Solar Powered Double H-Bridge LLC Resonant Converter Based Electrical Vehicle Battery Charger with Wide Charging Range and Low Output Voltage Ripples

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It is certified that these students of B.Sc. Electrical Engineering, University of Gujrat, Pakistan, worked under my supervision and the above stated declaration is true to the best of my knowledge.

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FINAL YEAR PROJECT CERTIFICATE OF THESIS COMPLETION

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ABSTRACT

Emerging technological innovation in the transport sector of solely electric vehicles has raised a lot of rampant issues such as deterrence of fossil fuels, environmental and CO_2. EVs are much more efficient than fossil fuel vehicles and have fewer direct emissions. Electrical vehicles are becoming famous worldwide because of their prominent benefits such as better energy efficiency and reduced carbon footprints etc. EVs are powered by batteries that needs to be recharged after usage. The vast extent of ultimatum current and voltage and ripples of output voltage are the most challenging issues for EV battery chargers. LLC Resonant Converters deliver soft switching extensions as well as permit that converter to be operated at high switching frequency and high efficiency. A low quality factor design operating beneath resonant frequency is preferred for vast output voltage with provision of low output voltage ripples. In this project, a Double h-bridge inductor-inductor-capacitor converter with dual full wave rectifier circuits is being employed. The inclusion of full wave rectifier circuits broads the operating extent of converter by abating the effects of parasitic capacitances of transformer's. The converter has dual operating modes; Instantaneous and Autonomous. In the prior mode, both converters operate together instantaneously but in the later mode, single converter operates. Hence, operation with joint mode altering and frequency modulation results in vast output voltage. Frequency modulation technique is being used in the Double H-bridge converter in order to control the vast switching frequency range in several KHz. In this project, a solar powered double h-bridge LLC resonant converter-based EV battery charger having wide charging range and low output voltage ripples would be developed.

CHAPTER-01

INTRODUCTION

1.1 Background Overview

For a number of reasons related to the economy, society, and the environment, transportation is essential in the twenty-first century on both a global and regional scale. Modern societies are dependent on their transportation infrastructure to transfer people, products, and services. The market for electric vehicles (EVs) was expanding, which fueled demand for effective charging infrastructure. EV charging stations were frequently powered by renewable energy sources, increasing the sustainability of the entire transportation industry. Comparing EVs to ICE cars, there are various benefits. It offers minimal running costs, energy efficiency, zero emissions, and benefits to the environment.

1.1.1 Global Need for Transportation

- **Economic Growth and Trade**
  The ability to transfer commodities across borders and among nations makes transportation a crucial factor in economic progress. Effective transportation networks, such as shipping, air freight, and road transportation, are crucial for facilitating global trade.
- **Supply Chain Resilience**
  Resilient supply networks are becoming more important in a world characterized by disruptions like the COVID-19 outbreak. For the flow of necessary items to be maintained and for disruptions to be kept to a minimum, effective transportation networks are essential.
- **Connectivity**
  Worldwide connections made possible by transportation promote international cooperation, tourism, and cross-cultural exchange. Particularly, air travel is essential for bridging different places and cultures.
- **Energy and Sustainability**
  In order to reduce carbon emissions, it is vital to create and implement sustainable modes of transportation, such as electric cars (EVs), public transit systems, and energy-efficient logistics.

1.1.2 Regional Need for Transportation

- **Urban Mobility**

  Transportation is necessary for daily travel and mobility in metropolitan settings. The usage of public transportation, such as buses, trains, and subways, is essential for lowering urban congestion, pollution, and carbon emissions.
- **Rural Access**

  In rural areas, transportation is critical to link isolated populations to vital services like markets, healthcare, and education. For rural development, a better road system and more inexpensive transportation options are essential.
- **Environmental Concerns**

  Environmental problems including traffic congestion and air pollution are prevalent throughout many places. It is crucial to create infrastructure for cycling and other environmentally friendly forms of transportation.
- **Economic Development**

  Business and investment tend to gravitate toward areas with effective transportation systems. Highways, railroads, and ports are crucial for local economic growth and job generation.
- **Emergency Response**

  When there are emergencies or disasters, efficient transportation networks are essential. They make it possible for first responders to be sent out quickly and for help and relief materials to be distributed promptly.

1.1.3 Means of Transportation

- **Electric Vehicles (EVs)**

  Because of improvements in battery technology and an emphasis on lowering greenhouse gas emissions, the use of electric vehicles such as cars, trucks, and buses keeps expanding. Automobiles known as electric vehicles (EVs) are propelled by electricity rather than conventional internal combustion engines (ICEs) that burn gasoline or diesel. Large rechargeable batteries are the main power source for the electric motor that propels EVs. The most typical battery used in EVs is a lithium-ion battery, which has experienced substantial improvements in terms of energy density, range, and longevity. EV's are divided into three categories such as PHEV's, EHV's and BEV's.

- **Public Transportation**
  In many areas, public transportation is being improved and expanded, with a focus on environmentally friendly solutions including electric buses and subway lines.
- **High-Speed Rail**
  Many nations are expanding their high-speed rail networks, which provide a quick and effective way to get between cities.
- **Autonomous Vehicles (AVs)**
  Testing and early deployment of autonomous vehicles, which could revolutionize transportation by enhancing efficiency and safety, are now underway.

1.1.4 Present Modes of Transportation

- **Private Vehicles (Cars and Motorcycles)**
  In many nations, owning a private car is still a common form of mobility. Electric vehicles (EVs) are becoming more and more popular, and numerous automakers now offer EV variants. Carpooling and ride-sharing services like Uber and Lyft kept expanding.
- **Public Transit**
  Public transportation systems, including buses, subways, trams, and commuter trains, remained essential in urban areas. Some cities introduced contactless payment systems and improved digital services for commuters.
- **Bicycles and Electric Bikes**
  Many cities extended their bike-sharing and electric scooter-sharing programs, providing greener options for local commuting.
- **Walking and Pedestrian Infrastructure**
  To encourage walking as a sustainable means of transportation, investments were made in pedestrian-friendly infrastructure such sidewalks, crosswalks, and pedestrian-only zones.
- **Trains**
  High-speed rail networks have continued to grow in a number of nations, particularly in Europe and Asia, offering quick and effective long-distance transport choices.
- **Maritime Transportation**

Despite improvements in containerization and automation, cargo shipping remained a significant part of international trade. Some areas made investments in passenger ferries for use in river and coastal transportation.

- **Emerging Technologies**

  Self-driving cars, trucks, and drones were being tested and developed as autonomous vehicles. Different regions were investigating the Hyperloop and other high-speed ground transportation systems.

1.1.5 Issue in Present Mode of Transportation Regarding Environmental Concerns

- **Greenhouse Gas Emissions**

  The excessive production of greenhouse gases (GHGs), particularly carbon dioxide (CO2), from the burning of fossil fuels in vehicles, trucks, ships, and airplanes is one of the most urgent problems. Due to these emissions, the world's temperatures are rising, extreme weather events are happening more frequently, and the ice caps are melting. These emissions are the main contributor to global warming and climate change.
- **Air Pollution**

  Transportation is a significant contributor to air pollution, emitting harmful pollutants such sulfur dioxide, nitrogen oxides, and particle matter (PM), in addition to carbon dioxide (CO2). Particularly in heavily populated metropolitan regions, these pollutants lead to smog formation, respiratory illnesses, and early mortality.
- **Noise Pollution**

  Road traffic and airplane noise have a negative impact on human health, disturbing sleep cycles, elevating stress levels, and resulting in a number of health problems. Additionally, it disrupts the habitats of species and may have long-term ecological effects.
- **Land Use and Habitat Destruction**

  Deforestation and habitat degradation may result from the construction and maintenance of transportation infrastructure, such as roads and highways. This can cause habitat fragmentation for species and harm biodiversity while upsetting ecosystems.
- **Resource Depletion**

- Minerals, metals, and petroleum are among the numerous natural resources that are depleted during the manufacture of automobiles and the extraction of fossil fuels. This increases the strain on ecosystems and adds to the loss of resources.
- **Congestion and Inefficiency**

  Traffic congestion is a common problem in cities, and it not only consumes time but also increases fuel use and pollution. Systems of transportation that are inefficient cause unnecessary environmental damage.
- **Waste and Pollution from Vehicle Manufacturing**

  From the extraction of raw materials to the manufacturing processes, the creation of cars produces waste and pollution. Environmental issues can also arise from the disposal of outdated, non-recycled automobiles.

1.1.6 Solution in Clean Energy Production of Clean Way of Utilization of Energy

- **Energy Efficiency**

  Reduce total energy consumption through increasing energy efficiency in buildings, transportation, and industry through cutting-edge techniques and technology.
- **Advanced Grids and Storage**

  To properly manage and distribute power, create smart grids. To store extra renewable energy for later use, make investments in energy storage devices like batteries.
- **Carbon Capture and Storage (CCS)**

  To absorb and store carbon dioxide emissions from businesses and power plants, CCS technologies should be used.
- **Electrification of Transportation**

  To minimize emissions from the transportation industry, promote electric cars (EVs) and the infrastructure for charging them.

1.1.7 Transportation Uses Nearly 30 % of World Wide Energy

The fact that transportation consumes almost 30% of all energy used globally is a big and crucial finding with numerous implications for energy use, sustainability, and environmental issues. On a worldwide scale, transportation is a significant energy consumer. The enormous energy needs connected with transporting people and things around the world are highlighted by the fact that it makes up close to 30% of global energy usage. The primary sources of this energy are electricity for electric vehicles as well as fossil fuels like gasoline and diesel.

1.1.8 Converting Transportation Methods of (ICE to EV) which Mitigate Environmental Issues

- **Technological Advancements**
  Adoption of electric powertrains is the main conversion. This entails creating more effective electric motors, new battery technology for increased energy storage and range, and the infrastructure needed to allow quick charging. Since EV technology has advanced significantly in recent years, ICE cars may now be replaced with them.
- **Vehicle Types**
  Changing from ICE to EV involves a range of automobiles, including two-wheelers, Lorries, buses, and even passenger vehicles. Automobile manufacturers are creating EVs for a range of market niches, from light trucks to tiny city automobiles.
- **Charging Infrastructure**
  Building a reliable charging infrastructure is essential. This comprises fast-charging networks along roads, workplace charging stations, public charging stations, and residential charging stations. To reduce "range anxiety" and encourage the adoption of electric vehicles, governments and private businesses are making significant investments in developing this infrastructure.
- **Battery Technology**
  The heart of EVs is battery technology. For EVs to become more competitive, improvements in battery chemistry, energy density, and charging speed have been crucial. Used battery recycling and reuse are crucial for sustainability.

1.2 Electric Vehicles

EVs uses electric propulsion system. The power required to propel the wheels of an electric vehicle (EV) is produced by the propulsion system. Unlike conventional internal combustion engine (ICE) vehicles, which propel themselves using gasoline or diesel, electric vehicles' propulsion systems are powered by electricity. The structure of an EV is as follows;

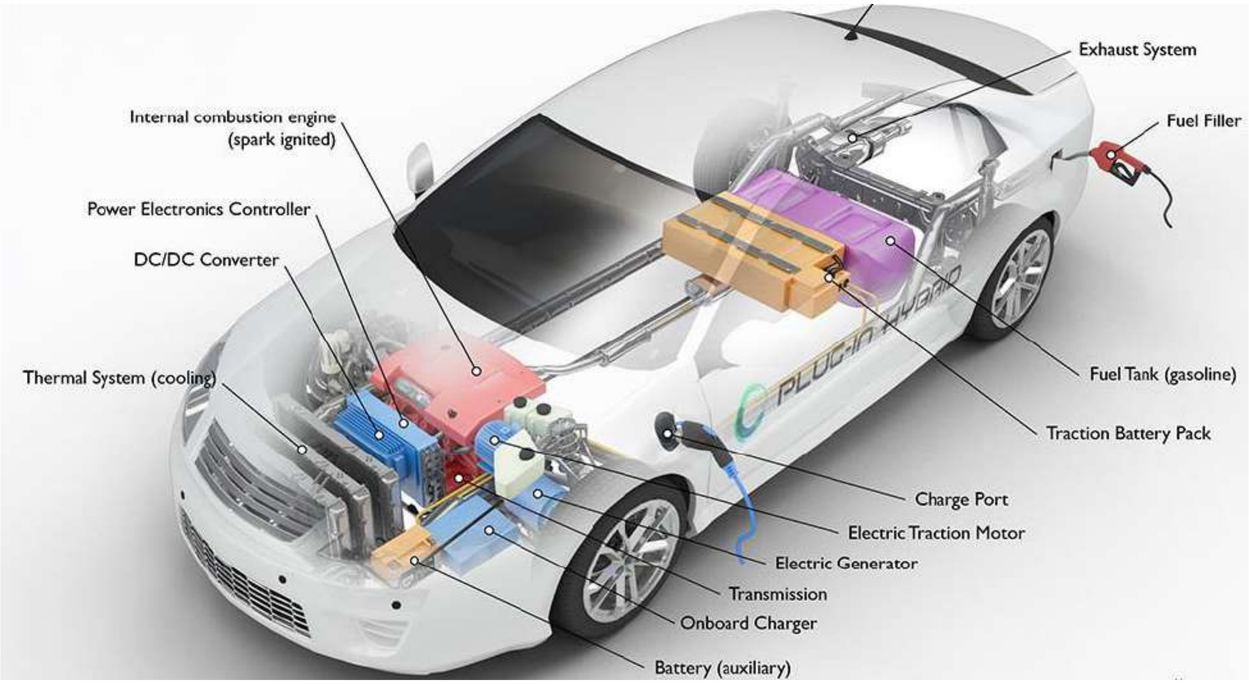


Figure 1.1: Operation of EV along DC-DC Converter [36]

- **Electric Motor**

  The main part of the electric vehicle's propulsion system is its electric motor. In order to power the wheels, it transforms electrical energy from the car's battery into mechanical energy. Electric vehicles (EVs) employ a variety of electric motor types, such as:

1. **AC Induction Motors**

   Simple and dependable AC induction motors are a typical choice for EVs. They frequently appear in early EV models and operate on the basis of electromagnetic induction principles.

2. **Permanent Magnet Motors**

   These motors produce a magnetic field using permanent magnets, which leads to excellent efficiency and power density. Due to their efficiency, they are frequently utilized in current EVs.

- **DC/DC Converter**

  A DC-DC converter is an electrical system (device) that changes the voltage level of direct current (DC) sources. To put it another way, a DC-DC converter takes a DC input voltage as input and outputs another DC voltage. The difference between the DC input voltage and the DC output voltage is possible. A DC-DC converter, as its name suggests, only functions with sources of direct current (DC) and not with sources of alternating current (AC).

- **Battery pack**

  The electric energy required to run the electric motor is stored in the battery pack. The majority of batteries used in EVs are lithium-ion batteries. The battery pack's energy density and capacity have a direct impact on the EV's performance and range.

