EFFICIENT ELECTRIC VEHICLES INTEGRATION IN MICROGRID.

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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).

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ABSTRACT

Electric vehicles integration to the conventional AC power grid system ensures the continuity of power supply under different circumstances. The conversion from AC-DC and DC-AC happens in G2V mode of operation and V2G mode of operation respectively. Buck and boost converters are for charging and discharging of electric vehicles. Power losses occurs across each converter and because of load variation of conventional AC power grid system, DC power system can overtake the AC power system. The AC power grid has many disadvantages but the primary disadvantage is the wide variation of load because of its operating frequency/duty cycle. This factor is not included in DC power system. The overall efficiency of the system improves and the system becomes more simple and controllable because numbers of converters are reduced. To maintain voltages on a DC bus bar according to the variation of load with the help of controllers (droop and PI controllers) will be simpler as compared to conventional AC power system.

This work considers the possibility of creating an electric vehicles integration to the grid at parking lots of work places. The system is designed for the parking lots to charge EV's as the mostly cars remain parked over there for a long time i.e. office time. The intention is to maximize the utilization of stowed energy of EV's in V2G mode of operation and to maintain voltages according to the load variation. Power sharing from individual electric vehicle's capacity is controlled by droop controller.

The described technique is carried out using MATLAB to analyse the charging system characteristics and discharging. The results are analysed to ensure the feasibility of the proposed technique.

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ABBREVIATIONS

EV’s	Electric vehicles
DG’s	Distributed Generator
RES’s	Renewable energy sources
V2G	Vehicle to grid
G2V	Grid to vehicle
EMS	Energy management system
MOSFETs	Metal oxide semi-conductor field effect transistors.
IGBTs	Insulated gate pulse bi-polar transistors
THD	Total harmonic distortion.
DERs	Distributed energy resources
PWM	pulse width modulation
PID controller	proportional integral derivative controller
PI controller	proportional integral converter
CC-CV	Constant current constant voltage

Chapter 1

Introduction

CHAPTER 1. INTRODUCTION

1.1. Introduction:

Rapid development in the electric vehicles (EV's) industry illustrates the significance of EV's in transportation sector. Survey from international energy outlook (IEO) demonstrated rise of energy usage up to 44% in future (up to 2035) in comparison to the consumption rate of energy in 2008 in transportation industry[1]. Environmental factors such as air pollution and greenhouse effect are under consideration because of emission of carbon dioxide as fuel is markedly used in power generation industries and for transportation purposes. In addition, due to lower flammability of battery, compatibility of battery power discharging features makes the EV's more reliable than fuel driven vehicles. To protect environment for next generation, this consumption of fuel in transportation and power generation sectors must be reduced by replacing them with EV's and RESs (Renewable energy sources) respectively. Different renewable energy sources (wind, solar, thermal and biomass etc.) are producing around 17.1% of world's total energy[2].

Distributed Generators (DG's) which produces AC power are interlinked directly with AC bus. In addition these DG's are further connected to the main conventional grid via different converters (AC/DC/AC). These converters are generally used for voltage and frequency stability. These DG's can be connected directly with conventional grids if satisfying the concerned parameters. Sometimes DC loads are directly linked to the AC with the help of power electronic converters (AC/DC). Some DG's such as PV's and energy storage device produce DC output which are directly connected with DC load and are connected with AC load with the help of converters (DC/AC)[3]. Different energy storage devices are integrated with conventional AC micro grids to ensure the continuity of power supply in urgent cases where supply power is required. In such cases, electric vehicles are used as back-up sources where charged EV's are considered as DG's and smart grid is considered as load[4]. Charging and discharging of EV's requires power converters (AC/DC/AC). Hence power losses also takes place. Electric vehicles can be charged from AC micro grid/ RES's and then discharged. The bidirectional power flow between conventional smart grid and EV's can be illustrated in Figure 1.1

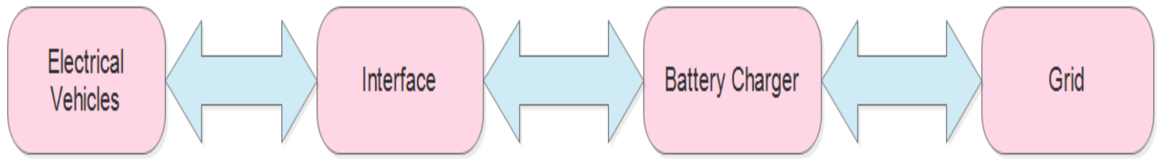

Figure 1.1 Bidirectional power flow system.

Integration of electric vehicles to conventional smart grids can be used as energy storage devices for back-up purposes in emergency (V2G mode). Such system contain bidirectional power flow to and fro from grid to vehicle (G2V, charging mode) and vehicle to grid(V2G, discharging mode) with protection[5].The charging and discharging mode of EV's are in figure 1.2.

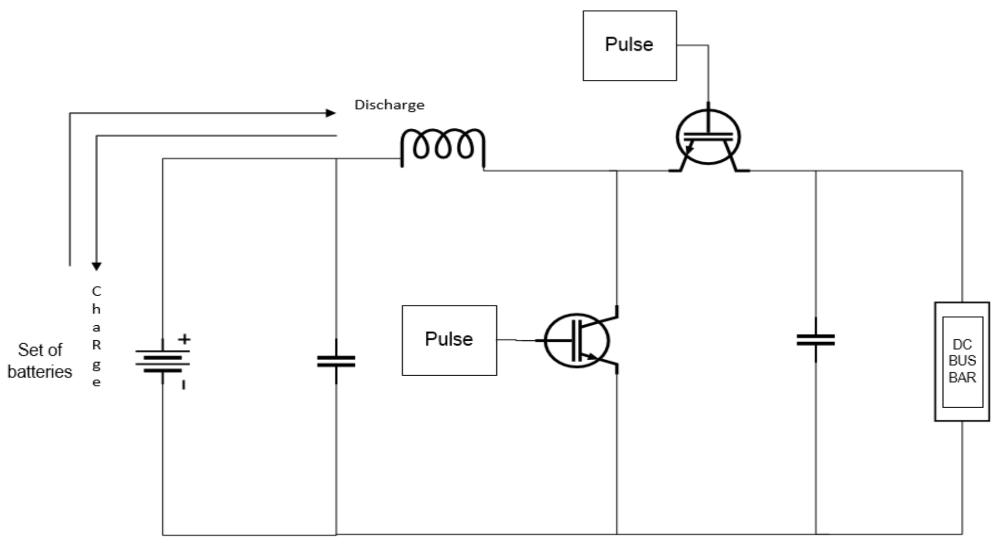

Figure 1.2 Charging and discharging of EV's.

Research work in 21st century (first two decades) on AC smart grids, DC smart grids and efficient EV'S for voltage stability on DC bus-bar is in progressive way[5, 6]. This work represented benefits of DC smart grid over AC smart grid in terms of stability, reliability and higher efficiency for integration purposes. These DC micro grids can be operated in both grid connected and islanded operating mode with proper controllers and protection systems[7].

Revolution in power sector thoroughly transformed the infrastructure of power grids. Now world is moving from conventional power grids to DC smart grids because of its numerous advantages over ordinary grid system in terms of low penetration of renewable energy sources, energy storage system and integration of EV'S with stability.

Most domestic and commercial loads are switched from AC to DC because of certain advantages. Many RES's are available in the world which are safe and cheaper than AC sources. Less converters are required and no problem of harmonics in the DC output power. The factor which is common in both AC micro grid and DC micro grid is "Energy Management System" but in DC Smart Grids only voltage stability on DC bus bar is required except frequency. Theoretically and practically it is proved that grid efficiency, reliability and stability is improved in V2G mode of operation if DC micro grid is integrated instead of AC micro grid[8].

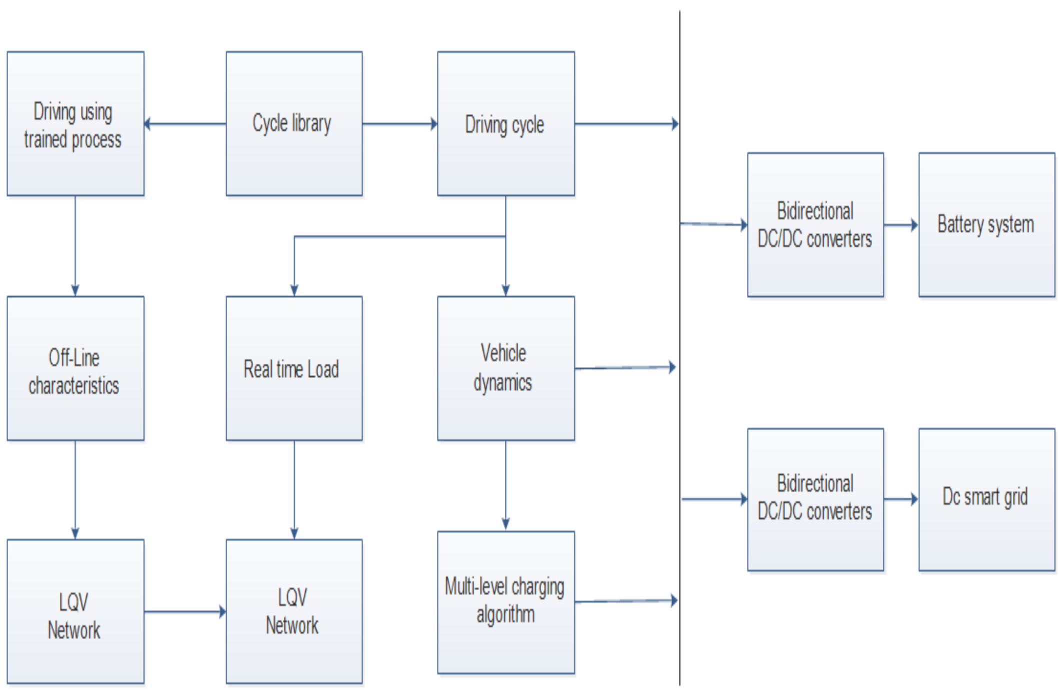

Figure 1.3 Energy management system.

1.2. Problem statement.

Power losses in both AC micro grid and DC micro grid are those which are un-wanted but these are compulsory because of AC/DC and DC/AC power conversion. With these losses, efficiency of the overall electric power system is affected/reduced. In AC micro grid, DG's are connected to the AC bus bar to maintain voltage stability with different controllers, loads which are AC or DC connected directly or with the help of converters to the bus bar. To ensure continuity of power supply, some back-up is required in terms of DG's which are connected with the grid. To keep in mind environmental factors such as emission of carbon dioxide, nitrogen oxides and other pollutants from power generation houses, renewable energy sources are best option for them. As electric vehicles (EV's), energy can be stored and used in different conditions are best possible option for backup sources. As EV's output is DC, DC/AC converters required for integration with conventional AC micro grid. Losses again occurs because of conversion. Different controllers are used for controlling voltages, active and reactive power, frequency and current in AC/DC/AC convertors in entire electric power system. If conventional micro grid is replaced with DC micro grid, entire power system can be simplified with improved efficiency as number of converters will be reduced and power losses will significantly decreases. EV's can directly be charged from different RES like "PV's parking lots". CC-CV chargers must be used for protection of batteries as it has vulnerable role in this scheme. For discharging, suitable connection between EV's are required to fulfil the load demand according to the EV's rating.

The main problem is to stable voltages on DC bus bar according to the load variation and contribution of each electric vehicle according to the load variation and their capacity (ratings). To stable voltages of AC bus-bar is done in recent research but research to replace conventional AC micro grid with DC micro grid and to stable voltages on DC bus bar is in progressive way. Different combination patterns of such EV's can be tested with closed and open loop controllers to control voltages according to the load and power delivered from respective vehicles according to their rating.

1.3. Aims and Objectives

The objectives of this research are:

- Design of controlled Buck converters for charging of electric vehicles according to the standards (CC-CV charging).
- Design of boost converters.
- Controlled and Un-controlled discharging of electric vehicles in V2G mode (vehicle to grid).
- Droop control design for power sharing from respective vehicle according to their capacity.
- Voltage stability on DC bus bar according to the load variation.
- Calculation of DC/DC converters power losses and their improved efficiency.

1.4. Thesis Organization

Organization of this thesis is as under:

Chapter 1 In this chapter introduction related to the problem and problem statement with aims and objective is provided.

Chapter 2 This section covers the history and introduction of EV's, their charging levels and techniques. Future of EV's will also be taken into account. Power sharing from vehicle to grid and vice versa will be explained and challenges according to their integration will be determined. Stability of voltages on AC and DC bus bar will also be discussed. Than a summary of all the papers which has been studied during this thesis will be given literature review of EV, AC micro grid and DC micro grid.

Chapter 3 This chapter contains all the proposed methods and detail of all the components used in the system which may droop control, buck converter of battery for charging and boost for discharging and also others which are necessary according to the proposed model.

Chapter 4 Presents the results and methods used for proposed scheme in the thesis.

Chapter 5 presents conclusion and future work of the research.

Chapter 2

Literature Review

CHAPTER 2. LITERATURE REVIEW

2.1. Overview

Concept of electric vehicles was brought in to the market in 1890-91 when first vehicle designed for six persons having average speed of 14.4 mph (23.1kph). After that growth in electric vehicles industry was rapidly increased but unfortunately due to the reduction of fuel prices in late 1970's, market rejected to accept electric vehicles because of its average speed and for charging again and again as it was convenient for individuals to refill the oil tank in no time. But once again environment concern was the main reason in the growth and development of electric vehicles industry. With the efforts of engineering staff of General Motors, first pair of high speed EV called "Electrovair I and Electrovair II" was designed. The body structure and techniques used were according to the environmental standards for making environment pollution free. Average speed of these vehicles was around 40-80 mph and battery pack rating voltages was 512V[9]. This proposed model got attention although there were some flaws as its silver-zinc battery was over weighted and expensive. Further development in power electronics matured the EV's concept and its growth rate.

Some features of "Electrovair I" and "Electrovair II" are given in the following table.

