Bidirectional Battery Charger: Design, Analysis and Simulation for Electric Vehicle

Minakshi Jangir[1] and Sunita Kumari [2]
M. Tech student (RE)[1], Assistant Professor & Head[2]
Department of Electrical Engineering, Mody University of Science & Technology, Lakshmangarh (Sikar)-Rajasthan

Abstract

This paper work proposes a design for a bidirectional electric vehicle charger that can transfer power from the grid to evaluate its functionality and performance, a bidirectional electric vehicle charging system is designed and modelled in MATLAB/Simulink.to the vehicle as well as from the vehicle to the grid. A simple power electronics topology is used. The primary goal of the research is to determine how well the charger interacts with the grid and its effects on battery voltage and current. In this research we work on the initial state of charge of battery is 80%. We can see the simulation output of SOC (%) of the battery for both grid to vehicle and vehicle to grid. In the mode of operation, the SOC (%) is increasing by 80% in Grid to Vehicle and decreasing by 80% in Vehicle to Grid. We can also find in this research voltage graph for grid to vehicle and vehicle to grid. In the voltage graph we can measure the Grid Voltage, Inverter Voltage and Grid and Inverter Voltage [34].

Keywords: Bidirectional battery charger, Vehicle to Grid, Grid to Vehicle, Buck-Boost Converter, DC-AC/AC-DC Converter, Battery Switching

1. Introduction

Carbon emissions attributable to human activity have increased exponentially over the last two centuries as a result of industrialization and an exponential increase in world population. for example, depicts the worrisome rate of increase in carbon emissions owing to the combustion of fossil fuels and cement manufacture. Furthermore, CO2 levels in the atmosphere and oceans have risen in lockstep with this trend. This effect has been exacerbated by emerging countries' fast industrialization [33].

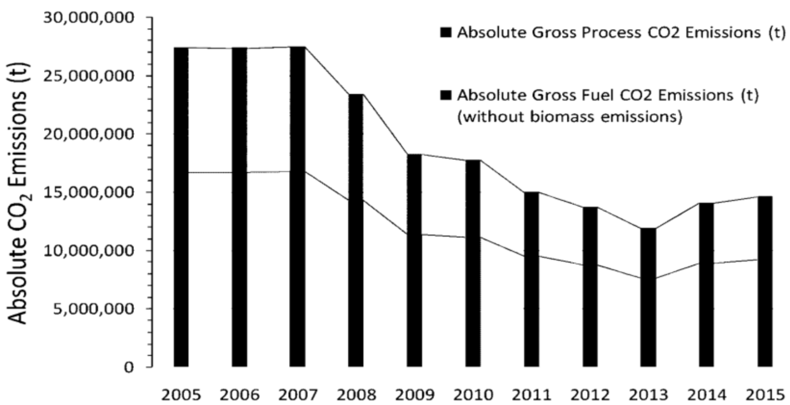


Figure 1.1 Total carbon emissions due to the burning of fossil fuels and cement production from 2005 to 2015 [33]

In the field of climate research, there is widespread agreement that man-made CO2 emissions are one of the primary causes of recent increases in global temperatures and associated climate anomalies Furthermore, new research suggests that even if all man-made CO2 emissions were to be stopped, the climate could take up to 1000 years to recover [33].

As a means of decreasing carbon emissions, there has been a shift in thinking about how power is generated, with more renewable energy sources being fevered, as well as a tendency toward more efficient use and storage of the generated energy [33].

Wind, hydro, solar, geothermal, tidal, and biodiesels made from bio matter are all examples of renewable energy sources. The trend toward more fuel-efficient automobiles, as well as the widespread deployment of electric and hybrid electric vehicles in the transportation sector, are examples of changes in the way energy is utilised. Government laws (such as the private leased sector energy efficiency standards and the climate change levy) have aided in the optimization of energy efficiency in both industrial operations and home power consumption [33].

1.1 Electric Vehicles

There is a global impetus for the development and transition towards electric, hybrid, and fuel cell vehicles as a result of concerns about climate change, which has resulted in tough pollution rules, increased global demand for energy, and the rapid depletion of fossil fuel sources [33].

Battery electric cars, hybrid electric vehicles (HEVs), and fuel cell vehicles are the three main types of vehicles that fall under the umbrella term "Electric Vehicles" (FCVs) [33].

1.1.1 Battery Evs

Battery electric vehicles (BEVs) are powered solely by battery (most often Lithium-ion batteries) and ultracapacitor-based energy storage technologies, which drive an electric motor(s) and emit no pollutants. Because of the low energy density of batteries, the long recharging time, and the expensive cost of batteries, battery-based EVs have a short usual driving range [33].

1.1.2 Hybrid Electric Vehicle

HEVs, which combine an internal combustion engine (ICE) with an electrical drive train in either a series, parallel, series-parallel, or complicated arrangement, have been created to alleviate the limitations with battery-based EVs. As a result, HEVs provide the same improved driving range as conventional ICE vehicles, with the added benefit of increased energy economy thanks to energy recovery, storage, and management systems [33].

In a series configuration, the ICE transfers chemical energy from a traditional fuel source to mechanical energy, which is then transferred to electricity via a generator, and then to electricity via an electric motor(s) to drive the wheels. Despite the simplicity of the power train architecture, the efficiency of series HEVs is lower due to the three-stage energy conversion process [33].

Both the ICE and the electric motor drive the wheels at the same time in a parallel HEV configuration. The absence of a separate generator, as well as the reduced size of the ICE and motor due to shared power delivery, are all advantages of this configuration [33].

With the purpose of merging the benefits of both designs, the series-parallel technique incorporates properties of both series and parallel type HEVs. The addition of a generator attached to the ICE distinguishes series-parallel HEVs from parallel HEVs. However, the method has the drawback of increasing the complexity and cost of the process [33].

1.1.3 Fuel Cell Electric Vehicle

Due to the hydrogen-based fuel cell energy source, FCVs are also zero-emission vehicles. In an FCV, the power delivery system consists of a hydrogen storage tank followed by fuel cells, which generate electricity. After that, there is an electric motor drive system. Although FCVs have the benefits of zero emissions and an acceptable driving range, they also have the disadvantages of expensive fuel cell costs and short cycle lives, as well as the difficulty of storing and transporting hydrogen as a fuel [33].

1.2 Electric Vehicle Charger

On-board and off-board charger systems are the two types of charging systems for electric vehicles. Off-board chargers are often capable of delivering a bigger quantity of power to the vehicle in the form of DC. It is feasible to relocate the weight of the AC-DC conversion hardware to the external infrastructure by employing off-board chargers, which is desirable because it reduces the total weight of the EV [33].

However, having an on-board charger gives the EV more freedom because it can charge in both home and commercial settings where an AC power source is accessible. Level 1 on-board chargers have a power rating of less than 3 kW, while level 2 chargers have a power rating of up to 20 kW (for example, the Tesla Model S twin wall charger). Wireless inductive chargers for electric vehicles are also available, albeit they are not as extensively utilised as conductive chargers due to difficulties with efficiency and cost [33].

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 06 Issue: 10 | October - 2022 Impact Factor: 7.185 ISSN: 2582-3930

1.2.1 Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G)

Although the primary purpose of an EV charger system is to replenish the battery (G2V), it is also possible to use the charger infrastructure to reverse the flow of power and provide power to the grid (V2G), which may appear paradoxical at first. Because the electric utility system must meet a wide range of demand conditions, the cost of power changes throughout the day, with night-time demand generally being lower and hence the cost being lower. Because electric vehicles are usually parked and not in use, they have been proposed as an energy storage method and are currently being tested in a number of nations (major countries include Japan, the United States, Germany, Denmark, South Korea, and the United Kingdom).

One of the goals of the V2G concept is to provide power for transient demands, such as "peak load levelling," where traditional generation can't keep up. Frequency stability and reactive power correction are two further objectives. There are also plans for using V2G technology to buffer excess renewable energy in EV batteries during low utility demand periods and to provide electricity during peak demand periods, optimising renewable energy production. Connection to a dirty grid and detection of an islanding scenario, which poses a safety risk to utility personnel, are two significant difficulties in V2G technology. With advances to grid synchronisation and islanding detection methods, this thesis tackles these concerns for single phase systems. Other problems with V2G technology include low overall efficiency due to battery charge-discharge losses, excessive battery wear, and the lack of a uniform standard for communication with the utility system. However, as battery technology improves and utility and vehicle systems become increasingly connected over the Internet, V2G technology has a bright future [33].

