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RESEARCH ARTICLE

Using a Pi-Fuzzy Controller and a Three-Phase Three-Level AC/DC Converter, Electric Vehicle to Power Grid Integration

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ABSTRACT

This paper presents the control and simulation of an electric vehicle (EV) charging station using a three-level converter on the grid-side as well as on the EV-side. The charging station control schemes with three-level AC/DC power conversion and a bidirectional DC/DC charging regulator are described. The integration of EVs to the power grid provides an improvement of the grid reliability and stability. EVs are considered an asset to the smart grid to optimize effective performance economically and environmentally under various operation conditions, and more significantly to sustain the resiliency of the grid in the case of emergency conditions and disturbance events. The three-level grid side converter (GSC) can participate in the reactive power support or grid voltage control at the grid interfacing point or the common coupling point (PCC). A fuzzy logic proportional integral (FL-PI) controller is proposed to control the GSC converter. The controllers used are verified and tested by simulation to evaluate their performance using MATLAB/SIMULINK. The comparison of a PI-controller and a PI-Fuzzy controller for the EV charging station shows the effectiveness of the proposed FL-PI controller over conventional

PI controller for same circuit operating conditions. A good performance for PI-Fuzzy in terms of settling time and peak overshoot can observed from the simulation results.

Keywords: EV charging station; three-phase three-level; AC/DC converter; FLC control

INTRODUCTION

Overview of Wireless Power Transfer (WPT)

Since Nikola Tesla invented the method of wireless power transmission, the innovation of wireless power transfer has attracted a lot of attention. Because magnetic resonance wireless transmission is effective and has a significant charging range, it is recommended[1]. It is extensively utilized in many contemporary and daily applications, such as wireless mobile phone charging, electric car charging , biomedical implants , etc. A study from 1980 that describes how wireless power transfer powers electric trains operating in a Soviet Union mine is one of the earliest examples of attempts to use wireless power innovation for large amounts of electricity . Most likely, the risk of fire in the mine led to the use of the wireless power transmission technology. Most likely, the risk of fire in the mine led to the use of the wireless power transmission technology[1], [2]. Then, the results indicate that the power transmission frequency was 5 kHz, indicating that the productivity was probably not very high. There was only a few millimeters between the two points of power transmission. Large currents could be controlled at relatively high frequencies of 20 kHz or more in the 1990s, which led to a rapid advancement in wireless power transfer technology. Its use is demonstrated by the autonomous carriages that operate in semiconductor manufacturing facilities where dust is prohibited. This led to a 90% power transfer efficiency, and this type of WPT system is now the norm. Still, not much is done to improve the transmission distance; the coil's size is a determining factor [3], [4].

Joint Improvement of Wireless Charging Systems

IHI and WiTricity Corporation (U.S.) have collaborated to enhance deeply coupled magnetic resonance charging invention, which has enabled very effective power transfer over many centimeters. This invention was the result of research done in 2007 by MIT researchers who were able to light a 60W bulb at a distance of two meters (Lu, 2015). This conclusion disproved the information that was available at the time about WPT innovation in terms of transmission distance, which contributed to its rise in popularity in 2007[5] . The corporation began working together to boost remote charging frameworks after assuming management of the innovation from MIT. Since there had been essentially little change at the research facility level, the focus of development has been on how to best leverage this innovation.. With our focus on EV and PHEV charging, we work hard to provide a framework that is easy to use. The comfort and ease of consumers are the top priorities in this progress.

Wireless Power Transmission System for Electric Vehicle Charging

The three most important things to consider in WPT systems when lowering the reluctance effect concerning the efficiency of the power transferred for great air gaps are shape, dimensions of coils, choosing coil and core materials. The charging operation for wireless electric vehicles is as depicted in Figure 1. Here, the inverter converts the AC power from the grid to a DC power needed by the converter and again rectified to AC suitable for the transmitting coil placed on the ground. The transmission of this AC power took place wirelessly by magnetic resonance method to the receiving coil placed under the vehicle’s chassis and converted back to DC power used to charge the battery[6].

