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DESIGNING OF A WIRELESS CHARGING SYSTEM FOR ELECTRIC VEHICLES

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ABSTRACT

Electric vehicles (EVs) are now commonly believed to be essential to the transition to smart transportation in the future. The biggest benefit is their contribution to lowering carbon emissions. Compared to conventional vehicles, EVs have advantages including reduced noise, economical maintenance, and zero pollution. But for EVs, the traveling range and charging process are major issues. The time required for charging the battery is more, and charging more vehicles at a time is difficult. According to this perspective, wireless power transfer (WPT) is a practical method for calculating EV trip distance and reducing the amount of time needed to charge the battery. So, in this proposed system a wireless charger allows an EV to automatically charge without the need for wires. To share electrical energy between two circuits by electromagnetic induction, a wireless charging device requires an electromagnetic field. The receiver coil was installed in vehicles below and the transmitter coil was fastened to the ground. When the main AC supply was given to the transmitter coil, it transferred electrical energy to the receiver coil through mutual induction, and with the help of converters the electric energy was given to the battery. The configuration of WPT to EV was simulated in MATLAB/Simulink and their physical parameters with mathematical calculations were analyzed through this proposed System.

Keywords: *Wireless Power Transfer, Electric Vehicle, Electromagnetic Induction, Transmitter Coil, Receiver Coil, Series-Series Compensation*

1. INTRODUCTION

The world is now quite concerned about air pollution due to the current situation. In theworld's major cities, automobiles are the primary cause of air pollution. Nearly 261 tonnes of CO_2 areexpected to be released into the atmosphere each year by the transportation industry, which also contributes to around 27% of all air pollution. EVs can lower carbon emissions, which lowers air pollution. EVs provide a number of advantages, including reduced pollution levels, environmental friendliness, and reduced noise pollution. The methodology of charging the EV currently is through the plug-in method where the charging station charges the battery of an EV. Despite the fact that wired charging is common, its main drawbacks are untidy cords and security in damp environments. Wireless charging grid-linked presents an alternative approach to power EVs. The electrical power transmission from one place to another without any wires is referred to as WPT. In WPT, receiver coils are attached to the EV, and transmitter coils are buried beneath the road. The wireless charging systems have certain advantages compared to the conventional charging. It is more user-friendly as there is no hassle of cables for charging. The deviceis not dependent on using a specific charger to charge. It is more convenient and safer for the user [1]. WPT is a method where energy is transmitted across an air gap using electromagnetic energy. Theinductive and capacitive approaches to WPT have the best practical application among its several methodologies. The most popular method is inductive power transfer (IPT), which is suitable fora range of power outputs

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and gap sizes. On the other hand, due to restrictions on the produced voltage, capacitive power transfer (CPT) is only suitable for power transfer with naturally short gap distances [2]. IPT can be used for huge air gaps about many meters and has a much higher output power than CPT, but CPT is only appropriate for low power applications with extremely narrow air gaps between 10 to 4m and 10 to 3m [3]. The advantages of magnetic inductive coupling are ease of use, practical functioning, and increased efficiency at close range. IPT method is therefore used to transfer the power in WPT to charge the EV[4]. Using a near field technique, the WPT by electromagnetic induction operates. It is well known that the alternating current going through the main winding creates an alternating magnetic field that interacts with the secondary winding due to electromagnetic induction. The interaction needs to be as near as possible to be effective. The majority of the magnetic field is not able to reach the secondary winding when it is separated from the primary, and as a result of the losses, the inductive coupling becomes less and less effective. Systems that only use inductive coupling are significantly less efficient. The flow leakage is increased by the wide air gap between the transmitting and receiving coils, which raises the leakage inductance [5].

The proximity effect, winding resistances, and leakage inductance all rise as the separation does. The magnetizing flux will also drop considerably, which will lead to much lower mutual and magnetizing inductance. Resonant circuits can be incorporated into the WPT systems with IPT to mitigate the drawbacks of IPT. When a system is at resonance, or when the supply frequency and circuit resonant frequency are equivalent, great performance is displayed. Resonance is used to slightly extend the transmission range. The transmitter and receiver are tuned to the same frequency when using resonant induction [6]. Additional compensating capacitors are required to produce the resonant condition by matching the impedance in both the primary and secondary sides, which will compensate for the leakage inductance and reactive power on the primary and secondary sides. Resonant compensation is used to lessen leakage inductance and enhance coupling between the transmitter coil and reception coil in order to transfer power effectively. There are four primary topologies for compensation, and they are as follows: series-parallel (SP), parallel series (SS), parallel-parallel (PP), and series-series (PS) [7] - [11].

In contrast to SS-topology, which maintains good efficiency throughout the WPT process, SP-topology is susceptible to changes in resonance frequency and coupling coefficient. In terms of power transfer effectiveness and maximum output power, SS-topology appeared to be superior to SP-topology [8]. Three types of wireless charging systems for EVs are classified: stationary, quasi-dynamic, and dynamic charging systems. While stationary systems are similar to modern plug-in chargers, they offer certain special benefits like "park and charge" [9]. Under the ground, a transmitter pad is positioned, and a receiver pad is positioned on the side of the car. The transmitter pad receives a supply, and the receiver coil receivespower via electromagnetic induction. For quick charging in a dynamic environment, quasi-dynamic devices can be put at bus stops, taxi stands, and traffic lights [10]. Motor ratings and calculations are taken from [13].

DWPT systems charge while a vehicle travels. Electrified highways or charging lanes are able to provide electric power to wirelessly charge electric vehicles. This system for wirelessly charging electric vehicles uses inductive power transfer, in which the magnetic fields of the transmitter and receiver coils are mutually inducted to communicate power wirelessly. Therefore, DWPT gives the battery energy and extends the driving range, which eliminates "range anxiety." While an electric vehicle (EV) is being transported, charging can be done via dynamic and quasi-dynamic wireless technology [14], [15], [16].

The main objectives of the proposed work are given as follows.

1. The main problem addressed in this research is how to charge EVs through WPT.
2. In order to achieve the objective, the design of the WPT through receiver and transmitter coils as series-series compensation for matching of resonance frequency is addressed.
3. To achieve efficient WPT, the rating of the motor and batteries are designed.
4. The simulation model is developed using MATLAB for wireless charging systems for EVs.
5. The performance of the designed wireless charging system is analyzed through battery parameters, motor parameters, range of anxiety, and input and output parameters of the EVs.

This paper is organized as follows, section I introduces the importance of EVs and WPT. Section II describes the compensation role, proposed block diagram and designed block diagram. Section III explains calculations of the system as per requirement. MATLAB simulated diagram of

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proposed system and EV configuration used in simulation was presented and also discussion on obtained results, waveforms are shown in section IV, finally section V concludes the paper.

2. MATERIALS AND METHODS

In this section importance of the compensation, series-series compensation, proposed, designed block diagrams, and calculation for matching the resonance frequency of primary and secondary windings was described.

2.1 Importance of Compensation:

The compensation for an inductive energy transfer can be thought of as a topology with at least one resonant element on one side. Figure 1 depicts the proposed classification of the topology compensation. It is suggested that the topologies be divided into groups according to where they exist (on the primary or secondary side, double-sided, and multi-coils if there are several transmitting or receiving coils). On either side, there can be one, two, or more resonances. These might be capacitors and inductors.