Table 2.1 characteristics of electrovair I and "Electrovair II

Motor type	3-phase induction motor
Max rpm	12500-13000 revolution per minute
Battery rating	512v
Battery weight	308.5 Kg
Inverter	DC/AC

Max speed	70-80 mph
Traveling capacity	60-80 miles depending upon traveling condition
Acceleration	0 to 60 mph in just 15-16 seconds
Total weight of vehicle	1590 Kg

With the collaboration of UCC (Union Carbide Corporation) in 1967, General Motors replaced silver-zinc battery with fuel cells. The model vehicle named "Electrovan". This was the first fuel cell van. The previous version of "Electrovan" was known as "Handivan"[10, 11].
The designed parameters of Electrovan are shown in the table 2.2.

Table 2.2 Parameters of Electrovan

Motor type	3-phase induction motor
Fuel cell rating	Continuous power supply of 32KW with additional 160KW for acceleration for short span of time
Max speed	70-75 mph
Inverter	DC/AC
Traveling capacity	150-155 mph miles depending upon traveling condition
Power	125 HP
Acceleration	0-60 mph in just 0.2 mint.
Total weight of vehicle	3220 Kg

Comparison of both model indicates that as weight is increased along with power, acceleration and distance covered capacity. Furthermore advancement in research led the idea to manufacture a car where fuel and battery can be used as to increase the efficiency of electric vehicles. In 1968, experiments showed that a car with Stirling engine can be possible. Hybrid electric vehicles with Stirling engine where fuel ignition will be done in an isolated ring. Experiments showed that emission of carbon oxides and other toxic oxides can be reduced as compared to the normal vehicle ignition engine. The driven mechanical forces were converted into electrical energy to charge the stored batteries with the help of converters.

The GPU-3 model with single cylinder 8 HP engine having 3000 rpm was used for first hybrid electric vehicle. Hydrogen gas used for cooling with 1000 pound per square inch pressure. Used lead acid batteries which were connected in series. AC/DC converter was used to converter the generator output into DC for charging purposes. In 1993, GM (General Motors) designed special electric vehicles with improved profile to integrate these vehicles with electric grid to meet the demand in emergency cases[10]. But as technology was not improved at that time, power losses were more and it was not economically feasible to design the whole power system according to the proposed technology[9]. Other two major reasons were efficiency and cost. Cost was very high so it was not suitable to launch the proposed system on large scale but to use it for domestic purposes was quite sensible.

2.2. Converters

Power factor correction is achieved by the improvement of power electronics where AC/DC conversion, unidirectional and bidirectional power flow have been obtained. This is achieved by the reduction of harmonics distortion where input is AC and output is DC with the help of inverters and converters. Improved power quality converters (IPQCs) are used for better power quality and efficiency. Converters are widely used in power systems such as in UPSs, interfacing of power grids with non-conventional energy sources and in recent era especially in electric vehicles. Converters have vulnerable role in charging and discharging of electric vehicles. Controlled or uncontrolled DC power is obtained by the rectification process with the help of thyristors and diodes. Because of some drawbacks like poor power factor, huge size of AC and DC filters, low efficiency and voltage distortion. New breed of rectifiers which are MOSFETs (metal oxide semiconductor field effect transistors) and IGBTs (insulated gate pulse bipolar transistors) developed for improved rectification process. Unidirectional and bidirectional converters can be buck, boost and buck-boost converters. Entire range of converters configuration are divided into ten type of categories[12]. The division pattern is explained in Figure 2.1.

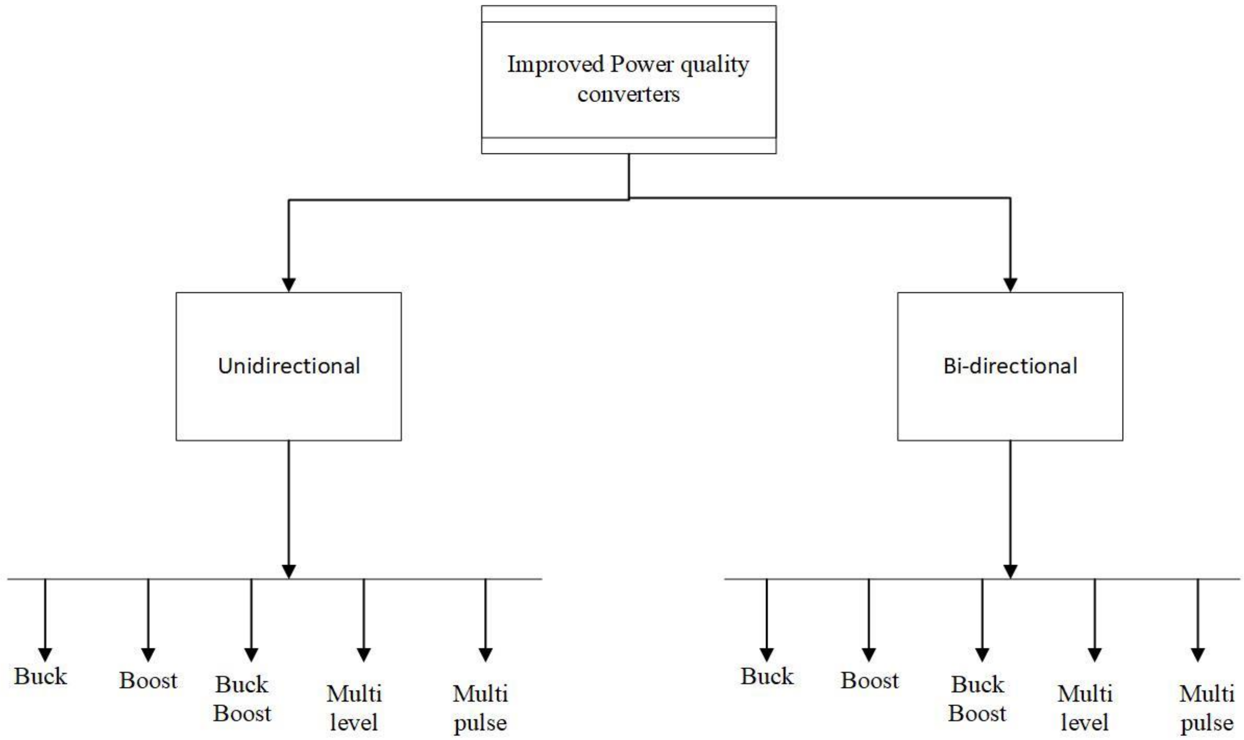

Figure 2.1 Division of converters.

2.2.1. Unidirectional boost converters

After MOSFETs and IGBTs, technology has been matured enough to feed good quality DC to loads ranging from fraction of kilowatt to megawatt power in different sort of applications. Control approaches, configurations and circuit combinations are developed in last couple of decades. Improved power quality converters are widely used in many applications where use of buck, boost, buck-boost and multilevel converters are extensive. Uninterruptable power supplies and air conditioners etc. requires unidirectional power flow while in contrast some requires bidirectional power flow so because of this reason boost converters are categorized as unidirectional boost converters[13] and bidirectional boost converters[14].

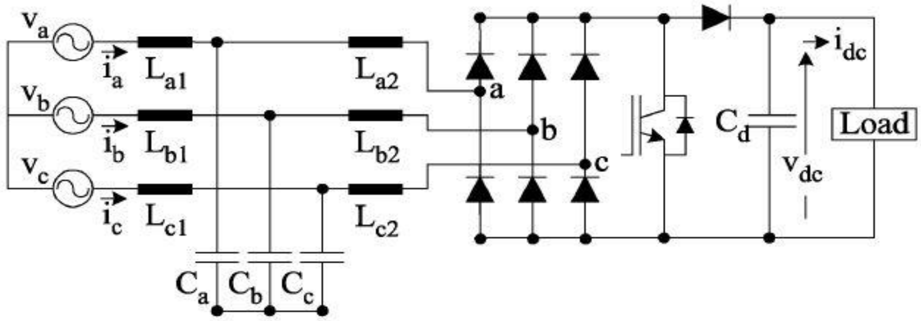

Figure 2.2 Single switch unidirectional boost converter.

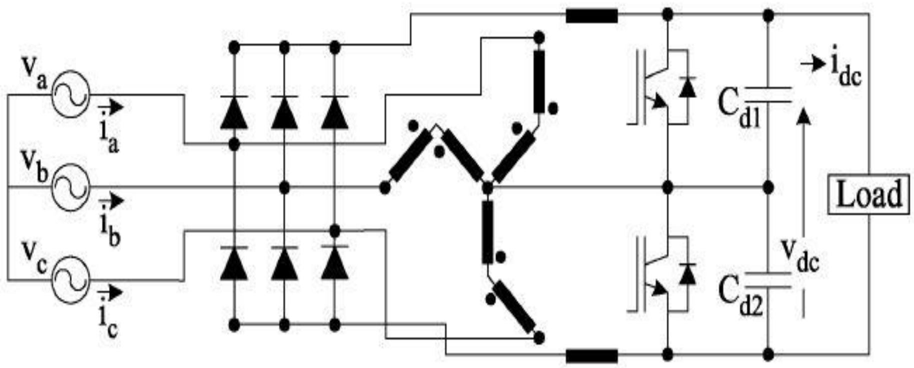

Figure 2.3 Minnesota rectifier (double switch unidirectional boost converter).

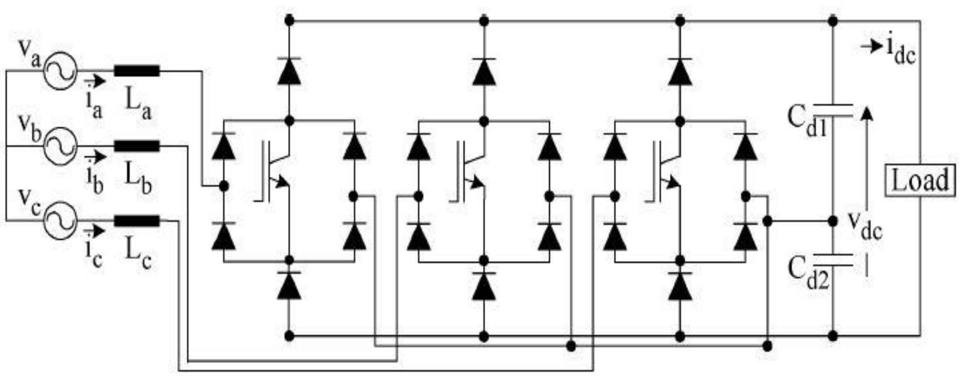

Figure 2.4 Vienna rectifier (three-switch unidirectional boost converter).

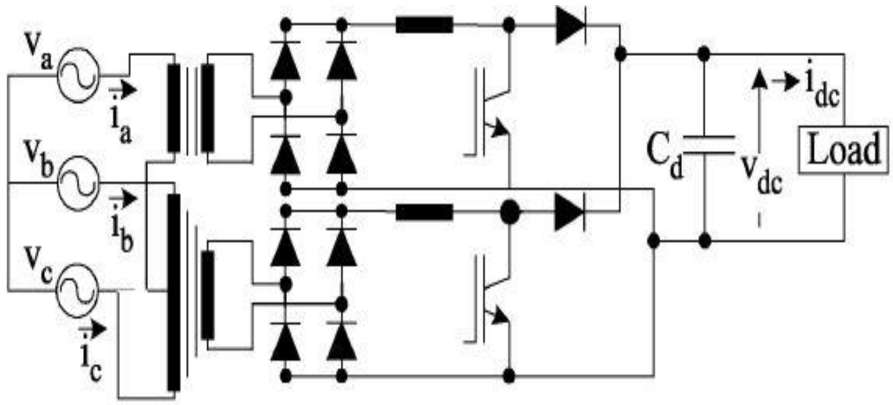

Figure 2.5 Scott connection transformer unidirectional boost converter.

Conventional diode rectifiers are replaced by unidirectional boost converters which are mentioned above to reduce total harmonic distortion (THD) at AC supply end and constant DC voltage is obtained at output end. Zigzag transformers are used in Minnesota rectifiers where current is introduced through transformer. The converter which is used widely in almost all type of power electronic circuit is boost converter but other are also used in different configurations like power supplies and motor speed control.

2.2.2. Bidirectional Boost Converters

Power flow between AC circuit and DC circuit like electric vehicle (EV's) chargers, lifts, UPSs and hoists are achieved by bidirectional boost converters where closed loop circuit decides the amplitude of referenced voltage/current. Boost converters are generally used to obtained more DC voltage than input AC voltage. This constant value of current/voltage is achieved on DC bus bar. Pulse width modulator current control of VSI based converters are used to preserve the stream of current nearby sinusoidal and in phase with source AC voltages. In power electronics, efficiency and cost are highlighted factors so to reduce cost four switches are used for this purpose. Configurations of bidirectional boost converters are given below.

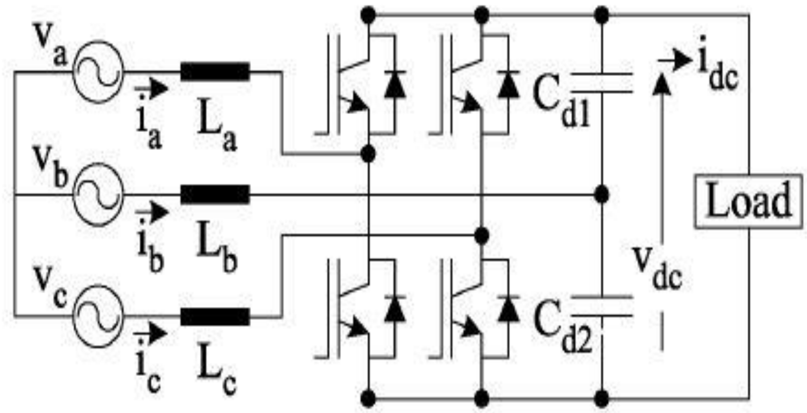

Figure 2.6 Four switch bidirectional boost converter.