Features of WPT Structure for Charging Electric Vehicles

There are three essential requirements an effective and suitable electric vehicle charging structure has to meet: large air gap, high power and high efficiency (Beh, 2010). Electromagnetic waves serve as a means of propagating energy in an RF & Microwave system (Sample, 2011). This transfer of power takes place over air gaps within some km;

however, it results in some drawbacks such as line of sight transmission, low power (less than 1 kW) transmission, a great loss in the air, low efficiency and an extensive effect on its environment (Wang, 2011). Inductive Power Transfer (IPT) (Xui, 2013) also referred to as non-resonant inductive method (Karalis, 2008) or electromagnetic induction or inductive coupling method (Sample, 2011) has low charging distance (about few centimeters) (Xui, 2013) because of its loose coupling between the receiving and transmitting coils respectively (Hasanzadeh, 2012). The MIT research team proposed the magnetic coupling resonant technique (Kurs, 2007), also referred to as resonant inductive power transfer (Musavi, 2012) in 2007 which has been demonstrated alluring for EV and PHEV charging applications due to its mid-range charging distance efficiency (100-300mm), low loss in its surrounding, low interference and its omnidirectional characteristics (Cheon, 2011). From the figure 1-3 and table 5, it is also noticeable that the amount of mutual inductance between the transmitting coil and the receiving coil slightly changes since each is the sum of its own self- inductance and the mutual inductance of the other coil. As the other coil gets closer due to the direction of the excitation current defined, the value slightly fluctuates because there is still some flux present. The design of the system circuit is created in ANSYS Simplorer while the design of the transmitting and the receiving coils is created in ANSYS Maxwell. This Maxwell design held the dynamic inductance information about the coil structure and imported the Simplorer as L parameters. At the transmitting side, the resonance capacitor is connected in series with the inductor to have maximum current flowing through the inductor, hence, maximum power is delivered to the transmitter. At the receiving side, the capacitor was connected in parallel with the inductor to have a maximum voltage drop on the load resistor.

An AC analysis needs to be set up to determine the efficiency of the system. Below I have shown the parameters for the analysis. From figure 1-6, the system's efficiency reaches its peak of about 98.3% at a resonance frequency of 0.35 MHz. At any frequency apart from the resonance frequency, the efficiency reduces. This indicates that the magnetic resonance method is a very efficient way of transferring power wirelessly over a mid-range distance. In addition, the 3D rectangular plot helps to verify the efficiency of the system with respect to the spacing between the coils and its operating frequency produced at 98.3%.The transient analysis is set up to determine the frequency analysis of the system. Below are the values for the setup. Figure 4-17 shows the complete system of a magnetic resonance WPT circuit designed in Maxwell. The circuit consists of a power supply source, rectifier, inverter, transmitting coil, receiving coil, and a load. The power supply, which is an AC source, needs to pass through the rectifier and then be converted back to AC by an inverter because the coils need an AC voltage to operate. The reason why the AC supply passes through the rectifier first is that, the AC voltage from the grid is not suitable for the transmitting and receiving coils.

Comparing with Magnetic Induction Power Transfer

In magnetic induction wireless power transfer, the current passes through the transmitting coil, which produces a varying magnetic field. This induces a current in the receiving coil which helps to charge the electric vehicle. Its power transfer efficiency depends on the closeness of the two coils. Using the same coil design and parameters and keeping the same distance between both coils as in the magnetic resonance method, results show that the efficiency of the inductive coupling method reaches its peak at 60.145%. This confirms that wireless power efficiency is low in the inductive coupling method over large distances.

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CONCLUSION

This research delved into the effectiveness of the wireless-based resonance charging system through simulation results. The simulation results obtained from ANSYS Maxwell verify the effectiveness of the electromagnetic resonance technique. The energy transfer efficiency depends on the operating frequency. Results show that the energy transfer efficiency of a resonance-based wireless energy transfer system reaches the maximum (98.3%) at the resonant frequency. If the system is set at a frequency other than the resonance frequency, there is an abrupt drop in the energy transfer efficiency. Additionally, the design of a magnetic induction verifies the effectiveness of wireless power transfer with magnetic resonance over large distances as simulation results show that the efficiency of power transfer with the induction method over large distances is about 60%. Therefore, the magnetic resonance wireless charging is a more efficient method for charging the electric vehicle.

