COMPARATIVE ANALYSIS OF FLEET OF EV INTEGRATION IN AC, DC AND HYBRID MICROGRID

BY

MUHAMMAD WAQAR HASSAN

01-244181-018

SUPERVISED BY

FAHEEM HAROON

Session-2018-2020

A thesis submitted to the Department of Electrical Engineering

Bahria University, Islamabad

in partial fulfilment of the requirement for the degree of MS(EE)

CERTIFICATE

We accept the work contained in this report as a confirmation to the required standard for the partial fulfilment of the degree of MS (EE).

Head of Department

Supervisor

Internal Examiner

External Examiner

DEDICATED

TO MY

BELOVED PARENTS

SISTERS

&

BROTHERS

WHO ALWAYS RAISE THEIR HANDS

FOR MY SUCCESS AND HAPPINESS

DECLARATION OF AUTHORSHIP

I **Muhammad Waqar Hassan,** Registration No. **01-244181-018**, hereby declare that I have produced the work presented in this thesis, during the period of registration. I also declare that I have not taken any material from any source except referred to wherever due to that amount of plagiarism is within the acceptable range. If a violation of HEC rules on research has occurred in this thesis, I shall be liable to punishment action under the plagiarism rules of HEC.

Muhammad Waqar Hassan
01-244181-018

ACKNOWLEDGEMENTS

First and foremost, I am highly grateful to Almighty Allah, the Creator and the Guardian of the universe, to whom I owe my very existence. I owe my deepest gratitude to my supervisor **Dr. Muhammad Aamir** and Faheem Haroon for mentoring and supporting me throughout my thesis work. I would also like to present my sincere gratitude for his patience, motivation, enthusiasm, and immense guidance during my entire research work.

I am also thankful to my friends Hussain Sarwar Khan, Ahmar bilal chudhary, Shoaib Ahmad who were standing with me in every hardship I had to face. Last but not the least; I would like to thank the faculty and staff of Bahria Islamabad for their support and help throughout my master's studies. Lastly, I would like to thank my parents and family who encouraged and supported me in all my pursuits.

Muhammad Waqar Hassan

ABSTRACT

Electric vehicles (EVs) are the prominent choice in the transportation sector to decrease the consumption of fossil fuels as well as greenhouse gases (GHG) productions. Microgrid operations especially hybrids AC/DC pave progressive development in the electrical vehicle by using renewable resources providing penetration of direct current (DC) into alternating current (AC). Power flow in AC, DC, and Hybrid-microgrid was made with the help of an isolated bidirectional battery charger with the potential of 1.5kW of 120 V. The proposed battery charger circuit was designed into two-stage conversion AC-DC and DC-DC. AC-DC conversion was done with the help of an inverter, while the rectifier was used for DC-DC conversion. Four switches operating at a High-frequency PI controller were used to maintain the output of 120V DC for battery charging while two controllers were used in the proposed battery charger circuit for battery power discharge system. Conduction losses were measured for comparative analysis of EV integration and future interventions. The mathematical equation and datasheet of IGBT were analysed by using MATLAB/SIMULINK software.

While the 2nd phase of the study was impressions of innumerable types of EV charging on AC and DC voltages and regularity of the commercial hybrid AC/DC microgrid were scrutinized. Results revealed that maximum losses were found in the AC grid while minimum losses shown in the DC grid system. While the harmonic distortion in the case of the DC grid is also very low as compared to the others. Results underlined the insinuations of substance synchronized EV charging to condense adversative functioning impacts and associated ventures.

TABLE OF CONTENTS

LIST OF FIGURES

List of Tables

ABBREVIATIONS

EV	Electric Vehicle
PHEV	Plugged in hybrid Electric Vehicle

Chapter 1

Introduction

CHAPTER 1. INTRODUCTION

Transportation and energy production industries damaged the environment massively. Around 60% of air pollution is just because of emission of carbon and nitrogen oxides from power houses and vehicles. To reduce it, concept of electric vehicles introduced. From the past few years due to abundant use of fossil fuels to produce power and transportation has put very harmful effect on the climate. The environment change also affects different sectors in different ways. Such as on the ecosystem, fresh water resources, agriculture and the mainly is the fitness and set-up of the human.

Basically, fossil fuels use in two major fields (1) Production of power (2) Automobile. The old and convenient method use to produce power is from the use of fossil fuels. These resources are decreasing day by day and not environment friendly. Mostly transportation sector depends on the oil and its use now a days is approximately 95%.LPG and CNG can also be used as a fuel. It's an assumption that transportation sector is the main cause behind this. Environmental hazards such as, greenhouse gas emission and the independence of energy is caused using fossil fuels.CO_2 mostly produced due to the use of fossils fuels. This gas is very poisonous and responsible for ozone depletion. As a result, population will get effected by Ultra violet rays. When the level of CO_2 increases in the atmosphere the vegetation processes needs a lot of water. The amount of the rainfall is decreasing day by day due to this change. As a result, the quantity of the fresh water decrease.

In addition to these problems these sources are also very costly for the generation purpose. Different types of mechanical system and electrical system work together in such a way that they can produce electricity. For the generation purpose it is the basic need to burn the fossil fuels but as mentioned that they are not environment friendly and this situation is responsible in climate change. Now, this is an alarming situation for the world to take in account for this issue and find the possible solution of this problem. So, the worlds come to this conclusion that renewable energy resources and the microgrid are the best choice to address this solution. Microgrid got a great attention during the past few years because of its cost effectiveness and environment friendly impact.

Different types of energy resources combined and feed the connected load and they are also synchronized with the previous grid. The main advantage is that they operate in such a way to keep the cost economically. They can perform their duties when the old grid is not connected to this. This mode of operation is called islanded mode. The best function of the microgrid is the easily penetration of renewable energy resources. It has tendency to supply the power in an emergency no matter whether it is in islanded or connected mode.

Due to so much attention people work on the development because of its environmentally impact and the cost point of view. Distributed energy resources compose of wind power, solar power, fuel cell and the EV's batteries. These resources can cause problems individually which can be solved. But the good way to realize distributed generation with the combination of load is called the micro-grid. These microgrid are responsible for supplying the power to the local areas.

The advantage of the microgrid are as follows

- Enhancement of the local reliability
- Feeder losses reduction
- Provide support to the local voltage
- Correction of the sag voltage
- Provide Uninterruptable supply

There are two modes of operation which are discussed previously one is called islanded mode and the other one is called the grid-connected mode. when different types of DG's are connected than direct connection to the grid is not possible. For this purpose, conversion from AC to DC and vice versa is required. The main control is the inverter control and it is the major in MG. The main function of the micro-grid is it manages the whole system in an economical way. The control function of the microgrid.

In 1868 the concept of the Electric vehicle started. Electric vehicle can be defined as such vehicles which has motors in their structure, and they need electricity for their working. Electricity is provided by the charging station. It is a place where the EV's are charged by the supply of the local distribution grid. The set-up for the charging of the EV needs charging station along the roads but it is an expensive method because it need energy from the Grid. This can be reduced by installing solar and wind station at different places like hospitals, universities and parking lots and feed their energy to the station. It can bring a lot of benefits for a country. Many countries are working on this project including Denmark, Netherland, Germany and UK.

Now-a-days, electric vehicle becomes very popular among the government and public sector. The main reason for popularity among the other renewable resources are follows

- Easiness
- Clean source of energy
- Cleanness

V2G mode is more stable source of renewable energy because it does not affect by climate change. It is also a clean source of energy because it is free from carbon oxides emission. In comparison to fossil fuel the cost of EV is less so it is considered as economical solution.

Electric vehicles are considered as environment friendly due to zero emission. The maintenance of the inside components of EV's is also very easy. There is one problem according to the cost. The manufacturer must limit the capacity of the battery. If you want a higher pack of the battery, then the cost of the battery increased. The range of the EV's is increased but as well as cost also increased. The most expensive component of the EV's is battery.

The range of the EV's keep small due to their cost. People needs cars to travel to home or offices and their range is short. So, people want to charge their batteries once and it's a common to charge the EV's at night. EV's owner need a solution to charge and discharge their batteries according to their practice.

EV's charging, might be the reason behind the over-loading of the transformer of the distribution system which are already present. Therefore, at the planning stage for the EV's use it must be kept in mind to keep the capacity of the Electric Grid according to the characteristic of the EV's. The charging property of the EV's batteries can cause problems for the load structures of EV's. The switching time of the EV's on time and off time also effect on the EV's load. So, these are the two hot topics for the research.

The combined structure for fleet of EVs is commonly examined in scale of hours. For the calculation of Electric Grid studies, the perfect model of battery is the basic requirement. The property of the EV's integration in/off time in contrast to the charging of the battery has more significant effect on the combined property of the load in case of fleet of EV's. The size and other constraint of the Electric grid are influenced by the time period of the EV's connection to the grid. The EV's load profile also effected by the temperature and the initial charging status of the battery.

The EV's also have some drawbacks like initial price, the short distance covered and lack of the infrastructure for the charging of the EV's. Due to these drawbacks the market share of the EV's is low. A model of the EV by the car company Nissan is made which has ability to cover the distance of 250 km and the reduction in annual cost of the battery is fourteen percent.

1.1. Problem statement

With the penetration of large number of EV's in the national grid, cause high load demand, grid fluctuations, and power electronics lost. Therefore, it is necessary to analyse the connectivity of fleet of EV in the AC, DC, and Hybrid microgrid. It helps in recommendation of the future selection of the grid for the EV connection.

1.2. Thesis Objectives

- To developing control techniques for the charging and discharging of Electric Vehicles.
- To simulate the Charging/Discharging of EV in AC, DC, and Hybrid microgrid.
- To analyse the performance of EV in AC Grid, DC grid and hybrid microgrid.
- Calculate the conduction losses during charging and discharging.

1.3. Thesis Organization

Chapter 1 is the introduction of the EV’s and the Microgrid. Literature review of the Electric Vehicles are presented in the Chapter 2. The integration of EV’s into the Grid is discussed in the chapter 2. The Methodology for charging from the Grid and discharging to the Grid is discussed in the chapter 3. In the chapter 3 controllers for charging and discharging are discussed. Charging and discharging techniques for the AC, DC and hybrid microgrid is discussed. The results of the simulation for AC, DC and hybrid microgrid is shown and discussed in the chapter 4. The conduction losses and their comparison in AC, DC and hybrid microgrid also presented in the chapter 4. The conclusion and discussion in the chapter 5.the future work is in the chapter 6 and the references are at the end of the chapter 6.

Chapter 2

Literature Review

CHAPTER 2. LITERATURE REVIEW

2.1. Literature Review

In the past, when the science is not so much advanced people wait for years to meet their beloved one. People travels for many months to meet their relatives[1]. With the advancement in science now distance does not matter because there are so many ways. Airplanes, Cars, bikes, buses etc are used for transportation now but that time people travel on the animals like camels or mostly they would like to travel on foot.

Cars are the most commonly source of transportation[2]. During the 1800s industrial revolution came into existence then steam power also become popular in those days. As a result, a steam car was built which got power from the steam, [3]but this was very insufficient method. Because this required a very large and heavy components to be installed in the car which include furnace and boiler[4]. In addition, this was time taking processes[5]. Moreover, there was possibility of accident due to the shaking of the car. This steam car has more demerits than its merits[6].so it was rejected. The people start working on this again because they were curious to find the solution.

At last, people got successes to find another way which was fossil's fuel, and this gain a lot of attention because of its properties[7]. The fossil fuels were used as to produce Power and for the transportation purpose also. So, the world does not pay attention to the big issue which was the depletion of the fossil's fuels and the pollution at that time[8] .

In the past decade a lot of environmental changing came into existence[9]. The number of the natural disaster increase day by day[10]. So, this was an alarming situation for the world. The researcher research on this topic. They came to the result that transportation increased and the use of fossils fuel also increase[11]. Burning of fossil fuels is the main reason behind the production of CO_2 gas in the atmosphere. This very poisonous gas. This gas is responsible for the depletion of the ozone layer[12]. As a result, different Ultraviolet rays are coming from the sun and effect the human being.

