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Simulation Based Design and Development of a Wireless Inductive Charging System for an Electric Vehicle

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Abstract. In this study, the simulation-based design and development of a wireless inductive charging system for an electric vehicle using Matlab-Simulink is presented. First, existing chargers are compared to extract some specifications. Secondly, design and simulation on Matlab-Simulink are performed. Finally, a small rendering study is performed.

Keywords. Wireless charging; Inductive vehicle; simulation motor; converter battery frequency.

1. Introduction

Not a day goes without thinking about mobility. Vehicles are essential in our everyday life and because of global warming, the world is trying to change all its habits and try to decrease greenhouse gas emissions.

Electric vehicles are developed because they offer hope. Their promises are to be more sustainable, to not emit CO_2 and to be a really strong alternative to classic motor vehicles.

The problem is that those vehicles need to recharge their batteries. The classical way is to plug the car through a classical station to charge the battery. This method can be inconvenient because it can take hours to charge the battery. However, some charging stations can charge batteries within an hour but most of the time they are installed on highways, where it's inconvenient to charge them.

So, car companies are searching to develop a new way to charge car batteries: Faster, compact and easy to use. That's why induction charging stations have emerged. Used since few years to charge phones and also in the kitchen as hob, vehicles manufacturers want it as the new way to charge vehicles.

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In order to understand the principle of this type of charging station, simulation can be performed on Matlab-Simulink. That software allows to simulate electric and electronic circuits thanks to a large and diversified choice of library into Matlab software. This study has the goal to explain through simulation the working principle of inductive charging stations.

2. Literature Review

In order to standardise the induction charging of car batteries, the J2954 norm has classified the induction charging systems by their nominal power and by the distance between the secondary coil and the ground. Thus, four ranges and three classes have been defined in the norm [1].

To prevent any health risks that could be associated with magnetic radiation, the J2954 norm specify that the public can't be exposed to magnetic fields of intensity above 27 uT for frequencies between 3 kHz and 10 MHz (according to the International Commission on Non-Ionizing Radiation Protection [1]).

Some companies already commercialised their solutions such as Evatran with its charging system of 7.2 kW named PluglessPower. This charging station is compatible with some cars such as Tesla S and BMW i3. Owners of those cars can install this charging station at home for 3500$ [2].

- Resonating frequency: The resonating frequency chosen by the SAE through the J2954 norm is 85 kHz. That's why the considered resonating frequency in the following study will be $f0 = 85$ kHz;
- Battery voltage range: According to the electric car market, the voltage range of the induction charging station has to be between 350 V and 550 V;
- Current and power of the charging station: Referring to the SAE J2954 norm, there's 4 level of power for charging stations (3,7 kW to 22 kW). The output of the charging station will be 22 kW (for a battery voltage of 550 V). Therefore, the maximum charging current will be of $I = 40$ A (voluntary high to design a demonstrative system).

3. Methodology

The study employs a two-step methodology. The initial step consists of a theory and calculation part. This part has the goal to find coils dimensions referring to frequency equivalent and magnetic flux equivalent. The second part of the study consists in modelling and simulating an Inductive charging station.

For the first step, by admitting M as the mutual inductance, the equivalent of the two parallel coils can be observed on figure 1.

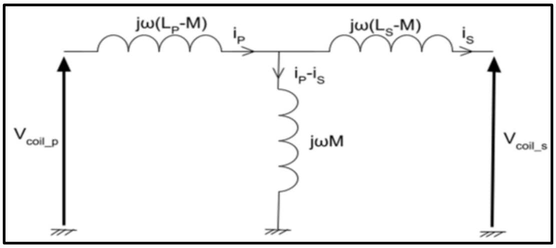

Figure 1. Equivalent schematic in frequency of the system.

The relation between *M*, *Lp* and *Ls* is the following:

$$M = k * \sqrt{Lp * Ls} \tag{1}$$

For choosing *Lp* and *Ls* values, the case when *Vcoilp* = *Vcoils* is chosen to simplify. In that case *Lp* and *Ls* formula are:

$$Lp = Ls = \frac{Vcoilp}{k*w0*Is} \tag{2}$$

By choosing *Vcoilp* = 550 V, *Is* = 40 A, k = 0.2 and f0 = 85 kHz values of *Lp* and *Ls* are 104 µH.