- **Thermal Management System**

  A thermal management system is necessary to maintain the battery and electric motor's ideal operating temperatures. Typically, this system consists of fans, coolant, and radiators for cooling.

- **Transmission or Reduction Gear**

  Some EVs shift the torque and speed of the electric motor to the wheels via a gearbox or reduction gear. However, many EVs just have a single gear or have no gearbox at all, depending instead on the torque control features of the motor.

- **Regenerative Braking System**

  Many EVs include regenerative braking as a feature. When the driver uses the brakes, it enables the car to recoup kinetic energy. The battery is subsequently recharged using this energy, which is then transformed back into electricity.

- **Electric Vehicle Control Unit (ECU)**

  The propulsion mechanism of the EV is controlled by the ECU. Power distribution, energy management, regenerative braking, and safety features are just a few of the tasks it oversees.

- **Charging Port**

  EVs include a charging connector that enables an external power source to be connected in order to recharge the battery. There are many charging port types, including Level 1 (for domestic usage), Level 2 (for use in a home or public location), and Level 3 (for DC rapid charging).

- **Onboard Charger**

  Direct current (DC) is used by the onboard charger to charge the battery by converting the alternating current (AC) from the charging station to DC. Charger capacity differ across EVs, which has an impact on charging times.

1.3 Battery for EV

EVs have advantages, but they also have technological constraints, including as higher costs than petrol vehicles of a same size, longer charging times, shorter battery lifespan, and a limited range on a single charge. The battery is one of the crucial elements that needs to be investigated and developed in order to overcome the obstacle. The main problems with EV batteries are safety, power density (power, volume, and weight), cost, reliability, and life span.

Safety is always the number one priority for the EV. One of the most important protective situations is when there are galvanic isolation and protection procedures, which include over-voltage, over-current, deep discharge, over-temperature, and cell charge balancing.

Second, due to their small size, EVs have a greater problem with power density. The driving range of an EV is impacted by the battery's energy capacity, measured in amp-hours (Ah). The power rating of a battery, measured in watts (W), dictates the rate of charging and discharging.

Thirdly, the minimum calendar life and the total number of charging/discharging cycles are two parameters that can be used to quantify battery life. A car battery's capacity is normally expected to last for 10 to 15 years on average [37]. Overall, even though trade-offs must be taken into account, EV batteries should meet all these requirements at an affordable price, as the high cost of batteries has previously been a significant barrier.

Currently, lead-acid, nickel metal hydride (NiMH), and lithium-ion (Li-ion) batteries are the most often utilized battery types for electric vehicles, whose key features are shown in Table 1-1.

Table 1.1 Comparison of different batteries for EVs [38]

Type	Discharge power capacity	Cost	Energy density	Self-discharge rate	Life span
Lead-acid	Good	Affordable	Low	High	Short
NiMH	Good	High	High	High	Long
Li-ion	Good	Reasonable	High	Low	Long

1.4 Problem Statement

Double H-bridge converter that was designed earlier have had a problem of output voltage ripples due to ripple cancellation gap in the converter because this converter had less capability to control voltage and current due to excessive ripple issue as well as such as there were two modes of operation; simultaneous and independent in the double H-bridge converter and specifically in the (simultaneous mode) converter was not able to operate and control wide voltage and current at 0° and 90° phase shift. Comprehensively, solution for the particular problem and converter modes would be discussed in chapter [3].

1.5 Objectives

The objectives of this project are:

- To propose a 90° phase shift approach for double H-bridge LLC resonant converter to exterminate the excessive ripples in output voltage.
- To design and implement the double H-Bridge LLC resonant converter topology with proposed 90° phase shift approach.
- To test and evaluate the operation and performance of proposed converter.

1.6 Sustainable Development Goals

- **Industry, Innovation and Infrastructure:**
  Infrastructure and innovation spending are essential components of economic expansion and progress. With an estimated 50% of the world's population residing in cities, mass transportation, renewable energy, and the development of new industries and communication technologies are all becoming increasingly important.
- **Sustainable Cities and Communities:**
  Building resilient societies and economies, safe and affordable housing, and career and business possibilities are all essential components of sustainable city development. Investments in public transportation, the development of green public areas, and enhanced urban planning and administration using inclusive and participatory methods are all part of it.
- **Climate Action:**

There is not a single nation that is untouched by the severe repercussions of climate change. Compared to 1990, greenhouse gas emissions have increased by more than 50%. If we do nothing, global warming will continue to alter our climate system, with potentially disastrous results. Disasters caused by climate change cause hundreds of billions of dollars in annual economic losses. Energy and environmental problems have been brought on by the growing number of internal-combustion automobiles that use nonrenewable conventional fuels. To lessen their reliance on oil and the air pollution that conventional automobiles produce, many nations have adopted new energy vehicles (NEVs) as alternatives to conventional vehicles. China has made a commitment to promoting NEVs in order to decrease oil imports and usage.

CHAPTER-02

REVIEW OF LITERATURE

2.1 Introduction

LLC resonant converter is a sophisticated power electronics topology that has gained popularity in electric vehicle charging due to its high efficiency, reduced EMI emissions, and adaptability to varying operating conditions. Its complex control and resonant operation enable efficient energy conversion, making it well-suited for the demands of modern electric vehicle technology.

2.2 State of Art of LLC Resonant Converter

2.2.1. On-board and Off-board Charger

As indicated in Table 1.2, there are two typical types of EV battery chargers: on-board chargers and off-board chargers. Off-board chargers, commonly referred to as standalone fast charging stations, permit high-speed, rapid charging in a manner similar to how gas stations handle charging for vehicles that use liquid gasoline. The range of pure-battery EVs can be substantially increased by off-board charging stations, which are frequently found in public places like shopping malls, parking lots, and highway facilities. These off-board stations can be built with fewer size, weight, or area restrictions; but, they need a substantial financial commitment and lengthy building durations.

Table 2.1 Comparison of on-board and off-board chargers [39]

Classification	Size limit	Weight limit	Space limit	Construction requirement	Power rating	Level type	Typical charging time
Off-board	less	less	less	yes	50 kW	3	fast charging 1 hour
On-board	yes	yes	yes	less	2-20 kW	1,2	slow charging 4-12 hours

On the other hand, on-board chargers, which are integrated into the cars, offer slow, low-power charging in the range of 6 to 16 hours [39]. On-board chargers provide speedy charging for EVs at user households when they are hooked into a domestic utility outlet overnight. The charger might be included within the EV, thus it won't cost as much as an off-board charging station. Due to its compact size, simple operation, and low cost, on-board charging is still an effective choice even though restrictions like size, weight, and space limit the input power level and consequently slow charging.

Two technologies—the conductive method and the inductive strategy—are viable for the on-board charger, depending on the direct electrical contact between the grid and the car.

2.2.2 Resonant Converters

Resonant converters are a sort of power electronic circuit that effectively converts electrical energy from one form to another by making use of the resonance-related features. They are frequently employed in systems including power supply, motor drives, and renewable energy generators. Resonant components, such as capacitors and inductors, are used as the fundamental building block of resonant converters to establish an oscillating energy exchange between the input and output sides of the circuit. These converters can operate more efficiently and with lower switching losses than conventional converters by operating at resonant frequencies.

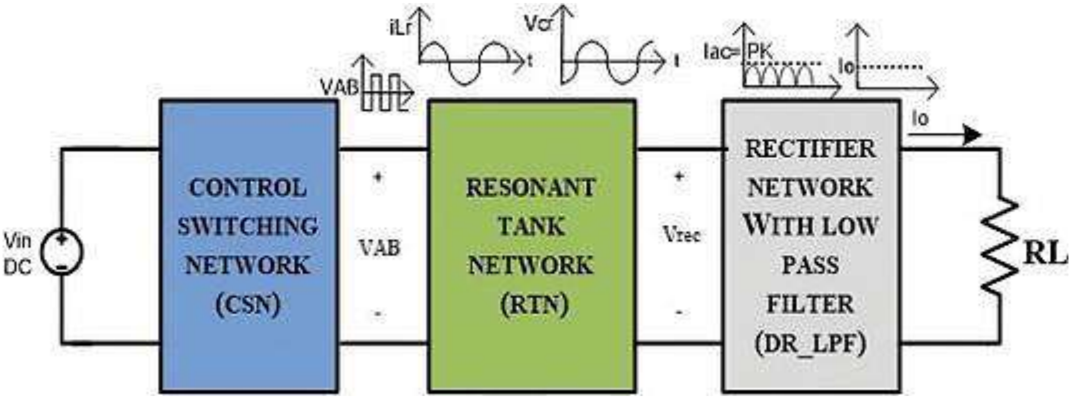


Figure 2.1: Block Diagram of LLC Converter [40]

There are several types of resonant converters, including:

2.2.2.1 Series Resonant Converter (SRC)

The primary and secondary sides of the circuit are connected in series with a resonant tank in an SRC. This architecture enables the converter to perform gentle switching, which reduces switching losses, by having the switching transitions occur at zero voltage or current. The FB-SRC switches the four transistors in the full-bridge architecture, as shown in figure 1.1. At the same moment, two switches that are diagonally opposed (top-left and bottom-right, or top-right and bottom-left) turn on. This makes it possible to apply the input voltage to both the resonant tank circuit and the primary side of the transformer.

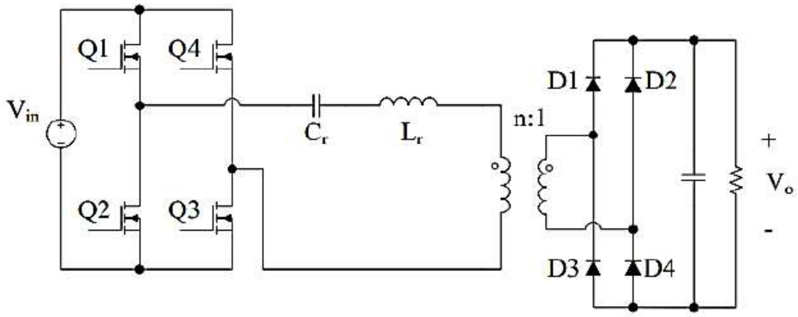


Figure 2.2: Full Bridge SRC [41]

2.2.2.2 Parallel Resonant Converter (PRC)

The primary and secondary sides of the circuit are connected in parallel with the PRC's resonant tank. It is renowned for its capacity to manage high power levels and for enabling soft switching as well. Four switches are arranged in a bridge configuration to form the complete bridge. These switches are typically metal-oxide semiconductor field-effect transistors (MOSFETs) or insulated gate bipolar transistors (IGBTs). The entire bridge permits voltage inversion when necessary and permits bidirectional power transmission. An FBPRC's control technique entails regulating the switching of the IGBTs or MOSFETs so that the converter runs at or very close to the parallel tank circuit's resonance frequency. Reduced switching losses and increased efficiency are benefits of operating at the resonance frequency.

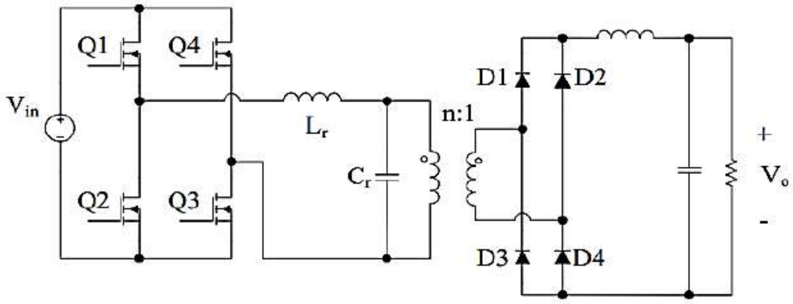


Figure 2.3: Full Bridge PRC [41]

2.2.2.3 Half Bridge LLC Resonant Converter

Inductor-inductor-capacitor, the three major parts of this kind of resonant converter, are referred to as LLC. The LLC resonant converter offers excellent efficiency, zero voltage switching (ZVS), and zero current switching (ZCS) while combining the advantages of series and parallel resonant converters. Converters with zero voltage switching (ZVS) and zero current switching (ZCS) To achieve gentle switching, these converters use resonant circuits and switching methods. When switching devices are turned on, ZVS converters make sure that the voltage across them is zero, but ZCS converters make sure that the current flowing through the switches is zero. Both methods increase effectiveness and reduce switching losses. As seen in the diagram, the converter is designed around a half bridge architecture, which consists of two switching components (usually power transistors or insulated gate bipolar transistors, or IGBTs) stacked in a bridge form. With this design, current can flow in both directions and the output voltage and current can be adjusted with ease.

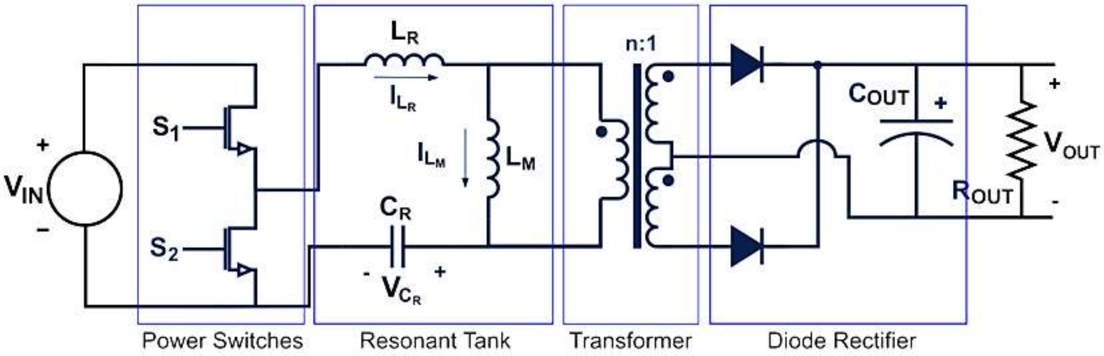


Figure 2.4: Half Bridge LLC [42]

2.2.2.4 Full Bridge LLC Resonant Converter

A full-bridge rectifier at the input of the Full Bridge LLC Resonant Converter transforms the incoming AC power into a high-frequency DC voltage. An LLC resonant circuit is then coupled to this high-frequency DC voltage. Under a variety of load circumstances, the Full Bridge LLC Resonant Converter operates with zero-voltage switching (ZVS) and zero-current switching (ZCS). As a consequence, typical converter switching losses are reduced to a minimum, leading to great efficiency and less electromagnetic interference (EMI).Various power conversion applications, including power supply for servers, telecommunications equipment, LED lighting, and renewable energy systems like solar inverters, frequently employ Full Bridge LLC Resonant Converters.

