

# Rectifier Load Analysis for Wireless Charging System for Electric Vehicles

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## ABSTRACT

We look at the rectifier-based load applied to the electric vehicle (EV) system under wireless charging schemes, along with its many applications to compensation network design and system loading prediction. The first stage is to construct a rectifier load-based model structure to establish its equivalent to the input impedance values. The properties of the rectifier circuit, including the component's resistance and inductance, can be used to independently estimate these values. The architecture of the compensation network is then suggested using the results of the rectifier load analysis. A method for evaluating the primary side load as well as a method for estimating the secondary side load are also suggested. Both of these techniques, which rely simply on voltage measurements, require an examination of the effect of the load connected to the rectifier. To show that different values of system load resistances, DC voltages, rectifier input inductances, and mutual-inductance values as circuit parameters can accurately estimate the rectifier equivalent load, an electric vehicle wireless charging prototype will be simulated, and experimental results will be compared.

**Key words:** electric vehicle (EV), DC voltage,

## 1. Introduction

The input side ports impedance, which includes the components of inductance and resistance, are equivalently calculated as part of the rectifier load design, while the parameters for the rectifying circuit are independently calculated. On the basis of the load analysis of the rectifier, a method for the compensation circuit system is being provided to achieve the decoupling system design for the primary and secondary side capacitors utilised for compensation. Additionally, a primary side load estimating approach that considers the impact of the rectifier load is proposed, as well as a secondary side load estimation method. It exclusively employs voltage measurements to prevent discrepancies brought on by various phase delays between the recorded current and voltage. Based on the creation of an EV wireless charging prototype, the established model, the proposed method of calculating rectifier load, the design method of compensation circuit, and the primary and secondary end load estimation approach are verified in the final step. The following conclusions can be drawn from the results of the experiment: System load resistance and rectifier input inductance have the most significant effects on the equivalent input impedance associated with the rectifier load; The rectifier load equivalent inductance has an effect on the system's performance and must be taken into account when designing the compensation circuit; The proposed

load estimation methods are accurate, but further development is needed to make them even better; The works in this report are conducted based on the specific model type, but they can be extended to multiple types of applications, such as wireless charging systems that consist of the other rectifying unit or topologies of compensation circuit, etc. The proposed calculation method of rectifier load and load on system estimation methods possess a high level of robustness on conditions related to the parameter variations in wireless charging systems. When creating wireless charging systems for electric vehicles, they will be useful as system models and controllers to achieve high performance and stable operation.

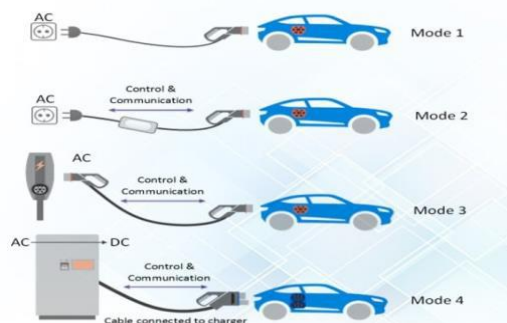
In addition to the cost point, the long time required for charge related to the electric vehicle systems storage units also made them unacceptable to most of the drivers. For the one time of charging, it takes approx one and half-hour minimum to the several hours that depends over the level related to the power related to the the associated charging device. In this way it is very long time compared to the refuelling procedure of the gasoline. The electric vehicle systems donot getting ready in small time duration if they are running out related to the battery energy. For overcoming this, the owners sould most probability prefer for finding any possible opportunity that is plugging and charging the storage unit. [5] It really brings some complex for the consumer may forget to plugging and

finding themselves run out related to the battery energy back up in later on. The cables used to charge on the floor may bring hazards if tripping. Leakage from cracked old cable, particularly in cold countries, may bring additional hazardous situations for the vehicle owner. Also, people can have to brave the rain, wind ice, or snow to plugging consist of the risk of getting the electrical shock. [7][8] The Wireless Charging System (WCS) technology, is capable of eliminating all the troublesome associated with charging, is desirable by the electrical vehicle owners.

