

ADDIS ABABA UNIVERSITY



ADDIS ABABA INSTITUTE OF TECHNOLOGY (AAiT)

SCHOOL OF ENGINEERING AND INFORMATION TECHNOLOGY
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

Title: Fuzzy Logic Control for Charging/Discharging Interface of Electrical Vehicle to Grid
(V2G) Technology

Prepared by: Endegen Abebe

Thesis submitted in partial fulfilment of the requirement for the Degree of Master
Of Science in Control Engineering

Advisor:
Asso.Proff: Mengesha Mamo (PhD)

November, 2020 Addis Ababa, Ethiopia

Addis Ababa University



Addis Ababa Institute of Technology

School of Electrical and Computer Engineering

Title: fuzzy logic control for charging/discharging interface of electrical vehicle to grid (v2g) technology

Prepared by: Endegen Abebe

Approval by board of examiners

Dr. Yalemzewd Negash

Department Head

Date

Signature

Dr. Mengesha Mamo

Thesis Supervisor

Date

Signature

Dereje Shiferaw (PhD)

Internal Examiner

Date

Signature

Yared Tadesse (MSc)

External Examiner

Date

Signature

Declaration

This thesis is a presentation of my original work. Wherever contribution of others are involved, every effort is made to indicate this clearly, with proper citation of sources. I undersigned, declare the thesis has not been presented for degree in any other university.

Name

Signature

Endegen Abebe Gebeyehu

This thesis has been submitted with my approval as a university advisor.

Dr. Mengesha Mamo (PhD)

Thesis Supervisor

Signature

November 2020

Addis Ababa, Ethiopia

Acknowledgement

Any accomplishment requires the effort of many people. This work also is no exception. I have to admit that without the help of some benevolent persons, my MSc class period would have been tiresome. Therefore, the first Glory be to the Almighty God and his mother (Saint Kidane Mehiret). I would like to extend a boundless gratitude to my Supervisor Dr, Mengesha Mamo for his insight guidance, and professional expertise. To Dr.Dereje Shiferaw and Yared Tadese for their supportive comment. I have to express my heartfelt gratitude to my brothers Henok Abebe, wondal Yerom, Muluken Nega, Tadesse Mesfin, Bamelaku Shiferaw, and Anteneh Nebeyu for their financial and moral support. My sincere ‘thank you’ goes to everyone who encourages, supports, and inspires me during my MSc class as a whole.

ABSTRACT

In this thesis, a two-stage non-isolated bidirectional electric vehicle charging system used for charging and discharging electric vehicle battery developed and presented. On the modern definition, the system named V2G /G2V power flow. Allowing EV to charge or discharge without proper control may lead to voltage variation and instability on the power network. However, the EV is charge and discharge in an effective controlled manner, it can support the electrical power network for peak load levelling, peak load shaving, and frequency regulation.

Using FLC for the first stage of the system under direct current control mode to minimize the error between the measured battery current and reference battery current, also to level the current that supplied to DC-DC converter through the PWM pulse generation, to determine bidirectional power flow between the electric vehicle battery and the electrical power grid. SPWM technique also applied for the second stage of the system, which is a single-phase bidirectional AC-DC inverter, to make its output current and voltage have a true sinusoidal wave shape.

MATLAB-based experiments are conducted to verify the system's feasibility and validate the theoretical analysis. From G2V operation the BSoC increasing from its initial state, which indicates the battery gains an additional percentage of charging capacity on its initial BsoC. In V2G BSoC decreased from its initial state, which indicates the battery loses its initial percentage of charging capacity. The battery terminal current for charging is negative and for discharge is positive the opposite sign of the current is indicated fuzzy logic controlled DC-DC converter is work efficiently for the bidirectional power flow. Besides, the V2G simulation verifies that the SPWM is effective to make inverter output current and voltage are in phase. In general, the selected topology within the proposed controller can supply 230V AC voltage with 5.60% THD and 1.048A AC Current with 5.57% THD to the AC grid. FFT analysis shows that inserted LCL filter is better to comply with IEEE 519 current and voltage total harmonic distortion standard.

Keywords:- battery charger; Electric Vehicle Battery; Electric Power Grid; Bidirectional power electronics Converter; Grid to Vehicle(G2V); vehicle to grid (V2G); fuzzy logic controller (FLC); sinusoidal pulse width modulation (SPWM) .

Table of Contents

Acknowledgement	iv
List of Figures	x
List of Acronyms	xii
CHAPTER ONE	- 1 -
INTRODUCTION.....	- 1 -
1.1 Historical Background.....	- 1 -
1.2 Statement of the Problem	- 1 -
1.3 Objective	- 2 -
1.3.1 General objectives.....	- 2 -
1.3.2 Specific objective.....	- 2 -
1.4 Methodology	- 2 -
1.5 Scope and Limitation of the work.....	- 3 -
1.6 Thesis Contribution.....	- 3 -
1.7 Thesis Outline	- 3 -
CHAPTER TWO	- 5 -
LITERATURE REVIEW	- 5 -
2.0 Introduction	- 5 -
2.1 Electric Vehicle (EV).....	- 5 -
2.2 Bidirectional Power Flow	- 6 -
2.3 Positive Impacts of EVs on power System Network	- 7 -
2.3.1 Load leveling	- 7 -
2.3.2 Peak load shaving.....	- 7 -
2.3.3 Frequency Regulation	- 8 -
2.3.4 Mitigation of Grid Congestion.....	- 8 -
2.3.5 Spinning Reserve	- 8 -
2.3.6 Support for Renewable Energy Resources.....	- 8 -
2.4 State-of-the-art V2G/ G2V Infrastructure	- 9 -
2.5 The power grid	- 9 -
2.5.1 Smart power Grid.....	- 10 -
2.6 Aggregator.....	- 10 -
2.7 EV Batteries	- 11 -
2.8 Types of EV Battery.....	- 11 -

2.8.1 Lithium batteries	- 12 -
2.8.2 Zebra Cells	- 12 -
2.8.3 Molten Air Batteries.....	- 12 -
2.9 EV batteries charging	- 12 -
2.9.1 Constant Current Constant Voltage (CCCV) charging	- 12 -
2.9.2 Build-in Resistance Compensated (BRC) charging	- 13 -
2.10 Types of EV Chargers	- 13 -
2.10.1 Unidirectional EV Charger	- 14 -
2.11 Bidirectional EV Charger.....	- 15 -
2.11.1 On-board charger EV Charger	- 15 -
2.11.2 off-board charger EV Charger	- 15 -
2.11.3 Contactless EV Charger	- 16 -
2.11.4 Inductive EV Charger	- 16 -
2.11.5 Capacitive EV Charger	- 16 -
2.11.6 Contact based EV Charger	- 16 -
2.11.7 Conductive EV Charger	- 16 -
2.12 power electronics device	- 16 -
2.12.1 Thyristor (SCRs).....	- 17 -
2.12.2 MoSFET.....	- 17 -
2.12.3 IGBT	- 18 -
2.13 power Electronics Converters	- 19 -
2.14 AC to DC Converter.....	- 19 -
2.14.1 Bidirectional AC-DC	- 19 -
2.14.2 A 3- phase bi-directional AC/DC converter.....	- 19 -
2.14.3 A single-phase bi-directional AC-DC.....	- 20 -
2.14.4 two-stage ac-dc bi-directional.....	- 20 -
2.14.5 Single-Stage Isolated AC–DC converter	- 21 -
2.15 DC/DC Converter.....	- 21 -
2.15.1 Bidirectional DC-DC converter	- 21 -
2.15.2 Topology Based Classification of Bidirectional DC-DC converter.....	- 22 -
2.15.3 Isolated bidirectional dc-dc converter.....	- 22 -
2.15.4 Non-Isolated Bidirectional DC-DC converters	- 23 -
2.15.5 Buck Boost Cascade DC-DC Converter	- 23 -
2.15.6 Cuk DC -DC Converter.....	- 24 -

2.15.7 Half-Bridge DC-DC converter.....	- 24 -
2.16 Summary of literature review.....	- 25 -
2.17 Related works.....	- 25 -
2.18 summary of related work	- 26 -
CHAPTER THREE.....	- 28 -
SYSTEM CONTROLLING MODELE.....	- 28 -
3.0 Introduction	- 28 -
3.1 Control Strategy	- 28 -
3.2 The AC/DC (PFC) controller strategies	- 29 -
3.2.1 Pulse width modulation.....	- 29 -
3.3 The DC-DC controlling strategies.....	- 32 -
3.4 Voltage Mode Control (VMC).....	- 32 -
3.5 Current Mode Control (CMC)	- 33 -
3.6 Types of Controller	- 34 -
3.6.1 Proportional integral derivative (PID)	- 34 -
3.6.2 Sliding Mode Controller (SMC)	- 35 -
3.7 Fuzzy logic controller.....	- 35 -
3.7.1 Motivation for using flc	- 36 -
3.7.2 Fundamentals FLC.....	- 37 -
3.7.3 The fuzzy logic main components	- 37 -
3.7.4 Fuzzy sets.....	- 38 -
3.7.5 Membership functions.....	- 38 -
3.7.6 Fuzzy rules	- 39 -
3.7.7 Inference system	- 39 -
3.7.8 Defuzzification.....	- 39 -
CHAPTER FOUR.....	- 41 -
MATHEATICAL MODELING OF THE SYSTEM.....	- 41 -
4.1 Introduction	- 41 -
4.1.1 Parameters for bidirectional dc-dc [6].....	- 42 -
4.1.2 Parametere for LCL filter.....	- 43 -
CHAPTER FIVE	- 46 -
RESULT AND DISCUSSION	- 46 -
5.1 G2V Operation	- 46 -
5.2 V2G Operation	- 51 -

CHAPTER SIX	- 58 -
CONCLUSION AND RECOMMENDATION	- 58 -
6.1 Conclusion.....	- 58 -
6.2 Recommendation and future work	- 59 -
REFERENCES.....	- 60 -
Appendix.....	- 64 -

List of Figures

Figure 2 1: electric vehicle EV when charging and discharging	- 6 -
Figure 2.2: bidirectional flow.....	- 7 -
Figure 2.3: State-of-the-art V2G/ G2V infrastructure.....	- 9 -
Figure 2.4: Visionary Graph of Smart Grid	- 10 -
Figure 2.5: EV Aggregator interaction with EVs	- 11 -
Figure 2.6: The battery package used in Tesla EV	- 11 -
Figure 2.7: constant current constant voltage (CC-CV) battery charging mode	- 13 -
Figure 2.8: EV chargers.	- 14 -
Figure 2.9: (a) semiconductor structure, (b) circuit symbol.....	- 17 -
Figure 2.10: Power MOSFET: (a) semiconductor structure, (b) circuit symbol.....	- 18 -
Figure 2.11: IGBT (a) equivalent circuit, (b) circuit symbol	- 18 -
Figure 2.12: Single stage a three phase bi-directional AC-DC converter.....	- 19 -
Figure 2.13: A single-phase bi-directional AC-DC converter	- 20 -
Figure 2.14: two-stage ac-dc bi-directional converter	- 20 -
Figure 2.15: Single-Stage Isolated AC–DC converter	- 21 -
Figure 2.16: Simple example of Isolated Voltage Fed Bidirectional DC-DC Converter.....	- 22 -
Figure 2.17: Non-Isolated Bidirectional DC-DC converters	- 23 -
Figure 2.18: Bidirectional cascaded buck boost converter	- 23 -
Figure 2.19: Bidirectional cuck converter	- 24 -
Figure 2.20: Half H- Bridge bidirectional DC-DC converter	- 24 -
Figure 3.1: Block diagram of system with controllers.....	- 28 -
Figure 3.2: waveform of bipolar modulation	- 30 -
Figure 3.3: waveform of unipolar modulation	- 31 -
Figure 3.4: control block of DC-to-DC converter.....	- 32 -
Figure 3.5: Voltage mode controlled dc-dc converter	- 32 -
Figure 3.6: current mode control of DC-DC	- 33 -
Figure 3.7: PID controller of DC-DC converter	- 34 -
Figure 3.8: sliding mode control of DC-DC converter	- 35 -
Figure 3.9: Fuzzy logic control of DC/DC controller.....	- 36 -
Figure 3.10: Membership function.....	- 38 -
Figure 3.11: Error membership function.....	- 38 -
Figure 3.12: Error rate membership function.....	- 39 -
Figure 3.13: Output membership function.....	- 39 -
Figure 3.14: Charging controller by direct battery current strategy.....	- 40 -
Figure 3.15: Discharging controller by direct battery current strategy	- 40 -
Figure 4.1: Circuit Representation of Studied System.....	- 41 -
Figure 4.2: an LCL filter connected between bidirectional ac/dc converter and the grid.	- 44 -
Figure 5.1: Simulink diagram for G2V operation.....	- 46 -
Figure 5.2: Battery recharging process SOC-time curve	- 47 -
Figure 5.3: Negative charging battery current	- 47 -
Figure 5.4: Charging battery terminal voltage curve	- 48 -
Figure 5.5: Battery recharging process SOC-time curve	- 49 -

Figure 5.6: Negative charging battery current	- 49 -
Figure 5.7: charging battery terminal voltage curve	- 50 -
Figure 5.8: Simulink diagram for V2G operation.....	- 51 -
Figure 5.9: Battery SOC in V2G operation (discharging)	- 52 -
Figure 5.10: Discharging positive Battery current.....	- 52 -
Figure 5.11: Minimum discharging Battery voltage	- 53 -
Figure 5.12: Inverter output voltage from EVB to the grid (V2G).....	- 54 -
Figure 5.13: The inverter output current injected to the grid (V2G).....	- 54 -
Figure 5.14: Total harmonics distortion spectrum inverter voltage to grid	- 55 -
Figure 5.15: Total harmonics distortion spectrum of inverter current to grid.....	- 55 -
Figure 5.16: In phase inverter output voltage and current on V2G operation	- 56 -
Figure 5.17: in phase grid and inverter voltage.....	- 57 -
Figure 6.1: charger configuration in MATLAB Simulink	- 65 -
Figure 6.2: Simulink model of fuzzy logic control of charging.....	- 65 -
Figure 6.3: Simulink model of fuzzy logic control for discharging.....	- 66 -
Figure 6.4: Simulink model of SPWM controller	- 66 -
Figure 6.5: Partial rule views of the FIS	- 66 -
Figure 6.6: Linear Fuzzy rules surface for DC-DC chopper.....	- 67 -

List of Acronyms

AC	Alternating Current
BESS	Battery Energy Storage System
BEV	Battery Electric Vehicle
BFEV	Battery Feed Electric Vehicle
BSoC	Battery State of Charge
CC-CV	Constant current-Constant voltage
CSP	Concentrated Solar Power
DC	Direct Current
DER	Distributed Energy Resource
EDV	Electric Drive Vehicles
EV	Electric Vehicle
G2V	Grid-to-Vehicle
GHG	Greenhouse Gas
HEV	Hybrid Electric Vehicle
ICEV	Internal Combustion Engine Vehicle
PEV	Plugin Electric Vehicle
PWM	Pulse Width Modulation
UPFC	Unity Power Factor Correction
V2G	Vehicle-to-Grid
V2H	Vehicle-to-House
V2V	Vehicle-to-Vehicle
VSC	Voltage Source Converter

CHAPTER ONE

INTRODUCTION

1.1 Historical Background

Willet Compton first introduced the concept of V2G at the University of Delaware. The initial objective of V2G is providing a chance for the electric vehicle owners charges their car at a low electricity price in low load and discharges the cars at a higher price in peak load, so that the owners of the vehicle can make significant benefit from the V2G initiative [17].

As per quantitative analysis 20 to 22 hours per day, most EVs are unused. The key concept of V2G is to use electric vehicle batteries as an intermediate source during peak hours; by injecting the stored energy of unused electric vehicles back into the grid, using an EV charger and owners of EVs can take power from the grid to charge their EV batteries during off-peak hours when load requirement is low. Contact the EV owner and the power grid owner to allow power inject into the power grid from the EV according to the clearly defined plan and energy levels. The association between the EV users and the power grid operators will give multiple benefits to both the utility company and the EV owners. This potential has led to a new practice known as the Vehicle to Grid or V2G technology [11].

1.2 Statement of the Problem

Global warming has drawn the attention of the world because of its negative effect on Earth's climate. Continuous burning of liquid fossil fuels has contributed to the increased atmospheric accumulation of greenhouse gas emissions (GHGs), in specific carbon dioxide. For these factors, changing global energy demand from fossil fuels to sustainable transport has become a critical issue across the car industry. To provide a clean transport and energy source with minimum pollution is the reason behind to increasing popularity of electric vehicle [1] [41].

Along with many of the advantages of EV growth, there are a few concerns raised regarding electrical grid constraints due to the vast spread of the EV market in the coming years. Integrating a large fleet of EVs into the electrical power system for charging EV batteries has unavoidable

negative effects on power grid infrastructure like voltage drop, phase mismatch, harmonics, overloading, and unstable power system network. These impacts are considered in the development and integration of the V2G concept, which is discharging of EVB power into the AC grid [4].

However, a sudden discharge of energy from the EVs can cause swelling of the voltage at the distribution node. Therefore, in order to preserve grid stability for both the charging/dischARGE circumstance. The DC-DC, AC-DC converter between the EVs and the grid needs an effective control system. In general, it needs to build a V2G charger device with a controller that takes care of the safe status of the EV and the grid during charging and discharging [9].

1.3 Objective

1.3.1 General objectives

Objective of the thesis is to construct two-stage non-isolated bidirectional EV chargers used for both V2G/G2V technology and to develop the FLC and SPWM controller for a two-stage EV charger to make the system reliable and viable.

1.3.2 Specific objective

The Specific objectives of the thesis, considering the V2G/G2V bi-directional power flow and charging/ discharging of EVs are as follows:-

- ✓ To design regulation strategies to make grid voltage stable.
- ✓ To choose a superior bi-directional dc-dc and ac-dc converter topologies for the system.
- ✓ To build and simulate a fuzzy logic controller for two-way power flow.
- ✓ To maximize the satisfaction of vehicle owners, minimize the operational costs of the electrical power system, reduce carbon emissions and increasing the effectiveness of the electrical system.

1.4 Methodology

The following methodologies are used for the fulfillment of this thesis: Literatures about the power electronics devices, power electronics converter those used to V2G/G2V system and different type of controller and control technique used to control power electronics converters are reviewed. The mathematical model and block diagram of the proposed system as well as the detailed

understanding of the controller is discussed. Then design and Integrating FLC to the dc-dc stage to minimize the error between the reference and measured battery current and level current supplied for the bidirectional dc-dc converter for the determination of charging and discharging condition of the overall system. SPWM controllers are also applied for the ac-dc part of the bidirectional EV charger, to make the voltage and current from the inverter in phase and have true sinusoidal wave shape. The mathematical model is done to determine the value of LCL filter parameters, dc-link parameters, and battery side parameters. Then after applying MATLAB Simulink based simulation for the proposed system topology and selected controller. Based on the simulation result discussion and conclusion held.

1.5 Scope and Limitation of the work

Describing and examining various types of power electronics converter and the multiple control system used to control both of the AC/DC and DC/DC converters and selecting one that has the best performance. MATLAB Simulink is built for a system with the selected converter topology and proposed controller to prove the system's feasibility. In particular, this master thesis deals with the design and verification of the operation of the V2G and G2V (charging /discharge of EV). To explore the effectiveness of the single-phase two-stage bi-directional charger used in the V2G/G2V technology. On this work beyond MATLAB Simulink, there is no prototype implementation.

1.6 Thesis Contribution

The contribution of this study can describe this way: - a different form of controller used to monitor the system and various kinds of power electronics equipment and converters used to build this two-way EV charger briefly presented. This study will include a systematic procedure for coordinating EV charging and discharging activities with the electric power grid. The charging and discharging technique that takes the EV battery as ESS (energy storage system) is established. This technique works to use the EV battery to store power during off-peak hours and to retrieve power at peak hours.

1.7 Thesis Outline

The rest part of this thesis is constructed as follows:- Chapter two covers the literature review of previous studies and general information about the charger, types of charger, power electronics

devices, theoretical review on different charger scheme used to V2G/G2V and related works by another scholar. Chapter Three will discuss and present a different kind of controller scheme use- for both bidirectional AC/DC and DC/DC converters, Fuzzy Logic, and SPWM control described. In addition, in this chapter, the effectiveness of different controllers is briefly described and compared theoretically. In chapter Five, try to show a mathematical equation about the devices which I have been using. Chapter Five presents the results of the MATLAB simulation and a discussion will provide about the system feasibility. Chapter Six states a conclusion about the work and some recommendations for future study, at the end of this thesis report next to chapter six references and appendix are placed.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

In this portion, I try to address theoretical and historical background and current state of knowledge on the topics related to the thesis. Electric vehicle, Electric vehicle charger, and power grid are trying to study, by evaluate and present papers published by qualified scholars and researchers focusing on V2G /G2V, AC / DC, DC / DC power electronics converter and devices.

2.1 Electric Vehicle (EV)

Electric vehicles (EV) is a vehicle which uses electric motors for the function of traction and its motors powered solely by battery packs, the only emissions generated by EV are from the generation of electricity to charging the EV battery pack. Emission is substantially lower relative to the emission produced by gasoline-powered engines. Battery packs can be charged at any public charging station or home. Electric cars are more suited for city driving conditions because batteries can be conveniently charged using an electrical outlet that is not favored for long-distance driving due to a lack of charging infrastructure and existing battery technology. Whereas hybrid cars are better for long-distance driving conditions besides city driving. Both electric and internal combustion engine (ICE) EVs are referred to as hybrid electric vehicles(HEVs). The internal combustion engine (ICE) is powered by gasoline and the electric car motors are driven by rechargeable battery[1].

The first EV was discovered during the 19th century, in 1834 manufactured and marketed by some United States, British and French companies, while its number of EVs is still far from conventional ICE vehicles. Now a day, EVs becoming a viable alternative to internal combustion engine vehicles, intending to reduce high oil reliance and comply with more stringent emission regulations arising from significant environmental concerns about global warming. The electrical vehicle is mainly considered as a clean transport system, but today it also serves as a large energy storage

system when connected to the power grid. Electrical energy stored in the battery vehicle is not used while the vehicle is parked. Stored electricity in the battery of EV can get back to the power grid, to operate the grid needs either bi-directional or unidirectional battery smart charger[1][18].



Figure 2 1: electric vehicle EV when charging and discharging [18].

2.2 Bidirectional Power Flow

The bidirectional charger would have to operate smoothly for both directions, which means that energy can be transfer from grid to the battery during the charging mode and from the battery to the grid during the discharge (V2G) mode. The basic requirement of G2V/V2G is the efficient control system that is capable of handling bi-directional power flow [6] [8].