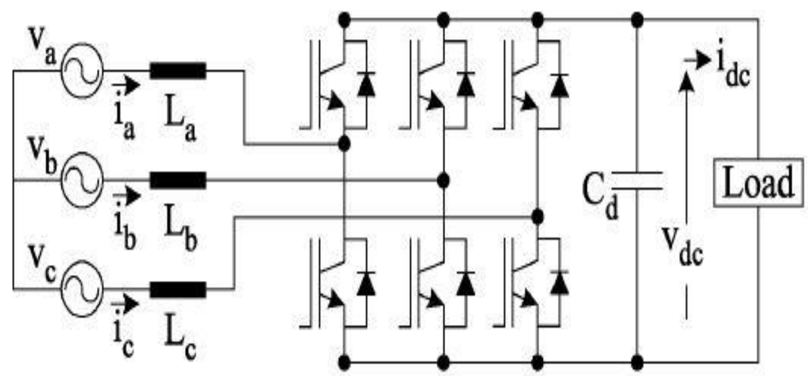

Figure 2.7 Voltage source inverter bridge-based bidirectional boost converter.

Ripples at DC bus bar can be eliminated and controlled current supply can be maintained by another type of boost converter which is four wire topology. Because they are sensorless controllers, complexity of hardware and cost is reduced. Three phase supply is connected to the neutral and eight switches are used for this configuration. Capacitor is used to remove ripples across the load[15].

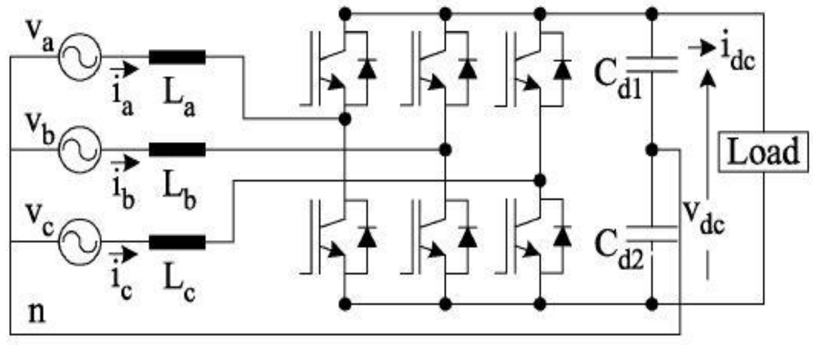

Figure 2.8 Four wire bidirectional boost converter.

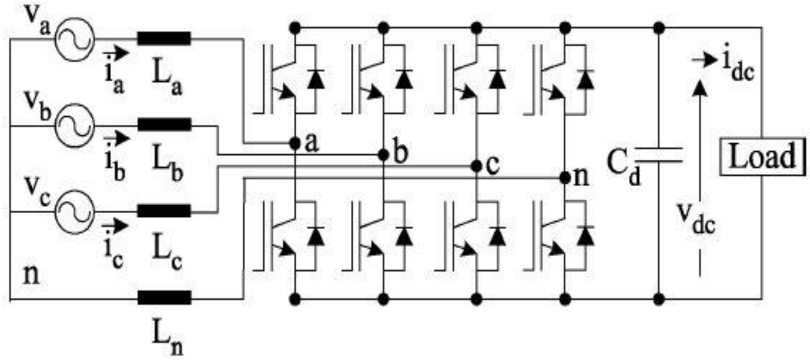

Figure 2.9 Four legged boost converter.

2.2.3. Unidirectional Buck Converters

Unidirectional buck converters are those whose output voltages are lower than base voltages (input voltages). Thyristor semiconductors are replaced by MOSFETs and IGBTs. Normally it requires high filter in some cases. Input and output filters size can be reduced by high frequency PWM control to reduce the cost as filter order is directly proportional to the cost factor. With the development of unidirectional and bidirectional buck converters, charging of EV's technique is matured as EV's are charged by buck converters. It is also used for motor speed control purposes.

The current is controlled up to the lower value for charging of EV's (CC-CV) because in the current path, IGBTs are connected in series which are control devices to control the inrush current.

With the help of buck converter, from 0 to nominal voltages can be obtained at output in very short span of time because of its quick response rate.

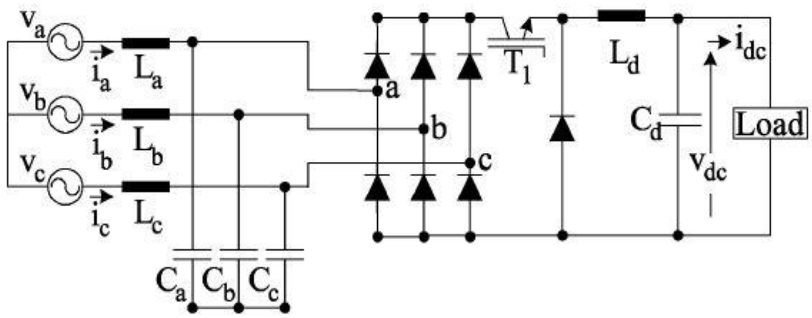

Figure 2.10 Single switch unidirectional buck converter.

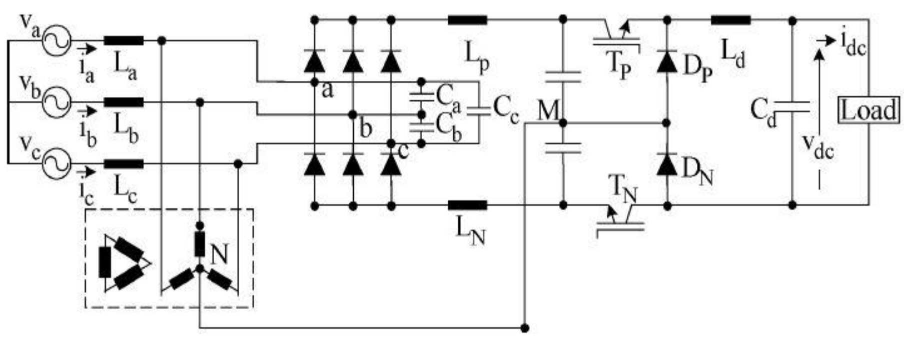

Figure 2.11 Double switch unidirectional buck converter.

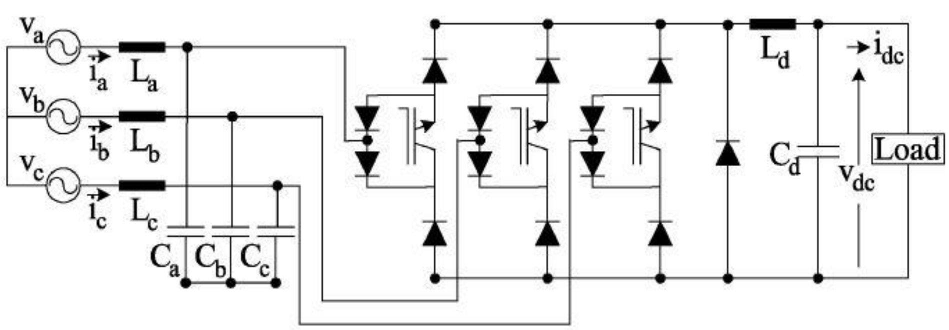

Figure 2.12 Three switch unidirectional buck converter.

2.2.4. Bidirectional Buck Converters.

Following circuit diagrams are bidirectional buck converters which works in the same way as conventional thyristor bridge converter but with improved power quality having high power factor and firm output voltage for bidirectional power stream. GTOs are used for high power rating and IGBTs where diodes are in series combinations are used for low power rating. Overall size of filter components are reduced[16]. Four leg bidirectional buck converter is used to reduce ripples at output end. It is also implemented for balancing purposes of current. To block reverse voltage flow, connection of diodes are necessary in series. This pattern is implemented on bipolar junction transistors, insulator bipolar gate transistors and metal oxide semiconductor field excite transistors.

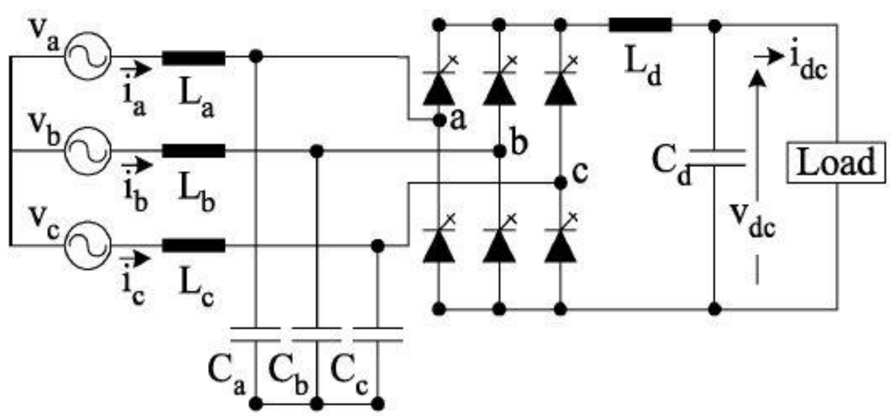

Figure 2.13 GTO based bidirectional buck converter.

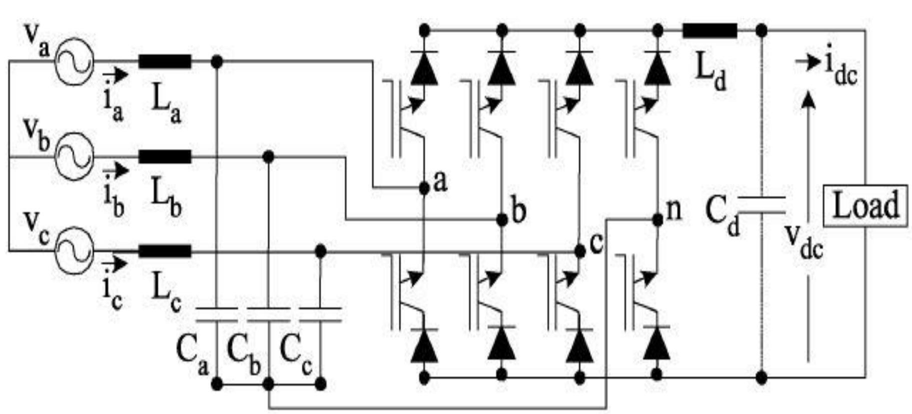

Figure 2.14 Four-pole bidirectional buck converter.

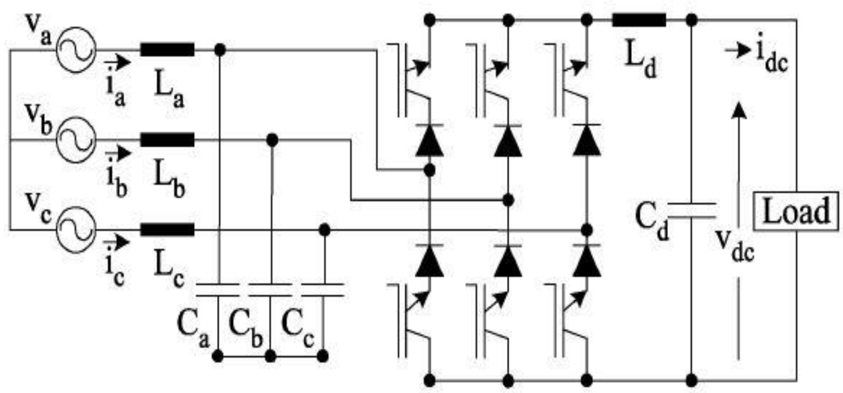

Figure 2.15 IGBT based bidirectional buck converter.

2.3. Unidirectional and Bidirectional buck-boost converters.

In unidirectional buck-boost converters, the DC output is either isolated or non-isolated with the main AC supply. Buck converters and boost converters are combined to form buck-boost converters. DC/DC buck-boost converters are combined with 3-φ diode bridge for smooth DC and sinusoidal AC output. The connection of 3-phase buck converter with 3-phase boost converter is in the Figure 2.16[12].

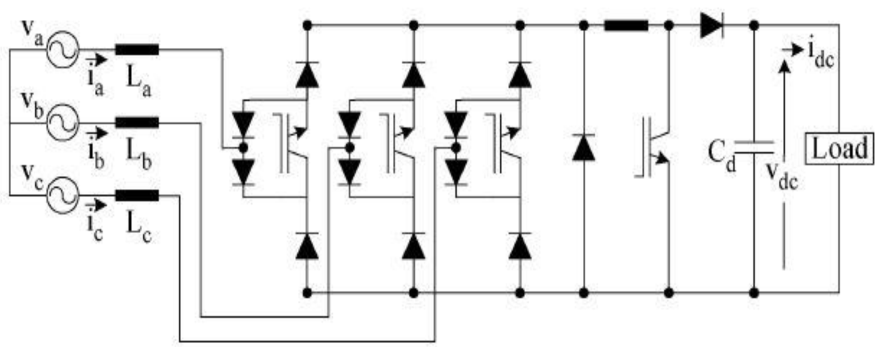

Figure 2.16 Unidirectional buck-boost converter.

Many applications demand high output DC voltage with bidirectional DC current. This configuration is achieved by cascading the buck and boost converters. Input and output filter size is reduced by using matrix converter which has high switching frequency. This configuration can be used either bidirectional buck converter or bidirectional boost converter. There are AC-DC, AC-AC and DC-DC converters. For high rating applications, its major drawback is its reduced switching frequency when used with GTOs other than its operating at normal conditions. The major advantage of bidirectional buck-boost converter is its efficiency as it does not need any connection with diodes in series. The bidirectional buck-boost converters are used for power flow between EV's and grid[17].

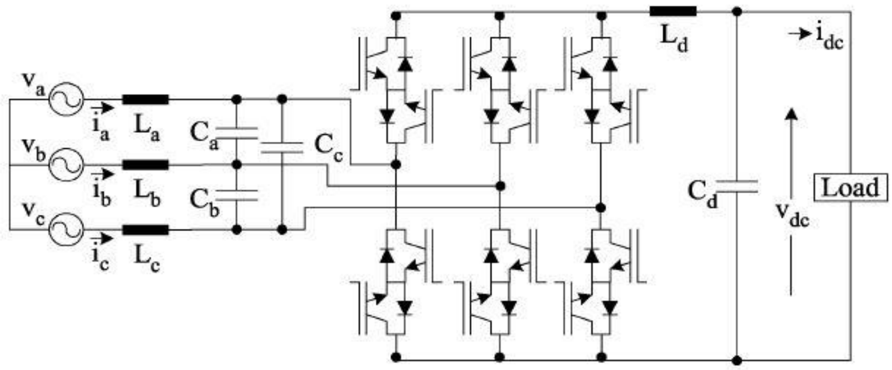

Figure 2.17 Three phase AC-DC converter.