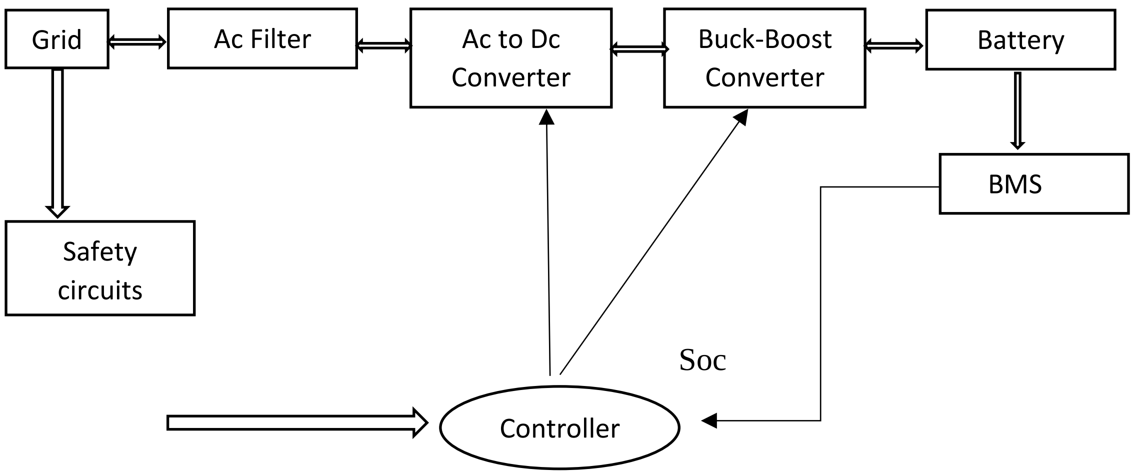


Figure 1.2 Block Diagram of Bidirectional Charger [34]

2. Literature Review

Balasundar, Sundararajan, et.al.[1], In this paper Power quality improved bidirectional EVCS in the distribution grid has been designed and analysed in this research. Both modelling and experimental analysis were used to analyse the proposed charging station for G2V and V2G operation. The charging station's quality has improved. By including an efficient controller-based DSTATCOM, the system has been improved. The PCC is located. The DSTATCOM reduces current harmonics by a factor of ten. Introducing a 180-degree phase shift in the converter current as a result, the current situation of the feeder's flow has been balanced and sinusoidal.

Yuan, Dorn-Gomba, et.al.[2], This paper presents bidirectional OBCs for EVs: a complete analysis and future developments Bidirectional OBCs have been evaluated in terms of architectures, smart operation modes, industry standards, components, and commercial examples. We looked into two-stage and single-stage methods. Because of its simple structure and great performance, most high-power bidirectional OBCs for commercial applications use a two-stage arrangement with a DC-link capacitor. The employment of a front-end totem-pole PFC converter with a downstream CLLC DC/DC converter is common.

Gorkem Berk Sahinler, Gokturk Poyrazoglu [3], The purpose of this paper is to look at how an electric vehicle (EV) charger with a controller works and how it impacts the EV battery when it is connected to the grid. To test its functionality and performance, a bidirectional electric vehicle charging system is designed and modelled in MATLAB/Simulink. The study's main concerns are how well the charger interacts with the grid and how this affects battery voltage and current. The research is carried out using theoretical analysis and simulations.

Rajesh Kumar Lenka, Anup Kumar Panda [4], The impact of a vehicle-to-grid (V2G)-enabled bidirectional off-board electric vehicle (EV) battery charger on grid current is investigated in this article. Harmonic compensation (GCHC) and reactive power compensation (RPC) are two types of harmonic compensation. It works as a battery charger and a power generator at the same time. As a result, without relying on any phase-locked loops, the suggested control method provides effective performance. (PLL). The proposed control algorithm improves the charger's performance. The simulation findings obtained using MATLAB/Simulink have been validated. In addition, an experimental prototype of an off-board EV battery charger has been created. to confirm the simulation results achieved in the lab.

Queen Okon, Javier Urquizo, et.al. [5], This paper describes control structure for a bidirectional battery charger, which comprises of three-phase PWM ac/DC converters connected to a DC/DC converter with a CLLC-type resonant tank circuit. It shows a control structure that accommodates an Energy Storage System's (ESS) constant current, constant voltage (CCCV) charging algorithm, a multiple battery charger setup, and the automation of the combined control system based on the fulfilment of specified circumstances. Using the PLECS software tool, the suggested control strategy was simulated and validated for a system integrating two battery charger modules while charging a Li-ion battery model.

Vijayalakshmi, Marimuthu, et.al. [6], This research examines a PV panel-based bidirectional converter for charging electric vehicles. A solar cell battery and a bidirectional dc-dc converter make up this system. When there is no sunshine, a battery is provided to power the dc motor. The bidirectional dc–dc converter can charge and discharge the battery in both directions and can manage the flow of power in both directions, allowing excess energy from the PV panel to be stored in the battery.

G. Mejía-Ruiz; M.R.A. Paternina, et.al. [7], This paper shows that the electric vehicles (EVs) are becoming more prevalent in the electrical grid, battery chargers and Plug-in EVs can be used as a distributed energy resource to supply ancillary services. A thorough control method for a bidirectional isolated charger for EVs capable of providing ancillary services is proposed in this research. This method leads to off-board three-phase smart chargers, which can support the grid by injecting active and reactive power during voltage and frequency changes. A bidirectional three-phase voltage source converter is followed by an isolated dual active bridge in the proposed charger.

Shandong Wang, Haoran Li, et.al. [8], This paper shows to boost power density, the SiC portable charger uses 300-kHz high-frequency isolation. When compared to conventional V2V mode employing an on-board charger, the suggested vehicle-to-vehicle (V2V) mode uses two-stage direct dc–dc power conversion to achieve improved efficiency (OBC). A 6.6-kW SiC bidirectional portable charger with a power density of 14.7 W/in 3 has been developed. V2V mode has a full-load efficiency of 96.1 percent, which is 4.7 percent higher than standard V2V mode. The EV's bidirectional energy connection with the 380-V dc microgrid is also confirmed. The portable charger has a 36–400-V wide output voltage range for dc loads and a 95.7 percent efficiency at 6.6 kW.

Ijaz Ahmed, Iftikhar Ahmad, et.al. [9], For the regulation of AC–DC power conversions in BEV chargers, this study proposes a super twisting sliding mode controller, an integrated backstepping sliding mode controller, and a backstepping sliding mode controller. The designed controllers were successful in achieving the goals of unitary power factor and output DC voltage regulation. They took into account nonlinear dynamics and provided superior dynamic responses. The fundamental disadvantage of SMC, BS-SMC, and IBSSMC, for example, is chattering, which is the main cause of heat and power losses in the system. This problem was overcome by developing ST-SMC for an AC–DC converter in a BEV charger, and comparing its performance to that of the proposed and other nonlinear controllers in the literature.

Gabriel Rojas-Duenas, Jordi Roger Riba, et.al. [10], In this paper we can see an approach for black-box modelling of a 48 V–to12 V DC–DC bidirectional. The model can imitate the behaviour of humans thanks to the deployment of a deep learning algorithm. a nonlinear switching device, such as a bidirectional converter, which is employed in MHEVs. A hyper-parameter is calculated based on the converter properties. The LSTM-NN has a specialised topology and tuning algorithm. discussed. To generate the data, a suitable experimental setup was required. datasets should be used in the LSTM-training NN's process.

Chandan T L; Poornima Kulkarni, et.al. [11], In this paper discussed about the well-known fact that vehicles with IC engines require fossil fuels as their oxygen and, as a result, send dangerous chemicals back into the atmosphere, forcing us to learn more about environmentally friendly automobiles to counteract the effect of ordinary IC engines: The Electric Vehicles, without a doubt. A two-stage converter connects the input grid supply and the battery in an on-board charger (OBC), whose output levels vary depending on the vehicle architecture. OBCs are commonly available in two voltage ranges: 48-72 V and 96-150 V. This paper examines and proposes a novel common battery charger for automotive applications with a voltage range of 50-400 V, as well as a control method for achieving an inconsistent DC link in the PFC stage.

Derek Chou, Zitao Liao, et.al. [12], This Paper Presents the implementation of a bidirectional single-phase ac-dc converter that converts between universal ac (120-240 V AC) and 400 V DC. An interleaved 6-level flying capacitor multilevel (FCML) power factor correction (PFC) stage with a twice-line-frequency series-stacked buffer (SSB) stage is discussed in terms of system architecture, control, mechanical design and assembly, and thermal management. The findings of experiments demonstrating dc-ac inverter operating on a kilowatt scale are presented. There is a peak efficiency of almost 99 percent, and a maximum power of 6.1 kW is measured.

Houssein Al Attar, Malek Ghana’s, et.al. [13], The input DC bus voltage regulation for such DC-DC converters is the new challenge of this paper to achieve the gains. The key contribution is the creation of control laws based on the gain inversion of the DC-DC LLC transfer function. Three traditional modulation schemes are shown, each based on an averaged small signal DC-DC LLC dynamic model converter with first harmonic approximation. The control of Pulse Frequency Modulation (PFM) is first investigated. Then, to avoid the limitations of PFM, control based on Pulse Width Modulation (PWM) and Phase Shift Modulation (PSM) is created. Each strategy's advantages and disadvantages are addressed. In terms of control performance and converter efficiency, a comparison of the various techniques is generated.

Deepak Kumar, Anmol Ratna Saxena [14], In this paper a non-isolated battery integrated three-port bidirectional dc-dc converter (BIBTPC) is developed and investigated for connecting light electric vehicles (LEVs) with a low voltage dc distribution system fed by solar photovoltaic (SPV) (LVDDS). The converter can be set to run in a grid-to-vehicle (G2V) or vehicle-to-grid (V2G) configuration depending on the power generation. Maximum power point tracking (MPPT) can be implemented using BIBTPC while simultaneously managing the LVDDS dc bus voltage.

