FEASIBILITY STUDY OF VEHICLE-TO-GRID SYSTEM

A Dissertation submitted in fulfilment of
the requirements for the Degree

of

MASTER OF ENGINEERING

in

POWER SYSTEMS

Submitted By
Anu Bhardwaj
802142006

Under the guidance of

Faculty supervisor	Host Mentor
Dr. Parag Nijhawan	Shadakshari Dileep
Associate Professor, EIED	Manager, MS/ENB53
TIET, Patiala	BGSW

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Post Bag No. 32, Patiala – 147004

BOSCH

Bosch Global Software
Technologies Private Limited
(CIN:
U72400KA1997PTC023164)
123, Industrial Layout,
Hosur Road, Koramangala
Bengaluru 560095 INDIA
Tel +91 80 6657-5757
Fax +91 80 6657-1404
www.bosch-softwaretechnologies.com

LETTER OF REFERENCE

Internship Completion Certificate

Date: 4/25/2023

This is to certify that **Anu Bhardwaj (E.No : 34792859)** from **Thapar Institute of Engineering & Technology** has carried out an internship on **"Patent study of power electronics"** from **6/20/2022** to **4/28/2023** under the guidance of **Shadakshari Dileep (MS/ENB53).**

We appreciate your valuable contribution and wish you success in your future endeavours.

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Date: 2023.04.26 11:00:49 +05'30'

Punjabi Mahesh Kishore
Senior Project Manager
Human Resource

DECLARATION

I hereby declare that the Project Report entitled, ***"Feasibility Study Of Vehicle-To-Grid System"***, submitted towards partial fulfilment of requirement of Masters of Engineering degree in Power Systems at Thapar Institute of Engineering and Technology, Patiala, is an authentic record of work carried out by me under the supervision and guidance of Dr.Parag Nijhawan, (Associate Professor, EIED) and Mr. Dileep Shadakshari (Manager, BGSW). It refers other researcher's work which are duly listed in the reference section. The matter contained in this dissertation has not been submitted, neither in part nor in full to any other degree to any other university or institute except as reported in text and references.

Place: **Patiala**

Date : **16/06/2023**

Anu Bhardwaj

Roll.no: 802142006

It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

Faculty Supervisor:

Parag Nijhawan

Associate Professor

EIED

T.I.E.T. Patiala

Industry Mentor

Dileep Shadakshari

Technical Project Manager

MS/ENB53

BGSW

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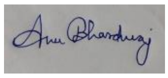

Anu Bhardwaj

(802142006)

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LIST OF ABBREVIATIONS

AC	Alternating Current
BEV	Battery Electric Vehicle
BMS	Battery Management System
CAGR	Compound Annual Growth Rate
DC	Direct Current
DOD	Depth of Discharge
DSM	Demand Side Management
EV	Electrical Vehicle
FFT	Fast Fourier Transform
G2V	Grid to Vehicle
HEV	Hybrid Electric Vehicle
ICE	Internal Combustion Engine
IEEE	Institute of Electrical and Electronics Engineers
IGBT	Insulated-Gate Bipolar Transistor
LD	Light Duty
MPPT	Maximum Power Point Tracking
OEM	Original Equipment Manufacturer
P1	Proportional Integral
PECs	Power Electronic Converters
PHEV	Plug-in Hybrid Electric Vehicle
PLI	Product Linked Incentive
PWM	Pulse Width Modulation
R&D	Research & Development
RT	Real Time

SOC	State of Charge
SOH	State of Health
SRC	Series Resonant Converter
THD	Total Harmonics Distortion
V2G	Vehicle-to-Grid

ABSTRACT

This project report is based on my internship at Bosch Global Software Technologies where I gained great experience. Electric vehicles are gaining worldwide recognition for their improved performance and low carbon emissions. The efficiency of electric vehicles depends on the integration of energy storage and energy conversion. However, energy storage systems generally have the characteristics of low energy consumption, unregulated and highly reactive. To solve these problems, EV converters, controllers and modulation schemes are essential to ensure safe and reliable power transfer from the energy store to the generator. However, these converters and controllers have some disadvantages such as large output, high current voltage, high switching frequency, slow response time and simplicity. One of the main factors hindering more electricity usage is fear of rising electricity costs due to home payments, power quality issues and battery life. Electric power converter is the main function of electric power and battery of electric car. Therefore, the cost of new and reliable electricity is changing rapidly, especially for advanced EV charging systems. The rapid development of power conversion topologies offers significant opportunities in electric vehicle charging. This report provides a comprehensive review of DC-DC converter topologies for battery management and includes simulation models for better understanding and analysis.

CHAPTER 1

INTRODUCTION

1.1 Introduction

In line for the growing problem of energy in addition environmental pollution, the continuous development of power electronics and its technology electric vehicles have become an vital factor in the development of new energy vehicles and in solving problems. Energy and environmental problems of new energy vehicles. The potential impact of EVs on electricity consumption could be significant as more EVs are merged into the power system. In the concern of the power the effect of power transmission cannot be unnoticed. For the electricity operator, the change and energy loss during charging is among the problems that need to be reduced, not only the fluctuations in load, but also power quality issues (for example voltage curves, phase unbalancing, alignment, and many more) are important for customers and consumers. In addition, the following issues for example operational planning, operational effectiveness, customer reliability, and EV user friendliness should also be considered. The concept of V2G has been projected by the overhead problems. The main idea of V2G is that EVs can power EVs when they are stopped, and when the demand is low electric batteries can be charged and discharged in the moment when power is required. In this way, electric car operators earn some profit by purchasing electricity via. grid at a low price then selling it at a great price.

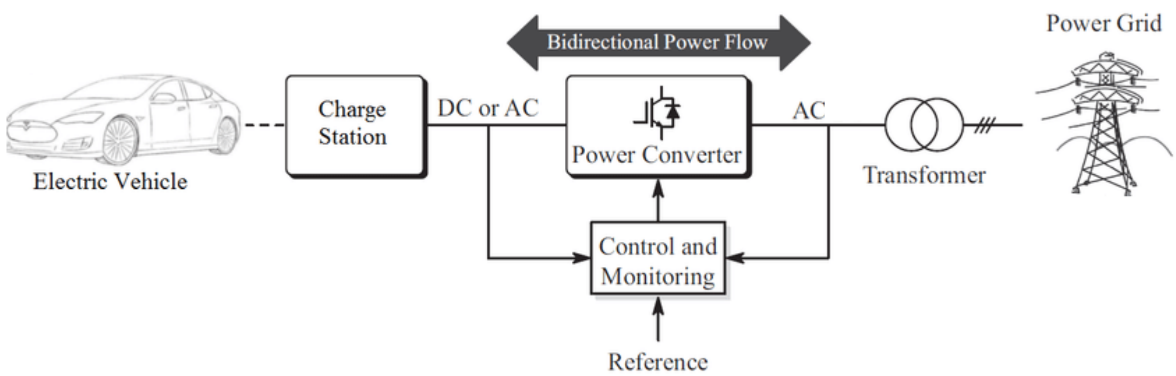

Figure 1.1 Block Diagram of V2G Structure

1.2 Need Analysis

In today's time, worldwide all the countries and their government are focusing on sustainable development. With the population growth the dependency on energy resources keeps on increasing day by day which is not only costly but at the same time, if specifically talking about fossil fuels, is polluting the environment and creating a lot of health issues. To overcome this in the past ten years many countries have come forward to shift to electrical vehicles instead of conventional ICE vehicles. But the main constraints because of which consumers are unsure to shift to electrical vehicles are battery life, charging time, and increased electricity bills at home, also when electrical vehicles are charged via grid supply there are lots of harmonics, power quality issues, and sudden load demands. If any of these problems are overcome then would be a great help for the system. Therefore a system is needed to be designed that can overcome the above-discussed issues.

1.3 Aim and Objectives

1. The motive of the dissertation is in the direction of increasing electrical vehicle charging discharging design performance considering grid efficiency to motivate the worldwide dependency on electrical vehicles.
2. To increase system performance from grid side and operate under unity power factor
3. To increase electrical vehicle performance
4. To improve vehicle battery charging and discharging
5. To control and monitor the different parameters related to performance in electrical vehicle

1.4 Organization of the Thesis

Dissertation report is divided into 7 chapters as described below:

Chapter 1 consists of introduction, need analysis, main aim and objectives and thesis organization itself

Chapter 2 covers the earlier work done, the gap of study, expected deliverables and novelty of project

Chapter 3 is dedicated to theory, standards and constraints

Chapter 4 contains briefs about Patent study, its importance in evolving new technologies in power electronics

Chapter 5 consists of the design methodology, simulations and constraints

Chapter 6 covers the result and discussion on the proposed system

Chapter 7 comprises of the conclusion of work done.

CHAPTER 2

LITERATURE SURVEY

2.1 Earlier Works- An Overview

Due to the worldwide issues such as energy deficiency and increasing environmental problems, its requirement of the time to find out alternates of fossil fuel in the automobile sector and shift from conventional internal combustion based vehicles to electric vehicles. Many countries have come forward with this idea from the past ten years. With this a lot of research points are being offered. Since in electrical vehicles the electric batteries are the source of supply to the motor and other equipment's in the vehicle, so battery charging and discharging has become the most important research point in the field of electric vehicles. For the charging point of view, there are special kind of chargers for solving the purpose and this is also one of the limitations. Also if the electric vehicle is kept stopped for long period of time there will be two major problems come into occurrence that is first of all energy stored in vehicle will not be utilized efficiently and secondly there will be effect of battery's life as well. With the planning and development of the smart grid technology, people are trying to discover and explore a new mode –V2G mode that is to allow the electric power in the electric vehicles to be in the slave mode, and operate in both mode as supplier and the receiver. With this the exchange can be improvised and there will be ease of use and economical for electric vehicle users.

