# WIRELESS CHARGING SYSTEM WITH INTERMEDIATE COILS FOR ELECTRIC VEHICLE

A

DISSERTATION

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FOR THE REWARD OF THE DEGREE
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**IN**

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SUBMITTED BY:

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UNDER THE SUPERVISION OF

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**MAY, 2022**

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I, **PUNEET AGRAWAL**, Roll No.- **2K20/PSY/15**, student of M.Tech (Power System), hereby declare that the project Dissertation titled "**WIRELESS CHARGING SYSTEM WITH INTERMEDIATE COILS FOR ELECTRIC VEHICLE**" which is submitted by me to the Department of Electrical Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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# CERTIFICATE

I hereby certify that the Project Dissertation titled "**WIRELESS CHARGING SYSTEM WITH INTERMEDIATE COILS FOR ELECTRIC VEHICLE**" which is submitted by **PUNEET AGRAWAL**, Roll No. **2K20/PSY/15**, Department of Electrical Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi **PROF. MUKHTIAR SINGH**

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# ABSTRACT

The usage of fossil fuel based vehicles supplies, as well as potentially catastrophic changes in environmental circumstances, are threatening the increasingly global economy. Besides that, it has also accelerated the development of ecologically friendly technology, resulting in breakthroughs in major sources of carbon dioxide emissions, such as transportation. To aid in the reduction of the environmental harm caused by carbon-based fuels, EVs are becoming more popular of viable alternative for gasoline and diesel automobiles. Aside from that, the market for electric cars (EVs) provides humanity with a new option to extend transportation's life expectancy at a lower cost than was before accessible to them. In this project, an electric vehicle charging technique that makes use of intermediate coils is detailed. This implementation work depicts about the novel inductive coupling method used Electric Vehicle charging with the help of wireless power topology using two coils at the transmitter and receiver side. Zero Voltage Switching has also been aimed to achieve to reduce the switching losses and to improve the overall efficiency The simulation is done by using the MATLAB/Simulink Software.

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**PUNEET AGRAWAL**

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| | |
|---|---|
| $V_B$ | Battery Voltage |
| $I_B$ | Battery Current |
| $V_{DC}$ | DC voltage source |
| $Ca_1$, $Ca_2$ | DC link Capacitors |
| $C_F$ | Filter Capacitance |
| $C_1$ | Primary Compensation Capacitance |
| $C_2$ | Secondary Compensation Capacitance |
| M | Mutual Inductance |
| k | Coupling Coefficient |
| f | Switching Frequency |
| $L_A$ | Auxiliary Inductance |
| $T_A$ | Auxiliary transformer |
| $L_1$ | Transmitter side coil inductance |
| $L_2$ | Receiver side coil inductance |
| $R_L$ | Load Resistance |

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# ACRONYMS

**WPT -** Wireless Power Transfer

**IPT** - Inductive Power Transfer

**ZVS** - Zero Voltage Switching

**ZCS** - Zero Current Switching

**ZVZCS** - Zero Voltage Zero Current Switching

**EV** - Electric Vehicle

**HEV** - Hybrid Electric Vehicle

**ZPA** - Zero Phase Angle

**UPS -** Uninterruptible Power Supply

**VSI –** Voltage Source Inverter

**CSI** – Current Source Inverter

# CHAPTER 1

# INTRODUCTION

## 1.1 INTRODUCTION

Operations in the construction sector, transportation, commerce, and a wide range of other activities are among the different sorts of energy-efficiency endeavors [1-2]. Wireless-based entertainment connections, including to laptops and mobile phones, as well as portable personal computers, are becoming more popular. A significant amount of study and analysis is thus required on this issue [3]. The relevance of electric cars for hybrid energy storage systems would be incorporated in a more focused understanding of the perspectives of electric vehicles. [4]. It is becoming clear that the depletion of fossil fuel reserves, as well as possibly catastrophic shifts in environmental conditions, pose a challenge to the growing global economy [5]. It has also spurred the development of sustainable technology, which has resulted in improvements in significant carbon emitters such as transportation [6-8]. Batteries and power shaping technologies, as well as their limitations, have historically prevented electric cars from attaining widespread adoption and commercial success. [9] But in recent decades, BT has been developed to have a high energy density while also being lighter and more efficient [10], as well as a reduced total weight.

Furthermore, when used in conjunction with an appropriate power shaping circuit, an efficient energy storage device has the potential to improve overall performance even further. Academics and businesses are investigating power conditioning topologies that have reduced power losses, longer lifespans, more trustworthy energy transfer, and greater charging-discharging cycles [11]. For short driving ranges, efficient, rapid chargers are now being employed when there is a concern about human health and safety, as well as for long driving ranges.

The electric vehicles that are running in both modes of dynamic and stationary the charging of the battery can be possibly provided by the topology known as inductive power transfer (IPT). This will enhances the safer charging of the battery [12]-[16]. If we need to increase the flow of EVs into the market then selecting of converter should be the most important one. As mentioned in [17], it effectively contributes to the elimination of environmental issues created by transportation difficulties.However, although it is feasible to achieve ZVS by optimizing traditional series compensation, it is conceivable to achieve ZCS by using an auxiliary network [18]-[22].

There are mainly 4 types of vehicles are compared over here on the basis of environmental and economical effects. They are hydrogen fuel based vehicles, traditional vehicles, electric vehicles and hybrid vehicles. As proposed in [23], the main aim is to develop a modern light-duty vehicle.Using of own electricity by the owner of the vehicles will leads to the energy arbitrage at the time of having more prices. So this may leads to do easier transaction costs. In addition to this, it also leads to the advantages like ignoring the investment of the utility grid and creates a good beneficial ways to the society. As mentioned in [24], it can be considered to be as the arbitrage services from the individual electricity consumer

**Fig 1.1 : Electric Vehicle**

Every country in the world is depending on the consumption of fuel to run a vehicle. But using of this vehicles are leading to the effects in the environmental degradation. Every country is promoting advanced technology capable of meeting rapidly rising energy demands while also ensuring long-term transportation development. So, the each country found ways in a transportation i.e.., electric vehicles [25]. In electrical vehicles utilize plug-in charging EVs mostly.

In this research, we show that Li-ion battery pack prices to BEV makers are continuing to fall, and that they are likely substantially lower than previously stated. These reduced predictions must be taken into account in future research attempts to anticipate scenarios for energy and transportation transitions [26].

For the production of ZV (zero voltage) and ZC (zero current) switching the proposed system is compressed of the small size auxiliary components along with the series LC compensation techniques. The obtained voltage variation is given to the suggested controller after some process the voltage at the output side will becomes constant. By controlling the input voltage the output current will be controllable.

But in PEV charging there is a chance for short circuits because of sudden change of loads or dynamic changes at the grid side. So, we will introduce vehicle charging without wire connections (WPT).

## 1.2 TYPES OF CHARGING

### 1.2.1 Conductive Charging

In conductive charging metal-to-metal contact is used, which is common in most appliances and electronic gadgets. Conductive charging necessitates a physical connection between the battery of the portable device and the charging station. The electronic item is fitted with certain attachments that make it compatible with the charging base. When a compatible gadget is placed on the wireless charging base, it detects it and sends an electrical current from the base to the electronic item via particular attachments [27]. A conventional electrical outlet (Level 1 or 2) or a charging station can be used to power the cable (Level 2 or 3).

There are already a number of charging stations available. Levels 1 and 2 chargers with basic infrastructure are used by available vehicles, such the Chevrolet Volt and Tesla Roadster (convenience outlets). The Nissan Leaf and Mitsubishi i-MiEV, which use either basic infrastructure or dedicated off-board chargers, also use conductive charging. The driver must plug in the cable, which is the biggest disadvantage of this arrangement.

### 1.2.2 Inductive Charging

Magnetic contactless power transmission underpins inductive charging. For Levels 1 and 2, this form of charger has been investigated. Contactless charging has a distinct advantage in terms of user convenience. Rather than deep-cycling the battery, it can be topped off periodically while parked at home or at work, while shopping, or even at traffic lights. There are no cables or cords. Convenience and galvanic isolation are two advantages. Charging strips can also be built into roadways, allowing for charging while driving. As a result, inductive charging has the potential to significantly minimise the requirement for fast-charging infrastructure [27-28]. Low efficiency and power density, manufacturing complexity, size, and cost are all disadvantages. Given how essential energy savings are for EVs, the extra power loss is an essential phenomena to consider.

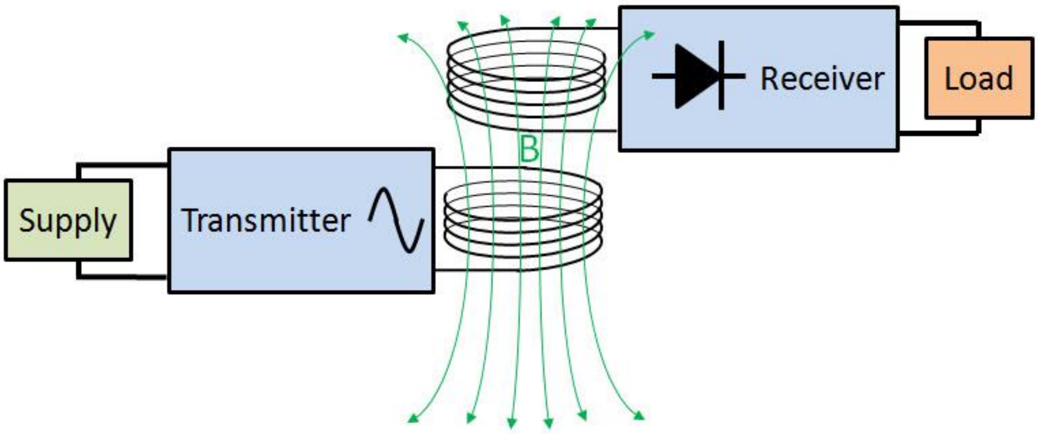


**Fig 1.2: Basic Inductive Charging Scheme**

## 1.3 WIRELESS POWER TRANSFER (WPT) :

The Electric power transfer between primary (source) to secondary (load) without any electrical wires is known as wireless power transfer system. It is done with the help of using electromagnetic field (WPTT). For implementing this type of work in the year 1980s resonant transformers were known to be Tesla coils was developed and many other researches like MIT scientists and they have come up with this WPT technology in the year 2007. They have done experiment with the resonance which is connected electromagnetically. The below fig: 1.1 shows the architecture of EV charging without wire connection (WPT).