2.4. Modes of operation

Two modes of operation are for inter-connected grid and electric vehicles, which are

1. Grid-to-Vehicles (G2V)
2. Vehicle-to-Grid (V2G)

In G2V system, grid support vehicles for charging to use for transportation while in G2V grid is supported by the help of vehicles to maintain continuous supply of power. To make this system more accurate and efficient, used electronic converters must be effective with advanced controlled technologies. Theoretically and practically it is proved that grid efficiency, reliability and stability is improved in V2G mode of operation if DC micro grid is integrated instead of AC micro grid. Converters design, controllers and their strategies suggest that how much V2G mode is efficient. AC/DC and DC/AC converters are frequently used in conventional mode of operations.

Most domestic and commercial loads are switched from AC to DC because of certain advantages. Many RES's are available in the world which are safe and cheaper than AC sources.

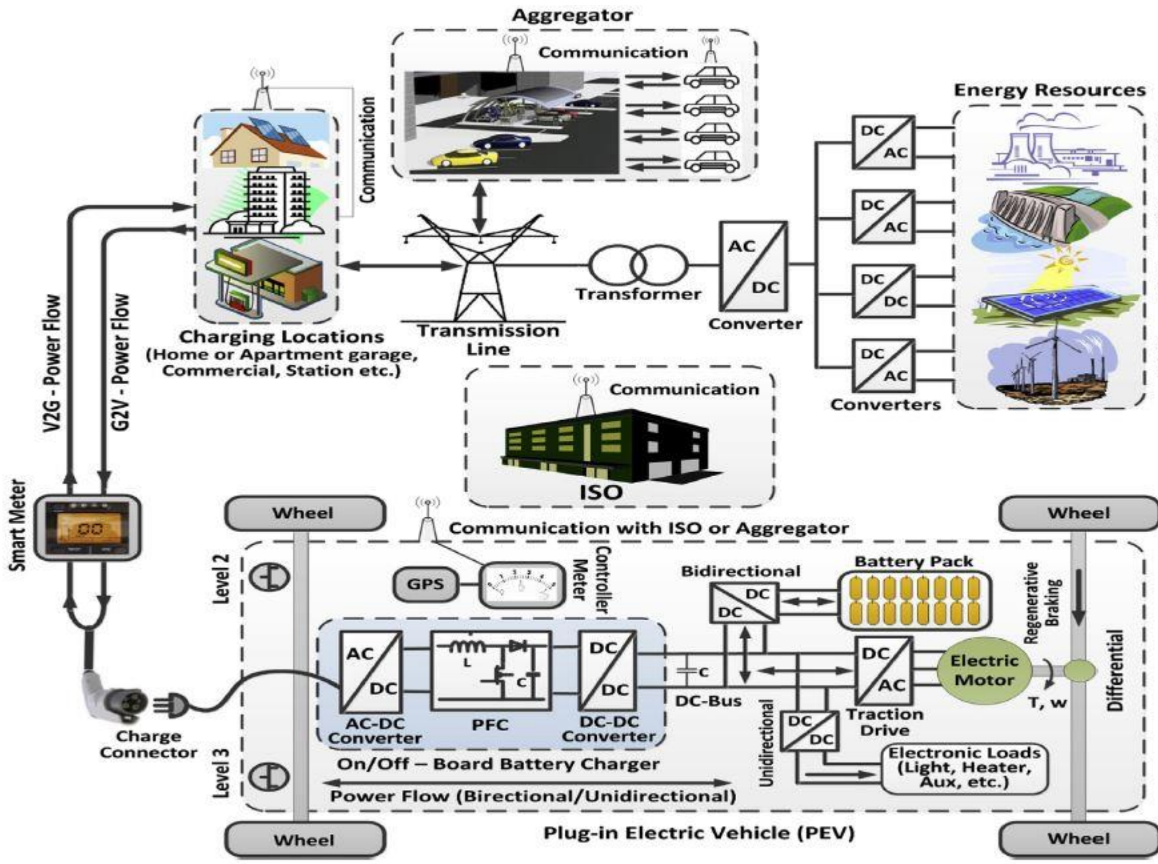

Figure 2.18 Plug-in Electric vehicles[15].

Less converters are required and no problem of harmonics in the DC output power. The factor which is common in both AC micro grid and DC micro grid is “Energy Management System” but in DC Smart Grids only voltage stability on DC bus bar is required except frequency.

2.4.1. Vehicle-to-Grid (V2G)

Using electric vehicles for different modes of transportation have lots of benefits over conventional transport system (fuel ignition based vehicles) especially in terms of emission of carbon oxides and to preserve environment from other harmful emission of oxides which play key role to make environment pollutant. There are too many benefits of using EV’s but the predominantly advantage is to get energy back from EV’s in special cases[15, 18]. In V2G mode, power is directly injected from EV’s to the distribution network (DN). Many other sources (renewable energy sources) can be used for this arrangement but why EV’s? Reason is quite simple because RES’s depends upon weather conditions and other natural factors which are not controlled by human. So the best way to store energy and to utilize it in certain conditions are EV's[19]. EV's can be charged from RES's or from conventional grid system by using DC/DC buck converters. Many battery charging levels have been developed. The most prominent is level 3 because it supports fast/quick charging scheme which is level 3.

V2G mode improves the overall efficiency of the grid which increase the performance of the grid. The basic notion of V2G mode is that EV's can be the load and can perform as an energy storage devices at same time. Vehicles to grid integration have many claims including[20];

- Continuity of active power flow/regulation
- Reactive power support
- Reduces overall transmission charges
- Economic support
- Load sharing during peak hours

Unidirectional and bidirectional converters are used in V2G and G2V depending upon the selected scenarios which are discussed above. In unidirectional and bidirectional power flow system two main connections are very important, one is to establish connection between vehicles and grid/RES's for charging and other is to establish logics and design of controllers for feedback signals to determine the direction and magnitude of power flow[21]. For this, IEEE defined some standards which are mandatory to follow. Single or combination of multiple vehicles can be connected for parallel to meet the demand the power from

Following standards need to be followed by EV's which are defined by IEEE in the form of codes[22]

Table 2.3 IEEE Standard codes

Standard code	Description
J2293/1, J2293/2	This standard is for requirements of electric vehicles (EV) and the off- board electric vehicle supply equipment (EVSE) are recognised which are used to transference of an electrical energy to an EV from an electric utility power system (Utility).

J1772	This code describes a communal EV and source apparatus vehicle conductive charging technique
J1634	This standard postulates even actions for analysis electric battery-powered vehicles. It also offers standard trials which will allow for resolve of energy depletion and variety.
IEC TC 69	This standard refers the Protection and charging structure
IEC TC 64	This code is for installation of electrical equipment and to provide them protection from shocks of electric.
ISO 6469-1:2009	It accounts for the on-board rechargeable energy storage systems (RESS) of electrically propelled road vehicles, including battery-electric vehicles (BEVs), fuel-cell vehicles (FCVs) and hybrid electric vehicles (HEVs), for the protection of person's inside and outside the vehicle and the vehicle environment.
The ANSI Electric Vehicles Standards Panel (EVSP)	This standard is a cross-sector organising body pointing at providing synchronisation and association on normalization matters among public and reserved sector participants to assist a seamless distribution of electric vehicles and associated set-up in the United States with international direction, flexibility, and engagement.
IEEE 1547	This standard explains the parameters for connecting electric power systems with distributed energy resources (DERs) It also contains necessities respective to the performance, action, checking, care, and repairing of the interconnection
IEEE 1901	It is linked to the data regularity and handling of entertainment while the EVs are charged throughout night. Networking products obeying with IEEE 1901 will carry data rates in excess of 500 megabits per second in LAN uses. In first-mile/ last-mile applications, such devices will cover distance of up to 1500 m.

2.4.2. G2V mode (grid to vehicle mode)

Buck converters used for EV's battery charging having vulnerable role in the EV's development because of their combination scenarios for voltage stability on DC bus-bar with controllers like PI controller. Battery charging characteristics associated with charging time and battery life cycle. DC-DC converters are used in charging station applications[23, 24]. The techniques used in battery charging process for protection is CC-CV (constant current and constant voltage) where during initial charging stage current remains constant and voltage are continuously increasing. When voltage reaches to the pre-determined value, current becomes minimum which is key to protect batteries during charging process. The output of a CC-CV charger should be as like as shown in Figure 2-19.

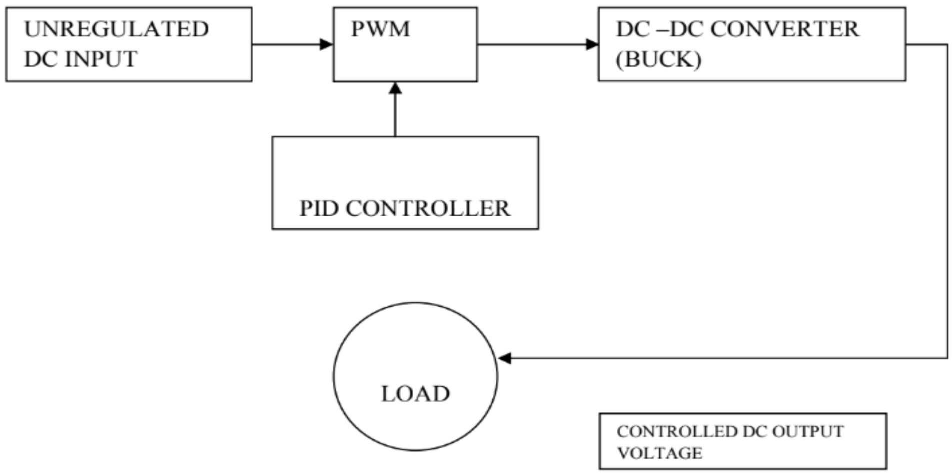

Figure 2.19 Controlled CC-CV charger.

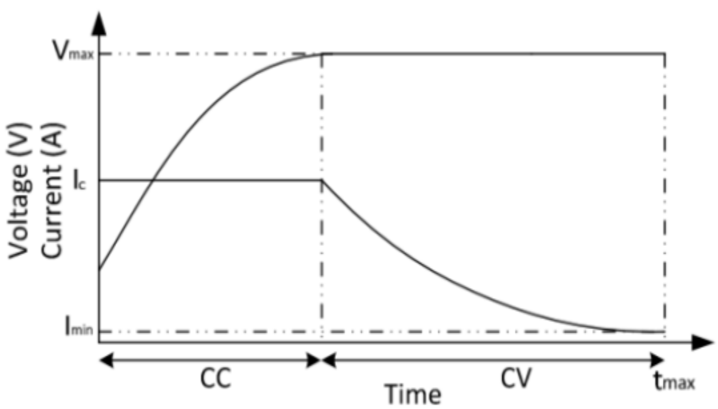

Figure 2.20 Output of a CC-CV charger.

2.5. Charging levels

2.5.1. Charging level 1:

Level 1 charger requires no additional infrastructure. It is not good for commercial drives because it demands more time for charging with standards 120V/15A single phase grounded outlet. These are suitable for domestic heights corresponding homes and small work sites. Its cost varies from $500 to $880[25, 26].

2.5.2. Charging level 2:

Level 2 charger can be feasible for commercial as well as public sectors i.e. hospitals, schools and small parks. It charge batteries up to 19.2KW (in between 208V/80A and 240V/80A). It follows proper pattern for installation[5]. International standards are 240V so most customers prefer such scheme because of less charging time. Its installation cost is in between $1000 and $3000[21].

2.5.3. Charging level 3.

It is fast charging level among all of them because of its charging time which is less than one hour. It is a three phase charger with typical operating voltages 480V or higher. It is an off-board charging scheme and its installation cost varies from $30000 to $160000[27]. Level 2 and level 3 effects the life span of transformers because it increases the harmonic distortion, transformer losses and voltage regulation which is considered hazardous for transformers. Infrastructure demonstrates the built-in scheme of all three levels that level 1 and level 2 does not require additional equipment and is located on the vehicle but level 3 requires special features for installation outside the vehicles[20].

2.6. Difference between fast, rapid and quick charging.

Overnight charging is known as slow charging because its demands more than 6 hours for complete charge. Charging period depends upon thermal consideration and charging algorithms. Charging of scheme else slow charging is associated with fast charging. In fast charging, rapid and quick charging is established on the basis of algorithm and charging period. In Zero Emission Vehicles (ZEV) mandate program list of above mentioned charging level are explained on the basis of their charging time, SOC (state of charging) and power (KW).

Table 2.4 Fast, rapid and quick charging

Charging mode	Time	SOC (state of charge)	Charging power(KW)		
			Heavy duty	Medium duty	Light duty
Fast charging	45 mints	80%	500	250	125
Rapid charging	60 mints	60%	250	125	60
Quick charging	1 hour and 30 mints	70%	75	35	20
PHEV’s	30 mints	N/A	40	20	10

2.7. Mathematical formulation of AC power flow analysis and power losses calculations.

To design an electric power system, power flow analysis is mandatory. Generally it is adopted to control power flow in real time, to optimize the network. Power system security and protection is considered in power flow analysis[28]. For AC system, power flow analysis ca be done by different methods but the most prominent method is node voltage analysis[29], with PQ, VQ and PV buses. In addition, P and V buses are only taken for DC system power flow analysis[30]. Previous methods of conventional power flow analysis are no more applicable because of following reason;

- Inappropriate control of power flow and power losses
- Limitations of individual distributor generators, especially in islanded mode where active and reactive power losses must be balanced on slack bus.
- Frequency continuously changes in islanded mode which is not measured in conventional methods[31].

Following mathematical equations are used for calculation of active and reactive power analysis between two buses 1 and 2 respectively[29].

$$P = \frac{V_1 V_2}{Z_{line}} \cos(\phi - \theta) - \frac{V_2^2}{Z_{line}} \cos(\phi) \qquad 2.1$$

$$Q = \frac{V_1 V_2}{Z_{line}} \sin(\phi - \theta) - \frac{V_2^2}{Z_{line}} \cos \qquad 2.2$$

Where P and Q are active and reactive from bus 1 and bus 2, Z_{line} is impedance of line and ϕ is the angle between two buses.