Youjie Ma *et al.* [1] describe how in recent years widespread of electric vehicles lead to wide attention toward vehicle's bidirectional power flow. At the same time since the number of electric vehicles interfacing with power grid is increasing day by day harmonics are also being introduced in the system along with other power quality issues which cannot be ignored. So there is need to design a control over the harmonics generated.

Jingli Guo *et al.* [2] presented vehicle-to-grid technology benefits to the power grid as well as the owners of the electric vehicles. At the same time, its application faces tasks due to battery deprivation. In many past researches it's been noticed it's not necessary that there will always be battery degradation issues with this technology but sometimes it also mitigates the problem of ageing process. A case study demonstrates that equated to the non-V2G situation (no supply to vehicle to grid from vehicle battery), battery capacity damage under V2G is concentrated.

Esra'a Alghsoon et al. [3] described the impact of V2G connection on power quality and stability. Outcomes are shown with respect to various case studies on the effect of vehicle-to-grid machinery on the steadiness of the power quality and its examination along with the harmonics distortions.

Lei Jing *et al.* [4] presented V2G being a new exploration point for the growth of smart grids and novel energy technology, for this bidirectional converter plays a major role in it. With the context of this modulation methods were compared considering various factors such as switching losses should be minimized, ripple current should be small and common noise mode should be small. Considering all the above stated parameters an optimized solution is discussed in the paper.

Shi Rui *et al.* [5] described the incorporation of vehicle batteries with the supply network. After this the observation was done between the interface of active distribution grid and the electric vehicle. The focus is to observe the likelihood of control capability of bidirectional converter of charging stations of electric vehicle in as long as voltage provision for the operation of distribution network. Simulation is also done for the proposed model in the research paper.

Sagar Navinchandran, Mini Sujith [6] proposed a single phase on-board charger to utilize in electric vehicle charger of bidirectional work mode with the main purpose of attaining Vehicle to Grid (V2G) & Grid to Vehicle (G2V) claim. The charger arrangement generally comprises a buck converter and the other one is a high-gain boost converter. The SOC is the important point for the charging and discharging of the electric vehicle. Simulation results are conducted with the use of Matlab Simulink model to authenticate bidirectional onboard charger practices with a high-gain boost converter.

Matt Liu et al. [7] proposed a new bidirectional battery charger for V2G submissions. A simple AC-DC converter variate the voltage of DC bus allowing charger's power flow. This way the series resonant converter that is working in buck mode can be operated in dual directions maintain the efficiency as well. The converter then operating in capacitive type region, causing the switches in the SRC to close at zero current. Additionally, Burst Mode controls output voltage in forward mode of light load.

M. Parvez *et al.* [8] presented a AC-DC converter of bidirectional form that can be utilized for the applications of V2G and G2V system. This converter algorithm in the vehicle to determine proper switching which further minimize the cost of function is discrete behavior algorithm. The planned analytical control scheme agrees on power transfer in bidirectional mode with immediate mode-changing proficiency and fast dynamic reaction. This paper also offerings the outcomes that are simulated with the help of Matlab.

Polly Thomas *et al*. [9] discussed in their paper that the key contest faced by power grid system is meeting the peak demand. The penetrations in vehicles, having V2G ability might condense the consequence of this peak deficiency and DSM also can be facilitated. In V2G capable vehicles bidirectional converters. Evaluation and model simulation of the 2 types of single-phase converter of bidirectional type suitable for V2G and G2V applications. Matlab/Simulink background is used fot the simulations performed.

Niancheng Zhou, Jiajia Wang [10] discussed about the features of process of uncontrolled 3-phase rectification charger device for the electric vehicles with submissive power factor improvement. Based upon the current at AC side also the circuit constraint at the time of charging exchange process, a technique of chargers is proposed in the paper. Then by distribution of same charger into groups there is a harmonics investigation model realized.

Yassine Benomar et al. [11] presented a technology of charging assembly based on Inductive Power Transfer of light-duty (LD) EVs for semi-fast charging. The validation about the power converters and applied control approaches are demonstrated with the use of Matlab/Simulink. The results analysed from Matlab/Simulink display that G2V and V2G are practical with the projected system of charging, with an overall effectiveness rate of 92 %.

Saleh Dinkhah et al. [12] proposed a fixed grid where a house with a Photo-voltaic system and a V2G can function on lines, tie line connection, and island mode. This model is used to study access, energy distribution, and error investigation. The system for controlling chokes difficult circumstances such as transient conditions with the solution of controlling the power of the battery and PV and controlling voltage & frequency in island mode. By changing the Maximum Power Dot Tracking (MPPT) to add a function to limit the power and fully charge the EV battery while in mode. In addition, the integrated control system uses droop control and virtual inertia. Matlab/Simulink was used to simulate the model and sent to simulation time by means of the simulator possibly OPAL-RT to verify the feasibility of the projected model.

Uwakwe C. Chukwu [13] discussed numerous worries on how the diffusion of V2G into the electric scheme will influence the 21st-century for electric distribution network. This article sightsees the possibility of using V2G for electricity reimbursement in distributed networks & how this disturbs the system. Considering the effect of reactive power reimbursement on both the power supply and the power, this research is difficult. This is all very interesting considering that using V2G to provide the reactive power charges can save battery life.

Kevin Metz et al. [14] described the potential explosion of plugin hybrid electric vehicles (PHEVs) that will cause many problems for the grid's loading point has increased a lot. Controlling PHEVs' appearance is one of the encounters and chances for the smart grid. an smart control system especially for the charging, can reduce the pressure upon the demand increase, for example, vehicle charging at household. In accumulation, the grid-connected vehicle battery might also be used to provide facilities on the grid, in particular, back-storage on the grid to help solve peak demand from, e.g. household goods.

2.2 Gap of Study

1. Non-linear loads present in electrical vehicles change the sinusoidal nature of AC mains current
2. Battery life degradation due to in-vehicular battery charging and discharging
3. Harmonics impact of electric vehicles charging on grid
4. Improper designing of filters for DC-DC converter affect battery performance

2.3 Expected Deliverables

1. More efficient Electric vehicle performance
2. More efficient battery performance
3. Operating the system model within limits defined by IEEE Standard 519-2022
4. Operating the system model under the unity power factor

2.4 Novelty

1. Design and simulation of the novel circuit for the Vehicle-To-Grid model using MATLAB-SIMULINK software
2. Decrease Total Harmonics Distortion (THD) of the system
3. Implement unity power factor control for single-phase H-Bridge converter
4. Implement DC-Link voltage control
5. Implement Battery current and voltage control and monitor charging & discharging of battery in both Grid-To-Vehicle (G2V) & Vehicle-To-Grid (V2G) modes.

CHAPTER 3

THEORY, STANDARD AND CONSTRAINT

3.1 Electrical Vehicle Architecture

The structure of electric vehicles forms the foundation of their design. There are mainly three types of electrical vehicles as listed below:

- Battery Electric Vehicle/Fully Electrical
- Hybrid Electric Vehicle/Semi Electric Vehicle
- Plug-in Hybrid Electric Vehicle

The architecture of electric vehicles consists of five main components, as depicted in Figure 3.1.

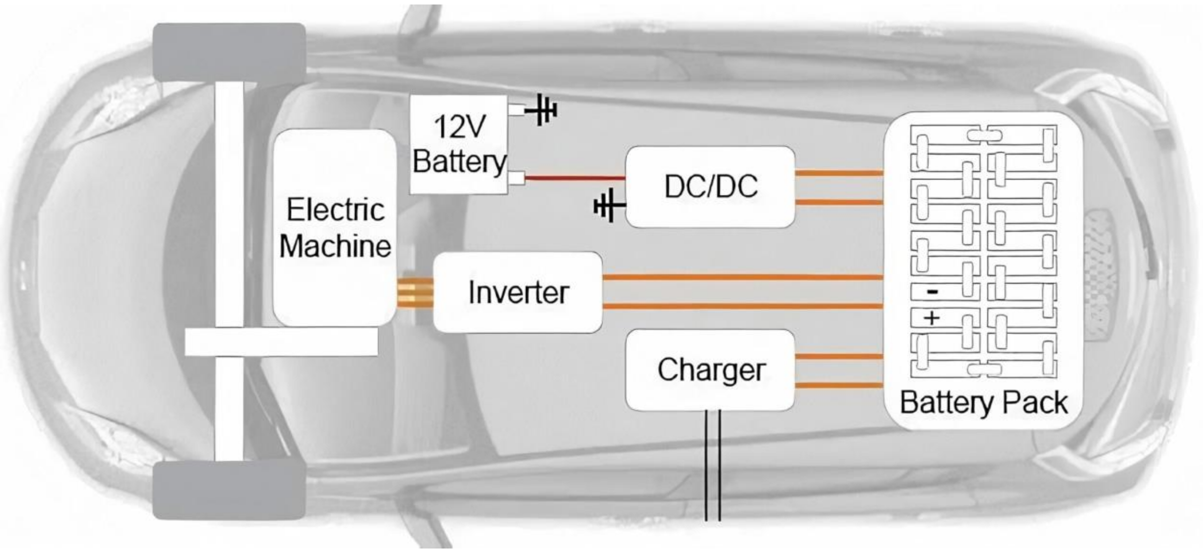

Figure 3.1 Electric Vehicle Architecture

1. Traction Battery Pack

The traction battery pack, also known as an Electric Vehicle Battery (EVB), serves as the primary power source for electric motors and other electrical equipment in an electric vehicle. It functions as an energy storage device, storing energy in the form of DC current. The battery's total kW capacity directly impacts the vehicle's range, and its design plays a crucial role in determining its lifespan. Typically, the estimated lifetime of a traction battery pack is 200,000 miles.

