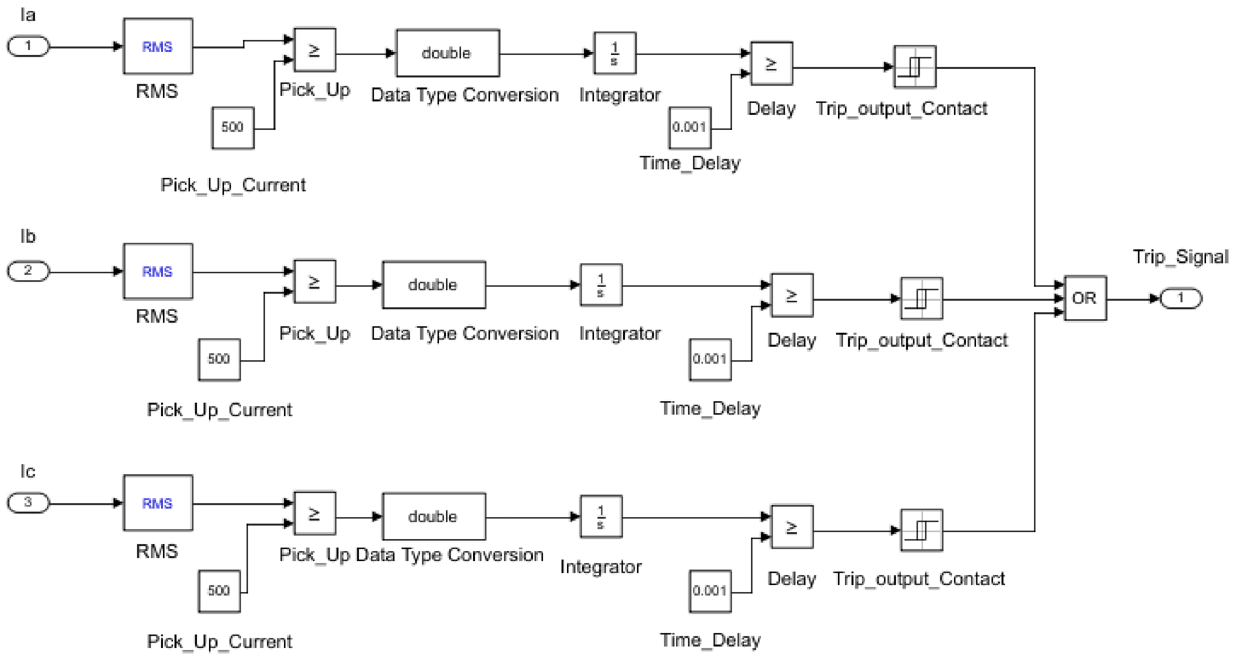

Figure 4.11 Simulink model of the Overcurrent Relay

The RMS block outputs the RMS value of the input current signal which is utilized to compare with the threshold value. If the fault current is increased beyond the threshold value, then the relational comparator generates active HIGH signal, which is integrated to reflect time delay. The integrated signal is compared with the time dial settings. When the integrated time increases beyond the time threshold, the relational comparator generates active HIGH signal. The relay block ensures that the relay does not reset by itself.

4.2.3.2 Over / Under Voltage Relay

Over/Under Voltage Relays provide protection to equipment where an over or under voltage condition is potentially damaging. They are designed to energize when the operating voltage reaches a pre-set value and drop-out when the operating voltage drops to a level below the pre-set value. **(Figure 4.12 and 4.13)** shows the over/ under voltage protection block modelled using MATLAB/Simulink.

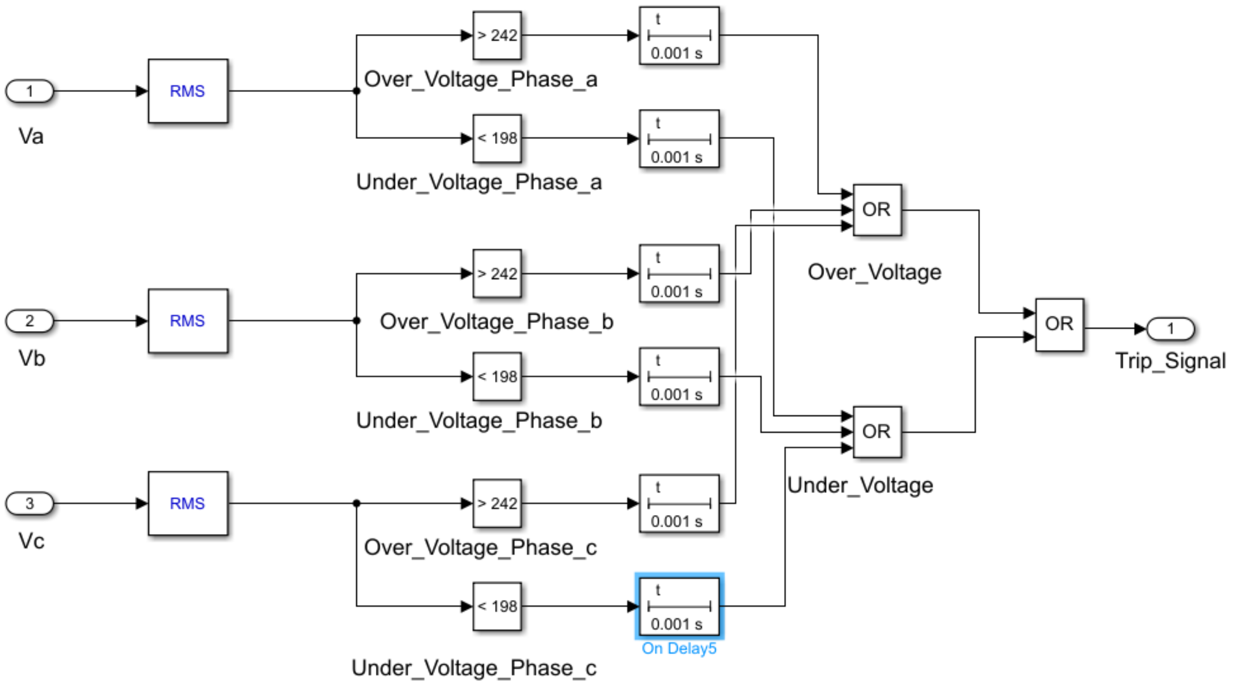

Figure 4.12 Simulink model of the over/ under voltage protection

Overvoltage and under voltage are quality problems, they happen due to many reasons. The effects of overvoltage and under voltage can be severe and can cause insulation failure in case of overvoltage and overheating and burning equipment’s in case of under voltage [37].

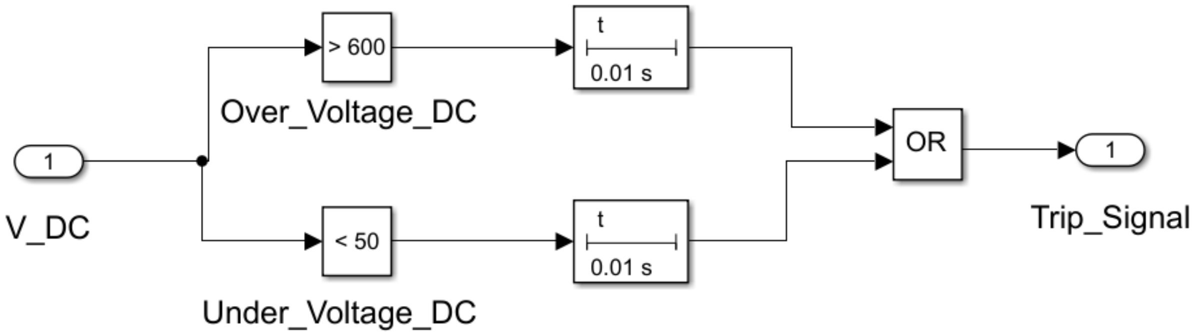

Figure 4.13 Simulink model of the over/ under voltage protection at DC side

4.2.3.2.1 Over-voltage:

The main causes due to which over-voltages are produced in the power systems can be generally classified into two categories as follows:

Internal over-voltages, this is classified to:

- Switching over-voltages.
- Insulation failure.
- Arcing ground: can be prevented by earthing the neutral.
- Resonance.