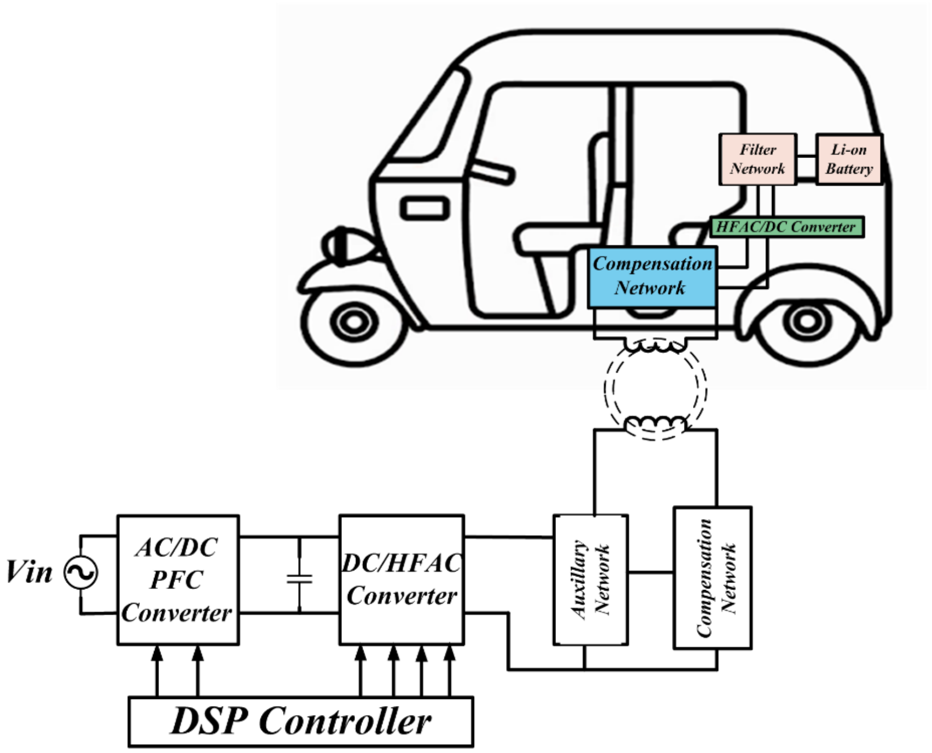


**Fig 1.3: Wireless battery charger topology in General configuration**

The electrical energy transfer for the load will be using electromagnetic wave transformation, it is not used for any physical components of transformation it is called wireless power transfer technology (WPTT). In recent time wireless charging will be used for some electronic device of cell phones and laptops in same power source production. In 1980's proposed for wireless power transfer in Nikola Tesla, Tesla used for resonant transformer and it is called Tesla coils. In July 2017 started for research and tested for wireless power transfer for MIT team. The research team will be research for used in electromagnetically coupled renounce system to two meter distance for 60W light bulb.

Electricity must be transported to the distribution lines via cables. Both electricity generation and power loss are increasing as demand rises. Furthermore, the cost of electricity generation is harmful to the environment. As a result, reducing transmission loss is crucial since the saved electricity can be used to reduce costs. Although power loss during transmission is unavoidable, there are some approaches to mitigate the problem.

- For millennia, wireless power transmission has been used as a clean source of electricity to reduce power losses in the distribution network. A unique way to battery charging involves wireless power transmission. The concept of WPT is not a new topology for EVs, but it has yet to be widely adopted [28].
- This method of transmission is employed when linking cables is risky or difficult. In the early period, several scientists demonstrated a variety of power delivery methods that are WPTS. Each wireless power transfer technology has its own set of properties and uses. To familiarize new scholars with this approach, we analyzed historical histories, modern technology, and potential advancements [29].
- Because of its clever applications and conveniences, WPT innovation is becoming more well-known in the modern technological era. This strategy can be used to solve a variety of wired technique problems, such as electric shocks, cable issues, charging method issues, and cost [30]. In recent years WPT system gain more popularity. Vehicle usage is rapidly increasing as gasoline prices fall. As a result, WPT technology can significantly reduce these factors [31].

Several works have been done to date, and this technique is also widely used in modern smartphone technology. Another futuristic invention that is well-known for its use in electric vehicles is wireless technology [32.] Nikola Tesla invented WPT technology in 1980s [33]. The implementation of this mainly depends on the three topologies. In WPT system implemented 2 windings mainly primary (transmitter) and secondary (receiver) [34]. The transmitter connected to the source and receiver connected to the load. Between these two coils magnetic field work as a medium [35].

# CHAPTER-2

## LITERATURE SURVEY

### 2.1 LITERATURE REVIEW

Electric cars offer a number of benefits, but the negative repercussions of continuing to depend on fossil fuels for transportation are the primary drivers for transitioning to electric mobility. [1] [2]. If the supply of oil is disrupted, the price of oil will increase, and the economy would become unstable as a result. As a result of human activity, a significant percentage of the world's original crude oil reserves has already been depleted, resulting in a scarcity of crude oil. [4] Crude oil consumption is predicted to grow in lockstep with increasing car ownership rates practically wherever you look in the coming years. Increasing numbers of people are becoming aware that fossil fuels will become more unreliable in the future and that we will need a stable alternative energy source to power transportation [5, 6].

The general public has access to a diverse variety of power production alternatives, including environmentally friendly options like as wind, solar, and hydrostatic generation, as well as conventional ones. [6] Given the fact that energy may be created in a number of different methods, there is less chance of a disruption in power supply [7]. The National Renewable Energy Laboratory estimates that the efficiency of converting stored energy to mechanical energy for electric propulsion is on the order of 80 percent, while the efficiency of internal combustion is at most 30 percent [8] [9] When compared to gasoline, electricity is far less costly, and its costs are more predictable.

When it comes to transportation, the difficulties associated with storing electrical energy for use in automobiles exceed the benefits of electrification in this area. Buyers are willing to purchase electric vehicles if they provide the same or better performance, range, and service life as conventional gasoline-powered automobiles at a price that is equal to or less expensive than the price of gasoline-powered automobiles [10], as long as the price is equal to or less expensive than the price of gasoline-powered automobiles. In today's world, there are a variety of feasible options for storing electric energy, including fuel cells, ultra-capacitors, and several other forms of batteries. When it comes to these exact parameters, none of these alternative fuels can currently compete with gasoline on their own terms. [11] Governments and consumers are getting increasingly interested in cars that are more fuel efficient and release less emissions. It is certain that the automobile sector must adapt to meet this increasing demand for its products. Initial efforts were made to address this issue in the early 1970s [12].

Automobiles with electric drivetrains are becoming more common, with hybrids and all-electric vehicles set to come in the not-too-distant future. There are a number of technical difficulties to reckon with as a result of this decision. Here are a few examples of how this might happen. It is critical to include electrical energy storage as a factor in long-distance transportation [14]. The most significant of these difficulties is the hardest to complete since it is the most time-consuming. Various methods of storing electricity are available, including fuel cells and batteries, each with its own set of advantages and disadvantages [15]. A decent balance between having enough energy storage to allow for an acceptable electric-only range and having enough power capabilities to give enough acceleration and deceleration [16] is challenging to achieve.

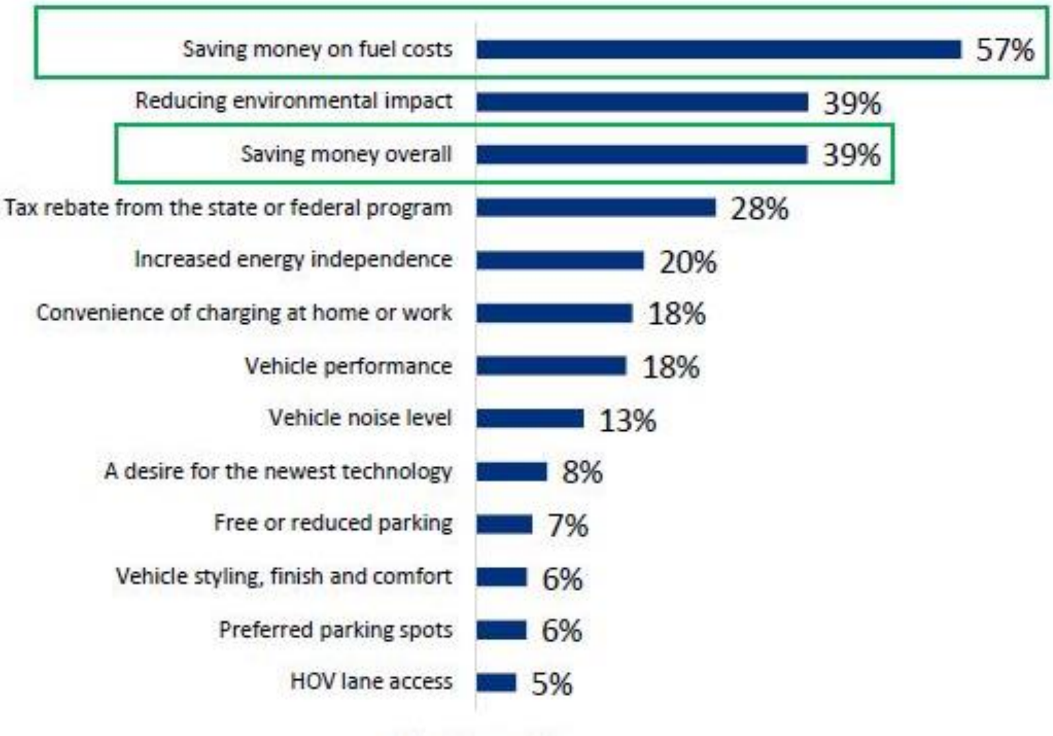


**Fig 2.1: EV pros from consumer survey**

It is possible to maximize the benefits of two separate storage technologies by using a hybrid energy storage device, which combines the advantages of both methods. Combining the advantages of two different types of energy storage devices, hybrid energy storage systems are able to provide the best of both worlds [20]. Several technical, design, and evaluation requirements for hybrid electric energy storage are examined in this study, as well as the ramifications of these requirements.

The Vehicle which is employed with Electric Motor along with charging system is known as Electric Vehicle. The power source for charging EV may be grid or solar PV or batteries. The some of the examples for EVs

- Vehicles running on rails and roads
- Water crafts
- Drones
- Marines

### 2.1.1 Experimentation with EV

At the Los Angeles Auto Show in January 1990, General Motors' President unveiled the "Impact," an electric vehicle concept two-seater. In September of that year, major automakers to begin selling electric vehicles in phases beginning in 1998 for California Air Resources Board ordered. GM built 1117 EV1s between 1996 and 1998, with 800 of them available on three-year lease [25].

- Chrysler, Ford, GM, Honda, and Toyota introduced the Limited numbers of electric vehicles were also built for California drivers. When the EV1 leases expired in 2003, GM discontinued them.
- The effectiveness of the oil and automobile industries' public relations campaigns to discourage people from purchasing electric vehicles.
- A high level of commitment requiring General Motors to fabricate and sustain replacement parts for the few thousand EV1s on the road.

### 2.2.2 Reintroduction of EV

The power consumption for electric vehicles can be considered from both renewable and non-renewable energy resources. So, we can define that the updated EVs are almost different from the past using vehicles [28]. The consumption of power from the fuel energy resources will leads to the environmental threats. So, to overcome this threat the world is moving forward to consume the power from the renewable energy resources which are eco-friendly to earth. So, in the process in the EV required charging facility. For this requires the supercapacitors, batteries and flywheels. The other most important merit of using EV can be regenerative braking which occurs from the kinetic energy which will undergoes some process on the batteries that are on-board [30].

### 2.2.3 Electricity source

The main source for EVs either grid or PV or battery for transferring the power from primary (transmitter) to secondary (receiver). By using mutual inductance principle transfer of power from primary to secondary within the medium of magnetic field. In this WPT system employed air as a medium between primary and secondary. The electricity source in EVs depends upon the availability

**C. C. Mi, Y. Zhang, Z. Yan, T. Kan, Y. Liu, and Y. Zhang,** [15] proposes a research that the construction of WPT system require the accurate modelling and the most frequently used approach is the FHA (First Harmonic Approximation). But the charging of electric vehicle does not obey the above mentioned principle.

**Y. Chen, H. Zhang, S.-J. Park, and D.-H. Kim,** [16] proposes a research work of providing the charging for hybrid architecture of CC/CV/EV with the switching topologies. The topologies like ZPA and CV will occur due to this. So, to overcome this a capacitor is connected for the controlling of the charging mode. But this will lead to attaining the topologies hybrid architecture for switching topologies with the compensation technology for the charging of CC/CV EV. So, this may lead to the weak communication.

**M. Chinthavali, S. L. Campbell, L. E. Seiber, and C. P. White are among the authors,** proposes the research work of the simulating and designing of the WPT based EVs. WPT can be utilized as a retrofitting solution before attaining the applicable standards.

**Moon and G.-W. Moon** presents the research work of asymmetric 4-coil resonant in the topology of WPT. The drawbacks in the conventional symmetric based 4-coil system can be overcome here. The primary side is called as transmitter and secondary side is called as receiver.