The second step consists in designing the charging station. Figure 2 shows the minimal architecture to build an inductive charging station.

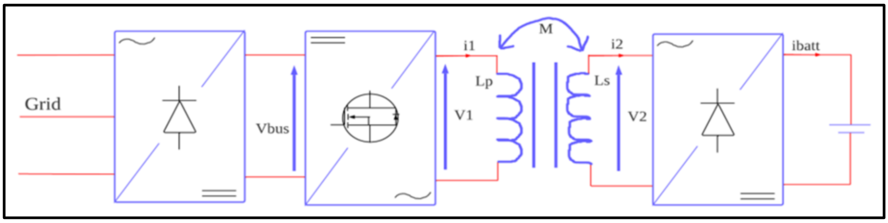

Figure 2. Minimal architecture.

The first step was to design the power supply. Two types of power supplies exist for charging stations. Single-phase power supply is usually used in residential homes, while commercial and industrial facilities usually use a three-phase supply. One key difference between single-phase vs. three-phase is that a three-phase power supply better accommodates higher loads. Single-phase power supplies are most commonly used when typical loads are lighting or heating, rather than large electric motors. The goal here is to have a 550 V power supply on primary coil input. The easiest way to reach this goal is to use a three-phase power supply because a much higher power can be obtained. So, a three voltage sources of 311V (220*✓2) with respective phases of 0°, 120° and 240°. A 3-stage diode rectifier is implemented to convert the three-phase voltage in AC mode into a DC voltage power supply.

Because the input voltage is lower than the expected output voltage, boost converter is the chosen solution for the DC-DC converter. The following procedure is directly implanted into the project script in Matlab so the circuit can take the values directly from it [3].

After implementing this Inverter in Simulink, the signal observed is composed by an AC and DC component. To extract the DC component a low-pass filter of a cut frequency of 300 Hz is implemented. The output signal has a mean value of 561 V +/−2 V [4]. The signal is filtered by a choke filter characterised by a frequency of 300Hz which is the frequency of the signal that is observed [5]. With an output voltage of $512.5V$, the DC signal now must be boosted to 550V to fit the specifications. DC -DC Converter Matlab procedure calculation is shown in Figure 3.

3-phase rectification is the process of converting a balanced 3-phase power supply into a fixed DC supply using solid state diodes or thyristors [6]. A short charging time is very important for the electric car industry, as the users of ICE cars are used to refuel their car in minutes. To provide insights into the most important factors that influence the charging time, a basic understanding of the underlying equations is needed.

Charge/Discharge rate (C-rate)**:**This parameter describes the magnitude of current drawn from or input into the battery, in terms of the nominal ampere-hour of the battery [7,8] A battery cell discharging at a rate of 1C will deliver its nominal ampere-hour for 1hr whilst a cell discharging at 2C will deliver its nominal capacity in 0.5hr. Maximum charge rates for currently available Li-ion cells are usually between 3C and 6C, even though there are some high power Li-ion cells that are optimized for 2C to 25C continuous discharge[9].

Now that the signal has the desired voltage, the DC voltage has to be converted in AC. To perform that, a simple voltage inverter with MOSFET is placed next to the DC inverter. Finally, the primary coil is placed at the end of the primary circuit and the signal on figure 4 is obtained. Choppers are direct current transformers with adjustable turn ratios [10,11]. Buck converters, also known as step-down converters, are DC-DC converters that convert an unregulated DC input voltage into a controllable DC output voltage that must be lower. Power electronics demand has grown steadily [12]. The experiment was conducted by using PWM (Pulse Width Modulation) and a clock voltage source to control the buck converter [13]. Another study was made by (A. Abdulslam, 2016) shows that multileveled converters are more advantageous when compared to the typical single-level buck converter. The study was made by simulating a single-level, three-level, and five level buck converter using SPICE, utilizing the same value for each level to maximize performance [14,15]. The simulation showed that the five-level converter had the highest efficiency, but their research showed that the three-level converter outperformed the five-level due to switching losses [16]. In terms of the effect of harmonics, a study was made by (V. E. Wagner et al. 1993) shows that harmonics have varied effects on electrical equipment. Harmonic levels may be changed by using shunt capacitors to increase voltage and power factor. However, capacitors do not produce harmonics, but the harmonic effect on the capacitor may increase equipment heating and dielectric stress. Another device would be the transformers, system harmonics increase transformer heating, requiring load capacity derating or non-sinusoidal load current transformers to stay under the transformer's temperature rating, this is because overtemperature operation shortens transformer life [17].