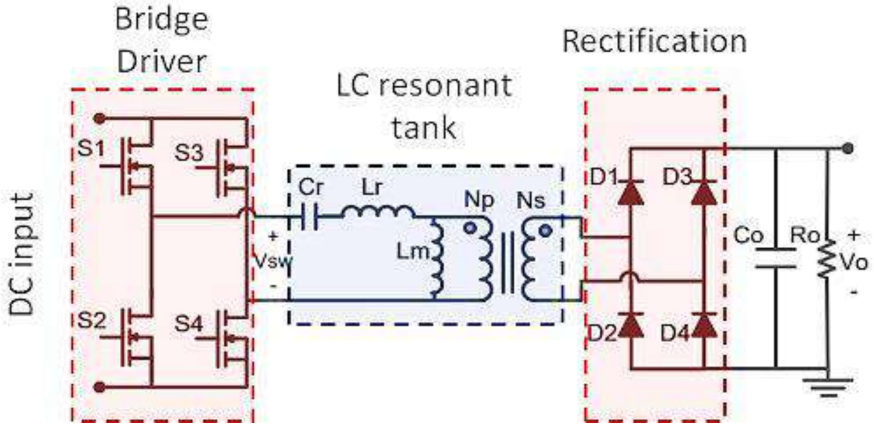


Figure 2.5: Full Bridge LLC [31]

2.2.2.5 Soft Switching

By producing gate drives for the switch devices, which entails turning on diagonal pairs of power switches during the ON stage and turning off all the switches during the OFF stage, the output voltage or current of conventional PWM DC-DC converters is typically controlled. When any pair of the diagonal switches is turned on, the rectifier diodes on the other side of the transformer are conducted to allow power to flow. Due to the fact that power losses during the switching on/off phase increase with switching frequency, large switching frequencies would result in large switching losses of the power devices and electromagnetic interference (EMI) emissions, which would subsequently limit the conversion efficiency. This issue is often solved with soft-switching technologies, such as zero-voltage-switching (ZVS) and zero-current-switching (ZCS) [43].

2.2.2.6 High Power Density

Full-bridge voltage/current source DC-DC converters that use a transformer have higher dependability and galvanic isolation, but they are also bigger, heavier, and more expensive than non-isolated chargers [39]. The overall cost and size of the converter are reduced because it is possible to reduce the volume of the transformer and other magnetic and passive components at high frequencies. Therefore, the most effective technique to increase the power density in the isolated DC-DC converter is to increase switching frequency.

2.3 Literature

In recent years, escalation in the innovation and advancement of technology and stark effects of greenhouse toxic emissions have risen to too much greater extent, causing stringent climate surging and CO_2 adverse effects. The huge reliance of power sector on extreme fossil fuels cannot cope stringent emissions [1]. The fossil fuels erosion has caused inimical environmental impacts in the vicinity and a lot of negative externalities where acute effects transcend the people because of utilizing fossils. According to 2018 fossil fuels consumption report, 8 million humans have died due to air pollution in world and subtle estimate recorded approximately 1 in 5 deaths globally [2]. Nevertheless, all sources of energy inherently have malignant effects, mostly consumption of fossil fuels causes the intense levels of greenhouse emissions which are quite injurious for humans. Contrary, advanced sources of renewable energy appear to be reliable and protective for humanity.

The efficiency of PV cells has been the focus of research. For instance, perovskite solar cells have attracted a lot of interest because of its promise for high efficiency and affordable production. Stability concerns are being addressed, and perovskite technology is being worked on for commercialization (Chen et al., 2023) [3]. Solar panels that can collect sunlight from both sides are becoming more and more common. These panels take advantage of sunlight that is reflected off of nearby surfaces, improving overall energy generation. More effective bifacial systems have been created using advanced modeling and optimization techniques (Ning et al., 2022) [4].

Emerging technological innovation in the transport sector of solely electric vehicles has raised a lot of rampant issues such as deterrence of fossil fuels, environmental and CO_2. EVs are quite efficient than fossil fuel generating vehicles and have fewer direct emissions. The trend in the increase of internal combustion engine driving cars which are driven by conventional fossil fuels has become the cause of both environmental and polluted energy issues. Electric Vehicles provides the reliable features over conventional fuel-driven vehicles such as negligible emissions, efficient performance, cost benefit, simplicity and reliability of system. Electric Vehicles are very efficient as compared to fuel-driven vehicles [5].

The detrimental effect of electricity generation from conventional fossil fuel sources has led to the need to avert to renewable and clean energy sources, such as solar energy, hydropower energy, wind energy, and geothermal energy**.** Consequently, utilizing this readily available resource should eventually reduce reliance on conventional fossil energy sources and contribute to decline in global warming, for a cleaner and safer world**.** Energy storage systems (ESS) are mostly used to ensure the suitability of renewable energy generation in all circumstances. The energy released by the sun upon the earth per hour can serve human energy need for one year. As a result, green energy has become a central component of major economic policies and a major focus in international politics [6]**.**

Growing interest in and innovation in the electrification of transportation as a result of worries about the environment, global warming, and the threat of the depletion of fossil fuels. The majority of modern electric vehicles come with single-phase on-board chargers and lithium-ion (Li-ion) battery packs. Compared to fossil fuel cars, EVs are significantly more efficient and emit far fewer direct emissions. They rely on electrical energy at the same time, which is often supplied by a combination of fossil fuel plants and non-fossil fuel plants. Consequently, by changing the electrical source, EVs can be made to be less polluting overall. People can ask utilities in some places to source their electricity from renewable sources. It takes time for a nation's fleet of automobiles to adopt efficiency and pollution requirements for fossil fuel vehicles. Due to the fact that older vehicles have reached their end of life, new efficiency and emission regulations rely on the purchase of new vehicles [7–8].

Energy and environmental problems have been brought on by the rising number of internal combustion cars that use nonrenewable conventional fuels. To lessen their reliance on oil and the air pollution that conventional vehicles produce, many nations have adopted new energy vehicles (NEVs) as alternatives to conventional vehicles. China, the country with the largest automotive market in the world, has made a commitment to developing NEVs in order to decrease oil imports and consumption. Germany wants to cut CO2 emissions in Europe by putting one million electric vehicles (EVs) into use by 2020. France and the UK likewise want to ban the domestic sale of conventional vehicles by 2040. Due to the expensive cost of electric vehicles and the quick advancement of conventional vehicles, however, the promotion of EVs has halted. Environmental pollution and energy-related problems have driven EV research since the start of the twenty-first century. Furthermore, and in accordance with a report by the European Union, the transport industry is chargeable for roughly 28% of the overall emissions of carbon dioxide (CO2), with road transport accounting for over 70% of those emissions. In order to reduce the concentration of air pollutants, CO2, and other greenhouse gases, the governments of the majority of developed nations are promoting the usage of electric vehicles (EVs) [9].

Pure electric vehicles (PEVs), hybrid electric vehicles (HEVs), and fuel cell electric cars (FCEVs) are the three basic types of EVs. Compared to conventional automobiles, EVs have the following benefits: (1) Zero emissions: These automobiles don't release any nitrogen dioxide (NO2) or carbon dioxide (CO2) from their tailpipes. Although the creation of batteries has a negative impact on carbon footprint, the manufacturing techniques also tend to be more environmentally friendly. (2) Simplicity: The Electric Vehicle (EV) engine components are fewer in number, making maintenance far less expensive. (3) Reliability: This sort of vehicle has fewer problems because it has fewer and simpler components. In addition, engine explosions, vibrations, and gasoline corrosion do not cause the intrinsic wear and tear that EVs do. (4) Cost: Compared to maintenance and fuel costs of conventional combustion cars, the cost of the vehicle and the power required is significantly lower. (5) Efficiency: Compared to conventional vehicles, EVs are more efficient. The efficiency of the power plant will also affect the well to wheel (WTW) efficiency as a whole. Compared to diesel vehicles, which range from 25% to 37%, gasoline vehicles' total WTW efficiency, for instance, ranges from 11% to 27%. The WTW efficiency of EVs powered by a natural gas power plant, however, ranges from 13% to 31%. EVs powered by renewable energy, however, exhibit up to 70% total efficiency [10].

On-board and off-board EV battery chargers can have a unidirectional or bidirectional power flow. Because it reduces hardware needs, clarifies interconnection concerns, and generally slows down battery deterioration, unidirectional charging is a natural initial step. A bidirectional charging system enables power stabilization with sufficient power conversion, charge from the grid, and battery energy injection back into the grid. Due to weight, space, and cost restrictions, most on-board chargers have a high power limit. To prevent these issues, they can be combined with the electric drive. Systems for on-board charging can be either inductive or conductive. Direct contact is made between the connector and the charge inlet in conductive charging systems. Magnetic energy transfer occurs in an inductive charger. For Levels 1 and 2, this kind of charger has been investigated; it may be permanent or mobile through. The size and weight restrictions are less stringent on an off-board battery charger [11].

Battery chargers are essential to the advancement of electric vehicles. The parameters of the battery charger have an impact on both charging time and battery life. A battery charger needs to have high power density, low cost, and low volume and weight while still being efficient and dependable. Components, controls, and switching techniques all affect how it operates. Depending on the rating, price, and kind of converters, charger control algorithms are implemented using analog controllers, microcontrollers, digital signal processors, and specialized integrated circuits. In order to reduce the influence on power quality and to maximize the real power available from a utility outlet, an EV charger must make sure that the utility current is pulled with low distortion and at a high power factor [11].

The total number of EV sales and publicly accessible EV chargers for both slow and fast charging have increased exponentially over the past few years. A large adoption of EV is still not achievable due to technological, economic, and policy obstacles. Major obstacles to the growth of EV technology include high battery costs, short battery lifetimes, reliability difficulties, reduced driving range, lengthy charging times, and complex charging infrastructure. To achieve dependable and affordable operation while delivering high power with greater efficiency, designing an appropriate power converter topology and putting modern control methods into practice are also crucial. The distribution, transmission, and generation of the electrical grid are typically not significantly affected by the adoption of EVs; however, if EV charging is not managed, utilities may be forced to make changes to the current infrastructure before their scheduled cycle. Additionally, damaging harmonics that lower power quality can be produced by EV chargers. This problem can be reduced using the charger's ac-dc power stage's harmonic adjustment technology [12].

Traditional PWM converters have lot of performance issues like electromagnetic interference problem and provides hard switching which causes loss, compulsion of large size specifically because of low operating frequency and low efficacy. Converters, especially inductor-inductor-capacitor resonant converters are being employed in the application of charging battery as on board Plug-in-EV charger. LLC converters have become quite notorious because of their unprecedented characteristics such as ZVS of mosfets or igbts, ZCS of diodes, and reliable regulation of voltage [13].

The switch mode power supply (SMPS) was created to run at higher frequencies in response to the recent demand for high energy density, which is an unavoidable trend in the development of power electronics. High-frequency, however, also means high electromagnetic interference (EMI) pollution and high switching energy consumption. As a result, in the most recent ten years, scholars from all over the world have been interested in and doing research on resonant converters with a soft-switching function and high-frequency feature. The LLC resonant converter combines the benefits of those other resonant converters, including DC isolation, stable no-load operation, low requirements on current ripple of capacitor filter, adjustment of resonant current as load, and advantages in the voltage adjustment and soft-switching range. As a result, academics have started doing in-depth research on it. The LLC resonant converters have advanced in maturity and have been used in a variety of industrial applications as a result of extensive research on resonant converters and the development of numerous control integrated circuits (ICs) [14].

One significant advancement is the ability to use LLC resonant converters at higher switching frequencies. This breakthrough enables smaller component sizes, increasing power density and efficiency. Because high-frequency operation minimizes EMI emissions, LLC converters are appropriate for noise-sensitive applications such as medical devices and automotive systems (S. Li et al., 2020) [15]. With the addition of digital control strategies, LLC resonant converter performance and adaptability have improved. Digital control enables precise output voltage and current modulation to enhance load transient response and maximize efficiency (D. Maksimovic et al., 2013) [16]. Its straightforward connection with digital control systems and communication protocols makes it useful for modern power management solutions. Effective thermal control is required for a converter to run reliably. LLC resonant converters can now handle larger power levels while retaining acceptable temperature levels. This innovation lengthens the converter's useful life and expands its range of demanding applications, such as renewable energy systems and the charging of electric vehicles (L. S. Yang et al., 2017) [17].

Because they are simple to use and may be applied to both current and voltage sources, series (SRC) and parallel (PRC) resonant converters are the most often utilized. Because their output voltage varies depending on the source and they are unable to control the acquired voltage at no-load conditions, series resonant converters can only be used in step-down applications. They are still often utilized for the upkeep of a spectrum of load variation despite these issues. PRCs have minimal current fluctuation and low efficiency. Given these, PRCs and SRCs are regarded as the most basic resonant converters (RCs), despite not being suitable for the majority of applications, including high voltage and wireless energy transmission. Due to their broad operating range, reduced EMI, and higher voltage gain, LLC converters were created as a remedy for the issues with SRC. Although LLC converters can be utilized in both half-bridge and full-bridge primary inverters and on the secondary side of full-bridge and center trapped rectifiers, they are not employed in center-tapped rectifiers since they expose the diodes to excessive voltage stress. To prevent simultaneous short circuiting of both arms, full bridge converters primarily use Phase-Shift (PS) pulse width modulation, followed by a derivative zero-voltage or zero-current phase-shift pulse-width modulation technology [18].

The LLC resonant converter may often function near the resonant frequency when it is constructed with a small output voltage range. As a result, it is simple to attain high efficiency with minimal core, switching, and conduction losses. In wide-output-voltage applications, the LLC resonant converter's efficiency has, nevertheless, declined. This is due to the fact that its operating frequency must fluctuate widely and differ from the resonant frequency. For instance, the LLC resonant converter experiences significant primary turn-off switching loss and reverse recovery issues brought on by the secondary diode if the operating frequency of the converter is higher than the resonant frequency, or in the above range. Contrarily, in the region below, there are significant magnetic core and conduction losses, which reduce conversion efficiency. As a result, it is difficult for the LLC resonant converter to be implemented in wide-output-voltage applications [19].

Mostly, the resonant converters are manufactured taking into account regarding narrow range of output voltage, so it may control and operate around f_r. Because while designing according to this criteria, it can attain highly efficient output with minor switching, conduction and core losses. Nevertheless, the resonant converter has delivered inefficiency in vast output voltage applications. This happens due to its frequency-operation range has to surge in a vast limit and differs from f_r. For instance, by providing the operating-frequency extent of the resonant converter is quite higher than the f_r. In case, the resonant converter endures reverse recovery issues and huge primordial turning off switching losses and that malfunctioning as well as performance issues caused by the secondary diodes. But in counter case, means in the region beneath, converted efficiency of resonant converter is deteriorated due to heavy conduction losses as well as magnetic core material. That’s why, capacitors-inductor-inductor converter has myriad challenges in the vast output voltage range applications [20].

