Design and Development of Prototype Model of Advanced Charging System for Energy Efficient Electric Vehicle

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Abstract

In the present scenario, the Electric Vehicles (EVs) are not much preferred by the customers because they have to search for fast charging stations, wait at long queues for recharging the batteries and also it is difficult to find an appropriate charging port. Hence wireless charging can have remarkable advantages over plug-in charging. The main purpose of introducing electric vehicle was to create a mode of transport which is energy efficient but in coal based countries like India this concept fails. This is because most of the electricity produced in these countries is obtained from coal which indirectly leads electric vehicle to cause equal pollution as the IC Engine vehicle. To ensure that the electric vehicles are energy efficient, charging of electric vehicle by utilizing solar energy is being introduced. The main aim of this paper is to introduce the prototype model of Advance Charging System for energy efficient Electric Vehicle. This paper deals with wireless charging through the concept of Resonant Inductive Power Transfer (RIPT). For Resonant Inductive Power to take place there is need of high frequency and high voltage at the primary coil. To operate the system at high frequency and high voltage, DC-DC Boost Converter along with Class-E Chopper is used. To operate the DC-DC Boost Converter and Class-E Chopper at switching frequency the PIC Microcontroller is used. To give proper pulse width modulation to the MOSFETs of DC-DC Boost converter and Class-E Chopper the gate Driver circuit is designed. The maximum variation in performance is compared with the conventional models and has been found 16% and the maximum output and the working of primary and secondary compensation circuit when charging the battery was calculated and the efficiency was found to be 48%.

Keywords: Electric Vehicle, Charging system, solar energy, Power transfer

1. Introduction:

In current scenario, the trend of Electric Vehicle in market is increasing. This is because, there is a widespread belief that electric cars can reduce carbon emissions and can prevent further deterioration of environment. But in bigger picture, the electricity required for charging EV is drawn majorly from thermal power plants which lead EVs to cause pollution as equal as a gasoline powered vehicle.
Schröder M et al., stated that electric cars running in coal dominated countries consume equivalent amount of energy as that of an average petrol car. Thus, from the above facts, it is very clear that going electric is not the key for greener environment. At present, the same stereotypic method is being used of wired charging wherein the vehicle is plugged in for hours to get full charge.

Olatunde O et al., stated that sometimes even improper fitting of charger ports or loose connection may leave the battery uncharged. Especially in cold zones, there is a chance of leakage of electric current from cracked old cables which may put the driver in hazardous condition. These limitations render the whole process almost pointless. Moreover, it must be noted that every vehicle has different battery and different charging ports and it becomes challenging for the driver to search the appropriate charging station. Thus, wireless charging allows the driver to be free from wires and provides a comfortable charging method by just parking the vehicle over the pod and leave. Also, wireless charging helps to standardize the charging of the entire car irrespective of their company.

In Figure 1, the legend to the right indicates the sources of power are the key difference between electric vehicle emissions in different countries. All the variation between Paraguay at 70 g and India at 370 g is the result of the difference in power sources. Hence it is very well understood that CO₂ emissions are not controlled even after using EV.

Sachan S et al., stated that utilization of solar energy will make the electric vehicle environment friendly. And this way the main purpose of using electric vehicles even in coal based countries can be achieved. Combining the wireless charging system and utilization of solar energy can lead to a better charging system for electric vehicle. This system will also prove to be efficient for dynamic wireless charging system.

Figure 1. Electric car’s carbon emission based on the source of energy utilized for charging
All the researches has been done on wireless charging system for electric vehicle, and the main research gap is that the purpose of using electric vehicle with wireless charging system is not being fulfilled. This gap can be overcome by using wireless charging system which utilizes solar energy to charge the vehicle. This paper focuses on wireless charging by utilizing the solar energy provides the solution to eliminate emissions produced due to charging of EV.

2. MATLAB Simulation:

The simulation model has been created in MATLAB 2009, which is shown in figure 2.