Nooriya Shahul, Siddharth Shelly [15], In this paper appropriate bidirectional battery charger design is provided. H bridge converter (combination of AC-to-DC and DC-to-DC converter) with the same DC-based capacitor is used to build bidirectional battery charger. Between the power grid and the DC-based capacitor, the first stage (AC-to-DC conversion) continues. The suggested system is made up of a series of power converters that manage the current through the grid and the voltage across the DC-based capacitor in tandem. Between the DC-based capacitor and the battery is a chopper (DC-to-DC conversion). The processor is in charge of controlling phase amplitude and frequency. The suggested technology improves a variety of applications, including battery charging, acting as an inverter during load shedding, and vehicle-to-vehicle communication in an emergency.

MD Mujahid Irfan, Shriram S. Rangarajan, et.al [16], This paper shows that the ANFIS-based DSTATCOM for electric vehicle charging stations was demonstrated in this article. Harmonics and unbalanced currents have an impact on the input side of charging stations due to non-linearities and the reactive nature of the load. DSTATCOM uses the ANFIS-based instantaneous reactive power control approach and HCC to alleviate power quality issues.

Flah Aymen, Majed Alowaidi, et.al [17], This paper's work has been enhanced to include mathematical analysis and translated into Simulink/MATLAB blocks. After the complete system was run, other metrics such as vehicle speed, motor speed, and others were tracked and collected. We also developed numerous PI controllers within the overall framework using the accessible control loops.

Andrea Burgalossi, Lucas Herfst, et.al. [18], In this paper we can see that Understanding how cognitive functions map onto neural circuits is a fundamental goal of neuroscience. For most cognitive operations this goal is not within reach, but in rodent spatial cognition there have been three impressive advances. First, physiological studies on hippocampal and Para hippocampal neurons have revealed rich and abstract representations of space.

Netra Lokhande, Aniruddha Deore, et.al. [19], This paper considers Battery Electric Vehicles and its components have been imitated based on the aforementioned assessment to explore the energy stream, execution, and efficiency. MATLAB-Simulink was used to display the results for Battery Voltage, Current, Power, and Stimulus State.

Ibrahim, A., & Jiang, F. [20], This paper shows that, one of the possible technological options to address the rising climate change challenges is to transition to an electrified transportation industry. Smart vehicles and pooled transportation schemes are also possibilities in such a transformation. To propel the car and maintain pleasant driving conditions, an electric vehicle uses only stored electric energy.

3. Methodology and System Design

3.1 DC-AC/AC-DC Converter

At the point of conversion, EVs emit no emissions from their tailpipes. They also produce less noise pollution than an indoor combustion engine vehicle, whether they are stationary or moving. EV adaptation would provide a significant net environmental benefit. Almost all domestic devices function on DC nowadays, yet we get AC from power generation. Because AC can be transported more efficiently and at a lower cost than DC, it is done so via transmission lines. A rectifier is used in an AC to DC converter. to change the voltage level and reservoir capacitor to smooth the pulsating DC, turn on AC input into DC output regulators [35].

3.1.1 Simulink Diagram

The circuit for AC/DC converter for EV charger has been simulated using MATLAB. Fig 3.1 shows the simulation circuit.

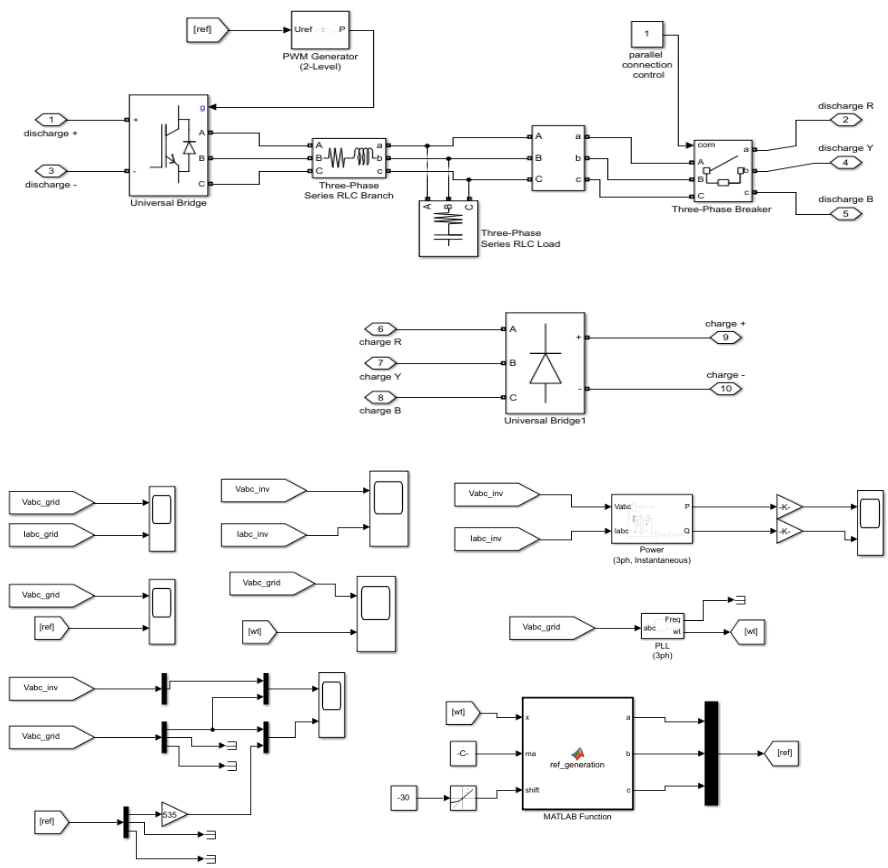


Figure 4.1 Simulation circuit of AC-DC/DC-AC converter for Charger

Different types of blocks are used in Simulink Diagram: -

a) Universal Bridge:

This block implements a bridge of selected power electronics devices. Series RC snubber circuits are connected in parallel with each switch device [33].

b) Three Phase Series RLC Branch

The Three-Phase Series RLC Branch block implements three balanced branches consisting each of a resistor, an inductor, or a capacitor or a series combination of these [33].

Set Resistance R (Ohms)= 0.004332

Inductance L (H)= 0.0013789184

c) Three Phase Series RLC Load

The Three-Phase Series RLC Load block implements a three-phase balanced load as a series combination of RLC elements. At the specified frequency, the load exhibits a constant impedance. The active and reactive powers absorbed by the load are proportional to the square of the applied voltage [33].

Set Nominal Phase to Phase Voltage Vn (Vrms) = 380 V

Nominal Frequency fn (Hz) = 50

Inductive Reactive Power QL= 0

Capacitive Reactive Power Qc = 5000

d) Three Phase Breaker

The Three-Phase Breaker block uses three Breaker blocks connected between the inputs and the outputs of the block. You can use this block in series with the three-phase element you want to switch. The arc extinction process of the Three-Phase Fault block is the same as for the Breaker block. See the Breaker block reference pages for details on the modelling of the single-phase breakers [33].

A control input appears in the block icon if the Three-Phase Breaker block is set to external control mode. The control signal connected to the Simulink input must be 0 to open the breakers or any positive value to close them. A 1 signal is usually used to close the breakers for clarity. The switching timings are provided in the Three-Phase Breaker block's dialogue box if the block is set to internal control mode. The signal that controls the three individual breakers is the same [33].

Breaker Resistance Ron (Ohm): 0.01

Snubber Resistance Rs (Ohm): 1e6

Snubber Capacitance Cs (F): Inf

e) PWM Generator

The PWM Generator block uses a two-level structure to generate pulses for carrier-based pulse width modulation (PWM) converters. The block can be used to power single-phase, two-phase, three-phase, two-level bridges, or a combination of two three-phase bridges with forced-commutated devices (FETs, GTOs, or IGBTs) [33].

Frequency (Hz): 4950

Sample time (s): 2.02e-6

f) MATLAB Function

```
function [a, b,c] = ref_generation(x,ma,shif)
%x=wt
shift_k=shift*pi/180;
a= (ma*(sin((x)+shift_k)));
b= (ma *(sin((x)+shift_k-(2*pi/3))));
c= (ma *(sin((x)+shift_k+(2*pi/3))));
```

g) Formula

$$L= \frac{2(Vac)^2\,(5.2) * (10^{-2})}{\omega p} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

$Vac = 230$ V, $\omega = 2\,\pi f$

There may be more than one output on an AC/DC converter, as well as overcurrent and overvoltage protection. Any apparatus or gadget that demands a certain level of voltage or current will use a high frequency transformer. The transformer was designed to be connected to a H bridge, which sends a high frequency voltage pulse to the primary coil, which is then converted into a higher voltage and delivered to a rectifier unit. In addition to the traction battery specialist systems used for industrial (or leisure) vehicles, an electric-vehicle battery (EVB) is a battery intended to power the system of a battery electric vehicle (BEV). Typically, these are secondary (rechargeable) batteries. A battery for electric vehicles, often known as traction batteries, delivers power to electric motors [33].

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 06 Issue: 10 | October - 2022 Impact Factor: 7.185 ISSN: 2582-3930

3.2 Buck-Boost Converter

A buck-boost converter's basic goal is to take an input DC voltage and output a different level of DC voltage, either reducing or boosting it depending on the application. A buck-boost converter is identical to a buck converter and a boost converter in design, with the exception that it is in a single circuit and usually has an additional control unit. The control unit detects the input voltage level and makes appropriate circuit action based on that value.

The buck converter is used to step down voltage, whereas the boost converter is used to step up voltage. Step-down or step-up can be accomplished with the buck-boost and Cuk converters. The charge-pump converter can be used for voltage step-up or inversion, but it's only for low-power applications [33].