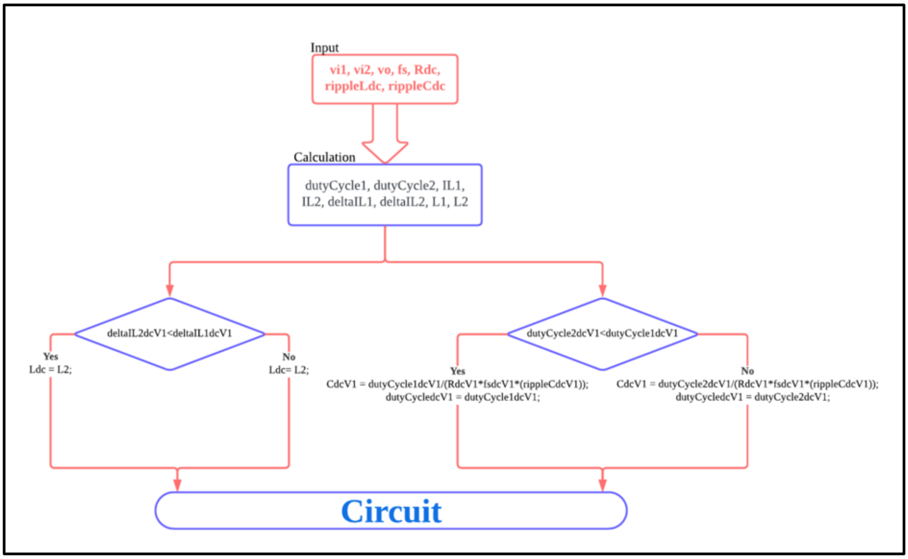

Figure 3. DC-DC Matlab procedure calculation.

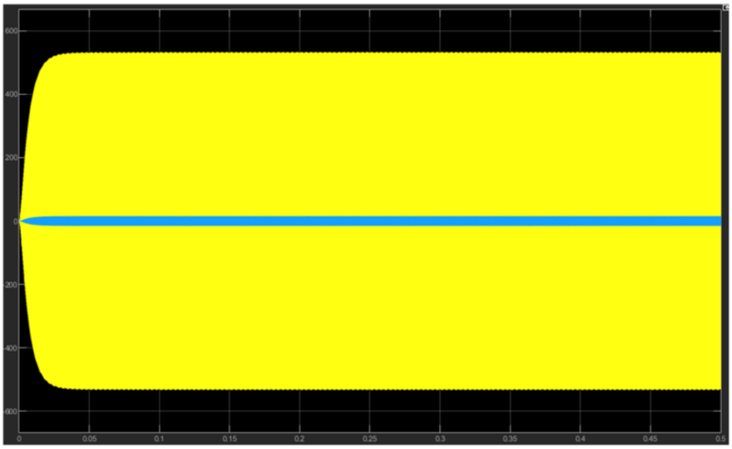

Figure 4. V1 circuit output.

