

# Three Phase Coil based Optimized Wireless Charging System for Electric Vehicles

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## Abstract

With modernization and technology enhancements on a global scale, environmental consciousness has also been increasing in recent days. Various technologies and automobile industries are vandalized with sustainable solutions and green technologies. Transportation via roadways is mostly preferred for distant travel as well, despite the advancements in airways and railways, due to less capital outlay, door to door service possibility in rural areas etc. The conventional fuel vehicles are a huge contributor to environmental pollution. Electric vehicles are an optimal solution to this issue. The lives of the common masses are not impacted largely by the electric vehicles despite their market commercialization since a few decades. It is due to certain challenges associated with the electrical vehicles. A 100% efficient perpetual machine does not exist yet. Predominantly, challenges related to charging, hinders the success of e-vehicles. Frequent charging is required in case of long-distance travel and other scenarios in the existing vehicles. Based on the respective governments, extensive changes are made in the infrastructure to overcome the issues at the charging stations. In this paper, an enhanced wireless charging module for electric vehicles is presented. The use of multiple coils is emphasized for building up energy and transmitting it. The inductive power transfer mechanism and efficiency of the system are improved with the design of a three-phase coil. The mechanism for assessment of the energy consumed in e-vehicles is also discussed.

**Keywords:** Energy efficiency, Charging Coils, Inductive power transfer, Electric vehicle



## 1. Introduction

Energy transfer while charging can be performed in wired or wireless manner. In wireless charging technology, electric and magnetic energy are used for loading electrical energy over various gaps to form cord connections that are exclusive. Hybrid e-vehicles [1] and other high to low end applications [2] make use of this technology due to its enhanced user experience. Damages to the environment and vehicle is reduced due to conditions like climatic change or public health as observed in conventional energy transfer models [3]. Interrupt is provided with susceptible energy forms like fuel and petroleum which forms the major dependency in the current scenario. The fuel cost observed in conventional vehicles is reduced largely with the plug-in feature in e-vehicles. The rechargeable batteries in e-vehicles are similar to those used in other electronic gadgets [4] that are used on an everyday basis. Charging of these batteries can be performed in various ways. The need for visiting fuel and gas stations can be reduced by frequent charging. Electric vehicles respond instantly to stimuli. They provide good torque and are extremely approachable.

Plug-in charging stations [5] are available as a customary public place for charging e-vehicles and to improve the movement of these vehicles. However, there are several ways in which e-vehicles can be charged. Rechargeable hybrid e-vehicle systems are used for enhancing the electric miles travelled by the e-vehicles especially on long travel routes. Electric Vehicle Supply Equipment (EVSE) [6] uses only DC in a public charger for charging hybrid electric vehicles in its transmission to the equipment. When compared to conventional charging schemes, DC fast-charge delivers energy at a rapid speed of 65 miles. Public charging facilities are located in crowded areas, government offices, hotels, airports, garages, city parking lots, shopping centers etc., where the concentration of vehicles are high [7]. When compared to conventional vehicles, several challenges are faced by electric vehicles. The plug-in charging is often time consuming

and is definitely a drawback compared to conventional vehicles. This paper provides a wireless charging solution [8] for electric vehicles that helps in overcoming this drawback.

## 1.1 Wireless Power Transfer

At roadside parking bays and parking lots, popularity is gained by the placement of wired charging points. However, the need for charging electric vehicles cannot be sufficed by the fixed charging point wired stations [9-11] that can be placed as road side units with the increase in the number of electric vehicles caused by the price increase and depletion of conventional fuels. The need for stopping at the charging station can be overcome by the wireless charging technique. A global standard [12] is followed for wirelessly charging e-vehicles by the automobile industries during the planning and launching stages of e-vehicles [13]. On an everyday basis, a large volume of global share is held by the wireless charging market which is increasing continuously. There is an expected increase in the revenue generated by wireless power globally from 8.5 billion dollars to 17.9 billion dollars from the year 2017 to 2024 according to a survey [14]. This represents the possibility of massive growth in the wireless market.