![MATLAB Simulation Model](image)

**Figure 2.** MATLAB Simulation Model

The simulation modal is divided into 4 parts which are DC-DC Boost Converter, Class E Chopper, Transmission through RIPT, Rectification Circuit.

2.1 DC-DC Boost Converter:

The function of DC-DC boost converter is to amplify the voltage, without much loses. In this setup the input of 12V is being amplified to 120V. Output is shown in figure 3.

![Output from Scope of DC-DC Boost Converter](image)

**Figure 3.** Output from Scope of DC-DC Boost Converter
2.2 Class E Chopper:

The function of Class E chopper is to amplify the input voltage from the DC-DC converter and to convert the DC input into AC output. 120V DC as input is being amplified and converter into 150V AC. The output from Class E chopper is shown in figure 4.

![Figure 4. Output from scope of Class E Chopper](image1)

2.1 Transmission through RIPT:

The transmission of energy for wireless power transfer takes place through resonant inductive power transfer. Input at primary coil is 150V AC and the output from secondary coil is 40V AC. Output from the Secondary coil is given in figure 5.

![Figure 5. Output from Secondary coil](image2)

2.3 Rectification Circuit:

For the rectification a full bridge rectifier is used to convert the AC into DC. A capacitor is used in parallel with the rectifier to reduce the harmonics. Input of 40V AC is converted into 10V DC. Final Output after rectification is given in figure 6.
3. Experimental Setup

The Block Diagram of experimental setup is shown in Figure 7.

Figure 7. Block Diagram of Experimental Setup

The specification of various components used in the experimental setup is discussed below.

3.1 Solar Panel:

In the setup mono-crystalline solar panel is being used. The specification of solar panel is it is of 10 W power and can deliver Voltage of 12V. Rated current output is 0.8 Amps and efficiency of solar panel is about 15-17%. Formula to find efficiency of solar panel is given below:

\[
\text{Efficiency} = \frac{P_{\text{max}}}{E \times Ac} \times 100 \%
\]
3.2 Battery:
In this setup, a sealed lead acid battery is used. The specifications of the battery are it is 12V and 1 Amps respectively.

3.3 PIC Microcontroller Circuit:
This PIC Microcontroller Circuit is used to generate the PWM signals to operate the switching of MOSFET. This gives output signals of 5V which needs to be converted into 12V to operate MOSFET, this is done by Gate Driver Circuit. In experimental setup PIC16F877A is being used. The main purpose of using this microcontroller is, it has FLASH memory technology.

This technology allows user to erase and re-write the code as many times possible. The other advantages of PIC are it is of low cost, high clock speed and the codes work efficiently allowing PIC to operate with less program memory.

PIC is Peripheral Interface Controller. PIC 16F877A is an 8-bit Flash microcontroller. Power consumption of this PIC is very low. PIC16F877A is a 40/44-pin device which can operate up to 20 MHz clock speed. It has 112,000 words flash program memory, 368*8 RAM data memory, 64 bytes of EEPROM non-volatile data memory.

The circuit diagram of PIC Microcontroller is shown in figure 8. and the real time microcontroller fabricated in shown in figure 9.

![Figure 8. Circuit Diagram of PIC Microcontroller](image-url)
Figure 9. Fabricated circuit of PIC Microcontroller

3.4 Gate Driver Circuit:

The Gate Driver Circuit is a kind of power amplifier circuit. This accepts low-power input from a microcontroller and produces a high-power drive input for the gate of a MOSFET. As shown in figure 8, the Driver Circuit receives 5V as input signal from PIC microcontroller and convert it into 12V to operate MOSFET.

TLP250 Gate Drivers are being used to give proper switching signals to MOSFET. The main purpose of using this driver is that, it is optically isolated. This means the input and output of driver will be isolated from each other.