P and Q will have linear relationship with angle of buses and voltage magnitude. For this

$\phi = 90$ and $\theta = 0$. Thus values of P and Q are[29],

$$P = \frac{V_1 V_2}{Z_{line}} \sin(\theta) \qquad 2.3$$

$$Q = \frac{V_1 V_2 \cos(\theta) - V_2^2}{Z_{line}} \quad 2.4$$

The relationship between complex power and impedance is demonstrated in Figure 2-21 where a distributed generator unit is connected with bus 1 and impedance is in between bus 1 and slack bus.

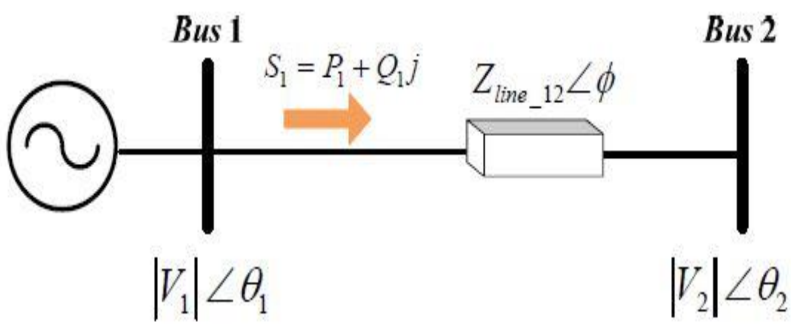

Figure 2.21 2 Buses connected DG system.

Frequency and voltage dependency of the AC system can be demonstrated as[32]

$$P_{DJ} = P_{rated} |v_i^{\alpha_i}| (1 + K_{pi} \Delta f) \quad 2.5$$

$$Q_{DJ} = Q_{rated} |v_i^{\beta_i}| (1 + K_{qi} \Delta f) \quad 2.6$$

Where exponential coefficient of real and reactive power are α_i and β_i respectively. Δf is the fluctuation of frequency between actual and nominal value. When both α_i and β_i have same value i.e. zero then load behaves as constant power. The value of K_{pi} and K_{qi} ranges from 0 to 0.3 and 2.0 to 0 respectively[32]. To get accurate results, virtual impedance should be considered as many methods are used for power flow analysis where virtual impedance is ignored.

Virtual impedance control concept in AC micro grids is shown in Figure 2-22[32].

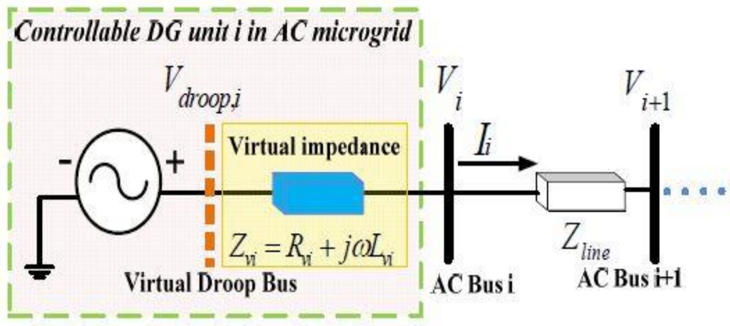

Figure 2.22 Controlled DG unit in AC microgrid.

2.8. Droop control

Primary, secondary and tertiary controllers are commonly used in AC micro grid to share load between converters, to remove steady state error and to monitor the system overall requirement respectively[33]. Primary control is a droop control which monitors the P (Active power) by regulating frequency and controlling the output voltages. Frequency and voltages are controlled according to the load variation to meet the demand. Micro grid is integrated to the DG'S (distributed generators) with parallel combination of inverters[34]. P and Q from each inverter can be calculated from following equations respectively[33].

$$P_{inv,n} = \frac{V_{integ} P_{inv}}{X_{inv}} * \delta_{vinteg,pin} \qquad 2.7$$

$$Q_{inv,n} = \frac{V_{integ} P_{inv} - V_{integ}^2}{X_{inv}} \qquad 2.8$$

Where V_{integ} is integration voltage of the inverter, P_{inv} is the inverter power, X_{inv} is the inverter impedance and $\delta_{vinteg,pin}$ is the angle between integration voltage and inverter power. P and Q of the individual inverter depends upon angle and inverter power respectively. Increased in power demand from consumer decreases the power system inertia[35].

Relationship between v and frequency can be demonstrated as;

$$f = f_{D.G} + k_{pf}(P_{set_{value}} + P_{demand}) \qquad 2.9$$

$$V = V_{D.G} + k_{qv}(Q_{set_{value}} + Q_{demand}) \quad 2.10$$

∴ $f_{D.G}$ and $V_{D.G}$ are DG's rated values, P_{set_value} and Q_{set_value} are set values of inverter.

Two schemes for parallel inverters can be used for power scheme, one is droop control and second is active current sharing. Active current sharing uses source voltage and droop control uses R_d which demonstrates that droop control works on its own style. Power sharing demand is adjusted by increasing or decreasing the value of R_d. Therefore it should consider that stability will have on maximum value of R_d. Following equation defines this statement well;

$$R_d < E_i - \frac{V_{DC,bus}}{I_{max}} = 0.87 \quad 2.11$$

The droop control in DC micro grid controls just active power. The voltage according to the load is maintained on DC bus bar and power is shared from individual DG's according to their power rating. Voltage and current loops are for delivering power from of EV's to feed grid in V2G mode of power supply.

Strategies applicable in DC power supply are explained in the fig 2.23[33].

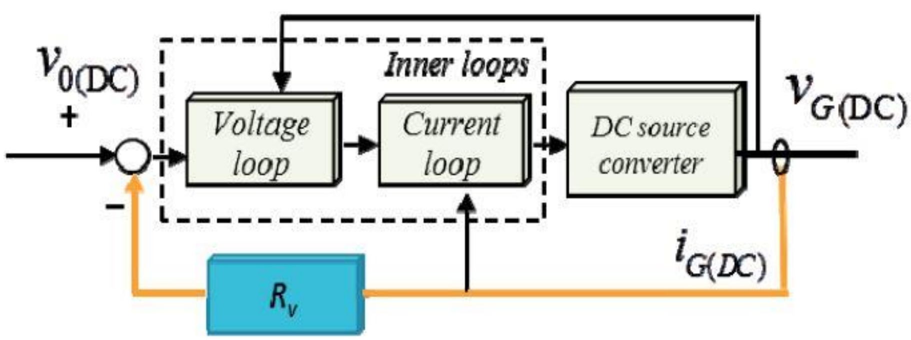

Figure 2.23 Closed loop system for DC-DC converters

Chapter 3

Methodology

CHAPTER 3. METHODOLOGY

3.1. Modeling of electric vehicles

European Union committee claimed that 2020 will be the historic year in the development of the electric vehicles industry. According to the committee, around 20% efficiency of the power system will be increased with this technology[36]. Moreover, contribution of RESs will also be increased around 22% because of this revolution in industry. Emission of carbon oxides and other pollutants which plays vital role in environmental pollution will decrease by 40% in comparison to the current situation (2017). In parallel, Germany took some major steps in this development by investing in electrical vehicles industry[37].

Development of EV's reflects the stability of microgrid in terms of vehicle to grid power supply mode because this mode helps to share power from different rating of vehicles into the grid. For this, a proper EV's chargers are designed to control the charging and discharging according to the demand of power supply and with under consideration the state of charge of the vehicle's battery for transportation[38]. Europe and Germany have established different charging stations with bidirectional power flow chargers to charge and to supply power from vehicles to the grid under different conditions. State of charge of battery represents the charging level of EV's battery. These EV's can be charged from different RES's such as PV car parking lots are common there in parallel with the conventional grids. In this scheme, EV's are directly charged from solar panels and to increase stability of the system are discharged and share power flow to the grid. This helps to ensure the continuity of power supply even in natural disasters situation like storm and flood.

This research lead to the different pattern of electrical vehicles combination to integrate with conventional grid system. But these schemes are not efficient for AC grid because power losses across converters are higher and to maintain voltages on bus bar required droop control. If the conventional grid is replaced by DC micro grid, power losses across converters are reduced because of the reduction of number of converters. The power losses in the AC micro grid are discussed in previous chapter with the help of proper mathematical formulas by including the line impedance between two buses. If number of cars are connected in parallel and power sharing between them are controlled by the droop controller, overall system efficiency can be increased.

A 1000W of open loop boost converter and three set of buck converters are taken as reference for charging and discharging of EV's and PID controllers are used for constant current and constant voltage charging for protection and droop control for DC bus bar which is used to share power between EV's and DC micro grid. Power losses across the converters are calculated with the help of derived formulas.

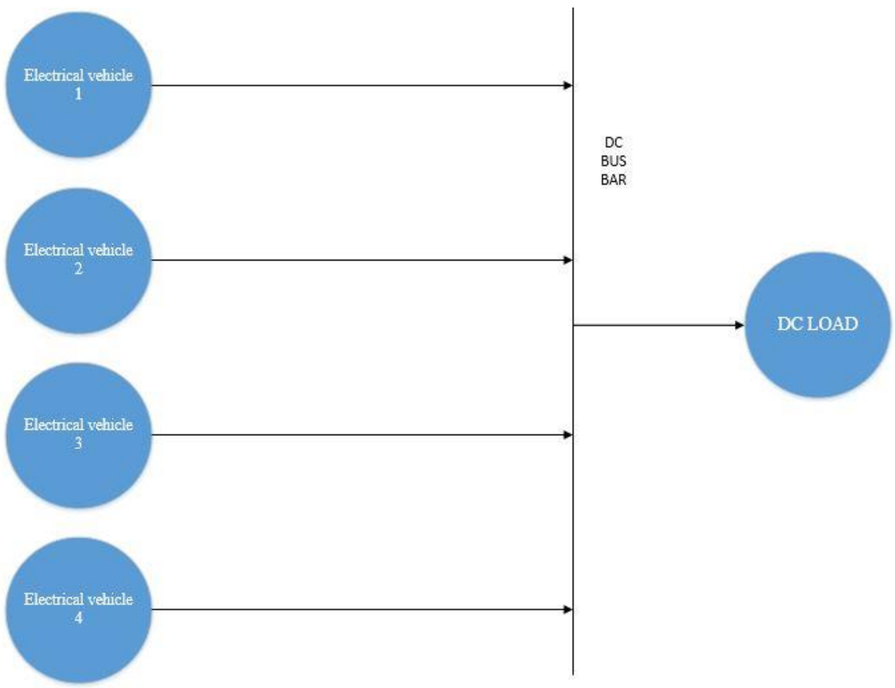

Figure 3.1 proposed EV's connection scheme.

The proposed system is shown is Figure 3-1 where model of electrical vehicle 1 is an open loop boost converter for discharging, model of electrical vehicle 2 is closed loop buck converter for charging of electrical vehicle where constant current and constant voltage is maintained. Model of electrical vehicle 3 and model of electrical vehicle 4 are the replica of electrical vehicle 2 and all these model are connected with a DC load through DC bus bar where voltage is maintained constant. Droop controller is also designed for power sharing according to the variation of load. PI controller is used for smooth and protected charging. Value of P and I are selected according to the desired output from the buck converter and according to the references value, parameters are managed constant.

3.2. Buck converters.

In this work, Buck converter is used for smoothing purposes to obtain the DC output from unregulated DC input. Controlled voltage and current for charging is achieved by PID controller in buck converter. It is a closed loop system. This can be achieved by the simulation of this scheme with the help of different software but the proposed software for this simulation is MATLAB. A Buck Converter is the basic switched-mode power supply topology. In buck converter which is a DC/DC converter, the magnitude of input DC voltage is greater than the output DC magnitude.

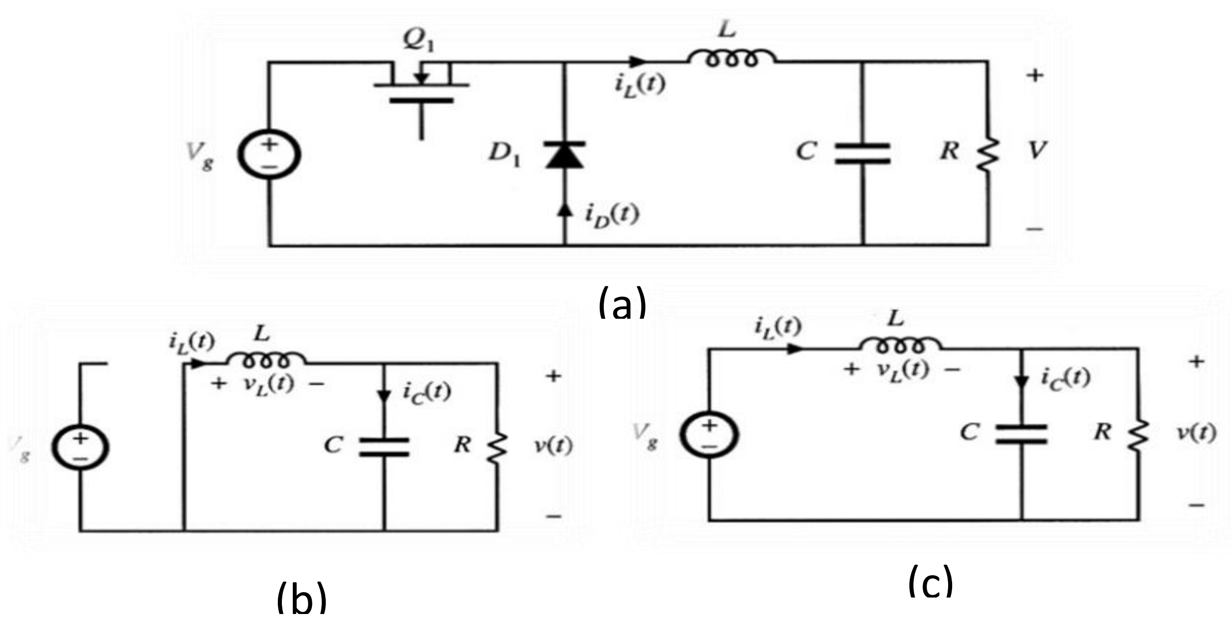

Figure 3.2 Buck converter.