By wireless transfer of the energy to the electric vehicle systems, the charging is getting easy. For the wireless charging system that are stationary, the vehicle drivers needs parking the car and leave. [9] For a dynamic type related to the wireless charging system, the electric vehicle systems may be powered while driving; the electric vehicle systems is possible for keeping in run forever without a stop. Also, the capacity related to the battery related to the electric vehicle systems consist of the wirelessly charge unit may be reduced to 30% or less in comparison to electric vehicle systems consist of the conductive charging. [10]

#### Wireless charging system technology for electric vehicle:

Depend on the power supply level and on the time of charging, electric vehicle charging is divided into Mode-1, Mode-2, Mode-3 and Mode-4 [11,12] Mode-1: This is the most cost-effective and convenient method for a home-based charging scheme, but it generally works the slowest. Electric vehicles have on-board circuit systems for the battery charger and cables that connect to the vehicle's outlet in the garage. This makes it possible for owners to plug their vehicles in. Electric vehicles are being charged in mode 1 using a standard household supply of 230 V and a limited



**Figure1 : Wireless charging system technology for electric vehicle**

15 Ampere current. Depending on the vehicle, charging times can vary significantly, but it typically takes between 8 and 20 hours for a fully charged battery in a compact electric vehicle to replenish its rating.

In order to connect the electric vehicle's system to the power outlet, Mode-1 necessitates the use of standard industrial plugs and sockets. Due to the requirement of an earthing connection, which is not a standard parameter in domestic electric plants in the United States, this mode of related charging is prohibited.



**Figure 2: Different modes related to the electric vehicle charging.**

Mode 2: This method of charging requires a single-phase or three-phase ac supply of 220 V or 440 V with no more than 30 Amperes. Similar to Mode 1, electric vehicle systems can be connected to wall boxes in garages or charge stations in public places like restaurants, shopping malls, parking lots in cities, and specific workplaces without the need for a socket or plug. The circuit needed to carry out safety functions like energizing and de-energizing the device, checking for continuity of the protective earthing conductivity, verifying the vehicle's proper connections, and so on are contained in charge boxes, charge stations, and the on-board charger for the battery storage. Because vehicles only use Mode 2 charging when they have the chance, it is typically referred to as "opportunity charging." The Mode 2 charge system scheme requires about four to six hours to fully charge a small car.

Mode 3: It typically runs on a three-phase 440 V ac supply and needs up to 63 kW of power to power the charger's on-board battery circuit through dedicated sockets and plugs. In addition to safety

features in Mode 2, battery circuit on-board chargers and charge stations used appropriate protocols to synchronize the entire operation. A mode 3 charging system enables a compact vehicle to fully charge in less than an hour thanks to the availability of high power. Mode 3 charging is available in airports, transportation corridors, commercial and public areas, and for large vehicles like electric buses [9].

Mode 4: In this mode, a rectifying unit installed in the charge station transforms the AC mains supply into the DC supply. An off-board charger that provides the electric vehicle with a battery supply of up to 450 Amperes through a plug and sockets. The widely dispersed mode 4 charging implementation of the standard Japanese model known as "CHAdeMO" With a power supply of up to 50 kilowatts, it can charge a small car in under 30 minutes. The Magne Charger, also known as the J1773, was used by General Motors to introduce two electric vehicles in 1998: the Chevrolet S-10 and the EV1. These vehicles were based on the inductive transfer of power principle. In place of plugging, the electric vehicle inserts a "pad," which houses the primary coil.

A wireless charging system (WCS) made with a transformer was designed with the slot that houses the secondary coil and the pad. These pads don't seem to be doing very well. When compared to the conventional plugging system, this pad must be manually inserted into the electric vehicle. A lot of research is being done right now to make electric vehicles the best choice for transportation in the future in response to the growing interest in electric mobility in the present.



Figure 3: Wireless electric vehicle charging station for multiuser in parallel processing at single time

The wireless charging method and charging mechanism have the potential to significantly alter public perceptions of electric vehicles. Having a limited driving range is expensive and inconvenient when it comes to charging. However, with the introduction of wireless system charging methods for charge replenishment, electric vehicles may emerge as an appealing option. The advantages of wireless charging include the ability to automate the charging process, make it simple and secure for users, and the large-scale introduction of the wireless charging system charging structure can help reduce the size of the battery box, which in turn makes electric vehicles very efficient. Be that as it may, this can't be satisfied by utilizing customary inductive charging and remote charging framework through high air expanding and low conceivable human communication prerequisite. Qualcomm, GM, Toyota, Delphi, and other major manufacturers in recent years are expressing an interest in a wireless charging mechanism, and Qualcomm is currently introducing an electric vehicle-specific wireless charging system. Additionally, this application's research is being followed by multiple research organizations from various academic institutions.