**W. Li, H. Zhao, J. Deng, S. Li, and C. C. Mi** presents the research work on the compensation of the 2-sided capacitor-capacitor-inductor and their related configurations. In this the transmitter and receiver coils resume tuning the mismatch. So, that we can overcome the tuning possibility. The voltage and current effects can also be described here.

**M. Pahlevaninezhad, P. Das, J. Drobnik, P. K. Jain, and A. Bakhshai**, suggests the research work of implementing the ZVZCS full bridge chopper over load variations. By implementing the proposed chopper circuit, it is possible to charge the plug-in EV battery. But in this research work the drawback will be the operation of full bridge converter under full load and no load.

# CHAPTER 3

## DESIGNING THE SYSTEM

### 3.1 INTERMEDIATE COIL

The coils must first be designed correctly that will be utilized as receivers and/or transmitters. This must be customized for the intended use. The coils in this case study must be adjustable to be positioned beneath the vehicle body.

Regarding the monitor of these characteristics on the coil, the parameters that must be monitored in order to investigate the coil coupling factor must be clarified. The main goal is to maintain the coefficient of coupling, inductance of mutual and self can be reviewed over here. Considering equivalent layers of ferrite and shielding, the primary and secondary coil shapes influence the distribution magnetic flux, and the link at the inductor side will have the increment of coupling in mutual act [36]. The proposed design technique provides a predictable output voltage and high transfer efficiency. This section takes you step by step through the design process.

**ASSUMPTIONS:**

The designing of the proposed converter can be implemented by using the following assumptions.

1) Dc source, transformers, diodes, switches, and capacitors, and internal switch diodes, are all ideal passive and active devices.

2) The transformer's interwinding capacitance and the inductor's electrical series resistance are neglected.

3) The $C_F$ and ($Ca = Ca_1 = Ca_2$) are the capacitors used to maintain the voltage constant at the output and input side.

4) The $T_A$ also known as magnetizing inductance of auxiliary transformer is not assumed here.

## 3.2 DESIGNING AND PARAMETERS OF THE COMPONENTS

By changing the center of the two coils the position of coils will be placed in the center if there is a higher value in the coefficient of coupling. The coupling coefficient is k and M denotes a mutual inductance with two circuits, and the two elements are said to be magnetically linked. This friction coefficient parameter controls the appropriate inductances at the primary side and secondary side i.e. Lp & Ls. The equation for the mutual inductance can be expressed as in equation 3.4 i.e

$$M = k \sqrt(LpLs) \tag{3.1}$$

Where, k represents the coupling coefficient. The mutual inductance can be varied on the basis of the above expression. In the receiver and transmitter coil the evaluation of magnetic flux can be attained. All of the screens shown for two separate the coil placements; the two coil centers are centralized, clearly parallel and roughly of the magnetic flux. [37] On other hand when the two coils are not centralized there is a variation of magnetic flux. This condition was illustrated with an 80 mm spacing between the two centers. Because we haven't crossed the coil radius too far, contact zone of two coils have get in. This is why a magnetic zone exists between the two coils. The resonance compensation capacitance C is designed next and the following factors influence C:

$$C = \frac{1}{L\omega^2{}_0} \tag{3.2}$$

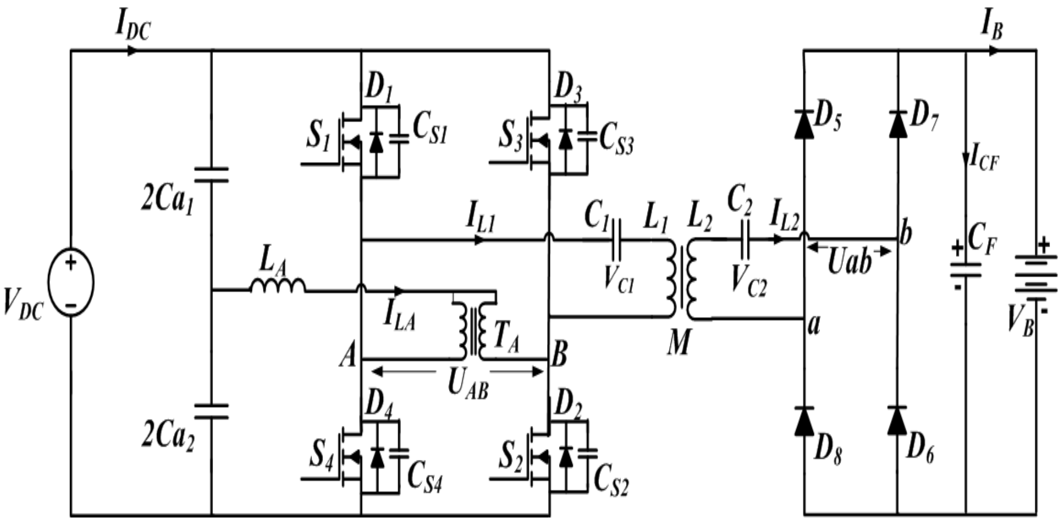


**Fig 3.1: Network Configuration with Single Coil**

**Table 3.1**: **Efficiency and Power transfer with Single and Multiple Receiver coils**.

| | Distance (mm) | Power transfer | Max eff. | $Max_{pow}$ | $Av_{pow}$ |
|---|---|---|---|---|---|
| Single receiver coil | 50<br>100<br>150<br>200 | 3.5kw<br>1.9kw<br>1.1kw<br>0.3kw | 92% | 4.9kw | 2.34kw |
| Multiple receiver coil | 50<br>100<br>150<br>200 | 5.2kw<br>5kw<br>4.9kw<br>3.7kw | 96% | 5.1kw | 3.95kw |

### 3.2.1: Magnetic Field Zones of Two Transmitter and Two Receivers Coils

The created model comprises of two coil transmitters with the same dimensions as the previous model, as well as coil receivers with the same capabilities of the transmitter coil. Two coils receivers is 80 mm have distance between centers.

Furthermore, the mutual magnetic fields are clearly confined between the best value of 1.428 Tesla and the 1.075 tesla is the lowest value. The magnetic yields are in the shape of parallel lines.

The change in the magnetic field does not provide any assurance on the parameters of the coil due to occurrence of the more space between the secondary (receiver) sides. 120mm is the diameter considered in the construction of primary (transmitter) and secondary (receiver) [38-40]. Due to this larger diameter the signals cannot be reached to the secondary. The assumption in the 40mm diameter will leads to the implementation of principle of super position.

In addition to this the Maxwell data is used to calculate the coefficient of coupling. The coupling coefficient of each coil is affected by the position of the transmitter coil. The total for each coil will be multiplied by two. 0.0058 is the higher value for coefficient of coupling is used in the construction. But this cannot be suitable for the one secondary.

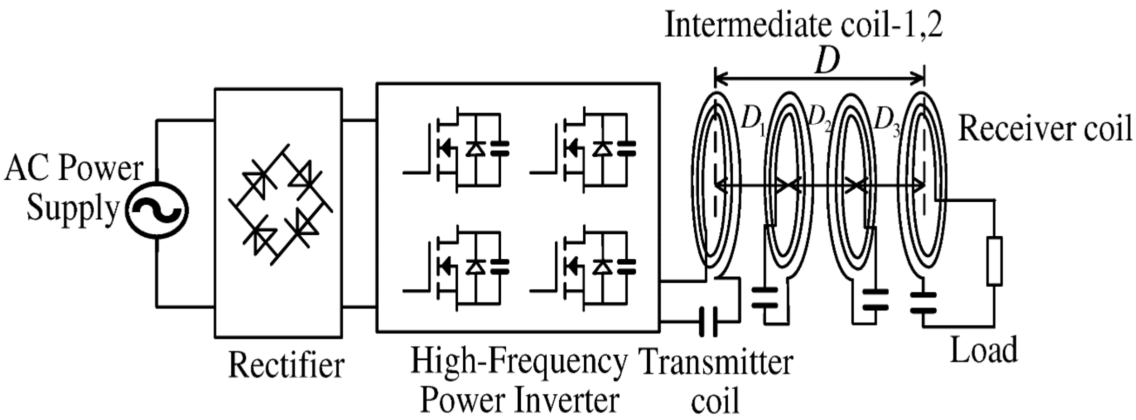


**Fig 3.2: Positioning of Intermediate Coil in WPT system**

Mutual inductance evolution in the situation of a single coil receiver and two coil receivers. Magnetic field from the transmitter when the two coils react to the provide, the total mutual inductance will be larger in proportion to the interpretation of the preceding results. When the middle of the two receiving coils center is in transmitter coil, this is obvious. If the total inductance is equal to 45H, the receiver coil will have 22.5 H of mutual inductance. The results reveal that the WPT's exceptional efficiency remains till 80 mm as a margin of variation when two receiver coils are relocated away from the center [41-45]. When the distance between the two points exceeds 200 mm, the efficiency drops to zero. 100% mutual inductance is ideal when two coil receivers are employed.

This will examine about the maximum power attained by the coil at the receiver side. The evaluated calculations will depict about the 96% of efficiency can be achieved by signifying the 2 coils.

## 3.3 The IPT System

The basic IPT transfer system analyzed in [5, 6] is similar to an IPT system that uses twin coils. It is split into two sections:

The circuit which is primary is connected at the side of transmitter and the circuit which is secondary is connected at the receiver side.

For driving the transmitter an inverter with high frequency is employed at the primary side. The compensating circuit and receiver coil are employed at the secondary side. An AC-DC converter also known as rectifier is placed.

A compensation circuit, which resonates with the inductor (transfer coil) and determines the IPT's resonant frequency, is a crucial aspect of the circuit. The compensation circuit normally includes a parallel (P) or series (S) capacitor connected to the coil, thus the capacitors $C_{Ti}$ and $C_{Ri}$ i = (1, 2) are added. Because a constant operating frequency was required, series–series compensation (SS) was adopted.

## 3.4 Constant Coil Parameters Definition

For attaining the balancing coordination between the coil, the below properties are assumed and the dependency is also taken to the great extent. They are as follows:

1. The space given at the bottom the EVs is the one of the most essential parameter to choose. For a standard sedan EV, a realistic space is around 480,000 $mm^2$ secondary coil occupied, whereas the outer charging pad dimensions must be greater to provide adequate shielding, according to [46]. Furthermore, as mentioned in [47], the diameter of the coils which are in rectangular shape, the vertical spacing should be 3-times. the diameter value of 200 mm is considered for the V2G system, hence the outside coil diameter is 600 mm. As a result, the coil diameters are chosen to be 800 and 600 $mm^2$ of 480,000 $mm^2$ for a total coil area.

2. For the eradication of the eddy currents produced in the system the stranded copper wires are implemented in this work.

3. Layers of ferrite and shielding: The enclosed space between the 2 coils is considered in the depth of the aluminium shield.

Aluminium shield = 2 * skin depth of aluminium alloy, is surrounded with the inductive connection to reduce 70% in intensity of the field.

## 3.5 Identification of Design Variables

### 3.5.1 Auxiliary Inductor

At the time of giving pulses to the MOSFET switch the inductor which is auxiliary will behave as a current source i.e. continuous and the value of the auxiliary inductance is then computed as:

$$L_a = \frac{D(1-D)t_d}{32Cf_s} = 17.7\ \mu H \tag{3.3}$$

### 3.5.2 Auxiliary Capacitors

To provide the constant voltage source into the capacitors $C_1$ and $C_2$ will behave as the passive elements and provides the sufficient energy in the switching period. The smallest capacitance mandatory to allow a voltage ripple is calculated as:

$$C_{a1} \geq C_{a2} \geq \frac{V_{in}}{256 L_a f_s^2 \Delta V_{ca}} \geq 3.65\mu F \tag{3.4}$$

### 3.5.3 Output Filter Capacitance

The ripples occurred in the output voltage can be rectified by using the filter named capacitor. The below expression is implemented for designing the capacitor.

$$C_f \geq \frac{I_o}{8 f_s \Delta V_{ca}} \geq 1.34\mu F \tag{3.5}$$

In this work, filter capacitance with a value of 2 µF is considered.

