Study of Wireless Power Transfer System for Electric Vehicle Application using MATLAB

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Abstract - *The increasing use of automobiles around the world are causing serious environment problems. As a solution to this problems, efficient, cleaner and safer vehicles are needed. The evolution of electric powered drive train technologies is one of the most promising vehicle solutions for the future. The currently adopted system of charging the batteries of electric vehicles is plug-in charging which has several disadvantages like the use of bulky cable wires, decreased efficiency due to transmission and distribution losses and exposure to connection wires that can have safety problems. As an effort to overcome these drawbacks, wireless charging system is developed. A wireless power transmission circuit designed using the principle of resonant magnetic coupling is simulated in MATLAB/Simulink. Resonant compensation helps in overcoming the inherent low coupling and large leakage inductance, thereby transferring power effectively and efficiently. Series-series resonant topology with feedback design is adopted as the wireless power transfer DC-DC stage due to circuit simplicity, easy analysis and control.*

Key Words: Electric Vehicles, Receiver section, Resonant frequency, Transmitter section, Wireless Power Transfer (WPT).

1.INTRODUCTION

Over the last decade, many technological advancements have taken place in the field of electric vehicles (EV). Reduction in size of batteries, reduction of charging time, longer driving hours in a single charge etc are some of the areas where big strides have taken place over the last few years. But there hasn't been any improvement in the charging methods used. Even today electric vehicles are charged via plug-in chargers. So, the development of a wireless power transfer (WPT) circuit is to be the latest approach [1] that is to be taken inorder for further development of the electric vehicle industry.

In 2013, Tesla.Inc announced building a charging station as a method not to swap the battery for charging. Tesla created fast-charging stations in order to enable the charging of the battery within the electric vehicle. The wireless power transfer technology can eliminate all the charging troubles [2] for electric vehicle owners. By wirelessly transferring energy to the electric vehicles, the charging becomes the easier. In a dynamic wireless power transfer system [3], the electric vehicle could be charged while driving so that it could be run forever without stopping. The battery capacity of electric vehicles with wireless charging could also be reduced.

In a stationary wireless power transfer system, the drivers just need to park their car and leave. In this case the EV is possible to run forever without stopping. Also, the battery charging capacity of EVs can be increased with wireless power transfer technology [4]. The working principle of isolation transformer is same applied to the wireless charging systems that has a notable advantage that the primary side is isolated from the secondary side, so that any fault occurring in either of the sides doesn't damage or interprets the flow of current on the other side [5]. Therefore, WPT has wide range of applications that varies from small to large range of power transfer.

2. LITERATURE SURVEY

In [6], high efficiency wireless power transfer system for EV applications is considered and implemented. Series-series topology with resonant frequency feedback design is espoused for the wireless power transfer system because of its constant voltage transfer ratio which is dependent upon the turns ratio but is independent of the load, when resonating at 182kHz. A 500W test site prototype is constructed to test the viability of the proposed design. The experiment is carried out in 15cm air gap and maximum sliding of 10cm is considered between coils for power transfer. Resonant magnetic coupling is used for power transmission. When resonance takes place the power transfer is done efficiently without interpose of leakage inductance. According to the results, the efficiency can be greater than 90% with 15cm air gap at 500W rated power at 120V input conditions. If misalignment of coils is too large, desired output voltage may not be achieved.

EV [7] is one of the effective solutions for decreasing the greenhouse effect and global warming. It is the best alternative for conventional vehicle. In power electronic circuit, charging unit is desired to deliver high performance with minimum power utilization. LCC compensation network is used with converter circuit of the charging unit of EVs because it has high efficiency with lower circulating current, and have an ample range of regulation for both output

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 08 Issue: 06 | June 2021 www.irjet.net p-ISSN: 2395-0072

voltage and current. The paper on the whole describes the advantages of wireless power transfer system over the conventional procedures. In wireless power transfer system mutual inductance should be high enough for efficient power transfer. The resonant frequency of wireless power transfer system remains constant even during the variation of load as well as coupling coefficient between transmitting and receiving coil at zero voltage switching. At higher resonant frequencies, the efficiency is also high and it becomes better than conventional method. Therefore, the resonant frequency is unchanged for different coupling coefficient.