External over-voltages: due to lighting.

4.2.3.2.2 Under-voltage:

Sag or under-voltage is a temporary decrease in power lasting up to over a minute. Sag or an under-voltage typically happens whenever heavy machinery is turned on. A great amount of power is used by the heavy machinery during start up, leaving a small amount or power available for other equipment to use. Voltage sags also happen when the main source of power is affected by natural events like lightning strikes, strong winds and power lines getting hit by falling tree branches. Sag or an under-voltage may affect equipment within 100 miles of the main power grid of a utility company [37].

4.2.4 Battery Charger Control

The control systems play an important role of any system. They monitor the working of a system at various points and vary the input parameters accordingly to ensure output to meet the required set values.

A schematic diagram for the control of EV charger is shown below in **(Figure 4.14).**

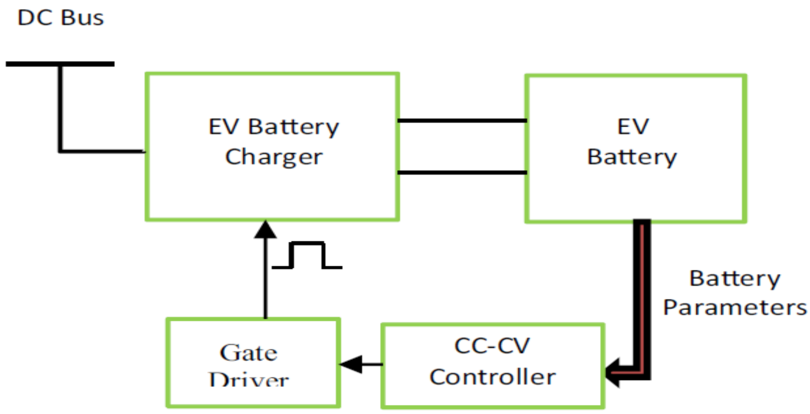

Figure 4.14 Control scheme for EV Charger

The Charging scheme used in this project for the charging of EV battery is Constant Current-Constant Voltage (CC-CV) charging scheme. The Constant Current-Constant Voltage control by which battery of an EV can be charged the charger is connected with the Constant current in the first phase to avoid sudden injection of high currents when connected to DC bus, and the charging voltage was maintained constantly in the second phase. At the begging of second phase the current become decrease gradually to the end of charging.

The battery voltage V_{bat} reaches the reference voltage V_{ref}. The system is switched to double closed loop control of the outer voltage loop and inner current loop. The voltage loop output becomes the input of the current-loop after the PI adjustment. In addition, it is compared with the battery feedback current and triangle wave. The output signal will inter to three PWM generator with phase shift 120 degree between them to share the current for the interleaved buck to reduce the output ripple current and reduce thermal effect. The current will follow the reference voltage to maintain the constant voltage [38-40].

The flow chart for the program of CC-CV controller is given in **(Figure 4.15).**

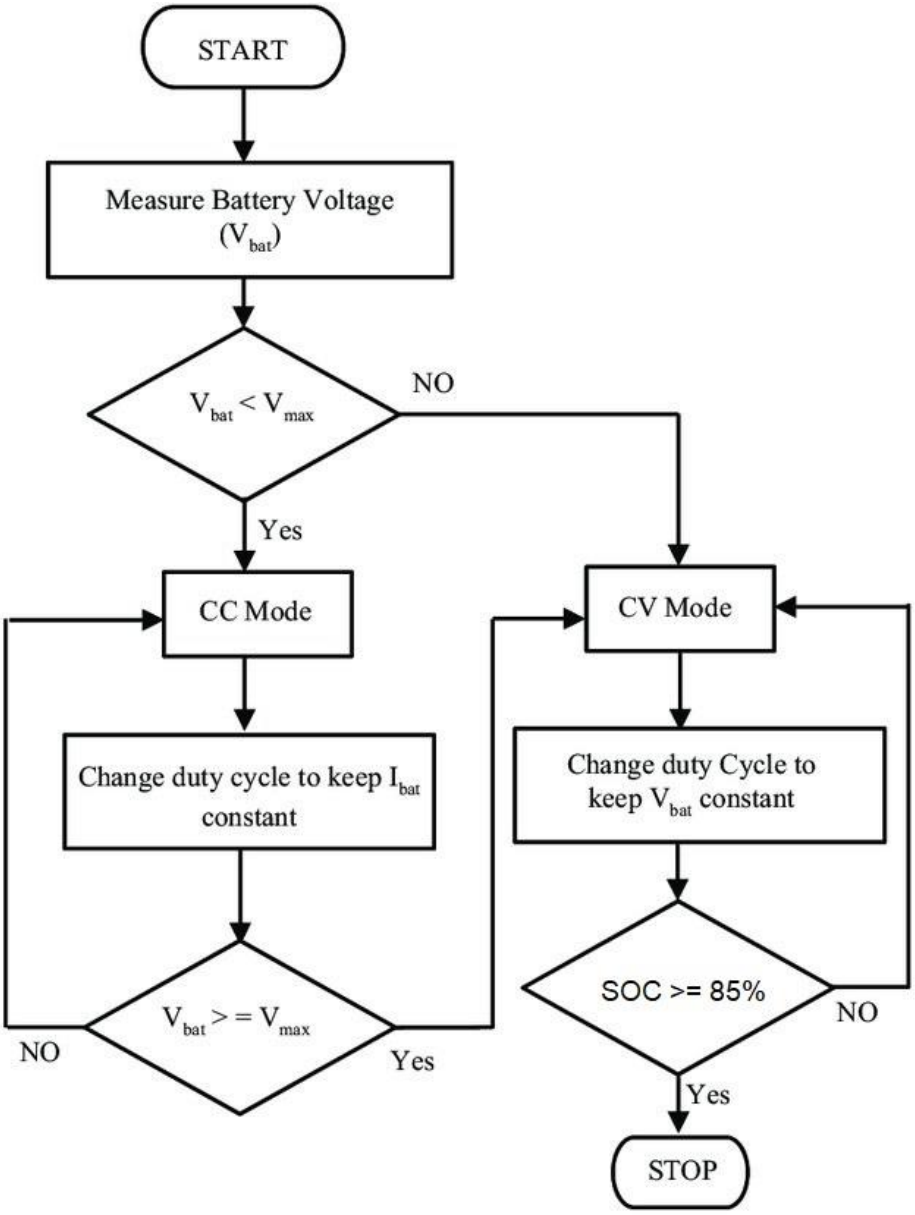

Figure 4.15 Flow chart for CC-CV charging.

The PI parameters of this thesis are chosen using a try and error approach. The criteria is as Follows:

- The charging current should rise to the set value as soon as possible in the beginning of charging.

- The charging current should decrease at a proper speed when the voltage reaches the preset limit.