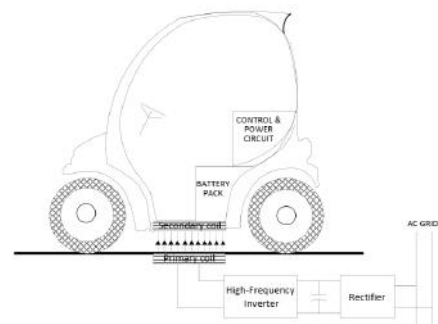


Figure 4 : Schematics related to the wireless charging system for electrical vehicle battery charging

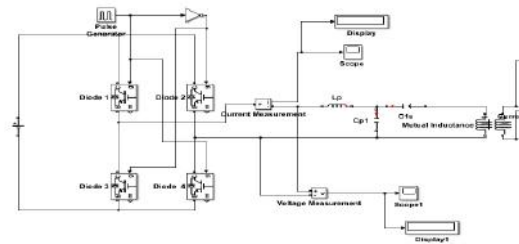
The wireless charging system for electric vehicles is depicted in Fig. 4. The wireless charging system mechanism's primary side winding is buried in the ground and connected to the grid via a converter system-based connection. This connection is based on transferring power to the wireless charging system method's secondary side winding coil. The charge circuitry that powers the storage battery is carried out by the secondary side connections, which are found inside the electrical vehicle.

## 2. Methodology

The wireless charging system technology for electric vehicles, getting recognition for delivering electrical power over the connected load in safe, efficient and convenient manner by applying the schemes of magnetic coupling without any type of wired connection, has significantly attracting most of the attention of the scientific organizations and academic institutes in recent time. This promising and emerging approach is evolving rapidly and implemented in a wide manner for most of commercial sectors like the electric vehicles charging system, power supplies if train, power systems in the underwater applications, implacable biomedical equipments , consumer electronics and different industrial schemes But, the major common method of charging used for most of the applications is the conventional charging by the plug-in, it is very inconvenient for the users and consist of safety issues like electrical shock, especially in a wet atmosphere or location. For solving such issues, the wireless charging system for electric vehicle technology is researched extensively and is expected for replacement of the recent method of charging by plug-in system in most of the future scopes.

In this work the Simulink model is designed for the wireless charging system mechanism for electric vehicle system. The complete model is divided into two parts. Source side present at the connection end of primary side of coil (mutual inductance) responsible for transmission of electrical power by electromagnetic induction. The load side is connected at the end of secondary winding of this coil.

The primary side mainly consist of a DC source, an DC to AC converter, pulse generator and Primary side compensation Circuit circuit. The DC source supply given to the DC to AC converter. This converter is controlled by pulse generator and the output of DC-AC converter passed through Primary side compensation Circuit circuit and finally connected to the primary side of electromagnetic coil as shown in the figure 1(a).

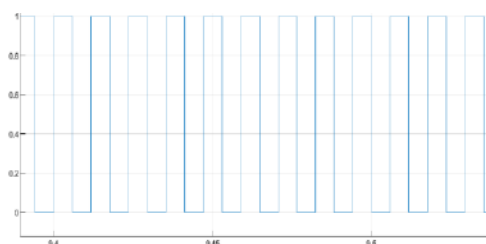


**Figure 5.: Simulink based designed model of wireless charging system connected to primary side of electromagnetic coil**

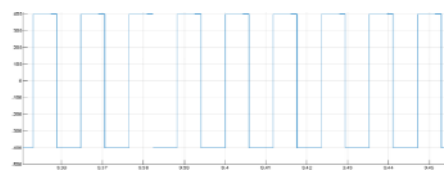
The first component of primary side consist of a DC voltage source. This source is of 400 V in magnitude and it is large source for long term charging of electric vehicle system. The supply of this DC voltage source is connected to the DC to AC converter acting as an inverter circuit design.

## 3. Results and Discussions

In this chapter the simulation results of the wireless charging system based Simulink model are shown and discussed. The wireless charging system model made on Simulink software of MatLab 2021 version. The toolbox used here are based on SimPower system tool. The block based designed model consist of two parts for charging system. Part 1 is called the transmitter side connected to the primary side of electromagnetic coil. The part two is connected to the secondary side of the wireless charging system and considered as receiver end of wireless energy. The model working hence starts from the transmitter side in which first of all a DC to AC converter circuit is present that converts the DC power of battery to AC.



**Figure 6: AC current produced from the DC to AC converter in transmitter side**



**Figure 7: Pulse signal from the pulse generator given to DC to AC converter in transmitter side**

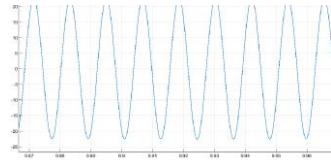


Figure 8: AC voltage produced from the DC to AC converter in transmitter side

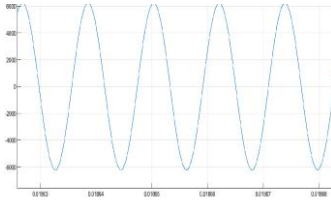


Figure 9: AC current produced from the LLC compensation circuit in transmitter side