The major challenges [15] hindering the substantial and phenomenal implementation of wireless charging are as follows:

1. The use of wireless control is comparatively low despite their availability. A true wireless experience is not provided to the users by the current wireless power technology leading to challenges in customer responsiveness. The wireless power is compromised at several stages as opposed to hard work principles. The adoption of wireless power transfer can be enhanced by providing better stability and control to the existing electronics. The currency reserve crunches are caused mainly due to battery removal.

2. There is a huge load imposed on the power grid with the large-scale commercialization of electric vehicles. The wireless charging device-based power consumption is not measured effectively by the existing systems.
3. When compared to plug-in charging, the implementation cost of wireless charging is high. Crafting wireless charging materials that optimizes wireless charging systems is also expensive considering the high temperature of hyperchargers.

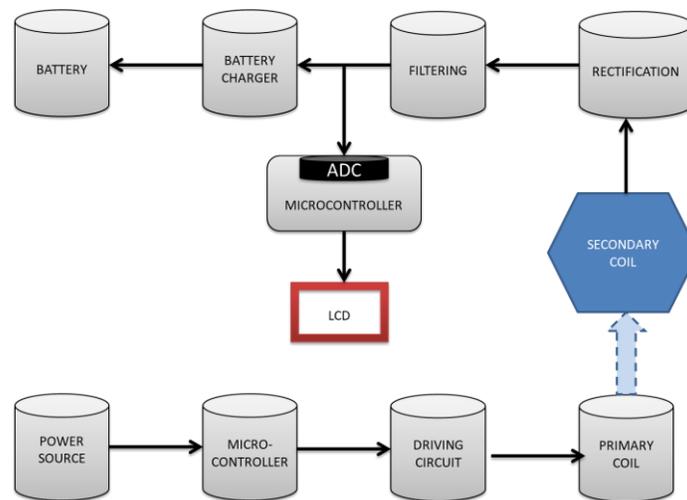
## 2. Literature Survey

For wireless charging of any equipment or device [16], several techniques are proposed by scientists globally. Radioactive RF-based inducting [17] and nonradioactive coupling-based arraign [18] technologies are the major classifications of wireless incriminated technology. Capacitive coupling, magnetic resonance coupling [19] and inductive coupling techniques [20] are used in various existing literature for sorting directive RF power beams [21] into non-directive RF power transfer [22] and structures. The attainable capacitance combination quantity in the electrical capacitive union process relies on the mechanism's accessible region [23]. The plan constraints must be overcome to produce energy that is sufficient to meet the indicated thickness for transferring substantial characteristic-volume for charging the device [24]. Limitation [25-27] lies in the stallion in directive RF power with the requirement of knowing the exact location. Wireless charging technique is the most preferred solution to overcome all these aforementioned drawbacks.

## 3. Proposed Method

Fig.1 shows the proposed work representing a chunk illustration of a wireless power supply system that can be used in electric vehicles for charging the battery. It is made up of a transmitter

that is used to transmit the analog signal generated by means of a powerful coil [28], for the sender. This signal is received by the receiver (non-wired) which further converts the AC signal into DC voltage which can be used for charging the electric vehicle's battery. The purpose of the proposed work is to build a wireless power system prototype that is capable of preventing power wastage and sequence of electric vehicles. Here, the design of the coil is highly crucial and can be used to identify the quality and quantity of power received as well as the power transmitted. In order to minimize the losses, both the receiver and the transmitter end coil are turned to match one frequency. The following section gives an outline of the three-phase coil structure designed. Ferrite core is the basic material that is used in both recipient and source [29, 30].