## Table 3.2: List of Parameters

| Parameters | Values |
|---|---|
| Frequency switching | 85 kHz |
| Link capacitor (DC) | 47 µF |
| Auxiliary Inductor | 17.7 µF |
| Ratio of auxiliary transformers | 1:1 |
| Nominal Power | 550 VA |
| Nominal Voltage | 325 V |
| Nominal inductance due to leakage | 0.4 µH |
| Magneto-static resistance | 20 k ohm |
| Magneto-static inductance | 8 m H |
| Inductance of primary coil | 232 µH |
| Inductance of secondary coil | 232 µH |
| Coupling coefficient | 0.16 |
| Mutual inductance | 37.2 µH |
| Primary side capacitor compensation | 15.8 µF |
| Secondary side capacitor compensation | 15.6 µF |
| Primary side series resistance | 0.2 ohm |
| Secondary side series resistance | 0.2 ohm |
| Capacitance of Switch peracetic | 870 pF |
| Resistance of switch ON | 270 m ohm |
| Resistance of Diode at on state | 80 m ohm |
| Capacitance of filter | 2 µF |

| | |
|---|---|
| Voltage of the Battery | 120 V |
| Resistance of Load | 19 ohm |
| Duty cycle of $S_1$ & $S_3$ switches | 45.5% |
| Duty cycle of $S_2$ & $S_4$ switches | 48.5% |

## 3.6 AC TO DC CONVERTERS (PHASE CONTROLLED RECTIFIERS)

Constant ac voltage is converted to changeable dc output voltage in these circuits. For commutation, these rectifiers need line voltage. These are utilized in synchronous machines, dc drives, and chemical industries. 1-∅ and 3-∅ sources can both be used to feed phase- controlled converters.

## 3.7 DC TO AC CONVERTERS (INVERTER)

The conversion of AC power into the DC power is known to be inversion process and the device is known as inverter. There are mainly two types of inverter topologies are existed. They are VSI and CSI. If the controlled output is a voltage waveform, then it is known to be Voltage source inverter [48][49]. Similarly, the controller AC output is a current waveform then it is known as current source inverter. There are many applications like UPS, FACTS etc. that comes under the inverter topology. The VSIs can be applicable for both 1-∅ and 3-∅ applications and the CSIs are only applicable for three phase applications.

## 3.8 BATTERIES

To supply the power to the loads in the absence of main supply, a battery is used. In this the combination one more electrochemical cells are formed to provide the power. The anode is the negative terminal in terms of electrical power supply, and the cathode is the positive terminal. For one external electrical circuit, the electron is placed in the negative terminal and moved to the positive terminal. The term "battery" used to refer to a multi-cell device, but it has now been broadened to include single-cell devices.

This lithium-ion battery definition is applicable to all batteries. Additional examples of lead-acid and nickel-cadmium (Ni-Cad). In the EVs the battery is utilized for charging through the process of electric traction [51,52]. Some other applications like electrical based bikes, drones, space crafts are equipped with this type of traction batteries.

### 3.8.1 Lithium-Ion Battery

The Li-Ion Battery is similar to the normal battery. It consists of the current collector with aluminium coated and the negative collector is coated with carbon. Salt product of Lithium ion is used an electrolyte. Totally this process is related to electrolysis.

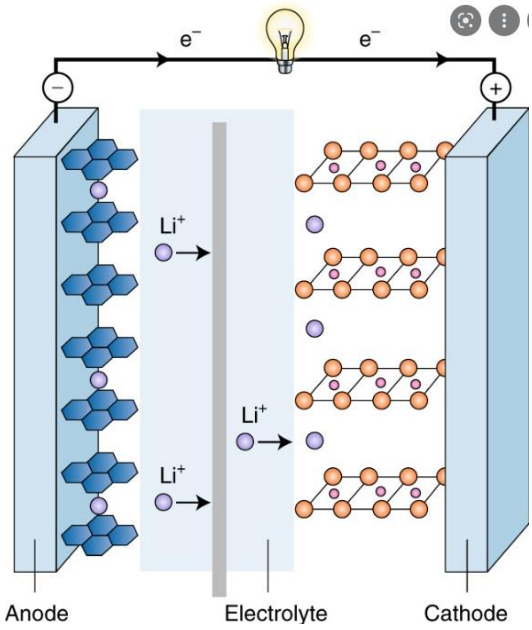


**Fig 3.3: Li-ion Battery**

The passage of lithium ions from anode to cathode will be evaluated by using electrolytic process. If the battery gets discharged then the electric current is produced. The charging of the battery can take place if the passage of lithium ion is considered from cathode to anode.

### 3.8.2 Li-Ion Battery in Electric Vehicles

Major reforms of lithium-ion chemistry are being used in subsequent electric vehicles to provide fire resistance, environmental friendliness, rapid charging (as little as a few minutes), and longer lifespans. These types of batteries (phosphates, titanates, and so on) have much longer lifespans, with A123 lithium iron phosphate batteries expected to last at least 10 years and 7000 charge/discharge cycles and LG Chem lithium-manganese spinel batteries expected will last up to four decades.

According to scientific research, heat and fast charging accelerate the degradation of Li-ion batteries faster than age and actual use, with the average electric vehicle battery retaining 90% of its initial capacity after 6 years and 6 months of operation. As per Tesla, the cooling of the battery will degraded by Nissan Leaf.

### 3.8.3 Advantages of Li-Ion Battery

- **Low self-discharge rate:** It has very less self-discharging rate than other type of batteries.
- **Low maintenance**: It does not require any type of maintenance by the user.
- **Cell voltage:** About 3.6 of Volts can be produced by each lithium- ion.
- **Load characteristics**: It has the adequate characteristics of load until the depletion of last charge in the process.
- **No priming required**: It does not require any priming. Once the battery is charged then it is ready to implement.
  The availability of li-ion batteries can be in different shapes and sizes. So, they can be used for any type of applications and it produces the higher currents in the system.

## 3.9 COMPENSATION

On primary side and secondary side compensated capacitors are required due to operating frequencies are becoming lower than the frequencies which are self-resonant in the WPT [27]. As mentioned in [19, 31] the existing circuits are implemented with correction of single sided. So, to satisfy all the WPT systems the doubly sided compensation is replaced in the place of single sided compensation.

There are four basic types of compensation techniques which is shown in Fig 3.4 below:

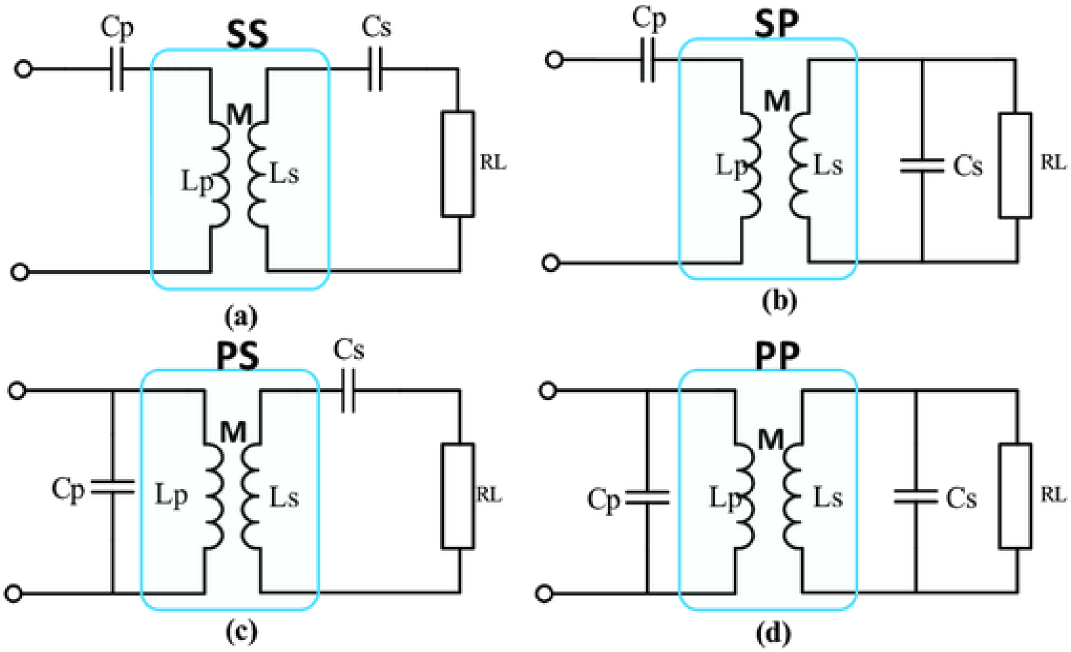


**Fig 3.4: Types of compensations; (a) Series-Series (b) Series-Parallel**

**(c) Parallel-Series (d) Parallel-Parallel**

## 3.10 BASIC POWER MOSFETs

A power MOSFET is a type of MOSFET that can handle a large amount of current. At low voltage condition this type of switch can outer perform the rate of fast switching than the existing MOSFETs. The channels like n and p-channel enhancement and n and p channel depletion mode will have the usage of Power MOSFETs.

Different types of MOSFETS are existed in the power electronic topology. They are VDMOS (Vertical Diffused MOS), DMOS (Double-Diffused MOS) and other. The above figure 3.7 provides the clear representation of the VDMOS.

The p-type region is formed by obtaining the G2S voltage positive. Where G denoted the gate terminal and D denotes the drain and S denotes the source. As more than just an outcome, current in VDMOS flows vertically from underneath the gate region via multiple n+ parallel sources between the source and drain terminals. Standard MOSFETs and power MOSFETs have different architectures, but the fundamental principle that governs their operation is the same. That is, the conduction channel in each of them is constructed in the same manner, which is nothing more than applying an appropriate bias at the gate terminal to deliver an insulating layer.

As a consequence, they have nearly identical transfer and output properties. Furthermore, the doping and thickness of the epitaxial layer determine the voltage rating of vertically constructed power MOSFETs, whereas the channel width determines the current rating. As a result, they can withstand high blocking voltage and current, making them suitable for low-power switching applications.

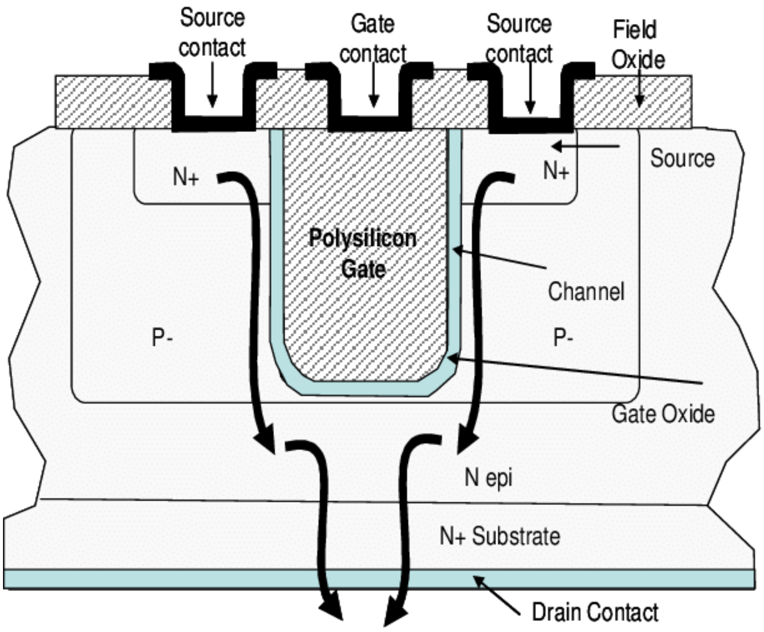


**Fig 3.5: Schematic of Power MOSFET**

Besides this, lateral-structure MOSFETs outperform vertical-structure MOSFETs in saturated working areas and can thus be used in high-end audio amplifiers. Because their forward voltage loss increases with temperature, power MOSFETs can also be paralleled, resulting in equal current distribution across all of their components. Power MOSFETs are widely used in power supplies, DC-DC converters, and motor controllers with low voltage.