The other prospective is the depletion of the fossil's fuels. The world moves to generate electricity from the renewable energy resources[13]. These resources are very cheap and environment friendly. These resources occur in nature and no disturbance in the nature will occur due to the usage of these resources[14]. After very research Electric vehicles are invented as a result.

In 1884, Thomas parker done his first practical to produce Electric car and he succeed[1]. He is also famous for his invention of the coalite. This is shown in the fig 2-1. The electric cars are more superior than other types of the car due to his advantages[15]. The electric cars are less noisy. These cars do not pollute the air. These are also not risky. Although the traveling distance is limited. User must charge it after some time according to the battery capacity[16]. At that time, it is the best choice of transport because people do not travel so much.

Figure 2-1.Thomas parker car[14]

At that time distribution of electricity was a hot topic. Power are consumed by the homes and factories. EV's are charged at home[17]. With the passage of time people realize that this is not so much effective. The use of this technology was also very small, so people do not pay attention to the public charging station[18]. With the passage of time roads and highways are built. World become globalized.so people need to travel for a very large distance. They have not much time to wait for long charging.so researcher introduced the V2G and G2V concept[19].

Now-a-days EV's shares increase due to its numerous advantages. In the past the percentage of EV's share in the market was less than the 0.1% observed on 1 august 2014[20].As compared to the previous years the sale of PHEV's and EV's doubled because the oil dependency decrease. According to survey oil dependency by the transport sector is 95% now a days[21]. By using electricity there is reduction in the Pollution and emission of CO_2.

Due to the so much increase in the pollution EU emission trading system set a value of CO_2 emission[22]. This is also a reason for the usage of EV's. Supercapacitor can be used instead of batteries.

Tesla motors in 2006, made a car they said that it covers distance of 320 km when it is single fully charge. Chevy Volt from Chevrolet, Nissan LEAF and Zoe from Renault companies also work on the Ev's after the Tesla motors. The Tesla roadster is also available in 2020[23].This is shown in fig 2-2. Its speed is 250mph.and by pone charge it can cover 1000km. A Semi-truck also introduced by this company.

Figure 2-2. Tesla Electric Car[20]

Norway and Estonia encourage their people to buy EV’s by providing them different facilities. Now in Norway there are large number of EV’s are present as compared to their population. Because now a days global warming is a big issue[24]. There are different types of Electric vehicles.

There are different types of drivetrain technologies are present. PHEV’S AND full EV’S are those two types. EV’s are different from the typical vehicles because of its construction[25]. In electric vehicles at least one electric motor is used whose function is to support the propulsion. Regenerative braking is another difference and advantage[26]. The energy which is in the form of heat and usually it is dissipated but in the EV’s it Is not dissipated[27].

PHEV’s batteries can be charged by the electrical socket. Electricity from the different plants is given to the electric motors which is in the EV’s [28]. Different plants are solar, wind and tidal.

The advantage of these plants is that their cost is not so much high as compared to the other conventional plant. An overview of EV's in the market is also presented[29].

Battery electric vehicle is also a type of electric vehicle [30]. In this the energy is drawn from the batteries. that's why it is called as battery electric vehicle. Normally there is no gear box in the EV. These are charged by the socket[31].

Plug in hybrid electric vehicles is also another type of EV.it has conventional ICE with an electric motor[32]. These are functional classified according to the hybridization degree.

2.2. Types of electric vehicle:

Micro hybrid: it's a conventional vehicle the electric driving not occur in this type.

Mild hybrid: It's a conventional vehicle in addition to regenerative braking.

Medium hybrid: In this type during the acceleration more power can be delivered which allow to downsize the ICE[33].

Strong hybrid: In this type regenerative braking charge the battery but the size of the battery is small.it can be used for the short distance.

Plug-in-hybrid: These types can be charged by the regenerative braking and the plug-in socket also[16].

2.3. G2V Concept:

For charging of Electric vehicles an external source is required which is electric grid. For this purpose a charger is required[34]. Charger is required because grid supply is AC and the battery of the EV is DC. The charger work as a rectifier which rectify the AC into the DC.

Convent-ally for conversion, a converter is required which convert AC into DC or a rectifier is required[35]. Fast charging system required an extra DC-DC converter is required for good conversion. Charger can be On-board or Off-board depending upon the level of the charging.

These types have different specification. For better EV propulsion less weight and compact is required[36]. However On-board charger have its own demerits. The power rating of these charger is low. They are also designed for the charging level which are slow. In comparison to the off-board charger they are installed on such location which are bulky and for fast charging DC-DC converter is added[37].

2.4. Charging Level:

There is some internationally standard design for the purpose of charging. The society of the automotive engineer (SAE), international electromechanical commission (IEC) and the CHADEMO EV standards which are given below[38].

2.4.1. AC Level 1:

According to the pre-define value of the standard 16A maximum current can be used for the purpose of charging of EV's battery from the AC grid either it is single phase or three phases. For this purpose, resistive coding is necessary for communication of EV's batteries to the grid.

2.4.2. AC Level 2 :

In this level 3 2A maximum current can be used by a standard plug but it also includes a protection system for in-cable. This protection system is responsible for connecting the Power of Grid to the EV's battery.

2.4.3. AC Level 3:

According to the pre-define value in this stage two cable are used.one is fixed and its current rating is 63A and the other is flexible having rated value of current is 32A.

2.4.4. DC Level 1:

In order to meet the requirement of the standard, in this level current of 400A is used by a DC source which is off-board.

2.4.5. DC Level 2:

In this level current of 200-450 dc up to 90 kW is used. This type off-board charger is required.

2.4.6. DC Level 3:

In this level current of 200-600 dc up to 240 kW is used. this type of charger is also off-board.

The application of the electric grid increased because grid technology is matured enough. By enhancement in the smart grid it's time to get benefit from the integration of EV's into the smart grid[39]. The penetration of EV's into smart grid has gone through a great progress. In the past only power flow from in one direction. The cost of this system is very low. The main idea was to manage the load. The EV's charging is done during the off-peak hours. More benefits from the EV's batteries can be get by more enhancement in the equipment[40]. For this purpose, bidirectional charger is required.

2.5. V2G concept:

Now this technology of power flow between EV's batteries and electric grid is popular[41]. This concept of power flow is called as vehicle to grid (V2G) technology. With the help of this concept power can be transfer between the electric vehicle and electric grid[42]. During the off-peak hours EV's are charged. During the peak load hours, the EV's provide power to the electric grid[43].

The V2G concept can be divided into three types which are vehicle-vehicle (V2V), vehicle - building (V2B) and the vehicle-grid(V2G)[44]. Among all the types power of the battery is utilized. In V2H it supplies power to the home[45]. This concept can be expanded on commercial level.

Regardless of benefits of awareness, 2-way flow of power in V2G, some approaches are essential for profit from this[46]. From the grid point of view, it has been stated before that EVs are an extra burden on electric grid. The scheduling of EV's charging is vigorous to divide burden in such a way that it does not put an additional burden on electric grids when the peak hours started and lessen harmful effects. So, EV's charging must be scheduled to attain advantages such as, peak shaving and valley filling[47].

2.6. Control of V2G:

The control of V2G are basically of two types. First control is known as centralized control. In this control sum of all of power of EV's available in a scheduled area for charging and discharging and it depend on electric grid demand[48]. They are managed by the help of the aggregator. This is shown in the fig 2-3.

The second control is called distributed control. In this type there is no central control is present which control the charging and discharging of the EV's. The owner of the EV make their own profile of charging according to their demand. There are merits and demerits of both types.

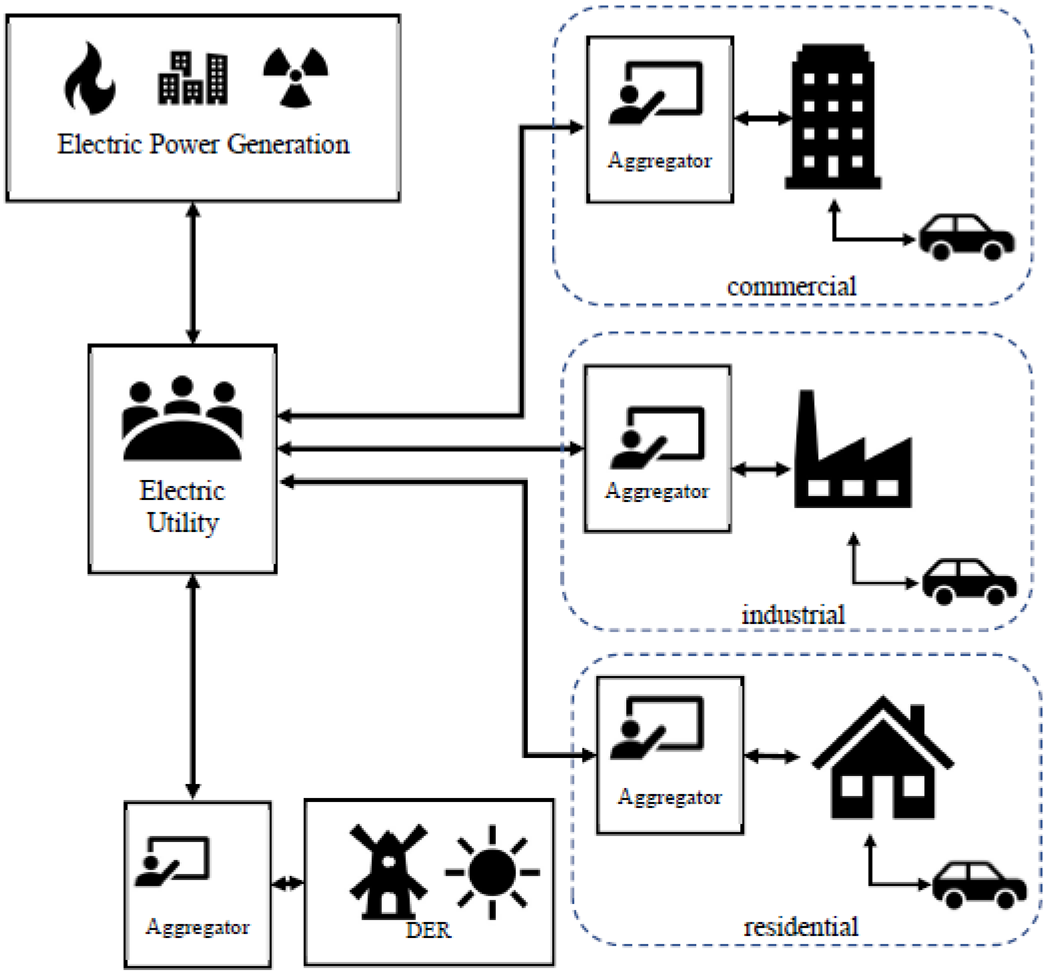

Figure 2-3. Aggregator concept[14]

2.7. EV's Fleet Operation:

The framework for the charging of EV's are propose by san romanet al. According to this two electricity market agents are introduced[49]. First one is EV charging manager and other is EV aggregator/fleet operator. The fleet concept is used when more than one EV's are introduced in the system. The penetration of more EV's cause the extra burden on the system and also it is very difficult to handle[50].

For the control of fleet operation, the control system also introduced. Comparison is done in the Table 1. Basically, for the fleet operation there are three types of the control. First one is known as centralized control the second one is known as transactive control and the third one is known as price control. These controls are shown in the fig 2-4 and fig 2-5.

In centralized control fleet operation is controlled in a centralized way. while the transactive control is based on the market. The price control uses one-way communication.