Constant Current-Constant Voltage (CC-CV) switching charging control method using MATLAB/Simulink is as shown in **(Figure 4.16).**

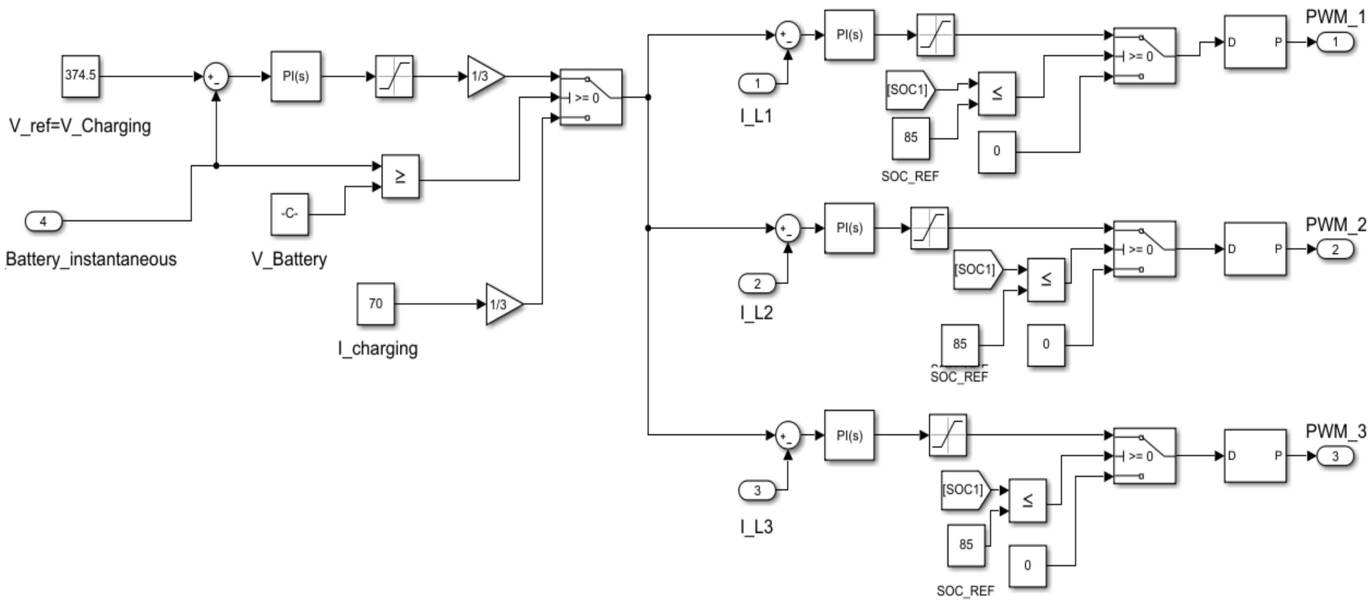

Figure 4.16 Simulink model of the Constant Current-Constant Voltage (CC-CV) charging control

4.2.5 Modelling Of Lithium-Ion Batteries

For the purpose of modelling of the battery, the battery packs and EV drives in different driving modes, the MATLAB/Simulink software is used In the MATLAB graphical editor Simulink a generic model of Lithium-Ion battery according to Shepherd's model is developed and verified **(Figure 4.17).** It is modelled as a controlled voltage source dependent on the actual state of the battery charge (SOC).

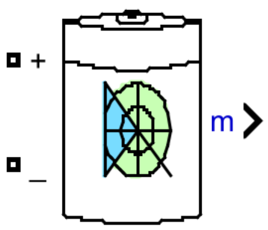

Figure 4.17 Simulink block mask of Lithium-Ion battery model (SimPowerSystems)

For verification of the model, input parameters of EV BMW i3 2017 were selected. In this regard, the base of the battery pack in model is a battery cell with nominal voltage 3.75 V with high voltage battery pack 352 V and 120 AH. The parameters obtained from the catalogue of the manufacturer.

5

Chapter Five

Simulation and Result

5.1 Power Source and Rectifier

5.2 Interleaved converter and control

5.3 Protection

5. Simulation and Result

In this chapter, the EV charger station simulation model built in Matlab/Simulink. The model consists of a three-phase grid AC supply connected to the charging station, and the three-phase grid voltage is rectified to a DC voltage by utilizing a three-phase rectifier, the EV battery is charged through the DC/DC buck converter to perform the charge.

5.1 Power Source and Rectifier

Results of simulation are shown in the figures. **(Figure 5.1)** shows the waveforms for voltage and current drawn by the charging station from the grid. Three phase sinusoidal source with 50HZ frequency.

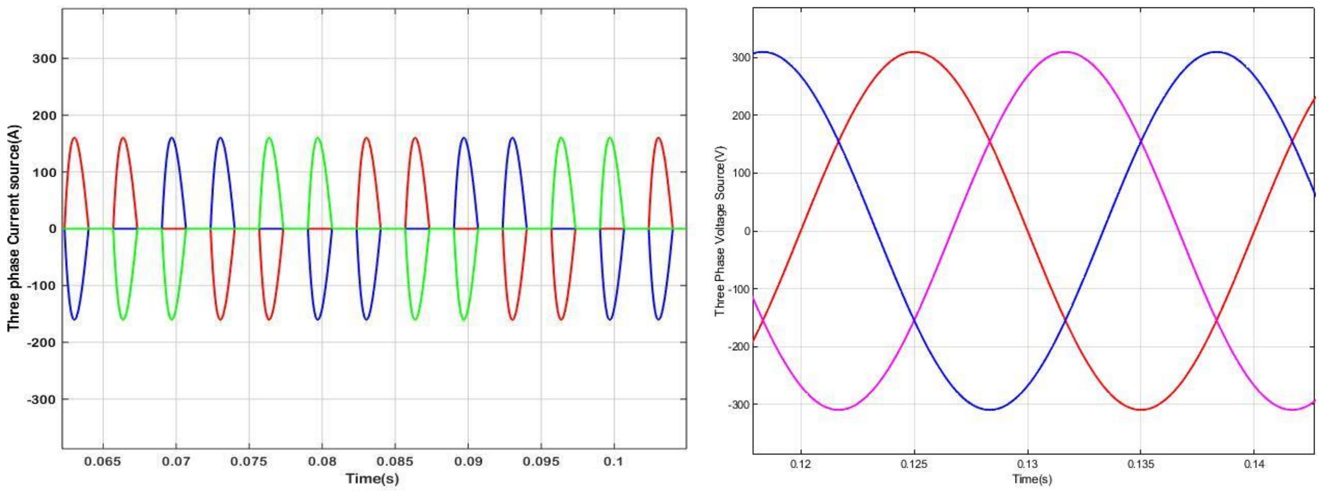

Figure 5.1 Waveforms of (a) Three phase current source (b) Three phase voltage source

For the Three-Phase Full Wave Uncontrolled Rectifier, **(Figure 5.2)** shows the smooth output voltage, 530V with low ripple voltage.

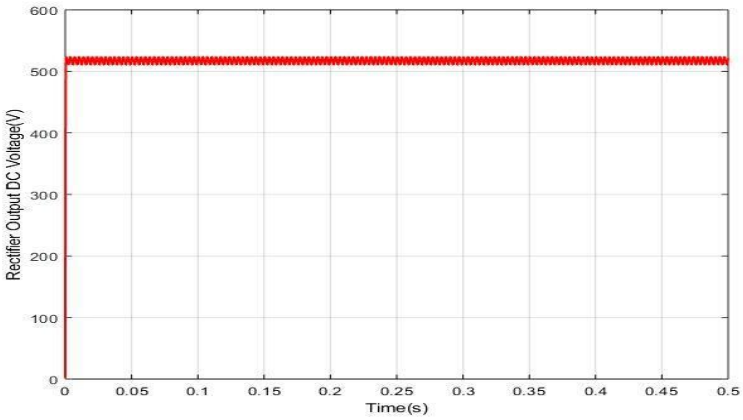

Figure 5.2 Rectifier Output DC Voltage

5.2 Interleaved converter and control

Interleaved Buck Converters has been simulated at 20 kHz switching frequency for 530-420V buck mode operation. In the simulation, MOSFET is used as the switching device. **(Figure 5.3)** shows the gate pulses for three phases of Interleaved DC-DC Converter. These pulses are 120 phase shifted from each other and these are applied to their respective legs.