2.2 Series-series compensation:

The circuit of wireless power transmission with SS compensation topology is given. Compensation topology is highly significant since it aids in adjusting resonance frequency. The compensation capacitors in this circuit are wired in series on both the main and secondary sides. The circuit of series-series compensation is given below.

Figure 1 displays the four series of compensation: SS, SP, PS, and PP. Here, the letters "P" and "S" indicate for the parallel and series connections that the capacitor (compensation/resonant capacitor) has to the coil. In this paper, figure 1 shows how a WCS system for EV is developed in MATLAB/Simulink using SS compensation topology. In this study, SS topology is used. The wireless power transmission circuit with an SS compensation scheme is shown. The compensation capacitors in this circuit are wired in series on both the main and secondary sides.

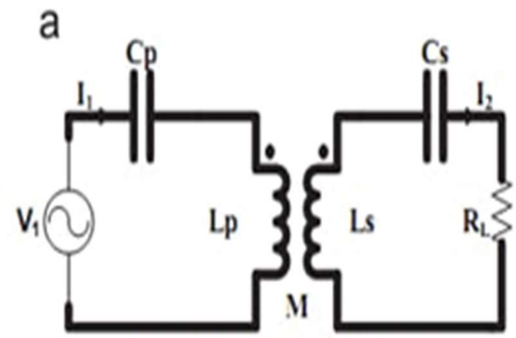

Figure 1: series-series compensation.

2.3 Proposed And Designed Block Diagrams:

The block diagram of wireless charging system for EV as shown in figure 2. It consists of inverter, primary side rectifier and secondary side rectifier, primary winding and secondary winding, compensation capacitors.

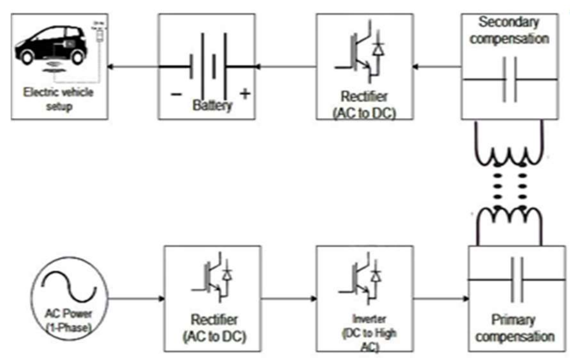

Figure 2: Proposed block diagram.

In figure 3, the rectifier is supplied a 230 V, 50 Hz AC supply. It transforms AC power into DC power. An inverter transforms a DC source into a high-frequency AC source. The primary winding is connected in series with a capacitor, is termed as series compensation. The power transfer efficiency is lower in the WPT system without the compensation circuit than it is in a circuit that uses compensation technology and reduces the leakage inductance in the WPT system in order to achieve higher efficiency. To account for the leakage inductance, a second capacitor is connected in series with the primary and secondary coils. The capacitive compensation fixes the leakageinductance issue and improves mutual coupling between the transmitting and receiving coils. Power transfer occurs at a specific resonance frequency.

2.3 Calculation For Matching Resonance Of Primary And Secondary Windings:

Power will transfers efficiently from primary to secondary with the help of compensation. The high-frequency AC supply is transmitted from primary winding to secondary winding with compensation.

Quality factor (q) as 4 and the coefficient of coupling (k) as 0.5 to determine the values needed to match the resonance of the main andsecondary coils. By adding a compensation circuit to the primary side, the resonant frequency (f_r) can be adjusted to transfer equally to the power supply's operational frequency. The values of inductance L_1 and capacitance C_1 can be used to determine the frequency of the primary coil, and the values of inductance L_2 and capacitance C_2 can be used to determine the frequency of the secondary coil.

$$f1 = 1/2\pi\sqrt{L1C1} \quad (1)$$

$$f2 = 1/2\pi\sqrt{L_2C_2} \quad (2)$$

f1 and f2 values are obtained to get the resonance condition with 30.006 kHz and 30.006 kHz respectively. Hence, we can match the resonance with the resonance frequency of 30 kHz on transmitting and receiving coils. The formula for the coefficient of coupling betweentwo coils is given in (3).

$$k = M/\sqrt{(L_1*L_2)} \quad (3)$$

Where M is the inductance that the primary and secondary coils have in common.

The formula for the relationship between the distance D and the coefficient of coupling k of two coils is given in (4).

$$k = \frac{1}{[1+2^{2/3}(\frac{D}{\sqrt{R_1R_2}})^2]^{3/2}} \quad (4)$$

Where R_1, R_2 are the primary and secondary coils' radii and D is their respective distance from one another. Here, assuming that R_1 and R_2 have values of 60 cm and 30 cm, respectively and that k is taken to be 0.5, the distance D is predicted to be around 25 cm for wireless charging.

3. CALCULATION OF PROPOSED SYSTEM:

In this section selection of motor rating considering the various factors, input power requirement and battery capacity are described.

3.1 Selection of Motor Power rating considering vehicle dynamics:

When designing an electric vehicle power rating, the weight of 800 kg, the motor rating must be chosen. When designing a vehicle's power rating, the dynamics of the vehicle such as rolling resistance, aerodynamic drag, gradient resistance, etc., must be taken into consideration.
The force required to move the object is designed as follows:

$$F_{total} = F_{rolling} + F_{gradient} + F_{aerodynamic\ drag} \quad (5)$$

Where $F_{rolling}$, $F_{gradientresistance}$, and $F_{aerodynamic\ drag}$ each represents a specific tractive force that must be overcome for the motor's output to move the vehicle:

3.1.1 Rolling Resistance:

It is the resistance that the vehicle experiences as a result of the tyres' contact with the ground. The calculation of the force due to rolling resistance is made possible by Equation (6).

$$F_{rolling} = C_{rr}*M*g \quad (6)$$

Where, C_{rr} is the coefficient of rolling resistance (0.01),M (800) mass in kg and g is the acceleration due to gravity (9.81 m / s^2)
Therefore, $F_{rolling}$ = 0.01*800*9.81 = 78.48 N
Power required to overcome the rolling resistance iscalculated as given in (7).

$$P_{rolling} = (F_{rolling}*V) / 3600 = (78.48*100)/3600 = 2.18\ kW \quad (7)$$

Where, V = velocity in kmph.

3.1.2 Gradient Resistance:

Equation (8) provides the calculation method forcalculating gradient resistance.

$$F_{gradientresistance} = \pm M * g * \sin\alpha \quad (8)$$

Let's use an electric automobile as an example; ittravels on a flat route, therefore the angle $\alpha = 0^o$

$$F_{gradientresistance} = 800*9.81*\sin 0^o = 0\ N \quad (9)$$

The gradient resistance in this case can be overcome with no power.

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3.1.3 Aerodynamic Drag:

Equation (10) provides the calculation method for the aerodynamic drag.

$F_{aerodynamicdrag} = 0.5*CA*A_{ft}*\rho*(V + V_O)^2$ (10)

For the purposes of this example, let's assume that

2.2 kW of power was sufficient to overcome aerodynamic drag and other resistive forces.

The result is that the total tractive power required to drive the vehicle is as follows (11).

$P_{total} = 2.18$ kW + 2.2 kW = 4.38 kW (11)

However, it is not advisable to choose an electric motor with a 4.38 kW output power rating. The power transmission losses to the wheel must be considered. The mechanical power output (M tractive) required to move the object is shown in equation (8).

