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Bidirectional Wireless Power Transfer System for Electric Vehicle

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Abstract-The automobile industry in India is on the verge of shifting from the conventional petrol or diesel engines to electric vehicles. The conventional fuel used for automobile is limited and has several problems such as hazards to the environment due to combustion of fuel. The electric vehicle overcomes the problems associated to fuel combustion and provides the effective solution for transportation. The flexibility with electric vehicles has opened the doors of opportunities for the researchers to develop the sustainable solutions in automobile sector. The problems associated with EV are the battery charging time and the performance of the battery. The bidirectional transfer of the power enables the grid connection of electric vehicles. As the power transfer is in both directions charging and discharging of the batteries is possible with fulfillment of controlled output requirements. The wireless transfer of power is introduced long back but is not implemented at large scale as the efficiency of the system is not so high. The implemented module for bidirectional wireless power transfer is presented in this paper.

Index Terms: Wireless power transfer, Electric Vehicles, Charger, Battery etc.

I. INTRODUCTION

The sustainable development of any country considers the efforts for improving the environment conditions and avoiding the hazards to the environment. The even-odd formula for the vehicles was implemented in Delhi since last three years. The pollution created by the vehicles is one of the major reasons in environmental hazards. The increase in use of the vehicles may increase the pollution. There were around 4 lakh electric vehicles running on roads in India in 2019. This number is very small as compare to the total number of vehicles in India but with the government policies the number will be encouraging in around year 2025.

The power which transfers between the vehicles and grid needs the operation to be bidirectional. The market share of E-vehicles in the world is growing as many countries are taking efforts for avoiding the pollution. The control method for power transfer includes phase shift and PI [1]. The charging of the batteries need more time, if one has forgot to turn on the supply for charging the batteries may land in to trouble of unavailability of vehicle when needed. The technology which provides charging solution of the batteries when the vehicle is running can be the system for making the electric vehicles popular [2].

It needs two converters to be used for designing the bidirectional power transfer circuit. When both the converter is in on state it becomes important to decide the direction of power. The control strategy needs to design to avoid the malfunctioning of the system in such situation. The synchronous bridge rectifier can be used to control the operation in said situations for the medium speed vehicles [3, 4]. The dc capacitors implemented for two stage power conversion to enhance the performance. As the power levels are increased, it decreases the stress on the devices [5]. The finite element analysis can be implemented for the circuit to understand the performance of the circuit components under various conditions. The reduction in core losses of the coils can also improve the performance of the system over long period thereby improving the efficiency. The bidirectional method may enable the transfer of the control signal by means of duplex method of communication [6, 7].

The series compensation with transfer of power between AC and DC source in both directions has been important for the EV applications. The system design in Simulink environment leads to experimentation at no cost as the physical components are not wasted for testing [8]. Since the invention of Tesla coil in 1891, many efforts have been taken by the researchers to improve the performance of wireless transfer system of power. The wireless system for the vehicles will help in reducing the cost and the maintenance of the system [9]. The inductive circuit implemented in resonant mode by varying the mutual inductances. The wireless charging system is commercialized by many companies for the applications such as the mobile battery charging, some biomedical applications and other small appliances [10]. The communication signal transfer with power based wideband found suitable to transfer the signal for controlling the operations. The system mainly consists of the two converters with the magnetic coupled coils. The performance of converter always effects on performance of overall system [11-14]. The issues associated with dead time can be resolved with proper compensation [15].