**Figure 1.** Proposed Wireless Power Supply System

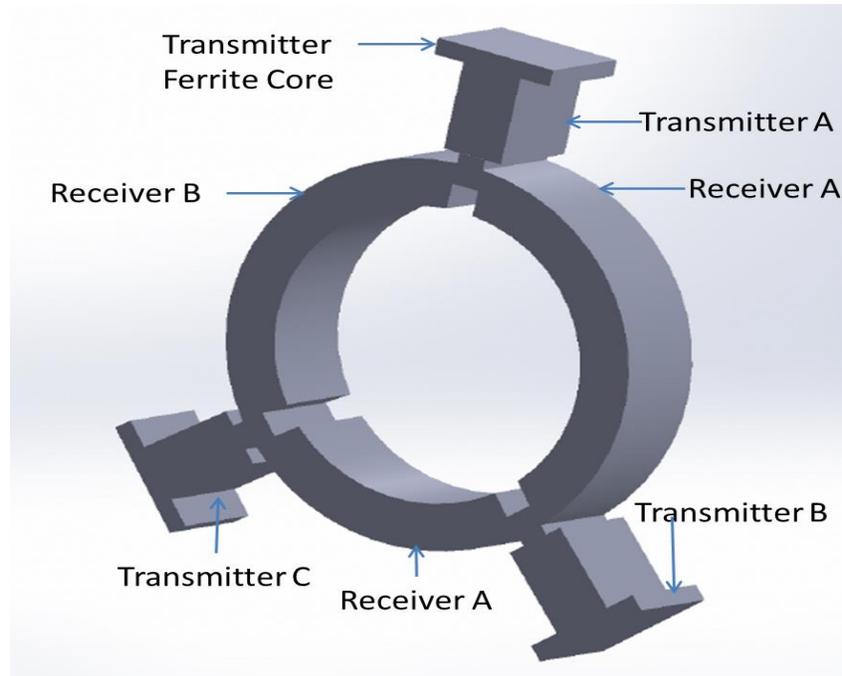
The battery used in the electric vehicle uses only DC supply for charging and in order to convert to DC from AC, a rectifier is used. IGCT and IGBT are the components used in the rectifier which incorporates SCR instead of a diode in order to decrease the conversion losses. For producing a ripple-free, regulated DC supply that can positively charge the battery, elimination of any harmonics is done with the help of a filtering block, LC strain. To reduce the DC supply

magnitude, a voltage regulator is also used prior to the charging phase. In order to attain high efficiency, the minor and major coil are placed at 5.8-8 cm distance from each other during inductive power transfer.

### 3.1 Coil Design

Since the efficiency and power of the wireless charging system depends heavily on the coil, coil design plays a crucial role. A three-phase coil structure made up of 3 receivers and transmitters are represented in Fig.2. The structure is designed in such a way that it can positively improve the power transfer efficiency. The purpose of attractive ground resulting from future spiral arrangement is denoted with 3D FEA simulations. This proposed coil is extremely efficient as it comprises of three receivers and transmitters which work together to ensure that the fluctuation developed through one transmitter is sent via the receivers located adjacently and is then sent back to the transmitter. The biggest dissimilarity between the proposed coil and coaxial coil is that when compared with coaxial coil, the proposed coil has a concentrated magnetic field. ANSYS MAXWELL simulation tool is used in this work to determine the parameters of the coaxial coil and three-phase coil as shown in Table 1 and Table 2. Based on the simulation analysis, the following are the conclusions:

1. In the YZ-plane, both the coaxial coil structure and the three-phase coil structure result in good performance. This is based on the consideration that the three-part spiral arrangement of the coil results in weaker field along the center and strong field around the receiver's coil. On the other hand, the attractive pasture is designed such that the field is weaker along receiver coil and stronger at the center.
2. In ZX-plane, the three-phase coil structure indicates better performance since the magnetic field generated is stronger in the coil structure and will have less impact on the existing devices.



**Figure 2.** Three-phase coil structure

**Table1.** Simulation Results

Parameters	Coaxial coil	Proposed Coil
Mutual inductance between $L_r$ and $L_f$	9.55 $\mu\text{H}$	9.22 $\mu\text{H}$
Coupling coefficient between $L_r$ and $L_f$	0.582	0.138
Receiver's self-inductance	15 $\mu\text{H}$	33.88 $\mu\text{H}$
Transmitter's self-inductance	17.94 $\mu\text{H}$	131.69 $\mu\text{H}$

**Table 2.** Excitation in Simulation

<b>Parameters</b>	<b>Coaxial coil</b>	<b>Proposed Coil</b>
Number of turns in receiver's coil	6	18
Number of turns in transmitter's coil	6	30
Receiver's self-current	15 A	5 A
Transmitter's current	3.58 A	3.71 A