For position P1

The switch is off line at P1 position as shown in the Figure 3-2(b) and voltage across inductor can be calculated by applying KVL we get

For position P2

The switch is off line at P 2 position and diode is conducting. Voltage across inductor can be calculated by applying KVL we get

$$V_L = -V \qquad 3.1$$

For buck converters, relationship between input voltage and output voltage is

$$V_{in\_put} > V_{out\_put} \qquad 3.2$$

For buck converters, the relationship between input current and output current is

$$I_{in\_put} < I_{out\_put} \qquad 3.3$$

The duty cycle of the buck converter can be calculated by the following equation;

$$D = \frac{V_{out\_put}}{V_{in\_put}} \qquad 3.4$$

Value of D varies from0 to 1.

3.2.1. Buck converter with PID Control

DC/DC converters are those where input and output is DC but why it is used. The reason is that it converters the unregulated input DC to controlled output DC. The PI controller is used for DC micro grid system but for AC power system, PR controller is used. Advanced DC/DC converters having digital control have advantages over simple DC/DC converters having analog control. It is preferred because of its more developed control method, its adoptability when software is changed and reduction of components. Advanced PID and PI controllers have ability to reach quickly desired referenced value without overshooting of the it[39]. A PID-controller is loftier for enlightening the phase margin of the voltage-mode DC/DC converter[40]. A general block diagram of buck converter incorporated with PI control is shown in the Figure 3.3.

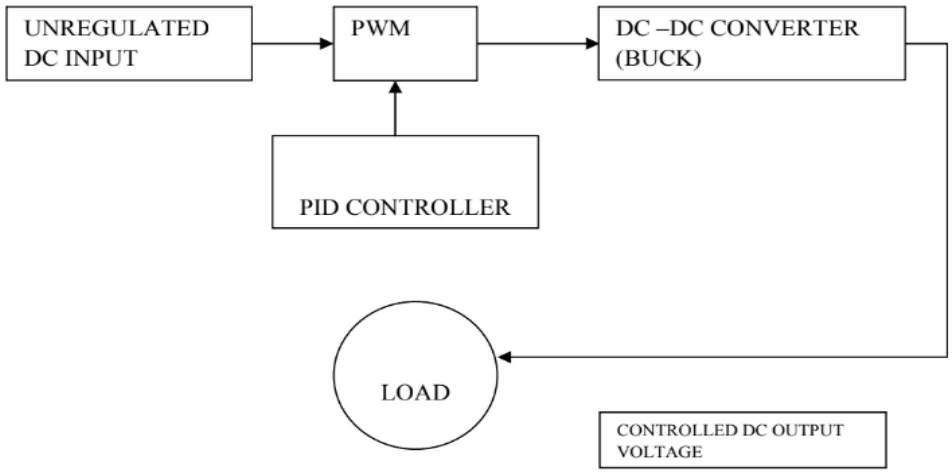

Figure 3.3 Buck converter with PID Controller.

3.3. Boost converters

DC/DC Boost converters (step up converters) are those where input DC is less than output DC. These converters are those which are used to magnify the output of the batteries in V2G mode. Boost converter can be controlled or uncontrolled depending upon the situation. To supply power from batteries of EV's, boost converters are connected in parallel. In proposed scheme, the used boost converter is uncontrolled.

Continuous power supply from batteries of EV's are supplied and the voltage is boosted according to the required power. The boost converter is like a step-up transformer but it is for DC voltage. SOC (state of charge) of EV's battery represents the level of charging. If the vehicle is in charging mode (G2V), the nature of SOC will be increasing but in discharging mode it will be decreasing in nature.

The circuit diagram of controlled boost converter is shown in Figure 3.4.

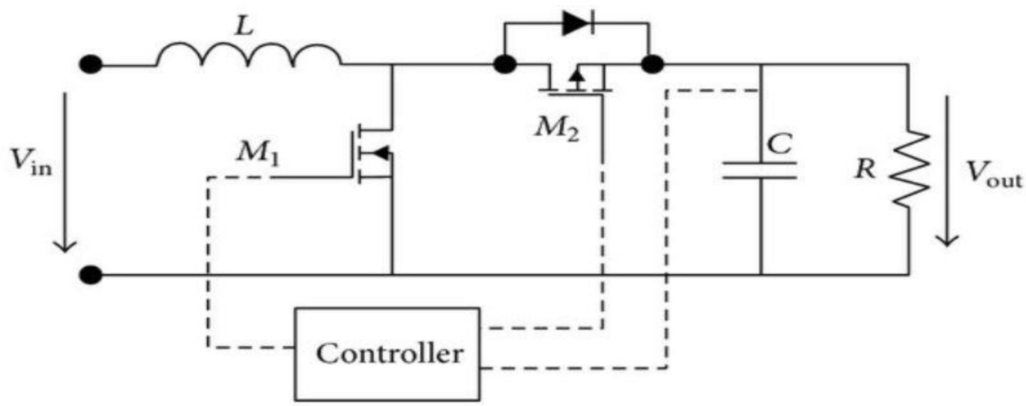

Figure 3.4 Boost converter.

In boost converter, relationship between input current and output current is

$$I_{in\_put} > I_{out\_put} \tag{3.5}$$

The relationship between input voltage and output voltage for boost converter is

$$V_{in\_put} < V_{out\_put} \tag{3.6}$$

The duty cycle defines the ratio between input and output. By changing the value of D, output can be varied according to the demand. Value of D is in between 0 and 1.

$$\frac{1}{1-D} = \frac{V_{out\_put}}{V_{in\_put}} \tag{3.7}$$

3.4. Constant Current Constant Voltage Charging Method

Constant current constant voltage charging method is the furthermost broadly accepted scheme in practice, owing to its lenience and easy to implement[41]. Initial stage of battery charging, a constant current is applied to the battery. When the battery's voltage reaches to the determined maximum voltage, the voltage becomes constant and the current decreases gradually, till the pre-set charging complete criteria is met. The CC-CV process consist of constant current (CC) charging level and constant voltage (CV) charging level. Therefore, it ensures quick charging practice because of the supply of current rate during initial stage of charging and restricted battery divergence at the end of the charging process, which ensures safety of the battery cells[42, 43].

General Control diagram of CC-CV charging method is shown in Figure 3.5.

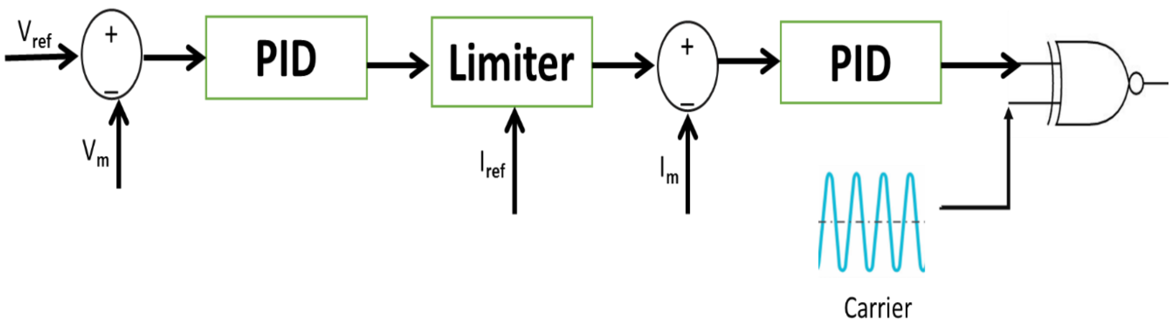

Figure 3.5 CC-CV charger model.

The parameters of PI controllers of this thesis are selected using hit and trial and error approach. The standards are selected for this CC-CV charger which are as follows:

I. In the beginning of charging, the charging current must rise to the defined value with in short period of time.

II. When the voltage reaches the defined limit and becomes constant, the charging current should decrease within short period of time.

The graph of output voltage and current for CC-CV charger is

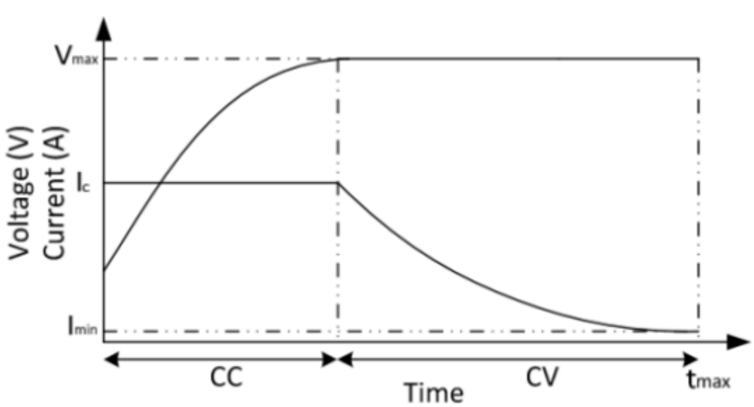

Figure 3.6 output of the charger.

3.5. Droop control

Primary, secondary and tertiary controllers are commonly used in AC micro grid to share load between converters, to remove steady state errors and to monitor the system overall requirement respectively[44]. Primary control is a droop control which monitors the P (Active power) by regulating frequency and controlling the output voltages. Frequency and voltages are controlled according to the load variation to meet the demand. Micro grid is integrated to the DG'S (distributed generators) with parallel combination of inverters[45].

Two schemes for parallel inverters can be used for power scheme, one is droop control and second is active current sharing. Active current sharing uses source voltage and droop control uses R_d which demonstrate that droop control works on its own style. Power sharing demand is adjusted by increasing or decreasing the value of R_d. Therefore it should consider that stability will have on maximum value of R_d.

Following equation defines this statement well**,**

$$R_d < E_i - \frac{v_{DC,bus}}{I_{max}} = 0.87 \tag{3.8}$$

Following diagram represents voltage stability of three converters which are connected in parallel way with a DC bus where load is resistive.

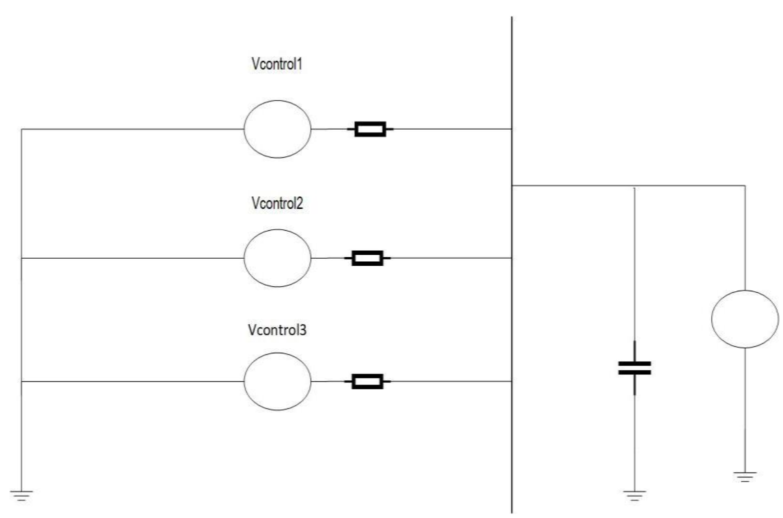

Figure 3.7 proposed droop control scheme

Additional feedback PI (proportional Integral) controllers can be used for the stability of droop current loop[46].

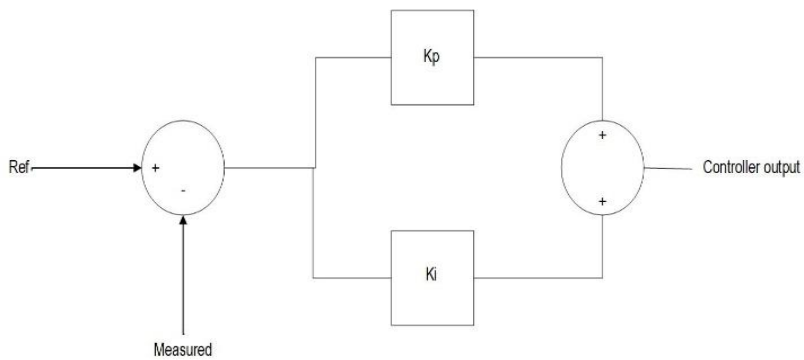

Figure 3.8 PI Controller

3.5.1. Advantages of Droop Control

Following are the most prominent advantages of droop control used for DC power system to maintain voltage on DC bus bar for power sharing[47].

- Different power is acquired from each inverter according to their rating.
- High dependability.
- Tractability is high.
- Informal implementation.

3.6. Formulation of DC power flow and power losses

In power flow analysis four variables are considered which are active power injection, reactive power injection, voltage angle and magnitude. Different methods are used for analysis. Newton Raphson, Guass Seidel and Fast Decoupled methods are used for analysis of non-linear problems. In contrast, DC power flow assumes constant voltages and non-linear problem is simplified into linear equation by iteration methods. Once linear equation obtain, no need to iterate to get desired value.

Active power on node i is

$$P_i = \sum_{j=1}^{n_r} B_{ij}(\delta i - \delta_j) \quad 3.9$$

$$\sum_{i=1}(P_{G,i} - P_{L,i} - p_i) = 0 \quad 3.10$$

Where

P_i is active power, $P_{G,i}$ is delivered active power at node i and $P_{L,i}$ is the withdrawn active power from node i.

Following Considerations are made for linear problems[48]

- Voltage angles of different nodes are negligible.
- Transmission lines are lossless because of the negligence of R i.e. R<<X.
- Flat voltage profile.

Power losses in conventional and DC/DC converters are calculated from following equations[49],

Power losses across switches

$$P_{avg,cond} = v_{CEo} I_{dC} + \frac{3}{8}\pi^2 R_{on}(I\,dc)^2 \quad 3.11$$

Power losses across diode

$$P_{avg,diode} = P_{cond,diode} + P_{rec,diode} \quad 3.12$$

$$\therefore \; P_{rec,diode} = \frac{E_{rec} * I_{pk} * F_{s.w} * V_{DC}}{\pi * I_{nom} * V_{nom}}$$

$$P_{cond,diode} = 0.5 * \left(V_{DO} * \frac{I_{peak}}{\pi} + R_D * \frac{{I_{peak}}^2}{4}\right) - m * \cos\theta \left(V_{DO} * \frac{I_{peak}}{8} + R_D * \frac{{I_{peak}}^2}{3\pi}\right) \quad 3.13$$

Where m is modulation index which is equal to one in this Simulink.