Such as previously mentioned causes, authors have proposed multiple approaches to attain quite immense efficiency of capacitor-inductor-inductor converter under vast range of output voltage [20]. Capacitor-inductor-inductor converter requires to be operated and controlled over a vast extent of frequency switching to produce broader variations of voltage gain. Actually, no extent exits for frequency switching-operation in the region of negative slope of inductor-inductor- capacitor converter and its variation of gain is possible over wide range. Pragmatically, the frequency switching-operation of resonant converters cannot be heightened 2 to 5/2 times fr. The particular constraint is inflicted because of junction capacitances of output diodes and the transformer parasitic capacitance of secondary winding [20]. Recently mentioned parasitic capacitances engender other fr above resonant frequency in the curves of gain because of this effect output voltage of resonant converter begins rising instead of plummeting as frequency switching-operation is set to 2 to 5/2 of fr at light loads [21]. An altered direct-current voltage approach in which direct-current follows the voltage of battery and inductor-inductor-capacitor converter is regulated around f_r to achieve 50-420 V. Albeit, the particular adopted approach exterminates the conduction and switching losses of inductor-inductor-capacitor converters, but to be adhere with alternating current, vast alteration of voltage is mostly demanded at power factor correction stage.

Authors have examined the LLC resonant converter as a constant output voltage source with synchronous or diode rectifications as its output stage .The LLC resonant converter for applications requiring consistent output voltage. However, the constant Vout, variable Iout and adjustable Vout, variable Iout resonant converters differ significantly from one another. The second is broader than the first. It has been demonstrated that by applying frequency control, this converter can manage a broad-range of regulated output voltage even when input voltage and load have considerable changes in earlier studies where it has been utilized to create wide output range SMPSs. One of the most crucial topics that must be realized for lowering electromagnetic interference (EMI) and enhancing the performance and efficiency of the converter is zero voltage switching (ZVS) operation even under the worst case scenarios. This converter's output stage diodes are consistently turned ON and OFF using zero current switching (ZCS), which lowers switching losses. ZVS operation results in less dissipation than ZCS in MOSFET-based primary-side LLC resonant converters because switching losses associated with the reverse recovery process are removed [22].

Numerous various modulation schemes have been suggested in order to narrow the switching frequency range or operate at a set switching frequency. Using phase-shift modulation (PSM) is one of the easiest ways to accomplish fixed frequency operation. By adjusting the phase-shift angle between two switching legs for primary-side PSM (PSPSM), the input voltage to the resonant tank can be changed, and the output voltage is then regulated. Although the PSM can control the output voltage over a large range, it might be challenging to get the lagging-leg switches to operate at zero voltage switching (ZVS). Then, the range of the adjustable output voltage is constrained. Several benefits according to (PSPSM) for wide-Charging range two things are 1) constant frequency and duty cycle operating and 2) load-independent voltage gain. There are some drawbacks to (PSPSM) under wide-Charging ranges as well, including the following: 1) the controllable voltage gain is constrained due to soft switching operation; 2) PSM is typically not used due to its low efficiency and constrained controllable voltage gain range; instead, it is combined with other modulation strategies; and 3) this strategy can only be used for full bridge and stacked structures [23].

On the other hand, pulse width modulation (PWM) is another method for achieving fixed frequency operation. By adjusting the duty cycle of the additional bidirectional switch, which can change the system topology from full-bridge to half-bridge, the output voltage for the primary side PWM (PSPWM) is regulated. By regulating the duty cycle of the extra switch on the secondary side of the transformer, which can change the secondary rectifier structure from full-bridge rectifier to voltage doubler rectifier, the output voltage for secondary-side PWM (SSPWM) is regulated. Additional switches and related gate drivers are needed for these two modulation techniques. Several benefits in line with (PSPWM) under a broad charging range. 1) fixed frequency and duty cycle operation and 2) System voltage gain is independent of load and 3) Many commercialized controllers. Additionally, there are some drawbacks to (PSPWM) under wide-charging ranges, including the following: 1) the output power is limited due to half bridge operation; 2) system voltage gain is in the range of [0.5, 1]; 3) additional bi-directional switch and input capacitor is needed; 4) the operation conditions for primary switches are different due to different duty cycle, which results in the uneven heat problem; and 5) this approach can be expensive [24].

Some adjustments have been made to the power circuit topology or its regulation in order to enhance the overall performance of the LLC converter. For instance, the control working at constant frequency or with a restricted range of frequency change has also been studied, despite the fact that variable frequency control is the most frequently utilized in LLC converters. In a converter version is suggested in which a controlled switch that uses pulse width modulation (PWM) in place of an output diode is used. As a result, the output voltage may operate over a larger range and is more efficient. However, in a three-phase LLC converter is created with a phase shedding method that operates one, two, or all three of its phases to increase efficiency, particularly at low power levels. Depending on the instantaneous power demand, the converter can operate in one, two, or three phases while the battery is being charged **[**25].

The use of a single LLC converter is limited to low and medium power levels, while parallel connections of LLC modules can be employed for high power applications. The efficient current sharing obtained by adding a balancing transformer between the paralleled modules is the relevant contribution in that work. Similar to this, parallelizes LLC converters (input and output) to boost the output current level. In contrast to other methods, the converter is controlled in that task utilizing the charge method. By utilizing this method, the control to output transfer function produces a first order system, allowing for the use of a straightforward proportional integral (PI) controller to ensure good performance. Traditional droop control is used to execute the control for current sharing. The use of a hybrid control scheme combining PFM and PWM to achieve interleaved functioning of two LLC converters is another method for using parallel LLC converters. For example, when running under light load, the H-bridge switches at 50% duty cycle to produce a bipolar square-wave, while when operating under heavy load, the system uses PWM to maintain output voltage control [25].

Many PSM multilayer based LLC topologies are offered for wide output voltage range applications to ensure fixed fs operation while enhancing efficiency. However, these techniques typically need more active power switches, which raises system costs, complicates the control system, and could jeopardize the charging system's dependability. For instance, when operating at a fixed frequency, a three-level architecture that can switch between three-level and two-level modes to increase output voltage gain range and decrease phase-shift variation range. On the primary side of a typical two-level LLC converter, the topology does require an additional two active switches. The addition of auxiliary switches on the secondary side to increase the output range when running at a fixed frequency is used two interleaved half-bridge (HB) LLC resonant tanks as the principal side in addition to multilevel solutions, managing the output voltage by altering the phase shift between the two HB LLC modules [26].

Because the output voltage of the DC-DC converter varies significantly and widely for charging the battery, the range of the control variables like duty-cycle or frequency in the DC-DC converter also varies tremendously and broadly. Because of this, it is challenging to maximize the converter's ability to convert power. The standard phase-shift full-bridge (PSFB) converter has been the most popular architecture for EV applications because to its inherent zero-voltage-switching (ZVS) operation and low ripple current in the battery charging current. However, due to its distinct disadvantages, such as its limited ZVS range in the lagging leg, high circulating current flowing in the transformer's primary side, and extremely high voltage stress in the rectifying diodes, the conventional converter cannot be optimized in terms of power conversion efficiency when the output of a DC-DC converter changes significantly and widely, as in the case of EV battery charger applications. In light of this, recent research has focused on hybrid-type DC-DC converters that incorporate an LLC series resonant converter (SRC) into the PSFB converter, which can significantly enhance the performance of the traditional PSFB converter for EV applications [27]. Several works have been published to gain highly efficient inductor-inductor-capacitor converter under the range of vast charging capability. For the sake of controlling the output of an inductor-inductor-capacitor converter, frequency modulation or joint frequency modulation with phase-shifted modulation are oftenly adapted [28]. Nevertheless, the phase-shifted modulation strategy is not implemented for quite big load conditions because it’s highly turning off current for the primordial switching devices while comparing with frequency modulation technique. In the frequency modulation is implemented to control and operate the output of inductor-inductor-capacitor resonant converter. An altering FM-technique inductor-inductor-capacitor converter as compared to other demands a higher quality factor such as $Q > 1/2$ circuitry for operating under vast range of input voltage alterations and load. Because of vast frequency-switching demand, the FM inductor-inductor-capacitor resonant converter can produce a quite broader extent of harmonics, which engenders higher EM-Interference issues. Researchers have endorsed multifarious modulation techniques in order to improve the problems attributed with switching frequency, K. Murata [29]. In the proposed converter, joint mode altering regulation with FM-method has been adapted to attain vast output voltage and ripple cancellation.

High-capacity lion battery packs are quickly charged using complex charging algorithms, high voltage, and high current. The fundamental specifications for an onboard charger also include high efficiency with high power density, high dependability, small size, and low cost. The design of an onboard charger is complicated and expensive as a result of all these variables, which has been identified as one of the obstacles preventing the widespread adoption of PHEVs. In the size, price, and mechanical packaging are thoroughly explored from a practical standpoint. Also thorough topological analysis of the charging solutions that are currently on the market. The most typical charger architecture comprises of an isolated dc-dc converter and a boost-type ac-dc converter for active power factor correction. Since the output voltage and current are controlled at the dc-dc stage, this sort of charger's characteristics are largely dependent on it. A wide operating range, high power density, high efficiency, and low electromagnetic interference (EMI) emissions make an inductor-inductor-capacitor (LLC) resonant converter the most appealing architecture among available options. These characteristics perfectly meet the requirements of PHEV and EV charger applications. Due to its numerous resonant components and varied operation modes, the LLC architecture is challenging to evaluate and design [30].

Over the years, numerous design techniques have been put forth for this kind of converter. Due to the intricacy of the model, exact analysis of LLC resonant converters provides correctness but is difficult to use to obtain a convenient design approach. First harmonic approximation (FHA) analysis-based approaches are easier to use. For operating points at and above the resonance frequency of the resonant tank, the FHA technique provides accurate results that are tolerable. As a result, it has been extensively used in applications requiring constant output voltage where the LLC converter is intended to resonate at nominal condition. The design of a wide-output-range LLC resonant converter based on FHA, with the increased range being primarily developed in frequencies above the resonant frequency. However, compared to the zone below resonance, this region loses zero-current switching (ZCS) for output rectifier diodes, which results in more diode reverse recovery losses. The FHA is effective for qualitative analysis but not for the best design process because it is still valid but less accurate in the below-resonance zone. On the basis of the operation mode analysis, optimal design methodologies are created. These methods necessitate the use of complex computation tools yet can produce rather effective design outcomes. Presents a straightforward but accurate design-oriented paradigm and a step-by-step design process that guarantee the majority of the benefits of an LLC converter [30].

CHAPTER-03

METHODOLOGY

3.1 Introduction

Double H-Bridge LLC resonant converters are being rapidly preferred in power systems because of their efficient characteristics of output waveforms and lessen voltage with respect to time stress. Now a days, a critical research is to be going on such innovative and advanced converters. The proposed Converter comprises multifarious direct current voltage supplies, switches, capacitors, diodes, resonant tank as well as gate driving circuits, to attain adequate range of output voltage with an apt sequence of switching. Double H-Bridge has been recommended for wide alteration of voltage power to mitigate the voltage suppression on switches. The proposed circuit includes single DC source which is linked to joint H-bridge and four MOSFETs or IGBTs. The LLC circuit is composed of an air core inductor, magnetizing inductor and capacitor in parallel, and a rectifier circuit with a filter capacitors and at the output side a battery is attached for charging. Resonant converter privileges in the main arena are magnificent due to their distinctive features such as; power switches bound to act with zero voltage switching over extensive load range, filter is engendered by a capacitor as a substitute of a conventional capacitor, diode rectification process can easily attain zero current switching and low electromagnetic interference and good performance.

3.2 Proposed Operating Method of Double H-bridge Converter

Proposed converter has the ability to achieve wide output voltage at 0° and 90° phase shift. By employing double h-bridge converter, problem regarding to the output voltage ripples would be resolved. The actual reason behind this problem was that double H-bridge converter had two H-bridges and in between the both bridges there was 180° phase shift and each bridge had two switches and phase shift between the switches was 180°. But in the case of proposed double h-Bridge converter, there would be given a 90° phase shift signals between the both converters. Albeit, phase shift between the switches of each converter will be similar. By adapting this technique, output voltage ripples will be exterminated.

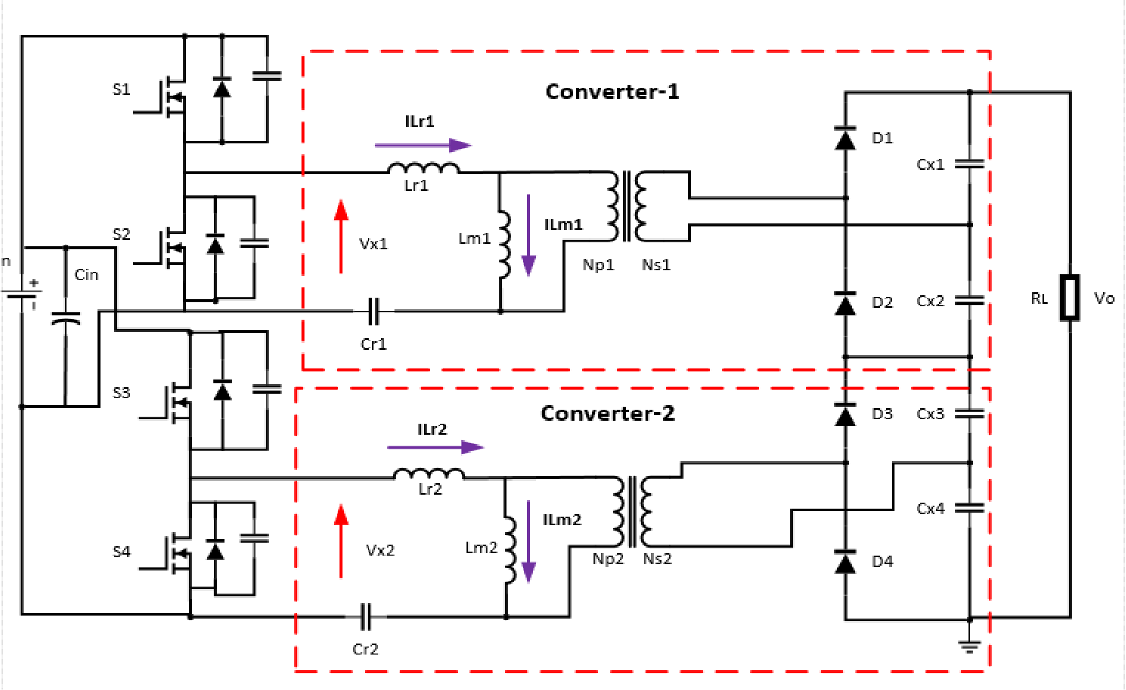


Fig.3.1 Double H-bridge LLC Resonant Converter Structure

3.2 Description of Proposed Double H-bridge Converter

Double h-bridge inductor-inductor-capacitor resonant converter structure has been sketched in fig.3.1 which portrayed design of proposed converter structure. It comprises parallel inter-connected 2 h-bridge converters with the addition of full-wave rectifier series connected circuit. Inductor-inductor-capacitor first converter includes 2 switching elements as switch-1 and switch-2, transformer-1, magnetizing inductor-1, resonant inductor-1, resonant capacitor-1, diode-1 and diode-2 as well as filter capacitors C_{x1} and C_{x2}. Likewise, second converter includes 2 switching elements as switch-3 and switch-4, transformer-2, magnetizing inductor-2, resonant inductor-2, resonant capacitor-2, diode-3 and diode-4 as well as filter capacitors C_{x3} and C_{x4} . First and second converter are parallel inter-connected to direct-current V-source and their rectifier circuits are attached in series at the output sides. Hence, overall gain of double h-bridge is the addition of the output voltage of 2 cascaded H-Bridge inductor-inductor-capacitor converters.