3.2.1 Simulink Diagram

The circuit for Buck-boost converter for EV charger has been simulated using MATLAB. Fig 4.2 shows the simulation circuit.

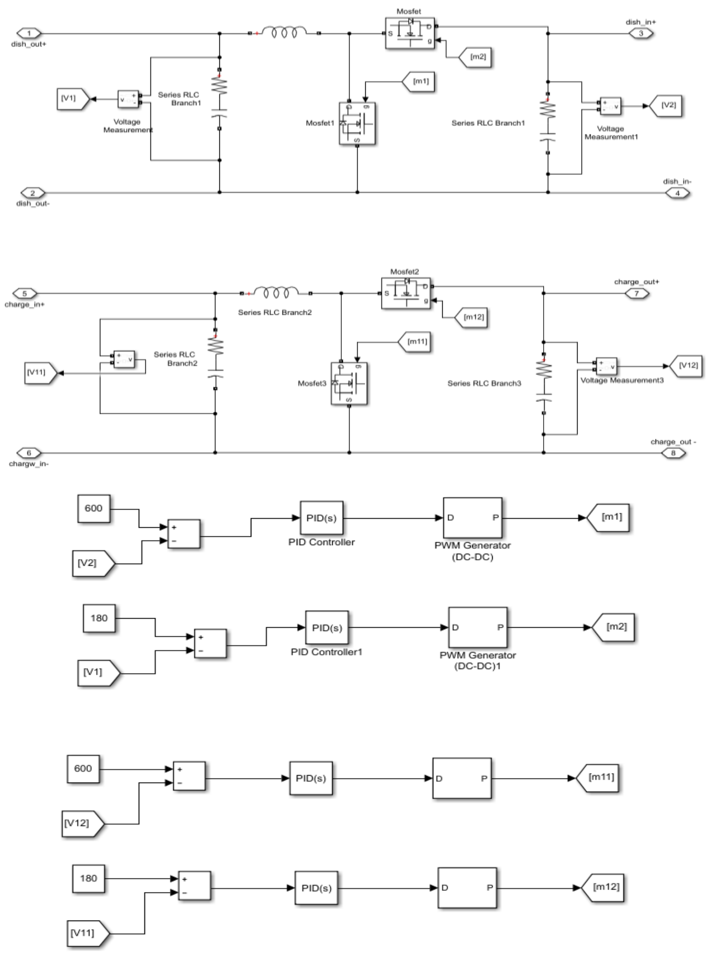


Figure 4.2 Simulation Circuit of Buck-Boost Converter for Charger

Different types of blocks are used in Simulink Diagram: -

a) MOSFET:

MOSFET and internal diode in parallel with a series RC snubber circuit. When a gate signal is applied the MOSFET conducts and acts as a resistance (Ron) in both directions. If the gate signal falls to zero when current is negative, current is transferred to the antiparallel diode [33].

Parameters:

FET resistance Ron (Ohms): 0.1

Internal diode inductance Lon (H): 0

Internal diode forward voltage Vf (V): 0

Snubber resistance Rs (Ohms): 1e5

b) PID Controller:

For triggering the IGBTs of the DC-to-DC converter, we use a PI and PID controller. The three different types of bidirectional dc to dc converters are compared. Then, for electric car applications, a boost converter is created over a typical boost converter by combining parallel combinations of IGBT and MOSFET [33].

c) PWM Generator:

The PWM Generator block uses a two-level structure to generate pulses for carrier-based pulse width modulation (PWM) converters. The block can be used to power single-phase, two-phase, three-phase, two-level bridges, or a combination of two three-phase bridges with forced-commutated devices (FETs, GTOs, or IGBTs) [33].

A triangular carrier waveform is compared to a reference modulating signal to generate the pulses. The modulating signals can either be created by the PWM generator or a vector of external signals attached to the block's input. For a single- or two-arm bridge, one reference signal is required to generate the pulses, and for a three-phase, single or double bridge, three reference signals are required to generate the pulses [33].

The output voltage (on the AC terminals) of the bridge attached to the PWM Generator block is controlled by the amplitude (modulation), phase, and frequency of the reference signals [33].

Parameters:

Switching frequency (Hz): 5000

Sample Time: 0

3.3 DC-DC Converter with Battery Controller

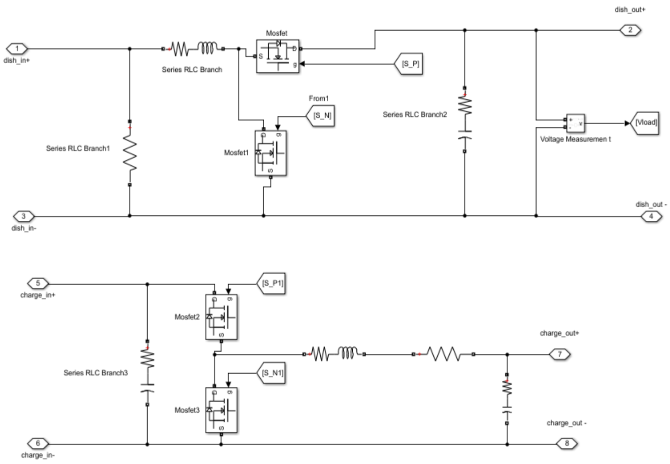
The DC-DC converter regulates voltage and raises the source voltage to the bus voltage. The battery energy storage system acts as a link between the input DC grid and the output DC bus. BES has been widely employed in a variety of applications, including Uninterruptible Power Supplies (UPS) [33].

Additionally, the DC-DC converter with battery energy storage (BES) can be used in conjunction to sustainable energy systems. Because of the variability in weather, the electricity generated by renewable energy systems is variable. As a result, a battery bank might be used to store the energy. The Voltage Regulator – Battery Energy Storage System (VR-BESS)8 is a single-structure design that combines a Buck converter [33].

Boost converter action feeds the load from a DC grid or DC source in normal mode, while buck converter operation charges the battery. When the load power exceeds the DC grid's capacity, the load is fed by the battery for extra power that cannot be supplied by the DC grid via Boost converter operation. When the DC grid voltage drops below the rated level, power switch duty cycles are modified to allow load feeding and battery charging to resume. All operation modes are simulated, and the results are provided [33].

3.3.1 Simulink Diagram

The circuit for DC-DC Converter with Battery Controller for EV Charger has been simulated using MATLAB. Fig 3.3 shows the simulation circuit.



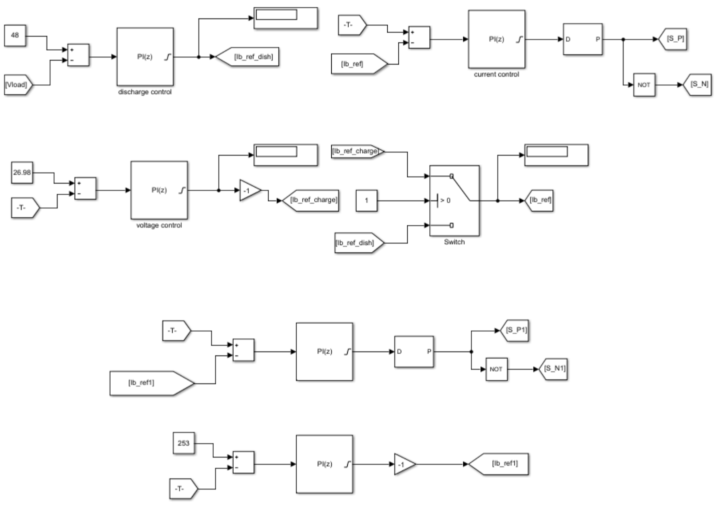


Figure 4.3 Simulation circuit of DC-DC Converter with Battery Controller for EV Charger

Different types of blocks are used in Simulink Diagram: -

a) MOSFET:

The gate signal (g > 0) controls a semiconductor device called a metal-oxide semiconductor field-effect transistor (MOSFET). When the MOSFET device is reverse biased (Vds 0) and no gate signal is supplied (g=0), it is coupled in parallel with an internal diode that turns on. An ideal switch controlled by a logical signal (g > 0 or g = 0) with a diode linked in parallel is used to imitate the model [33].

Whether the drain-source voltage is positive or negative, the MOSFET device switches on when a positive signal is applied at the gate input (g > 0). Only the internal diode conducts when voltage exceeds its forward voltage Vf if no signal is applied at the gate input (g=0) [33].

When the gate input becomes 0 with a positive or negative current flowing through the device, the MOSFET switches off. The switch turns off when the current I becomes 0 if the current I is negative and flowing through the internal diode (no gate signal or g = 0) [33].

Parameters

FET resistance Ron (Ohms): 0.1

Internal diode inductance Lon (H): 0

Internal diode resistance Rd (Ohms): 0.1

Internal diode forward voltage Vf (V): 0

Snubber resistance Rs (Ohms): 1e5

b) Switch:

Depending on the value of the second input, the Switch block passes through the first or third input signal. Data is entered in the first and third inputs. A control input is the second input. Using the Criteria for passing first input and Threshold parameters, specify the conditions under which the block passes the first input [33].

Parameters:

Threshold Voltage: 0

3.4 Battery Switching Control

The switching charger is essentially a Buck converter with voltage and current control loops that converts the VBUS supply to a voltage appropriate for system supply and battery charging [33].