TLP250 works like an opto coupler. Input stage has a light emitting diode and output stage has a photo diode. Whenever the input stage LED light falls on the output stage photo detector diode, output becomes high. And this way the driver will convert the 5V signals from PIC to 12V to operate switching of MOSFET efficiently. Fabricated Gate Driver Circuit is shown in figure 10.

Figure 10. Fabricated GATE driver circuit
3.5 Primary Circuit:

Primary Circuit comprises of DC-DC Boost Converter, Class E Chopper and Primary Coil.

3.6 Secondary Circuit:

Secondary Circuit comprises of secondary Coil, Ripple Capacitors and Full Wave Bridge Rectifier. The primary and secondary circuit realtime model is shown in figure 11.

Figure 11. Primary and secondary circuit

4. Results and Discussion:

The complete experimental setup of the prototype model is made and the reading of output from all the circuits is taken. The complete model is shown in figure 12.

Figure 12. Fabricated Model for Wireless charging
The comparison between the MATLAB Simulation and Hardware is given in table 1.

| Parameters                  | MATLAB Simulation | Hardware |
|-----------------------------|-------------------|----------|
| Voltage Supply at Inverter  | 12V               | 12.55V   |
| Voltage at Primary Coil     | 150 V             | 116V     |
| Voltage at Secondary Coil   | 40V               | 24V      |
| Final Output                | 10.2V             | 7.5V     |

The final output from the Hardware is 7.5 Volts. This is achieved when the setup is allowed to run for approximately 5 minutes. After this the output will be constant at 7.5V.

Experiment was done to determine the time it takes to get a constant voltage from the output of secondary circuit and the variation of voltage with respect to time is shown in table 2.

| Time(min) | Voltage(V) |
|-----------|------------|
| 0.5       | 2.8        |
| 1         | 3.5        |
| 1.5       | 3.9        |
| 2         | 4.2        |
| 2.5       | 5.5        |
| 3         | 6.1        |
| 3.5       | 6.66       |
| 4         | 7          |
| 4.5       | 7.27       |
| 5         | 7.49       |
The graphical representation of above data is shown in Figure 13.

![Voltage-Time graph](image)

**Figure 13.** Graph of Voltage Vs Time

The PWM Signal from the PIC Microcontroller is being tested by Cathode Ray Oscilloscope. The results obtained from CRO are shown in figure 14 and figure 15 respectively.

![PWM Signal to DC-DC Boost Converter](image)

**Figure 14.** PWM Signal to DC-DC Boost Converter

\[
\begin{align*}
T_{ON} &= 52\text{us} \\
T_{OFF} &= 56\text{us} \\
\text{Duty Cycle} &= \frac{T_{ON}}{(T_{ON} + T_{OFF})} = 48\%
\end{align*}
\]

![PWM Signal to Class E chopper](image)

**Figure 15.** PWM Signal to Class E chopper
5. Conclusion:

This research paper developed a prototype model of wireless charging system which has remarkable advantages over the wired charging infrastructure and the most importantly the energy requirement for charging the vehicle will be supplied majorly through the renewable source of energy (i.e.) solar energy. The primary battery used in this model will be charged through solar energy.

The following conclusions have been made based on the contents of the paper:

1. Charging the battery with solar energy until it reaches 90% SOC, and eliminate the saturation stage would reduce the charging time about 12% to 15%. This technique would also reduce the stress on the battery and thus prolong the battery life span and reduce the emission produced due to charging of EV.

2. The developed advanced charging system and its performance has been investigated and compared with the conventional models, the maximum variation has been found 16%, which is in close agreement between the advanced charger prototype and conventional charger to validate the prototype.

3. The wireless charging will not only provide the user with the flexibility of opportunity charging but will also help in improving the performance of the vehicle by battery downsizing, since in EV’s the battery pack accounts for about 1/3rd of the weight of the vehicle. The main focus was on charging the battery of the vehicle wirelessly for which the primary and secondary compensation circuit was developed to get the maximum output and the working of which has been discussed and the efficiency was found to be 48 %.

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