By employing the full-wave rectifier based circuit at the secondary side, transformer's secondary turns are extirpated to ½. Subsequently, the parasitic capacitances of transformer's secondary windings are extirpated. Hence, the second-f_r that exists because of parasitic capacitances are averted to quite awry value. In addition, adoption of rectifier also enhances the Q of LLC tanks. At last because of the above mentioned reasons, inductor-inductor-capacitor converter would have vast efficient operating extension and characteristics.

Double h-bridge inductor-inductor-capacitor resonant converter in order to attain vast range of output voltage by adapting FM-technique. Furthermore, the proposed double h-bridge inductor-inductor-capacitor resonant converter can be operated in two modes: **instantaneous** and **autonomous**. In the instantaneous-mode, converter-1 and 2 working at a time becomes the cause of getting higher gain but in case of autonomous-mode single converter works with 1/2 voltage gain. So, the operation of the double h-bridge with joint mode altering sequence such as autonomous to instantaneous, frequency modulation approach and vast range of output voltage may be gained.

3.3 Double H-bridge Converter SteadyState Operation

Double h-bridge inductor-inductor-capacitor resonant converter steady state analysis is shown below, the following assumptions are made:

1) Both inductor-inductor-capacitor tanks are similar to each other.
2) Switching elements have same $C_{ds.}$
3) Filter capacitors C_x are all similar.
4) The turn ratios of both transformers are same Np/Ns=n.
5) Capacitors size are quite large such that the ripples at the output side are much less.

There are 8 modes of operation of Double h-bridge converter operation cycle. The converter operation in first 4 modes is uniform to last 4 modes. Hence, only first 4 modes are described here. The waveforms of converter for instantaneous modes of operation are shown in Fig. 3.3. The double h-bridge circuits for first 4 modes are sketched in Fig. 3.1. So, cycle of switching starts when switch-1 and switch-4 initiate conduction at t_0. Before t_0 free-wheeling diodes of switch-1 and switch-4 were able for conducting and switch-1 and switch-4 were turning on with zero voltage switching. On secondary side, diodes D_1 and D_4 are conducting the currents n $[I_{Lr1}(t) - I_{Lm1}(t)]$, and $n[I_{Lr2}(t) - I_{Lm2}(t)]$, respectively, where, n is turns ratio, and I_{Lm1} and I_{Lm2} are magnetizing current.

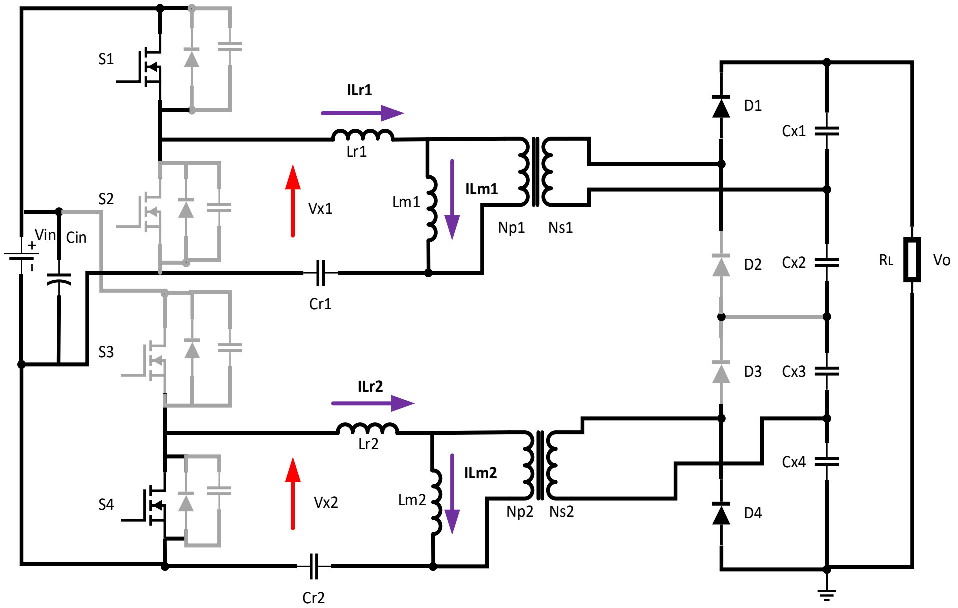
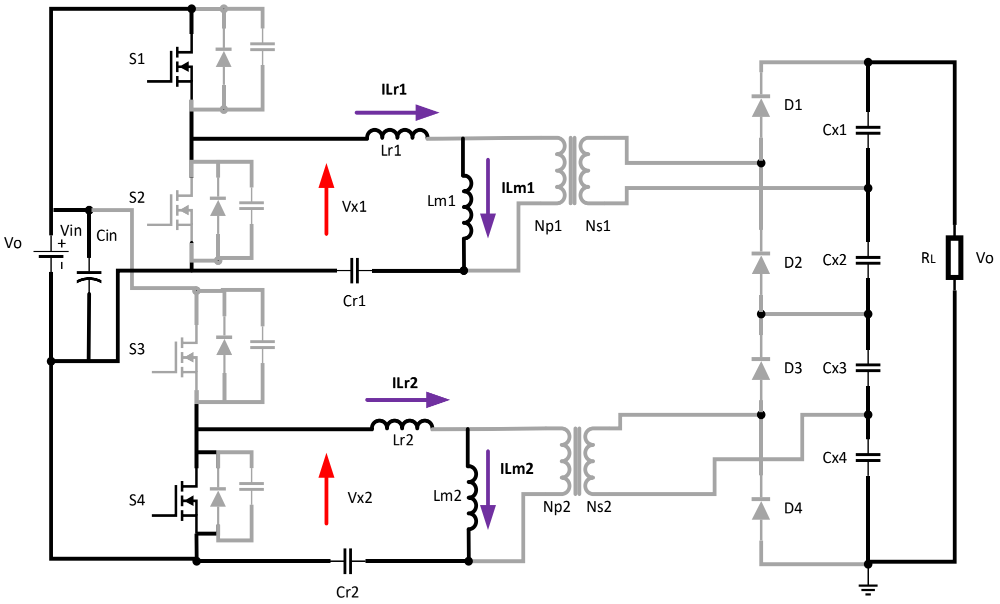
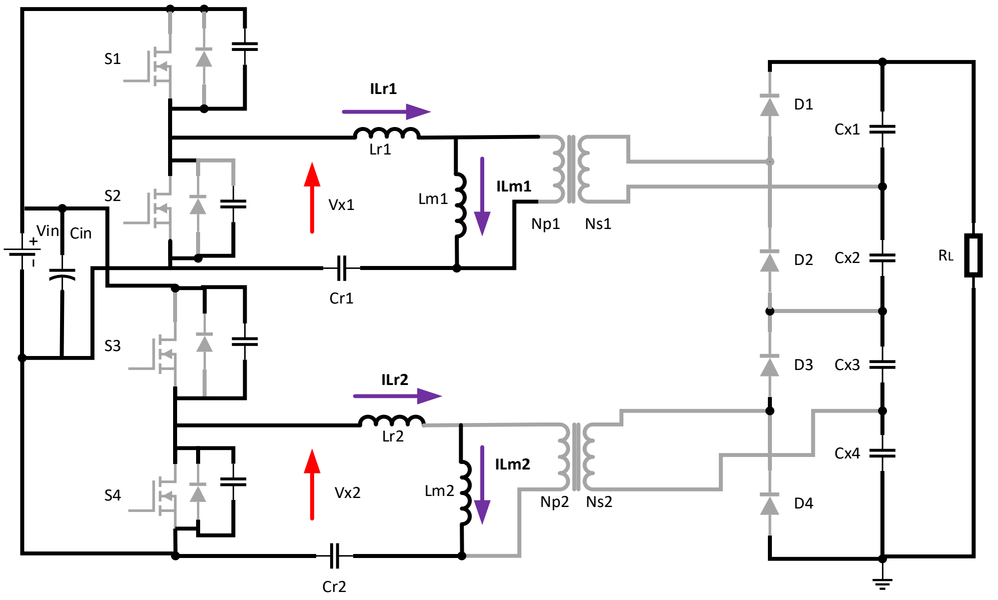


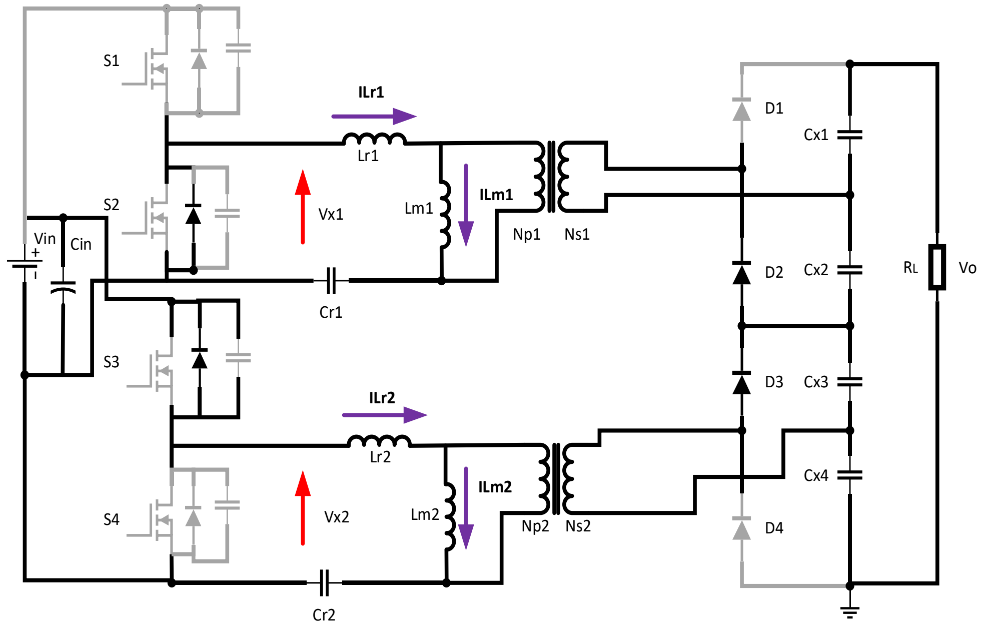
Figure 3.2: First half cycle instantaneous mode double H-Bridge LLC converter equivalent circuits for the first four intervals. **(a)** Mode 1 (*t*0–*t*1*)*



(b) Mode 2 (t1–t2)



(c) Mode 3 (t2-t3)



(d) Mode 4 (t3–t4)

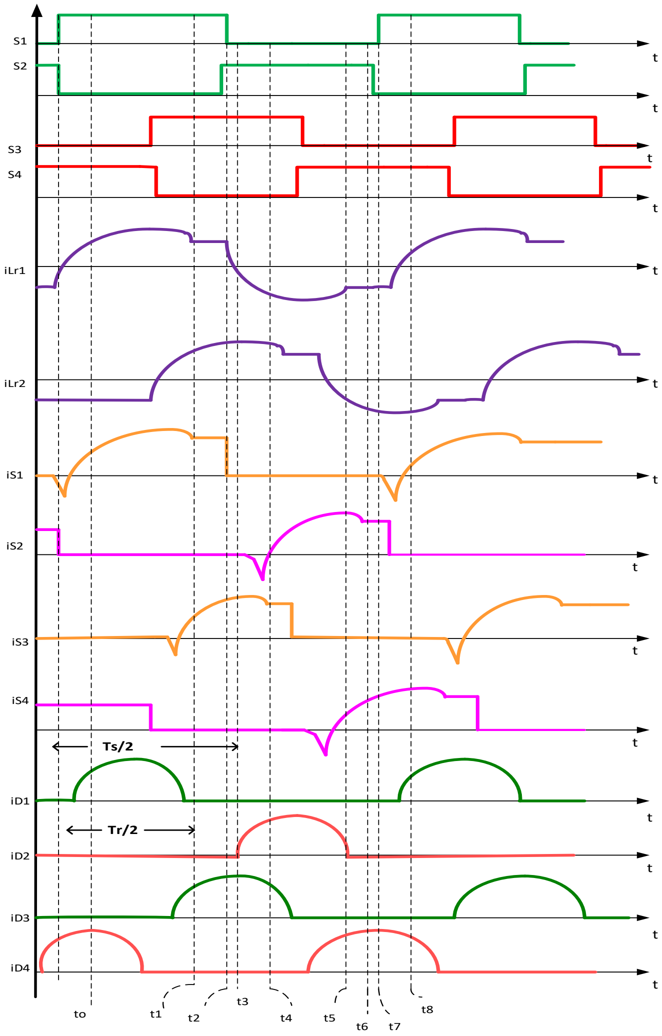


Figure 3.3: Key steady-state waveforms for the instantaneous operational mode of the proposed double H-bridge converter.

3.4 Instantaneous Modes of Operation

3.4.1 First Mode (t_0–t_1)

Switch-1 and 4 initiated the conduction of resonant inductor current-1 and 2 at t_0, respectively. In first mode, first resonant tank transmits energy from source side to load end and second resonant tank transmits its prior stored energy to the load end. Resonant inductor current-1 and 2 up and down surging sinusoid ally in positive side as well as negative side respectively. In addition, resonant capacitor-1 and 2 charge and discharge respectively. At load end, diode-1 and 4 are conducting. Furthermore, magnetizing current-1 and 2 rise and fall linearly with slopes $nV_0/4Lm1$ and $-nV_0/4Lm2$ respectively in this mode. So, the first mode terminates when resonant inductor current-1 and 2 become equal to magnetizing current-1 and 2 respectively. Output diode-1 and 4 are turned off at t_1.

3.4.2 Second Mode (t_1–t_2)

Magnetizing currents I_{Lm} became same to the resonant currents I_{Lr} and diode-1 and 4 are turned off with zero current switching at t_1. Then, resonance transpires between resonant capacitor-1 and inductor-1, magnetizing inductance-1 in first converter and between resonant capacitor-2 and inductor-2, magnetizing inductance-2 in second converter. This mode terminates by turning off of Switch-1 and 4 at t_2.

3.4.3 Third Mode (t_2–t_3)

Switch-1 and 4 are turned off at t_2. In first converter, resonant current-1 began passing through parasitic drain to source capacitors 1 and 2. Likewise, resonant current-2 began passing through parasitic drain to source capacitors 3 and 4 in second converter. Further, in first converter, parasitic drain to source capacitors 1 and 2 starts charge and discharge respectively with resonant inductor current-1. In second converter, parasitic drain to source capacitors 3 and 4 start discharging and charging because of second resonant current. The rising tendency of voltages across Switch-1 and 4 is sluggish by the parasitic capacitances then first and fourth switch is turned off with zero voltage switching. The instantaneous voltages across parasitic capacitors during this particular time period are presented with the assistance of below written equations:

$$V_{ds1}(t) = \frac{I_{Lr1}(t_2)}{2C_{ds}}(t - t_2) \tag{3.1}$$

$$V_{ds2}(t) = V_{in} - \frac{I_{Lr1}(t_2)}{2C_{ds}}(t - t_2) \tag{3.2}$$

$$V_{ds3}(t) = V_{in} - \frac{I_{Lr2}(t_2)}{2C_{ds}}(t - t_2) \tag{3.3}$$

$$V_{ds4}(t) = \frac{I_{Lr2}(t_2)}{2C_{ds}}(t - t_2) \tag{3.4}$$

Third mode terminates when the drain to source voltages 1 and 4 are ascended to input voltage, and drain to source voltages 2 and 3 plummeted to 0, and resonant currents began passing through the free-wheeling diodes of switches 2 and 3.