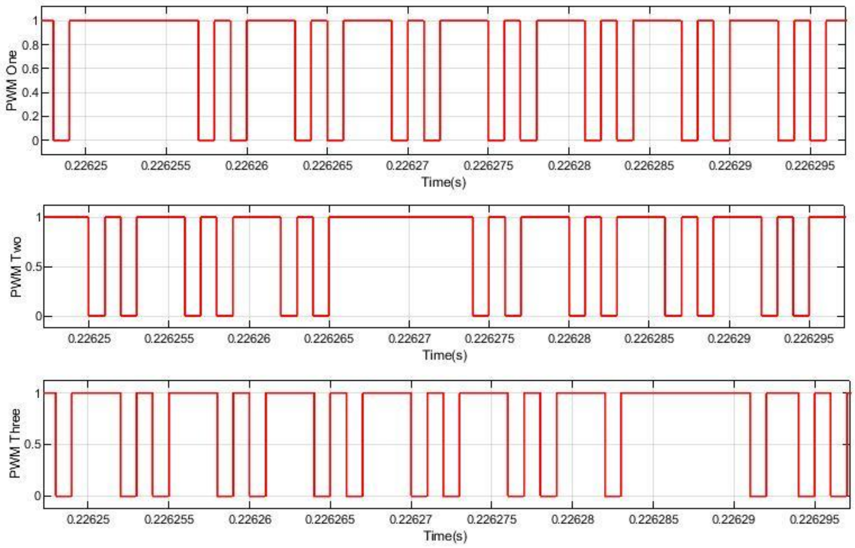

Figure 5.3 PWM Signal with phase shift 120 degree between them

By interleaving the phase currents of the different modules, to share the current for three phases of Interleaved DC-DC Buck Converter to reduce the output ripple current and reduce thermal effect. The smooth output current can be achieved. **(Figure 5.4)** shows simulation results of the three inductor currents. The total volume of the inductors is reduced by a factor of and due to the small ripple 1/3 of the output current. **(Figure 5.5)** shows simulation results of the total output current.

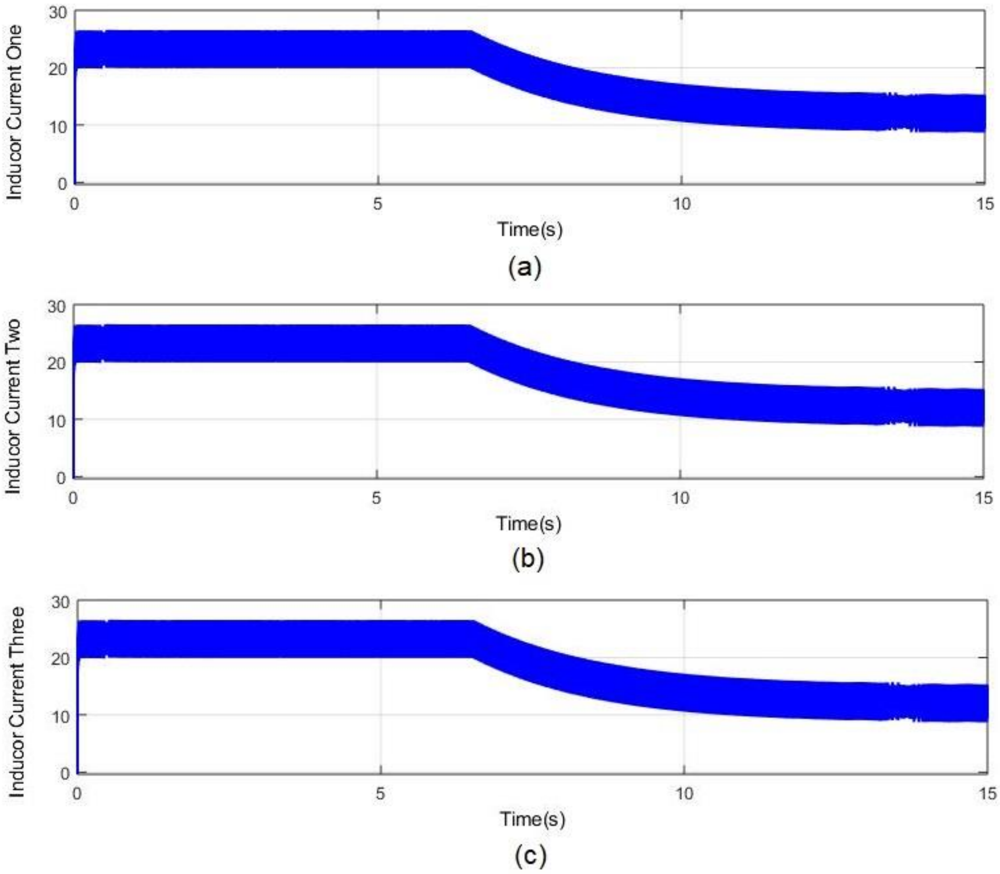

Figure 5.4 **(a)** Inductor current of phase one **(b)** Inductor current of phase two **(c)** Inductor current of phase three

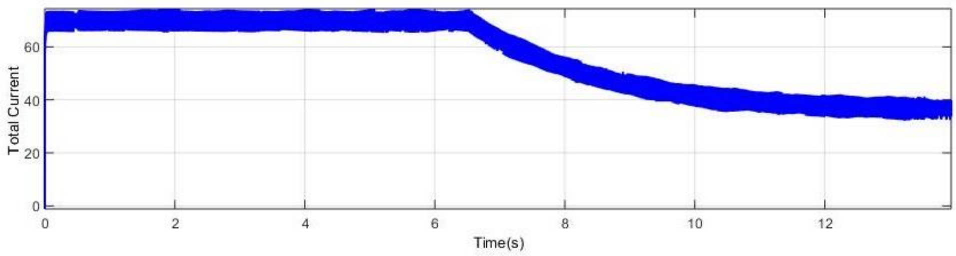

Figure 5.5 The total output current

Charging stage is meant to operate in two different modes: CC and CV modes similarly to the battery charging profile depicted in **(Figure 5.6).**

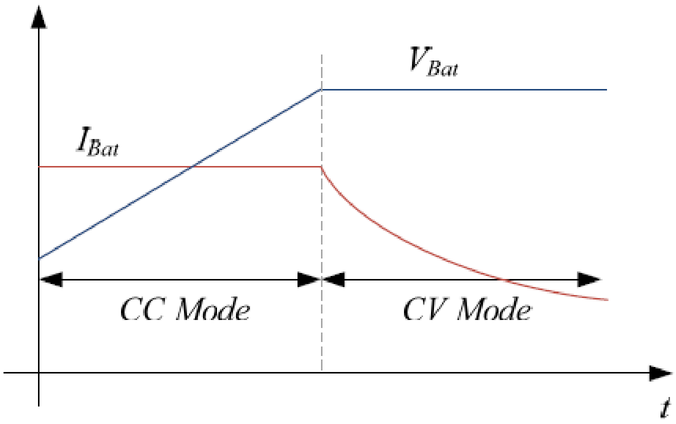

Figure 5.6 CC-CV battery charging profile.

While the battery voltage is below the nominal voltage of the battery (374 V in this case), the charger has to deliver a constant current to the battery (70 A in this case). Once the battery has reached its nominal voltage (see **Figure 5.7**), the system is switched to double closed-loop control of the outer voltage loop and inner current loop. The voltage loop output becomes the input of the current-loop after the PI adjustment. The charger has to start operating in CV mode and reduce the current delivered to the battery accordingly along with the SOC of the battery (see **Figure 5.7** and **5.9**) until the battery is completely charged.