Table 2-1. Types of Control in Fleet operation[18]

	Features	Computational requirements	Communication form and cost
Centralized control	• Control signals (i.e., set points) • High level controller makes the decision	• Low for Control object • High for controller	• One/Two way • High
Transactive control	• High level controller generates and sends the price to the units • Low level units respond with power schedule • Multiple iterations • Privacy improved	• Relative high for Control object • Low for controller	• Two way • Relative high
Price control	• High level controller generates and sends the price to the units • Low level units need not to explicitly respond. • Privacy improved	• Low for Control object • Relative high for controller	• One way • Low

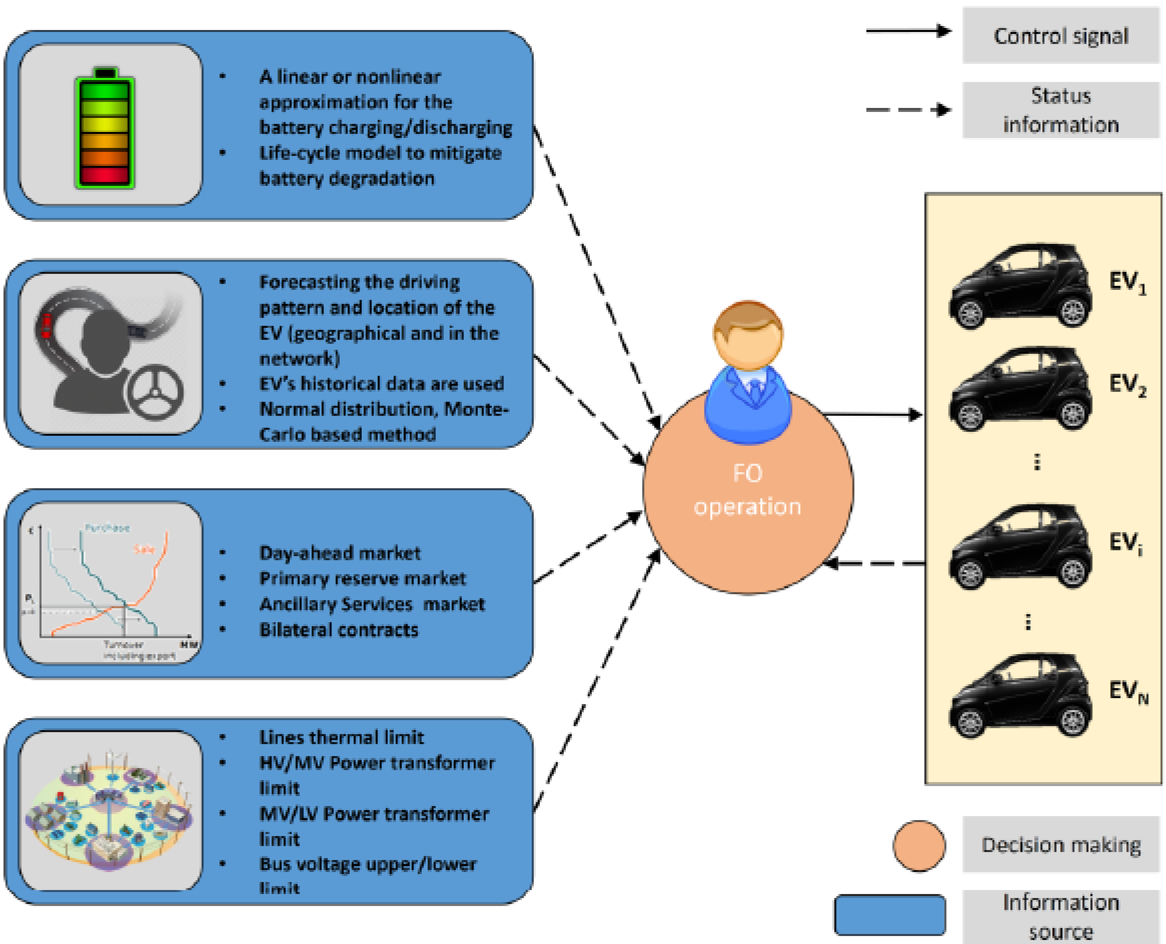

Figure 2-4. Fleet operation[18]

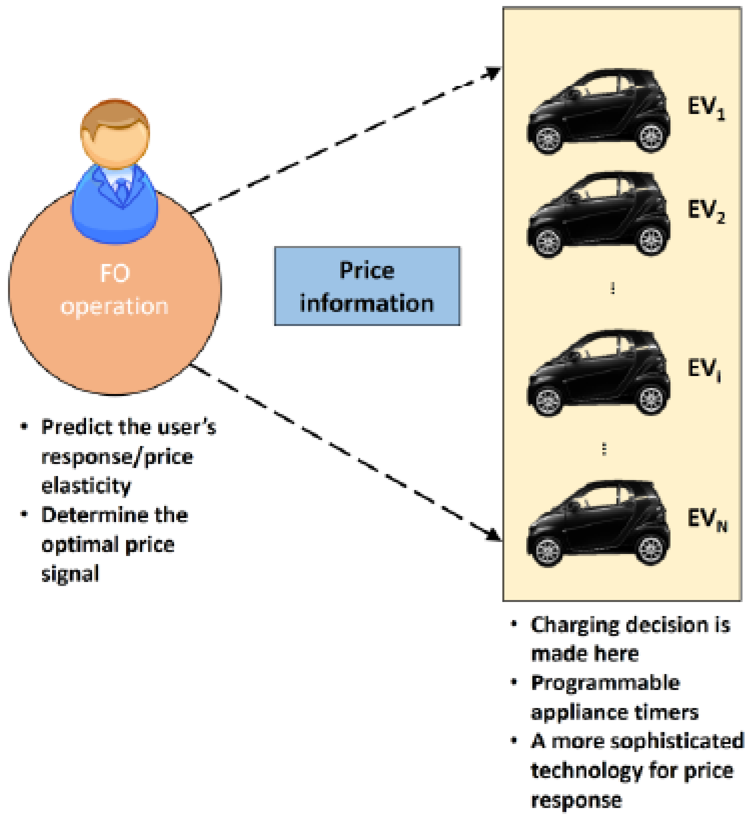

Figure 2-5. Fleet operation according to price[18]

.

Chapter 3

Methodology

CHAPTER 3. METHODOLOGY

3.1. Methodology

Battery charger can be constructed by different ways. It depends on the type of the battery and the source which used.in the literature review there two types of topologies used for the charging of the battery. One is called single stage and other is known as 2 stage converters as shown in the fig 3-1. For the low power rating single stage topology is used. The rating is low so that why no need for the galvanic isolation like transformer is needed in this type. These types of charger for battery is known as non-isolated battery charger. They are 1-phase.

They are controlled by a single controller. The function of the controller is to perform the process of rectification such as AC-DC conversion and power factor correction is also done in this. For the charging of the battery DC-DC conversion is required.

The cost of these charger is very low. The weight and size of these charger is also small. These chargers are designed for the power rating such as (<250). They do not applicable for high power rating because the problem of the isolation. In addition to the ripples are also present in output DC voltage which is used to charge the battery.

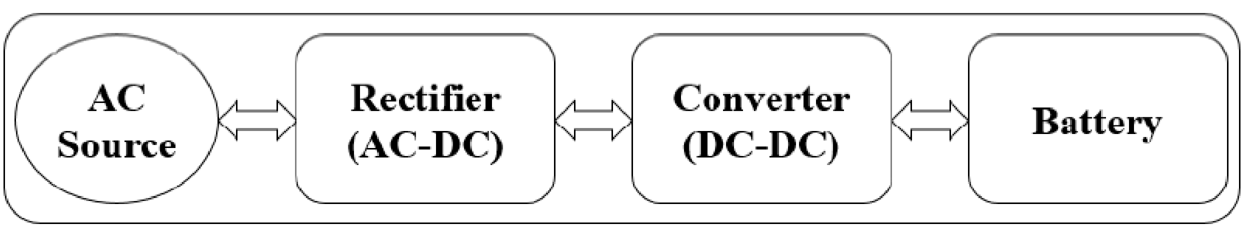

Figure 3-1. Block diagram of bi-directional charger

This other type which is known as two-stage is used for the high-power rating. The power rating is high, so the problem of galvanic isolation occur in this type and that's why high frequency transformer is required as shown in the fig 3-2. It is also very important to provide the protection in fault condition also this transformer work as voltage conversion such as for buck operation and for the boost operation according to the charging and discharging mode. So, this is the reason to call these chargers as isolated charger. It is available in single phase as well as three phases.

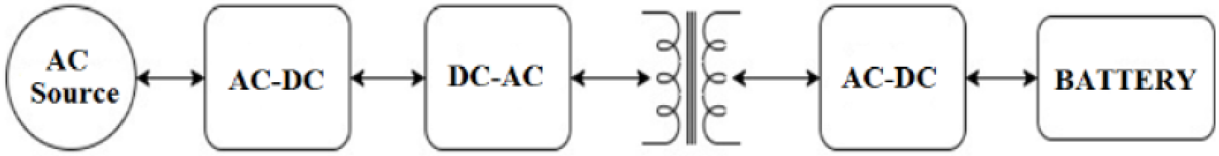

Figure 3-2. Block diagram of isolated battery charger

In this type the 2 controller is used.one controller perform the process of rectification such as from AC-DC with power factor correction. A DC link capacitor is also used which is controlled by another controller and perform the conversion process like DC-DC. This conversion is used to attain the DC voltage at the output terminal. They are both types single-phase and 3-phase. The selection process is done according to the power rating

.

These are also used for the uni-directional as well as bidirectional depending on the condition of the circuit. For rectification process of single phase mostly diode topology is used and for bi-direction H-bridge is used. Single phase bi-directional. This is shown in the fig 3-3.

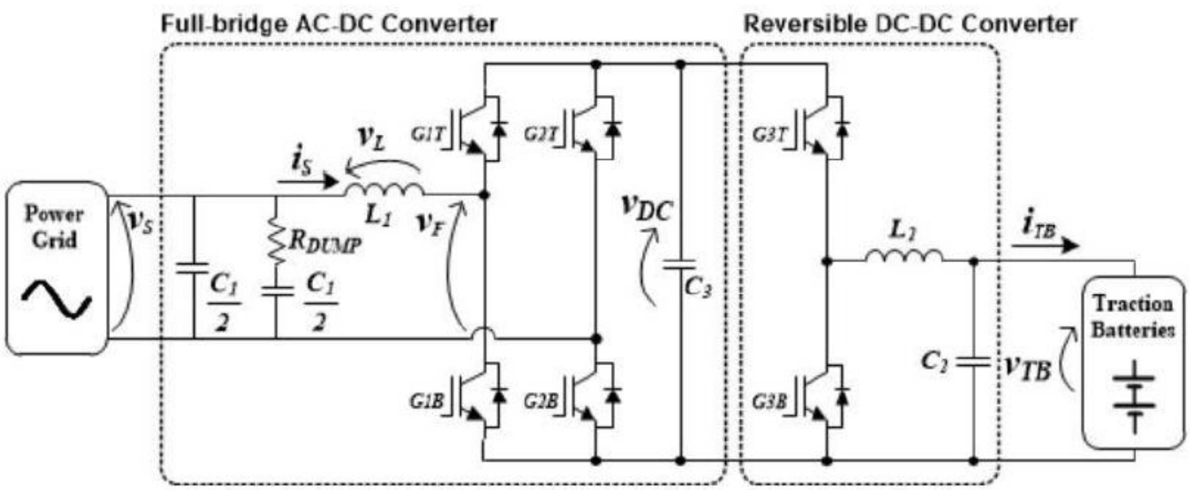

Figure 3-3. Block diagram of bi-directional single-phase battery charger[26]

The proposed 1-phase or 3-phase whether it is isolated or non-isolated battery charger it has at least one of the following drawbacks.

3.2. Drawbacks:

3.2.1. DC link Bus Voltage:

The two controller is used in the isolated charger to regulate the output at its both stages. while in Non-isolated the output voltage vary with the change in the load. This is the cause for producing the heat as a result power loss increase in non-isolated battery charger. This can damage the components also. So, the rating of the component must be high.