In the charging mode, the AC voltage from the grid has been rectified to the DC voltage as it passes through a bi-directional converter. The two-way DC-DC converter then switches the voltage down or up to the required level to ensure proper charging/discharging. In the discharging mode, the DC voltage from the battery passed through the unipolar SPWM regulated inverter and out through passive filter to eliminate unwanted harmonics and produce voltage and current have true sinusoidal wave shape, which is better to AC grid [6].

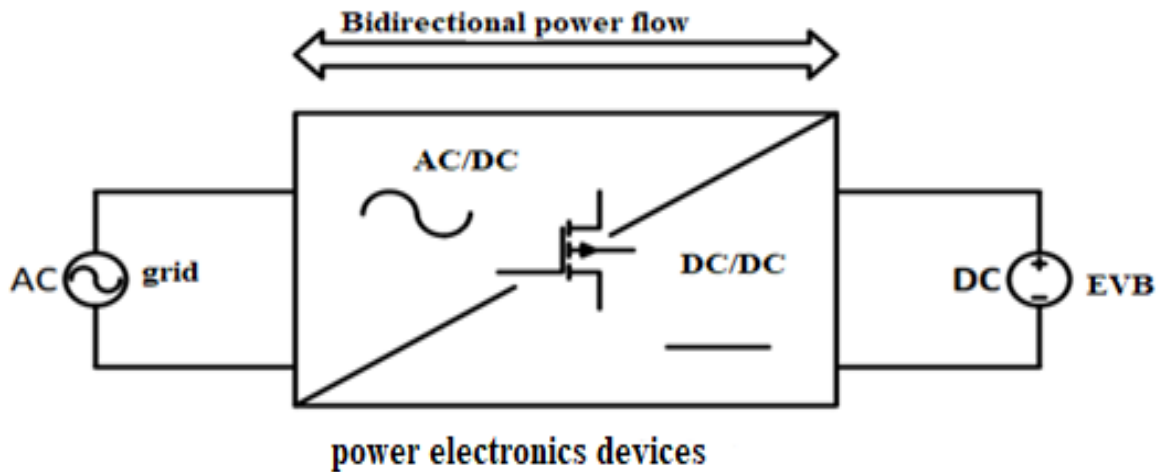


Figure 2.2: bidirectional flow [6].

2.3 Positive Impacts of EVs on power System Network

EV not only lowers the level of air pollution, but also add electrical power to the power grid when the EV battery has surplus electricity. Such V2G and G2V system helps to maintain a stable load demand by valley loading, peak shaving, voltage control, frequency regulation, grid congestion reduction, spinning reserve and harmonics etc.

2.3.1 Load leveling

The load profile of electricity mainly consists of peak and non-peak loads, as the disparity between peak and non-peak loads is large, as well as their capital and operating costs, making the process of power generation more difficult. Controllable and aggregated EVs can be charged during a non-peak hour (such as night and early morning) so that the overall load during a non-peak hour can be increased and the peak hour difference can be optimized [20].

2.3.2 Peak load shaving

In general, Peak load shaving found in manufacturing, commercial and residential distribution networks when loads have just a limited duration of peak power demand. Peak loads will occur at noon and night depending on the demand side of the area dominated by the industrial sector. During this peak load time, EVs with a certain state of charge can discharge their electricity and return to the grid. This technique would reduce the peak load on the electrical grid and the level

load resulting in desirable grid results. In addition, the price during peak load time is typically significantly higher than normal condition [4] [20].

2.3.3 Frequency Regulation

Frequency regulation can be describe as a service that corrects short-term changes that may have an effect on the stability/quality of the electrical grid. EVs discharge their electric city when the frequency is low and charged when the frequency is higher. It considered that frequency regulation is a very economical benefit from V2G service [20].

2.3.4 Mitigation of Grid Congestion

The high demand of electricity, including unregulated charging of EVs and air conditioning, may lead to congestion in the transmission and distribution network due to the transmission limitation of the grid. The EVs located in the area where the congestion occurs may discharge the electricity and send to the congestion area, thus the electricity load and balance may be satisfied and maintained, respectively. In addition, this form of congestion mitigation can reduce the power loss and minimize peak load [20].

2.3.5 Spinning Reserve

V2G act as a spinning reserve operation. Spinning reserve is supplied power to the electrical grid in periods additional power required to increase the power generation capacity of the systems. The energy stored in grid-connected EVs are provides additional generation capacity and can compensate for the power outage. Generation units always have the capacity to produce backups in event of error or fault. V2G technology has the potential to help recovery failure, decrease backup generation capacity, and reduce utility costs [4].

2.3.6 Support for Renewable Energy Resources

The integration of renewable energy resources into to the power grid is constrained by the availability of energy storage systems. Due this is to the intermittent question of renewable energy resources linked to the electrical grid. V2G could solve the intermittent question of renewable energy sources. EVs are charge when there is excess energy from the sources and discharge when energy sources do not produce enough power. Since V2G can solve the issue of energy storage,

more renewable energy resources can be integrate into electricity grids that reduce the environmental threats and maintain a sustainable energy system [4].

2.4 State-of-the-art V2G/ G2V Infrastructure

V2G/ G2V is a system that allows a power transmission in two directions between grid and electric vehicle. The key components, which required for the integration of the V2G/G2V system, are the EV Battery, the power grid, the complete EV charger, and the charger controller. The way of delivering electrical energy from the electrical vehicle to the electrical power grid is named V2G, in this case, EV is considered as a source of power rather than a load. The vehicle receives power from the power grid to full its battery; the system named G2V, in this event the electric vehicle is considered a load on the grid [6].

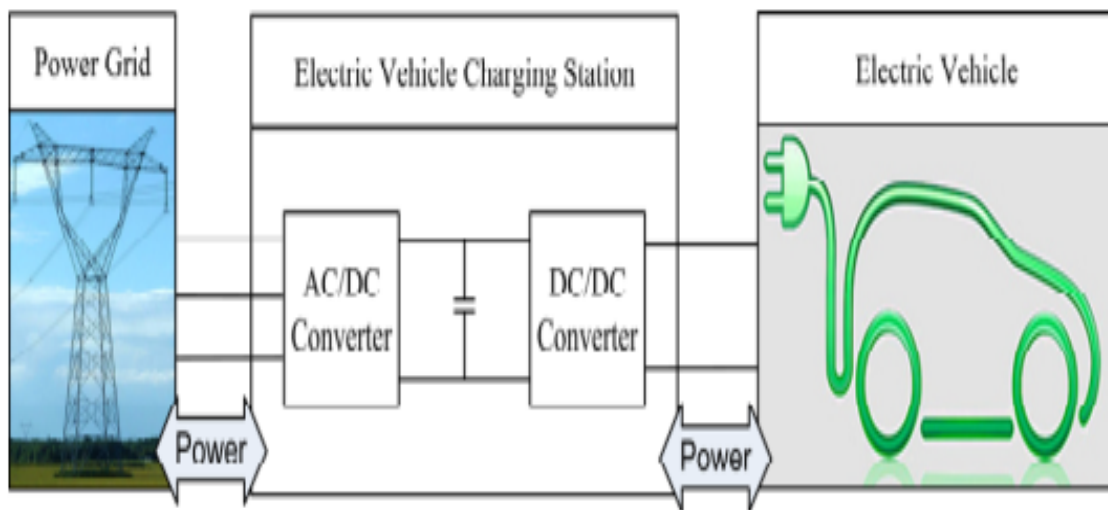


Figure 2.3: State-of-the-art V2G/ G2V infrastructure [6].

2.5 The power grid

Power grid is an interconnected of the manufacturing and utilization and transfer power from place it produced to place it used. The V2G power would act as an additional facility in the electrical power grid. The Power system must match production and load, as the energy flow is in the form of active and reactive powers. The system frequency must be maintained at or very close

to its nominal frequency of 60hz or 50hz based in the countries. Any variance from this would require intervention by the system operator[6].

2.5.1 Smart power Grid

Smart grid is the idea of modernizing the electrical power grid. Smart grid is combination of electrical and information technology (Smart Meters and Sensors) between every power generation and consumption point, To reduce negative impact on the environment, reduce costs, increase reliability and also increase operation efficiency [38].



Figure2.4: Visionary Graph of Smart Grid [38]

2.6 Aggregator

Optionally, the EVs will charge or discharge on the basis of the command from the grid operator and the owner of the EV to satisfy the requested demand for both the EV and power grid. The aggregator also monitors the charging or discharging sequence rate and distributes the power between multi-EV charging stations (CS). The aggregator Plays a vital role in the charging and discharging of more than hundreds or thousands of EVs, it is an intermediary mechanism for multiple small-scale EVs, and it makes efficient use of distributed EVs in the charging station (CS) to produce grid-scale power [23].

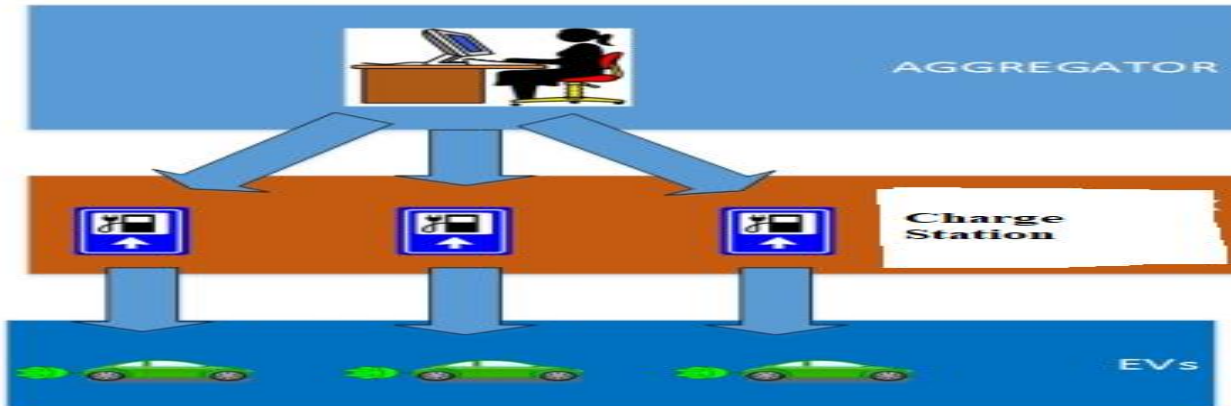


Figure 2.5: EV Aggregator interaction with EVs [27].

2.7 EV Batteries

Batteries are the key component of an electric vehicle and critical devices for V2G/G2V technology. The effectiveness of the electric vehicle much depends on the kinds of battery used. However, the Electric Vehicle Battery is susceptible to overheating, to prevent such problems that the vehicle is not powered during the charging time, and the EV must have a coolant device on its hood. The battery is also the main factor for making the electric vehicle too expensive. The electric vehicle battery pack is made up of many dry cell batteries that we have used throughout our day-to-day life, as shown in Figure 2.6[36].

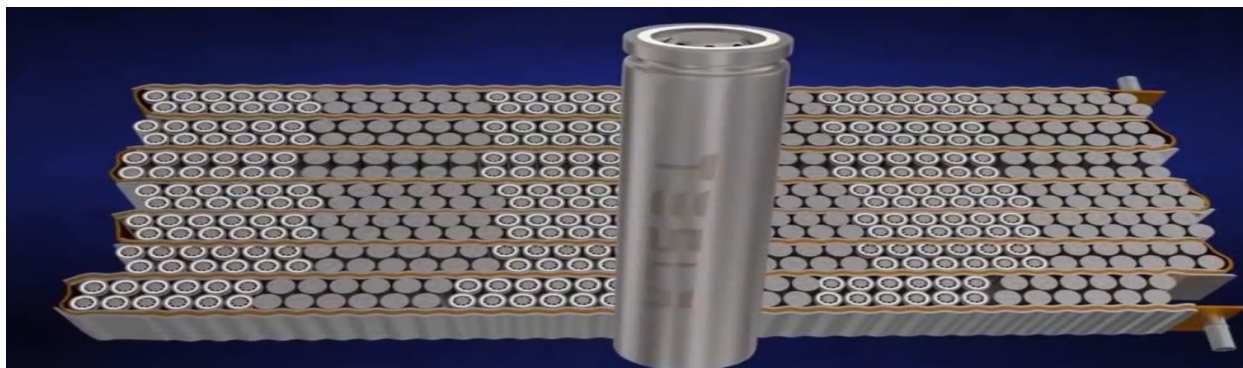


Figure 2.6: The battery package used in Tesla EV

2.8 Types of EV Battery

There are numerous types of batteries in the battery technology each kind has its own merits and limitations. However, in the case of V2G/G2V, the task to select of the battery the one that suits

to the desired design, left to the engineer, based on the number of factors such as the concentration of the reactant, the temperature and the range of reactions may affect the charging and discharging phase of the battery bank [13][16].

2.8.1 Lithium batteries

Lithium batteries provide high energy densities compared to all other non-toxic rechargeable batteries. The main disadvantage associated with Lithium batteries is their long charging time. Research is, however, searching for rapid charging of batteries. Those work is moving towards the creation of the structure of crystal that could charge a hundred times faster than the traditional lithium battery [22].

2.8.2 Zebra Cells

Zebra cells used for both traditional large-scale power utility applications such as backup systems and renewables such as wide photovoltaic regions and wind farms. Zebra cells tend to be more competitive compared to li-ion batteries due to lower price. Zebra cells to achieve maximum load in normal mode take 6 hours. In quick charge mode, they only need one hour to be fully charged [23].

2.8.3 Molten Air Batteries

Molten Air Batteries Molten Salt Storage is now available today for Concentrated Solar Power allowing for the use of solar power to be generated on demand and to back up infrequent sources of electricity, such as wind and solar power. The molten salt is non-volatile and non-flammable with a high ion and energy density is an excellent electrolyte ideal for battery operation. The only big drawback of this battery is require high-temperature operation [21].

2.9 EV batteries charging

2.9.1 Constant Current Constant Voltage (CCCV) charging

As shown in Figure 2.7 constant-current charging means, the charger supplies the current at a reasonably uniform rate, regardless of battery temperature or charging status. Constant-voltage charging assures almost the same input voltage of the battery during the charging process, irrespective of its charging status. Constant current and constant voltage battery charging methods

are incorporated together throughout the process of the battery charging. Generally, the charging schemes consist of CC charging until the EV battery voltage hits the charging voltage level, then CV charging is applied, allowing the charging current to taper until it becomes a very small value [13] [11].

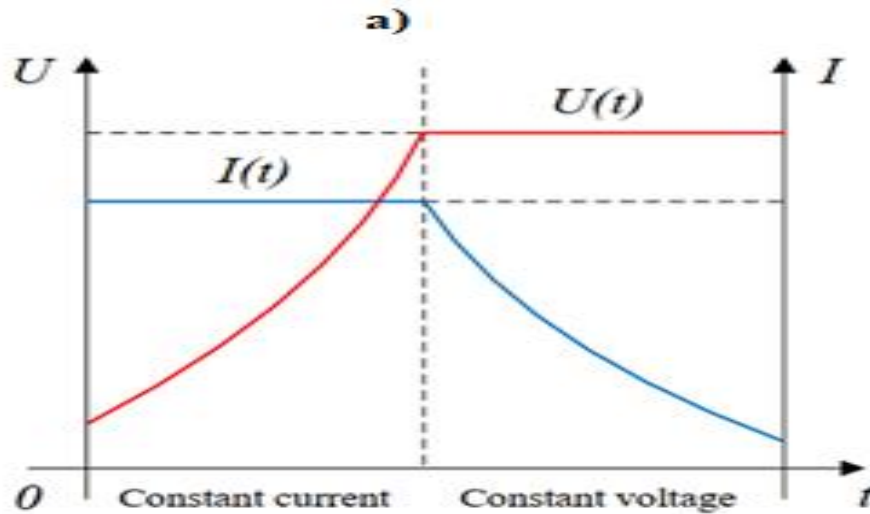


Figure 2.7: constant current constant voltage (CC-CV) battery charging mode [32]

2.9.2 Build-in Resistance Compensated (BRC) charging

Build-in resistance compensated (BRC) charging technique. Increased charging current during the CC phase will only result in the early switch over to the CV phase due to the increased over-potential and the voltage drop across the connected leads. The BRC technique prevent this early switch over by significantly estimating the resistance of the connection in and to the battery pack. Since the battery is charged with a high current at a high voltage, the life time might be adversely affected by this method [11].

2.10 Types of EV Chargers

For the V2 G concept, the power flow can be one or two-directional depends on the power utility requirement. Unidirectional V2G charger refers to the one-way power transfer from the power grid to the EV or vice versa. The unidirectional V2G has easy operation, low investment costs, and high availability as traditional battery chargers. On the contrary, bi-directional V2G provides more technological and financial benefits. The bi-directional V2G charger has the same advantages as

the unidirectional V2G charger as it will accomplish load leveling, peak load shaving, reactive and active power control, and harmonic filtering. Besides, a bi-directional V2G concept will provide more versatility to the power utility system and give substantial economic advantages to the EV owner [9] [11].

The charger can be categorized either on-board, off-board, unidirectional, bidirectional, or single-phase, three-phase with the property of conductive, capacitive, and inductive chargers. Typically, there are two charging strategies for EVs, namely AC and DC charging. A single-phase or three-phase AC power is supply to the EV through the on-board AC–DC power converter for AC charging. In the meantime, DC charging is done by directly supplying DC power to the EV battery through an off-board DC-DC power converter. The main components for the EV bidirectional battery charger are AC-DC converter and DC-DC converter, controller, and filter [11].



Figure 2.8: EV chargers [5].

2.10.1 Unidirectional EV Charger

In unidirectional chargers, the power flows in one direction, the unidirectional charger has less hardware requirements, easy interconnection. Unidirectional chargers have the advantages such as low cost, lossless, high efficiency and ease of access and control, but are not suitable for electric vehicle to grid and electric vehicle two-way power flow operation. In addition, the unidirectional V2G does not put additional negative factor on the battery and can extend the battery life. In general, the unidirectional V2G charger also has a simple operation, low expenditure costs and a high availability of conventional battery chargers for V2G technology [4] [5] [11].

2.11 Bidirectional EV Charger

When the power flows take place in both directions, the chargers are called bi-directional chargers. In the case of V2G / G2V, the charger is safer to be bi-directional, the bi-directional charger will have two stages, the first stage is a bi-directional AC-DC converter that enforces the power factor is better and the second stage is a bi-directional DC-DC converter that regulates the direction of the current of the battery. The most critical aspect of the bi-directional charger is the ability to operate in charging and discharging modes [5].

In contrast with unidirectional, in G2V operation the AC-DC converter converts AC power to DC power, and the DC-DC converter is responsible for regulating power flow direction using the direct current control technique and functions as a step-down converter. On the other hand during EV discharging (V2G) mode, the AC-DC bi-directional converter act as an inverter and injects the inverted voltage into the power grid, the DC-DC converter is responsible for boosting the battery voltage to match with the DC link voltage besides controlling the current flow using the direct current control technique. Bidirectional chargers require more hardware and extra cost, but it supports the discharging operations. This thesis focus on two-stage single-phase bidirectional chargers, which are used for charging and discharging [5].

2.11.1 On-board charger EV Charger

When all of the charging equipment are shown and install on the vehicle, we call this the on-board charger. On board charger is located on the vehicle itself, which means the charging circuit used to charge the vehicle will integrate as the design of the vehicle, charger always goes where the vehicle goes [23].

2.11.2 off-board charger EV Charger

When all of the charging equipment is, install out of a vehicle named as an off-board charger. It is not part of the vehicle, which means that the charger stays outside the vehicle, and the vehicle has to go where charger located may be at the charging station or else to charge the battery. A new electricity policy with various energy prices in different nations promotes the use of off-peak charging and forbids on-peak charging [11] [23].

2.11.3 Contactless EV Charger

The EV battery also charged using a contactless charging device based on the induction-coupling concept. The term contactless system can be used to describe the transfer of power between two physically disconnected objects. The word "contactless" inferred from some kind of remote action so that a transfer of power could occur over a physical distance, that means a galvanic isolation is formed between the high level side and the low level side that enables the transfer of power[23].

2.11.4 Inductive EV Charger

In induction coupling, charging system the power is transferred by the induction principle, which is a magnetic coupling between the winding of the separate coiler rather than the transfer of power by direct wire connection [23].

2.11.5 Capacitive EV Charger

In the case of a capacitive coupling charging system, power is transferred by an electrostatic principle, which is a pair of conductors or plates separated by a dielectric between the two systems, this type of charging did not develop much but was still used to a low power level [23].

2.11.6 Contact based EV Charger

The opposite of contactless charger is contact-based charger, which is charging platform held by conduction principle. The contact-based charger means, when there is a physical contact between the supply and the load to transferring power, which means that there is no galvanic separation of load and source [23].

2.11.7 Conductive EV Charger

The conductive charging device is a form of contact-based charger that uses metal-to- metal contact to pass electricity from the charger to the electric vehicle Similar to the conventional plugin charger [23].

2.12 power electronics device

The multipurpose use of an electronic power converter in an electric vehicle or V2G has a challenging issue, to minimizing device size, weight, and cost. In the case of design, the chargers,

the weight, and the size of the converter are a major concern, to ensure the flexibility of the charger to charging the EV at either the public charging stations or home. Power electronic converters are used as the system's power and energy manager and are located everywhere in the EV powertrain system. Power electronic converters use semiconductor and passive elements to convert electrical energy from the source form to the form needed by the load [2] [21].

2.12.1 Thyristor (SCRs)

The SCR named "thyristor" in many parts of the world, a four-layer, three-electrode semiconductor device, as it can see from Figure 2.9. The SCR acts as a regular diode as long as the current flow stays above the current holding stage. In the case of electrical converters, the SCR is switched on by a gate current supplied by an external source connected between the gate (G) and the cathode [37].



Figure 2.9: (a) semiconductor structure, (b) circuit symbol [37].

2.12.2 MoSFET

MoSFET is constructed by connecting the diode in series to the transistor. The technical advantages of the MoSFET are not limited to high switching speeds. The MoSFET switching losses are minimal, even with high switching frequencies, due to short turn-on and turn-off times. Switching frequencies can be from hundreds kHz in medium-power converters and around 1 MHz in low-power switching power supply. Power MoSFET is available with voltage and current ratings of up to 1.5 KV and 1.8 KA[37].