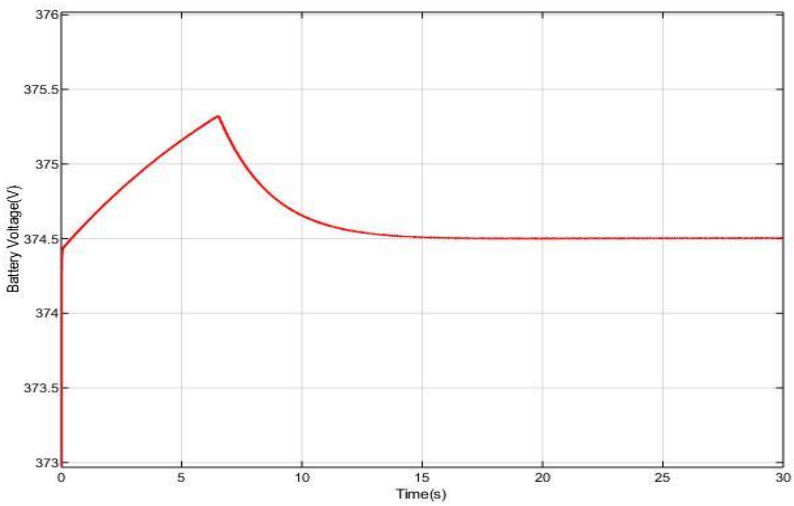

Figure 5.7 Battery Voltage

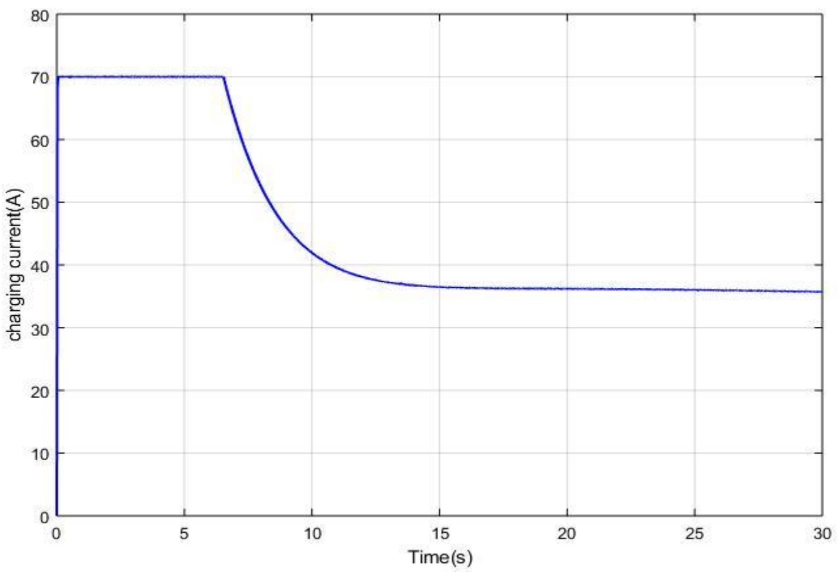

Figure 5.8 Charging Current

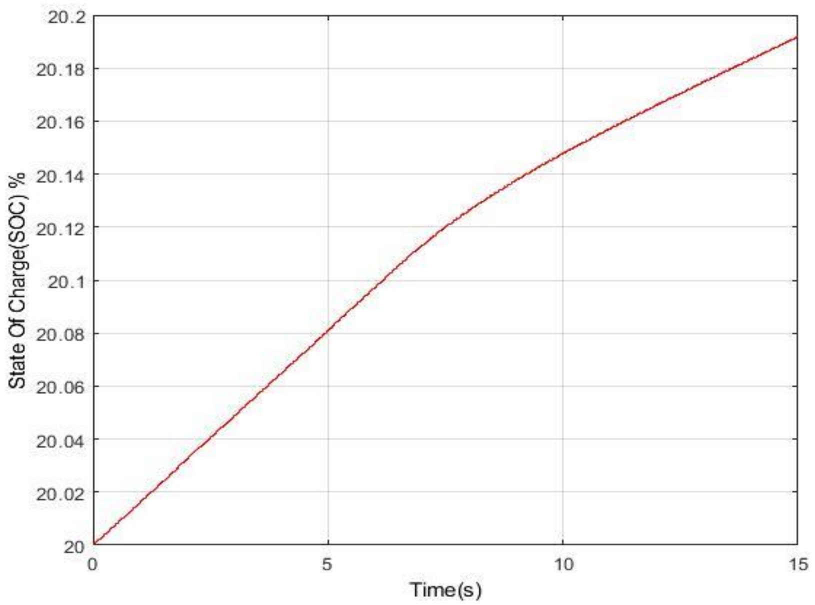

Figure 5.9 State Of Charge (SOC)

5.3 Protection

The main protections that can be applied are under/over voltage, and over current on AC side. The relays are placed accordingly in modelled EVCS (Electric Vehicle Charge Station) depending on the possibility of occurrence of a fault.

In this case we simulate the three phase fault at AC side. The protection relays used to protect the circuits in power system and EVCS when this fault happened is overcurrent relay and under/over voltage relay.

At The overcurrent relays, The RMS value of the input current signal which is utilized to compare with the threshold value (500A in this case). When the fault current is increased beyond the threshold value, then the relational comparator generates active HIGH signal, which is integrated to reflect time delay. The integrated signal is compared with the time dial settings. When the integrated time increases beyond the time threshold (0.001 s in this case), the relational comparator generates active HIGH signal as shown in (**Figure 5.10**).

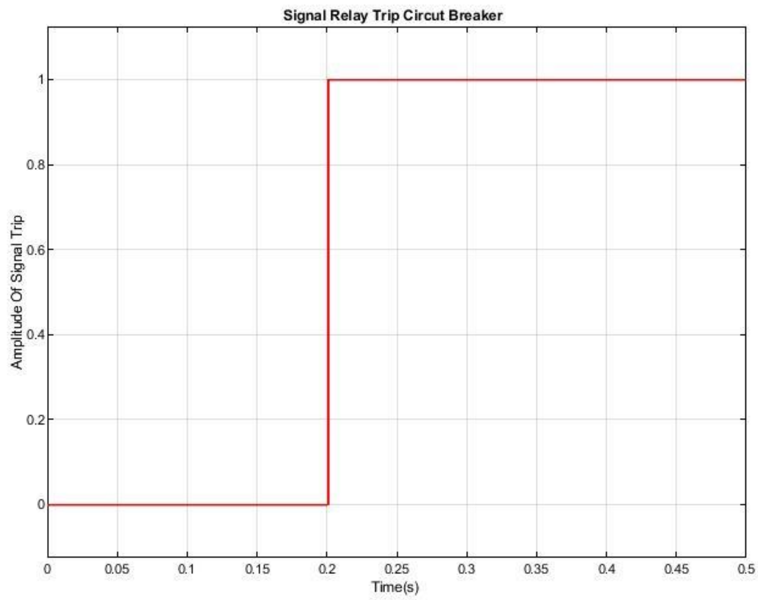

Figure 5.10 Signal Trip Circuit Breaker

After the HIGH signal generated, the trip signal is connected to circuit breaker.

As shown in the (**Figure 5.11 and 5.12**) is the three phase voltage and current source after fault when the circuit breaker is open.