$M_{tractive} = P_{total} / \eta$ (12)

Where η is the transmission gear system's efficiency. Let's assume that the transmission system has an efficiency of 0.85.

Consequently, the necessary mechanical power output is determined using (12).

$M_{tractive} = P_{total} / \eta = 4.38 / 0.85 = 5.15 = 5.2$ kW.

It is necessary to select a motor with an output power rating of 5.2 kW in the example of choosing the power rating for an electric automobile weighing 800 kg. The power rating needed to run an EV with a specific load is calculated in thismethod.

3.2 Calculations for Input Power:

Figure Let efficiency of the motor % η = 85 %

Pout = 5 kW, then the input power required for theprimary coil can be calculated as given in (13).

% Efficiency (% η) = (Pout / Pin) *100 (13)

Therefore, Pin = 5000 / 0.85 = 5882.35 W

Current (Iin) = Pin / Vout = 5882.35 / 72 = 81.69A

Motor Ratings:

Load Voltage = 72
VLoad Power = 5
kW

Load Current = Power / Voltage = 5000 / 72 =69.44A.

3.3 Battery Calculations:

From In this paper Lithium-ion battery was used, as it hassuperior performance than any other battery.

Battery current $I_{bat} = 81.7$A

Battery voltage $V_{bat} = 72$V

Ampere hour (Ah) = 81.7*5 (Here 5 is the journeytime in hours)

Battery Ah = 408.5 Ah

Take 20% extra capacity = 408.5*1.2 = 490.2 Ah

Battery energy = V_{bat}*Ah(14)

= 72*490.2 = 35294.4 Wh

Therefore, $E_{battery} = 35.3$ kWh.

4. SIMULATION RESULTS

Figure 4 depicts the simulation diagram for a wireless charging system. 230 V, 50 Hz AC power is connected to the rectifier. It converts the ACsupply to a DC supply to provide a DC output voltage. The inverter receives the DC power and converts it to AC at a high frequency. A DC to high-frequency AC inverter changes the DC supply. The battery needs DC and hence battery is charged by the WPT of 5 kW. Figure 4, shows the simulation of an EV and from the battery, the wireless charging is given to the motor terminals to run the vehicle. From longitudinal driver acceleration command is given to control the speed of the vehicle and from motor terminals, the power will transferred to the wheels of the vehicle body to run the vehicle. Hence through WPT, it concludes that the vehicle ismoving which is done in the above simulated diagram.

The above graph 5, shows the waveform of input voltage. A single phase 230 V of 50 Hz frequency is given as an input. Figure 6, represents the primary side Rectifier waveform. Rectifier converts AC to DC. An input of 230V AC is taken and gives rectifier output at 228V DC. Figure 7, shows an ACpower

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with high frequency is transferred to secondary winding with minimum losses. Voltage and current on secondary side output waveforms are obtained. Voltage -95.62V, current -81.79A and power-5079W.

Figure 8, represents an AC Power with high frequency is transferred to secondary winding with minimum losses. The secondary side output waveforms of voltage and current are obtained. Voltage – 95.62V, Current-81.79A and Power-5079W. Figure 9, shows the secondary side rectifier. Rectifier converts AC to DC. Here AC supply is taken as an input and gives an output of DC voltage of 90V. Figure 10 shows the battery SOC waveform. The figure shows SOC is increasing which states that the battery gets charged through wireless power transfer. When the battery is charging the corresponding current is decreased to a negative value (below 0) as shown in Figure 11. Battery charging current (-55.15A). Figure 12 represents the battery voltage when the battery is charging. Voltage starts increasing when the battery gets charged. Battery voltage: 93V. Figure 13, shows the battery SOC. The SOC is discharging which indicates that the vehicle is moving and the battery gets discharged. Figure 14 shows the batteryvoltage when the vehicle is moving and the voltage decreases. Battery voltage: 78.3V. Figure 15, represents the battery current when the vehicle is in motion. The current increases when the battery gets discharged. Battery current: - 58.23A. Figure 16 represents the output waveform of torque produced by the electric vehicle. Figure 17, shows the output waveform of speed and distance of the vehicle. Hence we conclude that when we provide wireless charging, the vehicle is moving with a certain speed and distance.

From Table 1, it is observed that the WPT scheme works very efficiently.

%Efficiency = (output power /input power) *100 =86.47%.

Table 1: Input and output powers.

Parameter	Primary Side	Secondary Side
Current	45.70A	83.63A
Voltage	229.6V	80.3V
Power	5102W	4309W

Table 2: Specifications used in simulation.

Component	Parameter	Parameter Value
V_{CP}	Primary coil voltage	230 V
C_1	Primary coil capacitance	105.74 nF
R_{CP}	Primary coil resistance	1 Ω
L_1	Primary coil inductance	266.16 µH
L_2	Secondary coil inductance	256.16 µH
C_2	Secondary coil capacitance	109.69 nF
R_{CS}	Secondary coil resistance	0.001 Ω
q	Quality factor	4
k	Coefficient of coupling	0.5
f_r	Resonant frequency	30 kHz
D	Distance	25 cm
R_1	The primary coil's radius	60 cm
R_2	The secondary coil's radius	30 cm
Motor	PMBLDC	5 kW,72 V, 69.44 A
Battery Rating	Lithium-Ion	35.3 kWh

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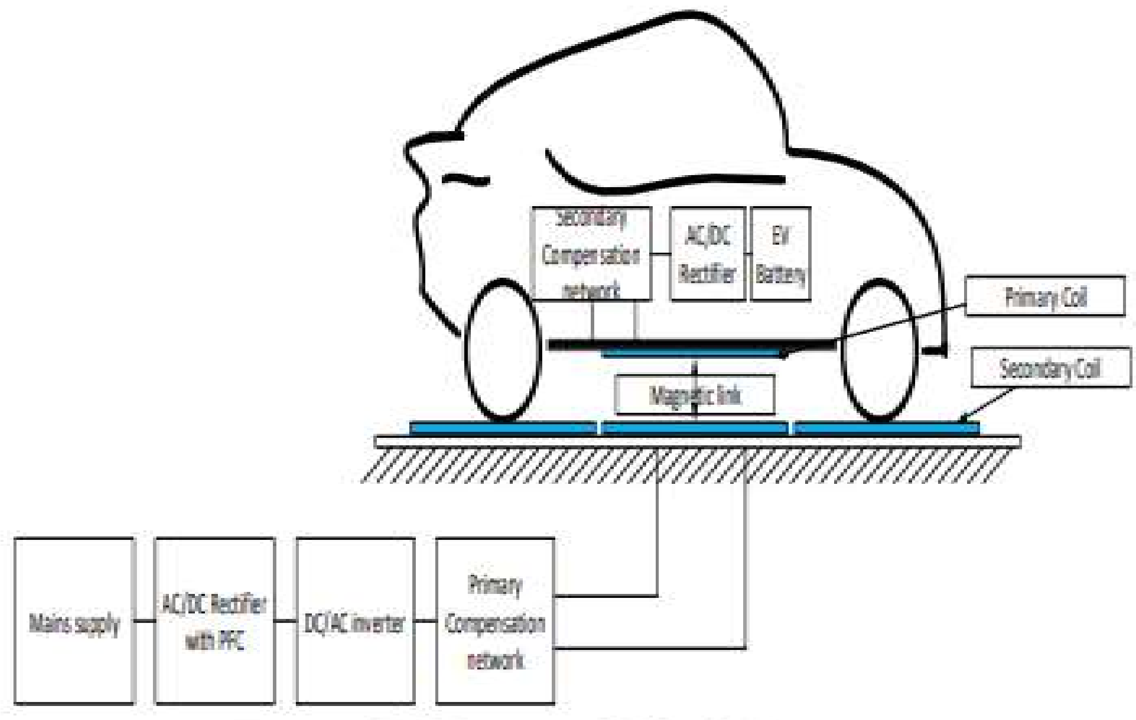

Figure 3: Designed Block Diagram.