3.4.1 Simulink Diagram

The circuit for Switching Battery Controller for EV Charger has been simulated using MATLAB. Fig 3.4 shows the simulation circuit.

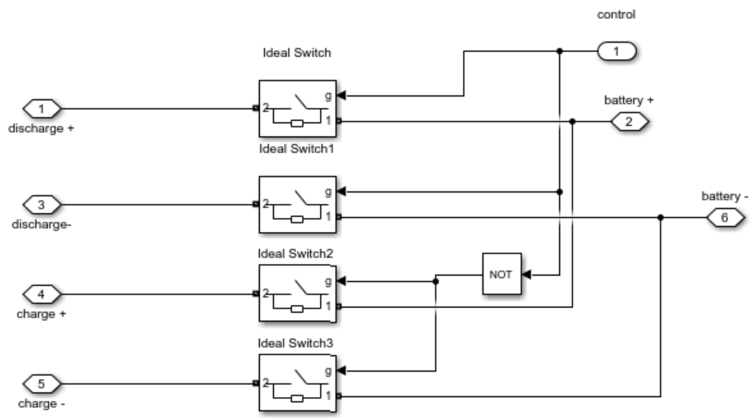


Figure 4.4 Simulation circuit of Battery Switching Control for EV Charger

Different types of blocks are used in Simulink Diagram: -

a) Ideal Switch:

The Ideal Switch block is not associated with any physical device. It can be used to represent simplified semiconductor devices like a GTO or a MOSFET, or even a power circuit breaker with current chopping, when combined with proper switching logic. A resistor Ron is connected in series with a switch controlled by a logical gate signal g to emulate the switch.

Switch controlled by a gate signal in parallel with a series RC snubber circuit.

In on-state the Switch model has an internal resistance (Ron).
In off-state this internal resistance is infinite. The internal resistance must be greater than zero. The switch model is on-state when the gate signal (g) is set to 1 [33].

Parameters:

Internal resistance Ron (Ohms) :0.001

Initial state (0 for 'open', 1 for 'closed'): o or 1 according calculation

Snubber resistance Rs (Ohms): 1e5

b) NOT Operator:

The NOT operator is a Boolean operator in Boolean algebra that returns TRUE or 1 if the operand is FALSE or 0 and FALSE or 0 if the operand is TRUE or 1. The operator, in essence, reverses the logical value of the expression on which it acts [33].

3.5 Connection Control

In the Wall Charger Connection Box of electric vehicle charger first subsystem is connection control box. Its main responsibility is controlling the all-connected subsystems connections [33].

3.5.1 Simulink Diagram

The circuit for Connection Control for EV Charger has been simulated using MATLAB. Fig 3.5 shows the simulation circuit.

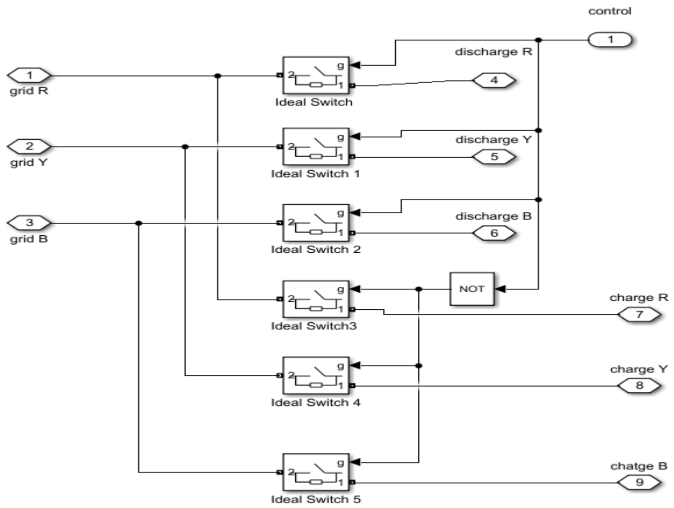


Figure 4.5 Simulation circuit of Connection Control for EV Charge

4. Working Principle

As shown in Fig. 5.1, the proposed bidirectional EV charger system consists of two stages: a three-phase AC/DC PWM converter stage, which is primarily responsible for regulating DC link voltage, and a DC/DC stage, which allows charging or discharging of the output battery depending on the power direction [35].

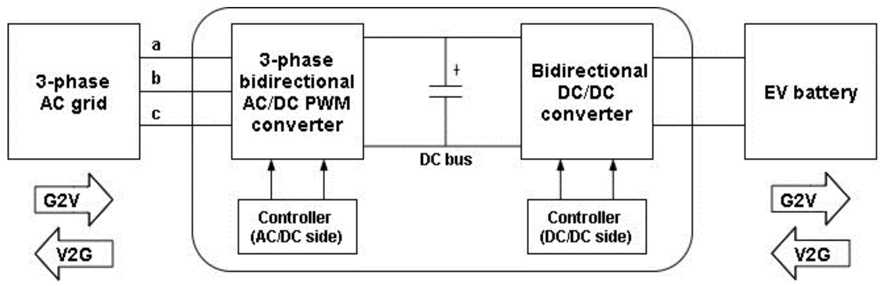


Figure 5.1 Diagram of the proposed bidirectional EV charger system [36]

In most circumstances, when using the Grid-to-Vehicle (G2V) mode of operation, it is preferable to charge the battery at a nominal voltage of 500V; however, depending on the state-of-charge, the charging voltage can sometimes be as low as 300V. (SOC). As a result, an extra DC-DC converter is necessary to step down or adjust the battery's charging voltage. However, in the Vehicle-to-Grid (V2G) mode of operation, the battery's power is removed and sent to the power grid [35].

5.1 Simulink Diagram

The circuit for Grid to Vehicle Bidirectional EV Charger has been simulated using MATLAB. Fig 4.2

shows the simulation circuit.

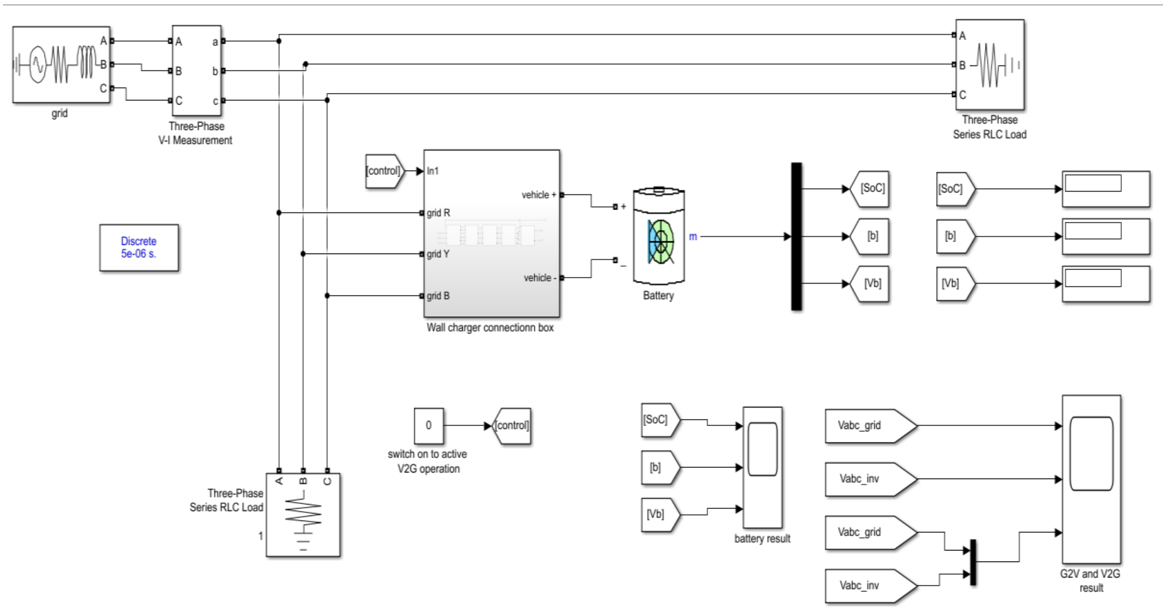


Figure 5.2 Simulation Diagram of Grid to Vehicle Bidirectional EV Charger

The circuit for Vehicle to Grid Bidirectional EV Charger has been simulated using MATLAB. Fig 5.3 shows the simulation circuit.