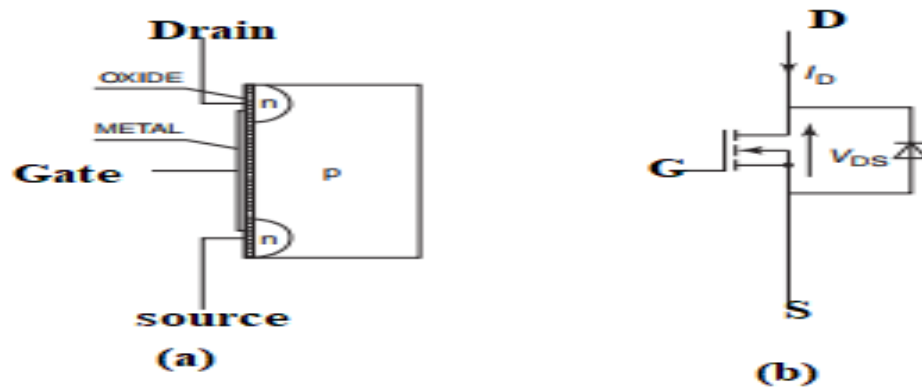


Figure 2.10: Power MOSFET: (a) semiconductor structure, (b) circuit symbol [37].

2.12.3 IGBT

The insulated gate bipolar transistors (IGBTs) are a hybrid semiconductor devices, it combine the advantages of MoSFET and BJTs. They are regulated, like MoSFET, but have lower conduction losses, higher voltage and current ratings. The IGBT corresponding circuit and circuit symbol is shown in Figure 2.11. IGBT can used for high voltage converter technology. IGBT is faster than BJT but not faster than MoSFET, but has a lower conduction loss. In addition to its operational superiority, IGBT has a broader range of voltage and current ratings than power bits [37].

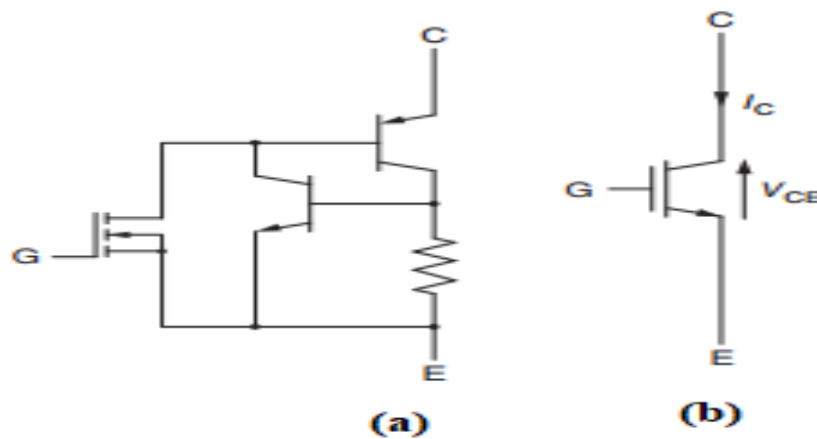


Figure 2.11: IGBT (a) equivalent circuit, (b) circuit symbol [37].

2.13 power Electronics Converters

There are four major types of converters: dc-dc, ac-dc, ac-ac and dc-ac. For each of this converter with active and passive semiconductor components may be arrange in several possible structures or topologies. In this thesis, system comprises a single-phase bi-directional ac-dc converter and a half bridge bi-directional buck-boost dc-dc converter.

2.14 AC to DC Converter

The classification of AC-DC converter topologies is based on the way of conversion, the method of construction and its principle of operation. On this basis, it may identify either three-phase, single-phase, multi-level, isolated, non-isolated, soft-switched, hard-switched, unidirectional, bi-directional, etc. In addition, converters can be listed as single-stage, two-stage, uni-directional, and bidirectional with an intermediate DC-linked or AC-linked converters [7].

2.14.1 Bidirectional AC-DC

The bidirectional AC-DC converter main performance can be defined as follows:

- ✓ Convert DC voltage to V_{rms} of 50Hz/60Hz sine wave output using a filter [6].
- ✓ Using the Pulse Width Modulator (PWM) scheme that operates at the desired kHz.
- ✓ Rectify voltage and current when operating in charging process.
- ✓ Converting a DC waveform to AC waveform during V2G operation [6].

2.14.2 A 3- phase bi-directional AC/DC converter

A 3-phase AC-DC converter can decrease the time taken for both charging and discharging operation of electric vehicles battery by charging and discharging the batteries at a higher power level [1].

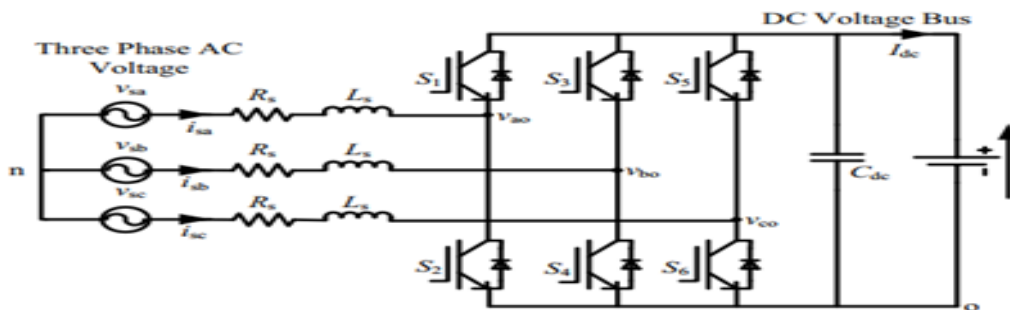


Figure 2.12: Single stage a three phase bi-directional AC-DC converter [1]

2.14.3 A single-phase bi-directional AC-DC

A single-phase, AC-DC converter uses large electrolyte capacitors to remove ripple currents in the DC link. Electrolytic capacitors are susceptible to device failures. These electrolytic capacitors can also be eliminate by eliminating the ripple current in the DC link by injecting a current of the same magnitude and opposite to the ripple current [1].

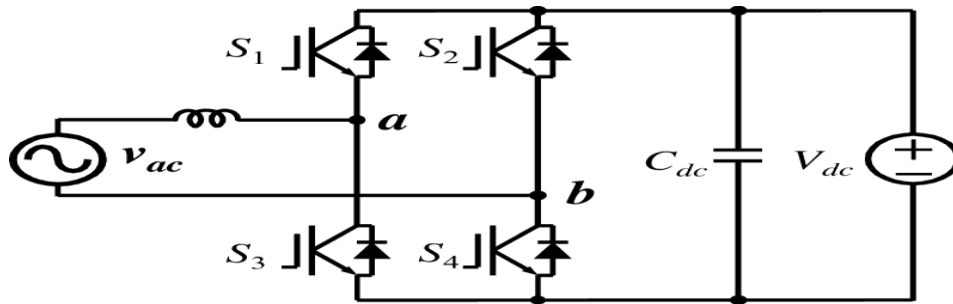


Figure 2.13: A single-phase bi-directional AC-DC converter [1]

2.14.4 two-stage ac-dc bi-directional

Two-stage ac-dc converter is a full bridge diode rectifier followed by a single boost converter typically used as a front-end AC-DC converter. The above-mentioned converter topology has a two-stage conversion that enables bi-directional power flow. Two-stage power conversion decreases system performance and power density as the system scales. The increased number of reactive elements due to multiple power stages reduce the stability of the system. In addition, due to the multiple stages involved, regulation becomes more complex [1] [5].

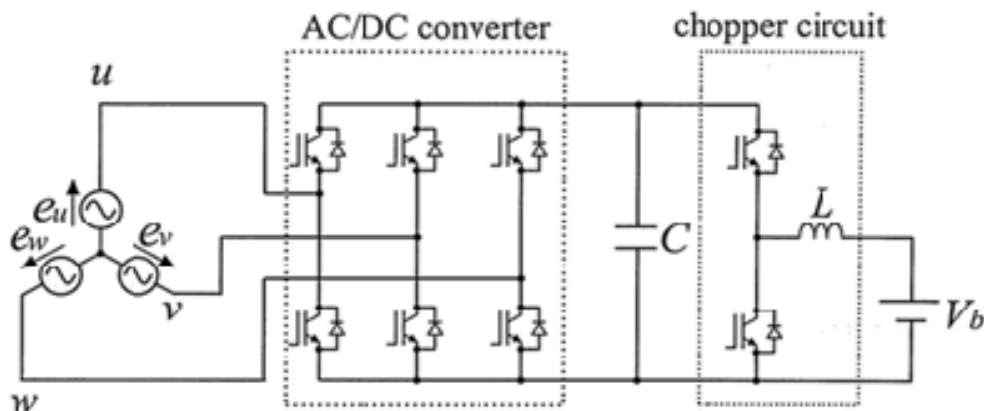


Figure 2.14: two-stage ac-dc bi-directional converter [5]

2.14.5 Single-Stage Isolated AC–DC converter

This converter has a high efficiency and is easy to implement, but the key downside of this circuit is the high output current ripple. The converter applications is powering the battery bank, but the batteries be charged with low ripple current to increase their longevity, which is why this converter is not the best solution for such V2G applications [1].

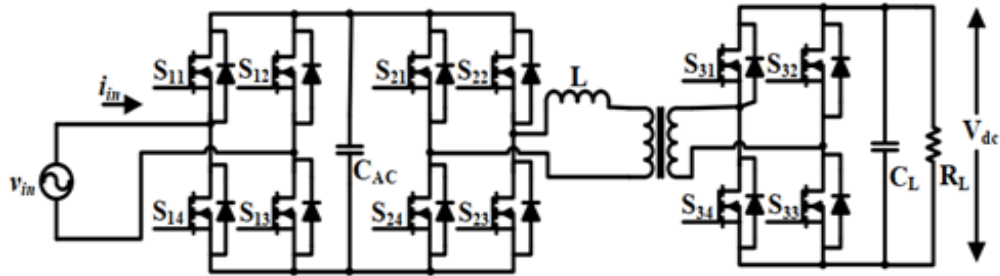


Figure 2.15: Single-Stage Isolated AC–DC converter [24]

2.15 DC/DC Converter

The DC-DC converter is a power electronic system used for the conversion of DC power by the addition or reduction of voltage. The DC-DC converter, based on its power flow, can be grouped into two groups, one-way and two-way. The one-way DC-DC converter is used to convert the voltage level and control power flow to the determined one direction. However, a two-way DC-DC converter is used for both convert voltage level and control current flow direction [24].

2.15.1 Bidirectional DC-DC converter

The two-way dc-dc converter is the main part of the charging and discharging operation, to regulate the power transmission in both G2V and V2G operation to provide the desired voltage for either the EVB or power grid. In EV charger used for V2G/G2V operation, Bidirectional DC-DC converters serve the purpose of increasing or lowering the voltage level between its input and output, with the controlling directions of power flow [21].

Some key performances required to selecting bidirectional DC-DC converter design for EV and V2G applications are listed as follows:-

- ✓ Single stage converter for simplicity

- ✓ using minimal storage elements;
- ✓ Allowing bi-directional current flow
- ✓ lower switch loss; High efficiency
- ✓ Light weight & compact size
- ✓ Lower Electromagnetic Interference
- ✓ Input and Output Current ripple is must be Low

2.15.2 Topology Based Classification of Bidirectional DC-DC converter

Bidirectional DC-DC converters can be classified into two categories depending on the Galvanic isolation between the input and output side [6].

1. Non-Isolated Bidirectional DC-DC converters
2. Isolated Bidirectional DC-DC converters

2.15.3 Isolated bidirectional dc-dc converter

The isolated bi-directional dc-dc converter provides galvanic separation between high voltage and low voltage sides of the converter. The main advantages of this converter are security due to the separation of the input circuit and the output circuit. This type of DC-DC converter is best used for high voltage systems from a safety point of view. Isolated bidirectional dc-dc converters are wide in size and heavier in weight, due to the existence of the transformer, because these converters appear to be unfit for electric vehicles charger [24] [21].

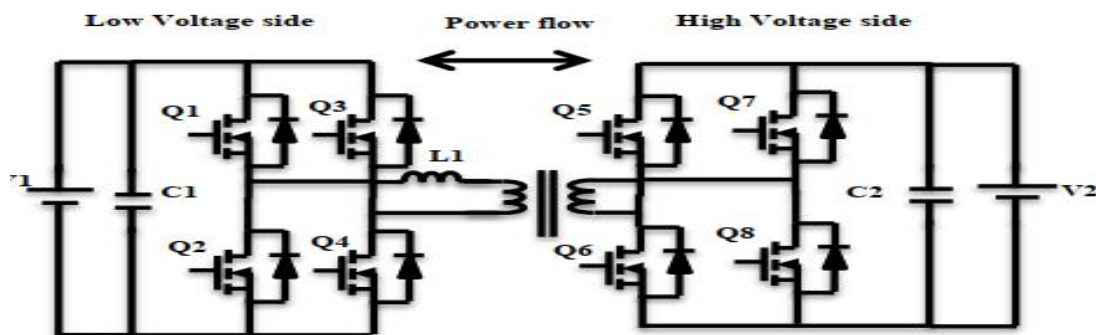


Figure 2.16: Simple example of Isolated Voltage Fed Bidirectional DC-DC Converter [24]

2.15.4 Non-Isolated Bidirectional DC-DC converters

A non-isolated bi-directional dc-dc converter does not use galvanic isolation between the high voltage and low voltage sides of the converter. Besides non-isolated bi-directional DC-DC converter, can be built by improve the unidirectional conduction capability of conventional converters by adding a Power MoSFET or IGBT with antiparallel diode across them [21].

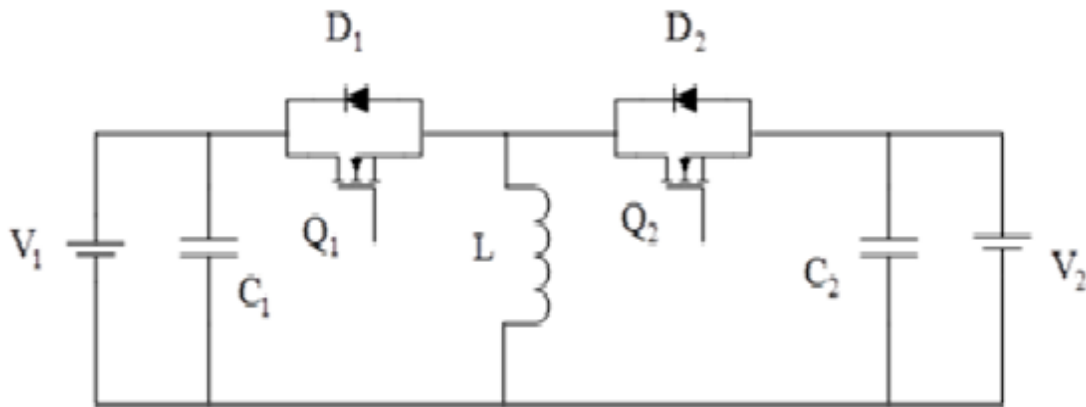


Figure 2.17: Non-Isolated Bidirectional DC-DC converters [21]

2.15.5 Buck Boost Cascade DC-DC Converter

The third type of bi-directional topology can be obtained by cascading a bi-directional buck converter with a bi-directional step-up converter, this topology allows the output voltage to be either higher or lower than the input voltage, depending on the switch combinations used and the current path. While either it is easier to step down or step up the voltage level, as we want based on the duty cycle, however, due to the more switches has more switch losses and additional power electronics costs [21].

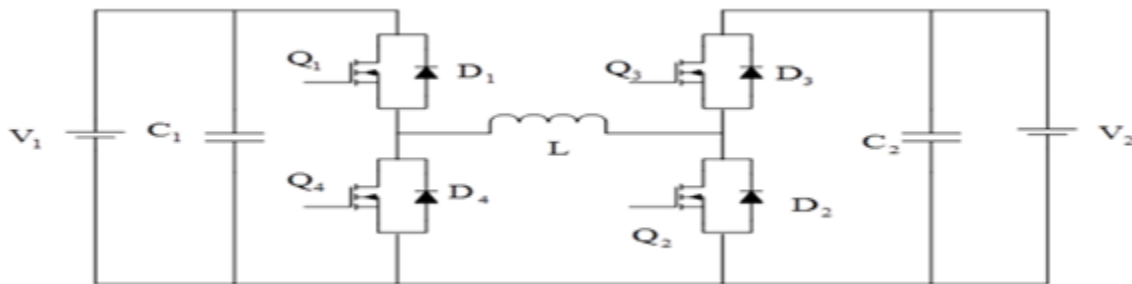


Figure 2.18: Bidirectional cascaded buck boost converter [21]

2.15.6 Cuk DC -DC Converter

The fourth topology is obtained by replacing the unidirectional switches of the traditional Cuk converter with the two-way switching devices. The resultant circuit is as shown in Figure 2.19. The capacitor acts as the main storage unit, while the C1 and C2 capacitors act as the coupling capacitors. It can also move up or down the input voltage like a buck-boost converter, but with an inverted polarity [21].

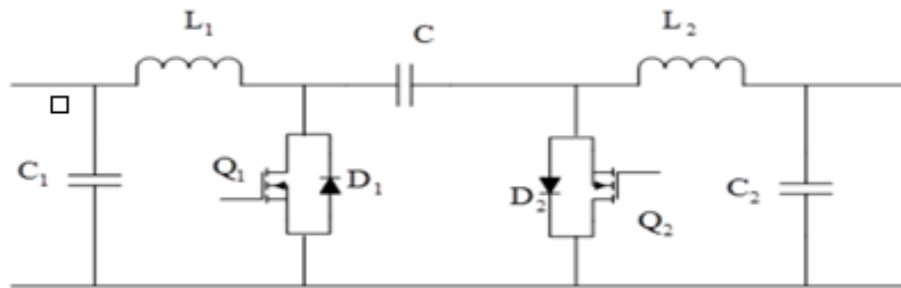


Figure 2.19: Bidirectional cuk converter [21]

2.15.7 Half-Bridge DC-DC converter

When the step-up and step-down converters are interconnected in antiparallel, the resulting circuit has the same as the basic Boost and Buck structure with the capability of bi-directional power flow. Figure 2.20 shows the basic configuration of the non-isolated half-bridge Bi-directional DC-DC converter. During charging, switch Q1 is work cycle in step-down operation at the appropriate duty ratio, while switch Q2 is kept off state. In the same principle during the discharge, the switch Q2 is designed to operate the step up process at the appropriate duty cycle, while the switch Q1 is stay turned off. Limited dead time has been given to avoid cross-conductance through switches and converter output capacitance during the transition [21].

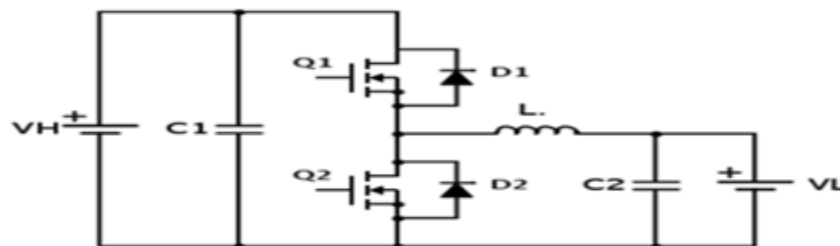


Figure 2.20: Half H- Bridge bidirectional DC-DC converter [21]

2.16 Summary of literature review

In this chapter, I have tried to show a general overview of the study, specifically on the power electronics devices SCR, IGBT, and MOSFET and AC-DC, DC-DC power electronics converters within their different types like bidirectional, unidirectional, isolated, non-isolated, 3-phase and 1-phase. The fundamental working principle of power electronics devices within their merit and demerit are described in detail to give an initial background about this work.

MOSFET are faster than both SCR and IGBT, and has low switching losses. However, it is suitable only to low voltage system. IGBT is faster than SCR and BJT but not fast as MOSFET. IGBT has low conduction loss also it is suitable for both high voltage and low voltage. Therefore, a single-phase non-isolated bidirectional ac-dc converter constructed from IGBT is best for an EV charger. Since it has low complexity, low switching losses and low material cost.

Half H-bridge DC-DC converter is potentially more effective than the Cúk and SEPIC. Because it has lower switching losses on the active component. The bi-directional half-bridge needs only a single inductor rather than two, and the power switches needed for the half-bridge bi-directional converter are much lower than the Cúk converter. Generally, due to the lower inductor current, lower conduction and switching losses, the performance of the half H-bridge DC-DC is higher than that of the Cúk DC-DC converter. In comparison with a full-bridge converter, the full-bridge chopper has more components and lower system tension, but costs more than the half-bridge; this full-bridge circuit topology also requires more pulse-width modulation (PWM) inputs result from the complexity and expense of the control circuit. Using half-bridge topology implies that less space would potentially less cost [21].

2.17 Related works

Many researchers attempt to increase the EV utilization for energy storage and source besides transportation purpose; however, several researchers have been developed a charger system for the transfer of power from EV to electric power grid without the consideration of converter correlation and their efficiency.

In [12] the designed system topology was single-phase inverter with a buck-boost chopper, but they use two-loop control system with PID controller, as I have studied PID has less performance than FLC, especially for the nonlinear system. It is obvious due to the switching device ON-OFF

behavior the power system network have non-linearity. PID is not suitable for a non-linear system, in addition PID requires an exact mathematical model of the system. The researcher [12] also use voltage-mode control for DC-DC converter, VMC has complicated dynamic behavior and slow response to the current situation. I deconstruct the research and I try to redesign it with FLC with direct current control mode.

In [42] the researchers use galvanic isolation and isolated DC-DC converter type. Even though they use it for the safety purpose against electric failures, it makes the system is complicated and expensive due to additional power electronics converter. Besides this, in [42] the bidirectional inverter output synchronized with the grid voltage by using the PLL (phase-locked loop) techniques, and the current controller of DC-DC with PID. The power electronics they used were the non-buck-boost chopper and three phase inverter with a communication link system between the grid and the battery. Usually, EVs used a single-phase, if there is an aggregator the communication link is redundant. Besides, for synchronization case the chopper is better to be a buck and boost in a different case.

In [43] the researcher considers a three-phase off-board charger; the power transfer design was as an inductive wireless power transfer system (IWPT). However, the inductive power transfer system has an advantage from a safety point of view, but it has less efficiency from a power flow point of view than a contact-based system. In [39], though the system is simulated only for DC-DC and the chopper is isolated type, which is a single phase and the controller for both converters is FLC. However, using a non-isolated half H-bridge topology implies that less space would potentially less costly than an isolated one.

2.18 summary of related work

Many researchers [12] [42] [39] have done their work on V2G power system is without the consideration of a single EV charger able to transfer power for both V2G/G2V with low switching and conduction loss of switching devices. Besides most of the researchers not considered the complexity and expensiveness of the system and the filter which reduce harmonics and EMI.