3.4.4 Fourth Mode (t_3–t_4)

At the starting of fourth mode, free-wheeling diodes of switches 2 and 3 are turned on and begin the conduction of inductor resonant currents 1 and 2 respectively. At load end, diodes 2 and 3 are conducting due to this voltages across primary and secondary windings are adhered to $–nV_0/4$ and $nV_0/4$ respectively. Hence, inductor-magnetizing currents 1 and 2 initiate rising and falling linearly with slopes $nV_0/4Lm$ and $-nV_0/4Lm$ respectively. The diode currents 2 and 3 may be expressed as:

$$I_{D2}(t) = n\,[I_{Lr1}(t) - I_{Lm1}(t)] \qquad (\mathbf{3.5})$$

$$I_{D3}(t) = n\,[I_{Lr2}(t) - I_{Lm2}(t)] \qquad (\mathbf{3.6})$$

In fourth mode, as the free-wheeling diodes of switches 2 and 3 are conducting, in case drain to source voltages of switches 2 and 3 are 0 within this particular mode. Hence, switch-2 and 3 is turned on under the conditions of zero voltage switching, prior to the termination of this mode. Fourth mode terminates at t_4, when inductor-resonant currents 1 and 2 begin passing through switch-2 and 3 respectively and their free-wheeling diodes are turned off with zero current switching.

3.6 Gain Characteristics of LLC Converter

The output voltage control range of converter can be determined by evaluating its gain characteristics. Fundamental harmonic analysis (FHA) approach is one of the widely accepted and employed methods for analyzing the gain characteristics of LLC resonant converters. The accuracy of FHA is at its maximum when converter is operated at or close to resonance. At resonance frequency, the input and output voltages of the tank circuit are square waves and input and output currents are sinusoidal. Since the proposed converter has two modes of operation, so gain analysis is done for both modes of operation as follows.

3.6.1 Instantaneous Mode

Since both H-bridge LLC converters have matched components, therefore, they have identical gain characteristics. Hence, it is enough to evaluate the gain characteristics of only one converter and the resulting ac equivalent circuit of converter-1 is shown in Fig.3.5. In instantaneous mode, the voltage across the primary winding of transformer of converter-1 swings between nVo/4 and –nVo/4 during positive and negative half-cycles, respectively. By adapting Fourier analysis technique, the fundamental frequency components of tank’s input voltage, output voltage, and output current of converter-1 in instantaneous mode are given as:

$$V_{ab1} = \frac{2}{\pi} V_{in} \sin(\omega_s t) \quad (\mathbf{3.7})$$

$$V_{01} = \frac{n}{\pi} V_0 \sin(\omega_s t + \emptyset_v) \quad (\mathbf{3.8})$$

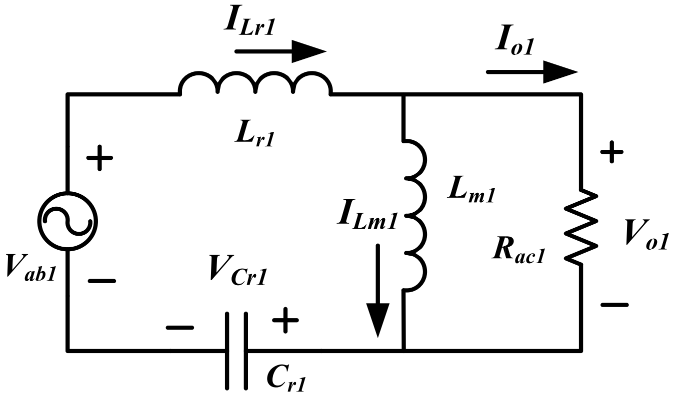


Fig.3.5. AC equivalent circuit of converter-1

$$I_{01} = \frac{\pi I_0}{n} \sin(\omega_s t + \emptyset_v) \quad (\mathbf{3.9})$$

where φ_v is the phase angle between input voltage Vin and output voltage V0, φ_i is the phase angle between output current I0 and output voltage, ω_s is the angular switching frequency, and n = NP1/NS1 is the transformer turns ratio. Thus, the equivalent ac resistance is obtained as:

$$R_{ac1} = \frac{V_{01}(\max)}{I_{01}(\max)} = \frac{n^2}{\pi^2} R_0 \quad (\mathbf{3.10})$$

From Fig. 3.5, the transfer function of ac equivalent circuit is given as:

$$H_{ac1} = \frac{V_{01}}{V_{ab1}} = \frac{sL_{m1}||R_{ac1}}{\frac{1}{sC_{r1}} + sL_{r1} + sL_{m1}||R_{ac1}} \quad (\mathbf{3.11})$$

Thus, the magnitude of ac transfer function can be obtained as:

$|H_{ac}$ (k, Q, fn)$|$

$$H_{ac}(\mathrm{s}) = \frac{V_{01}}{V_{ab1}} = \frac{k}{\sqrt{\left(1 + k - {f_n}^{-2}\right)^2 + k^2 Q^2 (f_n - {f_n}^{-1})^2}} \quad (\mathbf{3.12})$$

Where k = Lm1/Lr1, Q= (√(Lr1/Cr1)/Rac1), fn = (fs/fr), fr = 1/(2π √Lr1Cr1) and fs is the switching frequency.

Using rms values of Vab1 and V01 in (3.7) and (3.8) we get nV0|H (k, Q, fn)| = 2Vin. Hence, the normalized dc voltage gain of the converter in simultaneous mode is computed as:

G (k, Q, fn)

$$= \frac{nV_0}{2V_{in}} = \frac{k}{\sqrt{(1 + k - {f_n}^{-2})^2 + k^2 Q^2 (f_n - {f_n}^{-1})^2}} \tag{3.13}$$

3.6.2 Autonomous Mode

In this mode, only converter-1 operates and converter-2 is disabled. So the voltage across the primary winding of transformer oscillates between nVo/2 and –nVo/2. Therefore, the maximum value of fundamental component of Vo1 is 2nVo/π. The maximum value of Io1 is π Io/n. Thus the ac equivalent resistance is:

$$R_{ac1} = \frac{V_{01}(\max)}{I_{01}(\max)} = \frac{2n^2}{\pi^2} R_0 \tag{3.14}$$

The input voltage to tank circuit is the same as in instantaneous mode, so the equivalent circuit of Fig. 3.5 can be used to evaluate the gain. From the equivalent circuit, the normalized voltage gain of converter for autonomous mode is expressed as:

G (k, Q, fn)

$$= \frac{nV_0}{V_{in}} = \frac{k}{\sqrt{(1 + k - {f_n}^{-2})^2 + k^2 Q^2 (f_n - {f_n}^{-1})^2}} \tag{3.15}$$

Comparing (3.12) with (3.15), we can observe that the gain of converter in independent mode has been halved. This means, the proposed converter would produce half output voltage when operated in independent mode. Thus, the output voltage of converter can be further reduced by mode changing along with switching frequency variation.

CHAPTER-04

DESIGN AND IMPLEMENTATION

4.1 Introduction

To ensure the appropriate operation and efficiency of a Double H-bridge LLC resonant converter, numerous actions and considerations must be made. Clearly outlining the specifications for converter should be first step. This covers the range of input and output voltages, as well as the power and efficiency goals, and any other pertinent criteria.

4.2 Design Specification

The design specifications of the proposed LLC resonant converter are given as the following:

1. input dc voltage: 400 V
2. output dc voltage range: 50–420 V
3. maximum output power: 1.5 kW
4. primary resonance frequency: 90 kHz
5. output dc voltage at resonance frequency: 250 V.

A wide output voltage range (100-420 V) and excellent efficiency in the high-power region are the main design goals. The converter is developed for instantaneous mode with 250 V at resonance frequency since the suggested converter has a larger gain in that mode. The following steps outline the suggested design process.

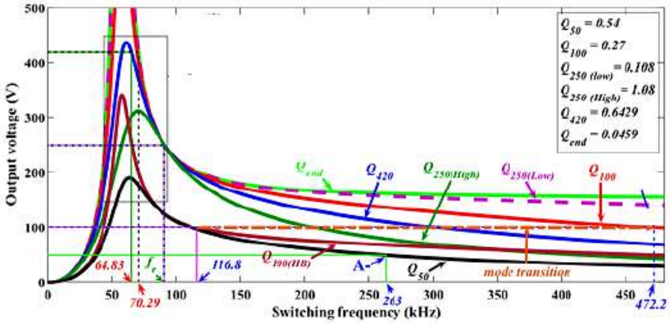
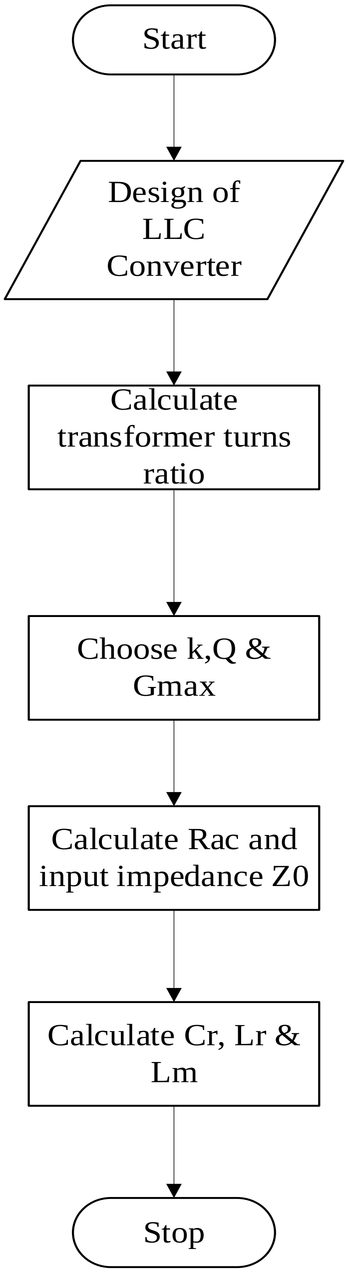


Figure 4.1: Output Voltage V_0 versus f_s curve

Flow Chart



4.3 Design of LLC Converter

4.3.1 Calculation of transformer turns ratio

Calculate transformer turns ratio n for above specifications using (3.13) and L1/L2= 3000uH/292.96uH with G = 1 at fr as:

$$n = 2V_{in}/V_o = 2(400)/250 = 3.2 \quad \textbf{(4.1)}$$

4.3.2 Selection of k and Q value

Choose k and Q to satisfy gain requirements. Since the required maximum gain of converter is G_{max} = 420/250 = 1.68. Using, k = 1.62 and Q = 0.606 in (3.13) the peak gain becomes, G_{pk} = 1.8, which is larger than the desired G_{max}.

4.3.3 Calculation of R_{ac} and Z_o

Calculate R_{ac} and input impedance Z_0 as:

$$R_{ac1} = n^2 \frac{V_0(\max)}{\pi^2 I_{01}} \tag{4.2}$$

$$Z_0 = QR_{ac} \tag{4.3}$$

4.3.4 Resonant Tank Parameters Calculation

Calculate the resonant tank parameters as:

$$C_r = \frac{1}{2\pi f_{r1} Z_0} \tag{4.4}$$

$$L_r = {Z_0}^2 C_r \tag{4.5}$$

$$Lm = kLr \tag{4.6}$$

The calculated parameters of the proposed converter have been shown in Table 4.1.

4.3.5 Design Values

Table 4.1: Design Specifications

Sr. No	Parameters	Values
1	Input voltage (Vin)	400V
2	Resonant Frequency	90 KHz
3	Output Voltage	50-420V
4	Output Current	8.82 A
5	Output Power	1.5 KW
6	Switching frequency	100 KHz
7	Rac	20.01
8	Turns ratio (N)	3.2
9	Resonant Capacitor (C_{r1}= C_{r2})	23.9 nf
10	Resonant Inductor (L_{r1}=L_{r2})	130.8 uH
11	Magnetizing Inductor (L_{m1}=L_{m2})	211.9 uH

4.4.1 Double H-Bridge LLC Converter Pspice Simulation

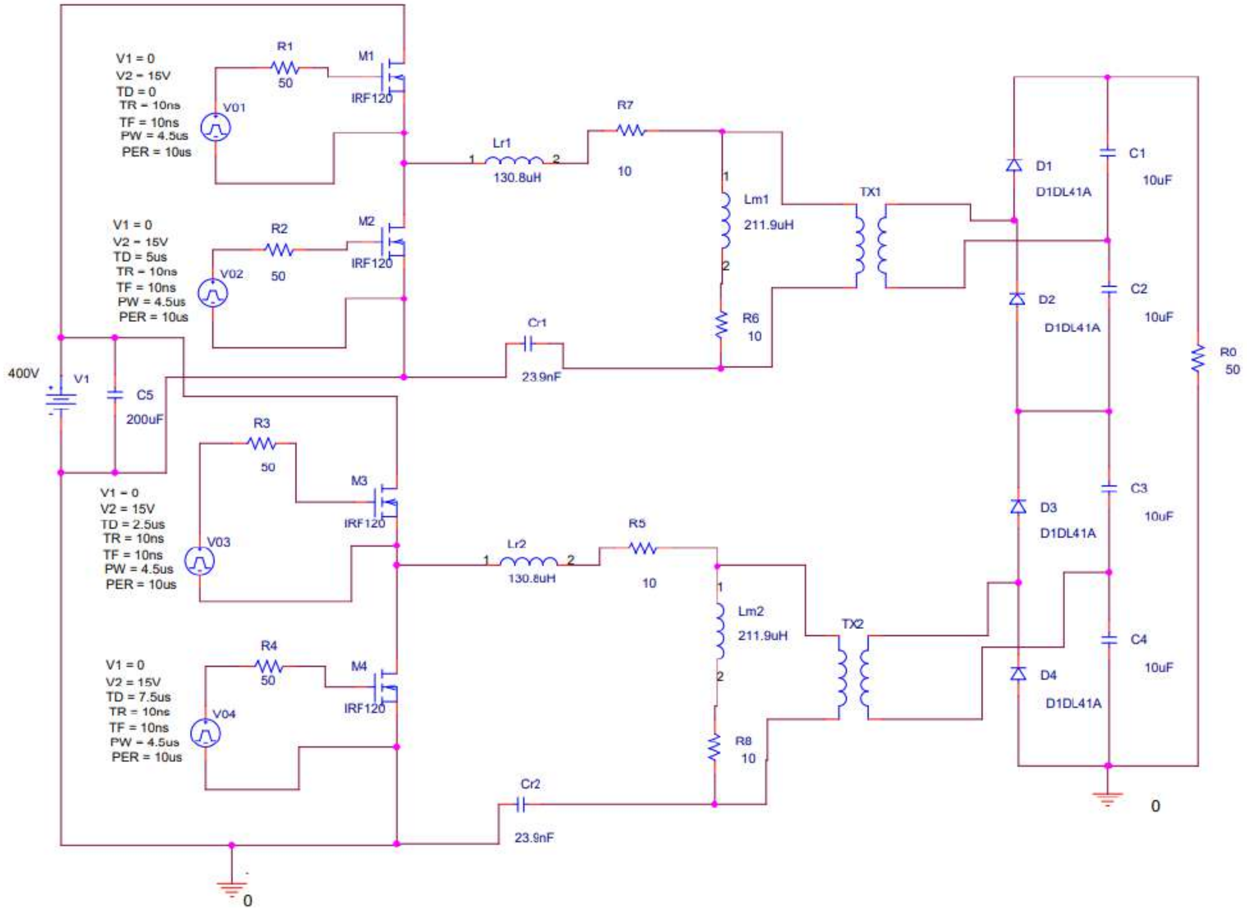


Fig. 4.2 shows the picture of converter implemented in Pspice Software

CHAPTER-05

RESULTS AND DISCUSSION

In instantaneous mode, both H-Bridge LLC converters operate simultaneously and charging range is achieved by frequency variation only. The switching frequency of converter will be determined by operating mode.