2. DC-DC Converter

In electric vehicles, the battery delivers a constant voltage. However, different electrical loads in the vehicle require varying voltage levels to operate optimally. To meet these demands, a DC-DC converter is employed to convert the voltage from the battery source to the specific voltage required by the equipment.

3. Electric Motor

The electric motor is a vital component of electric vehicles, as it converts electrical energy into kinetic energy, which propels the vehicle's wheels. It is a defining feature that distinguishes electric cars from conventional Internal Combustion Engine (ICE) vehicles. It also offers regenerative braking capabilities, converting kinetic energy into a stored form for coming use. There are two basic types of electric motors used: DC motors and AC motors.

4. Power Inverter

A power inverter is utilized to convert the DC voltage supplied by the battery into AC voltage, which is required to operate AC loads in the vehicle. Additionally, during regenerative braking, the power inverter converts the generated AC voltage into DC voltage for storage in the battery.

5. Charge Port

The charge port is the interface used to connect the electric vehicle to an exterior power supply for charging the battery pack. The charge port may be located either at the front or rear of the vehicle, depending on the design.

6. Onboard Charger

The onboard charger is responsible for converting the AC supply expected from the charging port into DC supply, which is then used to charge the battery pack. The onboard charger is typically fixed inside the vehicle and monitors various battery features, ensuring controlled and efficient current flow into the battery pack.

7. Controller

Electric power controllers play a crucial role in managing and regulating the power flow within the electric vehicle. They control the amount of electrical power delivered from the battery to the electric motor based on driver input through the pedal, thus influencing the vehicle's speed and voltage input to the motor. Additionally, controllers provide torque control and feedback.

8. Auxiliary Batteries

The auxiliary batteries are used as an alternative source of electrical energy for the equipment present in electric vehicle for the time when main battery is not available due to discharging or any other reason. The auxiliary batteries make sure there is a continuous power supply to the safety relevant loads.

9. Thermal System (Cooling)

For controlling the temperature of essential components in electric vehicles, such as electric motors and controllers thermal system in the vehicle is main responsible component. It employs various cooling techniques to maintain optimal operating temperatures and ensure the efficient performance of these components.

10. Transmission

For mechanical power from the electric motor to the wheels through a gearbox transmission system is used in electrical vehicles. Unlike traditional internal combustion engine vehicles, electric cars typically do not need transmissions in multi-speed. However, the efficiency of transmission is required to maximized to minimize power losses.

3.2 Vehicle-To-Grid (V2G)

Vehicle-to-Grid (V2G) systems comprise of bidirectional power flow between the battery of a plug-in electric vehicle (PEV) and the electrical grid. The inverter-based system used for injecting power requires a grid infrastructure capable of handling the load changes associated with V2G. The key components of a V2G system are shown in Figure 3.2 below, and considerations include availability and capacity of electrical equipment.

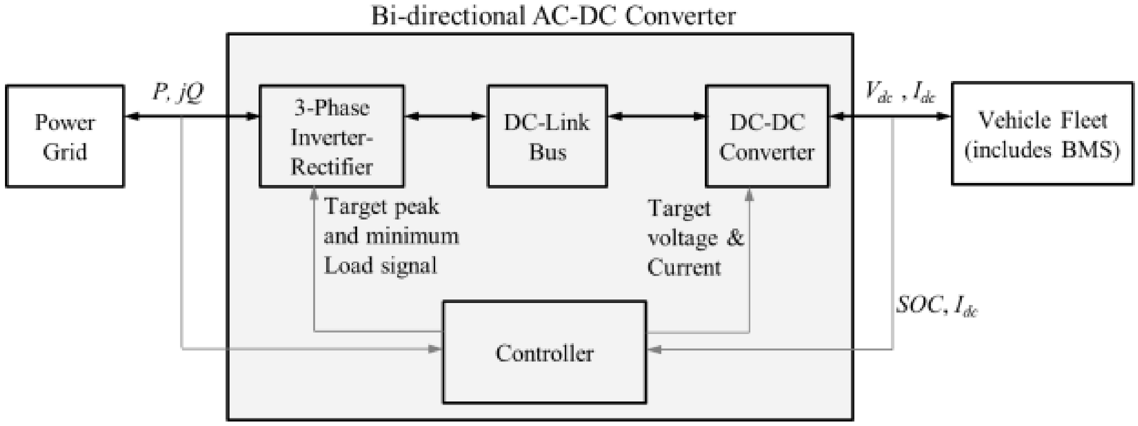

Figure 3.2 Bidirectional AC-DC converter

The figure 3.3 given below shows the topology of AC-DC converter that links the V2G system with the main supply grid.

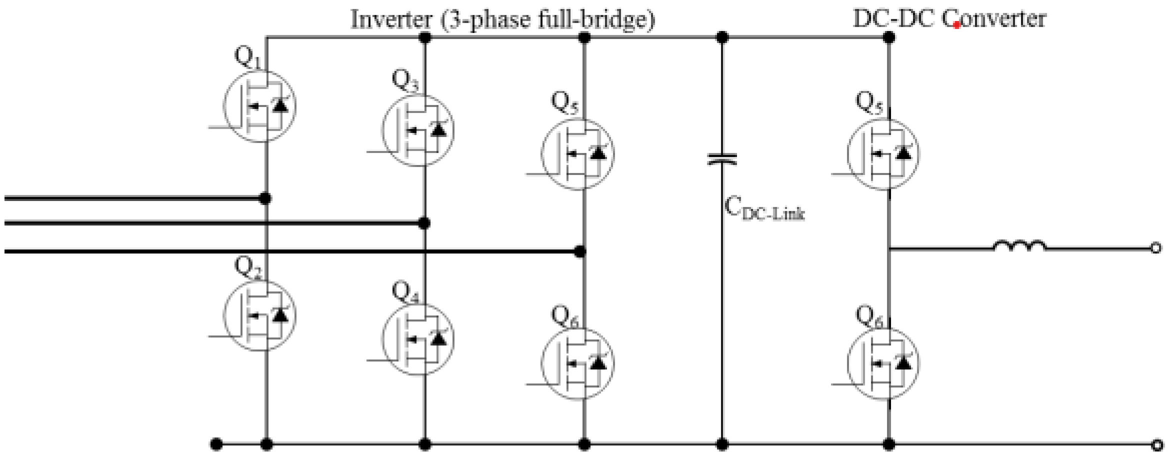

Figure 3.3 AC-DC converter topology

3.3 Charging Methods and Devices for Electric Vehicles

The charging process and equipment for electric vehicles are responsible for managing the battery and connecting to the power source. When the vehicle is plugged into charging equipment through the port of charging, an electricity request is sent from the power grid. The battery's state of charge and the inverter's maximum power capacity is monitored by BMS(battery management system). While the charging product specifications may vary among manufacturers. The standard of SAE J1772 defines the physical and electrical performance requirements. Currently, PEV charging equipment is compatible with standard 115V sockets, but higher capacity is desirable for Vehicle-to-Grid (V2G) scenario.

Power levels and respective charging modes are defined in Table 3.1.

Table 3.1 Charging Level Categorization

Charging Level	**Operating Voltage**	**Maximum Current**
AC Level 1 (1.9 kW)	120 V	16 A
AC Level 2 (19.2 kW)	240 V	80 A
DC Level 1 (19.2 kW)	200 to 450 V	80 A
DC Level 2 (90 kW)	200 to 450 V	200 A

3.4 Methodology for SOC & SOH estimation:-

The capacity released by a fully discharged operating battery is referred to as the releasable capacity (C releasable). The State of Charge (SOC) represents the percentage of releasable capacity relative to rated capacity of the battery (denoted as Crated) according to equation 3.1.

$$SOC = (C\ releasable) / Crated\% \quad (3.1)$$

In the case of a completely charged battery, the actual maximum capacity (Cmax) may not be the same as the rated capacity (Crated). It can vary due to recent usage and will gradually decline over time due to cycling. The Cmax is utilized for State of Health (SOH) calculations and can be expressed as a percentage of the Crated according to equation 3.2.

$$SOH = (C\ max) / Crated\% \quad (3.2)$$

During battery discharge, the Depth of Discharge (DOD) is defined as the percentage of the capacity that has been discharged relation to Crated, as indicated in equation 3.3.

$$DOD = (C\ released) / Crated\% \quad (3.3)$$

Here, C released represents the capacity that is discharged by some given value of current. By considering the measured values of charging and discharging current (Ib), the change in DOD over an operating period (Ʈ) can be calculated using equation 3.4,

$$\Delta DOD = \frac{-\int_{t_0}^{t_0+\tau} I_b(t)\,dt}{C_{\text{rated}}} 100\% \tag{3.4}$$

where Ib is positive value for charging & negative value for discharging. As time progresses, the DOD accumulates.

$$DOD(t) = DOD(t_o) + \Delta DOD \tag{3.5}$$

The operating efficiency, represented as ŋ, is taken into account, and the DOD expression is modified accordingly in equation 3.6. During the charging stage, ŋc is used, and during discharging, ŋd is employed.

$$DOD(t) = DOD(t_o) + \eta \Delta DOD \tag{3.6}$$

Considering the battery aging and operating efficiency, the SOC can be expressed as equation 3.7, where SOC(t) represents the SOC at time t.

$$SOC(t) = 100\% - DOD(t) \tag{3.7}$$

Therefore, the SOC can be calculated by subtracting the DOD from the SOH

(SOC(t) = SOH(t) - DOD(t)).