WPT has been an important topic of research discussion recently. In many related research works the coil is designed based on the classical methods where the parameters for the design is obtained either from the calculations or direct measurements. This technique has its own limitation when the coil has a complex shape and structure. In [8] discussions regarding the whole process of designing coils and building a wireless power transfer system using FEA model and MATLAB model is made and on the basis of simulation, the efficiency, coupling coefficient and maximum power transferred through the system has been calculated. Utilizing this data from the simulation, a prototype has been constructed. By comparing experimental result and simulation, it can be shown that the design procedure based on finite element analysis and MATLAB simulation is reasonable and valid.

Wireless power transmission circuits resonating at the frequency of 50 Hz and 60 Hz are used [9]. The purpose of this work is to develop a MATLAB simulation and MATLAB programming which can calculate the maximum efficiency that the system can achieve while transmitting power through concrete walls. The transmission efficiency is derived from the analysis of equivalent circuit after considering the copper and core losses, and it was found to depend on shape of the magnet pole pieces. For a load of 146.5 Ω, a transmission efficiency of 78.54% as well as a maximum efficiency of 76.57% was attained for a rectangular shape magnet. From the MATLAB program, it is very easy for calculating and tabulating the efficiency of the wireless power transfer system through concrete for the various parameters applied. Low frequency approach is not used as it is difficult to achieve large Q factor at lower frequencies.

EV batteries are advantageously charged by wireless power transfer system using inductive coupling method. The power supply circuitry is connected to transmitter side and receiving side is connected to load circuitry [10] and denotes the design and execution of WPT battery charger. Primary segment comprises of AC-DC converter followed by high frequency inverter. Secondary segment includes a diode rectifier followed by a chopper. The coupling coefficient of spiral coils is designed in Finite Element Method (FEM). As per the designed results, the prototype of wireless power transfer battery charger is developed and is tested to authenticate the design procedure. Controller used in primary side need to be taken care in order to avoid losses so that it does not affect the overall efficiency of the system at different stages of charging.

By studying the papers mentioned above, the design and implementation of wireless power transfer system for electric vehicle charging application was discussed and analysed according to different design considerations. Design aspects of power converters and coil designs capable of reducing power losses in the system was also mentioned. Connect an electric vehicle to the power grid to have a bi-directional power flow was also discussed. By conducting thorough analysis of the aforementioned papers, it has been inferred that the misalignment of coils has to be taken care in design to maintain constant output voltage. Also, the controllers used in the design have to be effective for power transfer, thus the overall efficiency of the system is not affected and regarding the resonant frequency, it has to be high enough so that for different coupling coefficient, the resonant frequency of the system does not change.

3. METHODOLOGY

In wireless power transfer system, a compensating network is added to the coil so as to produce resonance and to increase the coefficient of coupling and WPT efficiency of the system without considerable difference in the coil sizes. Generally, the magnetizing inductance of the coils used are small which in turn can induce large reactive power. To increase the inductance of magnetization, the number of turns can be increased at the cost of increasing the parasitic resistance of WPT and increasing conduction losses. Therefore, the reactive power and conductive losses of the WPT converter must be analysed properly to design the magnetizing inductance.

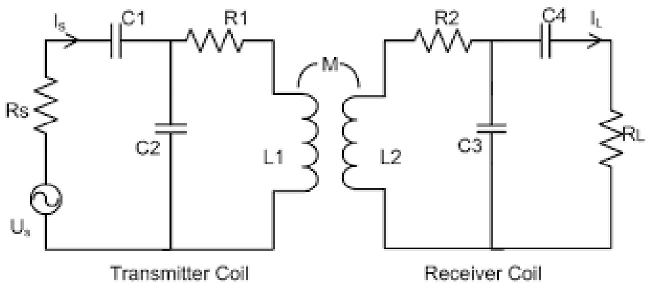

Fig -1: Model circuit of WPT system

Fig -1 shows the basic diagram of resonant WPT system. The system consists of an inverter followed by a transmitter coil and the compensation capacitor on the primary side. The secondary side consists of a receiver coil along with its compensation capacitor and a load connected via a rectifier. At higher power level with restricted input voltage there is a risk of reactive power values to exceed the required limits. This problem can be avoided by tuning the transmitter coil and making it slightly inductive for reducing inverter switching loss. Practically, a DC-DC link can be used between the battery and the rectifier output, and impedance matching stages can be introduced between coils and power stages. The given diagram only incorporates the basic structure of the system.