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Table 1 . Parameter values

Parameters	Value
Voltage	280V
Frequency	6.5KHz
R_1	9.8µΩ
R_2	9.8µΩ
C_{rx}	20µF
C_{tr}	20µF
R_{Load}	50Ω

Table 2: parameters and values

Parameters	Value
3 phase Voltage	280V
Frequency	10KHz
C1	900µF
C2	7µF
R1	7.1mΩ
R2	4mΩ
Ctx	1.6µF
Crx	4.7µF
RLoad	50Ω

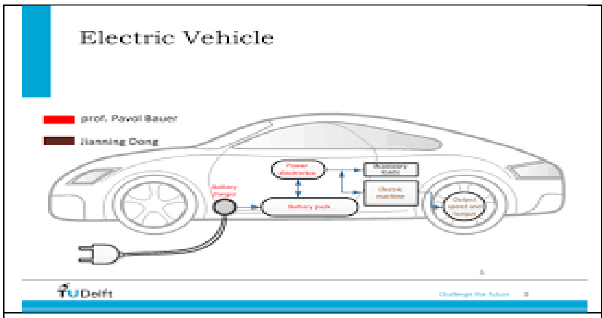

Figure 1-1 Wireless Power Transfer System for Electric Vehicle [7]

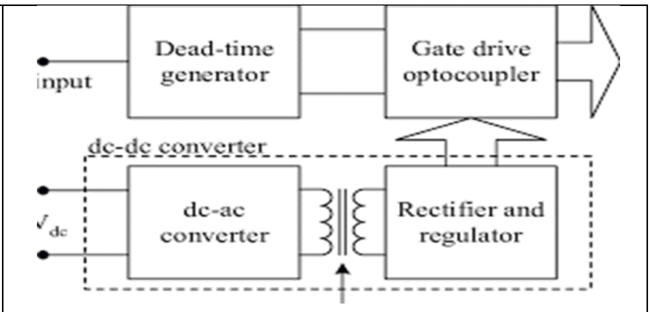

Figure 1-2 Wireless Power Transfer System Block Diagram [8]

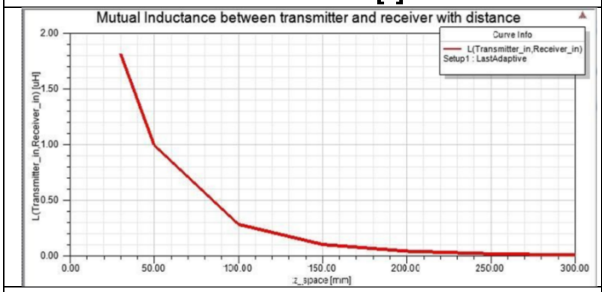

Figure 1-3 Mutual Inductance between transmitting coil and receiving coil[9]

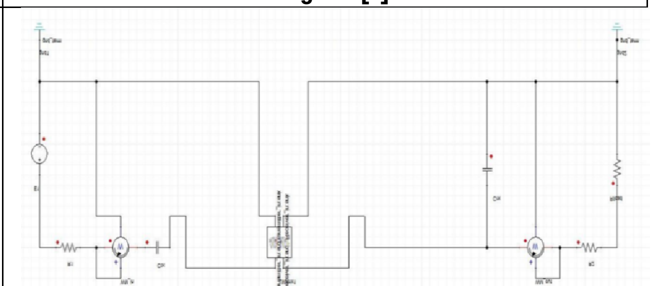

Figure 1-4 Incorporation of the Circuit design with Physical design of Magnetic Resonance Coupling

Figure 1-5 Ac Analysis set up Values

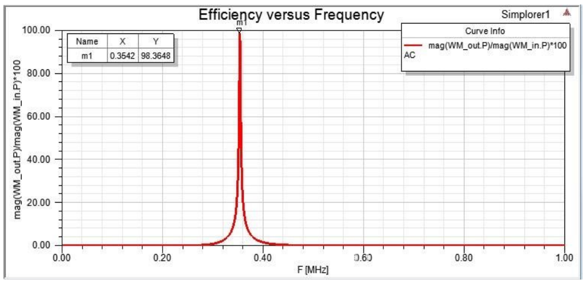

Figure 1-6 Efficiency with Frequency[10]

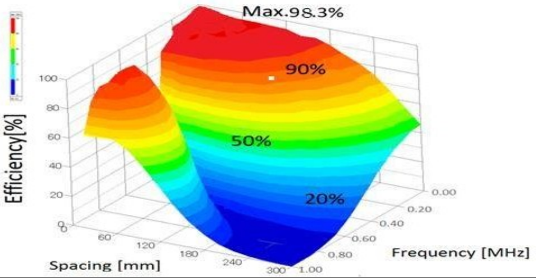

Figure 1-7 3D Rectangular Plot of Efficiency with spacing and frequency[11], [12]