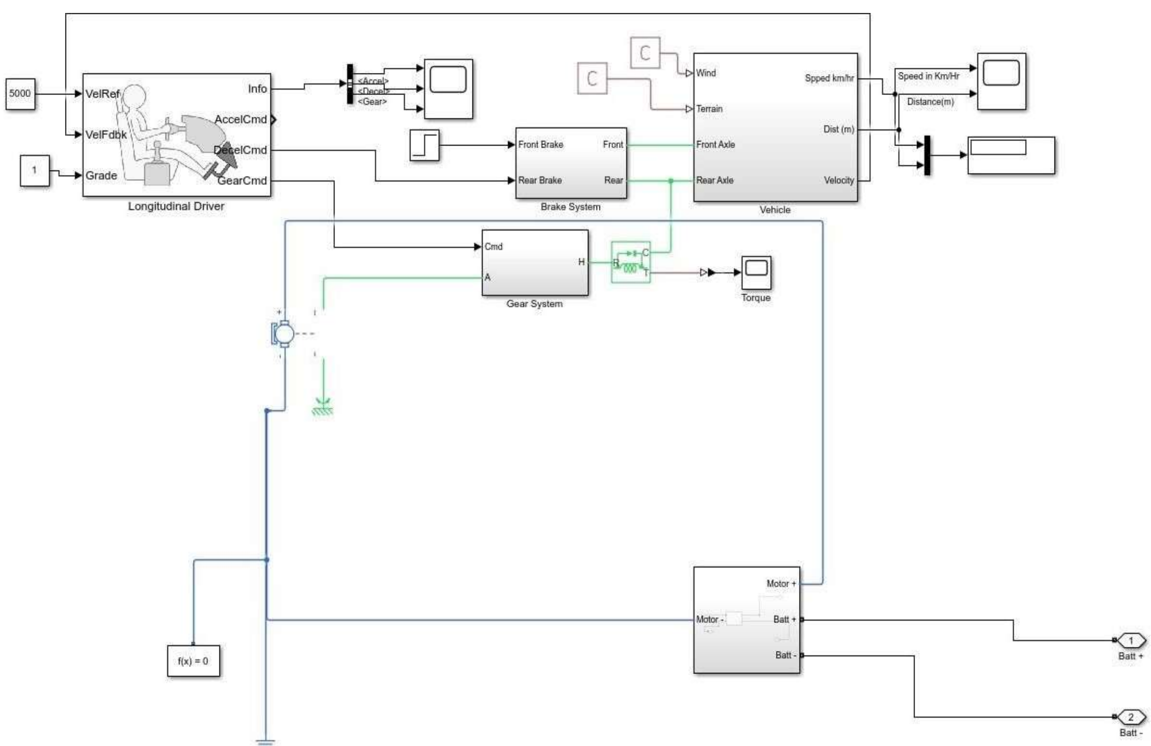

Figure 4: Simulated EV diagram.

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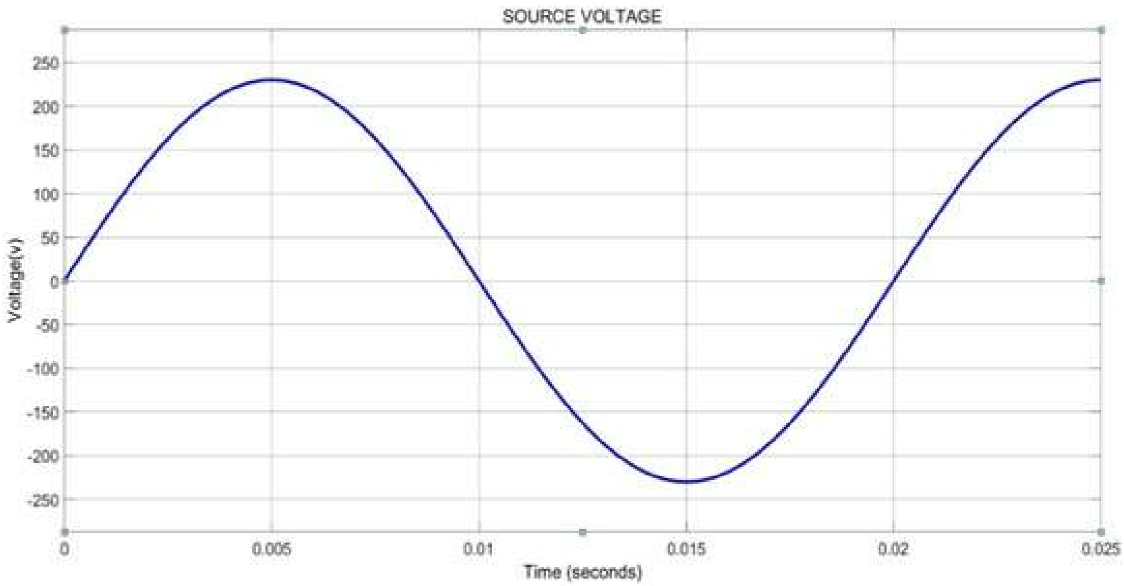

Figure 5: Waveform of Input Voltage.

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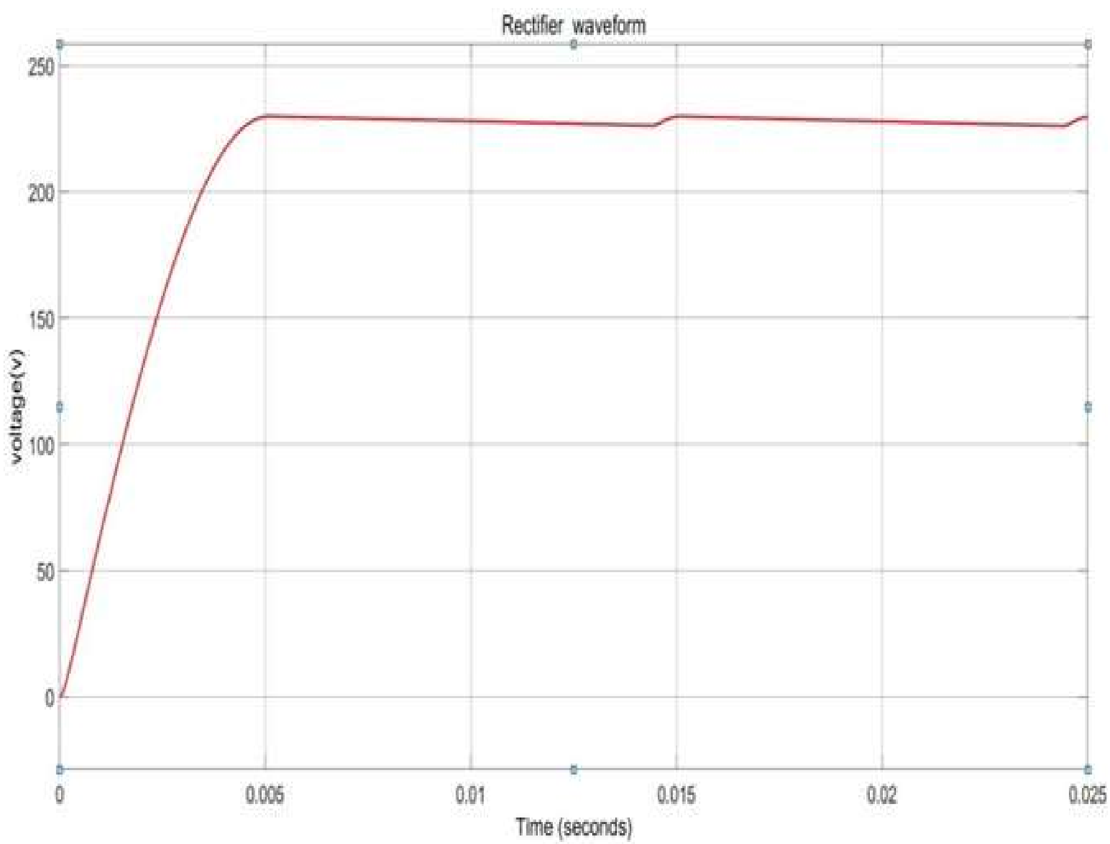