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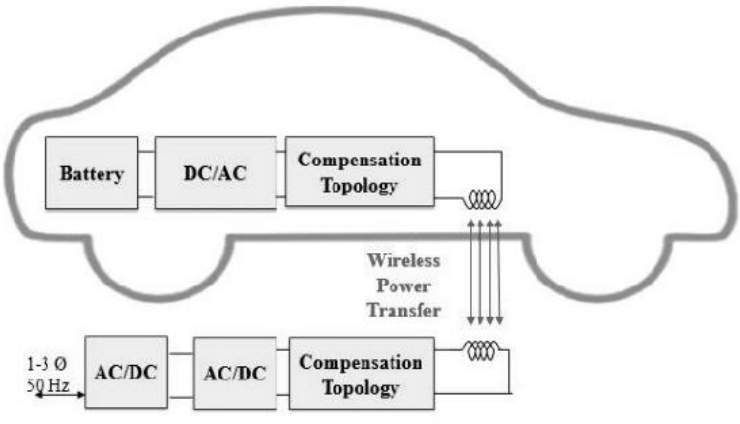

Fig. 1: Basic Structure of Bidirectional Wireless Charger

The figure drawn above shows the bidirectional charger for electric vehicle application. The single or three phase supply is connected to the converter. Then the series compensation circuit is connected. The magnetically coupled coil performs the work of wireless transfer from power circuit to the vehicles circuit. The batteries are charged with the help of the AC to DC converter.

II. MOTIVATION OF RESEARCH

The developing countries like India are dependent on the other countries for the fuel like petrol and diesel. The cost of these fuel controls the economy of the country as the major transport is dependent it. This is not only the only concern but also has severe effect on the environment. The pollution by the combustion of the fuel is one of the major sources of air pollution in India.

Around 27% of total air pollution in India is due to vehicles. The air pollution is very severe issue in many countries and it directly causing the hazards to human health. This situation can be drastically changed by making the electric vehicles reliable for the customers.

By means of developing the wireless charging system capable of providing bidirectional power transfer may lead to the customer satisfaction as no extra efforts need to be taken for charging the batteries. The government is willing to shift to the electric vehicles by 2025. The more number of electric vehicles may results in requirement of the charging stations. Mainly all the parking slots will be converted in to the charging slots.

III. OBJECTIVES OF RESEARCH

The work carried out has following objectives to be accomplished.

- Designing the bidirectional charging system for the applications of e-vehicles.
- Implementing the system in the Simulink environment.
- Validating the results with for the implemented system.
- Concluding on feasibility of the system for electric vehicle applications.

IV. PROPOSED METHODOLOGY

The system is designed with for electric vehicle charging. The calculations related to various circuit components are made and the suitable components are chosen in order to get the expected results.

The designed circuit is implemented in Simulink for the understanding of the performance of the system. The system implemented in software as a first part, in coming time authors have decided to develop the hardware prototype for the same system.

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V. BLOCK DIAGRAM OF IMPLEMENTED SYSTEM

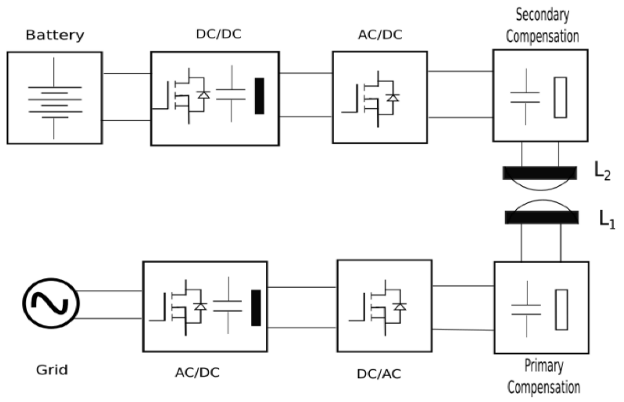

Fig. 2: Block Diagram of Bidirectional Wireless Charger

The block diagram shows the complete flow of power from the grid to the battery and vice versa. Power from grid is converted with the help of the converters. L1 and L2 show the magnetically coupled coils. Then the power is again converted with AC/DC and DC/DC converters to charge the battery.