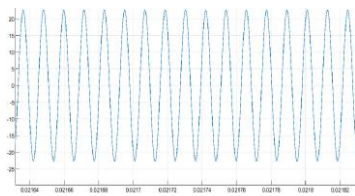


Figure 10: AC voltage produced from the LLC compensation circuit in transmitter side

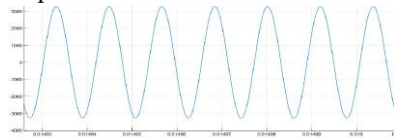


Figure 11: AC current at the secondary side of coil in receiving end

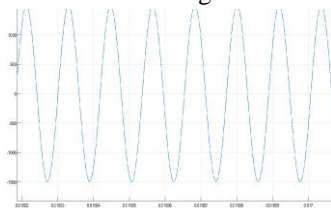


Figure 12: AC voltage at the secondary side of coil in receiving end

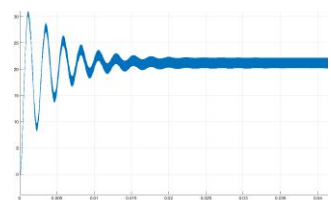


Figure 13: AC voltage obtained at the output of secondary side compensation circuit

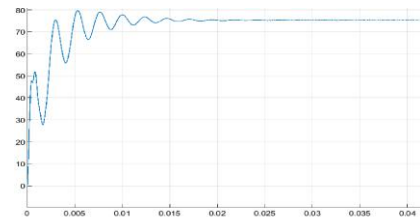


Figure 14: DC voltage at the output of full bridge rectifier.

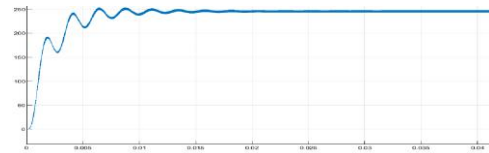


Figure 15: DC voltage after filtering the output of rectifier

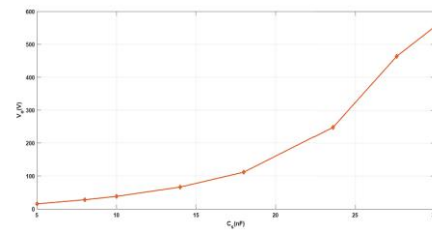


Figure 16: DC voltage after the DC-DC boost converter at the load end.

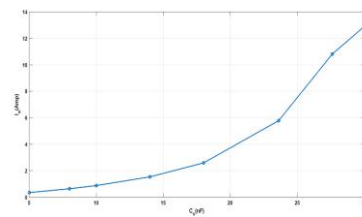


Figure 17: Variation of load voltage  $V_{out}$  with respect to compensating capacitance  $C_s$ .

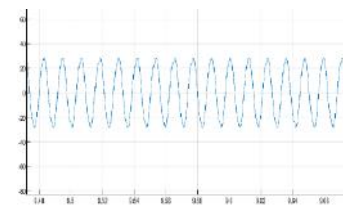


Figure 18: Variation of load current  $I_{out}$  with respect to compensating capacitance  $C_s$ .

### Conclusions and Future Scopes

In order to describe the benefits of the proposed model, the performance of the proposed model is observed in detail. The superiorities of the proposed model are found in terms of minimization of the use of passive components that ensures that the receiver side is getting lighter and smaller in size.

The wireless communication devices generally used for providing the feedback in real-time for parameters of charging in the transmitter and the receiver

is eliminated. This communication link free design of wireless charging system used on transmitter-side LCC compensator circuit reduced the cost and minimize the interference by the elimination of the wireless communication linking system used for the transmitter and the receiver side ends. It has ensured the miniaturization, portability and compactness of the receiver end side connected systems that is suitable for charging applications like portable electronic devices, biomedical implants, electric vehicles etc.

In this work, the wireless charging system's constant voltage output is provided by the LCC compensation circuit with CC output. The compensation capacitance is used to conduct a thorough analysis of the performance. In addition, the designed LCC compensation aids in minimizing power supply losses and increasing system efficiency, achieving the stable condition. The model for removing wireless communication links has been realized by the wireless charging method. The model has the advantage of providing a lightweight, miniaturized, and compact load side circuit without the need for parameter measurement.

To validate the proposed wireless charging system, a real-time application-based experimental design may be developed in the future. By measuring the rms value of the current during the charging process, a charging estimation method can be used to achieve a more accurate and feasible constant current voltage mode with a negligible estimation error. The simulation analysis and the experimental results may be brought into perfect agreement. The approach that has been proposed looks promising for a variety of charging applications, such as charging applications for portable electronic devices, low-power biomedical implants, and high-power electric vehicles.

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