Figure 6: Primary Side Rectifier Output Waveform.

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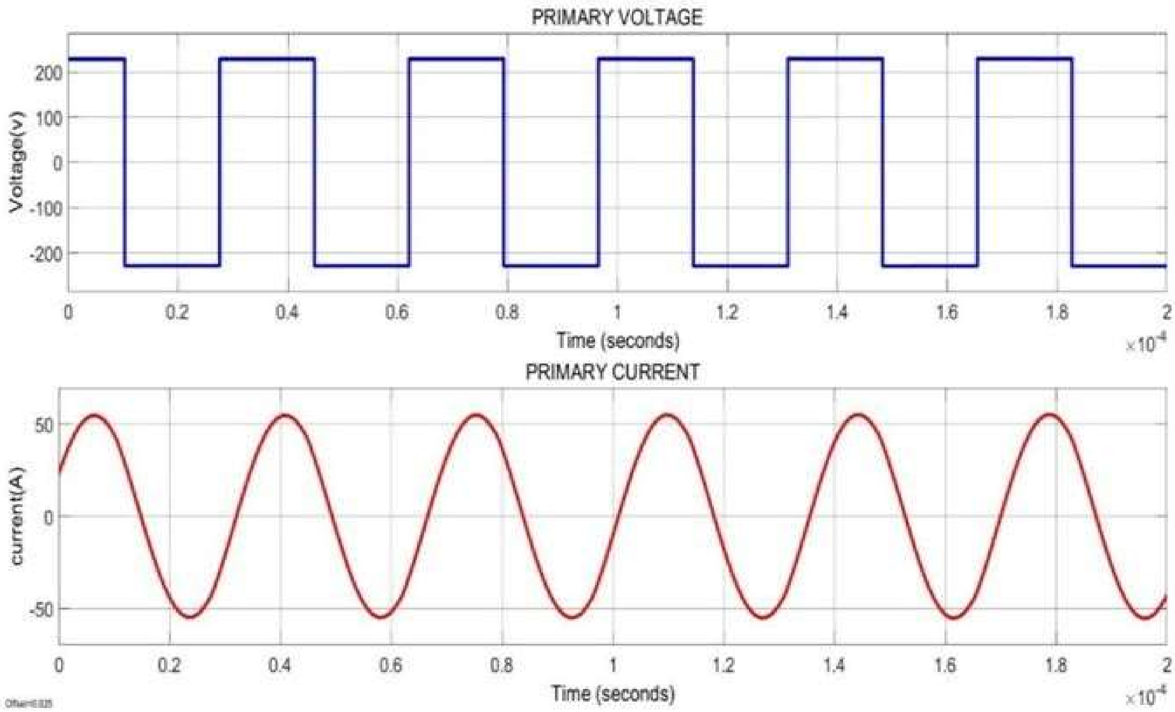

Figure 7: Output primary voltage and current.

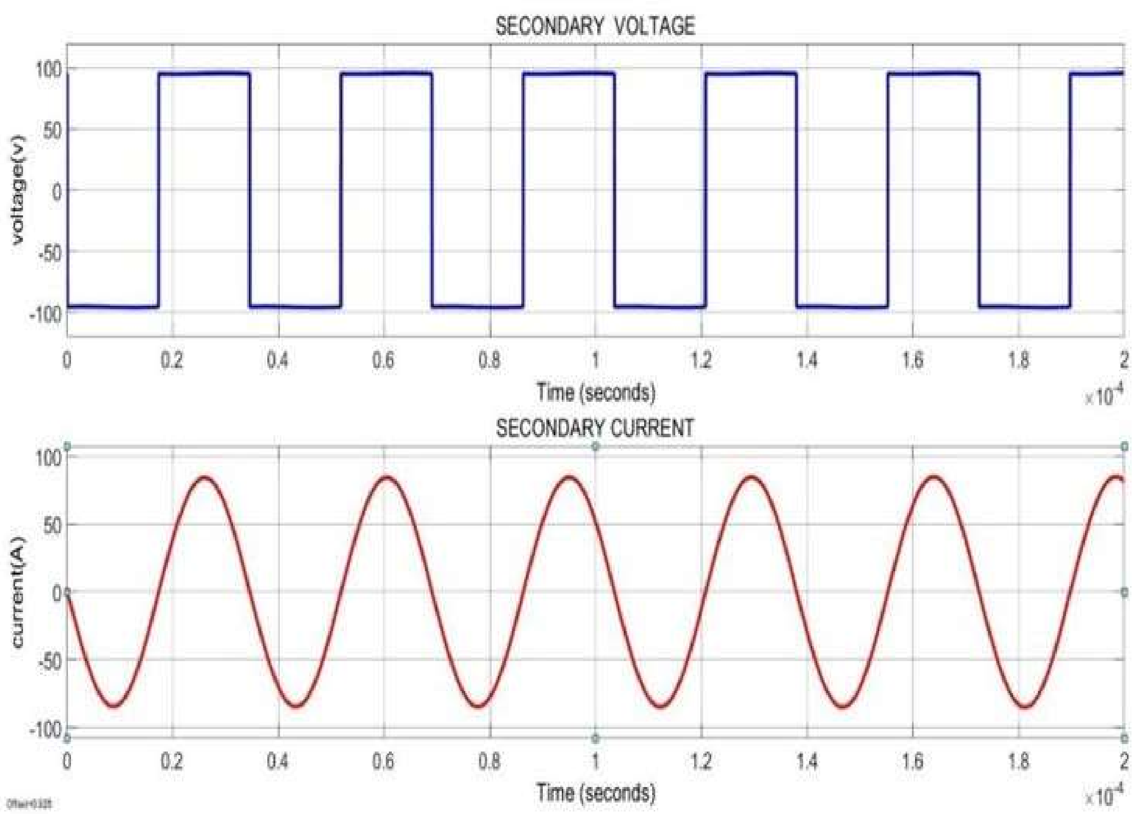

Figure 8: Output waveforms of secondary voltage and current.