Next to the first coil, the second coil is implemented at the same time as the mutual inductance through a Simulink model. The signal on the output of the inductance can be observed on figure 5. Because the transmit power is an AC signal, it has to be converted to DC following the car batterie requirements through a Monophasing diode rectifier. Next to this rectifier is placed a low pass filter with cutoff frequency of 300 Hz. The transmit voltage at 100 V needs to be at 550 V at battery input. To perform such a transformation a DC-DC boost inverter is designed and placed following the same steps as before. A final low pass filter is placed at the end of the inverter and the following signal on figure 6 can be observed:

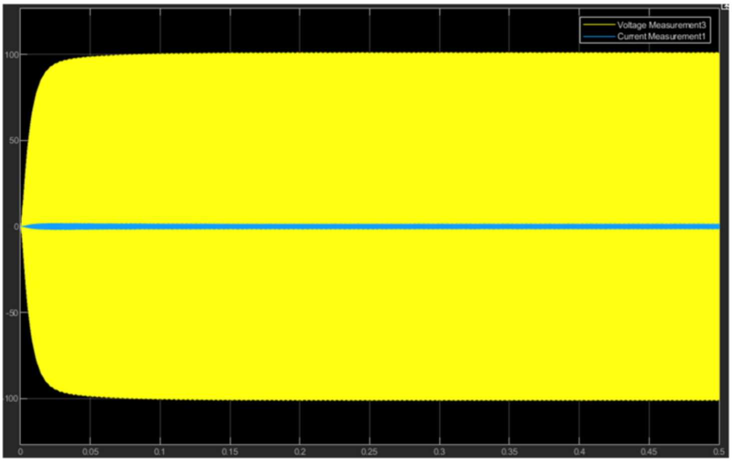

Figure 5. V2 circuit input.

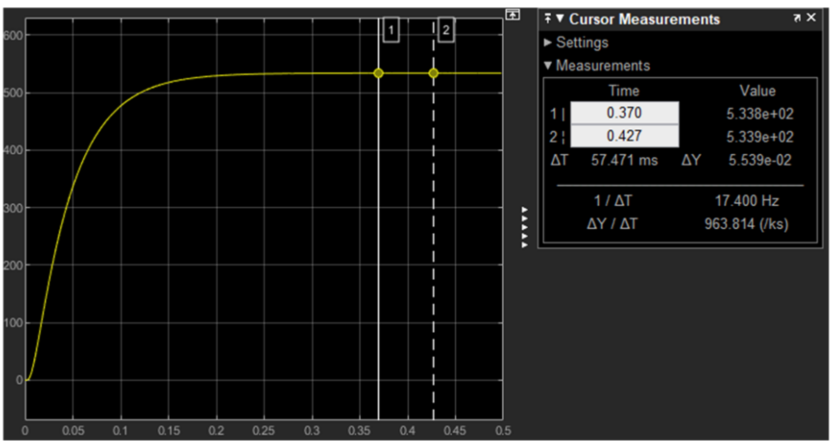

Figure 6. Final Voltage.

4. Results and Analysis

At the output of the first circuit the power value is 10.6 kW (533 V and 20 A). The power value of V2 circuit at the input is 200 W (100 V and 2 A). The transmit power is about 20\% the power value of V1 circuit output which is matching with the coupling factor *k* (=0.2).

Sadly, the battery hadn't be placed into the circuit because of the lack of time. Because of that, the circuit don't have a proper current that is deliver into the whole circuit which leads to miscalculation concerning the deliver power. Finally, there must be more efficient ways to design the circuit that could improve the efficiency of the delivered power.

5. Conclusion

This study presents an extensive and rigorous methodology for detecting glaucoma and identifying other ocular diseases, applying the U-Net model and multiple deep learning models to pre-processed retinal images. The U-Net model demonstrated considerable potential in calculating the CDR ratio for glaucoma detection, and it showed an impressive performance for the segmentation of the Optic Disc (OD) and the Optic Cup (OC).

For detecting other ocular diseases, we trained various deep learning models using pre-processed images with the CLAHE technique, which showed the best accuracy among all preprocessing techniques. In terms of performance, the Xception model emerged as the most effective, displaying the highest validation accuracy and the lowest validation loss among all models.

However, it is important to highlight that although we obtained promising results, the study had limitations, mainly related to the availability of a larger and more diverse dataset. Although we employed data augmentation to increase the diversity and size of the training set, the model's performance may improve with more training data, especially data representing eyes with multiple diseases.

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