Table 3.1 Datasheet at 125C

IGBT		DIODE	
$E_{on}(J)$	6.45	$E_{rec}(J)$	3.75
$E_{off}(J)$	4.65		
$I_{nom}(A)$	1200	$I_{nom}(A)$	1200
$V_{nom}(V)$	2800	$V_{nom}(V)$	2800
$V_{CEO}(V)$	1.44	$V_{dO}(V)$	1.79
$R_{on}(\Omega)$	0.001677	$R_{d}(\Omega)$	0.001167
$R_{th}(j-c)(C°/W)$	0.008	$R_{th}(j-c)(C°/W)$	0.016
$R_{th}(c-h)(C°/W)$	0.006	$R_{th}(c-h)(C°/W)$	0.006
$R_{th}(j-h)(C°/W)$	0.014	$R_{th}(j-h)(C°/W)$	0.022
$R_{th}(hs-a)(C/W)$	0.007	$R_{th}(hs-a)(C°/W)$	0.007

Chapter 4

Simulation and Results

CHAPTER 4. SIMULATION AND RESULTS

4.1. Simulation

The software used for simulation work is "MATLAB" because it is easy to use. Another reason to choose this software is that it has many built-in electronic models for simulation which can help to get desired results. All the pre-owned components in the simulation model of this research work like buck converters, boost converters, PI controllers, droop controllers, loads and power supply scheme for charging and discharging station of EV's are shown. The total simulation run time is 10 seconds because of the charging of EV's. During charging and discharging, SOC (state of charge) is monitored. To share power to the DC grid and to maintain voltage on DC bus bar under different load, power sharing from each vehicle according to its capacity is determined. The results of simulation shown in next section of the chapter.

4.2. Results

4.2.1. Buck converter output

The output of buck converters (controlled CC-CV) and different stages of SOC of the battery during the simulation run time are shown in Figure 4.1, 4.2 and 4.3, as time passes SOC of the battery increases. The current remains constant during the rising period of voltage when voltages becomes constant, current reaches to its minimum value. The charging current for all models are represented in Figure 4.4, 4.5, and 4.6. Different stages of SOC and charging current are shown in following figures.