# CHAPTER 4

## OPERATING PRINCIPLE OF THE PROPOSED TOPOLOGY

### 4.1 INTRODUCTION

$S_1$ to $S_4$ active switches on the main side and diodes $D_5$ to $D_8$ on the secondary side make up an H-bridge (conventional). $Ca_1$ and $Ca_2$ also serve at the input as a potential divider, with auxiliary $T_A$ and $L_A$ keeping for circuit soft-switching with BC. $L_1$ and $L_2$ are linked to $C_1$ and $C_2$, respectively on the primary and secondary sides of the circuit.

The following assumptions are considered in order to appreciate the recommended converter's functioning principle.

1. All passive devices and active devices, including dc sources, transformers, diodes, switches, and capacitors, are ideal, including capacitance and internal switch diodes.
2. The transformer's intertwining capacitance and the inductor's electrical series resistance are neglected.
3. The $C_F$ and ($Ca = Ca_1 = Ca_2$) voltage divider capacitors are large enough to maintain a constant voltage at the input terminal and output terminals of the converter.
4. The magnetizing inductance of $T_A$ is not considered.

### 4.2 OPERATION OF PROPOSED CONVERTER

There are eight modes of operation in the proposed system in the paper explained with in the chapter. The operating modes will be mention by (I to VIII)

1) Mode I ($t_0 <.t < t_1$), the time is $t_0$ and the current going for ($I_{L1}+I_{L2}$) and it is based on $D_1$ and $S_2$. After that the $S_1$ is turned on in ZVS mode control so, the difference in potential between AC and CB is created and current is according to the following equation,

$$i_{L_a} = \frac{|V_{ca1} - V_{ca2}|}{2L_A} T_{ON} - i_{L_A(t_0)} \qquad if \rightarrow R_{ON(s_1 - s_2)} \neq 0$$

$$|V_{ca1} - V_{ca2}| = 0 || I_{L_A} = 0 \qquad if \rightarrow R_{ON(s_1 - s_2)} = 0 \qquad (1)$$

2) Mode II ($t_1 < t < t_2$): Switch $S_1$ is active prior to $t_0$, and the switch current difference ($I_{S1}$-$I_{S2}$) is flowing from $T_A$ ($I_{TA1}+I_{TA2}=I_{LA}$)
Using minimal conservation and using KCL at location A and B

$$i_{C_{S1}} + i_{C_{S4}} = i_{T_{A2}} + i_{L_1} \quad (2)$$

$$2i_{C_{S1}} = i_{L_1} + \frac{i_{L_A}}{2} \quad (3)$$

When $S_3$, $S_4$, and $S_2$ are already off, and $S_2$ is still conducting at the start of this mode, $S_1$ is turned off. The dc power source has been unplugged from the dominant inductance $L_1$, and ($I_{L1}$ + $I_{LA2}$) the switch peracetic capacitor $C_{S1}$ has started charging. On the time $t_{11}$, $V_{CS1}$ reaches $V_{DC}$. After $t_{11}$, $I_{L1}$ finds a route by generating an $I_{LA}$ change. This change, and a current flows on ($S_2$ to $S_4$) for the inductor $L_A$ rejected, discharging $C_{S4}$. When the $C_{S4}$ voltage approaches zero, $D_4$ activates, causing $I_{S2}$ to decrement to zero for switch $S_2$.

$$t_{\left(V_{C_{S1}}=V_{DC}\right)} = \frac{\frac{1}{2}C_{S3}V_{DC}-\left(i_{L_{1(t_{1-})}}+\frac{i_{L_{A(t_{1-})}}}{2}\right)}{i_{L_{1(t)}}+\frac{i_{L_{A(T)}}}{2}} \quad (4)$$

3) Mode III ($t_2< t< t_3$): In this mode, $S_2$ ZCS switch is turned off first, followed by all other switches. After reaching its positive peak, the peracetic capacitor $C_{S2}$ proceeds to charge until $t_{21}$, when it reaches $V_{DC}$, and the current $I_{LA}$ begins to decrement toward zero. Following $t_{21}$, the current $I_{L1}$ + $I_{LA2}$ makes its way to the diodes $D_2$, $D_4$ by discharging capacitors $C_{S3}$, $C_{S4}$.

$$t_1 > 2C_{S1}\frac{V_{DC}}{i_{L_{1(t_0)}}+\frac{i_{L_{A}(t_0)}}{2}} \quad (5)$$

To calculate the voltage stress across the switch, it is as follows:

$$v_{S1} = V_{DC} + v_{C1} \quad (6)$$

$$v_{S4} = -v_{C1} \quad (7)$$

4) Mode IV ($t_3 < t < t_4$): In this mode, $S_4$ is turned on at the same time as $D_4$ and ZVS, and the voltage across $S_4$ is virtually zero after reaching a negative peak in the auxiliary inductor current, $I_{LA}$ rises linearly in a positive direction.

5) Mode V ($t_4 < t < t_5$): mode V explained for ZVS condition the $S_3$ is enabled. a sinusoidal wave pattern once its journey is completed for $I_{AB}$ begins to follow, $S_3$, $S_4$ is zero for the voltage across the condition.

6) Mode VI ($t_5 < t <$ t6): In this mode, causing $C_{S3}$ to charge to $V_{DC}$ at $t_{51}$ for, $S_3$ is disabled.

After reaching its peak, the auxiliary inductor current $I_{LA}$ decreases, causing $I_{S4}$ to fall for the ZCS turn-off condition. Power is returned to the source once the switch is turned on.

7) Mode VIII ($t_7 < t < t_8$) In this mode of operation, ZVS turns on switch $S_2$, and current moves from $D_2$ to $S_2$.

The battery maintains a constant voltage and current in modes I through VIII.

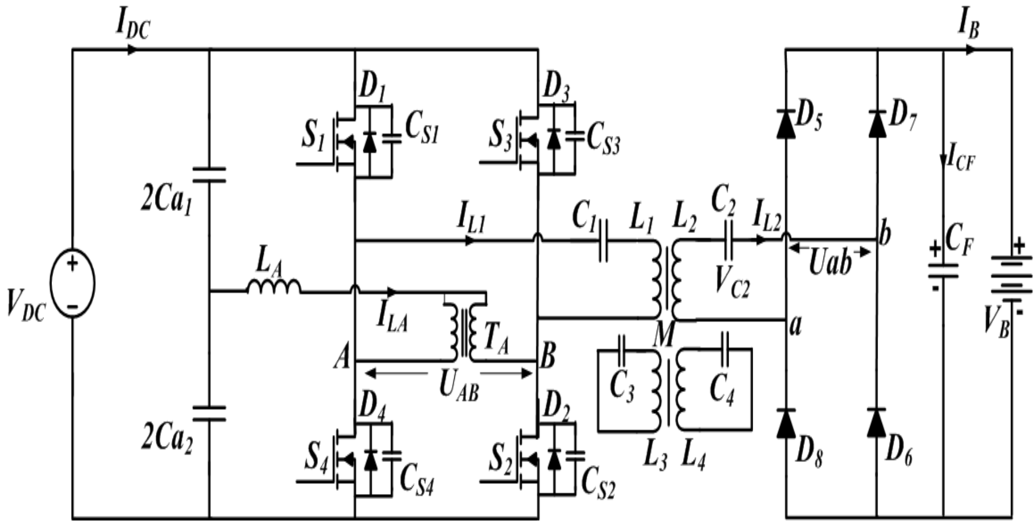


**Fig 4.1: EV battery charger Proposed network configuration**

## 4.3 ANCILLARY NETWORK WORKING

The resonant transmitter coil and auxiliary networks are shown in Figure 4.2. When KVL is applied to $L_A$, the voltage across $L_A$ is as follows:

$$Vc_{a1} = Vc_{a2} = \frac{V_{DC}}{2} \tag{8}$$

$$v_{OC} = v_{L_A} = \frac{V_{DC}}{2} - v_{CD} - v_B = \frac{V_{DC}}{2} - \left(v_A - \frac{V_{DC}}{2}\right) - v_B = V_{DC} - v_A - v_B \tag{9}$$

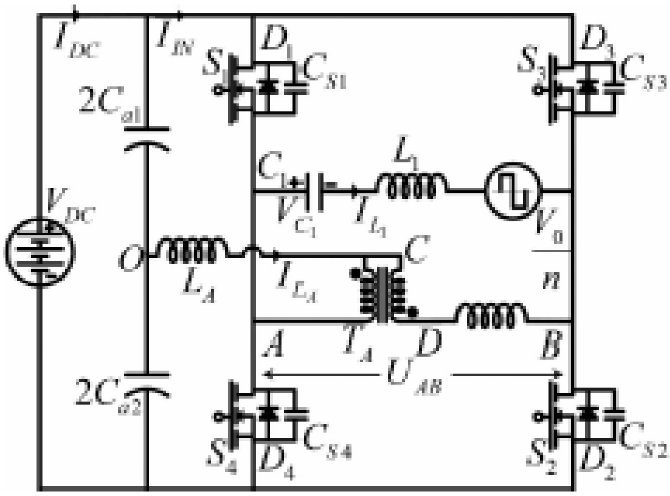


**Fig 4.2: Battery load referred to transmitter coil side of Simplified network**

The waveform of $V_{OC} = V_{LA}$, which is complimentary to $V_{AB}$, is seen in the expression (9). This means that the current in $L_A$ is light for strong loading, and it will be high for the weak loading condition. $V_{LA} = 0$, $V_{AB} = V_{DC}$ or $V_{DC}$ and $V_{Ca1} = V_{Ca2} = V_{DC}$ have the same voltages. As a result, the current of inductor $L_A$ remains constant. When $V_{Ca1} = V_{Ca2}$ and either $S_1$ $S_2$ or $S_3$ $S_4$ are in the ON state, $I_{LA}$ has value according to equation (10).

$$i_{L_A} = i_{T_{A1}} + i_{T_{A2}}$$

$$i_{T_{A1}} = i_{T_{A2}}$$

$$i_{T_{A1}} = i_{T_{A2}} = \frac{1}{2} i_{L_A} \tag{10}$$

Figure 4.2 and equation (11) explain how to compute the magnitude of $I_{LA}$ using KVL.

$$I_{L_A} = \frac{1}{4}\frac{V_{DC}}{L_A}(T - T_{ON}) + \frac{1}{2}\frac{|Vc_{a1} - Vc_{a2}|}{L_A}(T_D)\frac{T}{2} \quad (11)$$

$$I_{L_A\,max} = 2I_{L_A}(1 - T_D) \quad (12)$$

$$T_D = \frac{T}{2} - T_{ON} \quad (13)$$

$$T_{ON} = t_1 - t_0 = t_6 - t_5 \quad (14)$$

## 4.4 PARAMETER DESIGN

### 4.4.1 Switch Rating

Transient Analysis: The current at the start of the converter was determined while the switch was active for positive half-cycle of transmission coil current. Calculating $W_0$ and the switch's ON-time $T_{ON}$ using KVL in a simplified network, we get

$$L_1 \frac{di_{L_1}(t)}{dt} + R_1 i_{L_1}(t) + \frac{1}{C_1}\int_0^t i_{L_1}(t).dt = u_{AB}(t) \quad (15)$$

As after solving and simplifying (15) the output current waveform is provided.

$$i_{L_1}(t) = e^{at}[C_1\cos(at) + C_2\cot(bt)] \quad (16)$$

Where, $a = \left(-\frac{R_1}{2L_1}\right), b = \sqrt{(a)^2} - \frac{1}{L_1C_1}$ $and C_1\ and\ C_2$ may be derived from the network's initial conditions are constants. The second method for solving (9) is to use the Laplace transform in the frequency domain.

$$K_1 = 1 - \frac{2e^a\sqrt{L_1}}{\sqrt{4L_1 - R_1^2C_1}}, K_2 = \frac{\sqrt{4L_1 - R_1L_1C_1}}{2L_1\sqrt{C_1}}, K = \frac{1}{R}\frac{\sqrt{4L_1 - R_1^2C_1}}{\sqrt{C_1}}$$

$$i_{L_1}(t) = K_1\sin(K_2(t) + \tan^{-1}(K_3)) \quad (17)$$

Eq. 1 is used to compute the first zero crossing ($T_Z$) and current peak in the circuit (4). In the recommended technic, Taking $T_{ON}$ less than $T_Z$ results in successful ZCS.