Table 5.1

Operating Mode	Battery Status	Key Point	Voltage	Current	Power
Simultaneous	**Deeply Depleted**	**A**	100	0.51	51
		B	250	0.51	127.5
	Normally Depleted	**C**	250	3.57	892.5
		D	420	3.57	1499.4
		E	420	0.255	107.4

5.1 A-point (V_{ab1} and IL_{r1} & V_{ab2} and IL_{r2}):

The change from independent to simultaneous mode takes place after the battery voltage reaches 100 V, and fs is then adjusted to a new value of 440 kHz. Fig. 5.1 displays the input voltages and resonant current waveforms of both resonant tanks during the changeover. Both converters began working at new fs following transition, while the converter-2's tank current and voltage were both zero prior to changeover. When operating in simultaneous mode, both HB LLC converters work at once, and charging is only possible through frequency variation. The operational waveform of the converter is shown in Fig. 5.1(a)-(e) at key point A (100 V, 0.51 A). The converter's switching frequency is 442 kHz, and its current power efficiency is 76.95%.

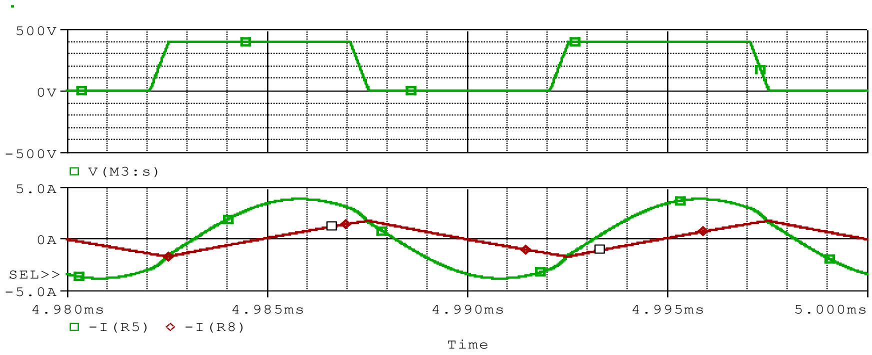


Fig (a)

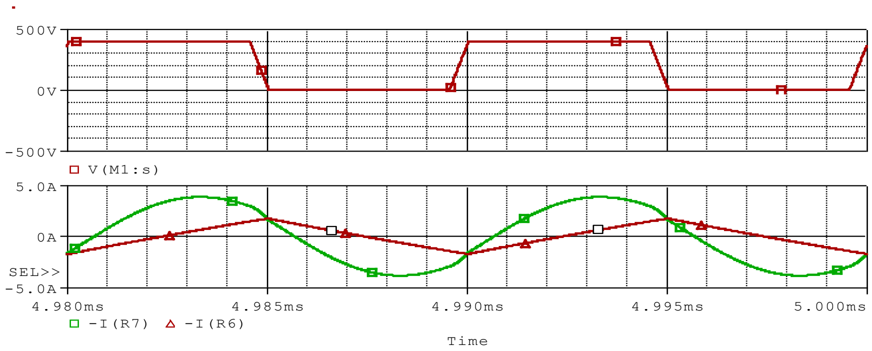


Fig (b)

5.1.1 VCr1 and VCr2

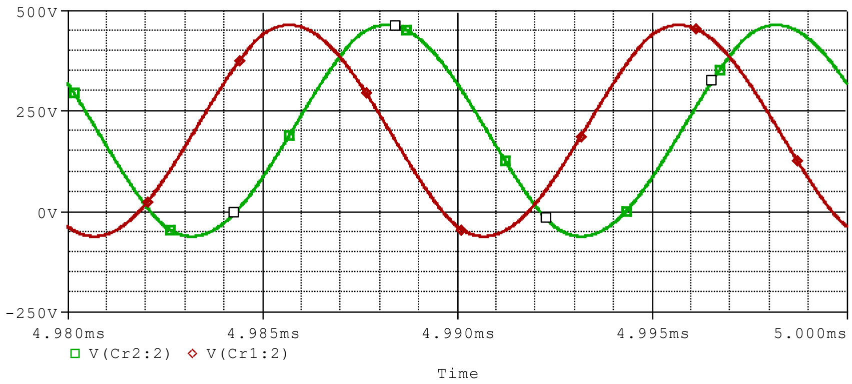


Fig (c)

5.1.2 Diode Current:

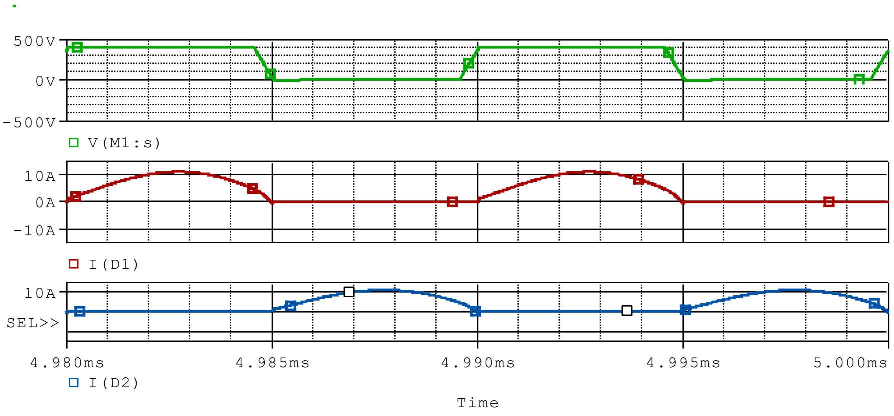


Fig (d)

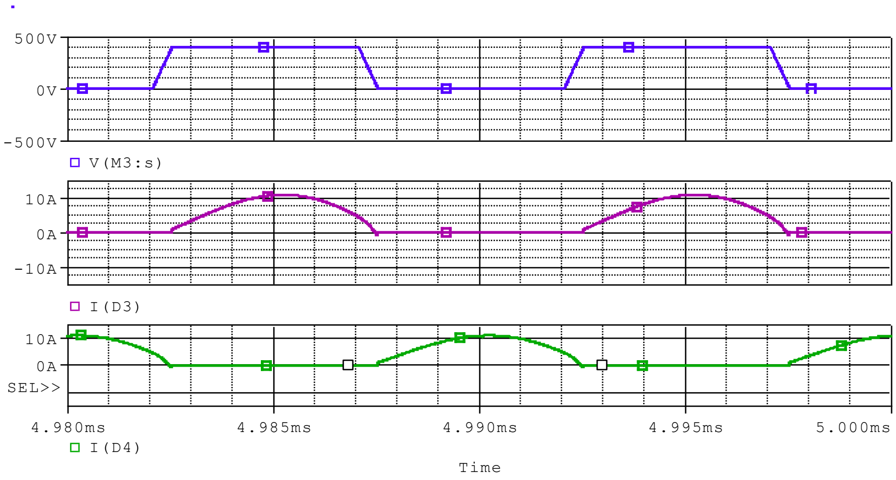


Fig (e)

Fig.5.1 Operating waveforms of converter for simultaneous mode (a)–(e) for key point A (100 V, 0.51 A)

5.2 B-point (IL_{r1} & IL_{r2}):

Up to this point, the converter processes relatively lower output power to revive the battery. After this, normally depleted battery charging begins. The operation of the converter at key point B (250 V, 0.51 A) at 92-kHz switching frequency is shown in Fig. 5.2(f)-(h) with 88.3% efficiency. For depleted battery charging (key point C to key point E), converter operate at or below fr. Therefore, power switches operate with ZVS and output diodes with ZCS. Thus, switching losses are minimum in this range.

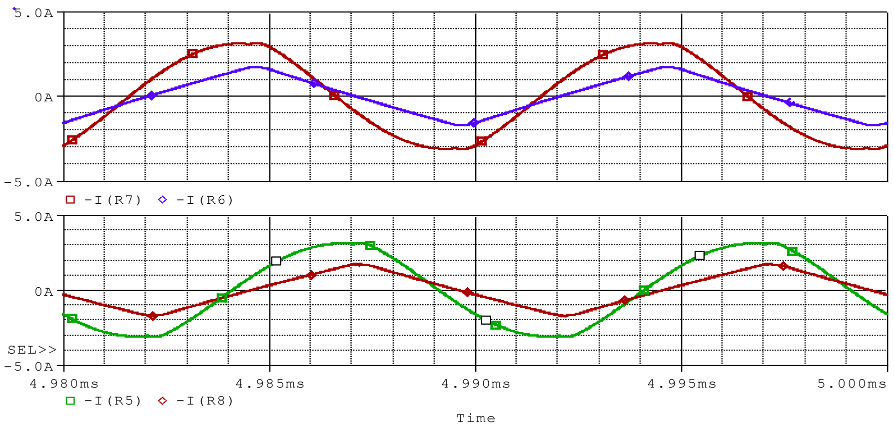


Fig (f)

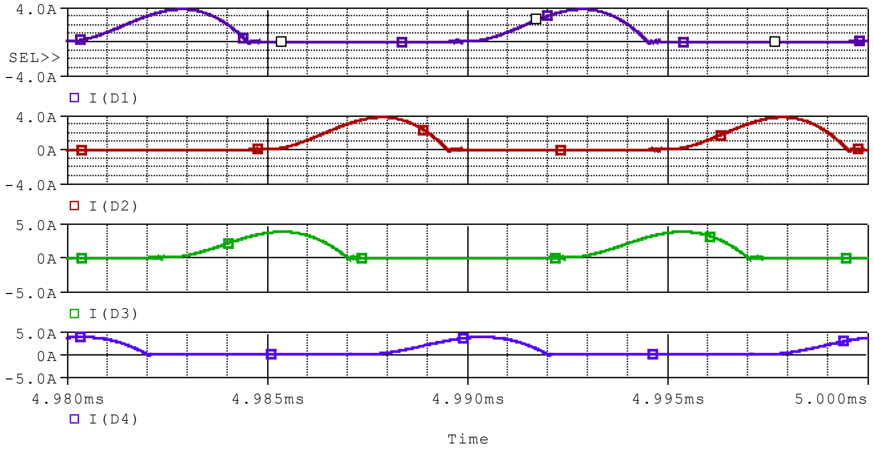


Fig (g)

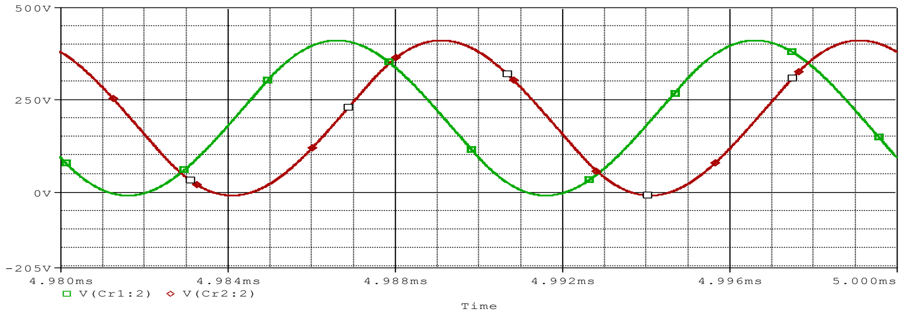


Fig (h)

Fig.5.2 Operating waveforms of converter for simultaneous mode (f)–(h) for key point B (250 V, 0.51 A)

5.3 C-point (IL_{r1} & IL_{r2}):

Fig. 5.3 (i)-(k) displays the operational waveforms of the converter at critical point C (250 V, 3.57 A). This is where CC charging with high current begins. At this moment, the converter's switching frequency is equal to fr. The proposed converter features a decent power sharing mechanism among its two H-bridge converters, as evidenced by the fact that the resonant currents of both HB-LLC converters are fairly balanced.