4. MATLAB SIMULATION AND RESULT

The goal is to develop a simulation in MATLAB/Simulink for wireless power transfer through air gap. The characteristics such as magnitude of voltage and current across the input, filter and output of full-length system can be discerned from MATLAB/Simulink simulation. The block diagram of MATLAB/Simulink simulation based on the proposed circuitry as shown in Fig -2. is conducted in order to determine the waveforms across different stages of wireless power transfer.

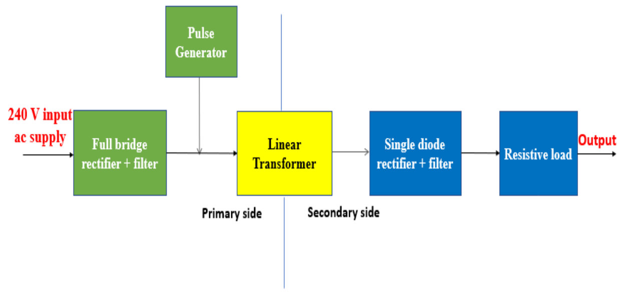

Fig -2: Block diagram of MATLAB simulated circuit of wireless power transfer system

Table -1: Circuit Parameters

Primary Capacitance	Secondary Capacitance	Load Resistance	Input Voltage
1500nF	47μF	20Ω	240 V

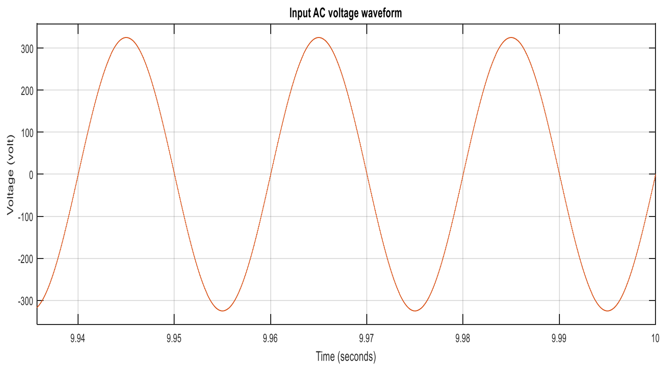

Fig -3: Input AC voltage waveform

The WPT system is provided with input of 240W 50Hz AC supply and a voltmeter is connected across it which helps in recording the values of voltage, followed by a scope to determine the input voltage waveform as shown in Fig -3. The input then enters the full bridge diode rectifier circuit which rectifies the AC power input and DC power having ripples within 20% is obtained as the output across the filter capacitor of 1500nF as mentioned in Table -1. This rectified output waveform is generated as shown in Fig -4 with the help of a voltmeter followed by scope.

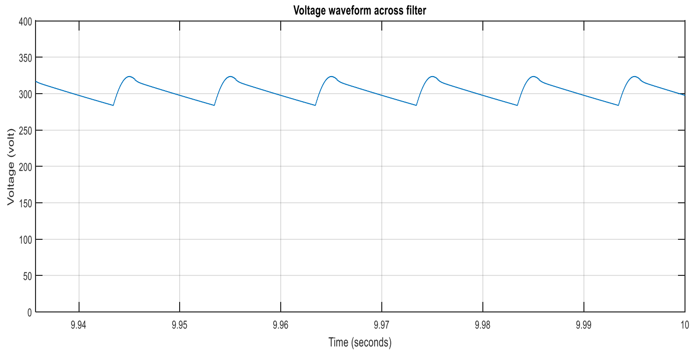

Fig -4: Primary side filter capacitor voltage waveform

The DC voltage is then transfigured into high frequency AC by using a pulse generator which is catered to the primary coil of linear transformer by employing a MOSFET switch. The pulse generator used is given a switching frequency of 125kHz. The AC power is transmitted to the secondary coil of the linear transformer when both the coils resonant at radio frequency of 125kHz and this phenomenon is referred to as resonant magnetic coupling. The received power is substantiated by the voltmeter in the receiver section which in turn is connected to a scope. The waveform across secondary coil is as shown in Fig -5.