In this thesis, CCM is developed for DC-DC converter since it has a simple design and implementation high reliability. Besides, FLC designed for DC-DC to minimize the error, and level the current supplied for the bidirectional DC-DC converter for the determination of system

charging and discharging conditions. FLC is simple and efficient for a non-linear system and FLC does not require any exact mathematical model of the system. SPWM controller also applied to bidirectional AC-DC converter, due to its simplicity for pulse generation. In general, in this thesis, a two-stage non-isolated bidirectional EV charger used to transfer energy from EVB to grid and from the grid to EVB is developed. For the first AC-DC stage SPWM controller and the second DC-DC buck-boost chopper stage FLC controller by direct current control technique applied, LCL filter inserted between the inverter and AC grid to satisfy the IEE 519 THD standard.

CHAPTER THREE

SYSTEM CONTROLLING MODELE

3.0 Introduction

In this topic, I try to discuss about theoretical backgrounds and current state of knowledge on controller topics related to the study. In addition, this portion tries to state about controllers, used to control bidirectional DC/DC, AC/DC power converter, within their advantage and disadvantage. The chapter tries to survey, analyze and present papers published by accredited scholars and researchers focusing on control system used in V2G/G2V as a system and AC/DC and DC/DC as a part of a system, the selected fuzzy logic controller, and SPWM controller are discussed deeply.

3.1 Control Strategy

The control strategies are used to control the transfer of power between EVB and electrical power grid (V2G/G2V) technology. The most common strategy design two independent converter for each stage of the charger.

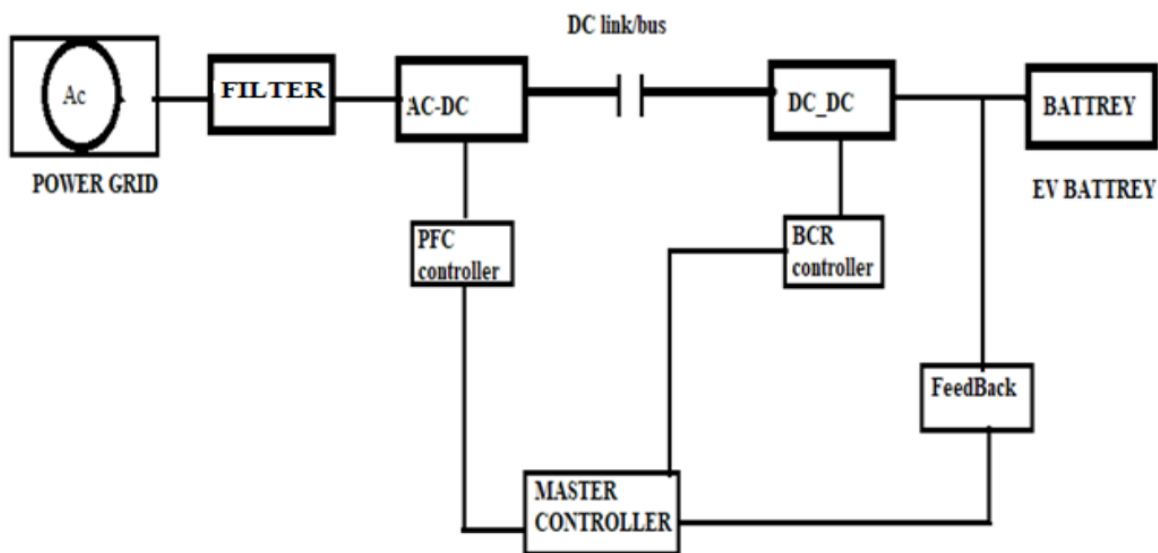


Figure 3.1: Block diagram of system with controllers

The primary focus of the thesis is to design a controlled non-isolated two-stage battery charger, as a form of Figure: 3.1. This means design an SPWM controller for a bidirectional AC-DC converter to provide current and voltage have a pure sinusoidal wave shape to the grid during V2G operation. The fuzzy logic controller that controls the error between the reference and measured battery current and level the current supplied to the bidirectional DC-DC converter to manipulate the two-way flow of battery current. In general, the FLC based DC-DC with direct control technique is used to prove the feasibility of G2V/V2G system, and SPWM controls AC/DC to ensure the proportionality between the voltage from the battery and grid voltage with in better power factor correction [4].

3.2 The AC/DC (PFC) controller strategies

In this thesis, the bidirectional AC/DC converter have used to match the DC voltage from the battery with the AC power grid. The single-phase bidirectional AC-DC/DC-AC converter is a multi-function converter, which is used to power factor correction AC port and second-order harmonic ripple power removal at the DC bus in this thesis, the SPWM technique used to control the Bidirectional AC/DC converter. SPWM technique can be either unipolar or bipolar [24].

3.2.1 Pulse width modulation

Two signals are contrasted in SPWM. The modular sinusoidal reference signal and triangular carrier wave . Gating pulses are produced through comparing the two signals, and the width of each pulse changes based on the amplitude of the sinusoidal waveform. The frequency and the amplitude of the sinusoidal signal shall determined the inverter output frequency and regulated modulation index and the rms value of the output voltage [15]. however, In order to obtain a pure sin wave, the signal must pass through a LCL filter. Some of the reasons for selecting an inverter based on SPWM are as follows :-

- ✓ Lower power loss switched circuits appear to have either lower power consumption since switching devices are off or hard-on [15].
- ✓ In SPWM – signals are very easy to generate and suitable linearity of voltage control [15].
- ✓ Enable low amplitude of low order harmonic output voltage to reduce harmonic current content 15].
- ✓ Reduced switching losses in converter switches [15].

- ✓ Enable enough time for better operation of converter switches and regulation system [15].

Based on the above listed character and advantage, SPWM are selected to control the AC/DC converter. But still needs to analysis and compare which types of SPWM have better fitness for this work, so selecting the which type of SPWM are better for the proposed system is another question which require some study. In order to select the better one I had make some literature review.

A) Bipolar modulation

Thus, in bipolar modulation, we consider two independent signals V_{g1}/V_{g3} that are produced by comparing the sinusoidal modulating wave V_m and carrier wave V_{cr} . The inverter terminal voltages are produced by V_{an} and V_{bn} and the inverter output voltage $V_{ab} = V_{an} - V_{bn}$. The upper and lower switches in the same inverter leg operate in a complementary manner with one switch on and the other switch off. Because the V_{ab} waveform switches between positive and negative DC voltages, this scheme is called bipolar SPWM [15].

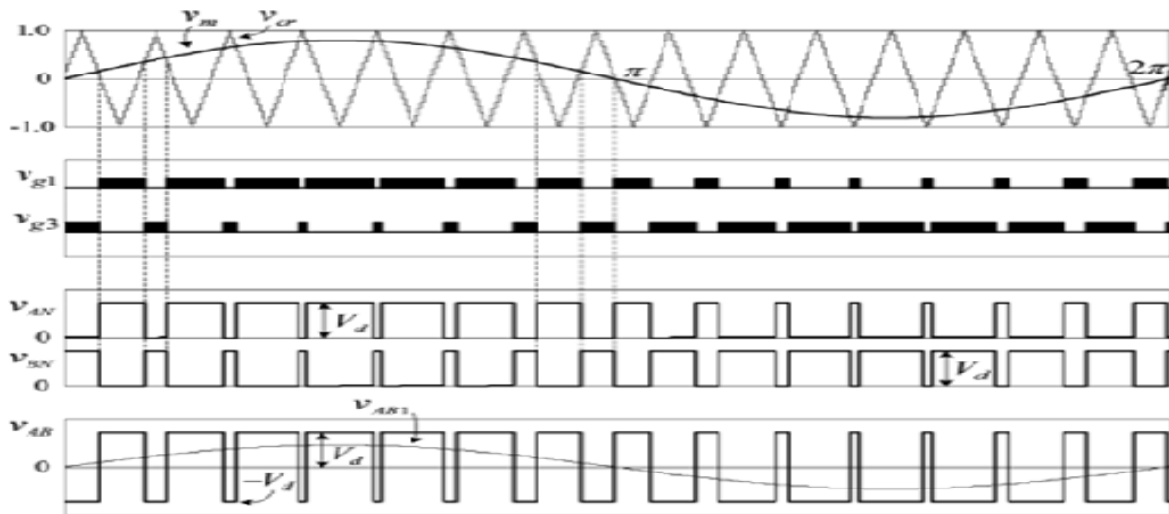


Figure 3.2: waveform of bipolar modulation [15].

B) Unipolar modulation

Unipolar modulation typically requires two sinusoidal modulating waves $+V_m$ and $-V_m$ with same magnitude and frequency as the 180-degree phase difference. The two modulating waves are

compared to the common triangular carrier wave V_{cr} to generate two gating signals V_{g1} and V_{g3} for the upper two switches G1 and G3 [15].

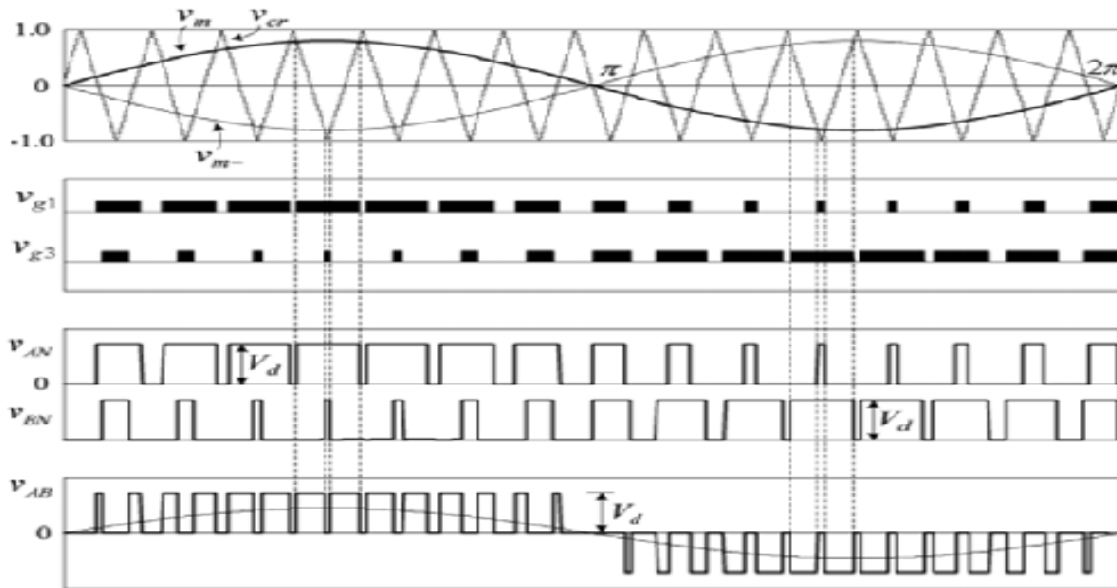


Figure 3.3: waveform of unipolar modulation [15]

The unipolar switching AC-DC converter gives reduced switching losses and produces less electronic magnetic interference (EMI). On the grounds of efficiency, the unipolar switched inverter has an advantage more than the bipolar one. It induces a reduction in the number of pulses on the line to the line voltage waveform leading to the formation of lower-order harmonics. Besides, the size of the notch and the pulse in the middle of the positive and negative half-cycle tend to disappear [15].

Based on the above advantage of the unipolar over the bipolar, in this thesis, the unipolar SPWM is used to monitor the grid-connected bi-directional AC/DC converter.

Principle of operation the unipolar SPWM

It can be seen that which varies from the bipolar PWM, the two upper devices do not switch at a time, where all four devices are switched at the same time. In unipolar modulation, the inverter output voltage switches between zero and positive V_d , while the positive half-cycle or between zero and negative V_d during the negative half cycle of the fundamental frequency [15].

3.3 The DC-DC controlling strategies

The generalized control system for DC-DC chopper is seen in the Figure:3.4. The controller can be either linear, non-linear or intelligent, depending on the desired steady state and dynamic output for any particular application. PWM generator generates the well-modeled pulse in order to activate switching devices in the converter a to obtain controlled DC output [16].

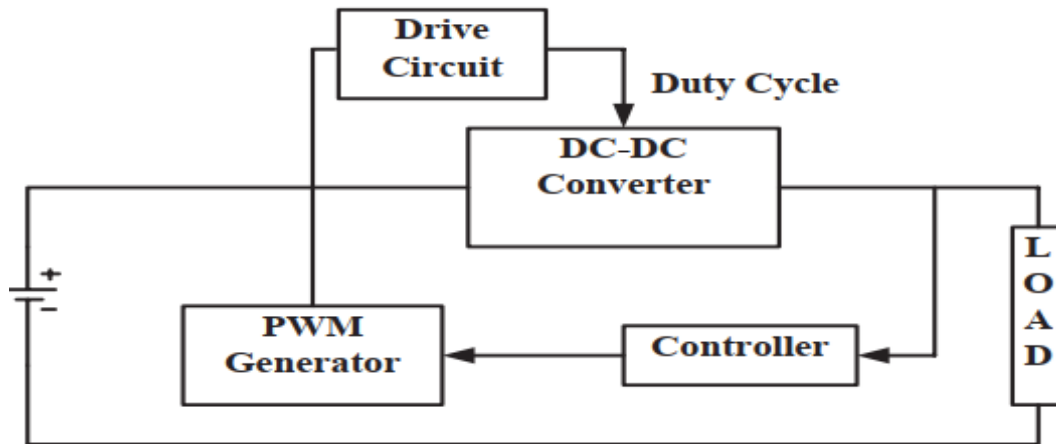


Figure 3.4: control block of DC-to-DC converter [16]

3.4 Voltage Mode Control (VMC)

The DC-DC chopper output voltage compared with the fixed reference voltage and the resulting error signal transmitted to the compensator to produces a carrier signal. A PWM is produced pulse for comparison, to monitor the performance of the converter. As seen in Figure 3.5, this referred to as single loop voltage-mode control [16].

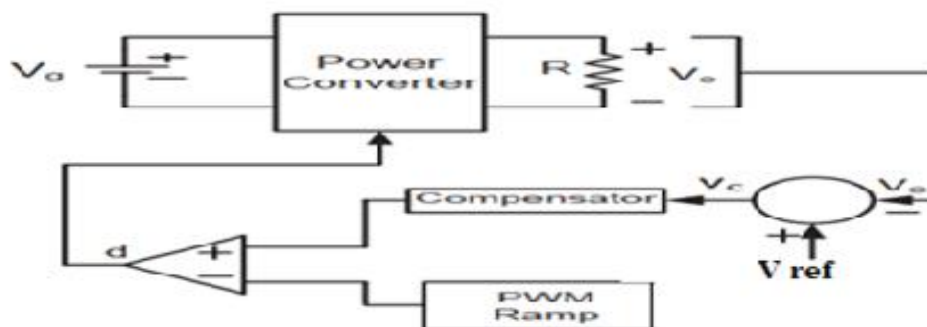


Figure 3.5: Voltage mode controlled dc-dc converter [16]

Advantages:

- ✓ Strong immunity to disruptions in reference input[16].
- ✓ Easy to simplifying compensation network[16]
- ✓ Can be used to monitor two or more parallel outputs at a time[16].

Disadvantages:

- ✓ Load changes are first detected as the output voltage shift and then monitored by the feedback loop, this making the device is slow[16].
- ✓ The slow response to the current situation[16].
- ✓ Complicated dynamic behavior[16].
- ✓ If the compensation is created by using filters, the gain of the loop often varies with the variance of the input voltage[16].

3.5 Current Mode Control (CMC)

Current mode control method overcomes the drawbacks of the voltage mode controller, such as the variation of the loop gain is independent from the variation of the input voltage. In addition, this technique makes it simple to apply the adaptive voltage positioning control, it's one technique used to control the output voltage[16].

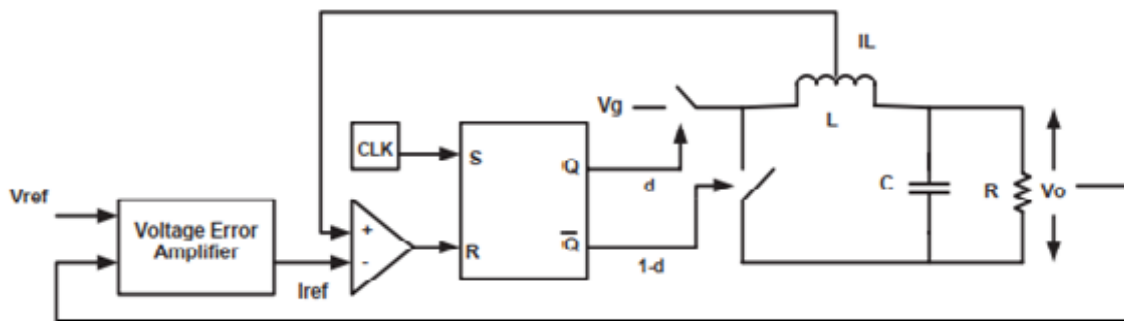


Figure 3.6: current mode control of DC-DC [16]

Advantages:

- ✓ simple to design and implementation[16].
- ✓ High reliability.

- ✓ Periodical current sensing provides protection against short circuit and overload as well.
- ✓ Instant response to input voltage changes [5].

Disadvantages:

- ✓ critical assessment due to two feedback loops.

3.6 Types of Controller

3.6.1 Proportional integral derivative (PID)

PID controller is a linear controller used to control DC-DC chopper based on feedback loop system. In industrial applications it's the most used controller due to its simple design [16].

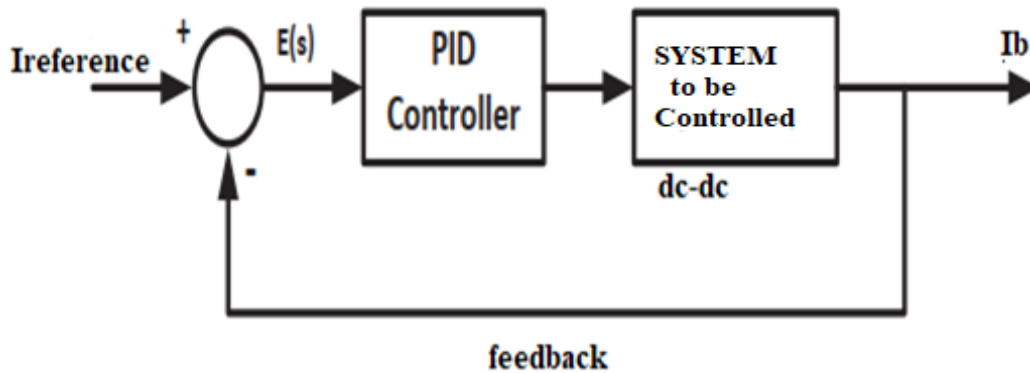


Figure 3.7: PID controller of DC-DC converter [16]

Advantages:

- ✓ simple construction.
- ✓ ease of implementation.

Disadvantages:

requires accurate mathematical modeling of the system to ensure a consistent and effective controller [16].

- ✓ Unappropriated for non-linear, higher order and time-delayed systems [16].
- ✓ Modeling is very difficult in the case of non-linear or large systems[16].
- ✓ It requires careful system modeling to controller tuning [16]
- ✓ It does not give a strong, large-signal transient[16].

3.6.2 Sliding Mode Controller (SMC)

SMC consists of two steps, first, the design of a balance surface; so that every state trajectory of the plant is limited to a sliding mode surface characterized by planned behavior, second the design of a discontinuous regulating rule push the system to move on a sliding mode surface at a finite time [16].

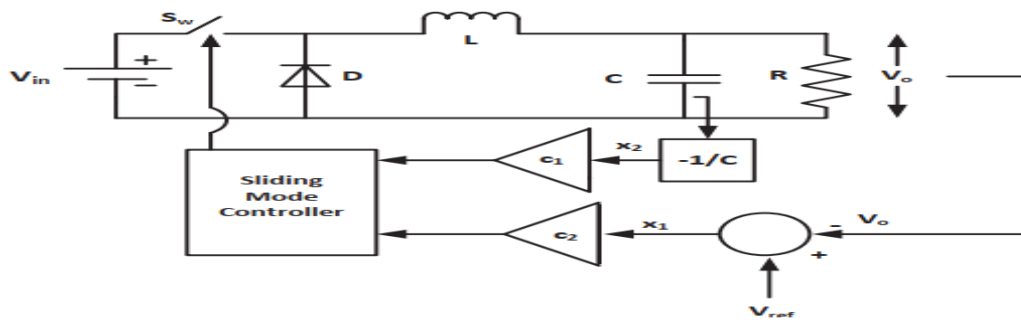


Figure 3.8: sliding mode control of DC-DC converter [16]

When x_1 is a voltage error, x_2 is a voltage error dynamic, c_1 , c_2 are sliding coefficients. Sliding mode regulation has number of merits and demerits.

Advantages:

- ✓ Stable and reliable with a strong dynamic response[16].
- ✓ Easy implementation, even for broad supply and load variations[16].

Disadvantages:

- ✓ Generally it suffers from switching frequency variation[16]
- ✓ steady-state errors could even affect controlled variables
- ✓ Difficult for proper control parameters selection because of the ambiguity of the sliding-mode control [16].

3.7 Fuzzy logic controller

Fuzzy logic scheme defines the process control operation in terms of basic 'if-then' rules. In the case of a fuzzy logic system, the control action is decided by evaluating a set of basic linguistic rules. The design of the rules requires a detailed understanding of the system to be regulated, but

does not require any mathematical design of the system A general fuzzy logic controller block diagram for dc-dc converters is shown in Figure 3.9 [16].

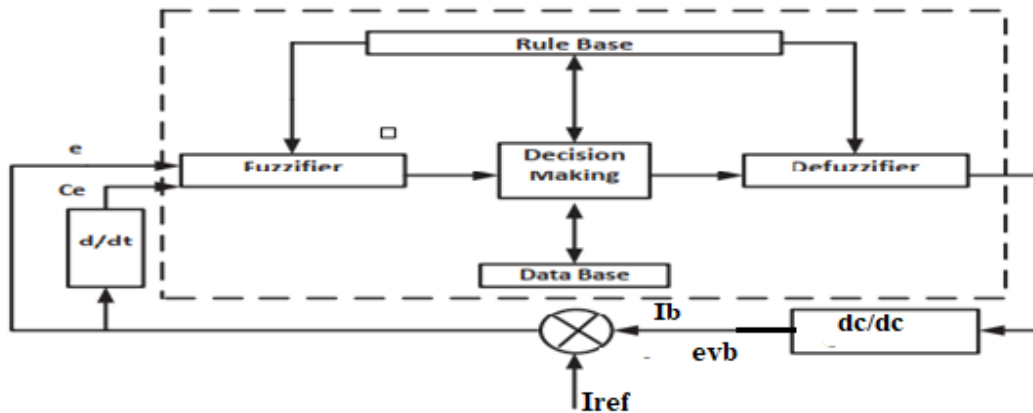


Figure 3.9: Fuzzy logic control of DC/DC controller [16]

Advantages:

- ✓ has a smoother and quicker answer with less control Complexity[16].
- ✓ enhances system dynamics with a better transient and robust response[16].
- ✓ Can be applied to several DC-DC converters by tuning the appropriate scale factors for the specified topology and parameters[16].
- ✓ It does not need an accurate mathematical model but based on the basic human thought and linguistic variables[16].
- ✓ It can manage nonlinearity with imprecise inputs [16].
- ✓ It is robust, versatile and can be used for congestion with other traditional control systems[16].