3.5 Market Report of Electric Vehicle

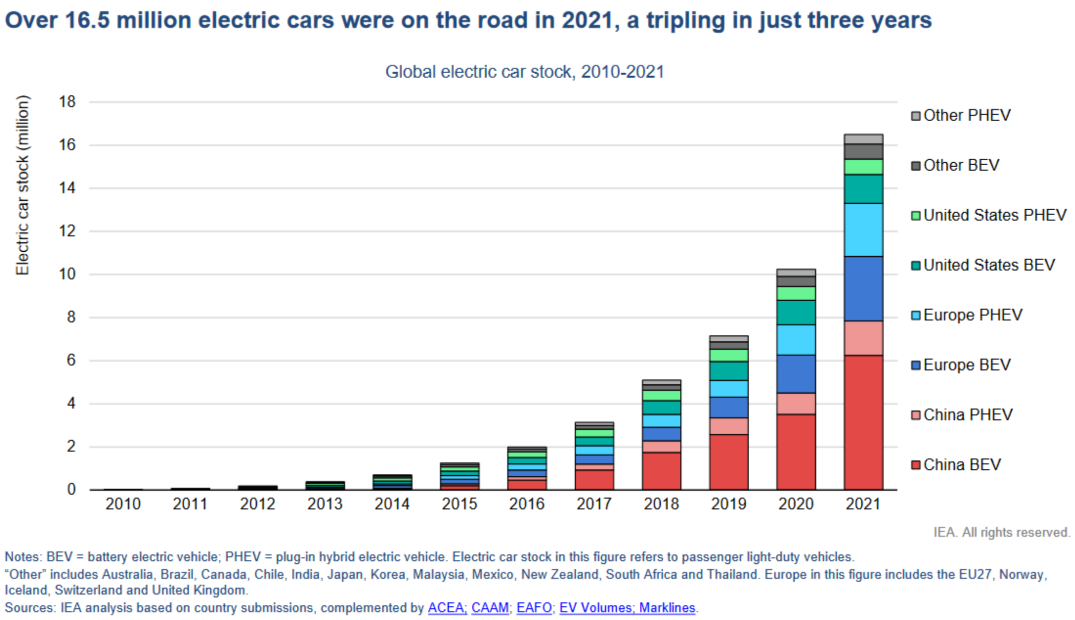

Figure 3.4 Market Report Of Electric Vehicle

According to the data presented in Figure 3.4, the global electric vehicle market recorded approximately 8.6 million units in 2018. Projections indicate a significant growth trajectory, with an estimated reach of 40.6 million units by 2026. This translates to a Compound Annual Growth Rate (CAGR) of 21.1% for the market of electric vehicle throughout the forecast period.

In the past, the electric vehicle market has predominantly been dominated by full hybrid electric vehicles (HEVs). This trend can be attributed to government initiatives focused on reducing CO2 emissions. To align with these emission reduction targets, automakers have enhanced their lithium-ion batteries and overall performance. Following the industry-wide trend of "strong electrification," there has been an increased emphasis on vehicles with extended electric driving range (measured in kilometers).

3.6 How Are EV/HEV Trends Paving The Way For Power Electronics?

The global electronics market is valued at US$17.5 billion and will grow with a compound annual growth rate of four point three percents over the period 2019-2025. According to the latest power electronics report "State of the Power Electronics Industry" [20] Released by Yole Development, the power electronics industry has gained momentum, and vehicle use is the strongest driving force for the. Today, the automotive industry, particularly EV/HEV, is driving the development and commercialization of technology is really great investment.

3.7 Key Players

The competitive landscape of the market of electric vehicle (EV) is driven by the advantages it offers, such as the utilization of cutting-edge battery technology, eco-friendliness, and cost-effectiveness in terms of maintenance and operational expenses. This increased competition among key players is further fueled by the growing market demand for electric vehicles, leading to a rise in patent application filings worldwide. Figure 3.5 highlights the major contenders in this field

Tesla, a prominent player, significantly contributes to the intensifying competition by actively developing and filing patents for advanced features related to electric cars. Notably, Tesla plays a crucial part in the strategy, manufacturing, and manufacturing of electric vehicles while also spearheading innovations in energy production and storage. The company has submitted a total of 140 patents focused on electric vehicles, solidifying its influence in shaping the industry's future direction.

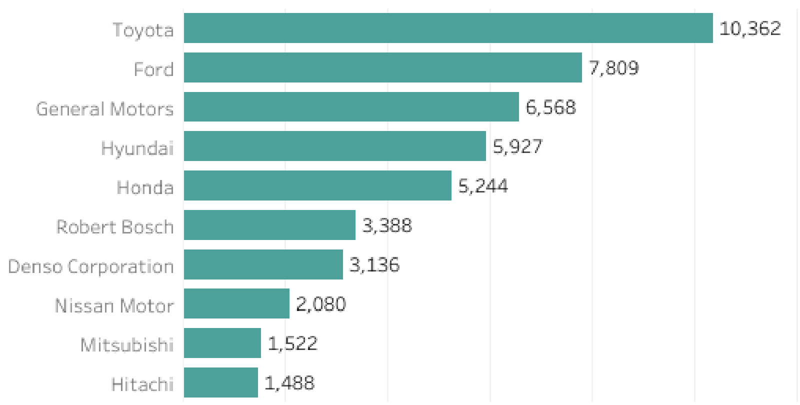

Figure 3.5: Electric vehicle key players in market

The electric vehicle industry is experiencing intense competition due to the numerous benefits offered by electric cars, including advancements in battery technology, environmental friendliness, and reduced maintenance and operational costs. The growing market demand for electric vehicles has resulted in a greater diversity of patent applications on a global scale. Figure 3.5 illustrates the prominent players in this field emerging as the major contributors with the highest number of patent applications.

CHAPTER 4

PATENT STUDY

4.1 Patent Study

A patent is a granted exclusive right for an invention, which can be a new product or process that offers a novel solution to a problem. In order to obtain a patent, detailed technical information about the invention needs to be disclosed to the public through a patent application.

Patents are widely utilized to describe and predict information, as well as to contribute to research and development efforts. They are valuable because they provide information about the inventor, the company that was granted the patent, and any prior art related to the invention. If a patent references another patent, it allows for tracing of information through the references to previous patents. Therefore, patent data is effective in categorizing technological fields compared to alternative indicators such as research and development expenditures.

Moreover, analysing patent data enables the study of individual entrepreneurial behaviour without restricting the analysis to specific sectors. However, it is important to note that patents only represent a strict measure of formalized firm knowledge and do not encompass informal or ambiguous information. Additionally, not all documents disclose prior information, as some may be included by patent attorneys to differentiate from similar products or to avoid potential issues

4.2 EV Technology Patent Publication Trends

The Indian government, aligning with global business strategies and objectives, has displayed a favorable response to the rationale and has made a commitment to prioritize energy security and fulfill its obligations under international climate change agreements. The annual trends in patent filings are depicted in Figure 4.1, which has been a significant area of focus for the government. To address this concern, the government introduced the Manufacturing (FAME) program for the adoption of hybrid and electric vehicles, which commenced its initial phase in April 2015 and has since continued with yearly projects. This policy encompasses various electric and hybrid technologies, including small hybrids, powerful hybrids, plug-in hybrids, and fully electric vehicles.

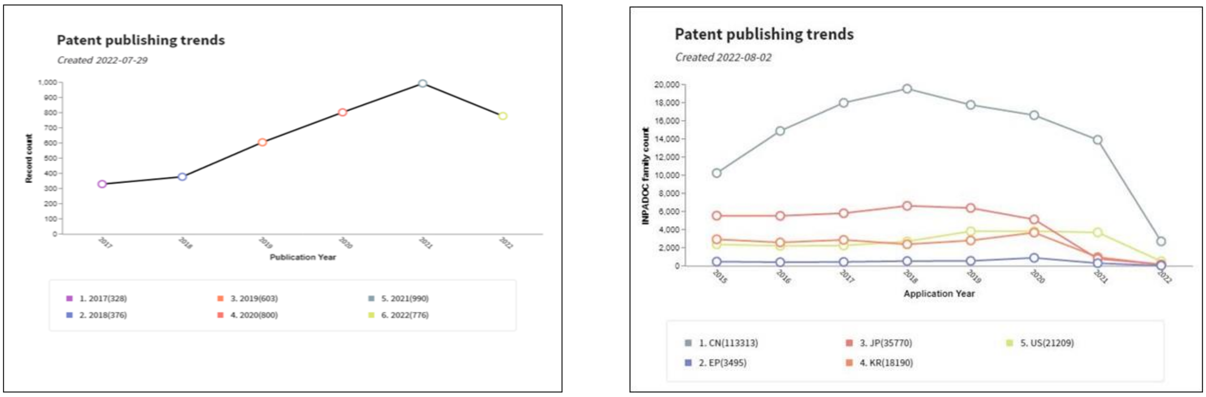

Figure 4.1: Patent Filing Trends

Recognizing the crucial role that batteries play in electric vehicles, the government has also granted approval for the Product Linked Incentive (PLI) scheme on May 12, 2021, aimed at promoting the production of advanced batteries. Figure 4.2 illustrates the data in the form of a bar graph, showcasing the allocation of companies for Lithium-ion battery production. The PLI scheme offers incentives to encourage manufacturing within India. Over a span of five years, the plan entails an expenditure of Rs. 18,100 crore (approximately $2.27 billion). Since the announcement of this initiative, numerous local and multinational companies have commenced the establishment of battery manufacturing facilities in India.