3.2.2. Low-frequency harmonics:

When the two power conversion stages such as first conversion is AC-DC conversion the second conversion is DC-DC conversion are executed by a single controller in non-isolated battery charger the input current is slanted. As a result, the low-frequency harmonics occur in bulk amount.

3.2.3. High-frequency harmonics:

A filter is device which is used for eliminating the high frequency ripple produced in the isolated or non-isolated battery charger. The filter can be active or passive such as L,LC,LCL etc. depending upon the harmonics produced by the DCM operation. While connecting with the grid LCL filter is used.

3.2.4. Separate module:

The size of the isolated battery charger is greater due to the two-stage conversion to regulate its output voltage. For the process of conversion separate modules are required.

3.2.5. Voltage or Current Fed:

L filter is used in non-isolated battery charger. The source behind this is voltage or current.in generally the Voltage fed is superior to the current fed because a storage capacitor is used which has higher power rating.

3.2.6. Controllability:

The controller of the non-isolated battery charger is fast and smart as it controls the battery charger output. It is principally right for converters that their type is resonant type.

3.3. Concept of V2G and G2V:

The aim is to charge the EV and to supply back to the grid. There are two terms which are used for this one is called V2G and the other one is known as G2V operation.

In G2V operation the power from the grid is supplied to charge the electric vehicle. In this buck converter is used for charging purpose. The block diagram for the G2V operation is as follows as shown in the fig 3-4.

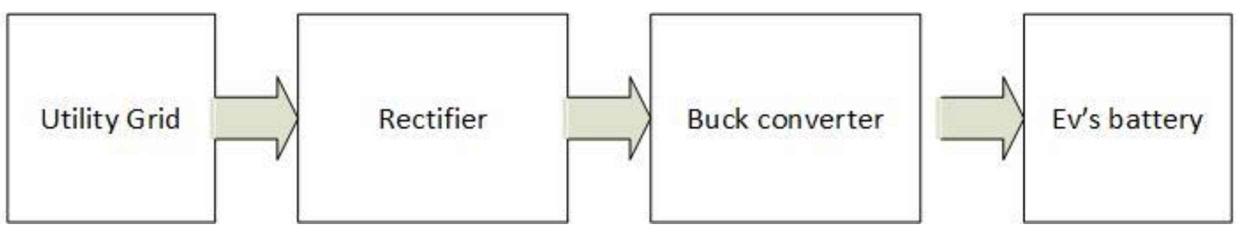

Figure 3-4. Block Diagram in G2V Operation

While in V2G operation the process is reverse. The battery supplies its energy to the grid. In this boost converter is used to supply power to the grid. The block diagram for the V2G is as shown in the fig 3-5.

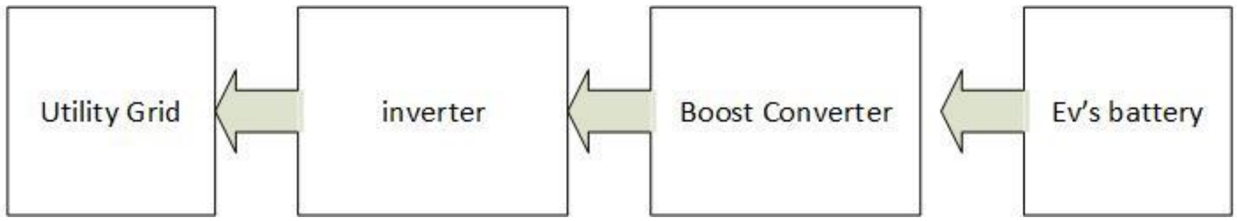

Figure 3-5. Block Diagram in V2G Operation

3.4. Proposed system:

To avoid from all above problems the constructed battery charger has capacity to charge and discharge the battery. The constructed battery charger is made up for single-phase AC source, DC source and hybrid and it is responsible for the both operation such as V2G and G2V operation. The construction of the proposed system is discussed in this section.

3.5. Construction for AC grid:

The proposed charger composed of single-phase AC Grid which is connected by a rectifier which is connected to a DC-link bus capacitor followed by a high frequency transformer. The Primary winding of the transformer is connected by a four switches and output is connected by a full bridge which further connected by a battery. The circuit diagram of the proposed system is shown in the fig 3-6.

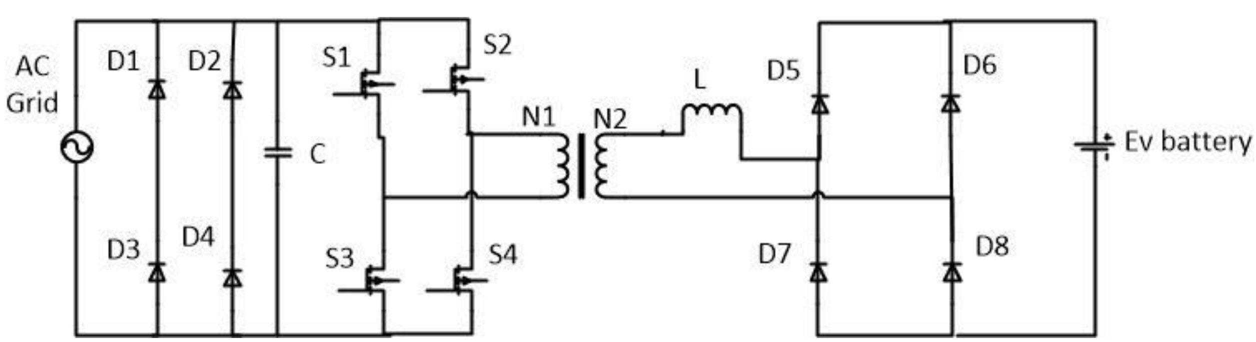

Figure 3-6. battery charger V2G operation diagram in AC grid

In grid connected mode of operation, generally LCL filter is used. This LCL filter is used because it has more advantages than the LC filter and L filter. The L_g is the grid side inductor while the L_i is the inverter side inductor. The L_i always smaller than the L_g. The capacitor is used to remove the harmonics. The bridge is used as rectifier when it is in charging mode of operation and it is used as inverter when it is used in discharging mode of operation.

To avoid from the voltage stress and current stress the leg of high frequency transformer is this leg is comprising of four switches act as an inverter in charging mode i.e. Change DC-link voltage into AC-voltage while act as rectifier in discharging mode. The high frequency cantered tap AC-AC transformer is used for multipurpose. One purpose is for buck-boost operation and the other purpose is isolation. In charging mode, it buck the AC voltage because to charge the battery of the electric vehicle. while in discharging mode it boost the AC voltage because to supply power to the grid.

3.6. Charging and Discharging Mode:

3.6.1. Charging Mode (G2V):

An isolated circuit is used in the proposed system. There are two stages in the charging mode in the proposed topology such as for conversion of AC-DC and for conversion of DC-DC.

For conversion of AC-DC full wave rectifier is responsible which alter the AC voltage into the DC voltage by a link capacitor which is DC. This is shown in the fig 3-7.

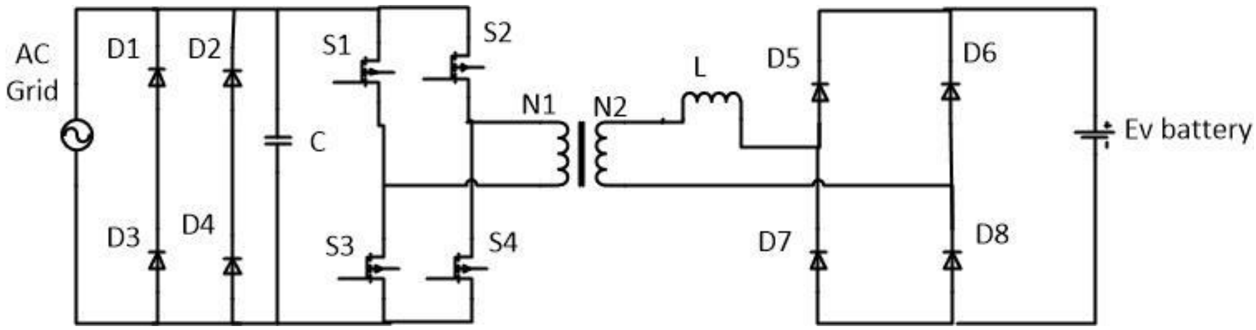

Figure 3-7. proposed charger in case of charging

In the conversion of DC-DC, the capacitor is used as DC-link capacitor provide a DC voltage which is constant. The high frequency transformer connected with four switches which act as inverter. This convert the AC voltage into DC voltage through the PI controller.

The transformer is centrally tap and it buck the AC voltage while operating in charging mode. If some fault occurs, it provides isolation. It protects the battery from the fault current from the source side. The buck voltage then applied to the full bridge act as diode which convert the AC voltage into DC voltage to charge the battery as shown in the fig. the required output is attain by the PI controller.

3.6.2. Discharging Mode (V2G):

In discharging mode, for conversion of DC-DC the battery voltage applies across the full-bridge which alter the DC voltage into AC voltage which is connected by a HF transformer which is centrally tap. Now this transformer work as boost and it boost the AC voltages. It also provides the isolation. The constant voltage is maintained by a PI controller.

Then DC voltage is converted into AC voltage to provide the supply to the grid this is constant and pure sinusoidal and controlled by PR controller. The circuit diagram is shown in the fig 3-8.

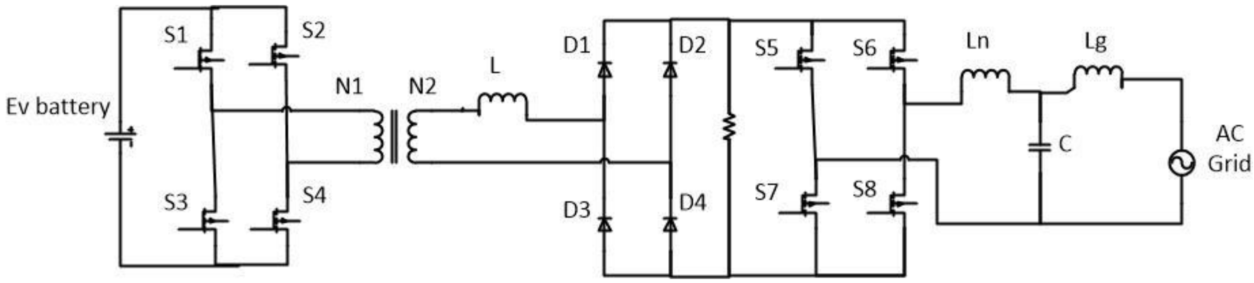

Figure 3-8. proposed system in case of discharging

3.7. Construction for DC grid:

In the DC grid, the proposed system is used for charging and discharging of the battery.

3.7.1. Charging Mode (G2V):

In the charging mode of operation DC supply is applied to the switches which converts the DC voltage into the AC voltage. This AC voltage is applied to the high frequency transformer. This transformer act as buck for the charging of the battery and then this AC supply is converted into the DC supply by a full wave rectifier which convert the AC voltage into the DC voltage and supply to the battery to charge the battery as shown in the fig. the desired output voltage is maintained by the PI controller. This is shown in the fig 3-9.