Disadvantages:

- ✓ It require professional knowledge about fuzzy logic to design the controller [16].

3.7.1 Motivation for using flc

Because of the on-off character of switching device, power network system retain non-linearity, Fuzzy logic is better for nonlinear system. However, in most case possible to get the same product without a fuzzy logic controller, but the fuzzy is quicker and cheaper. In general, in addition to the

advantages of FLC and the disadvantages of other controllers already mentioned above, fuzzy logic is a simple control method used to solve problems mostly with behavior of the power system network [3].

3.7.2 Fundamentals FLC

Fuzzy logic is a type of AI and deals with the design of computer programs on the basis of the nature of human thought and human intelligence, because human thinking are not type of crisp but it's uncertain, or fuzzy. Fuzzy logic is closer to how people identify things, and uses terms rather than numbers to identify variables. It allows for more flexibility and precision when explaining a variety of complex systems. Generally, people do not identify concepts such as quality, strength, and failure in specific terms. Rather, most definitions are defined in vague and imprecise terms. When it comes to classical set theory, a statement is either true or false, which refers to the logical value of one and zero. This is why it is unable to manage such human concepts as false being classified into categories ranging from quite false to not quite false [3].

The basic characteristics of fuzzy logic:-

- ✓ fuzzification.
- ✓ Facts are interpret as a collection of fuzzy constraints on a collection of variables.

The major elements of fuzzy logic can be sum arise as follows.

- ✓ Fuzzy sets
- ✓ Membership function
- ✓ Fuzzy rules
- ✓ Fuzzy inference system

3.7.3 The fuzzy logic main components

In general, the FLC consists of four main components, the fuzzification stage, the inference (rule base) stage, the defuzzification stage and, finally the output stage. The fuzzification stage converts binary logic inputs to fuzzy variables, while the defuzzification stage converts fuzzy variables to binary logic outputs. All this conversion is achieved by means of a membership function[3].

3.7.4 Fuzzy sets

Normal sets have specified groupings, everything is either included or removed, which means that the set membership values are either "1" or "0." However, fuzzy sets are not described in this way; instead, they belong to a range of values between zero and one indicating the degrees to which the value is included in the set [12].

3.7.5 Membership functions

A membership function is a curve that determines inputs and outputs as a membership degree. The form of the function depends heavily on the type of problem and its input, as well as on the experience of the logic designer. However, the curve just ranges from "0" to "1." If a membership function has been develop, fuzzy rules are then structured to make a decision on output results [3].

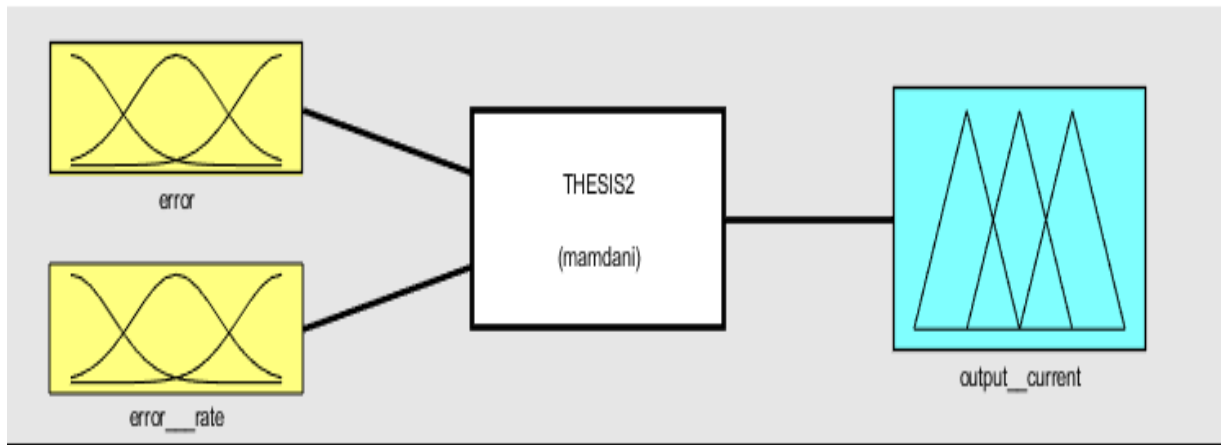


Figure 3.10: Membership function

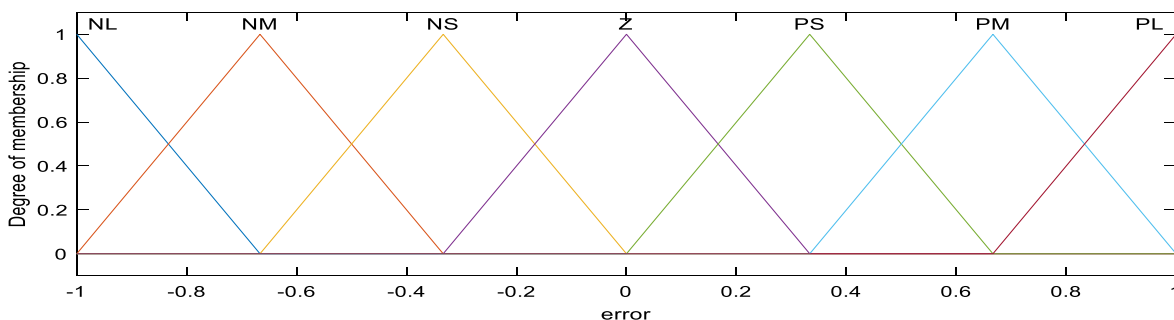


Figure 3.11: Error membership function

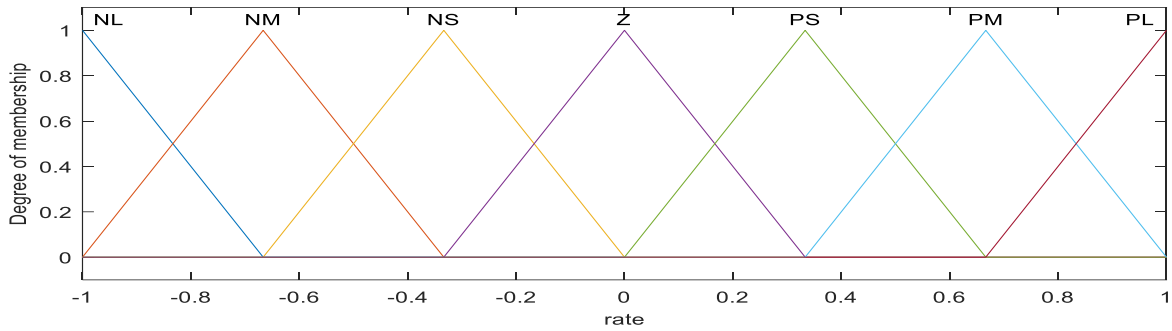


Figure 3.12: Error rate membership function

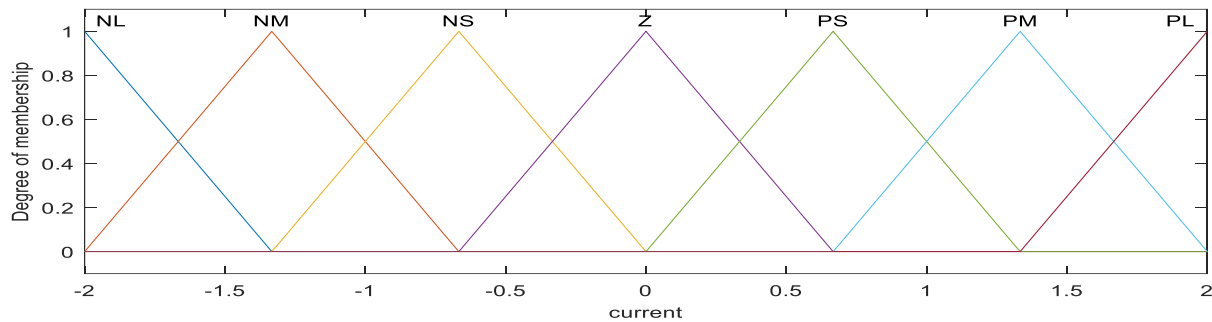


Figure 3.13: Output membership function

3.7.6 Fuzzy rules

The fuzzy rule or "if-then rule" is a basic concept of fuzzy logic based on the user's intuition of the actual application. When the fuzzy rules are defined, the system outputs will obey the user's description. As a result, outputs are adequate and acceptable as long as the system information is correct [3].

3.7.7 Inference system

Fuzzy inference system is the process of mapping the given input to the output using a fuzzy logic. There are *Mam dani* and *sugeno* type of fuzzy inference system. The Fuzzy inference method (fis) used for this thesis is a *mam dani* type [3].

3.7.8 Defuzzification

Defuzzification is the process of converting a fuzzy variable into numeric values that is finally done in order to obtain outputs that are practically meaningful [3].

3.8 System Controlling Strategies

3.8.1 Battery Current Regulation (BCR)

In this thesis, the FLC based direct current control method is applied to the half H-bridge DC-DC converter to determine the bidirectional power flow in V2G/G2V scenario as shown in Figure 3.14 and Figure 3.15. The controller initially compares reference battery current and measured battery current for deciding the controller's next move. In charging mode, the error between calculated battery current and reference current is detected and computed, this error passes through the Fuzzy logic-tuning controller. The output of the FLC controller will be used to produce pulses using the pulse width modulation technique. The pulses produced at this stage are used to activate MOSFET-1. Throughout the charging process, MOSFET-2 is switched-off. For the discharge mode, the controller measures error from the reference current and measured current of the battery. The FLC controller will then tune the measured error, and its output is sent to PWM to generate the required pulses to trigger the MOSFET-2. During the discharging mode, MOSFET-1 stays switched off.

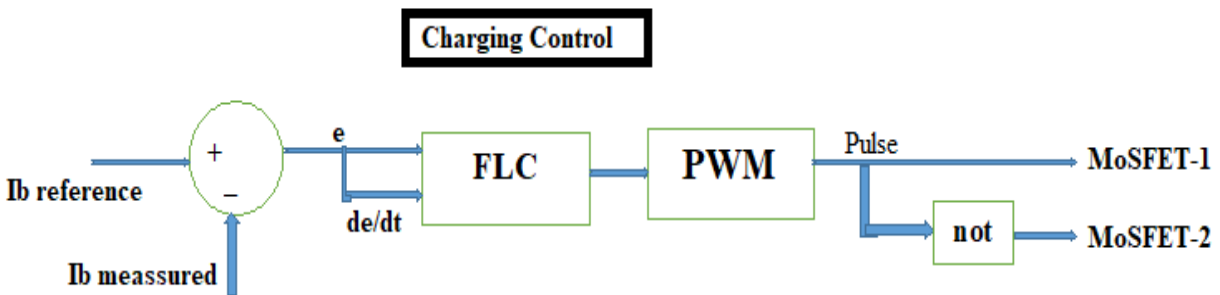


Figure 3.14: Charging controller by direct battery current strategy

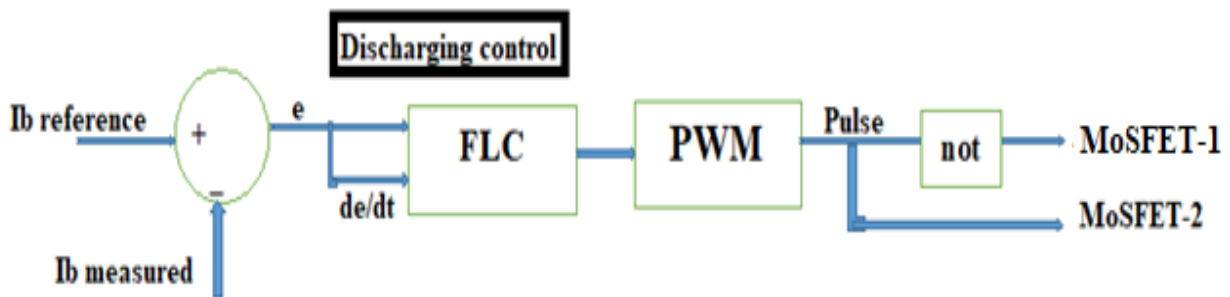


Figure 3.15: Discharging controller by direct battery current strategy

CHAPTER FOUR

MATHEMATICAL MODELING OF THE SYSTEM

4.1 Introduction

Control of single-phase power conditioning systems is usually very difficult due to the double frequency power ripple produced by the conversion of AC / DC power. The low-frequency ripple forces the designer to use a very slow control system to prevent the ripple from spreading to the control system. This challenge is particularly important when regulating the DC-bus intermediate voltage, which is used to store energy between the AC-side and the DC-side. The DC-bus capacitor serves as an energy storage capacitor and provides flexibility to alternate electrical energy between the two stages. The DC-bus capacitor is used in single-phase power conditioning systems to decouple the power ripple by supplying a low-frequency current. Due to the power ripple, the DC-bus voltage has a significant amount of double-frequency ripple. Usually, a low-bandwidth controller is used to filter out the low-frequency ripple and delete it from the closed-loop power system. Usually, a low pass LCL filter is used to reduce harmonic distortion from the inverter output inject n to the AC grid and used to comply with IEEE 519 standards [25].

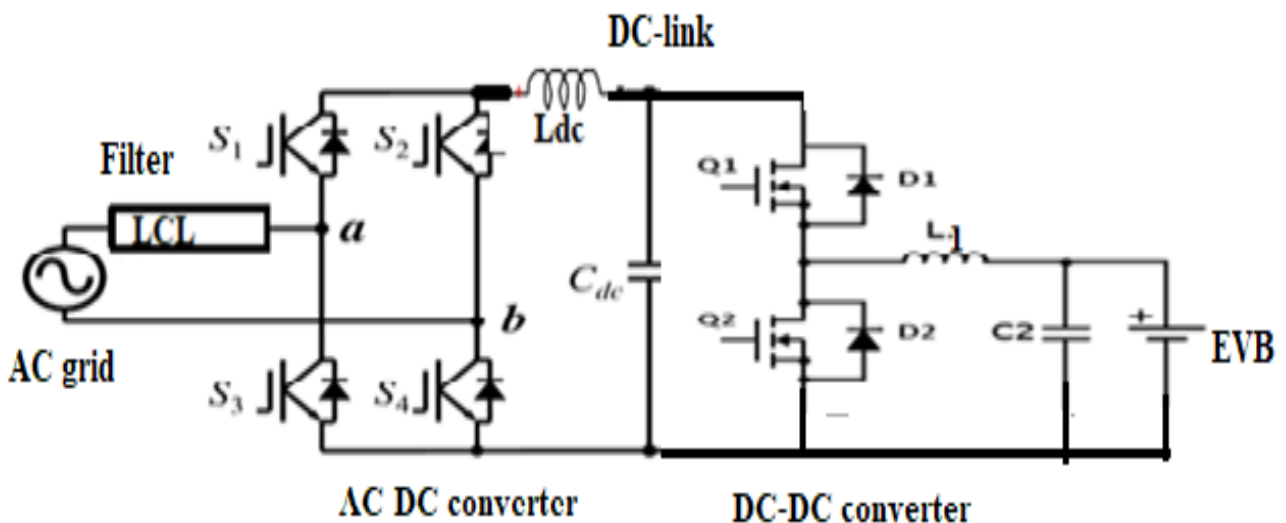


Figure 4.1: Circuit Representation of Studied System

4.1.1 Parameters for bidirectional dc-dc [6]

Given:

The low side or battery voltage

$$V_{battery} = 200V$$

The high side or Grid Voltage

$$V_{ac} = 230v/50Hz$$

Switching Frequency and Period

$$f_{sw} = 10 \text{ KHz}, T_s = \frac{1}{f_{sw}} = \frac{1}{10\text{kHz}} = 50\mu\text{s}$$

The maximum load current

$$I_{omax} = 50A$$

The minimum current in constant current mode is 10% of load current

$$I_{ccm} = 50A * 0.1 = 5A$$

The output ripple voltage

$$\Delta V_o = 1\% * 200V = 0.2V$$

The buck-boost converter operates as a step-up voltage when the duty ratio is high (around 1) and step-down when the duty ration is small (around 0).

Boost Calculations:

Critical inductance

$$L1 = \frac{D(1-D)^2}{2f_{sw}} * \frac{V_o}{I_{ccm}}$$

Output capacitance

$$C_{boost} = C2 = \frac{D * I}{f * \Delta V_o}$$

Duty Cycle

$$D = \frac{1 - V_{in}}{V_{out}} > 0.5 \quad \text{and} \quad \frac{I_o}{I_s} = 1 - D$$

$$V_s * I_s = V_o * I_o$$

Inducter current ripple

$$\Delta I_l = \frac{D(V_{in} - V_{out})}{L1 * f_{sw}} = \frac{0.5(230 - 200)}{L1 * f_{sw}}$$

Buck calculation

$$L1 = \frac{V_{bat} - V_{grid}}{2I_{cm}} * T_{on}$$

Duty ratio $\frac{I_o}{I_s} = \frac{1-D}{D} \Rightarrow I_o = \frac{1-D}{D} I_s \Rightarrow D < 0.5$

Output capacitance

$$C_{buck\ output} = C2 = \frac{\Delta V_o}{\Delta I_l}$$

$$C_{dc} = 1e - 6 \text{ and } L_{dc} = 4e - 3$$

$$V_s * I_s = V_o * I_o$$

$$\frac{V_s}{I_o} = \frac{V_o}{I_s}$$

$$V_o = \frac{V_s I_s}{I_o} \Rightarrow \frac{V_s I_s}{(1-D) * \frac{I_s}{D}} \Rightarrow \frac{D * V_s}{1-D} =$$

4.1.2 Parametere for LCL filter

The theoretical component value based on the given source

$$\Delta I_{max} = \frac{1}{n} * \frac{V_{dc}}{L1 * f}$$

The n is the factor that increases the number of waveform voltage levels. With the selected resonance frequency and, it can find the product from following equations [6].

$$Z_{lc}^2 = \frac{1}{[(L_g + L_2)cf]}$$

$$W_{res}^2 = \frac{Z_{lc}^2(L1 + L2 + Lg)}{L1}$$

In order to prevent instability, a resistor is inserted into a series of capacitors to damp the resonance generated by the filter[6]. The chosen minimum value of Rd is selected to prevent additional power loss. The transfer function is shown as follows:

$$G(s) = \frac{I(s)}{V(s)} = \frac{1}{Ls} \frac{\left(s^2 + \frac{Rd}{Lg}s + Z_{lc}^2\right)}{\left(s^2 + \frac{(L + Lg)Rd}{L}s + W_{res}^2\right)}$$

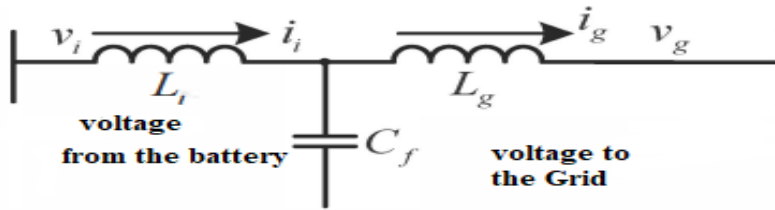


Figure 4.2: an LCL filter connected between bidirectional ac/dc converter and the grid.

Calculated: LCL filter for minor harmonics is shown below

$$V_{dc} = \sqrt{2} * 142 \text{ rms} = 200V_{pp}$$

The hysteresis-band is 10% of the current

$$h = 10\% * I = 10\% * 50A = 5A$$

The maximum f_{sw} 15 kHz.

$$L_{min} = \frac{V_{dc}}{8 * h * f_{max}} = \frac{170V}{8 * 5 * 15KHz}$$

$$Z_{bas} = \frac{V}{I} = \frac{142}{50} = 2.84\Omega$$

$$LD = L1 + L2$$

$$Ld = \alpha * L_{min}, \alpha \leq \frac{0.1(pu)}{L_{min}(pu)}, \alpha = 1.3$$

The resonant frequency will be affected by the capacitor value as it can be shown in the equation below

$$Q = \frac{1}{R} * \sqrt{\frac{L1}{C}}$$

Pick $C = 400\mu\text{F}$ & resonant frequency = 10kHz

$$m = 2\pi(10\text{KHz}) * \sqrt{Ld * Cpick}$$

$$k^2 - (m^2)m + 1 = 0$$

Solve for K, m from the above equation

$$L1(1 + K) = Ld,$$

We have Ld and K we can get L1

$$\frac{L2}{L1} = K, \quad L2 = L1 * K$$

When capacitor comes with internal resistance it calculated as follows

$$Rd = \frac{1}{2} [fres * c * \pi], Rd = \frac{1}{2} [10\text{KHz} * 400e - 6 * \pi]$$

Component	Specification
Battery side inductor (L1)	200e-4H
Battery side capacitor(C2)	400μF
DC link capacitor (Cdc)	5μF
DC link Inductor (Ldc)	5e-3H
Grid AC Voltage	230V
Battery DC voltage	200V
Filter inductor $L_i=L_g$	0.007H
Filter capacitor C_f	1e-3
Switching frequency	10KHz
Grid side load resistance	100Ω

Table1:-Design Component Specification for the system

CHAPTER FIVE

RESULT AND DISCUSSION

5.1 G2V Operation

As it shown in Fig.5.1 (the detailed Simulink model shown in appendix), in order to verify the effectiveness of the proposed control algorithm, and the feasibility of the system, the simulation model for energy transfer from the vehicle to grid and from the grid to vehicle system has develop in MATLAB Simulink block. MATLAB Simulink block consists, single-phase bidirectional AC-DC converter, a half-bridge DC-DC converter, and controller for each system. After conducting the simulation on MATLAB Simulink, discussion about the result will provide.