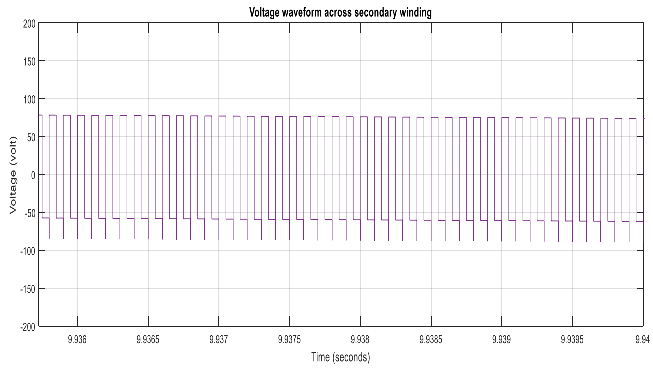

Fig -5: Secondary coil voltage waveform

High frequency AC power is used for power transfer so that the losses in air gap can be overcome and desired power can be given to the load in need. The output of secondary coil is put in as input to single diode rectifier so as to get rectified DC power output. Diode rectifier is used because of the moderate power in the secondary side. The rectified DC out is fed to a standard filter capacitor of 47μF as mentioned in Table 1. The filter output is fed to series RLC (load) and the final DC output is procured across the load as in Fig.6 with the help of voltmeter and a scope.

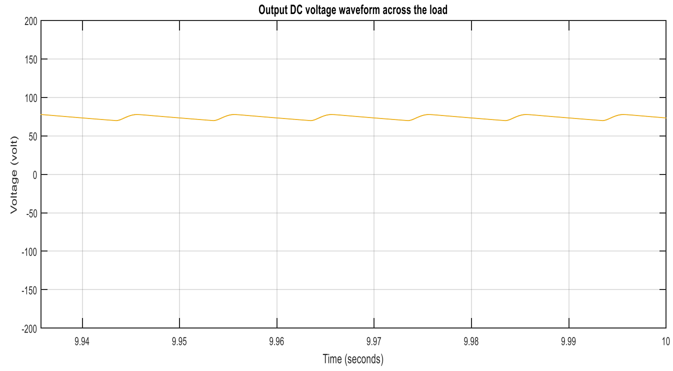

Fig -6: Output DC voltage waveform

From the above MATLAB simulations, the design and analysis of wireless power transfer system were conducted. It was seen that after providing a 240V ac voltage as input to the rectifier, after providing a high switching frequency from a pulse generator, and converting the voltage back to dc by using a single diode rectifier, a constant dc output voltage is obtained.

5. CONCLUSION

The necessity for operating energy efficient power mechanisms in high frequency environments led to the development of wireless power transmission. The literature survey depicts out the inefficiency of current methods for charging the EVs. Therefore, a high efficiency wireless power transfer system for EV charging applications is studied and simulated in MATLAB. From the MATLAB simulation, an 80V dc output voltage was obtained on the secondary side when a load resistance of 20Ω was provided. This flawless charging system is capable of balancing the power transfer and losses. Therefore, simulations in MATLAB substantiate that the required outputs are generated across each stage and hence the proposed circuit is suitable for wireless power transmission in vehicular application. In the coming future those EVs and its charging methods will be embraced over the conventional vehicles.

6. FUTURE SCOPE

Wireless power transfer technology is a field that has a huge potential of becoming a mainstream technology in the future. From the simulations that is conducted, the proposed wireless power transfer circuit can be used for EV charging applications. With the necessary research and development in this field, it is possible to create an electric bicycle from a conventional bicycle that is capable of charging wirelessly. Due to the inefficacy of designing coils of desired dimensions in MATLAB a famous 3D software known as ANSYS Maxwell 3D tool can be used to design the coils. In the future, the same circuit as used in this simulation can be replicated in ANSYS Twin Builder software and the coil design can be imported from ANSYS Maxwell 3D software to simulate the wireless power transfer circuit that is closer to the real-world hardware. With adequate development and innovation in this field, it is certainly possible to create wireless power charging stations capable of charging electric bicycles and electric cars or any heavy EVs from the same power charging station, at a faster charging rate than currently available charging techniques.

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