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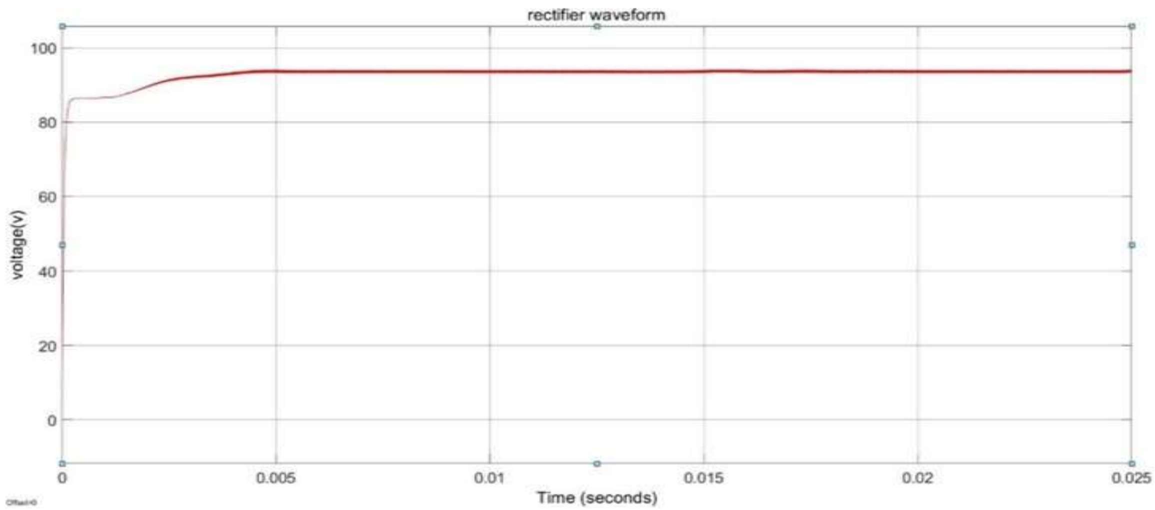

Figure 9: Output Waveform of Secondary Side Rectifier.

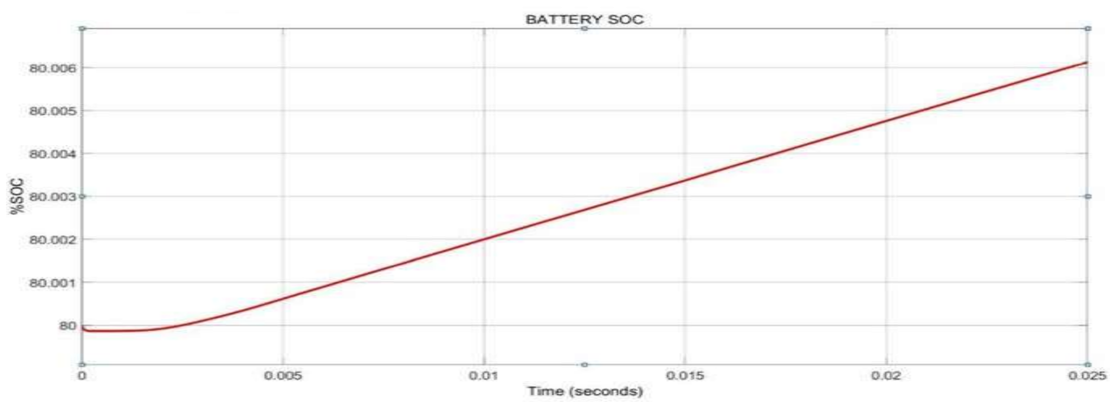

Figure 10: Output Waveform of Battery %SOC.

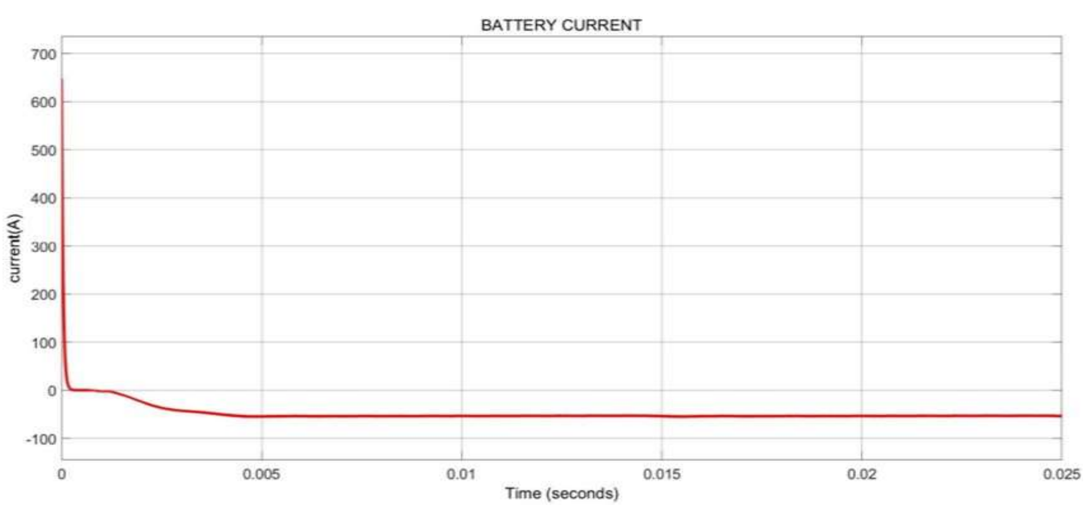

Figure 11: Output Waveform of Battery current.

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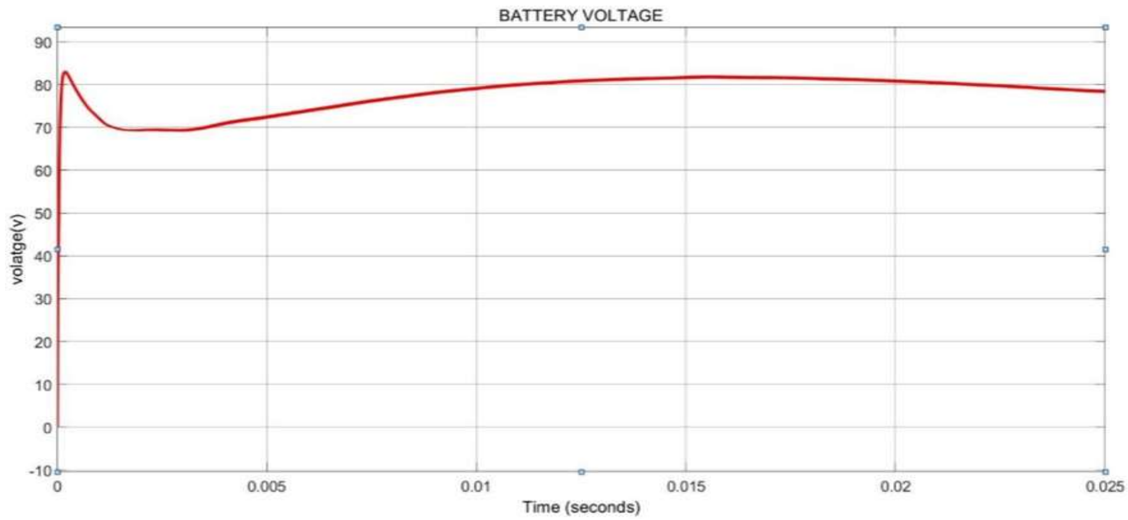

Figure 12: Output Waveform of Battery Voltage.