Stability Analysis: On applying the Fourier analysis are shown in Fig 4.1, we have

$$U_{AB(n)} = \frac{4V_{DC}}{N\pi}\cos(n\alpha) \tag{18}$$

$$I_{AB(n)} = \frac{1}{Z_n}U_{AB} \tag{19}$$

$$Z_n = \sqrt{K^4R_B^2 + \left(nw(L_1 + K^2L_2) - (\frac{C_1C_2}{nw(K^2C_1+C_2)})\right)} \tag{20}$$

$$\varphi_n = \tan^{-1}\frac{nw(L_1+K^2L_2-\frac{C_1C_2}{nw(K^2C_1+C_2)}}{K^2R_B} \tag{21}$$

$$R_B = \frac{V_B}{I_B} \tag{22}$$

The resonant frequency and quality factor of the recommended transmitter coil network are both high. As a result, the basic component is extremely large, and the dominant current is generated. Equations (18) and (19) can be used to calculate the fundamental component. The following is the maximum current flowing via $L_1$ and the switches ($S_1$–$S_4$):

$$I_{AB(01)} = \frac{4V_{DC}}{Z_{01}\pi}\cos\alpha \tag{24}$$

$$I_{AB(01)max} = \sqrt{2}I_{AB(01)} \tag{25}$$

$$I_{S1-S4(\max)} = I_{AB(01)max} + I_{L_A max} \tag{26}$$

The current second balance and the following expression are used to compute $C_1$'s voltage rating:

$$V_{C_1} = \frac{4V_{DC}}{C_1 Z_{01}} \cos(\alpha) \quad (27)$$

Where, $\alpha = \pi(1 - 2\frac{T_{ON}}{T})$

Alternatively, the following formula can be used to establish the switch's rating:

$$V_{ds} > V_s + k(V_B + V_D) \quad (28)$$

$$V_{ds} > 140+19135+1.4 \quad (29)$$

$$V_{ds} > 279.4\text{V} \quad (30)$$

Most MOSFETs can in non-repetitive scenario withstand three times their average current rating. As result, to obtain conservative current rating, the following relations is used:

$$I_D > 3XI_{S,avg} \quad (31)$$

$$I_D > 3X6 \quad (32)$$

$$I_D > 18A \quad (33)$$

As result, the current and voltage ratings for power switch chosen must be more than 276.4 V and 18 A. As result, the current and voltage ratings for power switch higher than 276.4 V and 18 A is chosen. Hence, accordingly the switch was chosen for this converter due to its 500 V and 20 A rating.

### 4.4.2 Auxiliary Components

The values of the auxiliary capacitors are chosen to maintain a constant voltage at the converter's input. The auxiliary inductor serves as a constant current source during peak and dead time periods. The current required to produce ZCS is supplied by a transformer with an auxiliary inductor. The auxiliary transformer prevents $U_{AB}$ from changing abruptly and allows current to flow back to inductor $L_1$. The transformer has a 1:1 voltage ratio and the lowest possible leakage inductance and series resistance. Figure 4.3 depicts the estimation of auxiliary components in a simplified circuit [21, 22]. We have utilized KVL in the network shown in Figure 4.2.

$$\frac{\Delta iC_a}{C_a}\Delta t - L_a\frac{\Delta IC_a}{\Delta t} - M\frac{\Delta IC_a}{\Delta t} = 0 \tag{34}$$

$$M\frac{\Delta iC_a}{\Delta t} + M\frac{\Delta Ic_s - \Delta ic_a}{\Delta t} - \frac{\Delta Ic}{C_s}\Delta t = 0 \tag{35}$$

t and Ca = $Ca_1$ = $Ca_2$ are determined using equations (34) and (35), where t is the time when the diode of a switch is turned on, and Ca = $Ca_1$ = $Ca_2$. Ton + t is the total turn-on time for a switch in half-cycle. ZVS for all four switches and ZCS for two switches in half-cycle are provided by these defined settings. Table II lists the parameters that were used in the simulation.

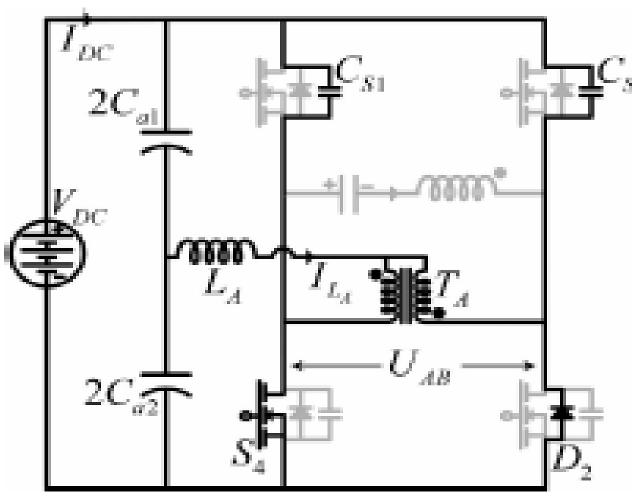

**Fig 4.3: Determining auxiliary component parameter in a simplified circuit**

## 4.5 AUXILIARY NETWORK LOSS CALCULATION

The following equation describes the auxiliary network's Cu loss:

$$P_{cu} = I^2 R \tag{36}$$

$I_{LA}$ and $I_{TA}$ represent auxiliary inductor and transformer currents, respectively. In the worst-case scenario, cu losses are calculated using $I_{LA}$= 2 A, $R_{LA}$=170 m ohm, $I_{TA}$ =2 A, and $R_{TA}$ =330 m ohm [24].

As a consequence, the auxiliary inductor has a Cu loss of 680 m W and the transformer has a Cu loss of 1.32 W. While the converter is operating at constant frequency, the following calculation is used to calculate core losses per unit volume for the transformer and inductor:

$$P_{core} = aB_{pk}^{b}V \tag{37}$$

For a Sendust Core, a is 0.043, b is 1.5, and $B_{pk}$ is approximately 1 T. The transformer core volume is 1164 $mm^2$ and the inductor core volume is 430 $mm^3$ . The calculated power loss for $L_A$ and $T_A$ using equation (37) and from [25], [26] is 18.49 and 50.05 m W, respectively.