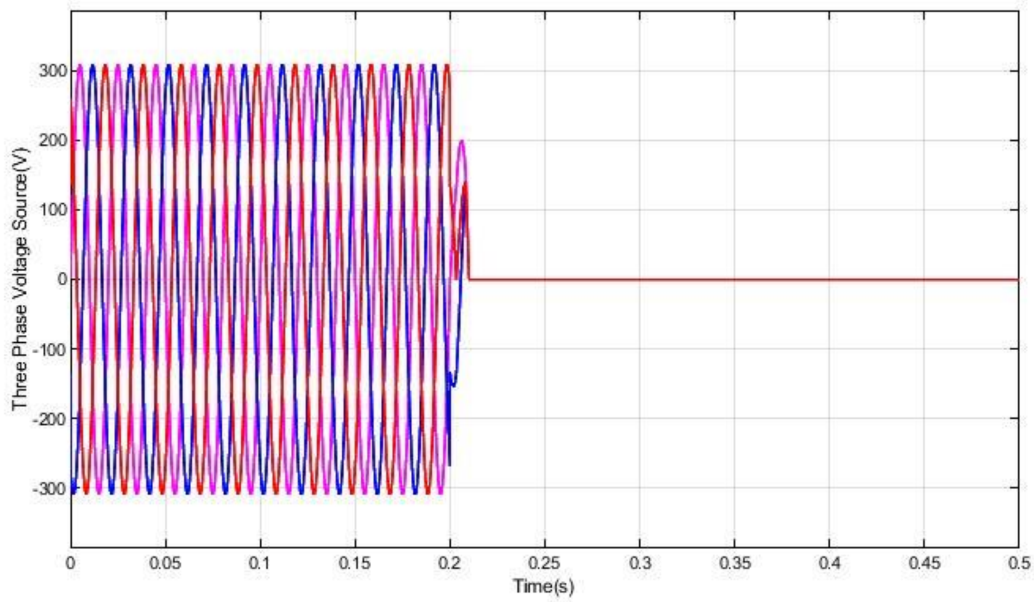

Figure 5.11 Three Phase Voltage Source

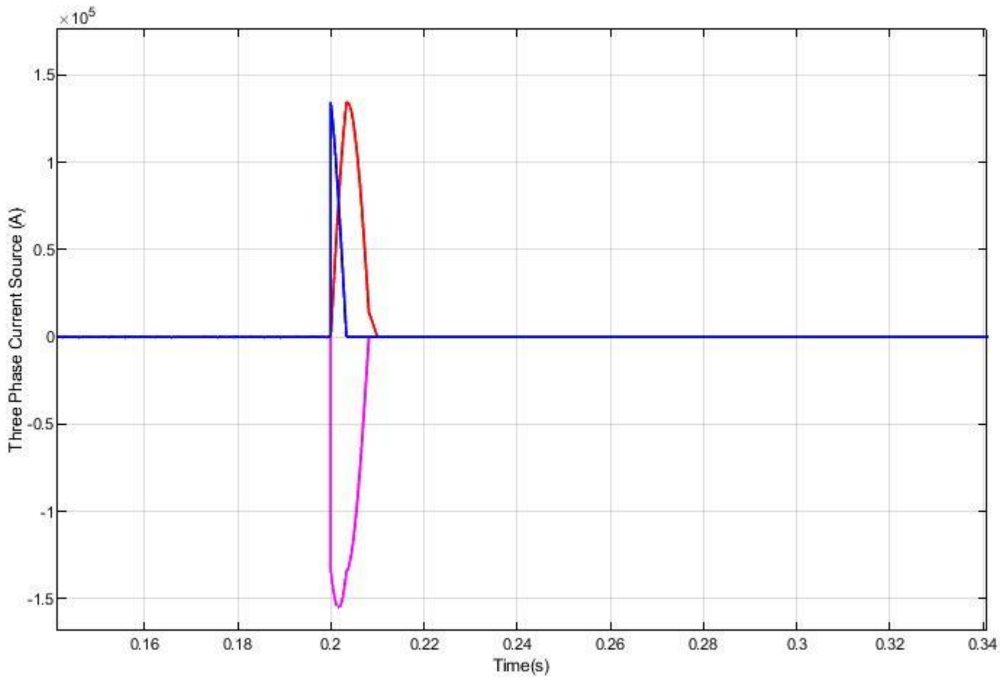

Figure 5.12 Current Source

As shown in the (**Figure 5.13**) is the rectifier voltage under fault.

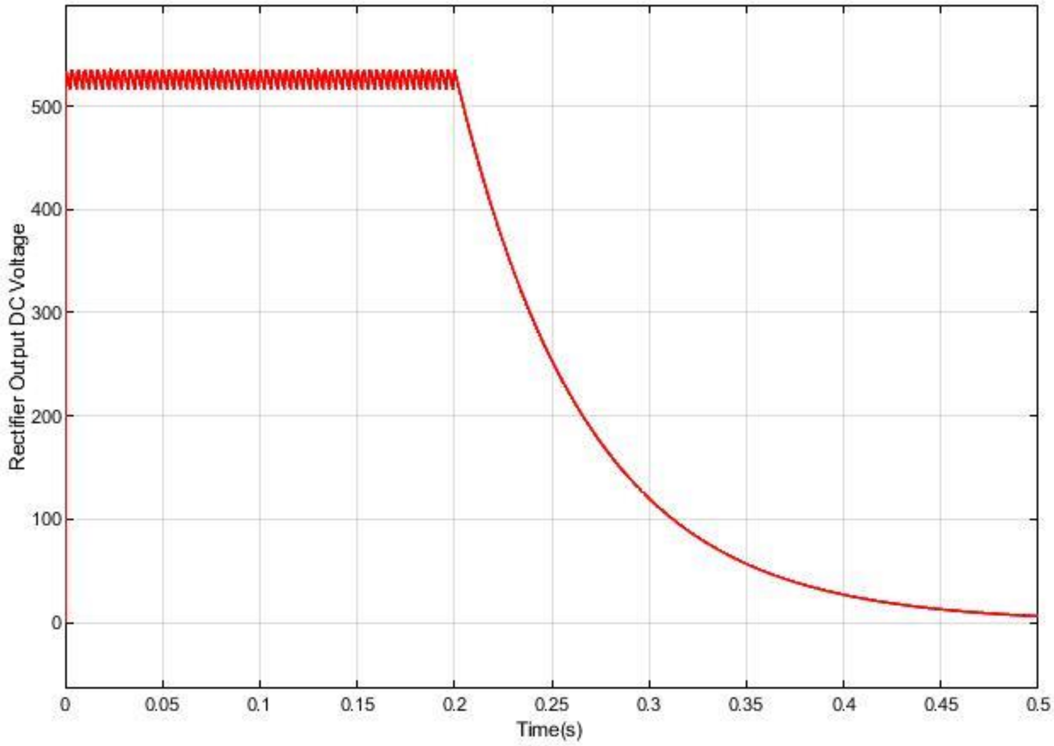

Figure 5.13 Rectifier Voltage under Fault

6

Chapter six

Participation and Recommendations

6.1 Participation in the installation of the first electric vehicle charge station in Hebron

6.2 Recommendations

6. Participation and Recommendations

6.1 Participation in the installation of the first electric vehicle charge station in Hebron.

We participated in the construction and installation of the first electric vehicle charge station in Hebron; Ein Sarah Street facing the Hebron Municipality implemented by PALEV company for shipping services and solutions for electric vehicles, which is the first charge station in Hebron and the fourth in the State of Palestine. (**Figure 6.1**) is the Image of the electric vehicle charge station in Hebron.

Figure 6.1 Electric vehicle fast charge station in Hebron

The name this station is EVBox (Troniq 50) design is safe and easy to use making it accessible to any electric vehicle and applicable anywhere. Its smart power management capabilities will always ensure cost-effective management and energy efficiency in multiple units.

The EVBox (Troniq 50) features fast charging for electric vehicles, The capacity of this plant is 50 Kw can charges up to 125 km in just 30 minutes and features a flexible, globally compatible body in every space, use case-by-case with automatically retractable cables, high-quality power electronic components, and more energy efficient with smart queue options and battery storage.

This station supports two made for charge Mode 4 (DC charging) and Mode 3 (AC charging). Specification for EVBox (Troniq 50):

1) Works as a standalone charger or as an EVBox (Troniq 50) Power Unit.
2) AC & DC charging connectors are included in the housing.
3) Can charge AC and DC simultaneous.
4) Has an AC / DC converter.
5) Includes AC and DC controllers.
6) Have independent AC and DC electrical protections.

A second section of this Participation, we did an interview with PALEV company in Ramallah the interview included project members, sales manager Hadeel Qasim, and engineer Muhannad Sobeih. We talked about the reality of electric cars and charging stations in Palestine, the challenges facing the company and the future view of the company and electric cars in Palestine. At the end of the interview, the company encouraged the work of these new technical projects and expressed any assistance that we might need during the project work.

6.2 Recommendations

In this section we have some recommendation to be taken in consideration for future development and improvement for this project and/or other similar project.

- Make Average model and Mathematical analysis for steady-state model for electric vehicle charge station.
- Create study for electric vehicle charge station effect on the grid.
- Work on electric vehicle charge station feed by PV panels
- Create electric vehicle charge station Supported G2V , V2G and V2V technologies by micro grid system

References

[1] C. Saber, "Analysis and optimization of the conducted emissions of an on- board charger for electric vehicles," 2017.

[2] G. Mouli, P. Venugopal and P. Bauer, "Future of electric vehicle charging", 2017 International Symposium on Power Electronics (Ee), 2017. Available: 10.1109/pee.2017.8171657 [Accessed 10 December 2019].

[3] A. Arancibia and K. Strunz, "Modeling of an electric vehicle charging station for fast DC charging", 2012 IEEE International Electric Vehicle Conference, 2012. Available: 10.1109/ievc.2012.6183232 [Accessed 10 December 2019].