VI. SYSTEM DESIGN

The compensation capacitance connected on primary side is calculated as below. This capacitor mainly helps in reduction of VA rating of the inverter and improves the power delivered to the load. The system is designed for 50 Hz frequency.

$$C_p = \frac{(-\omega^2 R_L C_s L_P + R_L)^2 + (\omega L_P)^2}{\omega\left[(-\omega^2 L_P{}^2)(1-k^2)\omega R_L C_s + \omega L_P R_L\right](-\omega^2 R_L C_s L_P + R_L) - \omega^2 L_P{}^2(-\omega^2 L_P{}^2)(1-k^2)}$$

The equivalent impedance is given by-

$$Z_{real} = \frac{R_L\,\omega^2 L_p{}^2\,k^2}{(-\omega^2 R_L C_s L_P + R_L) + (\omega L_P)^2}$$

$$Z_{imag} = \frac{1}{\omega C_P} + \frac{\left[(-\omega^2 L_p{}^2)(1-k^2)\,\omega R_L C_s + \omega L_P R_L\right](-\omega^2 R_L C_s L_P + R_L)}{(-\omega^2 R_L C_s L_P + R_L)^2 + (\omega L_P)^2}$$

$$-\frac{\omega L_P(-\omega^2 L_p{}^2)\,(1-k^2)}{(-\omega^2 R_L C_s L_P + R_L)^2 + (\omega L_P)^2}$$

The active power of the circuit is calculated as-

$$V_1 = \frac{4V_d}{\pi}$$

$$P_{in} = \left(\frac{V_1/\sqrt{2}}{\sqrt{Z_{real}{}^2 + Z_{imag}{}^2}}\right)^2 . Z_{real}$$

$$P_{in} = \frac{8V_d{}^2}{\pi^2}\,\frac{Z_{real}}{Z_{real}{}^2 + Z_{imag}{}^2}$$

$$P_{out} = \frac{V_0{}^2}{R_{dc}}$$

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DC voltage gain is calculated as-

$$M = \frac{V_0}{V_{dc}} = \sqrt{\frac{8R_{dc}}{\pi^2} \frac{Z_{real}}{{Z_{real}}^2 + {Z_{imag}}^2}}$$

Calculations of the isolation transformer are as below-

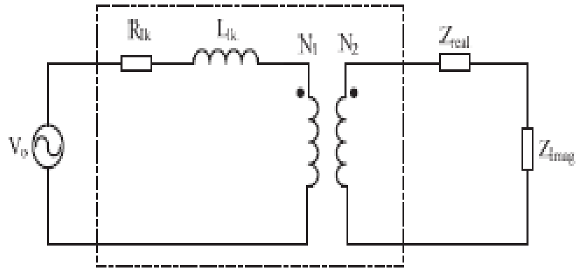

Fig. 3: Equivalent Circuit of the Isolation Transformer

$$Z_{real}' = R_{LK} + \left(\frac{N_1}{N_2}\right)^2 Z_{real}$$

$$Z_{imag}' = \omega L_{LK} + \left(\frac{N_1}{N_2}\right)^2 Z_{imag}$$

$$P_{in}' = \frac{8{V_d}^2}{\pi^2} \frac{Z_{real}'}{{Z_{real}'}^2 + {Z_{imag}'}^2}$$