# CHAPTER 5

## SIMULATIONS AND RESULT

### 5.1 Simulation Model with Single Coil at Transmitter and Receiver side

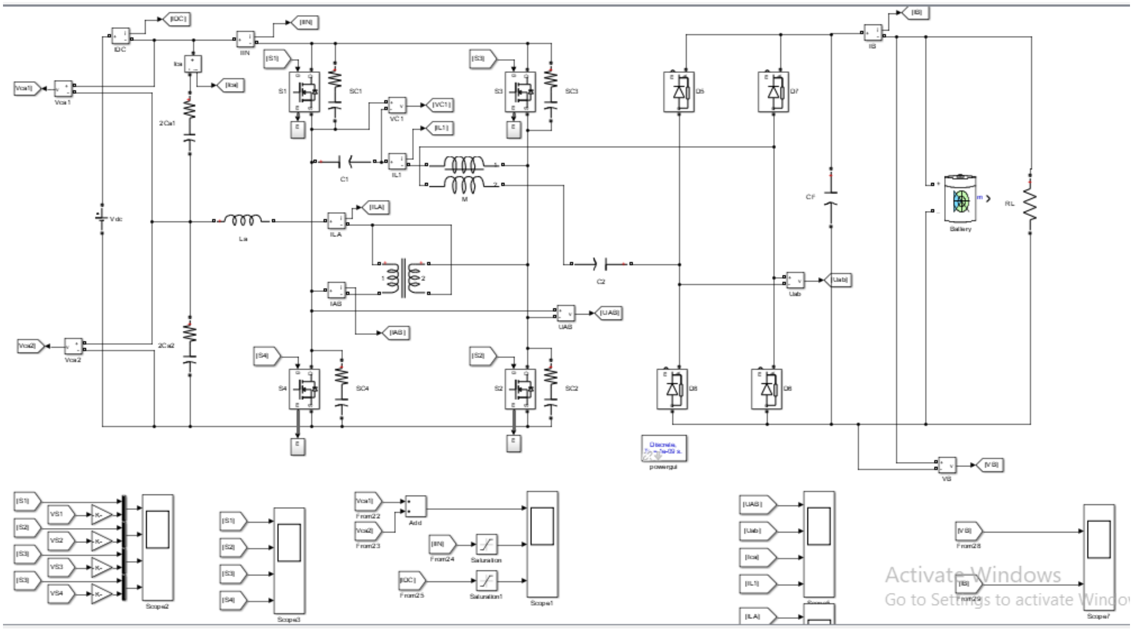

**Fig 5.1: Simulation Model with Auxiliary Circuit**

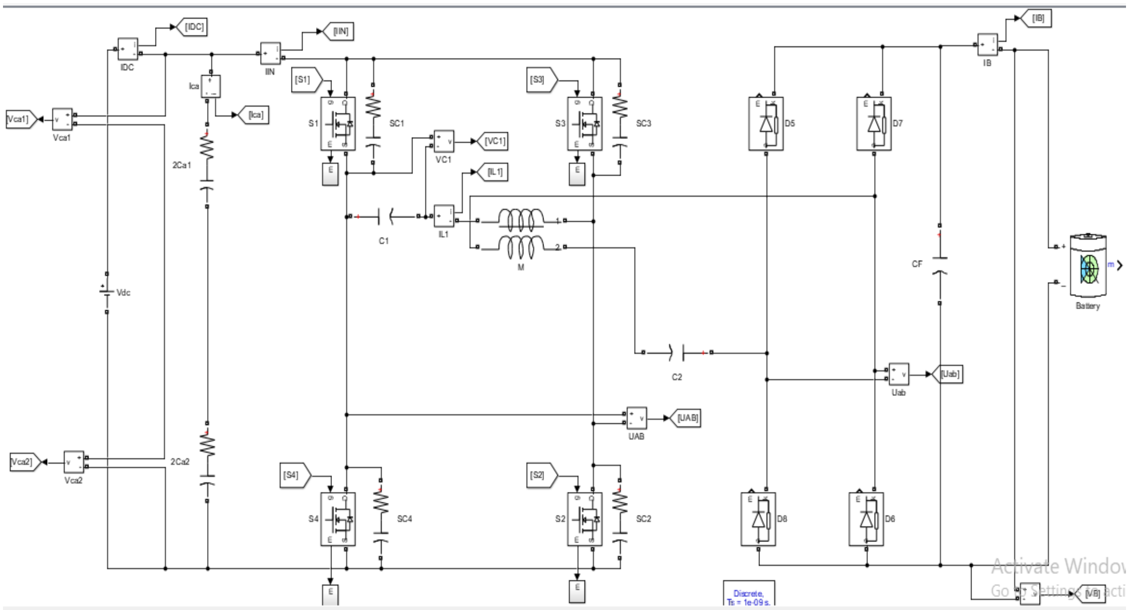

**Fig 5.2: Simulation Model without Auxiliary Circuit**

### 5.1.1 Pulse Input Waveform

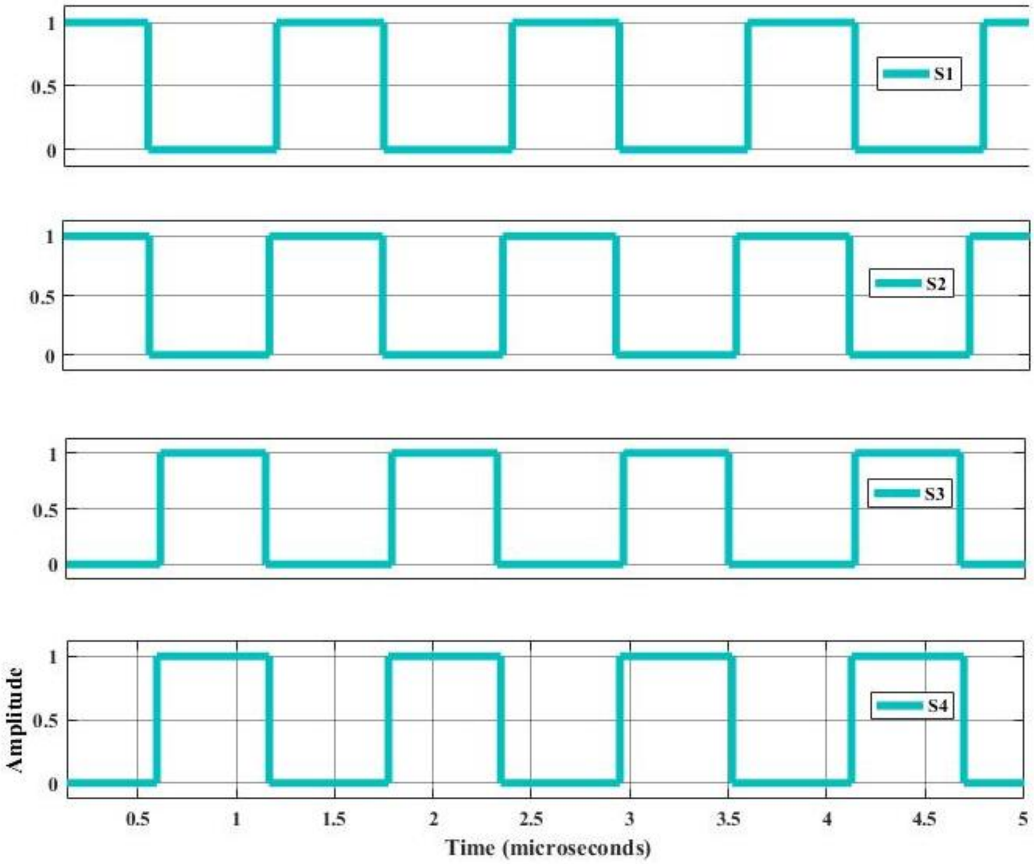


**Fig 5.3: Pulse Inputs for all 4 Switches**

## 5.1.2 Battery Voltage and Current with Single Coil Waveform:

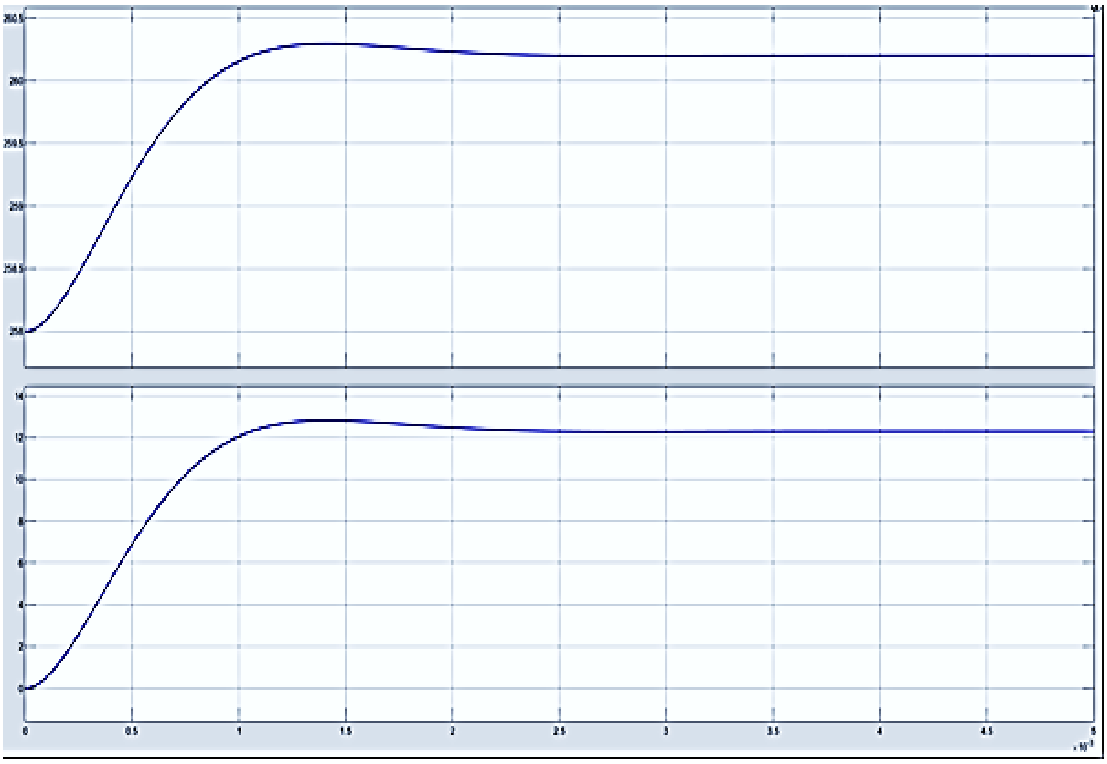

**Fig 5.4: VB and IB with Auxiliary Circuit**

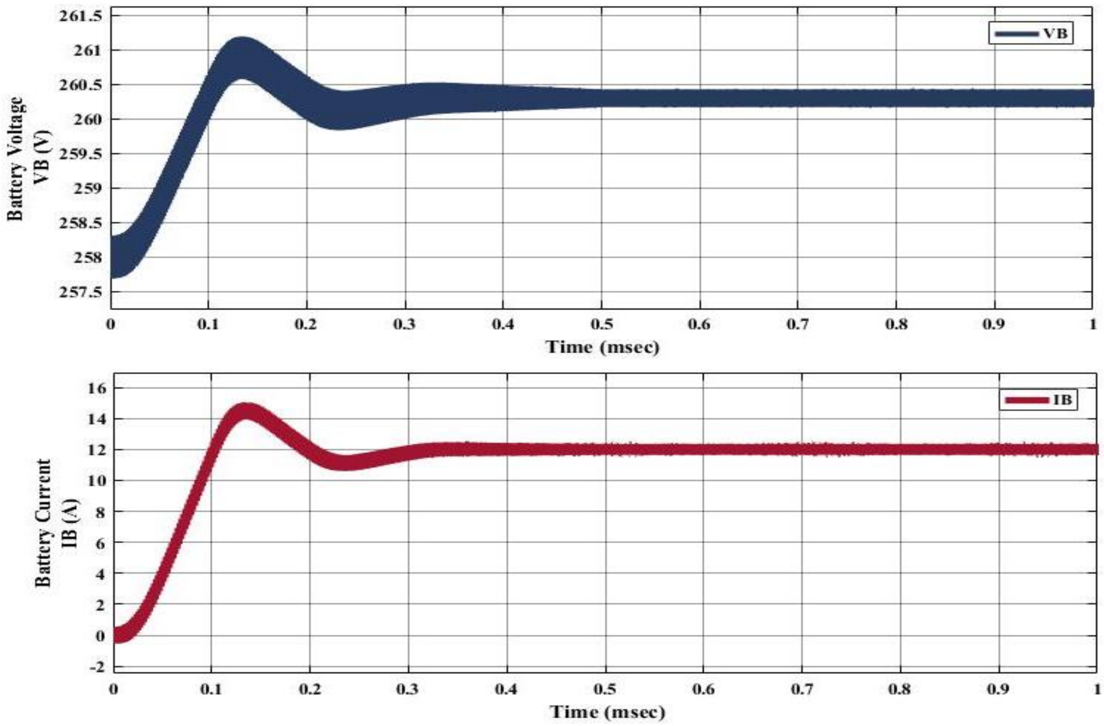


**Fig 5.5: VB and IB without Auxiliary Circuit**

## 5.2 Simulation Model with Two pair of Coils at Transmitter and Receiver side

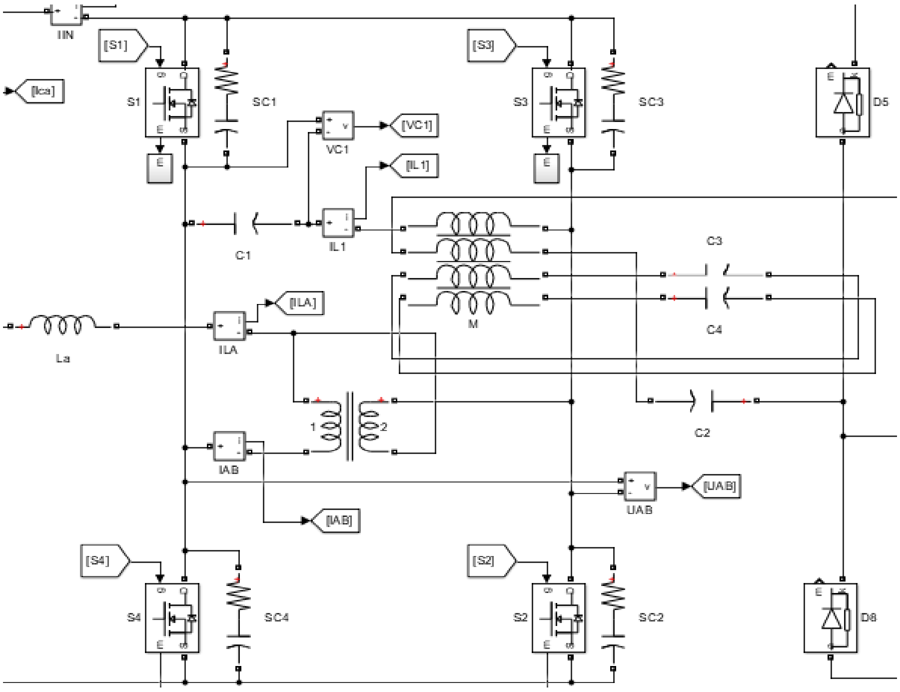


**Fig 5.6: Proposed Simulation Model with Auxiliary Circuit**

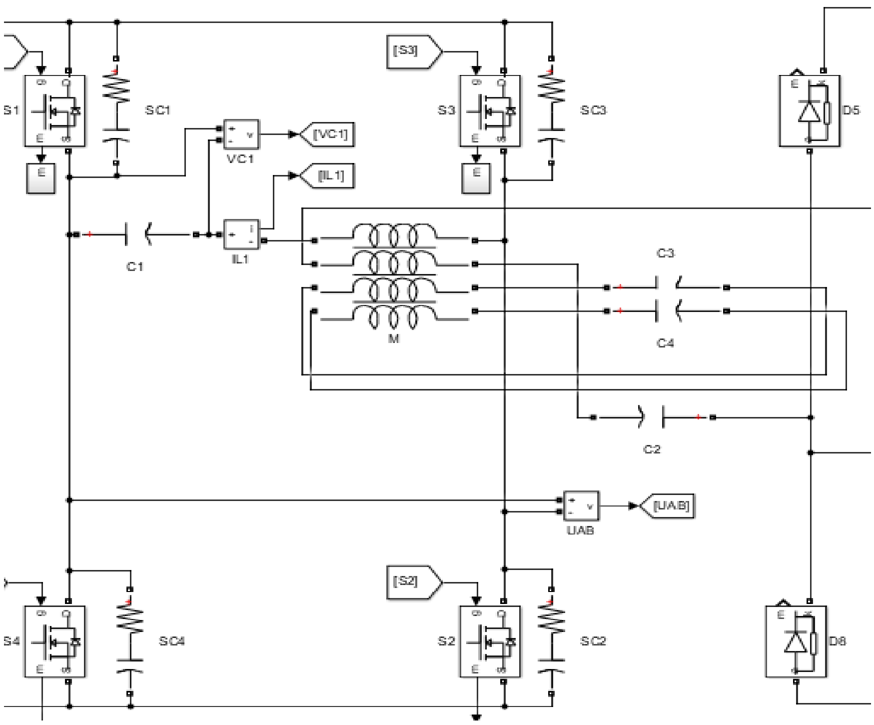


**Fig 5.7: Proposed Simulation Model without Auxiliary Circuit**

## 5.2.1 Battery Voltage and Current with Two pair of Coils:

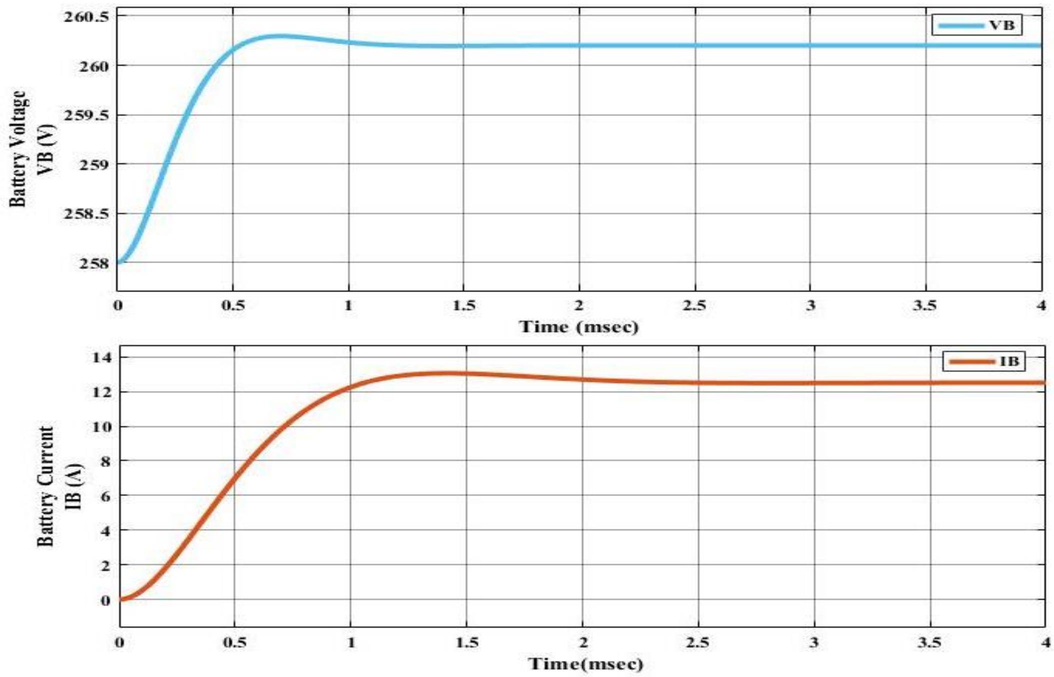


**Fig 5.8: VB and IB of the proposed topology with Auxiliary Circuit**

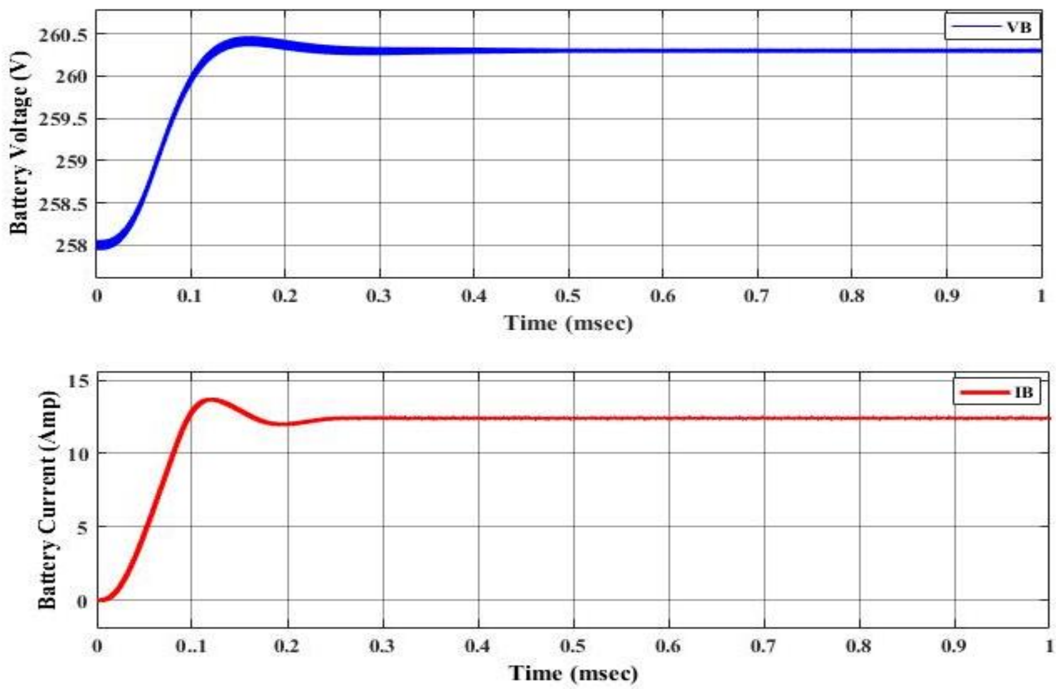


**Fig 5.9: VB and IB of the proposed topology without Auxiliary Circuit**

## 5.2.2 Zero Voltage Switching Waveform:

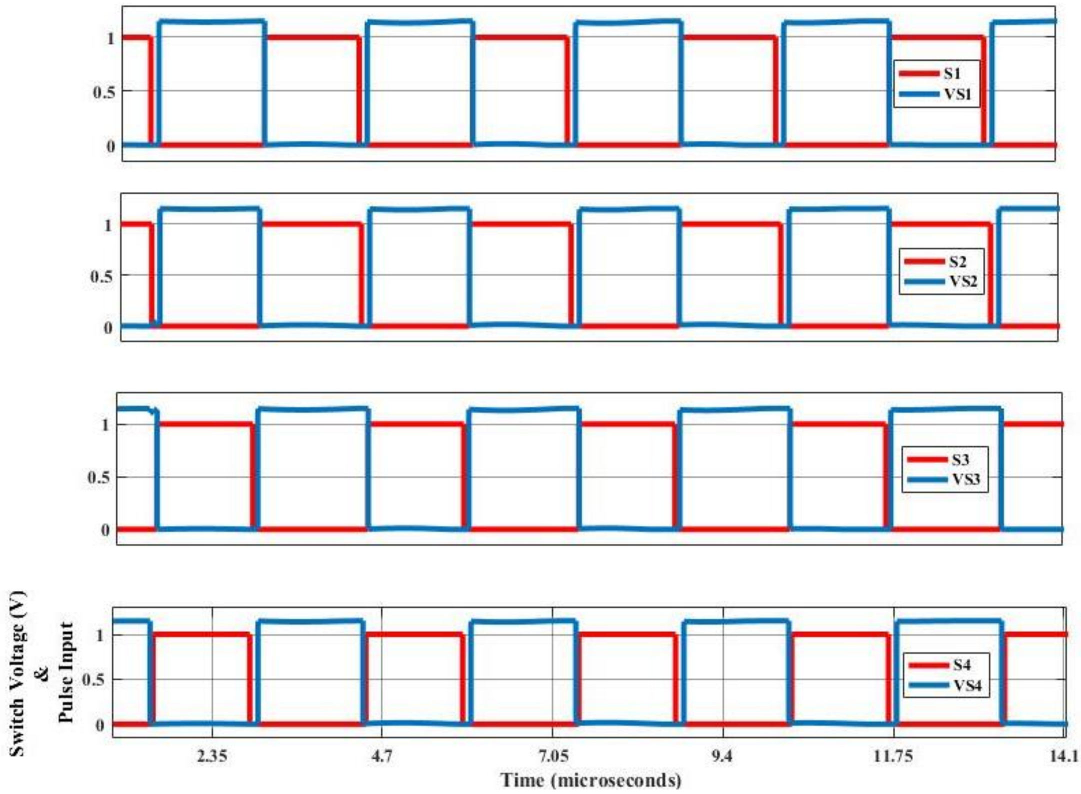


**Fig 5.10: ZVS for all the 4 switches**

Simulation is performed in MATLAB 2016a and the results for the implementation are presented in this section for the existing and proposed work. Fig. 5.4 and Fig. 5.5 shows the battery voltage and current with and without using auxiliary circuit of the existing topology with single transmitter and receiver coil which are compared with the battery voltage and current with and without using auxiliary circuit of the proposed topology shown in Fig. 5.8 and Fig. 5.9 respectively.

As seen from Fig. 5.8 and Fig. 5.9, the settling time has been improved and there is much less distortions in the battery voltage and current of the proposed topology when compared with the battery voltage and current of the existing topology using only single coil transmitter and receiver as shown in Fig. 5.4 and Fig. 5.5. ZVS turn ON for all the switches $S_1$-$S_4$ has also been achieved shown in Fig. 5.10. Hence, reducing the switching losses and improving the overall efficiency.