[4] Ç. Dericioğlu, E. Yirik, E. Ünal, M. Cuma, B. Onur And M. Tümay, "A Review Of Charging Technologies For Commercial Electric Vehicles", International Journal Of Advances On Automotive And Technology, 2018. Available: 10.15659/Ijaat.18.01.892 [Accessed 10 December 2019].

[5] H. Koten And S. Bilal, "Recent Developments In Electric Vehicles", International Journal Of Advances On Automotive And Technology, 2018. Available: 10.15659/Ijaat.18.01.890.

[6] A. M. Lulhe and T. N. Oate, “A Technology Review Drives used in Electrical Vehicle (EV) &Hybrid Electrical Vehicles (HEV),” IEEE, p. 5, 2015.

[7] S. J. Rind, M. Jamil and A. Amjad, "Electric Motors and Speed Sensorless Control for Electric .and Hybrid Electric Vehicles: A Review," ieee, 2018

[8] Lowe, Marcy, et al. "Lithium-ion batteries for electric vehicles." The US Value Chain, Contributing CGGC researcher: Ansam Abayechi (2017).

[9] Enache, Bogdan, Emilian Lefter, and Costin Cepisca. "Batteries for Electrical Vehicles: A Review." AUTONOMOUS VEHICLES: 409

[10] Bakker, Daan. "Battery Electric Vehicles: Performance, CO2 emissions, lifecycle costs and advanced battery technology development." Copernicus Institute University of Utrecht (2010).

[11] V. Sangwan, R. Kumar and A. K. Rathore, "Estimation of Model Parameters and State-of-Charge for Battery Management System of Li-ion Battery in EVs," IEEE Transportation Electrification Conference, 2017.

[12] Ç. Dericioğlu, E. Yirik, E. Ünal, M. Cuma, B. Onur And M. Tümay, "A Review Of Charging Technologies For Commercial Electric Vehicles", International Journal Of Advances On Automotive And Technology, 2018.

[13] C. Qiu, K. Chau, T. Ching and C. Liu, "Overview of Wireless Charging Technologies for Electric Vehicles", Journal of Asian Electric Vehicles, vol. 12, no. 1, pp. 1679-1685, 2016.

[14] M. HilmiNoh, "Fast-chargingofLithium-ionbatterieswithohmic-drop compensationmethod," 2017

[15] S. J. Rind, M. Jamil and A. Amjad, "Electric Motors and Speed Sensorless Control for Electric .and Hybrid Electric Vehicles: A Review," ieee, 2018

[16] J. Kim, J. Oh and H. Lee, "Review on battery thermal management system for electric vehicles", Applied Thermal Engineering, vol. 149, pp. 192-212, 2019

[17] M. Al-Zareer, I. Dincer and M. Rosen, "Novel thermal management system using boiling cooling for high-powered lithium-ion battery packs for hybrid electric vehicles", Journal of .Power Sources, vol. 363, pp. 291-303, 2017.

[18] M. Al-Zareer, I. Dincer and M. Rosen, "Novel thermal management system using boiling cooling for high-powered lithium-ion battery packs for hybrid electric vehicles", Journal of Power Sources, vol. 363, pp. 291-303, 2017.

[19] V. Sangwan, R. Kumar and A. K. Rathore, "Estimation of Model Parameters and State-of-Charge for Battery Management System of Li-ion Battery in EVs," IEEE Transportation Electrification Conference, 2017.

[20] Ç. Dericioğlu, E. Yirik, E. Ünal, M. Cuma, B. Onur And M. Tümay, "A Review Of Charging Technologies For Commercial Electric Vehicles", International Journal Of Advances On Automotive And Technology, 2018.

[21] Lowe, Marcy, et al. "Lithium-ion batteries for electric vehicles." The US Value Chain, Contributing CGGC researcher: Ansam Abayechi (2017).

[22] S. Habib, M. Kamran and U. Rashid, "Impact analysis of vehicle-to-grid technology and charging strategies of electric vehicles on distribution networks – A review", Journal of Power .Sources, vol. 277, pp. 205-214, 2015. Available: 10.1016/j.jpowsour.2014.12.020

[23] M. Yilmaz and P. Krein, "Review of Battery Charger Topologies, Charging Power Levels, and Infrastructure for Plug-In Electric and Hybrid Vehicles", IEEE Transactions on Power Electronics, vol. 28, no. 5, pp. 2151-2169, 2013. Available: 10.1109/tpel.2012.2212917 [Accessed 10 December 2019].

[24] Xiangwu Yan, Ri En and Yanyan Li, "Research on Power Supply Mode for Electric Vehicle Charging Devices in Residential Community", 2013 IEEE Vehicle Power and Propulsion Conference (VPPC), 2013. Available: 10.1109/vppc.2013.6671706 [Accessed 10 December 2019].

[25] Watertight Electrical Connector For Undersea Vehicles And Components", Naval Engineers Journal, Vol. 77, No. 4, Pp. 562-572, 1965. Available: 10.1111/J.1559-3584.1965.Tb04979.X [Accessed 10 December 2019].

[26] A. Arancibia and K. Strunz, "Modeling of an electric vehicle charging station for fast DC charging", 2012 IEEE International Electric Vehicle Conference, 2012. Available: 10.1109/ievc.2012.6183232 [Accessed 10 December 2019].

[27] G. Mouli, P. Venugopal and P. Bauer, "Future of electric vehicle charging", 2017 International Symposium on Power Electronics (Ee), 2017. Available: 10.1109/pee.2017.8171657 [Accessed 10 December 2019].

[28] Ç. Dericioğlu, E. Yirik, E. Ünal, M. Cuma, B. Onur And M. Tümay, "A Review Of Charging Technologies For Commercial Electric Vehicles", International Journal Of Advances On Automotive And Technology, 2018.

[29] O. Ruiz-Guzman, A. Ustariz-Farfan and E. Cano-Plata, "Modeling of electric vehicle chargers by its characterization in charging stages", 2015 IEEE Workshop on Power Electronics and Power Quality Applications (PEPQA), 2015.

[30] A. Ayob et al., "Review on Electric Vehicle, Battery Charger, Charging Station and Standards", Research Journal of Applied Sciences, Engineering and Technology, vol. 7, no. 2, pp. 364-373, 2014. Available: 10.19026/rjaset.7.263 [Accessed 10 December 2019].

[31] H. Shareef, M. Islam and A. Mohamed, "A review of the stage-of-the-art charging technologies, placement methodologies, and impacts of electric vehicles", Renewable and Sustainable Energy Reviews, vol. 64, pp. 403-420, 2016. Available: 10.1016/j.rser.2016.06.033 [Accessed 10 December 2019].

[32] V. Sangwan, R. Kumar and A. K. Rathore, "Estimation of Model Parameters and State-of-Charge for Battery Management System of Li-ion Battery in EVs," IEEE Transportation Electrification Conference, 2017.

[33] Cornea, O., Muntean, N. and Gavris, M., 2010. Interleaved 3 phase DC/DC converter for automotive applications. 2010 12th International Conference on Optimization of Electrical and Electronic Equipment.

[34] Balen, G., Reis, A., Pinheiro, H. and Schuch, L., 2017. Modeling and control of interleaved buck converter for electric vehicle fast chargers. 2017 Brazilian Power Electronics Conference (COBEP).

[35] Abdel-Salam, M., Kamel, R., Khalaf, M. and Sayed, K., 2014. Analysis of overcurrent numerical-relays for protection of a stand-alone PV system. 2014 Saudi Arabia Smart Grid Conference (SASG).

[36] Banu, I., Istrate, M., Machidon, D. and Pantelimon, R., 2014. A study on anti-islanding detection algorithms for grid-tied photovoltaic systems. 2014 International Conference on Optimization of Electrical and Electronic Equipment (OPTIM).

[37] Hussin, N., Idris, M., Amirruddin, M., Ahmad, M., Ismail, M., Abdullah, F. and Mukhta, N., 2016. Modeling and simulation of inverse time overcurrent relay using Matlab/Simulink. 2016 IEEE International Conference on Automatic Control and Intelligent Systems (I2CACIS),.

[38] Nandankar, P. and Rothe, J., 2016. Design and implementation of efficient three-phase interleaved DC-DC converter. 2016 International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT).