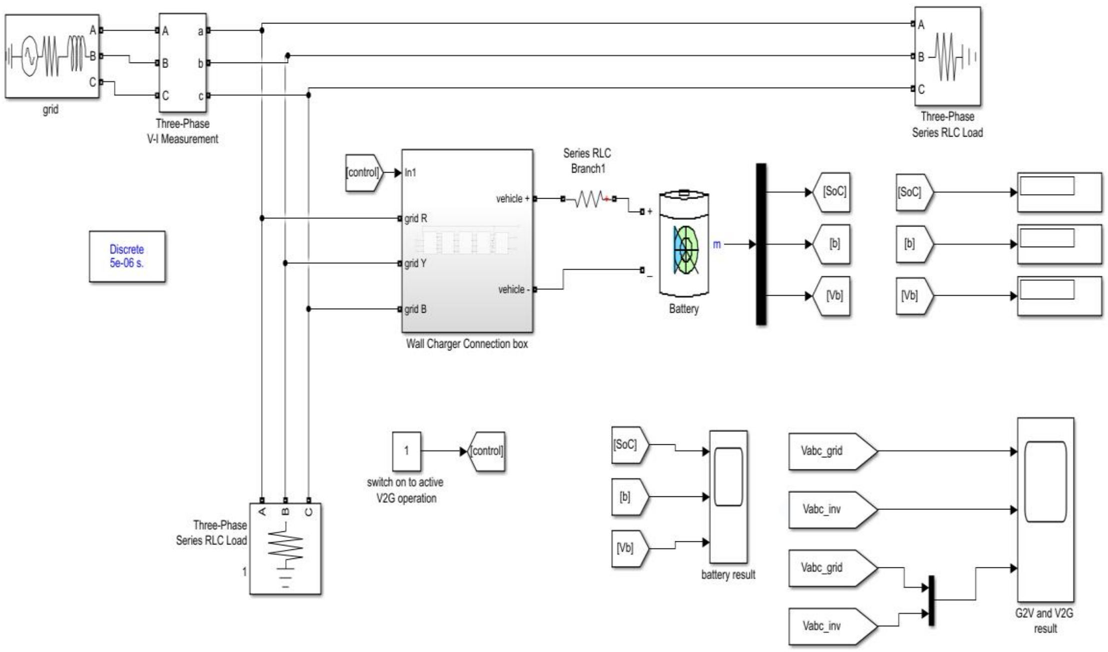


Figure 5.3 Simulation Diagram of Vehicle to Grid Bidirectional EV Charger

The values of the components used in the suggested electric vehicle charger model would be derived using relevant formulae. Some restrictions, such as line current ripple, filter size, switching ripple attenuation, and so on, must be considered while constructing LCL filters for AC-DC PWM converters. The LCL filter's parameters can be calculated using the system's power rating [35].

The power transistors used in the bidirectional EV charging system must be carefully chosen because they have an impact on the system's efficiency. Design requirements, such as permissible ripple values of inductor current and capacitor voltage, are used to define parameters for the bidirectional DC/DC converter to be modelled [35].

A battery pack is made up of single lithium-ion battery cells with a nominal voltage of 230V and a rated capacity of 100Ah [35].

In the V2G mode add resistor in series with battery. The value of resistor is 9 ohms.

5.2 Working of G2V and V2G

5.2.1 Grid to Vehicle (G2V) Operation Mode:

The full-bridge AC-DC bidirectional converter functions as an active rectifier with sinusoidal current and unitary power factor in this mode. The buck converter mode is used by the reversible DC-DC converter. The reversible DC-DC converter is operated in both constant and variable modes current and constant voltage [35].

The reference current is compared to the actual current during the constant current stage. The current error is fed into a PI controller, which modifies the output duty-cycle through a PWM modulator with a 20 kHz triangle carrier. When the control algorithm reaches the maximum voltage value recommended by the battery manufacturer, it switches to the constant voltage stage. A second PI controller is employed in this stage to keep the output voltage of the reversible DC-DC converter constant based on the voltage reference [35].

Formula to calculating SOC (%) for battery:

$$\text{Soc (t)} = Soc(t-1) + \frac{1}{c}\,(\text{int[i(t)] dt}) \;\ldots\ldots\; (2)$$

5.2.2 Vehicle to Grid (V2G) Operation Mode

The full-bridge AC-DC bidirectional converter functions as an inverter with sinusoidal current and a unitary power factor, while the reversible DC-DC converter functions as a boost converter [35].

The full-bridge AC-DC bidirectional converter in the V2G mode, like the G2V mode, must be synchronised with the power grid basic voltage. As previously stated, synchronisation is achieved using a single-phase - PLL in - coordinates. In order to facilitate collaborative integration of the EV in a smart grid setting, the active power to be given to the power grid is established as an external input variable received from a serial communication port [35].

In the V2G mode, as in the G2V mode, the full-bridge AC-DC bidirectional converter must be synchronised with the power grid fundamental voltage. Synchronization is accomplished using single-phase - PLL in - coordinates, as previously indicated. The active power to be delivered to the power grid is established as an external input variable received from a serial communication port to promote collaborative integration of the EV in a smart grid scenario. The DC link voltage must be somewhat higher than the peak value of the power grid voltage in order for the full-bridge AC-DC bidirectional converter to send the energy stored in the traction batteries back to the power grid. Once the traction battery voltage is lower than the needed DC link voltage, the reversible DC-DC converter must operate as a boost converter to achieve this goal. Because the traction batteries' voltage does not fluctuate much over short time periods, the absorption of a steady current from the traction batteries can be used to regulate the active power provided back to the power grid. However, as the battery voltage drops throughout the discharging process, the reference current must be increased to keep the active power constant. The traction batteries reference current is calculated by dividing the reference active power (P*) by the traction batteries voltage. A PI controller changes the duty-cycle for a 20 kHz PWM modulator based on the difference between this current and the actual current [35].

5. Results and discussions

Simulation is used to evaluate the proposed bidirectional controller's performance in both grid-to-vehicle and vehicle-to-grid scenarios. The battery's initial state of charge (SOC) is set to 80%. This figure was determined to ensure that the battery can receive and give power when it is required. The simulation will take some time to start up and stabilise at first. It takes around a minute to complete this procedure [35].

5.1 Grid to Vehicle

To operate in G2V (Grid to Vehicle) mode switch has to be set to 0 [35].

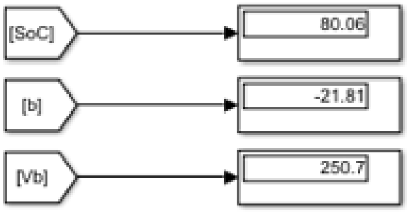


Figure 6.1 Simulation Results of G2V

a) SOC gradually increasing from point 78 because we have to set the initial state of charge to 80%.
b) Current = -21 A to -27 A (Negative value referring that the battery is charging state).
c) Grid voltage (Vgrid)will be positive and 250 V (+_3V) and Inverter voltage (V_inv) have to be '0' but there is a likage voltage is flowing on of (0.2-0.5) but if we observe the 3rd waveform combination, the V_inv is at 0.
d) V_inv can be made 0, by substituting the perfect filter circuit value after rectification process.

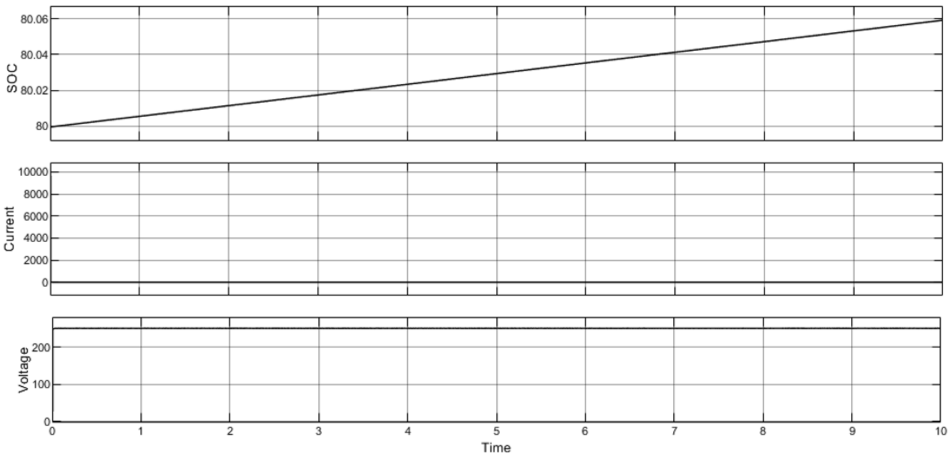


Figure 6.2 Simulation Result of Battery Graph for Gird to Vehicle with respect to Time (Seconds)

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 06 Issue: 10 | October - 2022 Impact Factor: 7.185 ISSN: 2582-3930

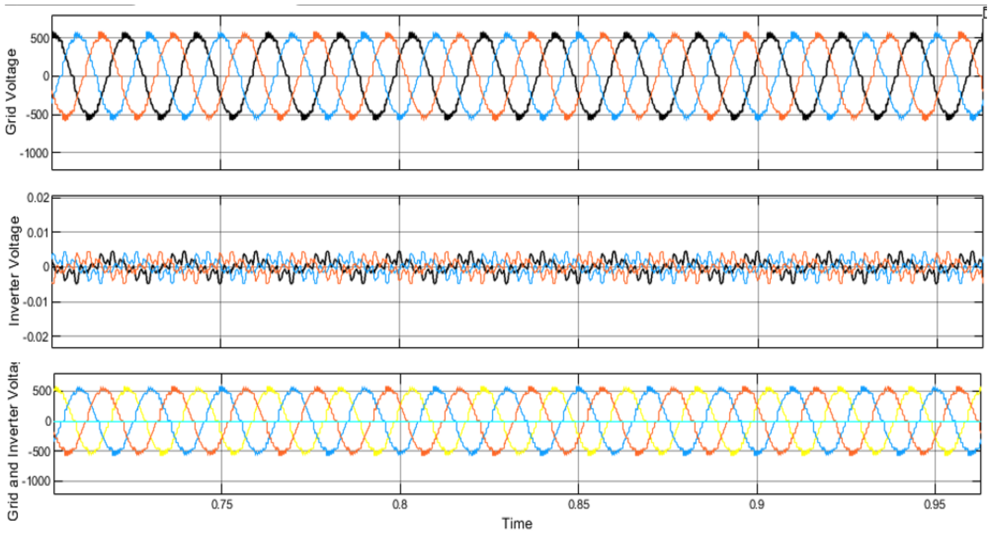


Figure 6.3 Simulation Result of Voltage Graph for Grid to Vehicle with respect to Time (Seconds)

5.2 Vehicle to Grid

During V2G operation, SOC will decrease and battery current and battery voltage will be positive [35]. To operate in V2G mode the switch has to be set to 1.