# CHAPTER 6

## CONCLUSION AND FUTURE SCOPE

As a result, when employing the intermediate coils idea, an improved output of wireless charging is obtained, as it has less noise and less settling time, all of which contribute to a longer lifespan of the electric vehicle and the components connected with charging. As a result of the success of such systems, researchers have focused their efforts over the past decade on developing systems that are more tolerant of misalignment and are capable of managing the variations in coupling that arise as a result of misalignment. Because of this, advances in magnetic design and power regulation have been made, allowing for the development of practical EV charging systems for stationary charging systems that do not need alignment aid. However, dynamic power transfer to EVs on the go continues to be an issue.

Based on the present situation, the future scope of wireless power transfer topology for Electric vehicle is very vast since the ICE vehicles will begin to decline in the share from current 95% of the global level to about half of whole vehicles by 2030-2035, with the other half of the market made up of HEVs and BEVs. Huge investments in R&D for wireless charging forecasts a significant decrease in the price of the system with improved charge speed. Some of the huge barriers for the adoption of EVs such as range anxiety can be solved by this dynamic charging method and hence it shows the future of EVs belong to wireless or inductive charging.

Also, a charge monitoring system can be developed for the authorized owner to get the notification about the status of the battery of the vehicle and moreover an In-wheel Wireless Charging System (IW-WCS) can be developed to reduce the air gap and coil misalignment issues in the dynamic wireless charging system. This can be done by integrating secondary coils with the wheels of the vehicle. The alignment system can be modified by giving the direction about the position of the vehicle to the owner whenever the vehicle is misaligned.

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