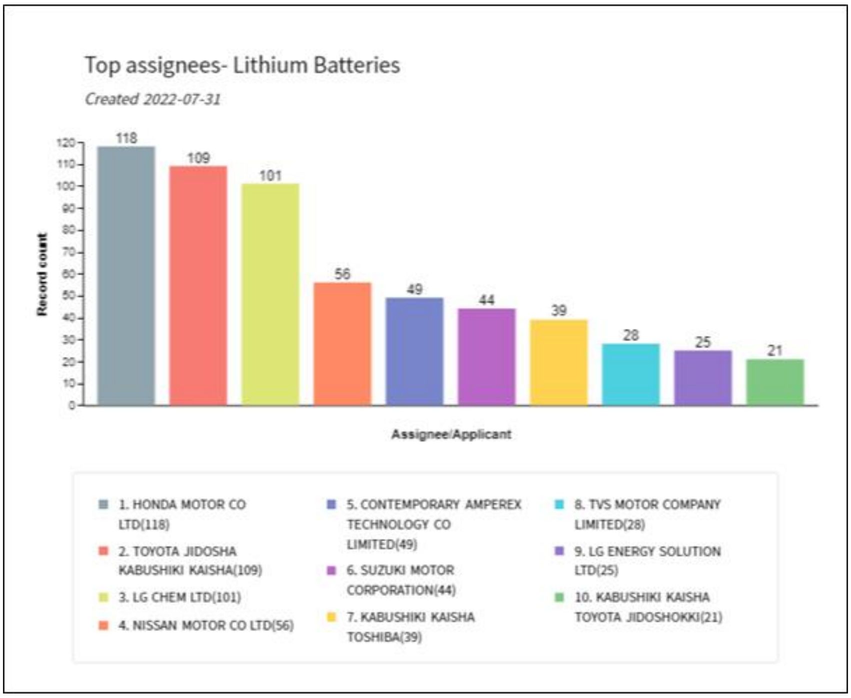

Figure 4.2: Patent Filing Trends in lithium batteries

4.3 Patent Study Of Power Electronics

Patent study of inverter and DC-DC converter for Electrical Vehicle

- Categorization (finding the relevancy for EV out of all patents) and make a summary report on patent study tool having maximum 6 points with title, prior art and technical solution along with advantages and a tree hierarchy.
- The elements covered for the summarization that supports Electrical vehicle as outcome are inverter (bidirectional, quasi six pulse inverter multilevel inverter), coolant flow and structure for inverter, charger and for all electrical assembly, DC link capacitor, housing/yoke for BMS and Motor-Inverter assembly.
- DC-DC converter, onboard charging, battery management system, charge control circuits.

The patent study process is as presented in figure 4.3 given below;

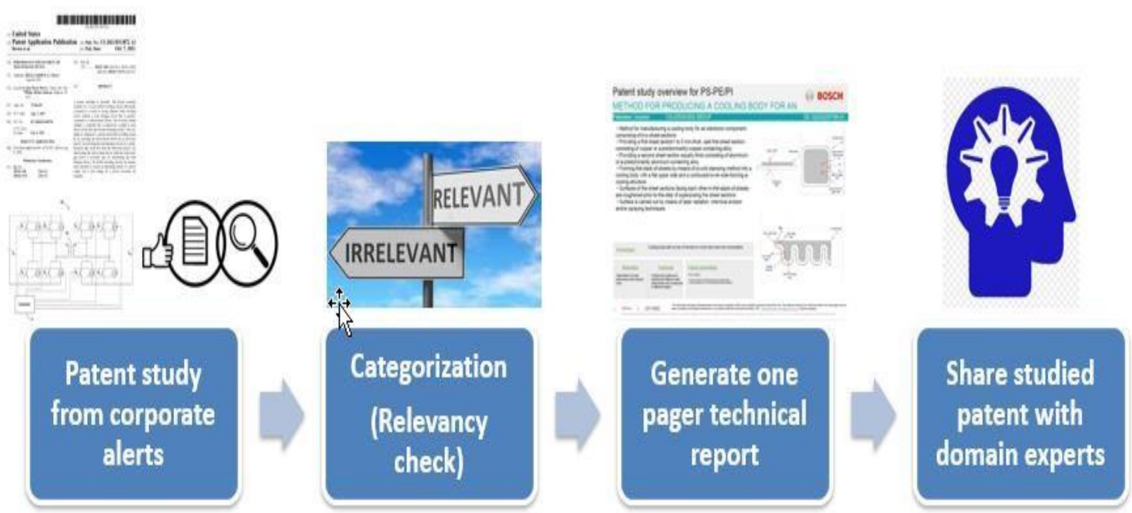

Figure 4.3: Patent Study Process

4.4 Patents Competitive Statistics

The patents statistics for the electric vehicle relevant patents for the year 2022 according to technologies used is shown in the figure 4.4

Table 4.1 Patent statistics according to technology used

Technical Path	No of Relevant Patents
Software(Inverter Internal)	128
Cooler	64
Sensors(Controlling Hardware & Mechanics)	43
DC link Capacitor	22
High Voltage Safety	15
HV PCB Gate Driver	15
Bus bar Connection	7
EMC Filter/EMC Measure	4

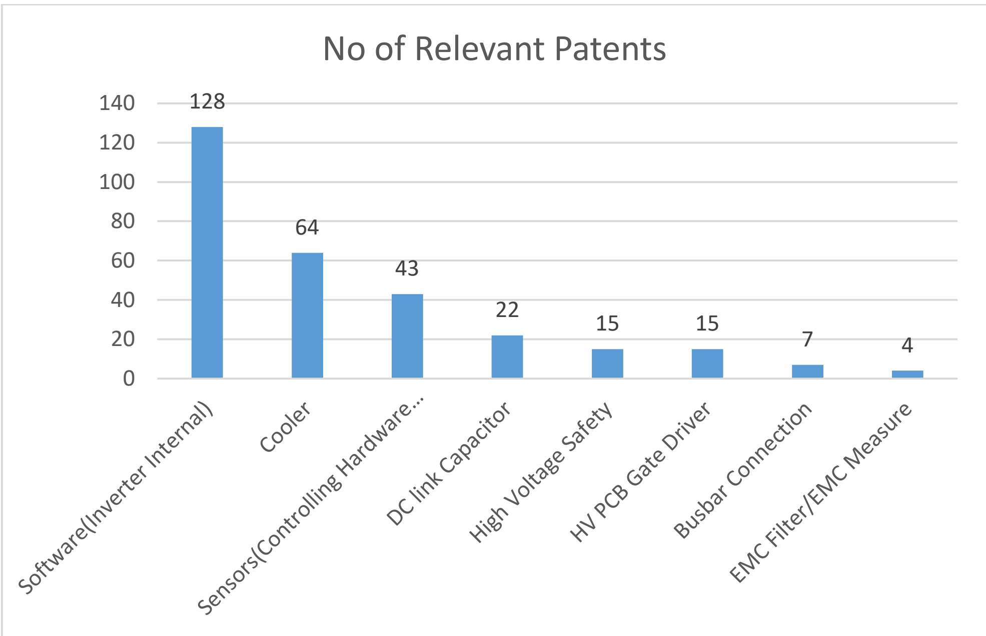

Figure 4.4: No. of relevant patents wrt technology used

CHAPTER 5

DESIGN METHODOLOGY

5.1 Proposed Work Flow/Methodology

As per IEEE Standard 519-2022, IEEE Standard for Harmonic Control in Electric Power Systems, there will be a certain permissible amount of THD allowed as listed in the table below;

Table 5.1 THD values as per IEEE Standard 519-2022

Bus Voltage V At PCC	**Individual Harmonic (%) H ≤ 50**	**Total Harmonic Distortion THD (%)**
V ≤ 1.0 kV	5	8
1 kV < V ≤ 69 kV	3	5
69 kV < V ≤ 161 Kv	1.5	2.5
161 kV < V	1	1.5

The loads of non-linear nature contains the capability to distort the sine wave nature of AC mains nature current that resultantly produce the harmonics current in the power system. These harmonic currents can introduce intervention in circuits of communication and other devices, and also result in increased losses and heating in electronic equipment such as motors and transformers. To amplify the distortion in voltages and currents can be done by using reactive power compensation approach.

Similarly in the case of electrical vehicles charging when the vehicle is plugged into charging system then because of presence of non-linear loads in the vehicle there could to harmonics distortion in the system.

The figure below illustrates the harmonic current characteristics produced by EV during the charging process, with the Fast Fourier Transform (FFT) method being used for analysis.

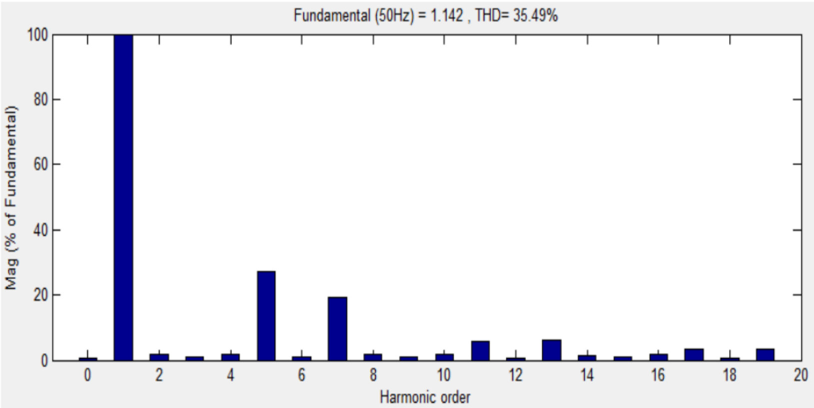

Figure 5.1: FFT analysis of current in the charging station

The figure depicted in Figure 5.1 displays a total harmonic distortion (THD) value of 35.49%. However, it is essential to adhere to the maximum permissible limit for THD as specified by the IEEE Standard 519-2022. The impact of harmonic currents on the power grid cannot be disregarded, necessitating the consideration of harmonic suppression techniques in electric vehicle charging stations.

For the above state issues, to overcome it, this report introduces the application of bidirectional power supply technology known as Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) using MATLAB simulation. The literature survey conducted highlighted the significance of V2G technology in mitigating battery-related challenges in the long run, particularly regarding harmonic distortion and power quality enhancement. To address these concerns, a novel V2G architecture is proposed, which is illustrated in the figure 5.2 below.