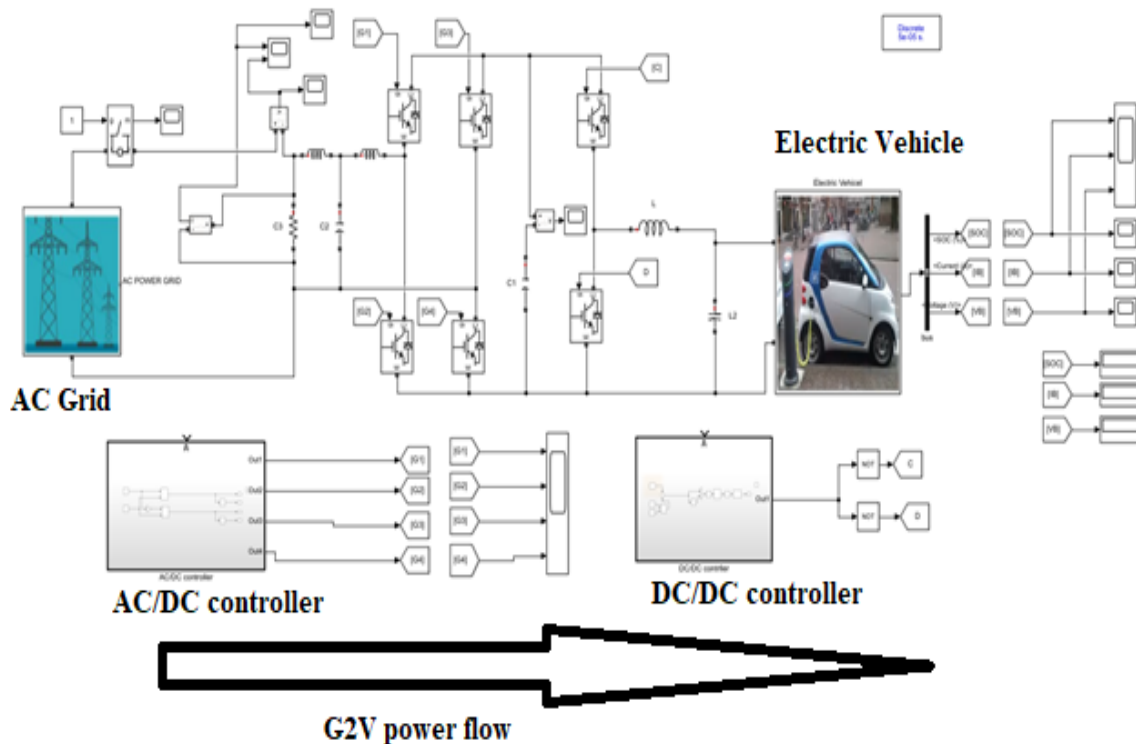


Figure 5.1: Simulink diagram for G2V operation

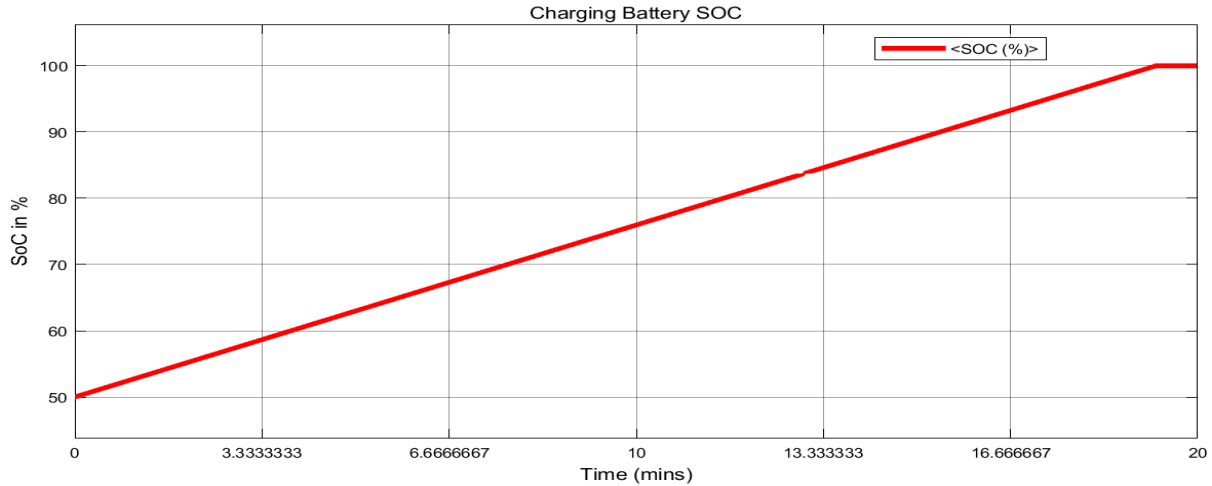


Figure 5.2: Battery recharging process SOC-time curve

The battery state of charge (BSOC) is the main parameter for V2G/G2V system. It expresses the percentage of charge remaining in the battery. Figure 5.2 shows percentage of BSoC in the charging condition, how the battery percentage of charge increase through the time change from 50% SoC to 100% SoC for 35Ah battery. In G2V operation the SoC of a battery linearly increases, which indicates the battery gain additional charge (capacity) from its initial state of charge by designed charging techniques.

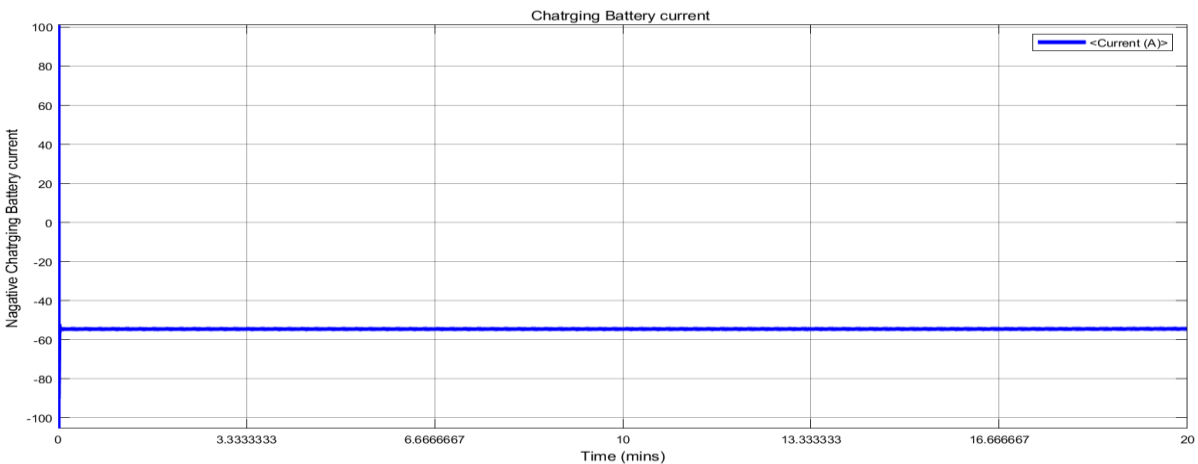


Figure 5.3: Negative charging battery current

The charging-discharging curve is a plot of cell voltage and current versus time duration, it is an electrical characteristics curve used to define the charging/discharging voltage and current across

the battery terminal. Figure 5.3 show the constant negative terminal current of 35Ah charging battery. The negative direction mention that the power flow direction is from grid in to the battery.

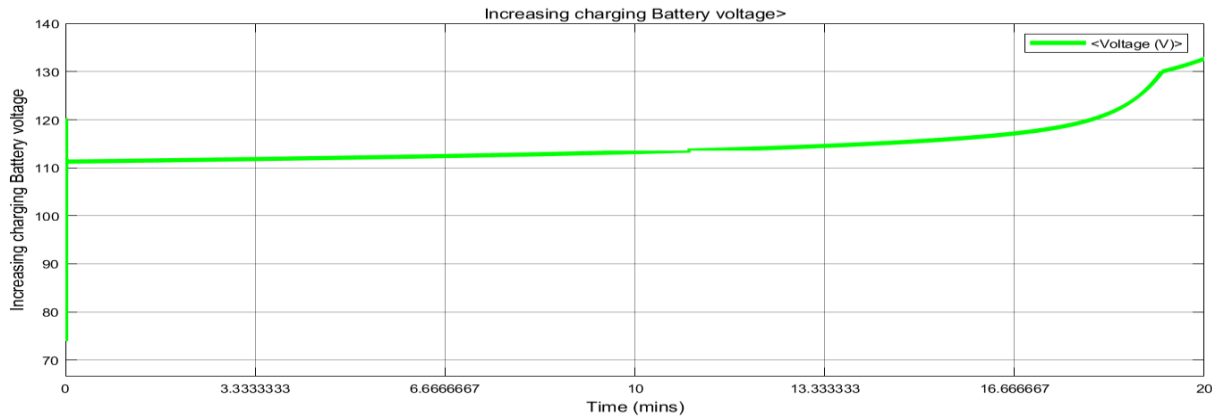


Figure 5.4: Charging battery terminal voltage curve

Figure 5.4 show how the battery terminal voltage behave for the charging 35Ah capacity battery. The battery charging through build-in resistance compensated (BRC) charging technique followed by constant current (CC) technique. The voltage and current characteristics curve depends on the battery designing specification like nominal voltage, maximum cutoff voltage and the selected charging algorithm.

The average current of the battery can be determined from the time it takes to full the battery 50% SoC to 100% SoC and the nominal capacity (accumulated charge) of the battery. In this case battery capacity is 35Ah, as it seen from figure 5.2, the time taken to charge the battery from 50% to 100% SoC approximately 18.5 minutes.

$$I = \frac{Q}{t}$$

$$I = \frac{\frac{1}{2} * CAh}{t} = \frac{\frac{1}{2} * 35Ah}{18.5 \text{ min}} = 35A * \frac{\frac{1}{2} * 60min}{18.5min} = 57A$$

To compare and validate how battery charging time and battery current rating is depend on the battery capacity, I have conducted simulation for 1.5Ah battery for the full state of charging from 0% SoC to 100% SoC. In addition, V2G operation will have done on this battery specification, because the electric vehicle battery pack is made-up of several dry cell batteries that have such a kind specification.

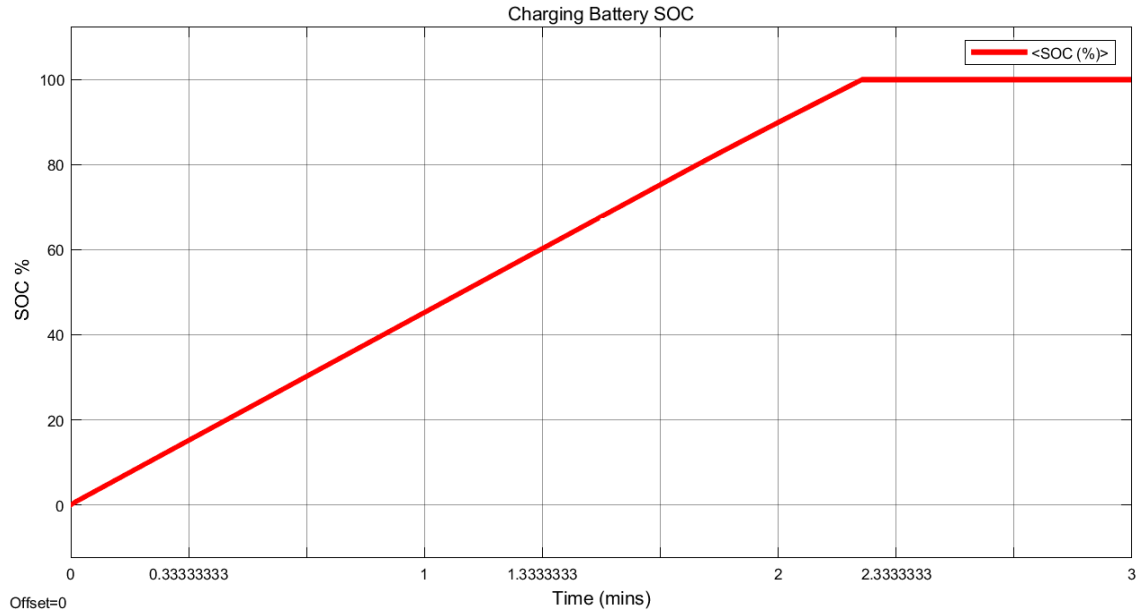


Figure 5.5: Battery recharging process SOC-time curve

Figure 5.5 shows percentage of SoC in the charging condition and the time taken to charge this battery from 0% SoC to 100%SoC for 1.5Ah battery. In G2V operation the SoC of a battery linearly increases, which indicates the battery gain additional charge from its initial state of charge by designed charging techniques.

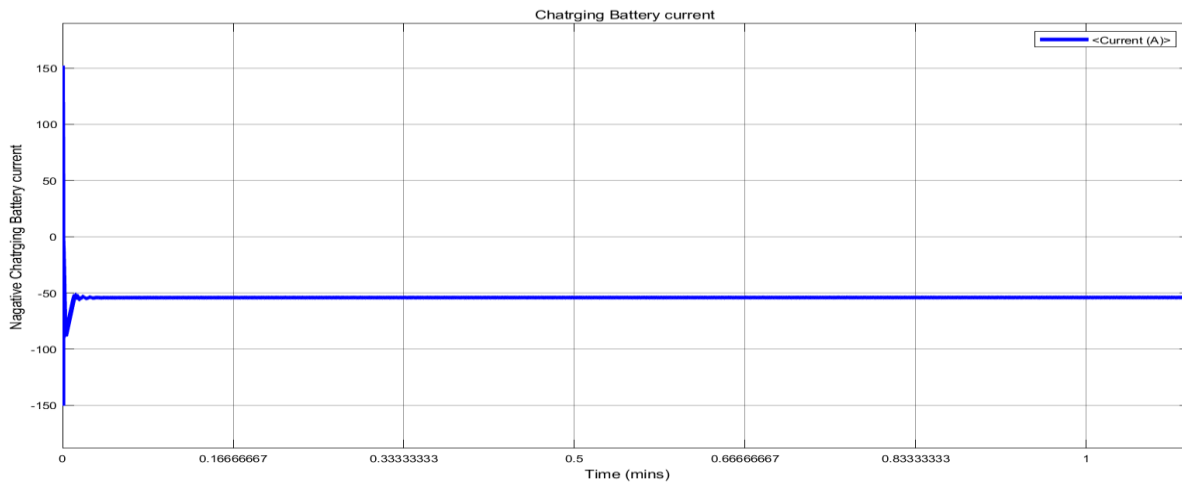


Figure 5.6: Negative charging battery current

Figure 5.6 show the constant negative battery terminal current for 1.5Ah charging capacity. The current curve indicate the battery designing specification and the selected CC charging algorithm. The negative direction mention that the power flow direction is form grid in to the battery.

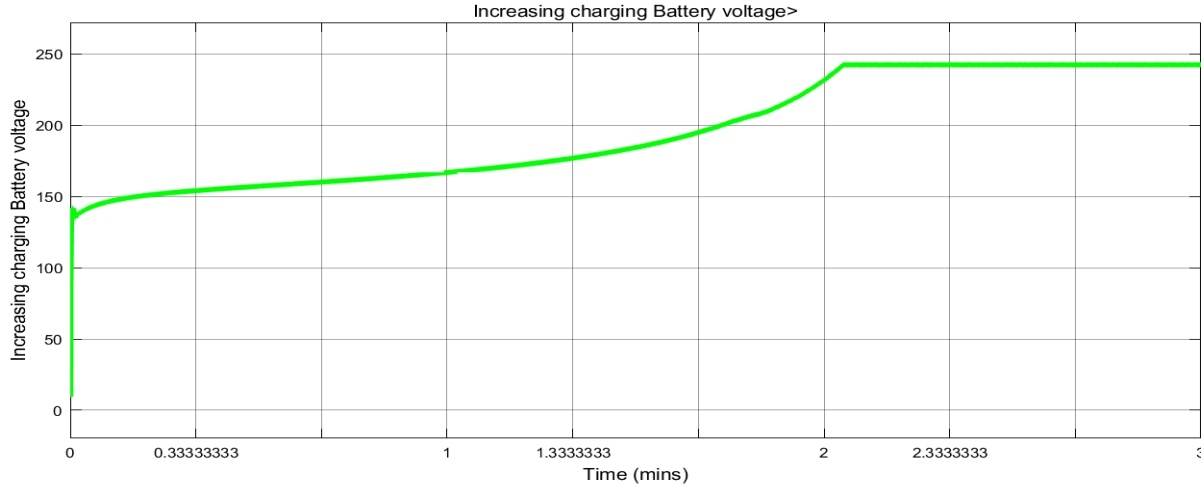


Figure 5.7: charging battery terminal voltage curve

Figure 5.7 above show that the battery terminal voltage for 1.5Ah battery capacity, it indicated how the charging battery terminal voltage behave through a time change, and it depends on the battery nominal specification like maximum cut off voltage, nominal voltage, and the selected charging algorithm. There are different charging techniques like CC, CV, CC-CV, BRC, and floating, each technique has its own merit, demerit, current, and voltage characteristic curve. For this case, charging mechanism seems BRC-CC, because in BRC, the voltage reaches its maximum at a short time and the battery is charge with a high current at a high voltage, due to this, the lifetime of the battery may affected adversely.

The average current rating can determined as follows. Here approximately 2.2 minutes is the time take to charge the battery from 0% to 100% SoC.

$$I = \frac{Q}{t} = \frac{CAh}{t} = \frac{1.5 Ah}{2.2 min} = 1.5A * \frac{60min}{2.2 min} = 41A$$

For better energy density accumulation, charging a battery for a long time by a small current is better than charging a battery for short time by a large amount of current. From this scenario, the first battery can store better energy at the same percent of SoC and the same charging time. However, this thesis has trying to validate a bidirectional power transfer between the EVB and power grid, from the current direction and percentage of battery SOC. The specification design of battery voltage, battery current and charging mechanism are beyond the realm of the thesis.

5.2 V2G Operation

Simulation also conducted for V2G operation to ensure two-way power flow. In this thesis, a two-stage non-isolated bidirectional EV charger used to transfer electric power from AC grid to EVB and from EVB to AC grid, while keeping power factor correction and THD reduction, are designed and validated through MATLAB Simulink based experiment. FLC based bidirectional buck-boost DC-DC is used to charging/discharging of EVB, and the low pass LCL filter inserted between the grid and inverter to reduce THD. Figure 5.8 below show the Simulink block and the V2G power flow direction

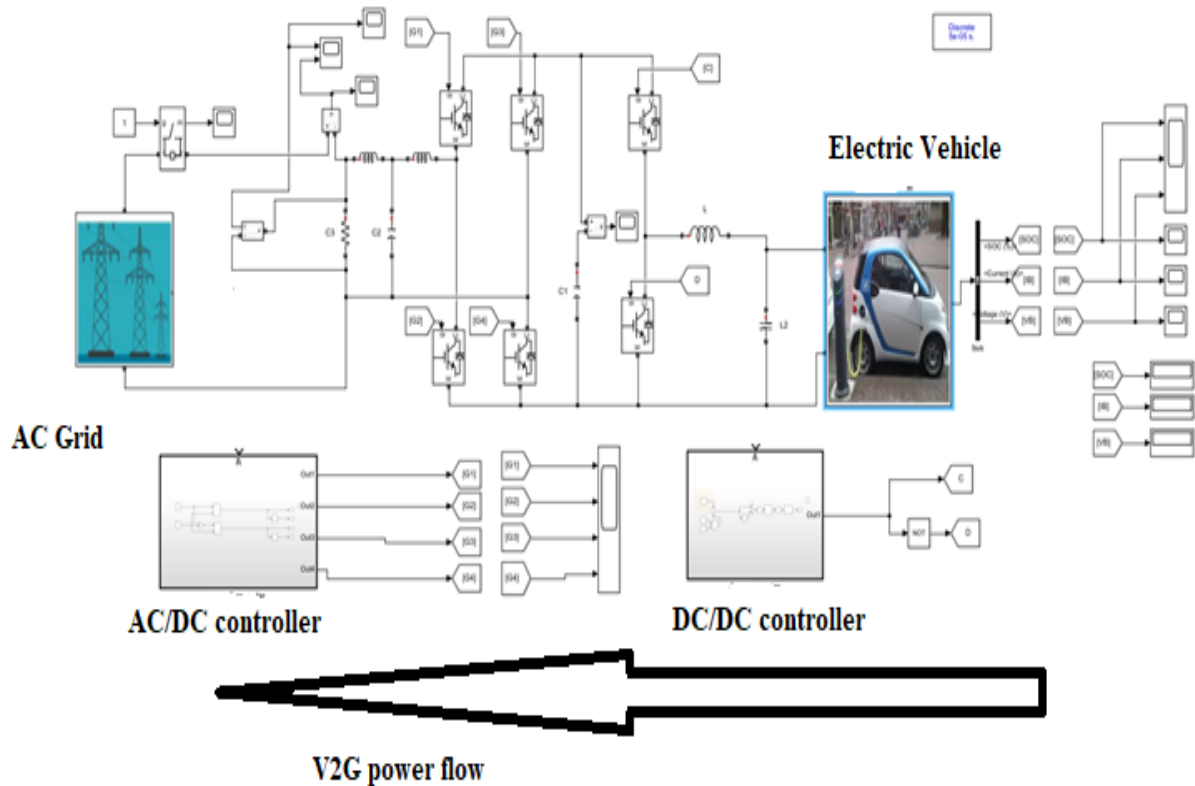


Figure 5.8: Simulink diagram for V2G operation

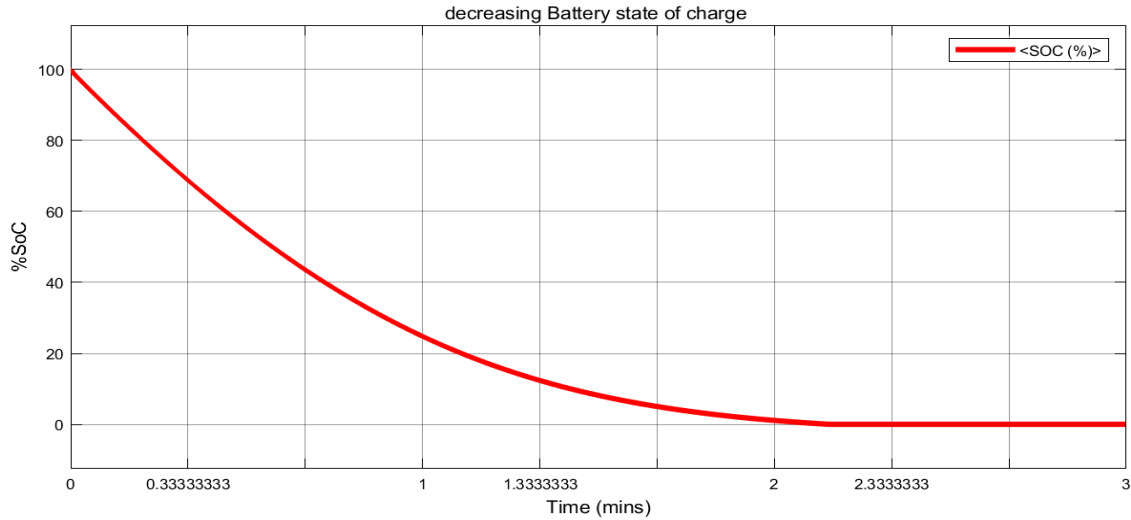


Figure 5.9: Battery SOC in V2G operation (discharging)

Figure 5.9 show how percentage of charge in the battery is decreased from its initial percent of state of charge, which means, the SoC versus time curve indicate how the battery discharge effectively through the time change. However, the battery continuing draining the current after its SoC getting to zero, this phenomenon known as over-discharging. Plug-in charger after the battery SoC getting to zero leads to over-discharging. Over discharging, has its own negative effect on the battery like permanent damage of active component due to the corrosion of the current collector. That is why most battery manufacturer recommends avoiding fully discharging/charging the battery to the long battery life cycle.