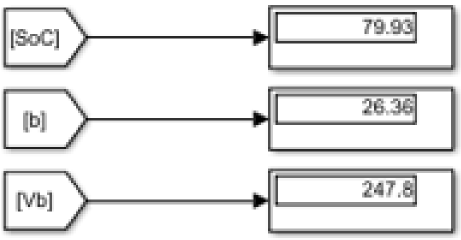


Figure 6.4 Simulation Results of V2G

a) SOC gradually decreasing from point 79 because we have to set the initial state of charge to 80 %
b) Current = 26 A to 28 A (Positive value referring that the battery is discharging and been utilized by grid, motor, home or Emergency Purposes).
c) Voltage =247 (+_3V).
d) V_grid and V _inv need to synchronous because we are sending back the power to grid so, the voltage magnitude should be equal and need to be in Phase. (Similar concept when we try to perform two transformers in parallel, we need to check for the synchronous between them).

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 06 Issue: 10 | October - 2022 Impact Factor: 7.185 ISSN: 2582-3930

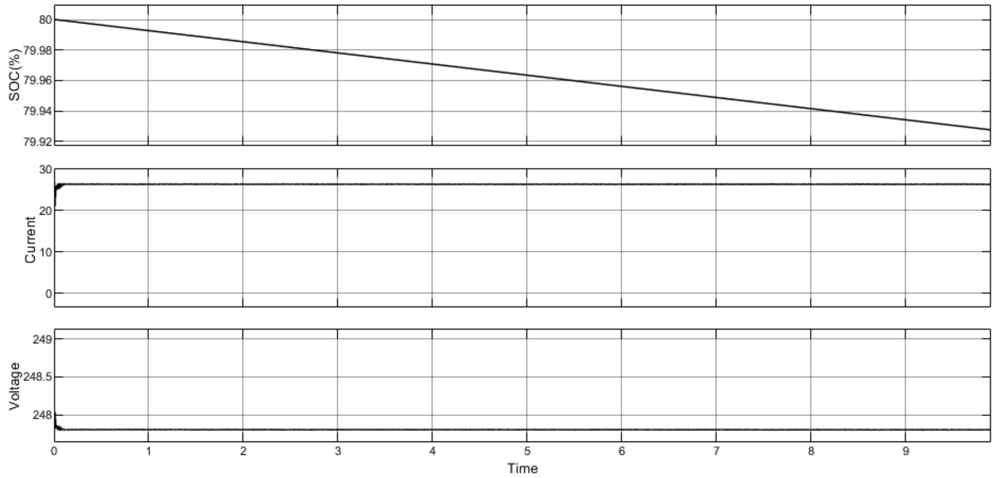


Figure 6.5 Simulation Result of Battery Graph for Vehicle to Grid with respect to Time (Seconds)

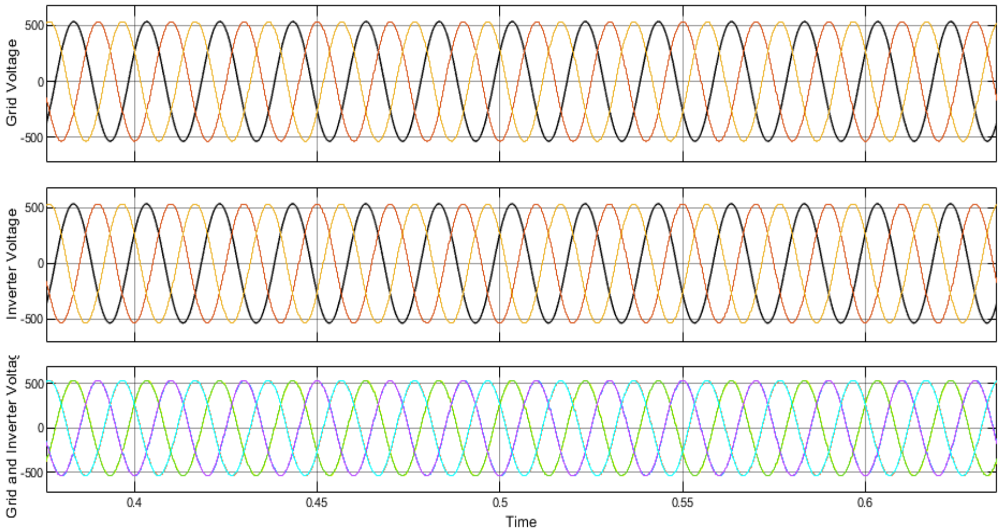


Figure 6.6 Simulation Result of voltage Graph for Grid to Vehicle with respect to Time (Seconds)

1.1 Comparison between previous results and proposed model [35]

Mode of Operation	Previous Work Results			Proposed Results		
	SOC (%)	Voltage	Current	SOC (%)	Voltage	Current
G2V (Grid to Vehicle)	60% (increasing)	249V	-22 A	80% (increasing)	250.7 V	-21.8 A

V2G (Vehicle to Grid)	60% (decreasing)	247.2 V	24.72A	80% (decreasing)	247.8 V	26.36A

6. Conclusion

This Dissertation work focuses on the development of an on-board bidirectional battery charger for Electric Vehicles (EVs) that can operate in the Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) operating modes, both of which are critical technologies for addressing the future smart grids scenario. Computer simulations utilising the MATLAB software are used to test the hardware topology and control algorithms of the described battery charger, and also through experimental results obtained with a laboratory prototype that has been constructed. The created prototype that supports this work is purposefully bigger because the purpose of this effort is merely to validate the topology and control algorithms. The experimental findings obtained with the two operation modes (G2V, V2G) are consistent with expectations, proving the suggested topology's feasibility [35]. Bidirectional technology (which allows electricity to flow into and out of electric vehicles) has just recently improved to the point where it can be used by more people. With time, as technology improves, so will its capabilities. Going for a bidirectional charger as an EV owner will only benefit you. Going bidirectional has a lot of benefits, from making extra money by selling electricity back to the grid to being energy self-sufficient [35].

A bidirectional charger is being developed for use with the V2G and G2V power flows. It indicates that, with the proposed design, charging and discharging can be done with a single unit. It runs on a constant current, while constant voltage battery charging methods change the unit power factor. Variation of the controller's control signal can be used to change the operating parameters. This architecture enables charging and discharging at a variety of power levels [35].

7. Future research directions

a) "Bidirectional charging is expected to become a crucial feature to help electric vehicle uptake," said Kevin Mask, Principal Analyst in Strategy Analytics' Automotive Practice. "We're already seeing collaborations form between automakers, power suppliers, and platform providers to provide fleets and consumers with the benefits of bidirectional charging" [32].
b) When an electric vehicle is charged, the grid's AC (alternating current) energy is transformed to DC

(direct current) energy, which is then stored in the vehicle's battery. This is usually done by the car's own converter, which is located inside the vehicle. The DC energy stored in the EV's battery must be removed and then converted back to AC energy if you want to utilise it to power your home or send it back to the grid [32].

c) Until the development of bidirectional charging technology, this energy conversion was not conceivable. Cars like the Nissan Leaf may be used as a backup storage system and a source of energy in your home's energy ecology thanks to these innovations [32].
d) Bidirectional charging is already possible, and with advancements in automobiles, rules, and chargers, it is part of a growing business [32].
e) With the help of electric car batteries, utilities will have another resource available to support the grid, balance electricity demand, and smooth consumption surges. It marks a new possibility for automakers to branch out beyond transportation and into the energy management market. Bidirectional charging is the way of the future [32].
f) If we look into the future, we will witness significant advancements in current charging technology. For example, it will resemble the refuelling experience. The charging voltage of cars will be increased from 500V to 800V in the next years, and the capacity of a single charger will be boosted from 60kW to 350kW. In fact, this implies that charging time will be cut in half, from an hour to 10 to 15 minutes [32].
g) The number of public EV chargers will continue to grow at a double-digit rate each year. This makes the industry one of the most promising in terms of growth and development. In comparison to the previous year, public fees increased by 85 percent in 2019 [32].
h) The covid-19 epidemic accounted for half of the growth in 2020. Currently, the majority of electric vehicle owners charge their vehicles at home or at work, using largely sluggish chargers [32].

References

[1] Balasundar, C., Sundararajan, C. K., Sharma, J., Srinath, N. S., & Guerrero, “Design of power quality enhanced sustainable bidirectional electric vehicle charging station in distribution grid,” *Sustainable Cities and Society*, Vol 74, pp 1-16, November 2021.

[2] Yuan, J., Dorn-Gomba, L., Callegaro, A. D., Reimers, J., & Emadi, A. “A Review of Bidirectional On-Board Chargers for Electric Vehicles,” *IEEE*, Vol 9, pp 51501-51518, 29 March 2021.

[3] Gorkem Berk Sahinler, Gokturk Poyrazoglu, “Modelling and simulation of three phase bidirectional electric vehicle charger,” *2021 3rd Global Power, Energy and Communication Conference (GPECOM)IEEE*, 5 October 2021.