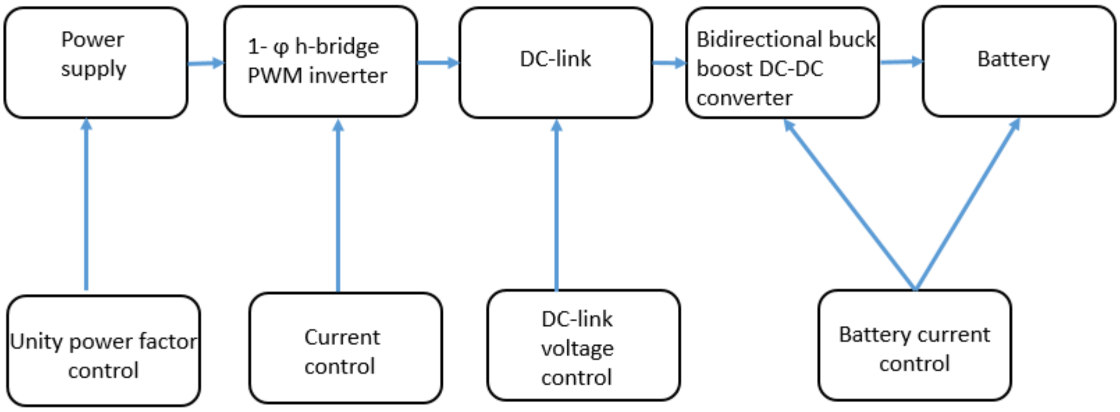

Figure 5.2: V2G-G2V Proposed Architecture

5.2 MATLAB-SIMULINK Simulation-

The design and modelling of proposed V2G-G2V model has been done in Simulink software "MATLAB R2023a". The Simulink model and the subsystems are shown in Figures 5.3 & 5.4, 5.5 respectively

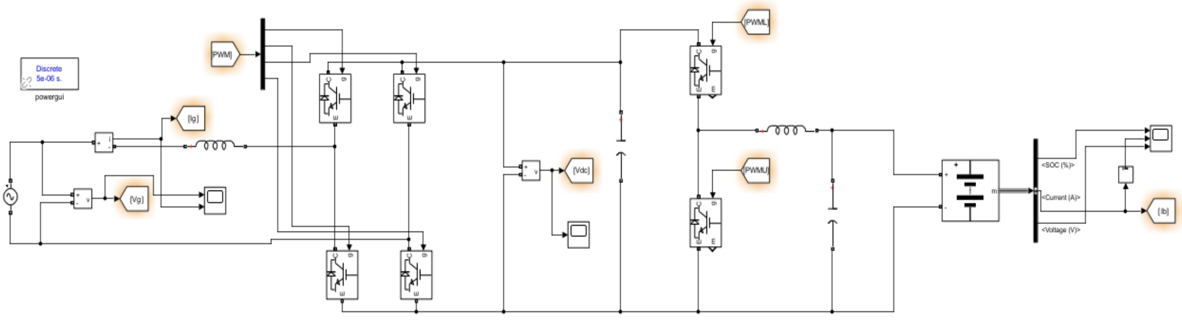

Figure 5.3: MATLAB-SIMULINK Model for Vehicle-to-Grid Technology

The simulation is done considering the input supply from single phase AC. AC voltage source block properties are as given in the table 5.2.

Table 5.2 AC Voltage Source Parameters

AC Voltage Source Parameters		
Parameter	**Value**	**Unit**
Peak Amplitude	325	v
Frequency	50	Hz
Generator Type	Swing	

For the simulation purpose the battery type used is Lithium-ion battery, more specifications are given in table 5.3

Table 5.3 Battery Block Properties

Battery Block Properties	
Type	Lithium-Ion
Nominal Voltage	120
SOC	50
Discharge rate	20.8696
Nominal Q	48
Maximum Q	48
Minimum V	90

For AC-DC voltage conversion there is single-phase H-Bridge converter is used. The switching device used in the H-bridge converter is IGBT, followed by DC- link capacitor and bidirectional Buck-boost DC-DC converter along with LC filter, and then battery connected at the last. For the better performance of the model, control circuits also connected as subsystems.

For DC-Link voltage control(as shown in figure 5.4) reference 380 is set in the control subsystem that is compared with DC voltage calculated from the system, which is further given to PI Controller which will generate the reference peak magnitude for its current control that should be further converted into sinusoidal form. For that grid voltage need to be measured for which PLL (phase lock loop) is used. For generating sine wave wt is needed for which sin block is used. the sine wave generated will be multiplied by the peak reference current then we will get the peak reference current in sinusoidal nature, further the reference current will be compared with the source current or grid current again with the help of the PI controller and it going to be further process via PWM generator. The output of this two-level PWM generator will be given to the single-phase h bridge PWM inverter which will supply the power to the battery. Also, the whole system and its control are designed to work under unity power factor mode along with THD as per findings came in permissible limits.

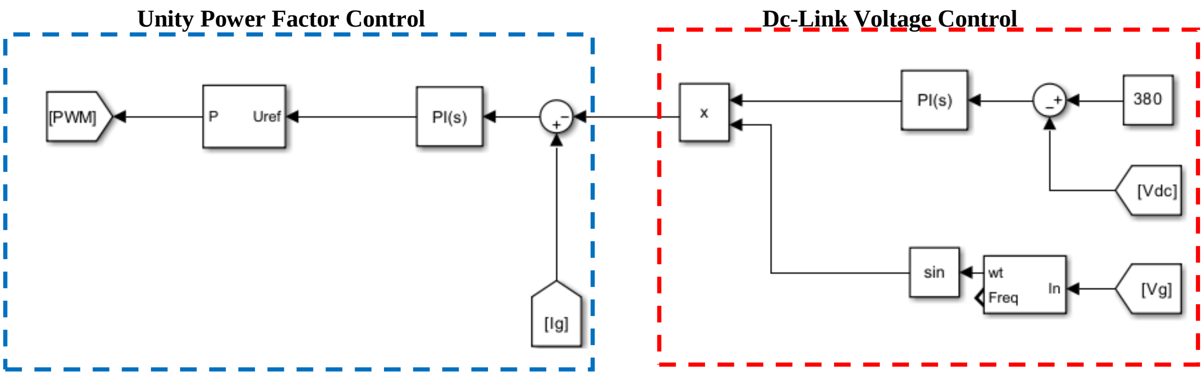

Figure 5.4: Power factor control and DC-Link Voltage Control

For current control for buck-boost DC-DC converter the subsystem used is shown in figure 5.5, for this we are comparing the battery current Ib with the reference current provided in the current control circuit after summing this will be compared via PI controller, the output of PI controller here known as duty cycle which will be processed by PWM generator i.e. 1

pulse PWM generator used in the circuit. The first pulse will be given to upper IGBT bidirectional DC-DC converter and its inverted pulse will be given to the lower IGBT. So this controller is going to control the current flow in the battery i.e. charge of battery from G2V and discharge of battery from V2G.

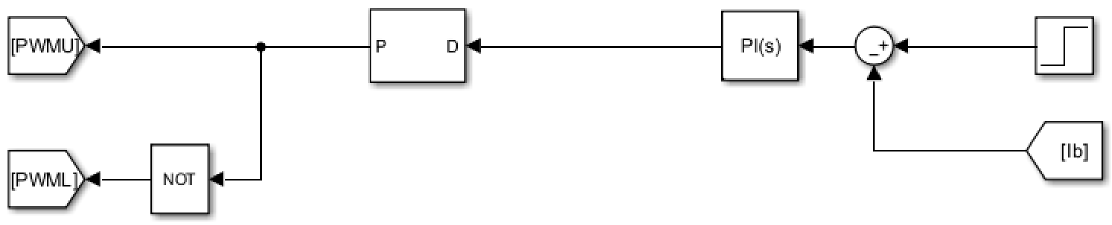

Figure 5.5: Battery Voltage & Current Control

CHAPTER 6

SIMULATION RESULTS

6.1 Simulation Results

For getting the simulation output for battery charge and discharge the Step block parameters used are shown in the figure 6.1;

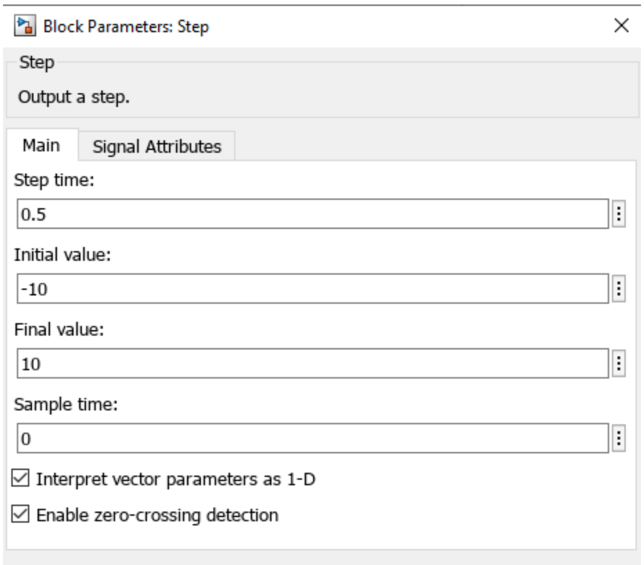

Figure 6.1: Step Block Parameters

According to the set parameters for the first 0.5 sec the model is working in G2V mode means charging the battery and after 0.5 seconds it will start discharging and will start working in V2G mode. The waveform for the same along with SOC is shown in the figure 6.2 ;