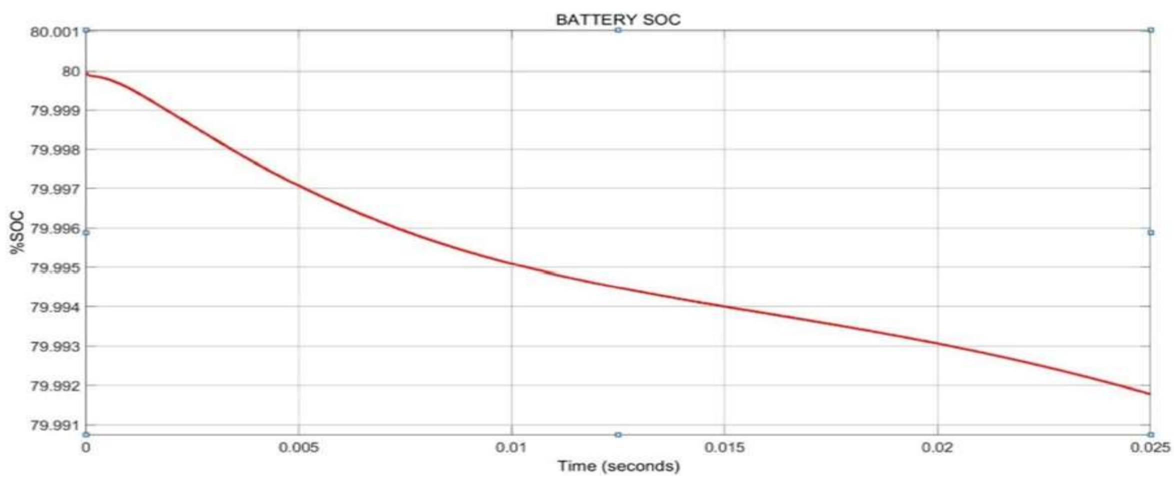

Figure 13: Output Waveform of Battery SOC.

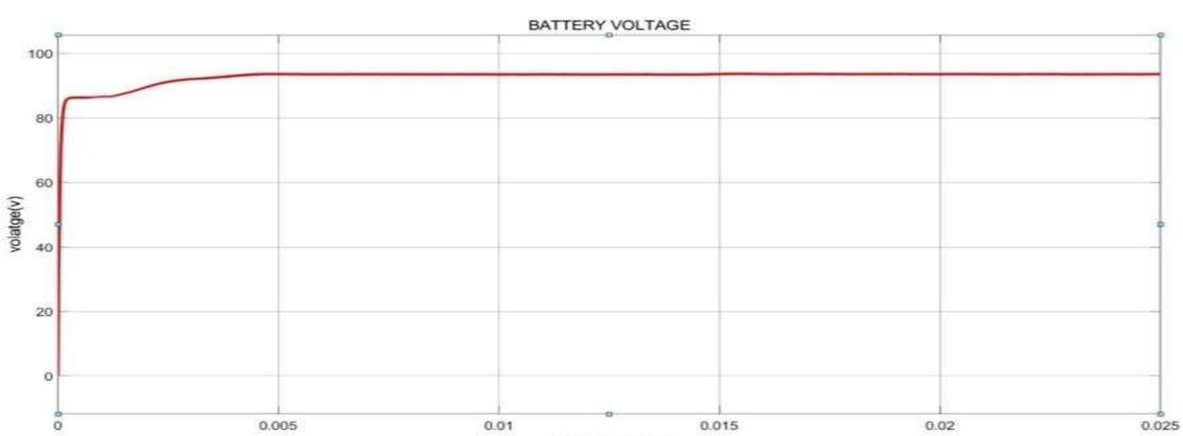

Figure 14: Output Waveform of Battery Voltage.

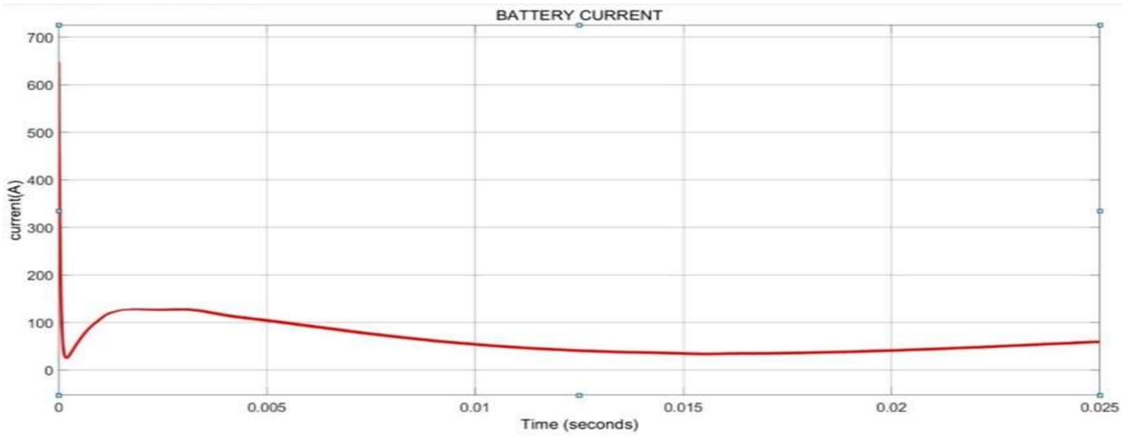

Figure 15: Output Waveform of Battery current.