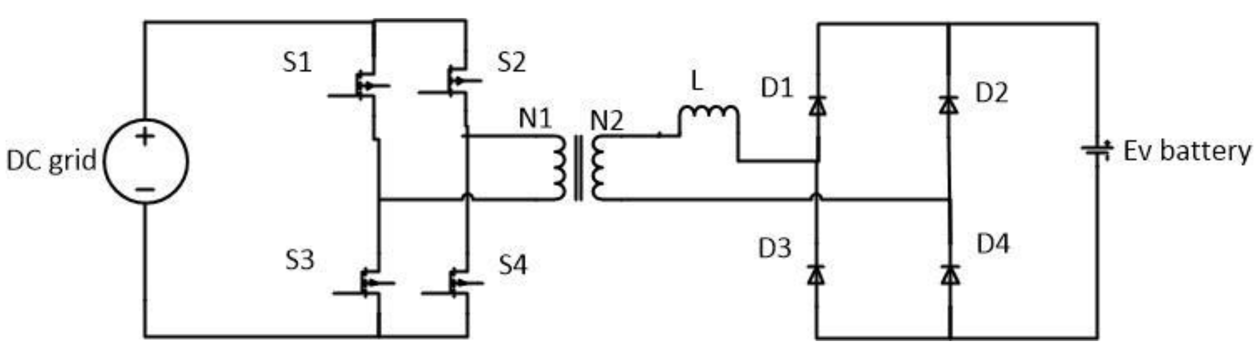

Figure 3-9. Proposed diagram in charging Mode

3.7.2. Discharging Mode (V2G):

In the discharging mode of operation, the battery voltage is applied to the switches to convert them into the AC voltage. Then these voltages are provided to the transformer which act as a boost transformer and the boosted voltage is applied to the full bridge rectifier which convert the AC voltage into DC voltage and supply to the grid as shown in the fig. In this the desired output can be obtained by PI controller. This is shown in the fig 3-10.

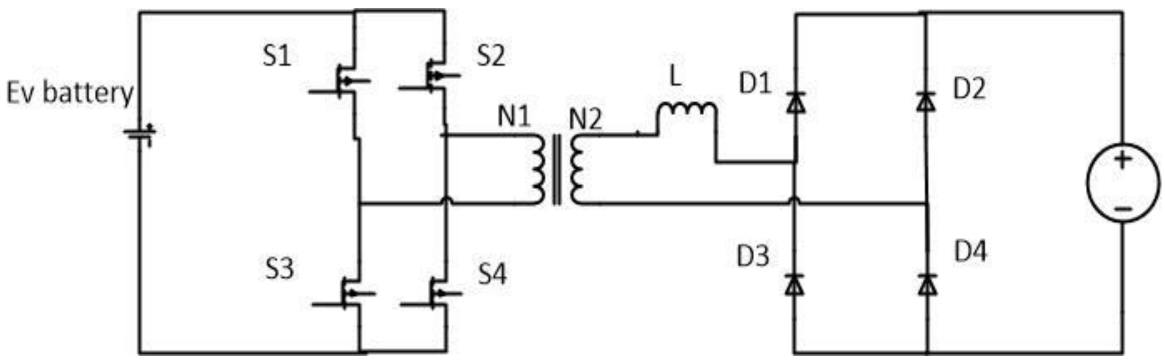

Figure 3-10. Proposed system in case of discharging

3.8. Construction of hybrid microgrid:

3.8.1. Charging Mode (G2V):

In the charging mode while operating in hybrid microgrid the Electric vehicle can be charged by AC and DC grid. The topologies used in this is same, but the battery is charged by the AC and DC grid simultaneously. The supply from the AC grid is converted into DC supply by two stage topology and the supply from the DC grid is buck to charge the Electric vehicle battery. The proposed topology is shown in the fig 3-11.

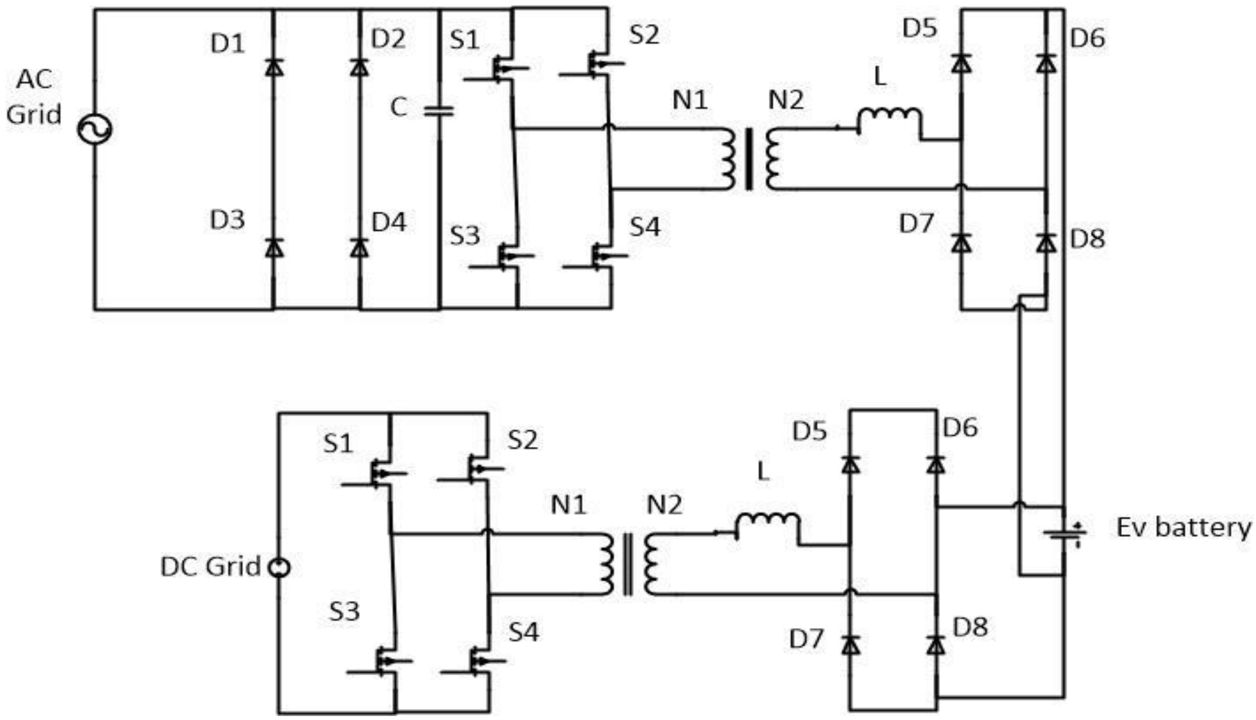

Figure 3-11. Proposed system in case of charging

3.8.2. Discharging Mode (V2G):

In the discharging mode the supply from the battery is again given to the AC grid and the DC grid as required. The diode work as the switches and the switches used as diode. The buck mode is converted into boost mode in the AC and DC grid respectively.

3.9. PI Controller:

The control of the PI with the grid voltage is feed-forwarded. It is denoted by (V_g). The current of the inverter output is denoted by the L_i and it is used as feed-back. L_i is the current of the inverter which is use as reference and (V_g) is the voltage reference. This is shown in the fig 3-12.

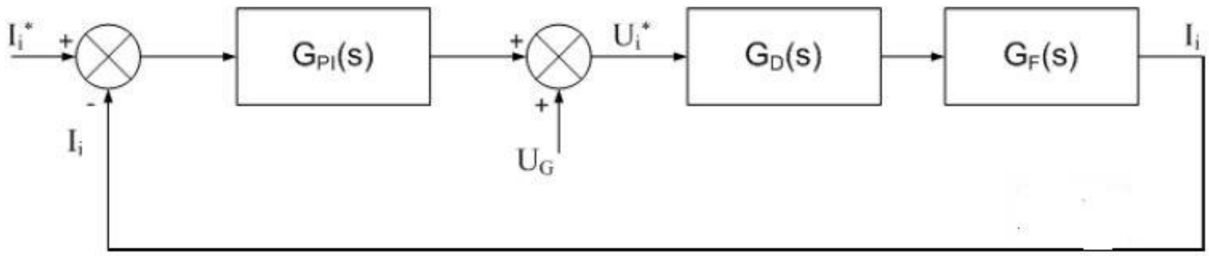

Figure 3-12.PI controller

The PI controller is represented by

$$Gpi(S) = Kp + \frac{Ki}{s} \tag{1}$$

The proportional term in this equation is Kp and the integral term is Ki.

The tine of the one sample is equal to the Gd(S).

$$Gd(s) = \frac{1}{1 + sTs} \tag{2}$$

3.10. PR Controller:

The control of the PR is given below. The inverter current is Li and it is further used as feedback reference and Vg is known as inverter voltage. It is also used as reference. This is shown in the fig 3-13.

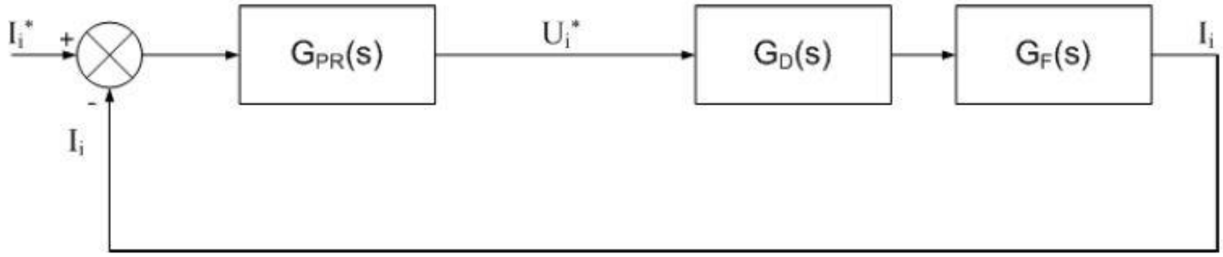

Figure 3-13. PR controller

The PR controller is represented by

$$Gpr = K_p + Ki(\frac{s}{(s^2 + \omega^2)} \tag{3}$$

In this equation Kp is the proportional integral and Ki is the integral gain term. The resonant frequency is wo. It provides an infinite gain at the ac frequency w_o. There is no phase shift at the other frequency.

This problem can be avoided by non-ideal.

$$Gpr = K_p + Ki(\frac{s}{(s^2 + \omega^2)} \tag{4}$$

In the above equation ωc is the total bandwidth of the frequency of the AC.

3.11. LCL filter design consideration:

LCL filter is selected due to its better performance and its design is very simple. This filter is used for the grid-connected mode. The filter design depends upon the ripple and harmonic current.

For design there are some instruction to follow. The total inductance (L1+L2) must be less than 10% .The advantage of this is to avoid the large voltage drop across the inductor. The ripple current is also in the limit of 20% of the rated current. The capacitance value is neither small nor so large.

The inverter harmonics must be limited according to the IEEE

$$10fg < fres < 0.5fs \tag{5}$$

The unipolar modulation is famous because the efficiency of this is very high. The switching frequency is doubled as compared to the carrier frequency. The size of the filter is small in the unit-polar modulation.

Chapter 4

Simulation and Results

CHAPTER 4. SIMULATION AND RESULTS

4.1. Simulation:

A 1.5 KW isolated battery charger with voltage of 120V is constructed and simulation is done in Simulink/ MATLAB. The proposed battery charged by single-phase AC source, DC source and hybrid, while the constructed charger has ability to discharge the battery when there is power is required. The battery charger work on nominal frequency i.e. 50 HZ, while the switching frequency of the proposed battery is 20000 HZ. The input single phase supply for AC source is 220 V. It is same in the case of DC and Hybrid-microgrid. The output voltage of the battery is 120 V.

4.2. Parameters:

The parameters of the proposed battery charger are given in the table 2. Each value is given from the simulation which is done in the MATLAB/Simulink. By using these value the results can be achieved.

Table 4-1. Parameters

Sr.no	Parameters	Values
1	Source side inductor L_i	400e-6
2	Source side capacitor	100e-3
3	Inverter side inductor L_g	100e-3
4	DC link bus capacitor	500e-6
5	Transformer Primary winding	220 V
6	Transformer Secendary winding 2	120 V
7	Output capacitor	100e-3

These parameters are same in the case of AC,DC and hybrid microgrid. Some of the component are not used in the case of DC. The values of these parameters are same in all three cases.

4.3. AC Grid:

4.3.1. Charging Mode (V2G):

In the charging Mode while operating in AC grid the battery is charged by the input supply voltage of 220 V AC. PI controller is used to maintain the output voltage of 120 V DC with the help of the proper switching on HF leg. The SOC in the G2V mode is shown in the fig which shows the increment behaviour which means that battery is in charging mode as shown in the fig 4-2. The output voltage of the proposed battery in shown in the fig 4-1.