[39] Khan, W., Ahmad, F. and Alam, M., 2019. Fast EV charging station integration with grid ensuring optimal and quality power exchange. Engineering Science and Technology, an International Journal, 22(1), pp.143-152.

[40] Cuoghi, S., Mandrioli, R., Ntogramatzidis, L. and Gabriele, G., 2020. Multileg Interleaved Buck Converter for EV Charging: Discrete-Time Model and Direct Control Design. Energies, 13(2), p.466.

[41] Sayed, K. and Gabbar, H., 2016. Electric Vehicle to Power Grid Integration Using Three-Phase Three-Level AC/DC Converter and PI-Fuzzy Controller. Energies, 9(7), p.532.

[42] Naveen, G., Yip, T. and Yuyu Xie, 2014. Modeling and protection of electric vehicle charging station. 2014 6th IEEE Power India International Conference (PIICON).

[43] Standards.ieee.org. 2020. 1159-2009 - IEEE Recommended Practice For Monitoring Electric Power Quality. [online] Available at: <https://standards.ieee.org/standard/1159-2009.html> [Accessed 30 May 2020].

Appendix

In this section we're attaching EVBox (Troniq 50).

EVBox Troniq 50

fast charging solution

50 kW
Charges up to 125 km in just 30 minutes
Flexible architecture and universally compatible in every space and use case
Made to last with auto-retractable cables, high quality power electronic components, and more
Consumes power efficiently with smart queuing and battery storage options

- 50 kW fast charging capacity
- Flexible architecture
- Tariff settings
- Universally compatible
- Roaming
- Utility power cabinet
- Auto-retractable cables
- Easy transportation, installation and maintenance
- Advanced cooling and heating system
- Remote maintenance
- 3-year warranty
- Smart queuing
- Color touchscreen with 4 languages
- Optional battery storage

evbox.com

Product **portfolio**

EVBox Troniq 50

- Works as a standalone charger or as a EVBox Troniq Power Unit
- AC & DC charging connectors are included in the housing
- Can charge AC and DC simultaneously
- Has an AC / DC converter
- Includes AC and DC controllers
- Has independent AC and DC electrical protections

EVBox Troniq User Unit 125 A (UU)

- Must be connected to a EVBox Troniq 50
- AC & DC charging connectors are included in the housing
- Can charge AC and DC simultaneously
- Does not have an AC / DC converter
- Includes only an AC controller

Product **combinations**

EVBox Troniq 50 Standalone*

- Ideal for places that allowing short parking times (around 30 min.)
- Has the biggest customization surface
- Requires minimum installation work

(EVBox Troniq 50 + 1 x EVBox Troniq User Unit 125 A) **

- Ideal combination for longer parking times (>1 hour)
- Allows for easy parking and plug handling
- More connectors are available
- If a connector has an error, the user has a second option, enabling a continuous service
- Smart queuing for AC and DC can be used

* When only 1 car is connected, charger provides the maximum required power, when 2 cars are connected (one in AC and another in DC) the charger splits the maximum output power between 2 cars. ** Only 1 DC car can be charged at one time, even though there is more than one DC connector. Queuing is available in AC and CHAdeMO. Maximum 2 User Unit can be used per EVBox Troniq 50.

General **specifications**

EVBOX

Charging modes	
Mode 4 (DC charging)	CHAdeMO; CCS2 up to 500 V / 120 A
Mode 3 (AC charging)	Up to 43 kW / 63 A or limited up to 22 kW / 32 A
Mode 2 (AC charging)	Up to 2.3 kW / 10 A
Connector type	
Mode 4	JEVS G105 (CHAdeMO), CCS2
Mode 3	Type 2 attached cable (43 kW), Type 2 socket (22 kW)
Mode 2	Type E/F socket
Cable length	
Mode 4	3.95 m with auto-retractable cable
Mode 3	3.95 m with auto-retractable cable
Mode 2	--
Structure and physical properties	
Enclosure material	Galvanized steel (structure), aluminum (casing), stainless steel (feet)
Enclosure ratings	IP54 / IK10
Ambient temperature	-30°C to +50°C
Storage temperature	-40°C to +70°C
Operating humidity	5% to 95% non-condensing
Enclosure fire ratings	M3 (NF P 92-501)
Cooling	Forced ventilation
Mounting method	Floor / Ground (recommended with the optional clamping-sealing kit)
Maximum installation height	< 2000 m
Dimension (W x H x D) and weight*	
EVBox Troniq 50	765 x 1920 x 465 mm / 340 kg (Mono-standard) 820 x 1920 x 465 mm / 345 kg (Bi-standard) 920 x 1920 x 465 mm / 350 kg (Tri-standard)
EVBox Troniq User Unit 125 A	331 x 1895 x 467 mm / 85 kg (Mono-standard) 421 x 1895 x 467 mm / 90 kg (Bi-standard) 513 x 1895 x 467 mm / 95 kg (Tri-standard)
Connectivity	
Authorization	RFID/NFC (ISO 14443, ISO 18092, ISO 15693, ISO 18000-3, Calypso, Mifare Ultralight C, -Classic, -Desfire)
Status indication / HMI	2 beacon RGB LED Indicators / 7" anti-vandalism LCD touch screen
Communication standard	GPRS/3G modem and Ethernet
Communication protocol	OCPP 1.5 S and 1.6 J
Positioning	GPS
Certifications	CE, EMC Directive 2014/30/EU, Low Voltage Directive 2014/35/EU, EN/IEC 61851-1, EN/IEC 61851-21-2, EN/IEC 61851-22, EN/IEC 61851-23, DIN 70121, ISO15118, CHAdeMO, EV/ZE-Ready

*The weight can be increased depending of the battery modules installed. (+ 45 kg 2 modules; + 55 kg 3 modules; + 85 kg 6 modules)

Electrical **properties**

EVBox Troniq 50

AC input

Voltage range	400 VAC +/- 10%
Number of phases	3 P + N + PE
Frequency	50 Hz
Required power supply capacity	54 kVA (36 kVA with battery storage)
Nominal input current	77 A (60 A with battery storage)
Power factor	> 0.99
Efficiency	95%
Grounding system	IT, TT or TN-S
Stand-by power consumption	100 W + 40 W

DC output

Output power	50 kW
Output voltage range	50 VDC – 500 VDC
Output current range	1 A – 120 A

AC output (mode 3)

Output power	43 kW with attached cable / 22 kW with socket outlet
Output voltage range	400 VAC +/- 10%
Maximum output current	63 A with attached cable / 32 A with socket outlet

AC output (mode 2)

Output power	2.3 kW
Output voltage range	230 VAC +/- 10%
Maximum output current	10 A

Electrical protections

Internal electrical protections	RCBO 30 mA Type A, RCD 30 mA Type A + 6 mA detection, MCB curve C/D
Required circuit breaker upstream	MCB Curve D, 100 A & RCD 300 mA, Type A, HI, (S)

Models	CHA	CCS	CCS + CHA	CCS + CHA + T2 CABLE	CCS + CHA + T2 SOCKET
Required power supply capacity	54 kVA	54 kVA	54 kVA	54 kVA	54 kVA
Nominal AC input current	77 A	77 A	77 A	77 A	77 A
Maximum output power	DC: 50 kW	DC: 50 kW	DC: 50 kW	DC: 50 kW AC: 43 kW	DC: 50 kW AC: 22 kW
Maximum output current	DC: 120 A	DC: 120 A	DC: 120 A	DC: 120 A AC: 63 A	DC: 120 A AC: 32 A
Output voltage range	DC: 50 - 500 V	DC: 50 - 500 V	DC: 50 - 500 V	DC: 50 - 500 V	DC: 50 - 500 V
Number of plugs	1	1	2	3	3
Connections	JEVS G105	CCS2	CCS2 - JEVS G105	CCS2 - JEVS G105 Type 2 cable	CCS2 - JEVS G105 Type 2 socket
EVBox Troniq 50	✓	✓	✓	✓	✓
EVBox Troniq 50 + 1 x UU	✓	✓	✓	✓	✓

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