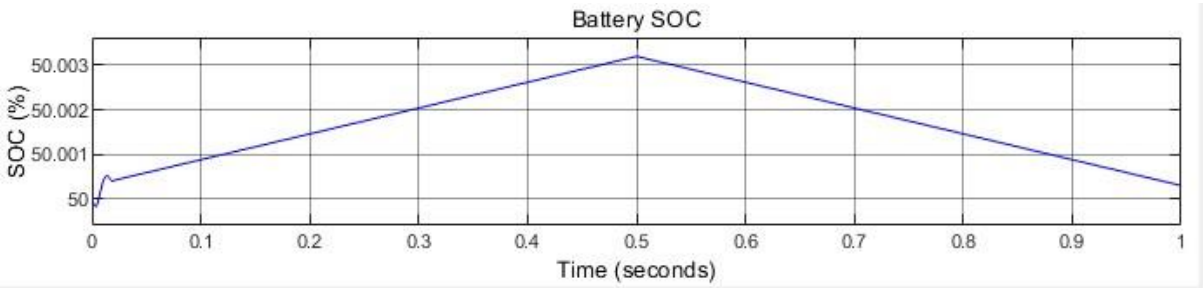

Figure 6.2: Battery SOC Plot

The performance of battery current with the simulation and shifting from one mode to another is shown in the figure 6.3 below;

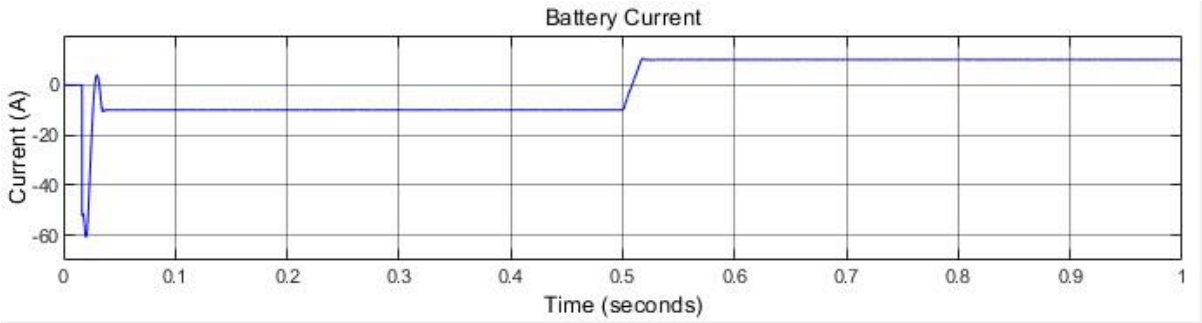

Figure 6.3: Battery Current vs. Time Graph

The battery voltage in both cases comes out to be 120V as required shown in figure 6.4

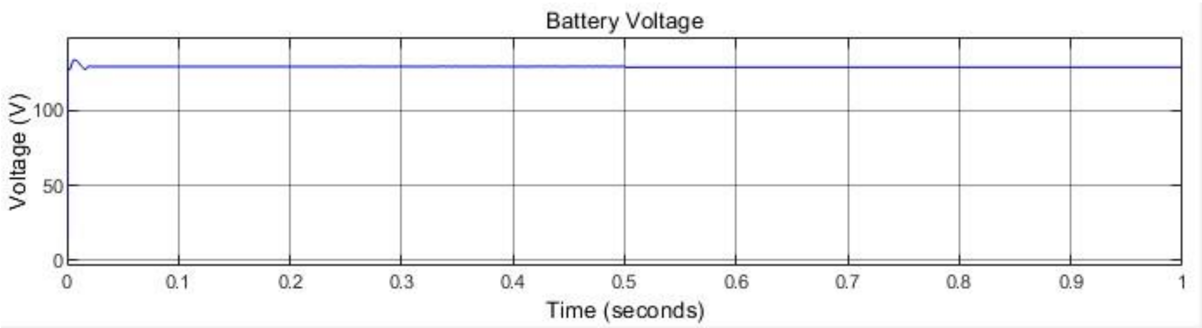

Figure 6.4: Battery Voltage vs. Time Graph

The figure 6.5 given below shows the battery statistics.

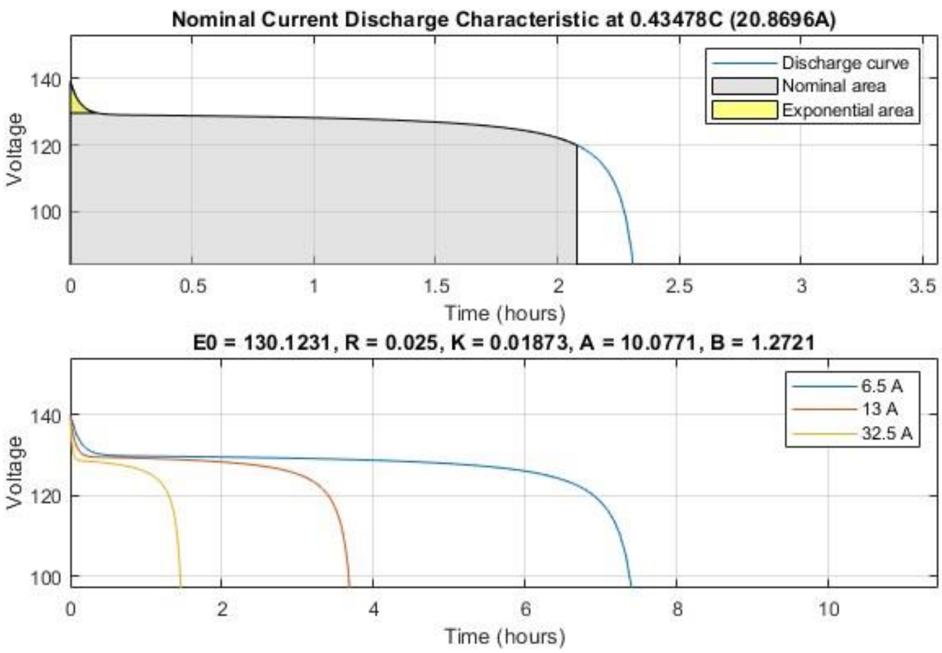

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Figure 6.5: Battery Statics Plot

The waveforms for source voltage and source current is shown in the figures 6.6 & figure 6.7 respectively

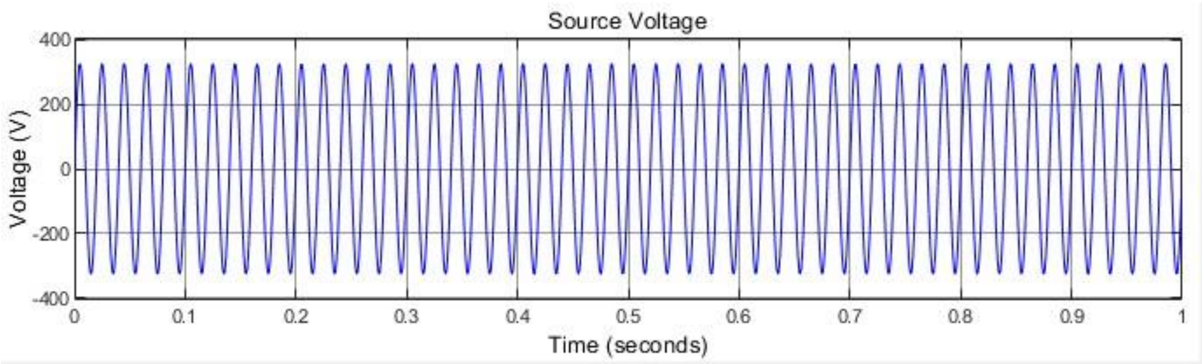


Figure 6.6: Source Voltage Plot

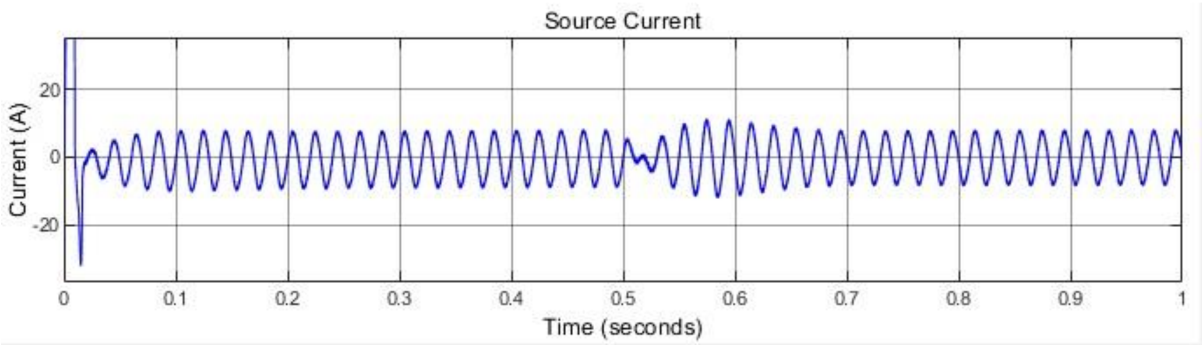


Figure 6.7: Source Current Plot

The wave form of source voltage and current during G2V mode is in phase and completely sinusoidal as required for unity power factor operation shown in figure 6.8