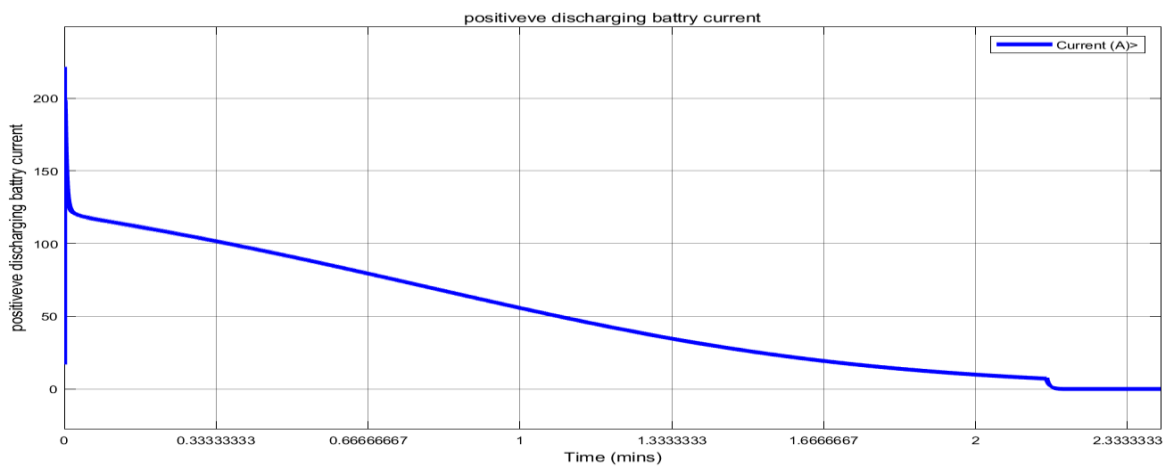


Figure 5.10: Discharging positive Battery current

Figure 5.10 current versus time curve shows the positive discharging battery terminal current. The direction of the battery terminal current indicate the power flow is out from EVB to the grid, it is opposite from current direction of G2V operation.

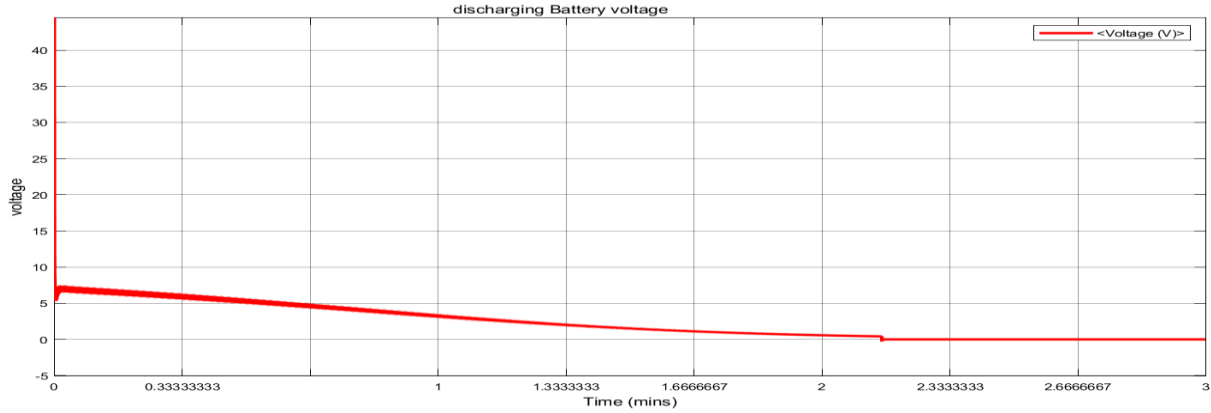


Figure 5.11: Minimum discharging Battery terminal voltage

Figure 5.11 show that the discharging battery terminal voltage of 1.5Ah battery, discharging the battery with Build-in Resistant Compensation (BRC) technique is make the voltage reaches fast to its minimum cutoff voltage and the current decreases from time to time until the percentage of SoC equal to zero percent.

In general, the simulation result from figures 5.3, 5.6, and 5.10, the opposite sign of the current indicated the bidirectional power flow capability of the charger, for the battery charging /discharging mechanism. The discharging rate is given by the battery capacity (1.5Ah) divided by the time it takes to discharge the battery. The battery capacity is 1.5Ah, as it shown, Figure 5.9 the time taken to full discharge battery from 100% SoC to 0% SoC is approximately 2 minutes. Mathematically can express as follows:-

$$Q = I * t, \text{ energy capacity by Ah}$$

$$t = 2 \text{ min}, Q = 1.5 \text{ Ah}$$

$$E = Q * v, \text{ energy density by Wh}$$

$$I = \frac{CAh}{t} = \frac{1.5 \text{ Ah}}{2 \text{ min}} = 1.5 \text{ A} * \frac{60 \text{ min}}{2 \text{ min}} = 45 \text{ A}, \text{ is average terminal current of the battery}$$

To calculate the discharging power from 1.5Ah battery is

$$P_{\text{discharge}} = V_{\text{nominated}} * I_{\text{discharge}}$$

$$I_{\text{discharge}} = \frac{C}{T}$$

$V_{\text{nominated}} = 200V$, and $C = 1.5Ah$ capacity of the battery

$T =$ the total life of the battery from battery specification

In general, in V2G operation, the main question is how we can inject a pure sinusoidal voltage and current with a better power factor correction to the power grid. However, in this thesis the question answered based on the following figure.

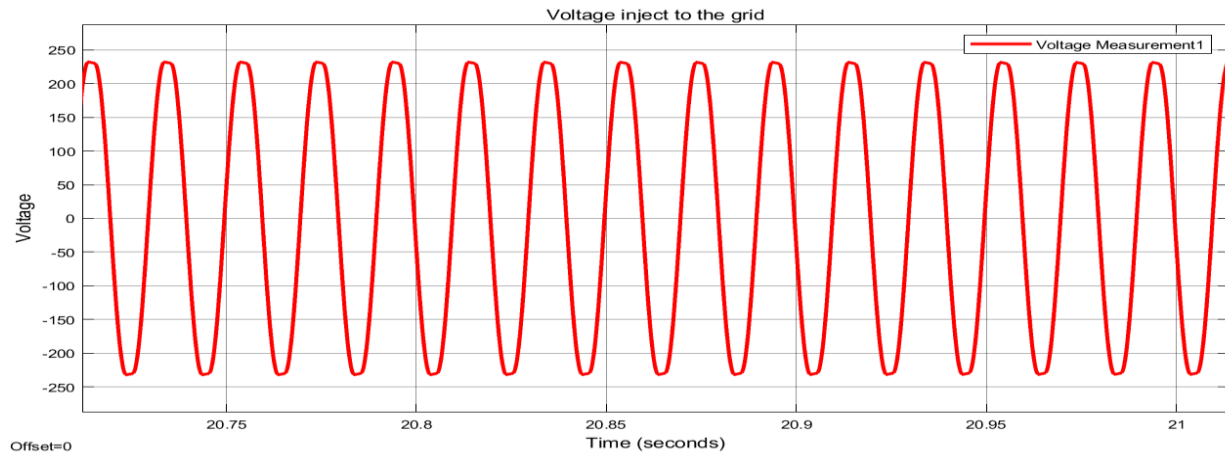


Figure 5.12: Inverter output voltage from EVB to the grid (V2G)

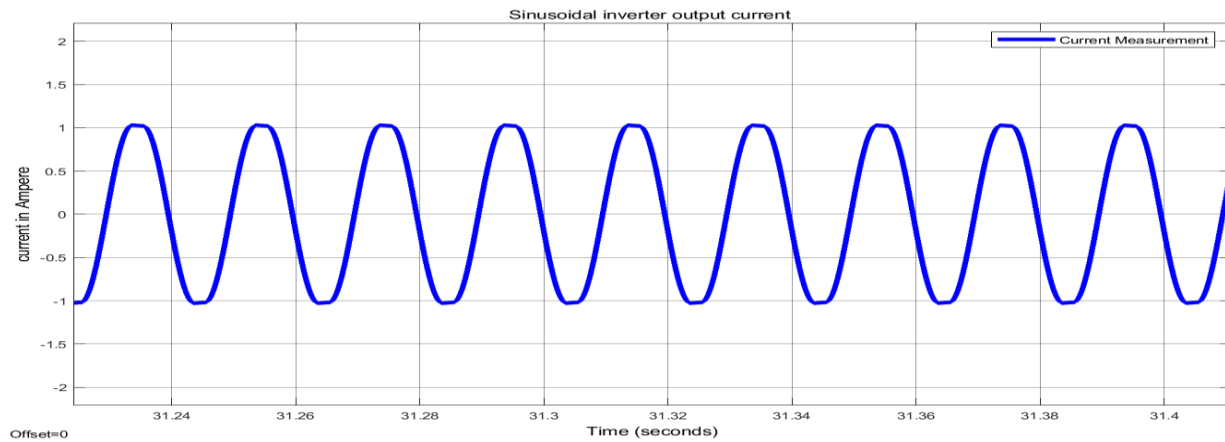


Figure 5.13: The inverter output current injected to the grid (V2G)

The above figure 5.12, and 5.13, shows the voltage and the current inject into the grid from the EVB, have a pure sinusoidal wave shape, with the operation of the SPWM controller and LCL filter.

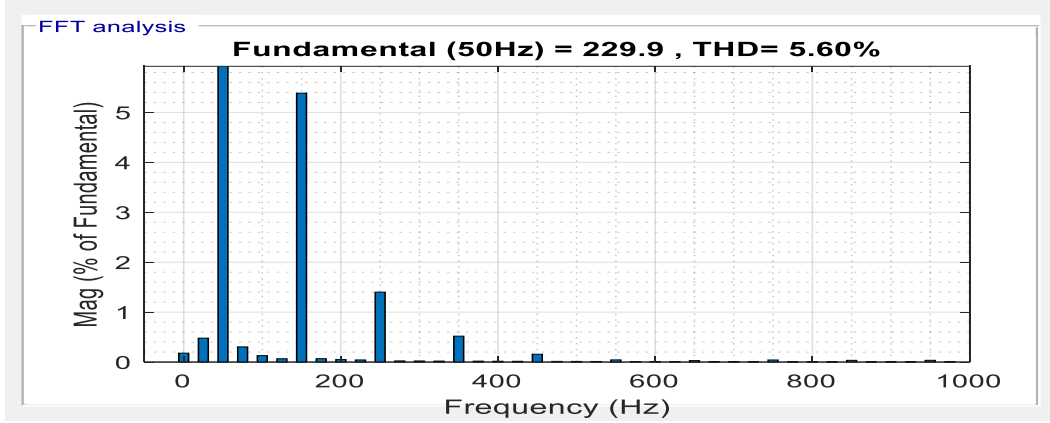


Figure 5.14: Total harmonics distortion spectrum inverter voltage to grid

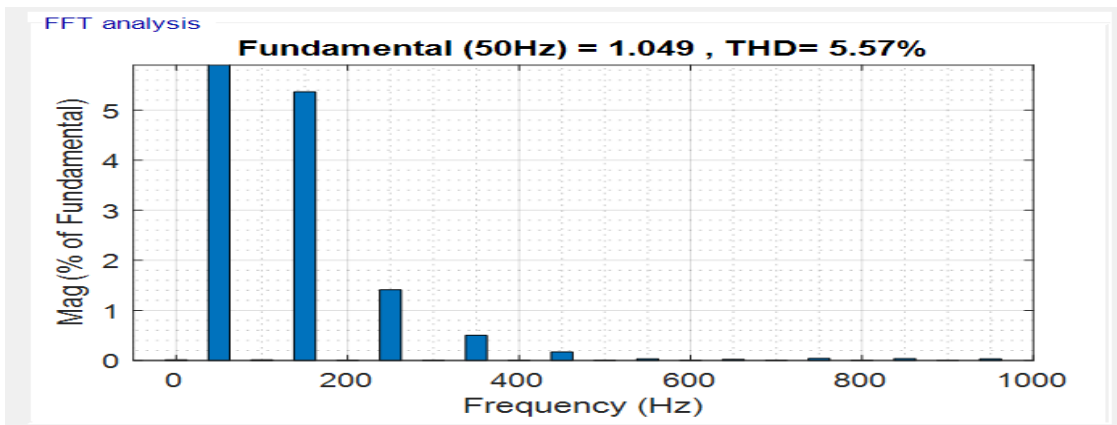


Figure 5.15: Total harmonics distortion spectrum of inverter current to grid

Figure 5.14 and 5.15, show the FFT analysis, which indicate the THD of the current injected into the Grid is 5.57% and the THD of voltage from the inverter to the grid is 5.60%. The FFT analysis, verified that, designed V2G/G2V charger with the proposed controller can deliver AC power from electrical vehicle battery with complying IEEE-519 standard.

The RMS value also known as effective or virtual value of an AC current, RMS is the value of AC current when flowing through a circuit for the specific period and produces the same amount produced by the DC. Mathematically it can express as follows:-

$$I_{rms} = \frac{I_m}{\sqrt{2}}, \quad V_{rms} = \frac{V_m}{\sqrt{2}}$$

$$I_{rms} = 0.707 * I_m \text{ and } V_{rms} = 0.707 * V$$

However, for a pure sinusoidal signal no need above mathematical calculation, since the ampere meters and voltmeters connected in AC circuits always showing the RMS values of current and voltage. Therefore from the simulation result of figure 5.12 and 5.13:-

$$I_{rms} = 1.049A, \quad V_{rms} = 229.9V$$

The figure 5.16 below show that the SPWM regulated inverter output current and voltage are in-phase and approximately have unity PFC.

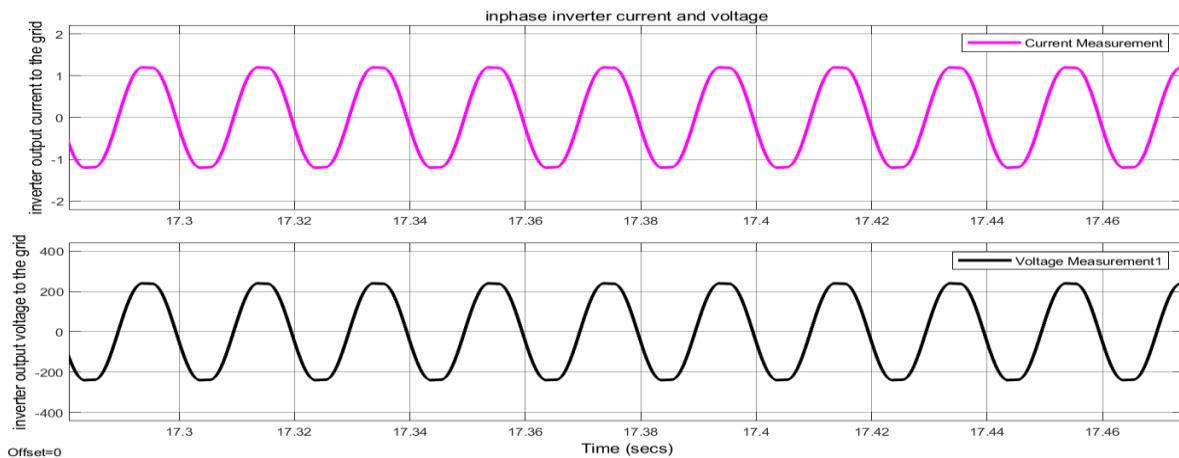


Figure 5.16: In phase inverter output voltage and current on V2G operation

The figure, 5.16 above shows in-phase voltage and current, so it is possible to assume the phase angle between current and voltage is zero, and the cosine of zero is unity, the RMS power deliver to the grid from EVB can be determined as follows:-

$$P_{rms} = I_{rms} * V_{rms}$$

$$P_{rms} = 229.9v * 1.048A = 239.92W$$

However it is impossible to deliver power to an electrical grid, unless it is running at the same frequency. Before the synchronization, the source must have equal line voltage, frequency (most country 50Hz), phase sequence, phase angle, and waveform that of the system, to which it is being synchronized, to prevent damage to the machine, and disturbances to the power system.

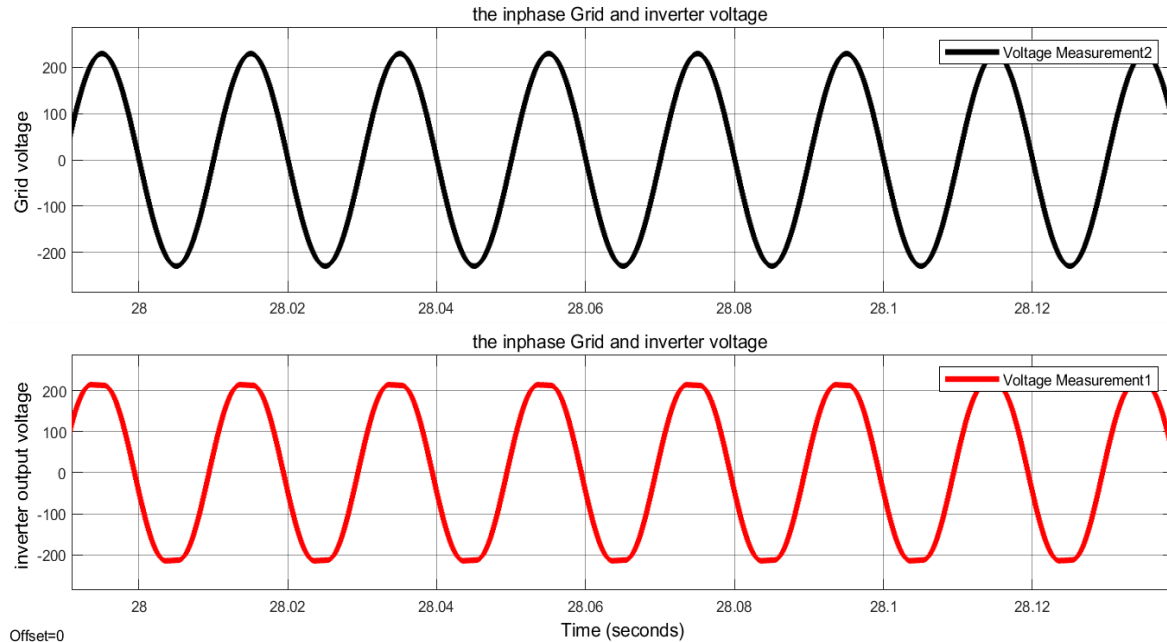


Figure 5.17: in phase grid and inverter voltage

Figure 5.17 show that the voltage from the EVB and the voltage from the grid have same line voltage and frequency approximately similar phase angle. Buck-boost converters are designed to fulfill the specifications for the achievement of the bidirectional power flow systems with duty ratio control. Besides, the inductor between the single-phase AC and bidirectional AC-DC rectifier used to raise the DC output, to sustain the DC bus voltage during charging conditions. During G2V (charging) condition, the DC-bus voltage greater than the EVB voltage. The buck-boost DC-DC converter is acting like a buck chopper to step down the dc-link voltage into the battery level. Whereas in V2G case bidirectional DC-DC converter function in boost mode, to step up the voltage from the battery to match with the DC-link and then to the grid voltage. Voltage matching done by regulating the PWM duty ratio, chopper output voltage and the battery current.

In general, the simulation validated, the proposed system and controller are capable to transfer power in two-ways, between the EVB and power grid. By satisfying power factor correction and harmonic distortion standards set by IEEE, to prolong the life of the converter and minimizes the risk of distorting the grid system.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

This thesis proposes a two-stage, non-isolated, bi-directional charger for electric vehicles, with a direct current control strategy while considering both vehicles to grid (V2G) and Grid to vehicle (G2V) power flow. From the MATLAB Simulink experiment, it can be confirmed that the proposed bi-directional EV charger can transfers energy from EVB to the power grid when the power demand is greater than the produced power, such as the peak load condition for the regulation of either frequency or voltage, and returns the power from the power grid to the EV battery when the EV owner requires it, and the power grid is ready to supply the power.

The FLC network is applied to regulating the flow of energy from Grid to Vehicle or vice-versa, by direct current controlling technique of the DC-DC converter. SPWM controller technique is applied to the bidirectional AC-DC converter to obtain better power factor in the inverter modes of operation, to make the inverter output voltage and current have true sinusoidal wave shape, which injected to the AC grid. As shown on various waveforms in the simulation result. The THD is low during the inverter operating modes due to the LCL filter besides the SPWM controller. SPWM is an easy and simple but efficient method to control such kind of system. In general, the simulation result shows that the two proposed controllers are efficient for a bidirectional EV charger power transfer in the applications V-2-G or G-2-V technology.

The grand contribution of this thesis is to demonstrate V2G is another forward-looking technology, focused on the interaction between EV and power grid. By applying the proposed system modeling and control scheme, it is possible to build a more efficient use of electrical energy from the EV battery. In addition to the traction purpose of an electric vehicle, which offers substantial advantages to both the government its power grid owners and individual EV owners. The findings of this investigation also play a significant role to enhance the high-performance bi-directional EV charger and it opening a new viewpoint in the power electronics researching area.

6.2 Recommendation and future work

In this thesis, the primary focus is to validate the feasibility of V2G/G2V power flow technology within fuzzy logic controller. To make broad the scope of the thesis I want to recommend some possible directions:-

- Enable the charger capable to charge/discharge two or more EV at a time.
- Enable the system inject power to the DC grid.
- Add a voltage controller besides to the current controller by tolerating the complexity.