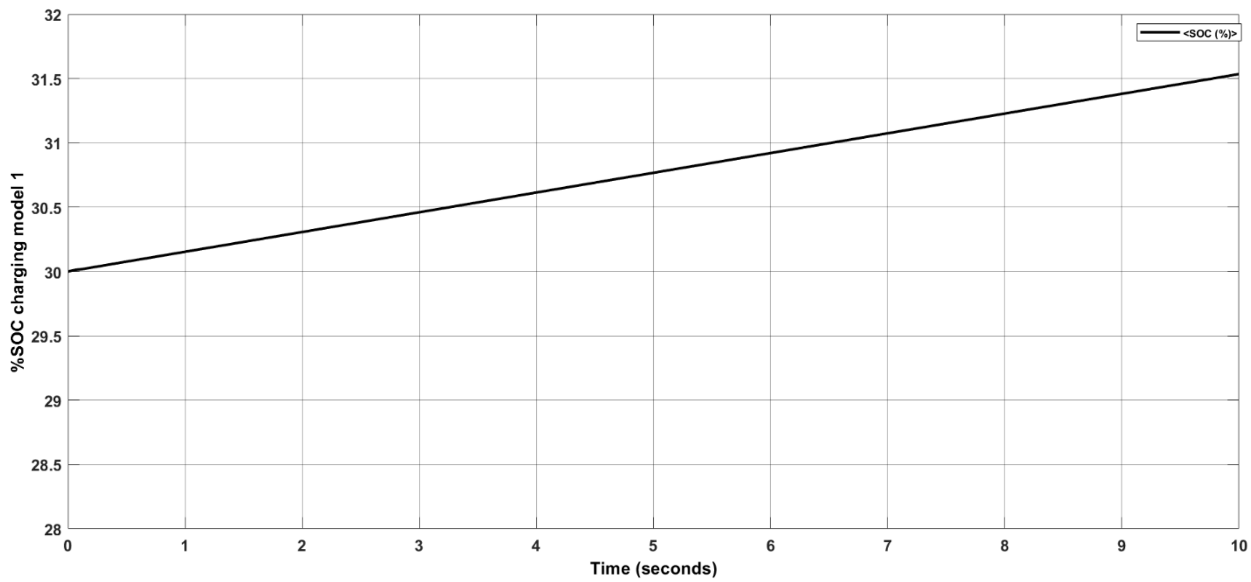

Figure 4.1% SOC of charging model 1

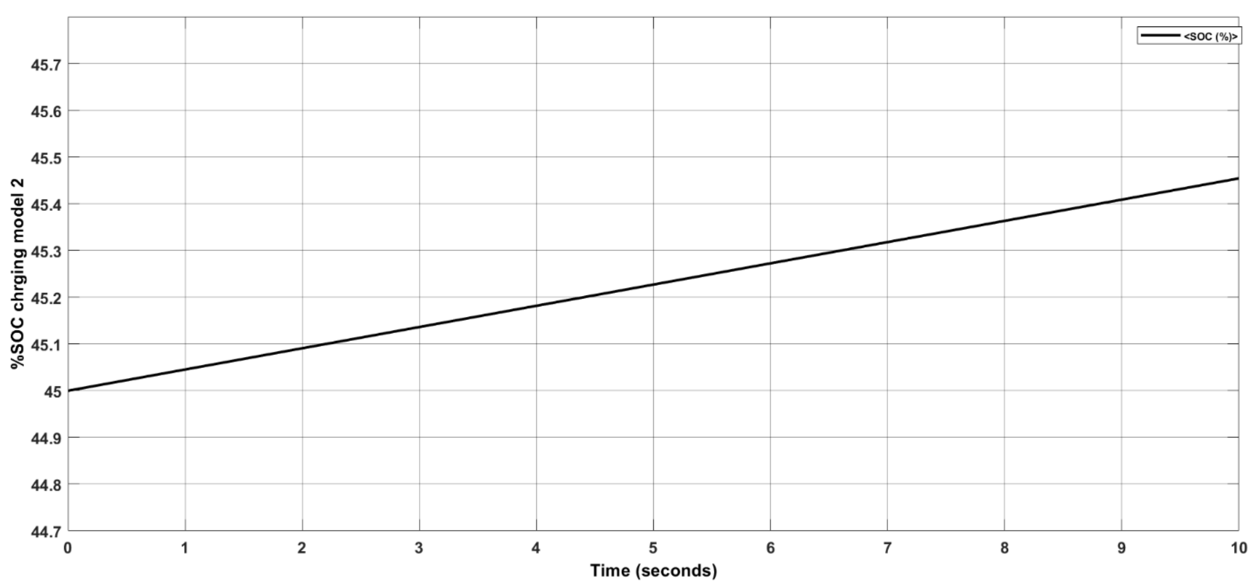

Figure 4.2 %SOC of charging model 2

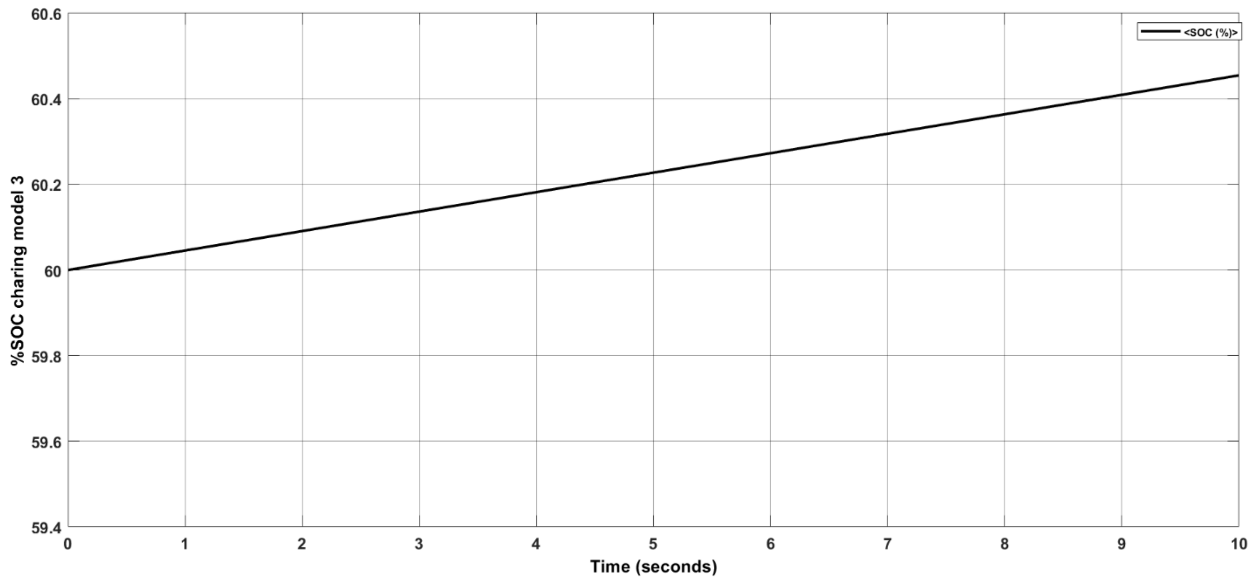

Figure 4.3 %SOC of charging model 3

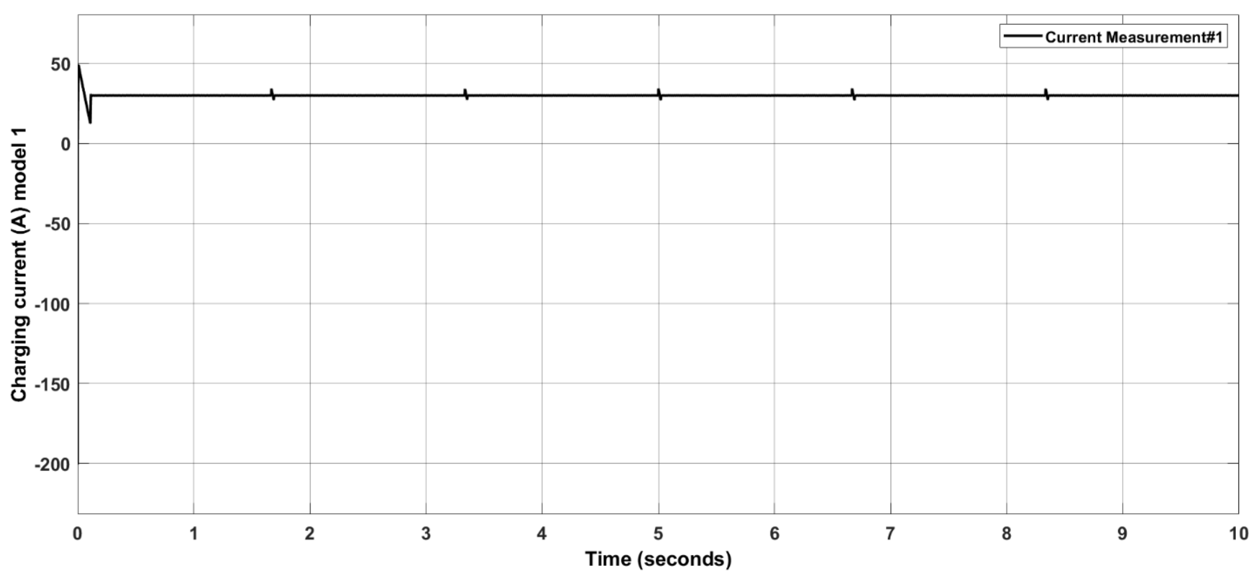

Figure 4.4 Charging current of model 1

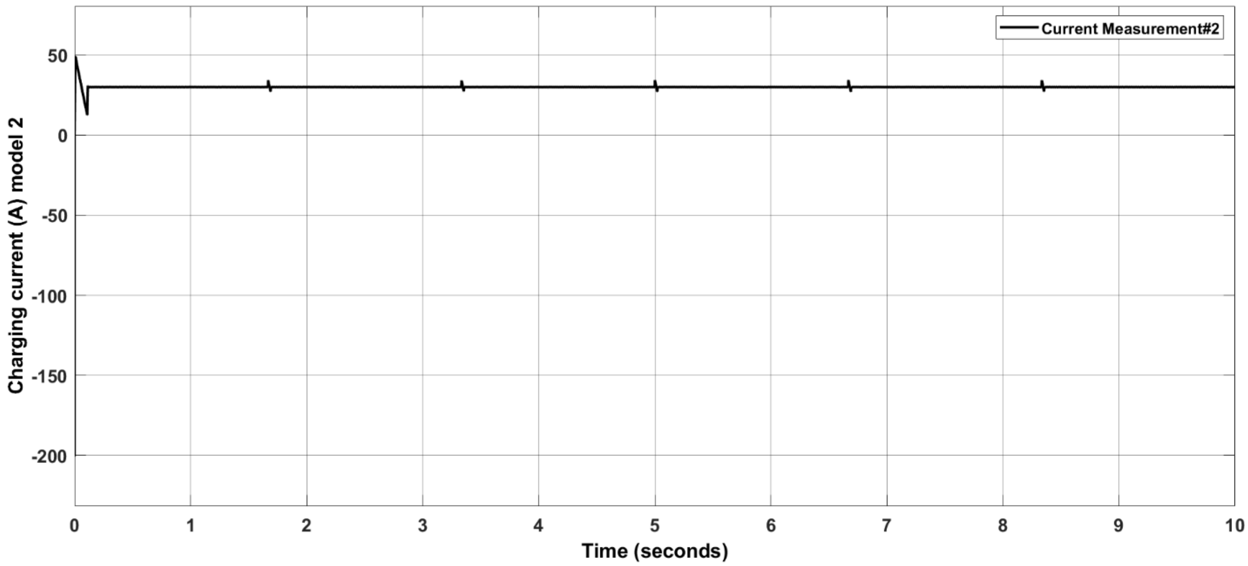

Figure 4.5 Charging current of model 2

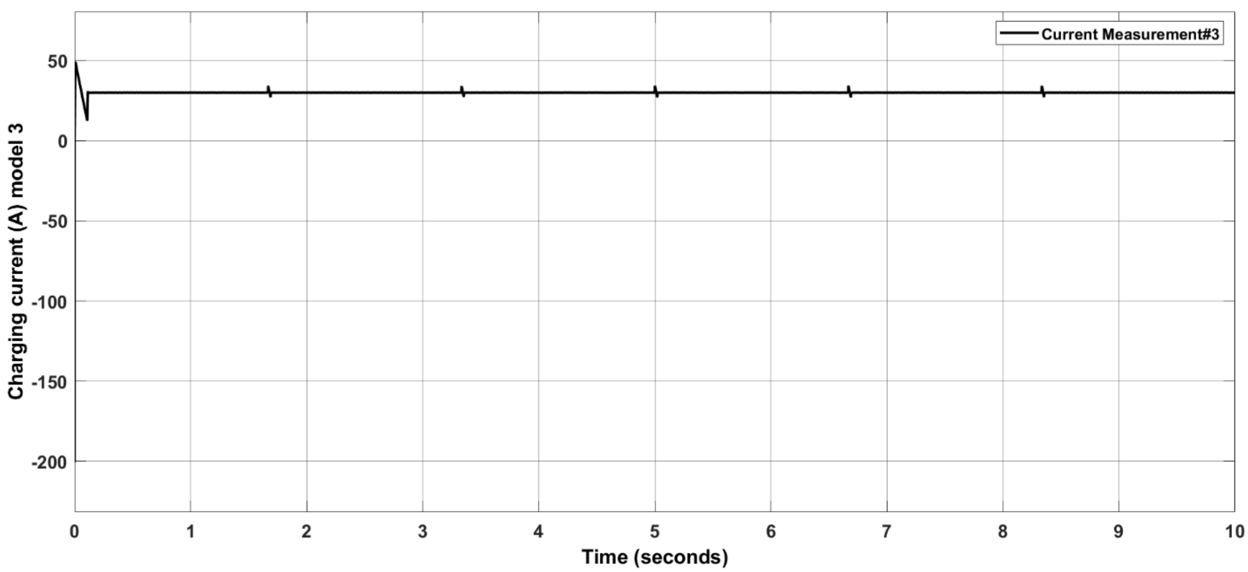

Figure 4.6 Charging current of model 3

4.2.2. Boost converter output (V2G)

Boost converter (uncontrolled) is connected in parallel combination with the charged electric vehicles to supply power to the grid. Each converter is sharing power according to its capacity to maintain the voltages on DC bus bar. Droop controllers are used as a reference of active power to maintain constant supply at varying load. The SOC and voltage of boost converter (uncontrolled) are shown in Figures 4.7 and 4.8 respectively.

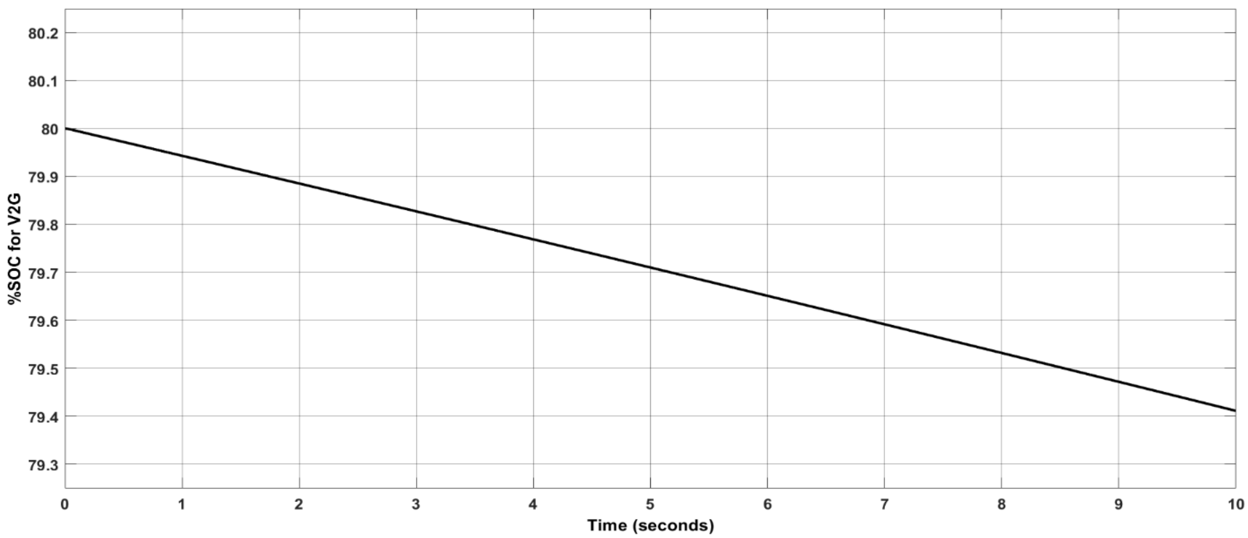

Figure 4.7 %SOC of boost converter (uncontrolled) in V2G mode

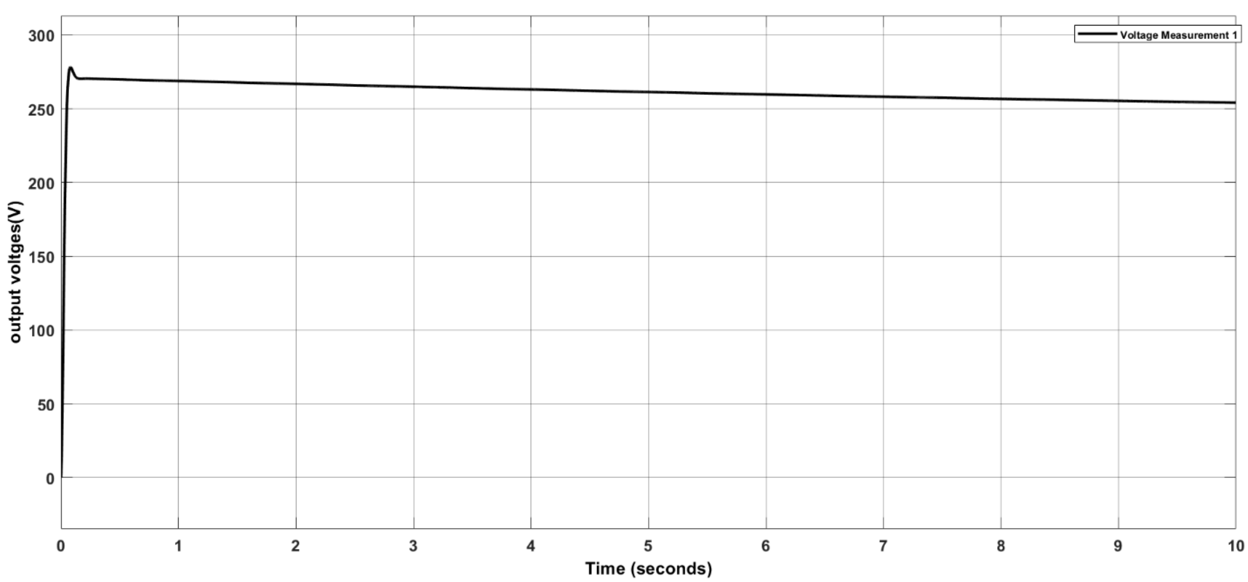

Figure 4.8 voltages of boost converter.

4.2.3. Balanced power sharing from each vehicles

Balanced power is shared from each vehicle to stable voltages on DC bus bar. Results in Figure 4.9 are the voltages required for load and the power shared from each vehicle which is identical.

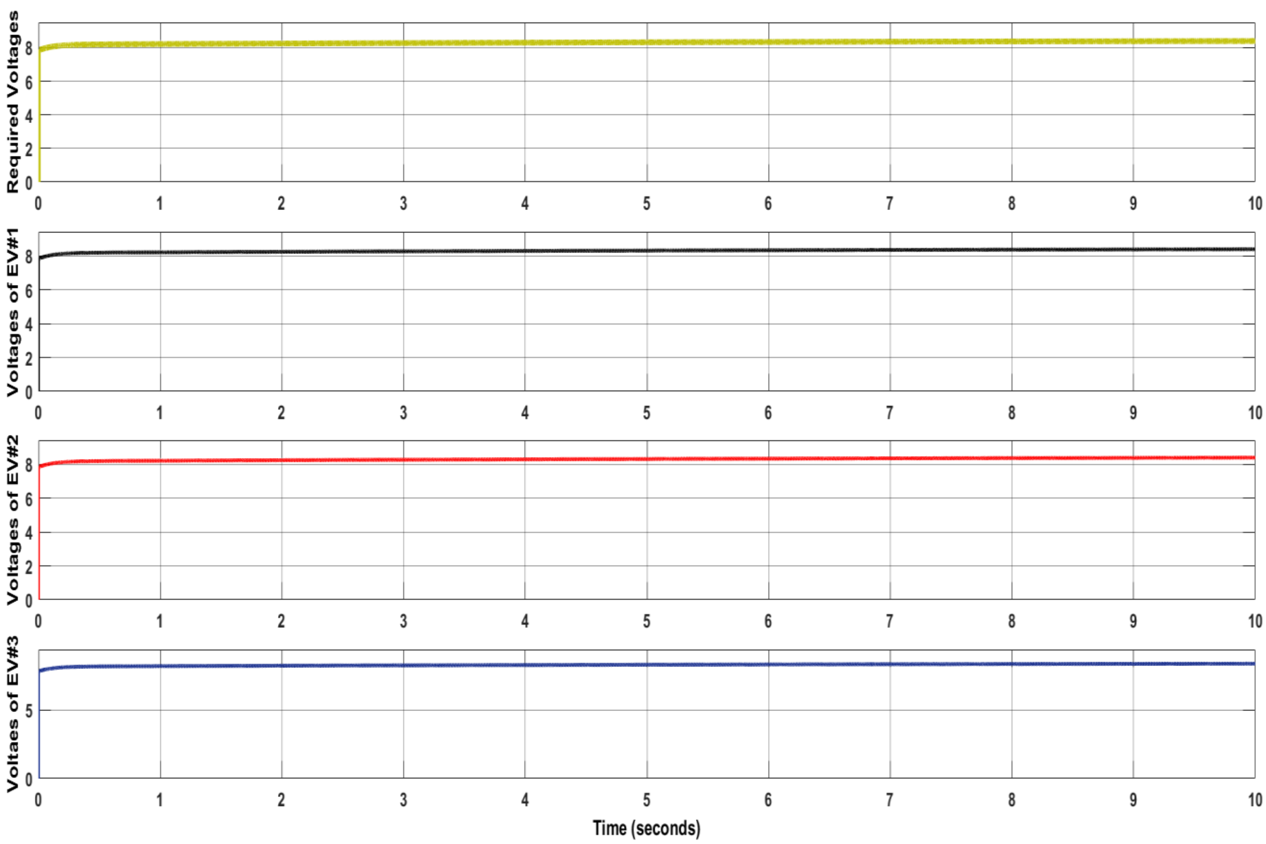

Figure 4.9 voltage stability of DC bus bar with balanced power sharing from EV's

4.2.4. Power losses across individual converters.

Following table represents the used data to calculate the power losses across MOSFETs and diodes in each converter by using equ (3.11) and equ (3.13) and all constant parameters are expressed and taken from table 3.1.

Table 4.1 System ratings for calculation power losses

$V_{nom}(V)$	7.8
$I_{nom}(A)$	5.4
$I_{paek}(A)$	30
$V_{dc}(A)$	50
$E_{rec}(J)$	3.75
$R_{on}(\Omega)$	0.001167

The power losses across the witches and diodes in buck converters for charging and in boost converter for V2G mode using above mentioned values are shown in table 4.2.

Table 4.2 Power losses of overall system

S.r No.	Switches losses (W)	Diode losses(W)
EV Model #1	48.5	12.75
EV Model #2	48.5	12.75
EV Model #3	48.5	12.75
EV Model #4	64.5	107
Total losses	210	145

Losses across switches of controlled power supply can further be decreased by changing the values of current and voltages as these values are selected by hit and trail method. Losses across diodes of controlled power supply from vehicles to grid and to integrate these EV's to the DC power system are negligible as total losses of diodes for set of three vehicles model is just 38.25W. In addition, the contribution from EV (un-controlled) losses across switches can negligible as compared to the power supply to the load but losses across diodes can be control by adjusting the values of different parameters according to the IEEE standards.

Chapter 5

Conclusions and Future Work

CHAPTER 5. CONCLUSIONS AND FUTURE WORK

5.1. Conclusion.

Endless, less expensive and free of carbon energy is gained from RES’s and EV assurances an oil independent transport sector. The coupling of power grids and EV can be done by converting normal parking lot into a smart parking lot which ensures the bidirectional power supply from grid to vehicle and vehicle to grid. Power from EV’s is injected into the power grids. The conventional grid has disadvantages so an idea is discussed through this thesis to replace the conventional grids with DC grids and power is shared from EV’s to the DC load. Contribution from individual EV’s is according to their ratings. Therefore, in this work we develop an EV CC-CV charger through buck controller at parking lots of work places. This system is designed for three parking lots to charge EV’s as the mostly cars remain parked over there for a long time so they will be charged at workplaces. A charged EV to share power in V2G is connected with charging EV’s in parallel across the load to share power. The motive was to maximize the utilization of power from EV’s and to inject this power into the DC grid where the load is continuously changed. The voltages on DC bus is maintained w.r.t the load and demand of power with the help of controllers. The results are analysed to ensure the feasibility of the proposed technique. The described technique is carried out using MATLAB to analyse the charging system characteristics and behaviour of EV’s in V2G mode.

5.2. Future Works

For the future work following suggestions can be taken into account for further research

- This system has three EVs which are being charged and discharged including one electric vehicle which is already charged and feeding the DC grid according to its power rating.
- This system can be expanded to more parking slots and EVs according to the power demand.

- Power losses in AC power system and DC power system can be calculated and efficiency can be calculated of the both systems.
- It is suggested that this work can be further extended for market based and real time operations.
- This work can be used as a base and further extended to connect with the Grid and may send and take energy from the Grid under different combination of EV's.

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