VII. IMPLEMENTED SIMULATION MODEL

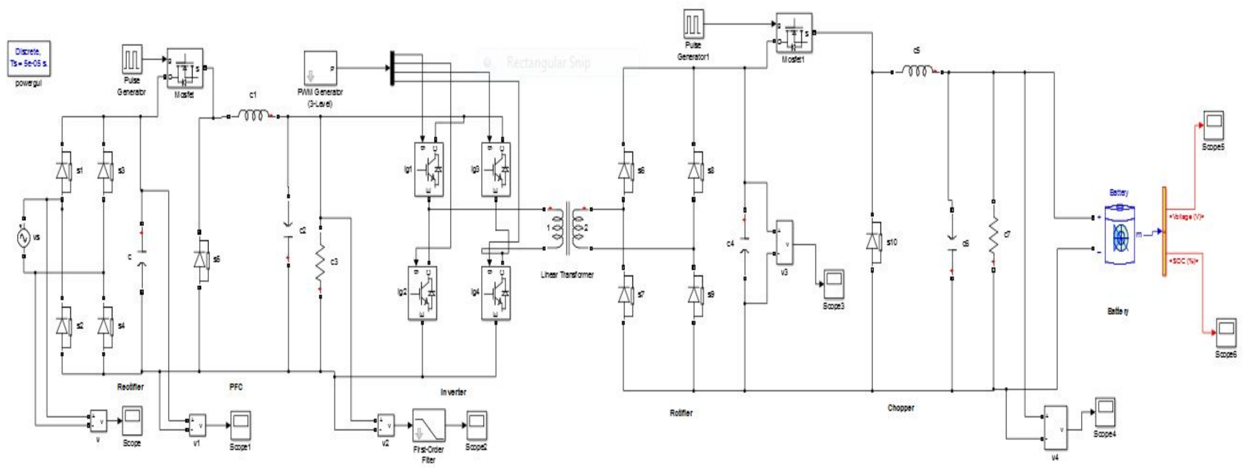

Fig. 4: Implemented Simulation Model of bidirectional wireless power transfer circuit

The implemented circuit in Simulink is shown above in figure 4. Starting from the left side, the structure included the AC-DC converter, DC-AC converter, compensation components, linear transformer, AC-DC converter, secondary compensating components and battery. The circuit is implemented with the designed parameters and the components selection is made in order to satisfy the needs of battery charging for electric vehicles.

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VIII. SIMULATION RESULTS

The output of the rectifier is shown below and it is observed that the output of the rectifier is 229 V.

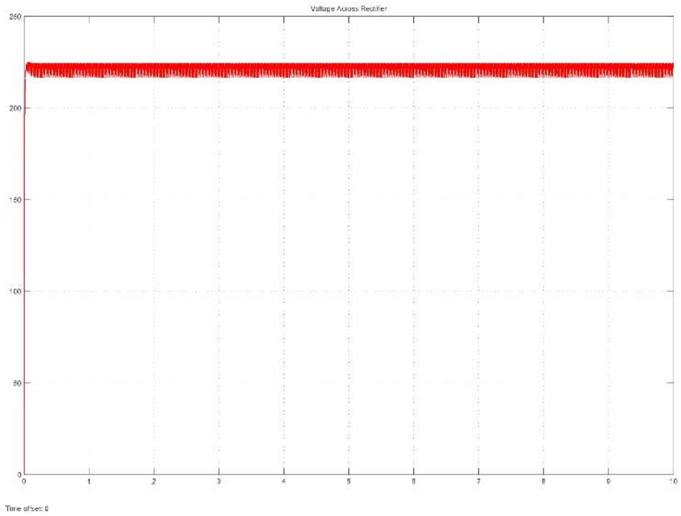

Fig. 5: Time versus Voltage output of AC-DC Converter

The output of the secondary rectifier is 58.2 Volts as shown in the waveform below.