#### **4. Measuring Energy—An Experimental Setup**

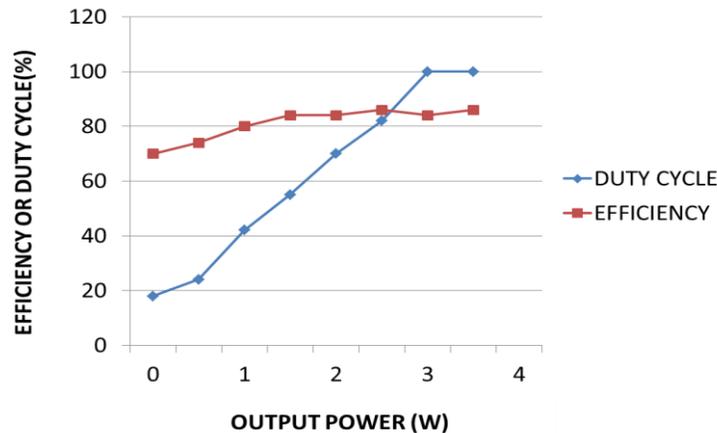
In this proposed work, the microcontroller used for operation is the Arduino Uno. It behaves as the channel of communication between the energy meter and the GSM module. Coding of the Arduino controller takes place using simple programming languages. The primary purpose of the board is to use a predefined formula to determine the amount of energy consumed by the electrical load. Simple and cost-efficient LEDs are used to indicate the power consumption representation in energy meters. Here 1kilowatt-hour (kWh) energy is equivalent to 3200 blinks of the LED light. Hence, on applying simple mathematical calculation, one can come to a conclusion that every pulse/blink denotes 0.0003125 kWh energy of power consumption. Arduino captures/counts the total number of pulses or blinks used to measure the total consumed energy. Here, with the help of connecting wires, a GSM 900 and Arduino board are interfaced together. The open-source Arduino is used to program the board and the GSM module provides the extra feature of sending messages with the help of If This Then That (IFTTT) software. This is also an open-source software service that has an ‘applet’ of uncertain announcements. In this work, the data received in an android phone is transferred onto the google drive, and saved in a Google sheet.



Fig.3 shows the data saved on to the sheet for a shipment unit with the cost consideration. A 16MHz crystal oscillator triggered ATmega 328 is used as the Arduino board for this experimental setup. This methodology is incorporated real-time in an electric vehicle to determine the total amount of energy produced and consumed. It can be easily and efficiently installed in electric vehicles for monitoring the energy consumed by the vehicle.

	A	B
1	Time Stamp	Messages
2	November 20, 2021 at 12:15PM	Unit: 0.000313 Price: 0.00158
3	November 20, 2021 at 12:15PM	Unit: 0.000542 Price: 0.00242
4	November 20, 2021 at 12:15PM	Unit: 0.000731 Price: 0.00352
5	November 20, 2021 at 12:16PM	Unit: 0.000963 Price: 0.00524
6	November 20, 2021 at 12:17PM	Unit: 0.001256 Price: 0.00742
7	November 20, 2021 at 12:18PM	Unit: 0.001439 Price: 0.00946

**Figure 3.** Applet for saving data on Google Sheets



**Figure 4.** Efficiency of Output Power Vs. Duty Cycle

Fig.4 depicts the results of the proposed work such that it doesn't include the final step-down. 4MHz switching frequency is recorded. The efficiency level should be maintained across the range of output powers to achieve first order. However, due to the dynamics related to switching of the transmitter, there is a possibility of efficiency drop when handling light loads. At 3 W of output power, a peak efficiency of 89% is observed. Fig.11 indicates the duty cycle of the proposed work. Below 3.2 W, the transmitter will turn off and will continue to be turned on otherwise. The threshold power is based on the reference tank current. Below this threshold, the duty cycle will scale in a linear fashion, as predicted.

## 5. Conclusion

Electronic gadgets which operate on cord connection make use of frequent elimination option which improves their performance. In this paper, this frequent elimination is also incorporated in wireless power transfer. This methodology when incorporated in electric vehicles will decrease the drawbacks of conventional fuel usage and will also strike a balance in ecological development. A wireless power transfer-inductive power transfer is introduced in this work with focus on new methodology for wireless energy consumption measurement and innovative coil design. Output results also indicate that the performance and reliability are high when used in macroscale.

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