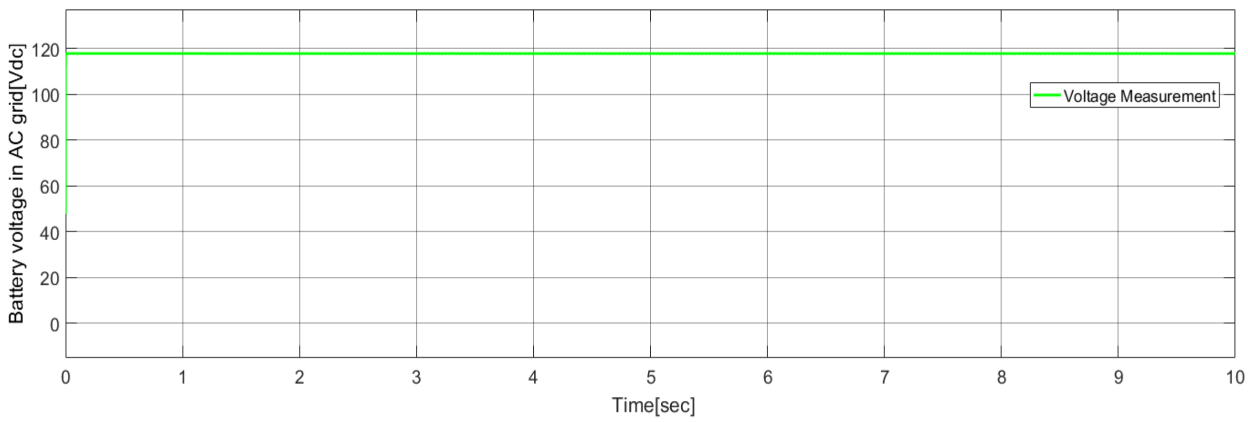

Figure 4-1. Battery voltage in AC grid

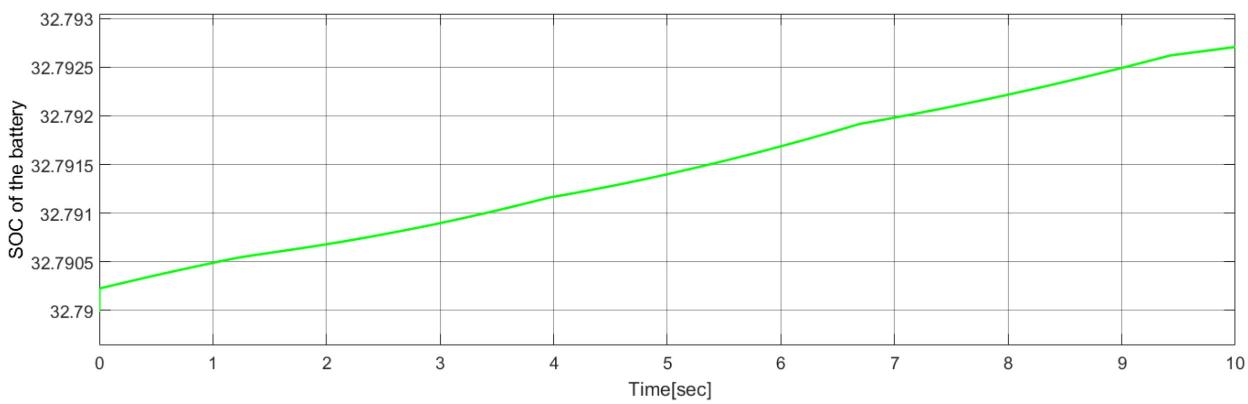

Figure 4-2.SOC of the battery in G2V mode

4.3.2. Discharging Mode (V2G):

In the discharging mode while operating in AC grid, battery is discharged and supply 220 AC Voltage to the grid. The PI and PR controller are used to main 220 AC Voltage. This is shown in the fig 4-3.The SOC in the V2G mode is decreasing which means that the battery is discharging and supply power to the grid as shown in the fig 4-4.

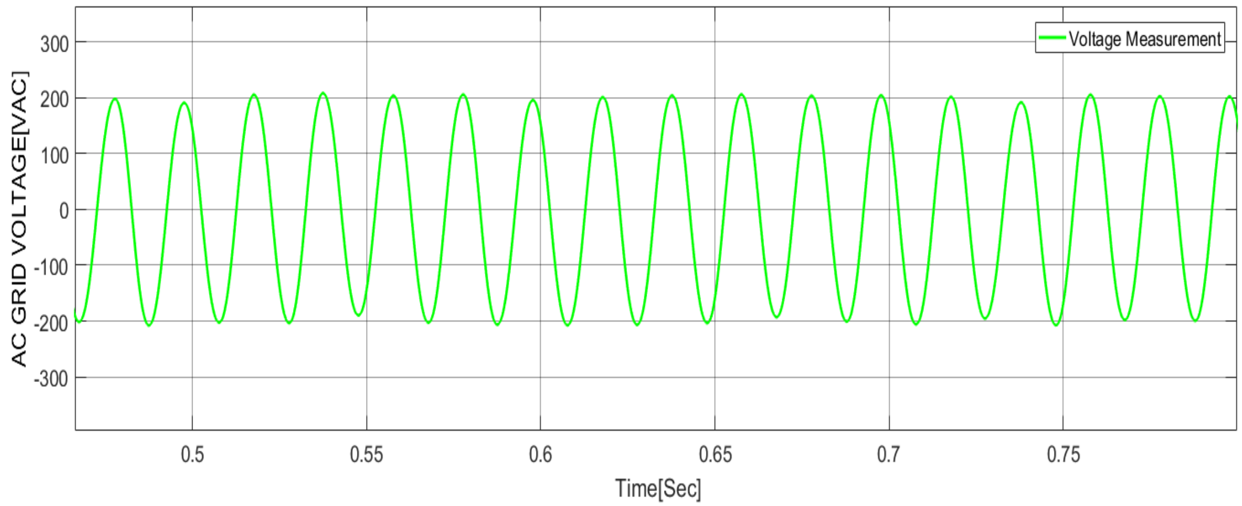

Figure 4-3. Grid Voltage

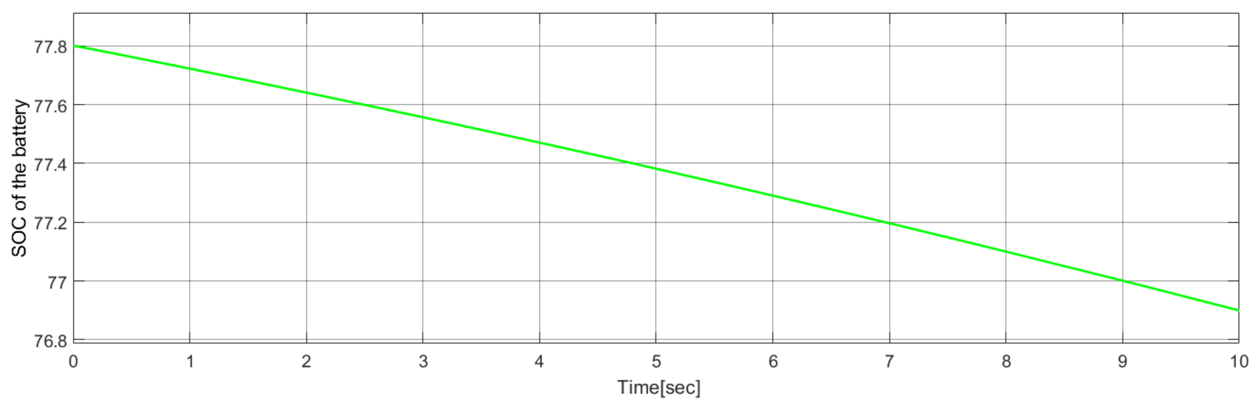

Figure 4-4.Percentage SOC in V2G mode

4.3.3. THD In Grid Connected Mode:

The THD in grid connected mode is allowed 5%. The proposed system has the THD of 2.37% as shown in the fig 4-5.

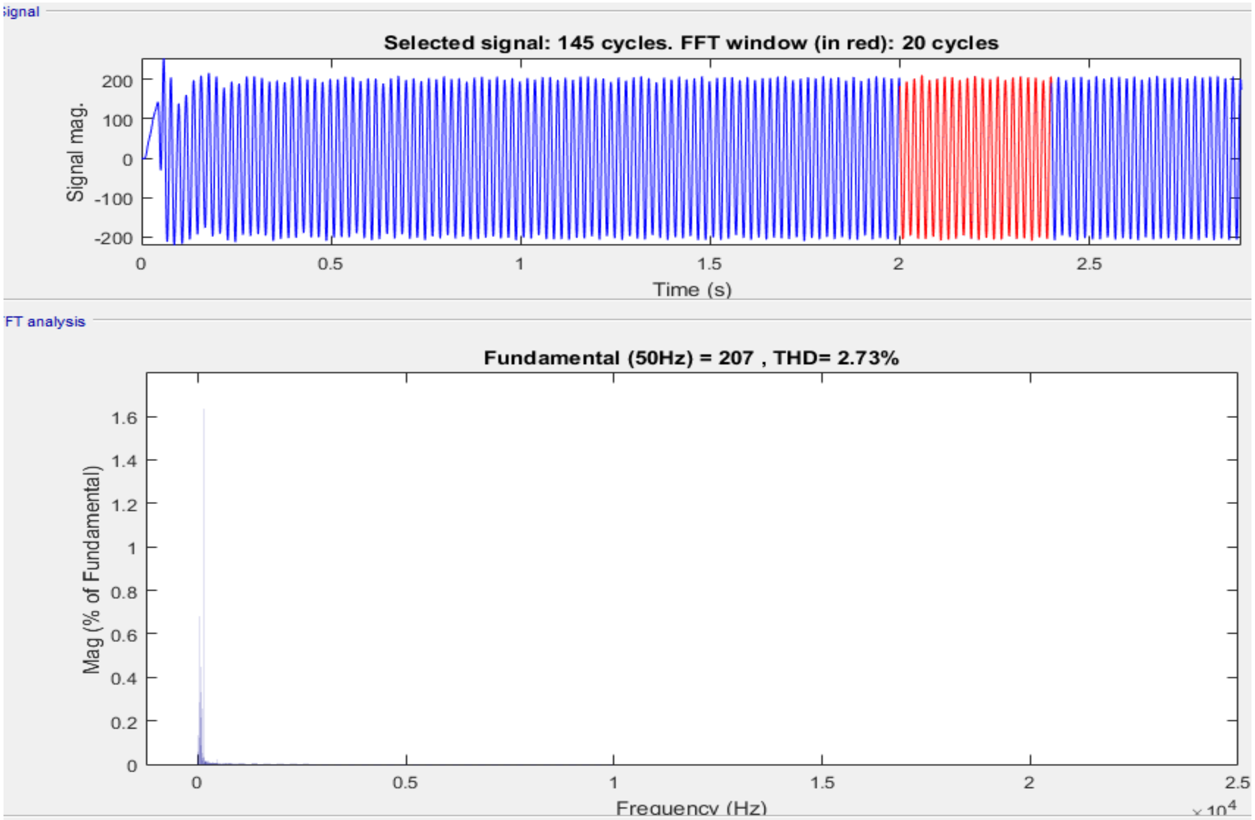

Figure 4-5. THD in case of Grid connected mode

4.4. DC Grid:

4.4.1. Charging Mode (G2V):

While operating in charging mode the charging of the battery is done by the DC Grid which has voltage of 220 V and this voltage is DC and the 120 V of the battery is also DC . This 120 Voltage is maintained by the PI controller as shown in the fig 4-6.