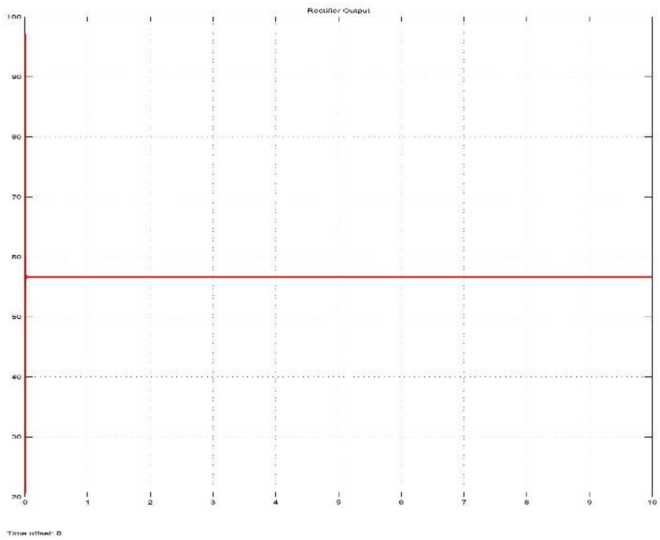

Fig. 6: Output of secondary AC-DC Converter

The graph drawn below shows the time verses voltage characteristics of the battery. It is observed that when the battery is discharged over the period of 10 seconds, the voltage is reduced from 56.625 V to 56.613 Volts.

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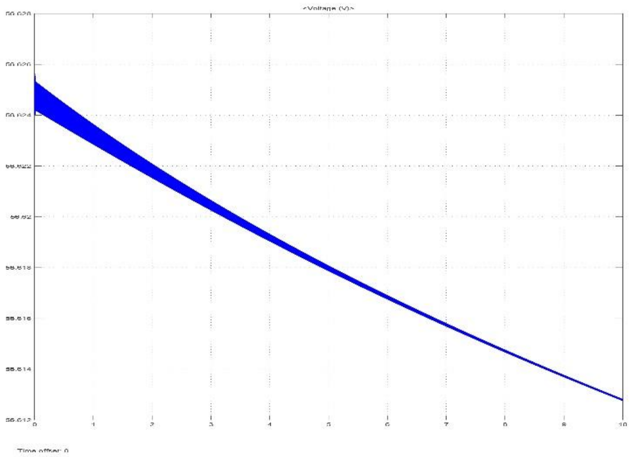

Fig. 7: Time versus Voltage Waveform of Battery

The simulation results are showing the small decline in the battery voltage when connected to the load. Figure 6 below shows the time versus % SOC (State of Charge). It is observed that over the period of 10 seconds the state of charge reduced from 100% to 99.992 %.

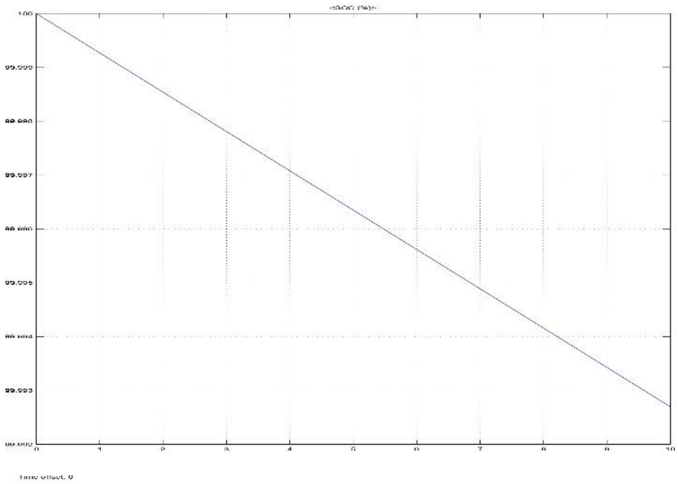

Fig. 8: Time versus % SOC Waveform of Battery

From the simulation results, the designed system is found suitable for the application of electric vehicles. The compensation circuit improves the performance of the system.

IX. CONCLUSION

The conventional vehicles in India are producing around 27% of total air pollution. This is an important concern and need to be improved. Electric vehicles are going to be the future of all transportation needs of the world in coming years. One of the problems associated with electric vehicles is if the user forgot to charge the batteries then the vehicle may not be useful to be used until it is charged.

To overcome this situation, it is necessary to develop the effective grid connected wireless charging system for the e-vehicles. Authors have implemented the wireless charging system for e-automobile in Simulink. It is observed that the system is suitable and reliable for the electric vehicles. The % SOC and charging characteristics of the battery are satisfactorily validated and found effective.

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