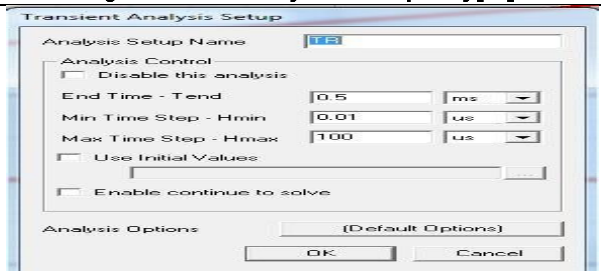

Figure 1-8 Transient Analysis Setup Values[13], [14]

Figure 1-9 Bode plot of efficiency with spacing

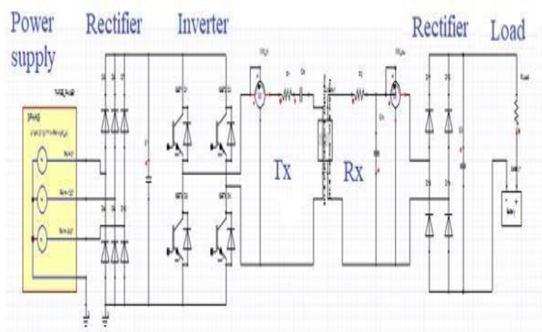

Figure 1-10 Complete magnetic resonance WPT circuit

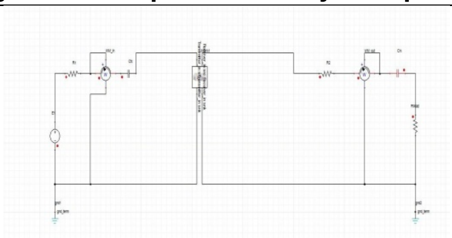

Figure 1-11 Incorporation of the Circuit design with Physical design of Magnetic Induction[12]

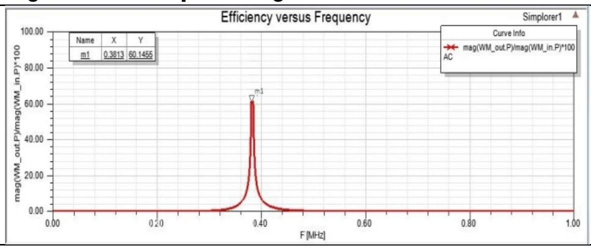

Figure 1-12 Efficiency with Frequency

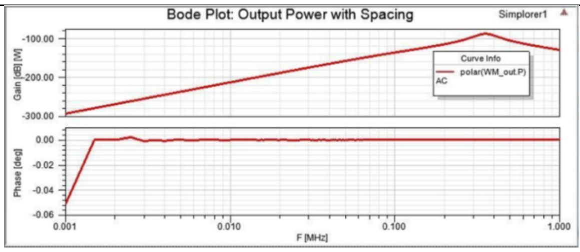

Figure 1-13 Bode plot of Output Power with Spacing

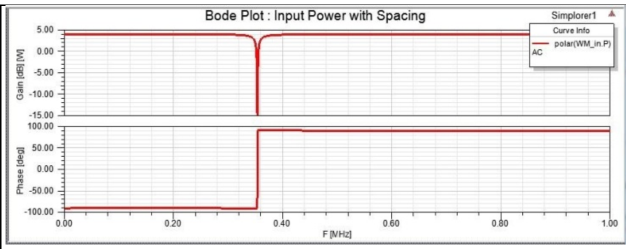

Figure 1-14 Bode plot of Input Power with Spacing

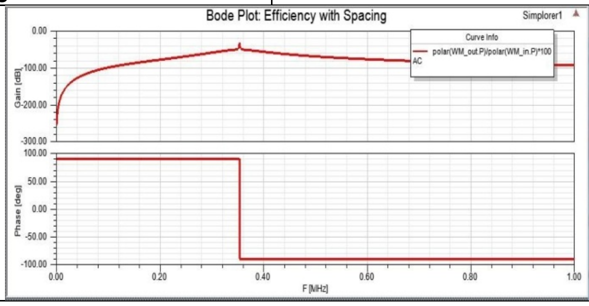

Figure 1-15 Bode plot of Efficiency with Spacing