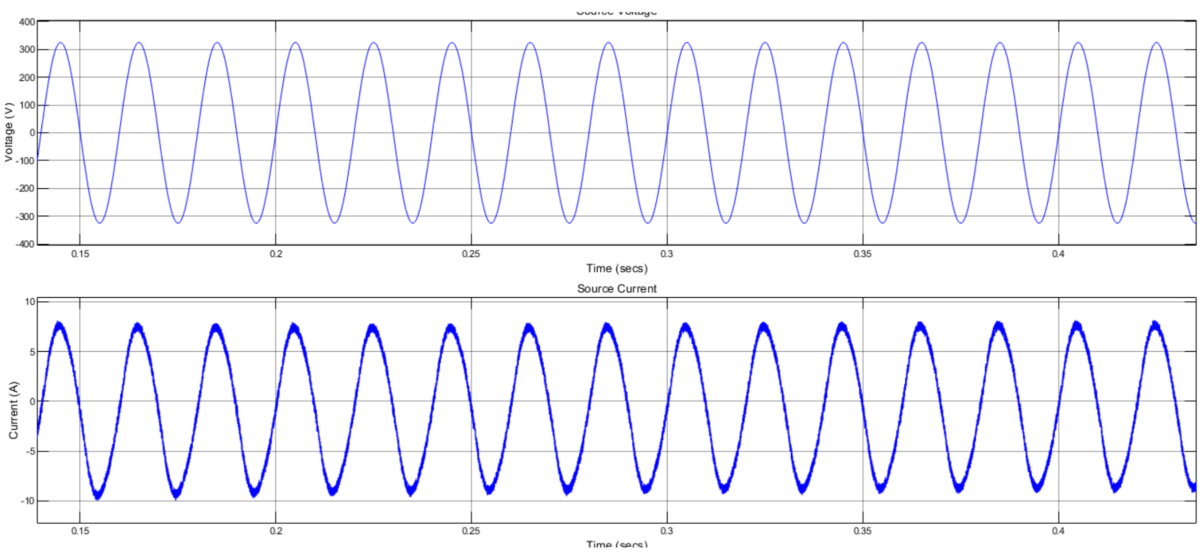


Figure 6.8: Source current and voltage wave form- G2V Mode

Similarly in figure 6.9, the wave form of source voltage and current during v2g mode is in 180 degrees phase shift and completely sinusoidal as required for unity power factor operation

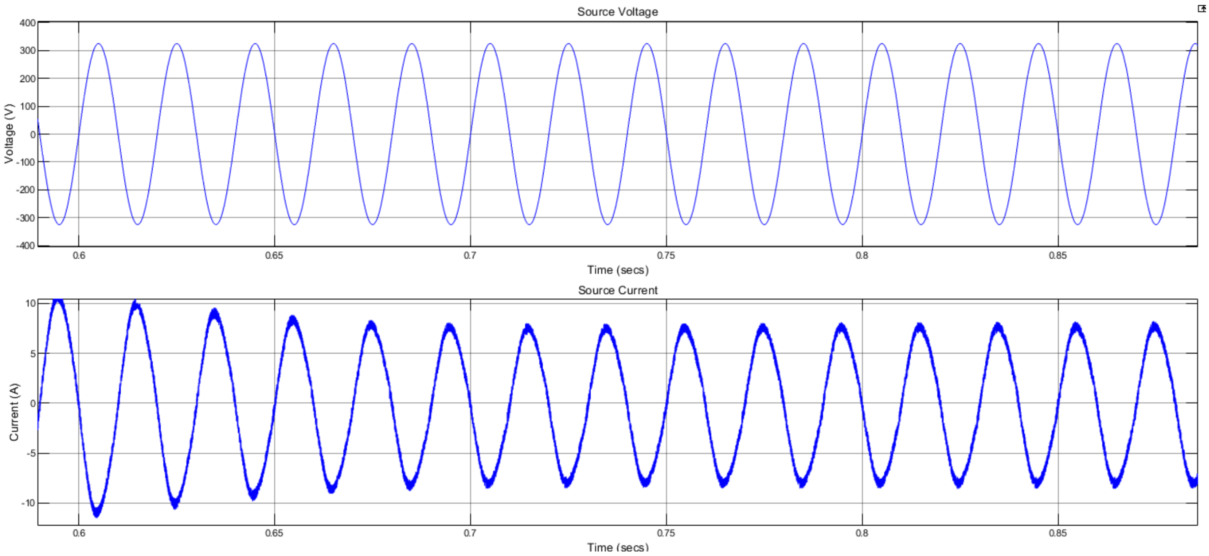


Figure 6.9: Source current and voltage wave form- V2G Mode

DC-Link voltage wave shape is as shown in the figure 6.10 below;

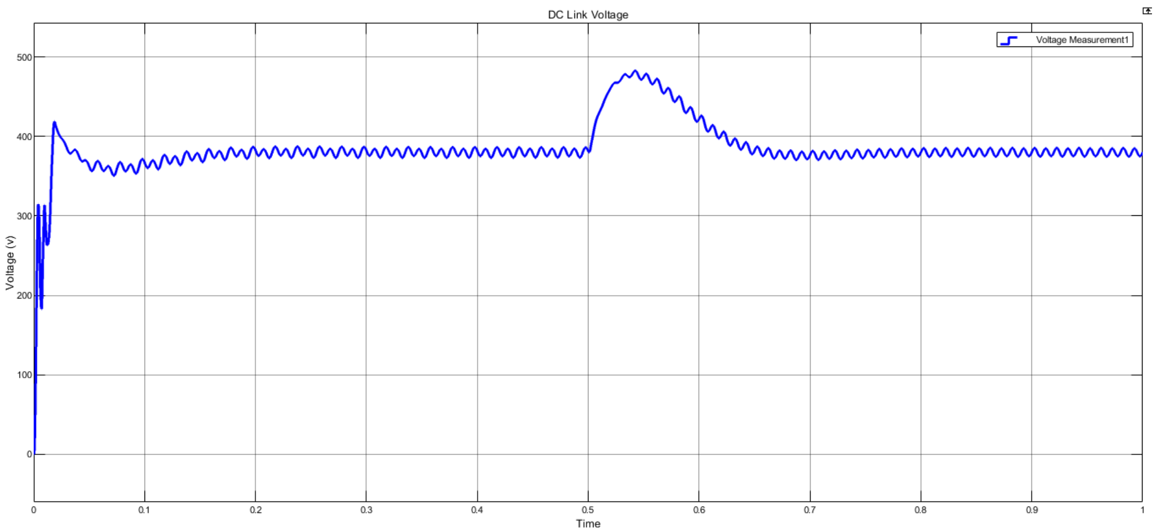


Figure 6.10: DC-Link Voltage Plot

The THD is also calculated for the simulation using the FFT method. THD without vehicle charging mode comes out to be negligible as shown in the figure 6.11 below. If the harmonic is not properly handled, it may do great harm to the utility grid.[19-20]

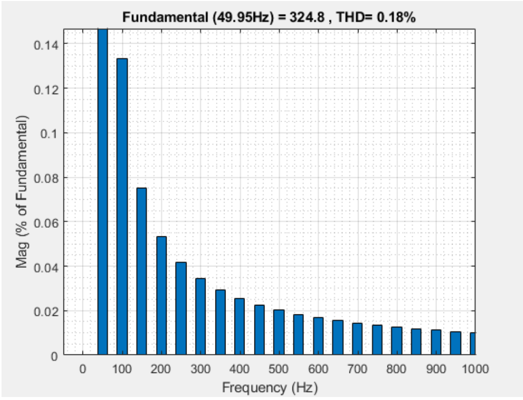
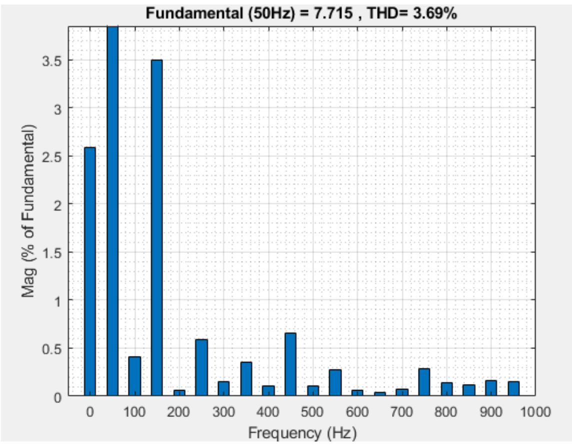
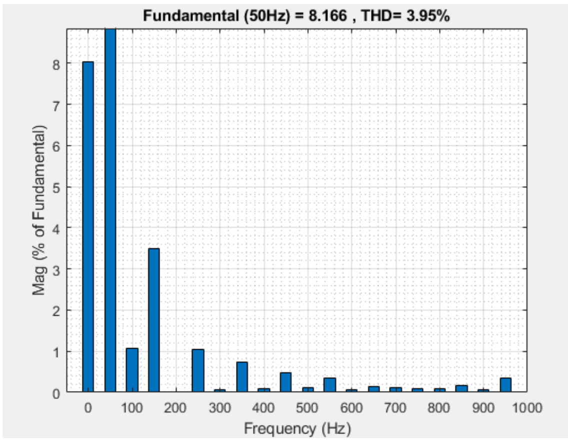


Figure 6.11: FFT analysis of voltage waveform without EV charging

THD for the system with vehicle charging and discharging or for V2G and G2V mode comes out to below permissible limits that is 3.69% & 3.95% respectively as presented in figure 6.12



13(a) Grid-to-Vehicle Mode



13(b) Vehicle-to-Grid Mode

Figure 6.12: Simulated results for FFT analysis of voltage waveform with EV charging

6.2 Discussions

With the correct selection of all the blocks parameters and proper unity power factor control, DC-Link voltage control and battery current & voltage control the results came out to be in permissible limits according to IEEE Standard 519-2022.

CHAPTER 7

CONCLUSIONS

7.1 Conclusion

Power electronics components and non-linear loads presence in the electric vehicle charging systems create harmonics distortion and power quality issues while charging the vehicle from the grid or giving the supply back to the system/grid in Vehicle-to-Grid technology. According to the proposed model of V2G, THD is reduced to even lesser than 4% as compared with previous research papers and stays within the permissible limits as per IEEE standard 519-2022. Also with the proper PWM modulation and unity power factor control, power quality issues are also sorted.

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