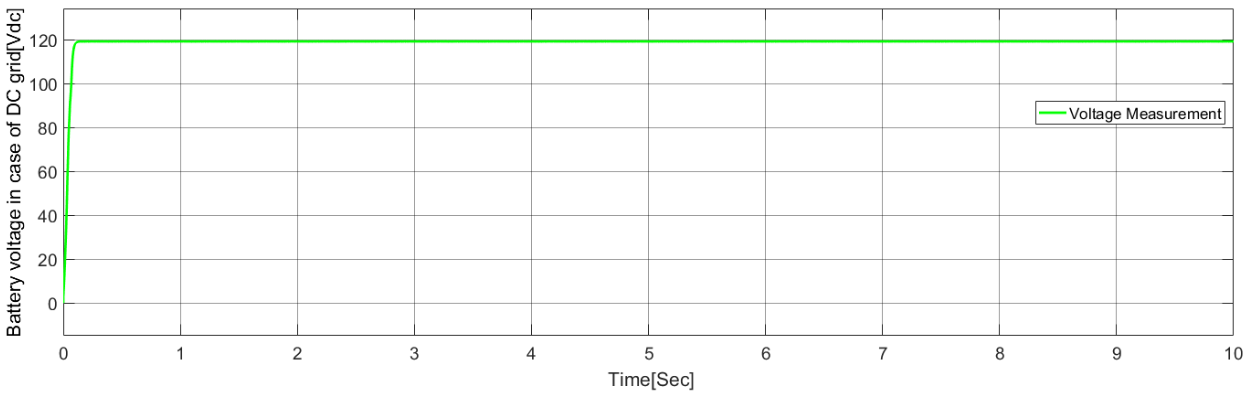

Figure 4-6. Battery voltage in case of DC Grid

4.4.2. Discharging Mode (V2G):

In the discharging mode the battery is discharged and supply energy to the DC grid. The DC grid has the voltage of 220 V DC. These voltage are maintained by the PI controller as shown in the fig 4-7.

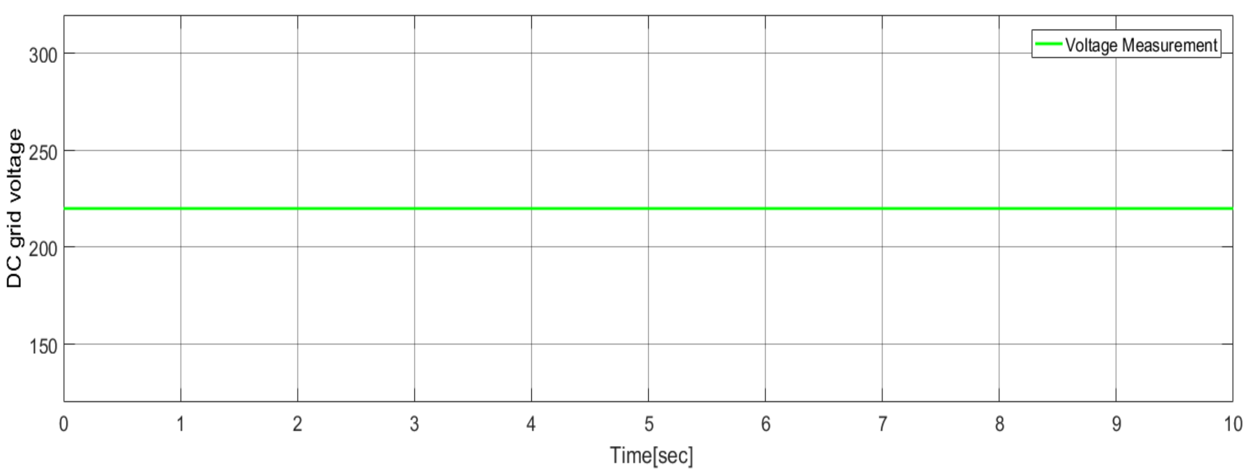

Figure 4-7. DC Grid Voltage

4.5. Hybrid Grid:

4.5.1. Charging Mode (G2V):

In the charging Mode the battery is charged by the DC and AC source. The battery voltage is maintained 120 V DC by the help of PI controller as shown in the fig 4-8.

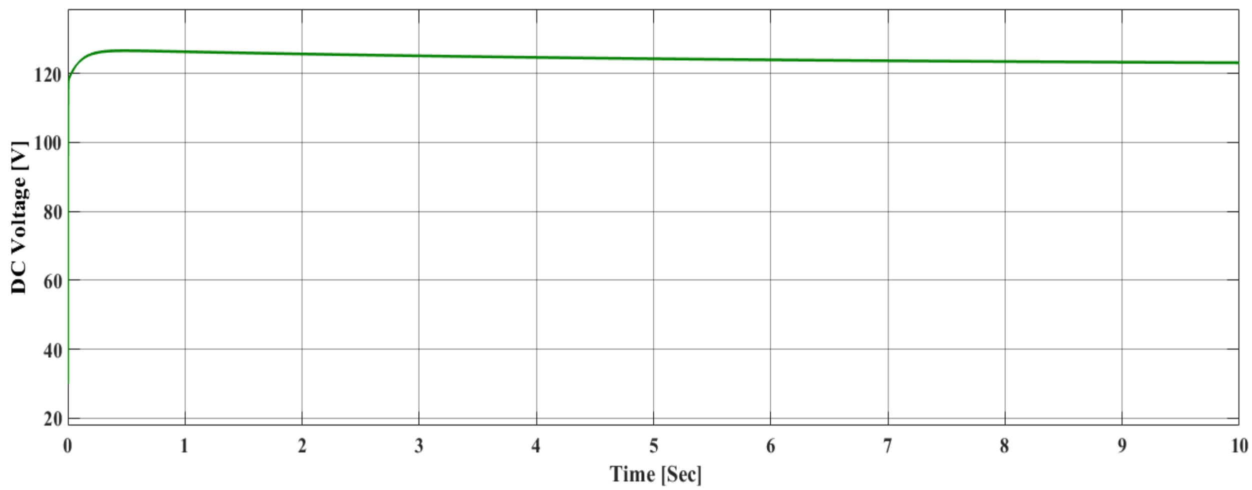

Figure 4-8. Battery voltage in case of Hybrid microgrid

4.5.2. Discharging Mode (V2G):

In the discharging mode the battery is used to supply the AC voltage to the AC grid and the DC voltage to the DC grid. This is done with the help of PI controller and PR controller as shown in the fig 4-9.

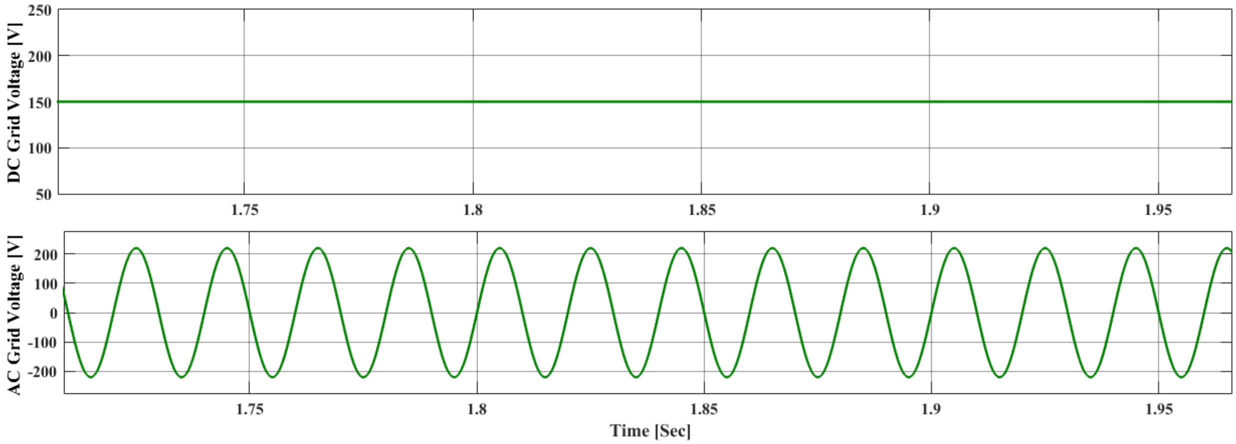

Figure 4-9. AC and DC grid Voltage

4.6. Comparison of conduction losses:

4.6.1. Conduction losses:

The dissipation of a power in a switch during the conduction can be written as :

$$Pcon(t) = Von(t)Isw(t) \tag{6}$$

In this equation V_{on} are the voltages of the on state and i_{sw} is the current of the on state. These equations are taken from this paper. [43]

The voltage of the IGBT when it is On state can be obtained as

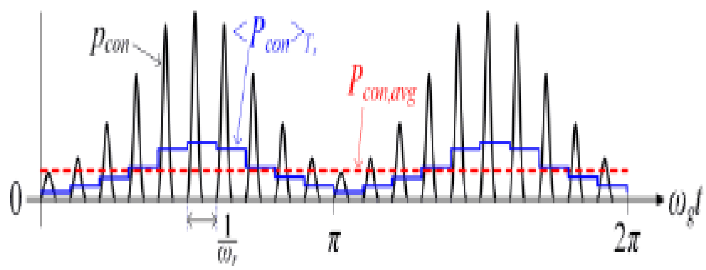

Figure 4-10. Conduction Losses in One switch

$$Von(t) = Vceo + Ron\,Isw(t) \tag{7}$$

If we want to find the average power loss of the IGBT we can find from the following equation

$$Pavg.cond = \frac{1}{T}\int_{0}^{t} [\,Vce(t) * Ice(t)dt] \tag{8}$$

As we know that time period (T) is the reciprocal of the frequency (f)

$$T = \frac{1}{f} \tag{9}$$

$$Pavg = f\int_{0}^{t} [P(t)dt] \tag{10}$$

The complete average power loss of the IGBT can be found in three steps

1: when the device is in on-state.

2: when it is conducting.

3: when it is in off-state.

$$Pavg(IGBT) = Pon + Pcond + Poff \tag{11}$$

The conduction losses do not depend on switching frequency, but they depend on the duty cycle.

4.6.2. Switching losses:

The switching losses must be kept in mind to improve the reliability of the system. It can be find as

$$Psw(IGBT) = (Eon + Eoff)fsw \tag{12}$$

The switching power loss can be find with the help of the data sheet .

$$Psw(IGBT) = \frac{[(Eon + Eoff) * Ipk * fsw * Vdc]}{\pi * Inom * Vnom} \tag{13}$$

4.6.3. Total losses :

The total switching losses of the IGBT can be find as

$$Pavg.IGBT(total) = Pcond(IGBT) + Psw(IGBT) \tag{14}$$

4.6.4. Diode losses :

The losses of the diode can be found as

$$Pavg(diode) = Pcond(diode) + Prec(diode) \tag{15}$$

$$Pcond(didoe) = 0.5\left(Vd0 * \frac{Ipk}{\pi} + Rd * \frac{(Ipk)^2}{4}\right) - m * cos\emptyset(Vd0 * \frac{Ipk}{8} + Rd * (Ipk)^2/3\pi \tag{16}$$

$$Prec.(diode) = Erec * fsw \tag{17}$$

4.6.5. Total losses:

The total conduction losses can be found by the equation 18. These are the sum of the P_{rec} (diode) and the P_{cond} (diode).

$$Pavg(diode) = Prec(diode) + Pcond(diode) \tag{18}$$

Table 4-2. Comparison losses in AC, DC and Hybrid-microgrid

Serial no	**Results**	**IGBT**	**Diode**
1	P(conduction losses) W	9.36	11.94
2	P(switching losses) W	2.084	18.14
3	P(total losses)	11.4	30.08
4	AC grid losses W	11.4*8=91.2	30.08*4=120.32
5	DC grid losses W	11.4*4=45.6	30.08*4=120.32
6	Hybrid Grid Losses	114*12=136.8	30.8*8=246.4

The table 4.3 depicted significant results while frolicking AC, DC and hybrid microgrid losses. P conduction losses were found 9.3W in IGBT while 11.94W in Diode. Whereas P switching losses were found high in Diode 18.14W and low in IGBT 2.084W. Average P total losses showed 30.08W in Diode and 11.4W found in IGBT. Significant AC grid losses were found during the study with 91.2W in IGBT while 120.32W in diode. Similarly, in DC grid 120.32W losses were again found in Diode but minimum DC grid losses were found in IGBT 45.6W. Hybrid grid losses were found minimum in IGBT with 136.8W while maximum losses were found 246.4W in Diode. Results revealed that maximum losses were found in AC grid while minimum losses shown in DC grid system. While the harmonic distortion in the case of DC grid is also very low as compared to the others.