[4] Rajesh Kumar Lenka, Anup Kumar Panda, "Grid power quality improvement using a vehicle-to-grid enabled bidirectional off-board electric vehicle battery charger," *International Journal of Circuit Theory and Application.* Vol 49, pp 2612-2629, August 2021.

[5] Queen Okon, Javier Urquizo, Nisha Kondrath,Pritpal Singh, "Control Design For 3 Phase Bidirectional Battery Charger With Multiple Charging Capabilities For Electric Vehicle Fleet Applications," *2021 North American Power Symposium (NAPS) IEEE*, 14 November 2021.

[6] Vijayalakshmi, S., Marimuthu, M., Venugopal, R., Shivabalan, N., Shashikumar, V., Pravin raj, T., & Thayananth, T. "Analysis of PV Panel based Bidirectional Converter for Electric Vehicle," *2nd International Conference for Emerging Technology (INCET) IEEE*, pp 1-7, 21 May 2021.

[7] G. Mejía-Ruiz; M.R.A. Paternina; J.R. Rodríguez; A. Zamora; G. Bolivar-Ortiz; C. Toledo-Santos, "A Bidirectional isolated charger for electric vehicle s in vehicle to grid systems with the capacity to provide ancillary services," *52nd North American Power Symposium (NAPS) IEEE*, 21 June 2021.

[8] Shandong Wang, Haoran Li, Zhiliang Zhang, Mengrui Li, Jingfei Zhang, Xiaoyong Ren, Qian Hong Chen, "Multiplication Capability of Sic Bidirectional Portable Charger for Electric Vehicles," *IEEE Journal of Emerging and Selected Topics in Power Electronics* Vol 9, pp 6184 – 6195, 19 January 2021.

[9] Ijaz Ahmed, Iftikhar Ahmad, Shahzad Ahmed, Hafiz Mian Muhammad Adil, "Robust nonlinear control of battery electric vehicle charger in grid to vehicle applications," *Journal of Energy Storage*, Vol 42, pp 1-9, 10 August 2021.

[10] Gabriel Rojas-Duenas, Jordi Roger Riba, Manuel Moreno-Eguilaz, "Modelling of a DC-DC bidirectional converter used in mild hybrid electric vehicles from measurements," *Measurement,* Vol 183, pp 1-8, 10 July 2021.

[11] Chandan T L; Poornima Kulkarni; Channa Keshava S M; Rakshith P, "Modelling and Analysis of a Wide Range On-Board Electric Vehicle Charger," *4th International Conference on Recent Developments in Control, Automation & Power Engineering (RDCAPE) IEEE*, 10 December 2021.

[12] Derek Chou; Zitao Liao; Kelly Fernandez; Tarek Gabriel; George Popovic; Raya Mahony; Nenad Miljkovic; Robert C, " An Interleaved 6-Level Gan Bidirectional Converter With An Active Energy Buffer For Level II Electric Vehicle Charger," *IEEE Applied Power Electronics Conference and Exposition (APEC),* 21 July 2021.

[13] Houssein Al Attar; Malek Ghana's; Mohamed Hamida; Miassa Taleb, " Control Strategies Design And Comparison Of DC-DC LLC Converter In V2g Mode For Electric Vehicle Charger Application," *IEEE Conference on Control Technology and Applications (CCTA)*, 3 January 2022.

[14] Deepak Kumar, Anmol Ratna Saxena, "A battery integrated three-port bidirectional charger/ discharger for light electric vehicles with G2V and V2G power flow capability," *International Journal of Circuit Theory and Applications*, pp 1-26, 16 May 2021.

[15] Nooriya Shahul, Siddharth Shelly, "Bidirectional Battery Charger for Electric Vehicles," *Proceedings of International Conference on Sustainable Expert Systems* , Vol 176, pp 185-198, 31 March 2021.

[16] MD Mujahid Irfan, Shriram S. Rangarajan, E Randolph Collins, and Tomonobu Senju, "Enhancing the Power Quality of the Grid Interactive Solar Photovoltaic-Electric Vehicle System," *world electric vehicle journal*, Vol. 12, pp. 1-13, 9 July 2021.

[17] Flah Aymen, Majed Alowaidi, Mohit Bajaj, Naveen Kumar Sharma, Shailendra Mishra 5, and Sunil Kumar Sharma, "Electric Vehicle Model Based on Multiple Recharge System and a Particular Traction Motor Conception," *IEEE Access, Vol.9, pp. 49308-49324, 23 March 2021*.

[18] Andrea Burgalossi, Lucas Herfst, Moritz von Heimendahl, Henning Forste, Kurt Haskin, Martin Schmidt, and Michael Brecht, "Data driven estimation of electric vehicle battery state-of-charge informed by automotive simulations and multi-physics modelling," *Journal of power Sources*, Vol 483, pp 773-786, 31 January 2021.

[19] Netra Lokhande, Aniruddha Deore, Jaya Diani, Nsawam Sayed, "Range Estimation of Electric Vehicle Using MATLAB," *International Conference for Convergence in Technology (I2CT*), 4 April 2021.

[20] Ibrahim, A., & Jiang, F, "The electric vehicle energy management: An overview of the energy system and related modeling and simulation," *Renewable and Sustainable Energy Reviews*, Vol 144, pp 1-28, July 2021.

[21] B. Sharmila, K. Srinivasan, D. Devasena, M. Suresh, Hitesh Panchal, R. Ashokkumar, R. Meenakumari, Kishor Kumar sadasivuni & Ronak Kumar Rajnikant Shah, "Modelling and performance analysis of electric vehicle*." International Journal of Ambient Energy*, pp 1-8, 1 January 2021.

[22] Bhatti, A. R., Butt, A. D., Sheikh, Y. A., Paracha, K. N., & Zareen, N, "Comparative Analysis of Proposed Photovoltaic-Grid and Grid-Only Systems for Uninterrupted Charging of Plug-in Electric Vehicles," *Technology and Economics of Smart Grids and Sustainable Energy*, pp 1-8, 8 may 2021.

[24] Shende, V., Singh, K. V., Bansal, H. O., & Singh, "Sizing Scheme of Hybrid Energy Storage System for Electric Vehicle," Iranian Journal of Science and Technology, *Transactions of Electrical Engineering*, pp 1-16, 15 March 2021.

[25] Akhil A. G., Harisankar S, Jishnu K, Sreenand S., Vivek Vijay, Asha C. A., Dr. Preetha P. K, "Coupled Wireless Charging system for Electric Vehicles," *Proceedings of the Third International Conference on Intelligent Communication Technologies and Virtual Mobile Networks (ICICV 2021*). pp 475-479, 4 February 2021.

[26] Podder, A. K., Chakraborty, O., Islam, S., Manoj Kumar, N., & Alhelou, H. H., "Control Strategies of Different Hybrid Energy Storage Systems for Electric Vehicles Applications," *IEEE Access*, Vol 9, pp 51865 – 51895, 29 march 2021.

[27] D. Thiruvonasundari, K. Deepa, "Optimized Passive Cell Balancing for Fast Charging in Electric Vehicle," *IETE Journal of Research*, 23 February 2021.

[28] K. S. Kavin, P. Subha Kartvelian, "PV-based Grid Interactive PMBLDC Electric Vehicle with High Gain Interleaved DC-DC SEPIC Converter," *IETE Journal of Research*, 2 august 2021.

[29] Adrian König, Sebastian Mayer, Lorenzo Nicoletti, Stephan Tumphart and Markus Lienkamp, "The Impact of HVAC on the Development of Autonomous and Electric Vehicle Concepts, "*ResearchGate* pp 1-21, January 2022.

[30] Naghmash Ali, Zhizheni Liu, "Double integral sliding mode controller for wirelessly charging of fuel cell-battery super capacitor-based hybrid electric vehicle," *journal of energy storage*, Vol 51, July 2022.

[31] WenyuXiong, Jie Ye, Oichangyi Gong, HanFeng, JinbangXu, AnwenShen, "Multi input model predative speed control of lean-burn natural gas engine gas in range extended electric vehicles," *ELSEVIER*, Vol 239, part B, 15 January 2022.

[32] Mary Ann George, Datta guru V Kamat, ciji pearl Kurian, "Electric Vehicle speed tracking control using an ANFIS-based fractional order fractional order PID controller," *Journal of king Saud university*, 11 January 2022.

[33] S. Pragaspathy, R. V. D. Rama Rao, V. Karthikeyan, Ramu Bhukya, Praveen Kumar Nalli, K. N. S. D. Prakash Korlepara, " Analysis And Appropriate Choice Of Power Converters For Electric Vehicle Chargers Infrastructure," *Second International Conference on Artificial Intelligence and Smart Energy (ICAIS) IEEE*, 30 March 2022.

[34] Narabhaya Chaththa Kalhana Colom age, "Design and Control of On-board Bidirectional Battery Chargers with Islanding Detection for Electric Vehicle Applications," December 2015.

[35] Kotla Aswini, jillimudi Kamala, Lanka Sriram, Bhasuru Kowshik, Damararju Venkata, Sai Bharani, "Design And analysis of Bidirectional Battery Charger for Electric Vehicle*," International Journal and Engineering Research & Technology (IJERT)*, Vol 10, 7 July 2021.

[36] Bouchaib Radi, Abdeikhalak Elham, "INTRODUCTION To MATLAB," *ISTE Ltdand John Wilky & Sons*, pp 179-188, May 2018.