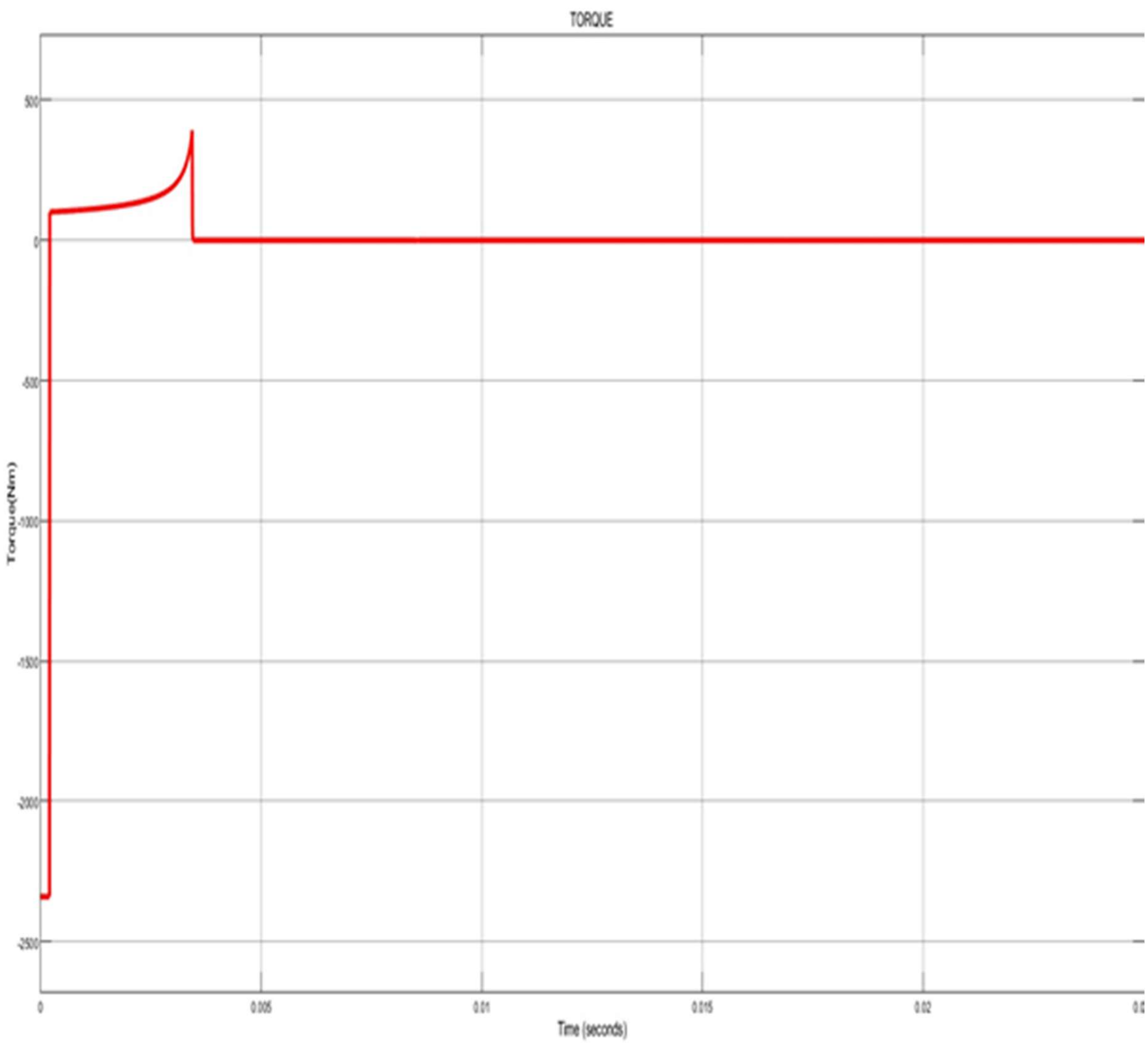

Figure 16: output waveform of torque in EV.

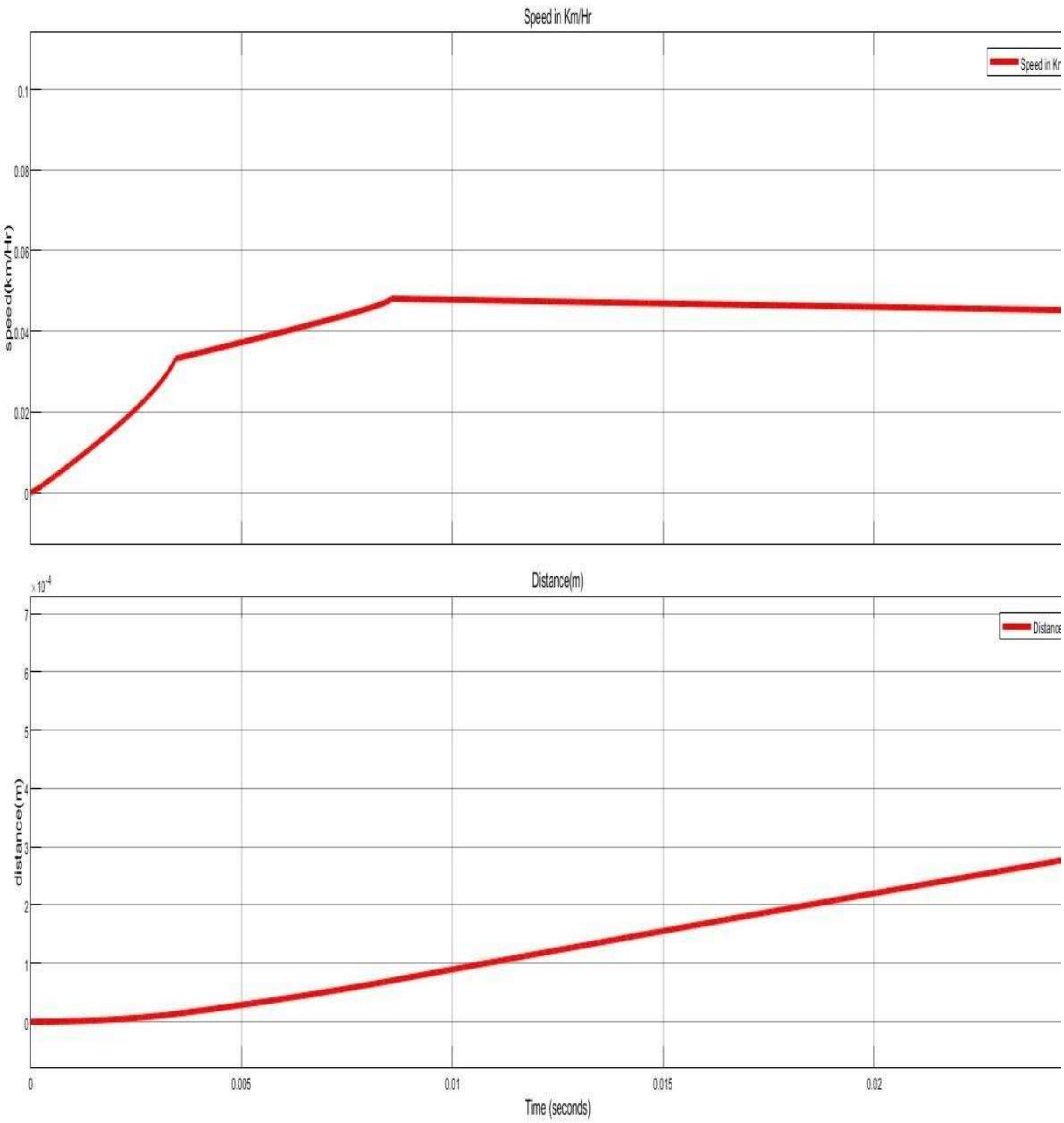

Figure 17: : Output Waveform Of Speed And Distance.

5. CONCLUSION

This paper presents the design of a wireless charging system for EVs. It presents an alternative approach to power EVs. It is more user-friendly as there is no hassle of cables for charging. It is more convenient and safer. The proposed system includes additional features like adding SS compensation and matching resonant frequency in an efficient way has improved the power transfer between two coils. It was observed that the interaction between the coils must be as near as possible to provide greater efficiency. More capacitors are added to generate the reactive power on the primary and secondary sides. In a resonant circuit, the supply frequency is tuned the same as the circuit resonance frequency. Whenever a system reaches resonance, it was observed that power transfer takes place very efficiently. In this project, 5kW power is transferred from primary winding to secondary winding with minimum losses and it wasconnected to EV. The selection of motor rating and battery capacity are discussed to get more efficiency. The physical parameters with mathematical calculations are analyzed through the designed system. The output waveforms of the rectifier, inverter, and battery %SOC, voltage, and current waveforms are observed when the EV position is both static and dynamic by using the MATLAB/Simulink model.

Future Scope: Other compensation techniques like LCC and LCL can be implemented. A combination of different compensation techniques like LCC-SS, and LCL-SS can be implemented, and their efficiency. Battery swapping techniques can be implemented for fast charging of EVs.

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