REFERENCES

- [1] Arjun raj Prabu, A. S. (2009), "*Bidirectional ac-dc converter for vehicle-to-grid (v2g) applications*". Marquette: Marquette University.
- [2] Kun Zhuge. (2013). "*Development of an efficient hybrid energy storage system (Hess) for electric and hybrid electric vehicles*". Canada: Ontario University, Ontario.
- [3] Ali Mofleh A. b. (2016). "*Vehicle-to-grid (v2g) integration with the power grid using a fuzzy logic controller*". Kansas: Kansas state university Manhattan.
- [4] Moez. (June.2017). "*Electric vehicles and vehicle-to-grid technology how utilities can play a role. Norway*", Norway: University of Norway.
- [5] Osama. (2016). "*Charging and discharging algorithms for electric vehicles in a smart grid environment.*" Ottawa, Canada: faculty of engineering, university of Ottawa.
- [6] Allan Agatep. (2011). "*Design and simulation of v2g bidirectional inverter and dc-dc converter. California*": California polytechnic state university.
- [7] Erb, d. O. (Feb 2010). "*Bi-directional charging topologies for plug-in hybrid electric vehicles*". An in applied power electronics conference and exposition (pp. vol., no.pp.2066-2072, 21-25). Twenty-fifth annual IEEE.
- [8] Yitao liu, j. p. (9 February 2017). "*LCL filter design and analysis of grid-connected converter for power quality and EMI compliance*". Shenzhen: Shenzhen University, china.
- [9] Joshi, M. C. (May 2013). "*Modeling and control of bidirectional dc-dc converter fed pmdc motor*". India: India national institute of technology.
- [10] Mithat c. Kisacikoglu, l. m. (2014). "*Single-Phase on-Board Bidirectional PEV charger for v2g reactive power operation*". *IEEE transaction on smart grid*, vol., no., pp.2066-2072, 21-25.
- [11] Kang Miao tan, V. k. (May 2014). "*Bidirectional Battery Charger for Electric Vehicle*".
- [12] Arun Kumar Verma, B. S. (n.d.). "*Grid to Vehicle and Vehicle to Grid Energy Transfer Using Single-Phase Bidirectional DC-DC Converter and Bidirectional DC-DC Converter*". IEEE.
- [13] Khairy Sayed and Sossam A. Gabbar. (2017). "*Electric Vehicle to Power Grid integration Using Three-Phase Three-Level DC-DC Converter and PI-Fuzzy Controller*". Egypt: University of Ontario Institute of technology, Oshawa, 2, , sohag university, sohag.

- [14] Majid Pahlevani, P. J. (May 2017). "A Fast DC-Bus Voltage Controller for Bi-directional Single-Phase AC-DC Converters". In IEEE Transactions on Power Electronics, vol. 32, no. 5, pp. 3970-3988.
- [15] Anuja Namboodiri (student), H. S. (December 2014). "Unipolar and Bipolar PWM Inverter". International Journal for Innovative Research in Science & Technology, Volume1.
- [16] Nishtha Bbajoria, P. S. (January 2016,). "Overview of Different Control Schemes Used for Controlling of dc-dc Converters".
- [17] Adrià Marcos pastor. (2015). "Design and control of a battery charger for electric vehicles". Iarragona: Universitat Rovira Virgili .
- [18] Muhammad Aziz. (09 February 2018). "Electric vehicle utilization for ancillary grid services". Tokyo, Japan: Tokyo institute of technology.
- [19] Josh Chandra, M. (May 2013). "Modeling and control of bidirectional dc-dc converter fed pmc motor (for hev applications)". Rourkela: national institute of technology rourkela.
- [20] T.p.lshil reena joy. (March 2015.). "Modeling and Analysis of Electric vehicle charging interface. India: institute of technology", India.
- [21] Deepak ravi, b. m. (2015). "Bidirectional dc-dc converter an overviews of various topologies, switching scheme and control technique",Allahabad:motilal nerhunnational institute of technology.
- [22] Negash, p. M. (2017). "Fuzzy logic control based bidirectional power low capability between the electric vehicle and dc or ac grid, Telangana, institute of technology.
- [23] Krishna Moorthi Siva Kumar. (January 2017). "A Bidirectional converter using fuzzy controller". International Journal for Research in Applied Science & Engineering Technology (IJRASET), Volume 5 issue I.
- [24] Hao Wu, S.-C. W. (2015). "Control and Modulation of Bidirectional Single-Phase AC-DC Three-Phase-Leg SPWM Converters with Active Power Decoupling and Minimal Storage Capacitance". Transactions on power electronics, (pp. vol. X, no. X,).
- [25] J. G. Pinto, V. M. (Nov. 2013). "Bidirectional Battery Charger with Grid-to-Vehicle, Vehicle-to-Grid and Vehicle-to-Home Technologies". Industrial Electronics Conference, (pp. pp.5934-5939, Vienna). Austria.
- [26] V. Vaideeswaran, N. S. (December 2018.). "Control techniques of three-phase PWM rectifier", international journal of engineering and advanced technology,, volume-8, issue-2s.

- [27] Jean, R. (September 2017). “*Neuronal control strategies for ac-dc converter with power factor correction*”, (pp. conference paper).
- [28] Dr. P Usha. (May – June 2017.). “*Fuzzy logic controlled bi-directional dc-dc converter for electric vehicle applications*”. Journal of electrical and electronics engineering 1676, p-issn: 2320-3331, volume 12, issue 3 ver. IV pp 51-55.
- [29] Pranita Rajkuwar, S. A. (jul.-2017). “*Bidirectional ac/dc converter PWM strategy to reduce switching loss with feed-forward control in grid-tied micro grid system*”. International journal of industrial electronics and electrical engineer in India, volume-5.
- [30] Dr. P usha. (June 2017). “*Bi-directional dc-dc converter for electric vehicle applications*”, Journal of electrical and electronics engineering, volume 12, pp 51-55.
- [31] Haoyan Liu Harbin. (2012). “*Control design of a single-phase dc/ac inverter for PV applications*”. University of science and technology.
- [32] Liwen pan and chengning Zhang. (Received: 1 march 2016; accepted: 22 June 2016, published). “*An integrated multifunctional bidirectional ac/dc and dc/dc converter for electric vehicles applications*”. Beijing, China: Beijing institute of technology.
- [33] G. Themozhi and S.RamaReddy. (February 2011). “*Model-based design of regulated zero voltage system bidirectional dc to dc converter*”. International journal of computer and electrical engineering, vol.3, no.1, 1793-8163.
- [34] (n.d.). *Battery-characteristics/battery-charging-and-discharging-parameters*. Retrieved from <https://www.pveducation.org/pvcdrom>.
- [35] Osama Loqaily. (2016). “*Charging and discharging algorithms for electric vehicles In the smart grid environment*”. Canada: University of Ottawa.
- [36] Laura Albiol Tendillo. (2015). “*Design and control of a bidirectional dc/dc converter for an electric vehicle application*”. Tarragona: Universitat Rovira Virgil.
- [37] Andrzej M.Trzynadlowski. (2016). “*Introduction to Modern Power Electronics*”. John Wiley & Sons, Inc, (p. Third edition). New Jersey: Published Canada.
- [38] Md. Parvez akter, S. M. (101: 165-175). “*Model predictive control of bidirectional ac-dc converter for energy storage system*”. Journal of Electrical Engineering Technology, 2015.
- [39] Josiah Haruna. O. (2019). “*Comprehensive Steady-State and Small Signal Analysis of a Full Order Off-board Bi-directional Plug-in Electric Vehicle (PEV) Charger for Vehicle to Grid (V2G) Operation*”. IEEE PES/IAS Power Africa, IEEE.

- [40] R.Lakshmi Narayana, G. M. (October 2019). "A Fuzzy logic based controller for the bidirectional converter in an Electric vehicle". ISSN: 2249-8958, Volume-9 Issue-1.
- [41] Ali Saadon al-ogaili 1, I. B. (20 June 2019). "A Three-Level Universal Electric Vehicle Charger Based on Voltage-Oriented Control and Pulse-Width Modulation". Energies 2019, 12, 2375, p 1-20.
- [42] Iason Vittoria, M. M. (2014 I). "A bidirectional battery charger for electric vehicles with V2G and V2H capability and active and reactive power control". Conference: IEEE Transportation Electrification Conference and Expo (ITEC). DOI: 10.1109/ITEC.2014.6861855.
- [43] Dongqi Liu, G. Z. (SEPTEMBER 2018). "Modeling and Control of a V2G Charging Station Based on Synch converter Technology". CSEE Journal of power and energy systems, vol. 4, no3.

Appendix

Fuzzy rules for DC-DC controller

[System]

Name='THESIS2'

Type='mamdani'

Version=2.0

NumInputs=2

NumOutputs=1

NumRules=49

AndMethod='min'

OrMethod='max'

ImpMethod='min'

AggMethod='max'

DefuzzMethod='centroid'

[Input1]

Name='error'

Range= [-20 20]

NumMFs=7

MF1='NL': 'trimf', [-26.66 -20 -13.33]

MF2='NM': 'trimf', [-20 -13.33 -6.668]

MF3='NS': 'trimf', [-13.33 -6.668 0]

MF4='Z': 'trimf', [-6.668 0 6.668]

MF5='PS': 'trimf', [0 6.668 13.33]

MF6='PM': 'trimf', [6.668 13.33 20]

MF7='PL': 'trimf', [13.33 20 26.68]

[Input2]

Name='rate'

Range= [-20 20]

NumMFs=7

MF1='NL': 'trimf', [-26.67 -20 -13.33]

MF2='NM': 'trimf', [-20 -13.33 -6.668]

MF3='NS': 'trimf', [-13.33 -6.668 0]

MF4='Z': 'trimf', [-6.668 0 6.668]

MF5='PS': 'trimf', [0 6.668 13.33]

MF6='PM': 'trimf', [6.668 13.33 20]

MF7='PL': 'trimf', [13.33 20 26.68]

[Output1]

Name='voltage'
 Range= [-50 50]
 NumMFs=7
 MF1='NL':'trimf', [-66.67 -50 -33.33]
 MF2='NM':'trimf', [-50 -33.33 -16.67]
 MF3='NS':'trimf', [-33.33 -16.67 0]
 MF4='Z':'trimf', [-16.67 0 16.67]
 MF5='PS':'trimf', [0 16.67 33.33]
 MF6='PM':'trimf', [16.67 33.33 50]
 MF7='PL':'trimf', [33.33 50 66.7]

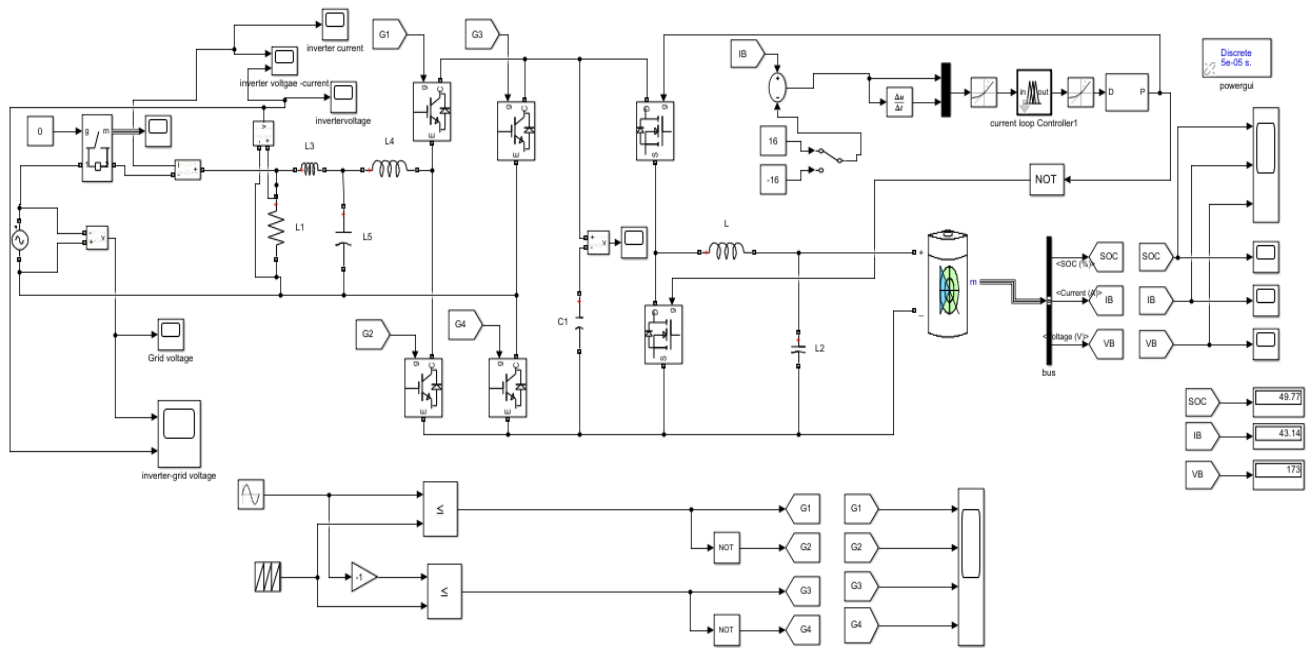


Figure 6.1: charger configuration in MATLAB Simulink

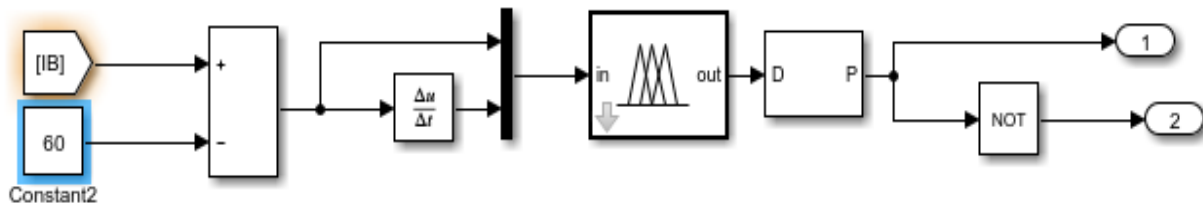


Figure 6.2: Simulink model of fuzzy logic control of charging

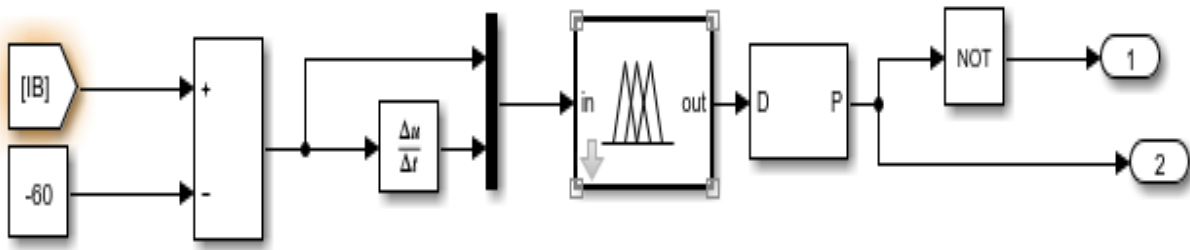


Figure 6.3: Simulink model of fuzzy logic control for discharging

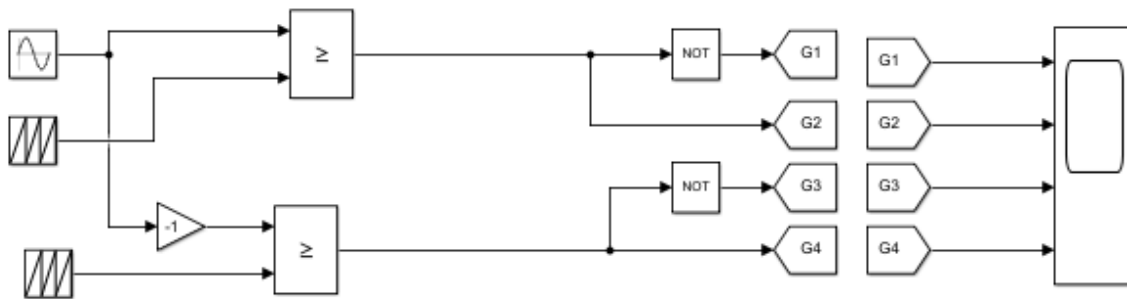


Figure 6.4: Simulink model of SPWM controller

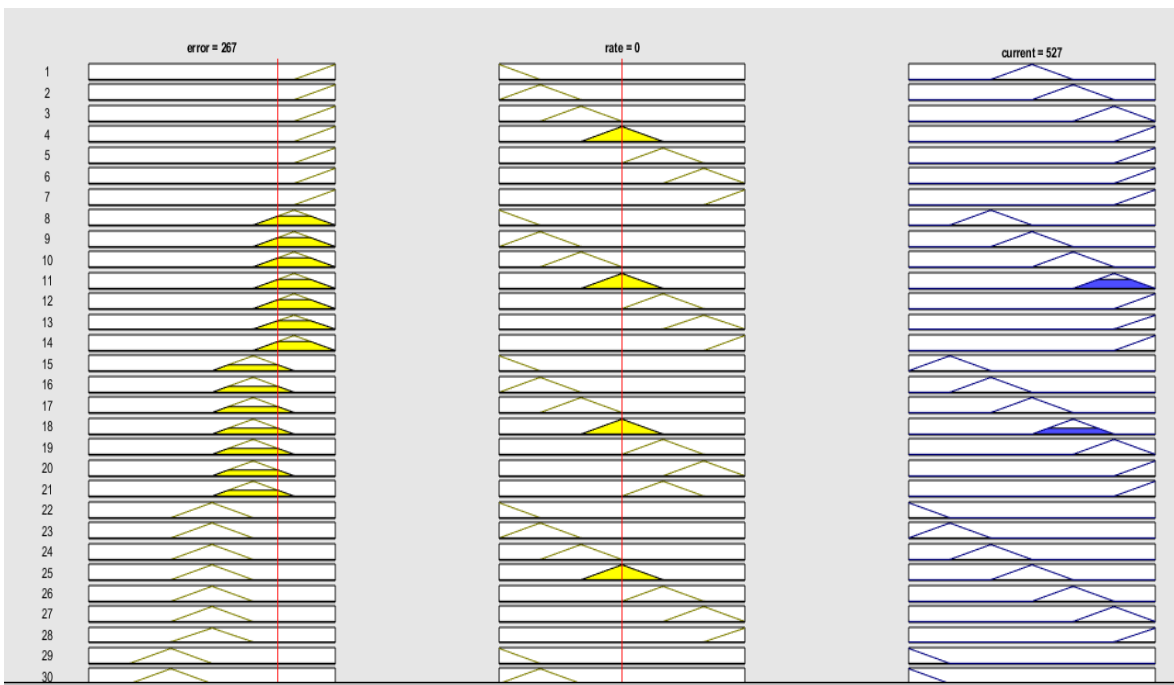


Figure 6.5: Partial rule views of the FIS

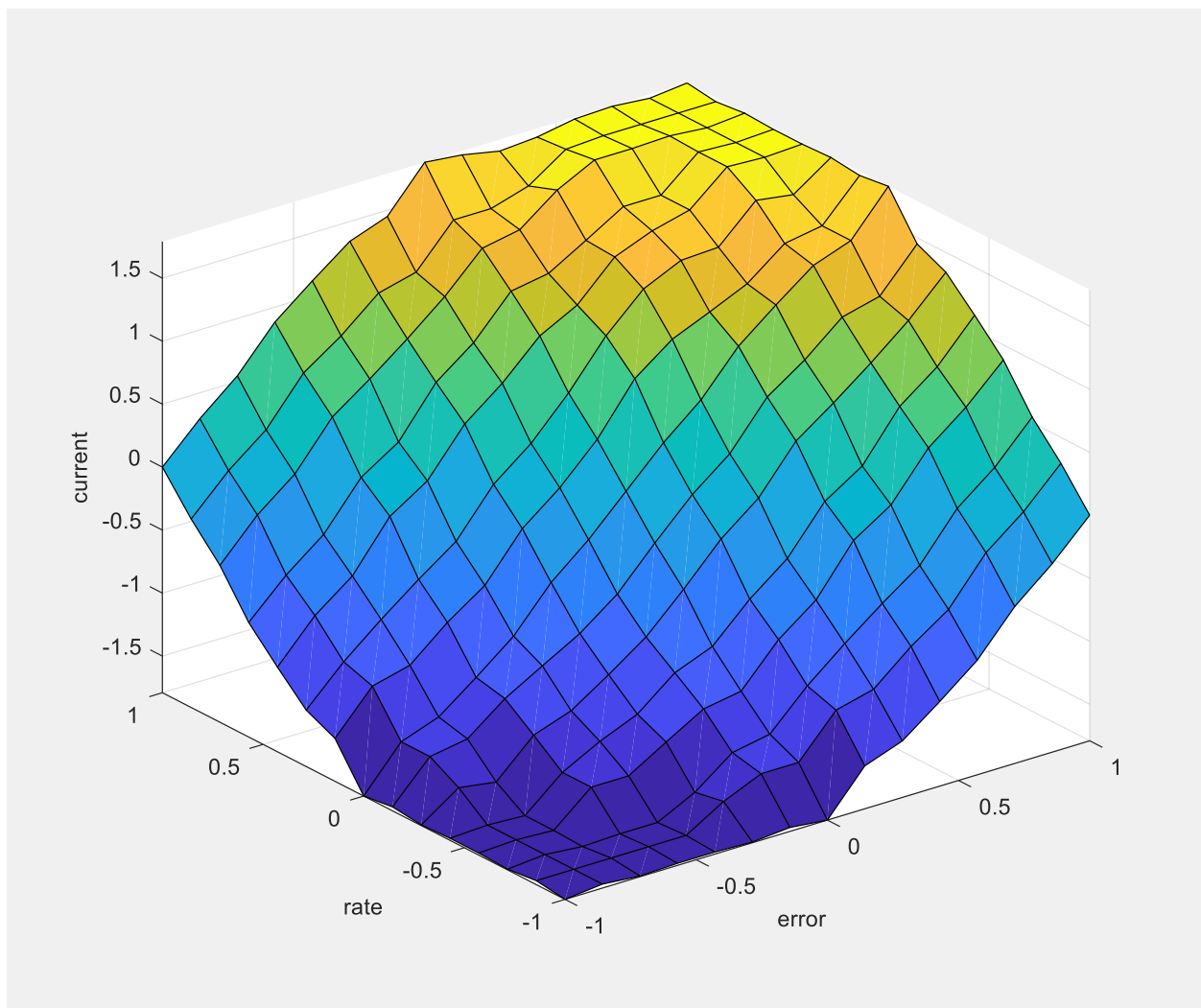


Figure 6.6: Linear Fuzzy rules surface for DC-DC chopper