Chapter 5

Conclusions and Future Work

CHAPTER 5. CONCLUSIONS AND FUTURE WORK

5.1. System setup:

A 1.5 KW isolated battery charger is constructed and simulation is done in Simulink/ MATLAB. The proposed battery charged by single-phase AC source, DC source and hybrid, while the discharging of the the constructed battery when the load is increased. The battery charger work on nominal frequency i.e. 50 HZ, while the switching frequency of the proposed battery is 20000 HZ. The input single phase supply for AC source is 220 V. It is same in the case of DC and Hybrid-microgrid. The output voltage is 120 V DC.

5.2. Conclusion:

The proposed battery can charge the battery from single-phase source with voltage of 120-V with 12.5-amp current for connected battery, while the proposed battery charger discharge when the load increase.

As the output of proposed battery charging mode is DC voltage, a PI controller is used to control the output of the proposed battery charging circuit, the proper switching of only four switches (S1, S2, S3 and S4) of High-frequency leg through PI controller maintain the output 120V DC for the battery which is connected for charging mode of constructed battery charger. There is only one PI controller is used in charging mode of proposed battery charger circuit.

The performance of the EV's are analyze in AC Grid, DC Grid and hybrid microgrid. The conduction losses in AC,DC and hybrid-microgrid observed. From the table in the chapter 4 it is concluded that the losses in the Hybrid-microgrid is more than the AC and the DC grid. The minimum conduction losses occur in DC grid. The DC grid is the best choice in the case of Electric vehicle integration due to its minimum conduction losses.

5.3. Future Work:

For the future work following suggestions can be considered for further research:

- This system may extend the system to more parking slots and EVs.
- This research work can be implemented using MPC to predict the arrival and departure of EVs.
- It is suggested that this work can be further extended for market based and real time operations.
- This work can be used for future recommendation of the Grid selection.

References

1. Vandael, S., et al., *A Scalable Control Approach for Providing Regulation Services with Grid-Integrated Electric Vehicles*, in *Design and Analysis of Distributed Energy Management Systems*. 2020, Springer. p. 107-128.

2. Zeng, X., et al., *Commercialization of lithium battery technologies for electric vehicles.* 2019. **9**(27): p. 1900161.

3. Yue, M., et al., *Review on health-conscious energy management strategies for fuel cell hybrid electric vehicles: Degradation models and strategies.* 2019.

4. Xiong, R., et al., *A sensor fault diagnosis method for a lithium-ion battery pack in electric vehicles.* 2019. **34**(10): p. 9709-9718.

5. Cikanek, S. and K. Bailey. *Regenerative braking system for a hybrid electric vehicle*. in *Proceedings of the 2002 American Control Conference (IEEE Cat. No. CH37301)*. 2002. IEEE.

6. Hiermann, G., et al., *Routing a mix of conventional, plug-in hybrid, and electric vehicles.* 2019. **272**(1): p. 235-248.

7. Cusenza, M.A., et al., *Energy and environmental assessment of a traction lithium-ion battery pack for plug-in hybrid electric vehicles.* 2019. **215**: p. 634-649.

8. Shabbir, W. and S.A.J.A.E. Evangelou, *Threshold-changing control strategy for series hybrid electric vehicles.* 2019. **235**: p. 761-775.

9. Xie, S., et al., *Predictive vehicle-following power management for plug-in hybrid electric vehicles.* 2019. **166**: p. 701-714.

10. Liu, T., et al., *A heuristic planning reinforcement learning-based energy management for power-split plug-in hybrid electric vehicles.* 2019. **15**(12): p. 6436-6445.

11. Sun, X., et al., *Study on segmented-rotor switched reluctance motors with different rotor pole numbers for BSG system of hybrid electric vehicles.* 2019. **68**(6): p. 5537-5547.

12. Yang, G., et al., *Interoperability Improvement for Wireless Electric Vehicle Charging System Using Adaptive Phase-Control Transmitter.* 2019. **7**: p. 41365-41379.

13. Bhatti, A.R., et al., *Optimized sizing of photovoltaic grid‐connected electric vehicle charging system using particle swarm optimization.* 2019. **43**(1): p. 500-522.

14. Shi, J., et al., *Operating Electric Vehicle Fleet for Ride-Hailing Services With Reinforcement Learning.* 2019.

15. Morrow, K., D. Karner, and J.J.U.D.o.E.-V.T.P. Francfort, *Plug-in hybrid electric vehicle charging infrastructure review.* 2008. **34**.

16. Zhou, X., et al. *Multi-function bi-directional battery charger for plug-in hybrid electric vehicle application*. in *2009 IEEE energy conversion Congress and exposition*. 2009. IEEE.

17. Donnelly, R.B., et al., *Charge Control System for Mobile Energy Storage Fleet*. 2019, Google Patents.

18. Loeb, B., K.M.J.T.R.P.A.P. Kockelman, and Practice, *Fleet performance and cost evaluation of a shared autonomous electric vehicle (SAEV) fleet: A case study for Austin, Texas.* 2019. **121**: p. 374-385.

19. Ban, M., et al., *Electric vehicle battery swapping-charging system in power generation scheduling for managing ambient air quality and human health conditions.* 2019. **10**(6): p. 6812-6825.

20. Yeh, J., *Optimal Vehicle Fleet Size and Routing of a Fleet of Electric Vehicles for Ride-Sharing*. 2019, California State Polytechnic University, Pomona.

21. Zhang, H., et al., *Enhancing fuel cell durability for fuel cell plug-in hybrid electric vehicles through strategic power management.* 2019. **241**: p. 483-490.

22. Xue, L., et al., *Dual active bridge-based battery charger for plug-in hybrid electric vehicle with charging current containing low frequency ripple.* 2015. **30**(12): p. 7299-7307.

23. Rosekeit, M., C. van der Broeck, and R.W. De Doncker. *Dynamic control of a dual active bridge for bidirectional ac charging*. in *2015 IEEE International Conference on Industrial Technology (ICIT)*. 2015. IEEE.

24. Pinto, J., et al., *Onboard reconfigurable battery charger for electric vehicles with traction-to-auxiliary mode.* 2013. **63**(3): p. 1104-1116.

25. Das, H.S., et al., *Fuel cell hybrid electric vehicles: A review on power conditioning units and topologies.* 2017. **76**: p. 268-291.

26. Joós, G., M. Lévesque, and M.J.I.T.o.S.G. Maier, *Integrated V2G, G2V, and renewable energy sources coordination over a converged fiber-wireless broadband access network.* 2013. **4**(3): p. 1381-1390.

27. Shin, C.-J. and J.-Y.J.I.T.o.P.E. Lee, *An electrolytic capacitor-less bi-directional EV on-board charger using harmonic modulation technique.* 2013. **29**(10): p. 5195-5203.

28. Liu, C., et al., *Opportunities and challenges of vehicle-to-home, vehicle-to-vehicle, and vehicle-to-grid technologies.* 2013. **101**(11): p. 2409-2427.

29. Yilmaz, M. and P.T.J.I.T.o.p.e. Krein, *Review of the impact of vehicle-to-grid technologies on distribution systems and utility interfaces.* 2012. **28**(12): p. 5673-5689.

30. Mischinger, S., W. Hennings, and K. Strunz. *Integration of surplus wind energy by controlled charging of electric vehicles*. in *2012 3rd IEEE PES Innovative Smart Grid Technologies Europe (ISGT Europe)*. 2012. IEEE.

31. Yilmaz, M. and P.T.J.I.t.o.P.E. Krein, *Review of battery charger topologies, charging power levels, and infrastructure for plug-in electric and hybrid vehicles.* 2012. **28**(5): p. 2151-2169.

32. Choi, J.-M., et al., *Design of leakage inductance in resonant dc-dc converter for electric vehicle charger.* 2012. **48**(11): p. 4417-4420.

33. Ngo, T., et al. *Study of single-phase bidirectional battery charger for high power application*. in *Proceedings of The 7th International Power Electronics and Motion Control Conference*. 2012. IEEE.

34. Wong, N. and M. Kazerani. *A review of bidirectional on-board charger topologies for plugin vehicles*. in *2012 25th IEEE Canadian Conference on Electrical and Computer Engineering (CCECE)*. 2012. IEEE.

35. Mitra, P., G.J.I.g. Venayagamoorthy, transmission, and distribution, *Wide area control for improving stability of a power system with plug-in electric vehicles.* 2010. **4**(10): p. 1151-1163.

36. Kisacikoglu, M.C., et al. *Single-phase inverter design for V2G reactive power compensation*. in *2011 Twenty-Sixth Annual IEEE Applied Power Electronics Conference and Exposition (APEC)*. 2011. IEEE.

37. Segaran, D., D. Holmes, and B. McGrath. *High-performance bi-directional AC-DC converters for PHEV with minimised DC bus capacitance*. in *IECON 2011-37th Annual Conference of the IEEE Industrial Electronics Society*. 2011. IEEE.

38. Du, Y., et al. *Review of high power isolated bi-directional DC-DC converters for PHEV/EV DC charging infrastructure*. in *2011 IEEE Energy Conversion Congress and Exposition*. 2011. IEEE.

39. Guilin, T., et al. *A novel driving and control system for direct-wheel-driven electric vehicle*. in *2004 12th symposium on electromagnetic launch technology*. 2004. IEEE.

40. Ellabban, O., J.V. Mierlo, and P.J.J.o.P.e. Lataire, *Control of a bidirectional Z-source inverter for electric vehicle applications in different operation modes.* 2011. **11**(2): p. 120-131.

41. Su, W., et al., *A survey on the electrification of transportation in a smart grid environment.* 2011. **8**(1): p. 1-10.

42. Jiang, Y., et al. *Improved method on flux-weakening control of permanent magnet synchronous motor in electric vehicles*. in *2011 International Conference on Electrical Machines and Systems*. 2011. IEEE.

43. Kramer, B., S. Chakraborty, and B. Kroposki. *A review of plug-in vehicles and vehicle-to-grid capability*. in *2008 34th Annual Conference of IEEE Industrial Electronics*. 2008. IEEE.

44. Sioshansi, R., P.J.E.s. Denholm, and technology, *Emissions impacts and benefits of plug-in hybrid electric vehicles and vehicle-to-grid services.* 2009. **43**(4): p. 1199-1204.

45. Pan, L. and C.J.E.p. Zhang, *Performance Enhancement of battery charger for electric vehicles using resonant controllers.* 2017. **105**: p. 3990-3996.

46. Zhang, C. and A.J.I.T.o.C.S.T. Vahidi, *Route preview in energy management of plug-in hybrid vehicles.* 2011. **20**(2): p. 546-553.

47. Koushki, B., P. Jain, and A. Bakhshai. *A bi-directional AC-DC converter for electric vehicle with no electrolytic capacitor*. in *2016 IEEE 7th International Symposium on Power Electronics for Distributed Generation Systems (PEDG)*. 2016. IEEE.

48. Vandael, S., et al., *A scalable three-step approach for demand side management of plug-in hybrid vehicles.* 2012. **4**(2): p. 720-728.

49. Cao, J. and A.J.I.T.o.p.e. Emadi, *A new battery/ultracapacitor hybrid energy storage system for electric, hybrid, and plug-in hybrid electric vehicles.* 2011. **27**(1): p. 122-132.

50. Green II, R.C., et al., *The impact of plug-in hybrid electric vehicles on distribution networks: A review and outlook.* 2011. **15**(1): p. 544-553.