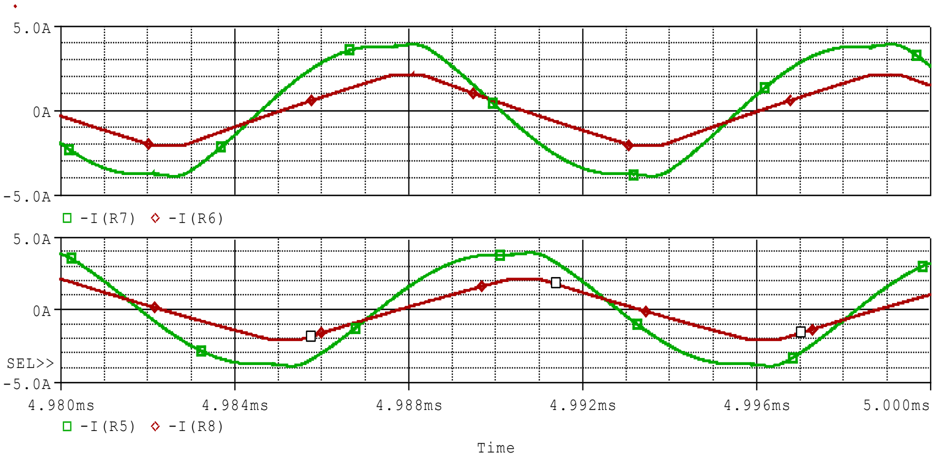


Fig (i)

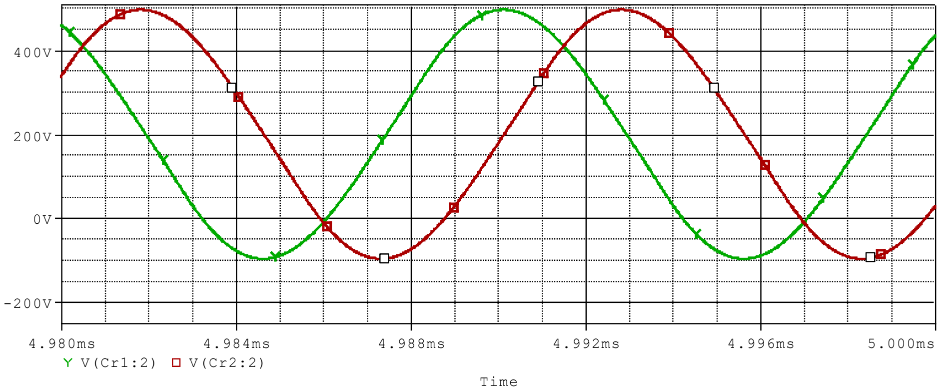


Fig (j)

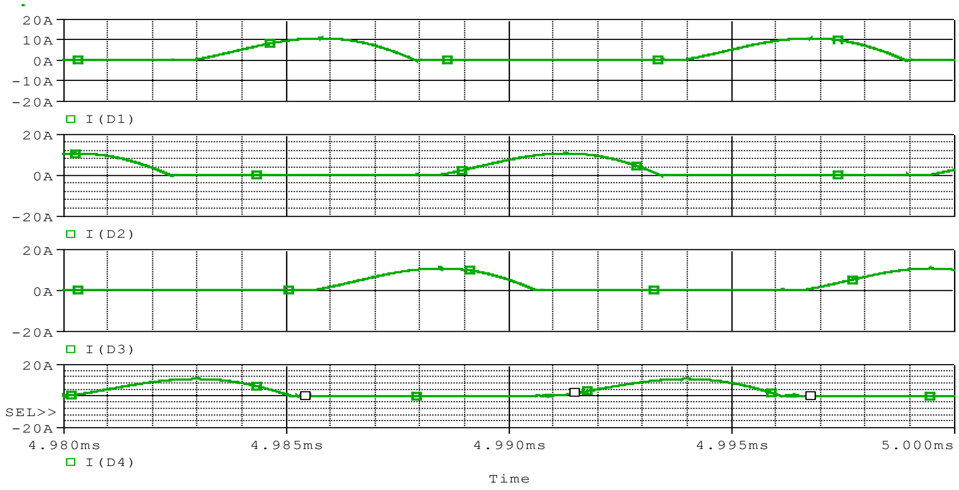


Fig (k)

Fig.5.3 Operating waveforms of converter for simultaneous mode (i)–(k) for key point C (250 V, 3.57 A)

5.4 Above Resonance Frequency Operation (100 KHz):

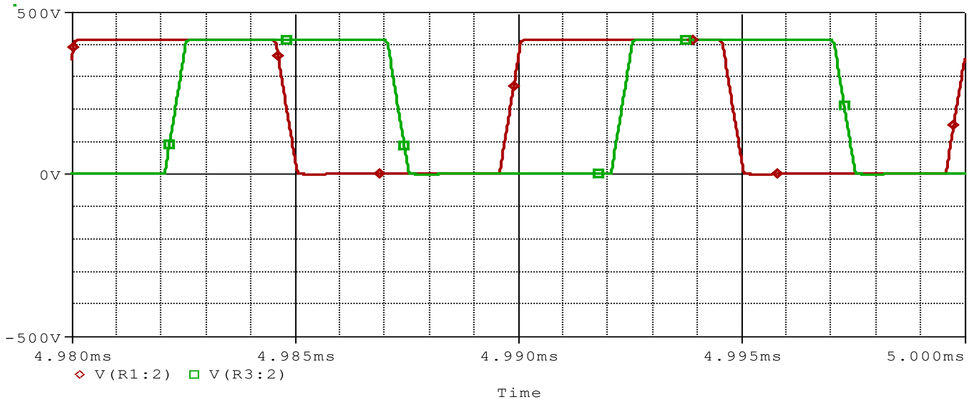


Fig.5.4 (a)

5.4.1 Resonant and Magnetizing Inductor Current of Tank-1 & Tank-2:

The resonant currents of both H-bridge LLC converters are quite balanced having 90 degree phase shift in between the both converters as shown in Fig.5.4 (a). In the above resonance operation mode, resonant and magnetizing currents rise and fall linearly as shown in Fig.5.4 (b). It shows that the proposed converter has good power sharing mechanism among its two H-bridge converters.

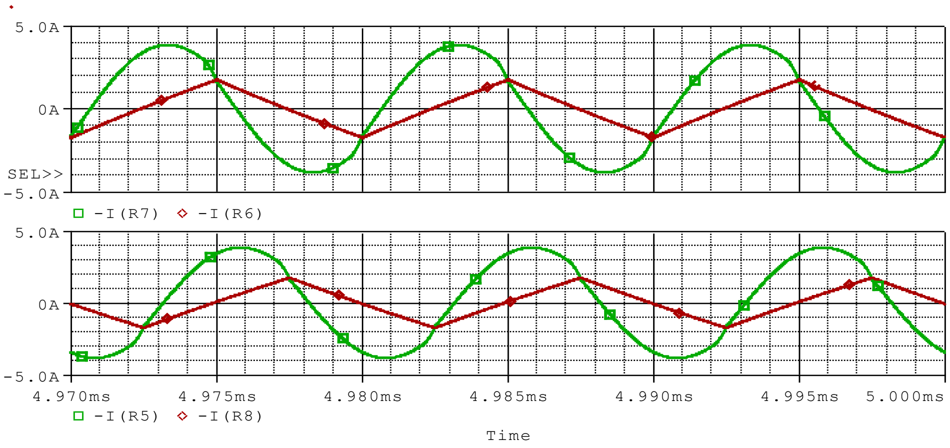


Fig.5.4 (b)

5.4.2 ZVS (at I_{Lr1} & I_{Lr2}) **and ZCS** (at I_{D1} & I_{D3}):

Power switches operate with ZVS and output diodes with ZCS. Thus, switching losses are minimum in this range. The switching frequency of the converter is equal to fr at this point. ZVS offers certain advantages such as low switching losses, energy conservation required to move switches, low noise and generation of EMIs. Diode turns off at zero current of transformer secondary current so ZCS across the output diodes is achieved as shown in Fig.5.4 (d). Drain to source voltage falls to zero until resonant current becomes zero so switches run with ZVS as seen in Fig.5.4 (c).

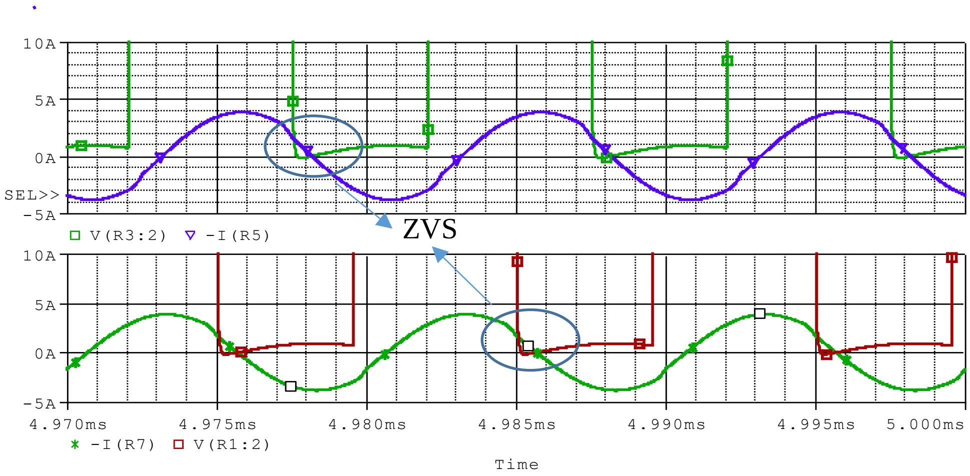


Fig.5.4 (c)

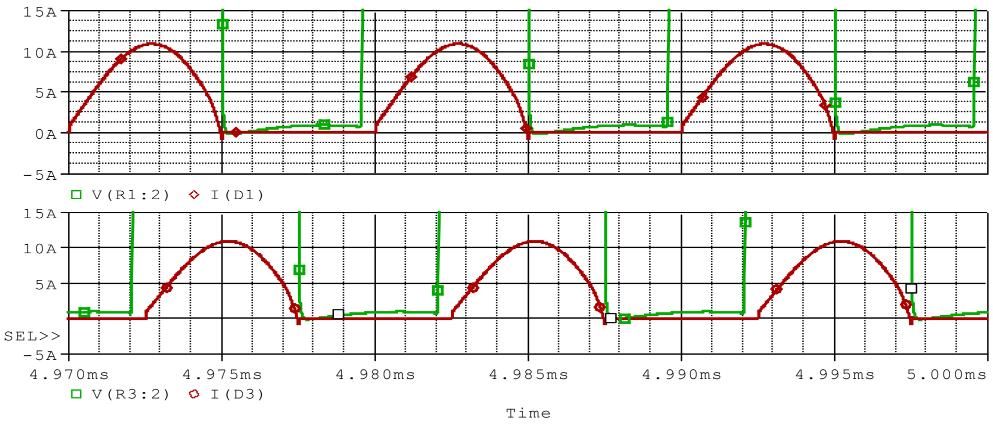


Fig.5.4 (d)

5.4.3 V_{Cr1} and V_{Cr2}:

A 90 degree delayed has been achieved between converter-1 capacitor voltage and converter-2 capacitor voltage and it is operating at 400 V with switching frequency of 100 KHz as shown in Fig.5.4.

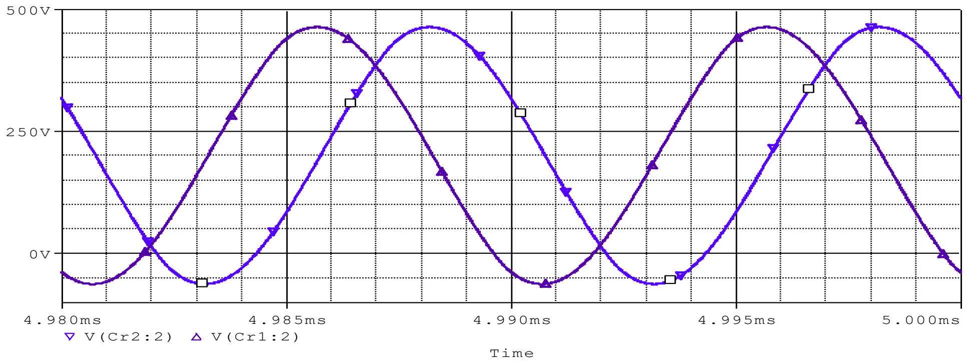


Fig.5.4 (e)

5.4.4 Diode Current:

It can be verified from the previously discussed modes of operation that 90 degree delayed diode current operating at 400 V with switching frequency of 100 KHz as shown in Fig.5.4 (f) has been attained.

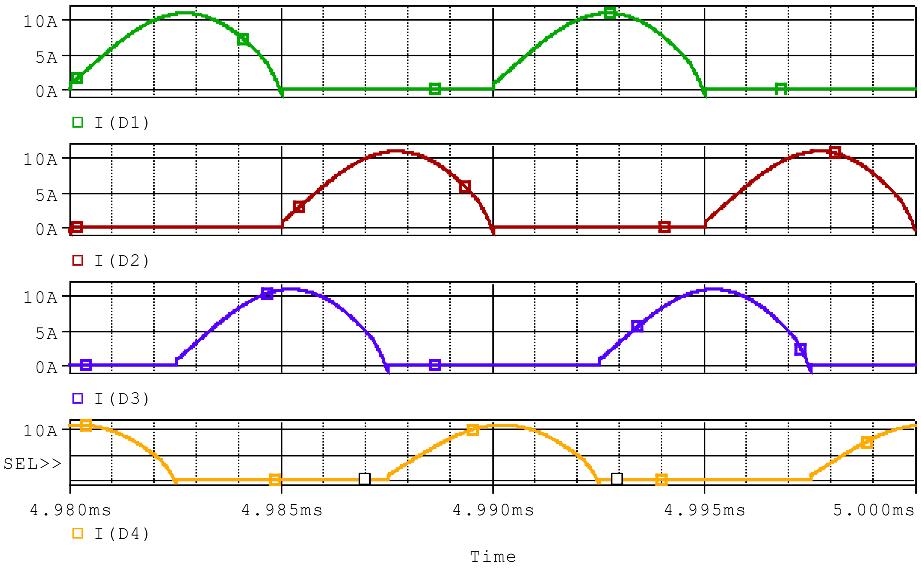


Fig.5.4 (f)

5.4.5 Output Voltage of Double H-bridge Converter:

Hence, we have become successful in attaining an objective of wide charging range and low output voltage ripples using a solar powered double h-bridge LLC resonant converter-based EV battery charger as shown in Fig 5.4 (g).

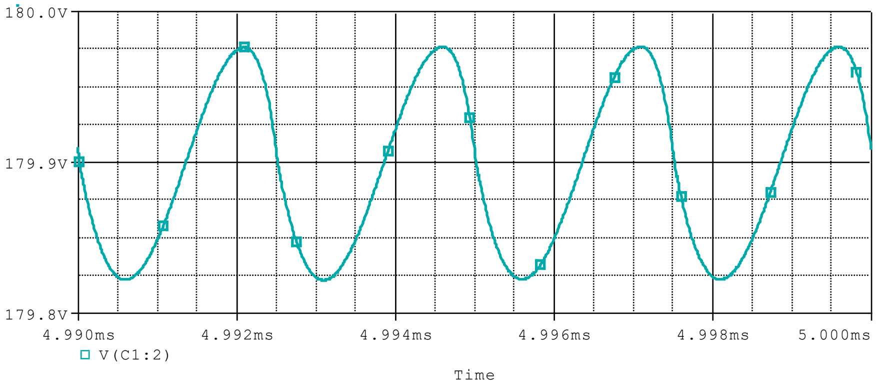


Fig.5.4 (g)

CHAPTER-06

CONCLUSION

6.1 Conclusion

The project calls for a double h-bridge LLC resonant converter with series linked rectifiers for PEV battery charging. In-depth descriptions of the converter's structure, functioning, and analysis were provided. It was demonstrated that the suggested converter has two operating modes: autonomous and immediate. The converter's specifications called for a voltage range of 250-420 V and a range of 100-250 V working above and below the resonant ZVS area, respectively. The suggested topology used simple frequency management to reach 100-420 V in simultaneous mode without any structural variation at the primary or secondary side. On the other hand, by using the converter in independent mode to obtain 50-100 V with above and below resonance frequency operation, the voltage range was further expanded. Simulation findings demonstrated that the suggested architecture attained 50-420 V effectively with with 1.5 kW of maximum power and 95.65% peak efficiency in instantaneous mode. As a result, the suggested topology works well for the dc-dc stage of PEV battery chargers.

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