

System and Electromagnetic Compatibility of Resonance Coupling Wireless power Transfer in On-Line Electric Vehicle

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1. Introduction

Recently, KAIST has introduced the novel on-line electric vehicle (OLEV), in which the automotive vehicle constantly receive and recharge their power from the power lines embedded underneath the surface of the road. OLEV has the reduced battery capacity to about 20% compared to that of the conventional battery-powered electric vehicles, while it can consequently minimize the weight and the price of the vehicle and power station.

The concept of the wireless power transfer system applied for electric vehicles, where energy is transferred continuously even while the vehicle is moving, has been introduced even tens of years ago [1]. However, it is reported that the previous system could not be the substitute of fuel engine very efficient to substitute because of noise problem and low efficiency of overall power transfer system. In this paper, we introduce the OLEV system and its non-contact power transfer mechanism. The design methodology for high efficient wireless power transfer system and active and passive shielding techniques for the reduction of electromagnetic field (EMF) from the power line and vehicle are proposed.



Figure 1: (a) The On-line Electric Vehicle (OLEV) and the power transfer system using power lines placed underneath the road surface for non-contact charging (b) An OLEV commercially used at Seoul Grand Park

2. OLEV System Overview

The key elements which differentiate the OLEV from the other electric vehicle consist of wireless power supply system and power receiving system. For efficient transmission of electric power, resonant coupling between road-embedded power lines and vehicle-embedded pickup module is applied. With this wireless power transfer system, an OLEV successfully receives 100 kW power while it is moving as well as it is stopped on the road.

2.1 Power Supply System

For wireless dynamic charging while a vehicle is in motion on a road, a road-embedded power supply system and a power receiver system in a vehicle are required, as shown in Figure 2 schematically. The power supply system can be a part of the public infrastructure of the road or highway system, while the power receiver device, or a pick-up system, can be a part of the vehicle. The pair of the power supply and the receiver system is tuned to maximize the transmission efficiency through the optimized magnetic field shapes and properly tuned resonant frequency. As shown in Figure 2, the power inverter introduces constant-current controlled electricity of 20 kHz to the road-embedded power cables from the commercial grid electricity. The power cables can be composed of a set of segments which separately receive electricity via the switching control of the power inverter. The vehicle has a completely integrated communication and control network to charge the battery or power the motor to drive the vehicle.

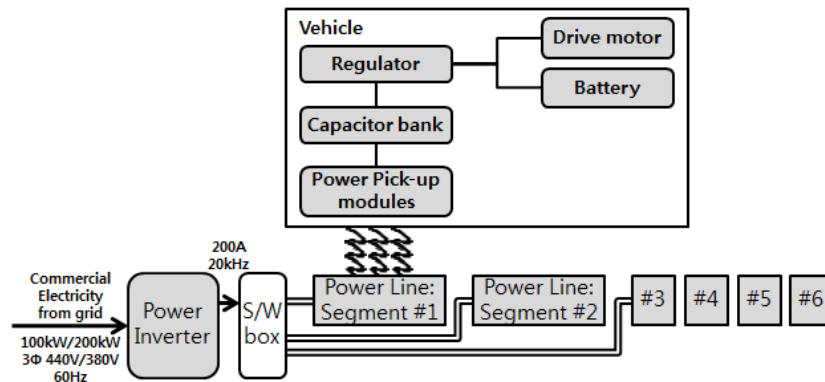


Figure 2: An schematic overview of the OLEV system architecture

2.2 Coil Design for OLEV

Generally, a pair of power lines and pick-up module is designed for a non-contact power transfer system according to the direction of the magnetic flux at the pick-up module. As shown in Figure 3, there are two power lines with opposite current directions underneath the road surface which form a current loop, and magnetic flux is induced around each power line due to the current in the power lines. The magnetic fluxes from the two power lines are combined between the power lines, and the pick-up module catches the vertical magnetic flux using the copper coils around the ferrite core.

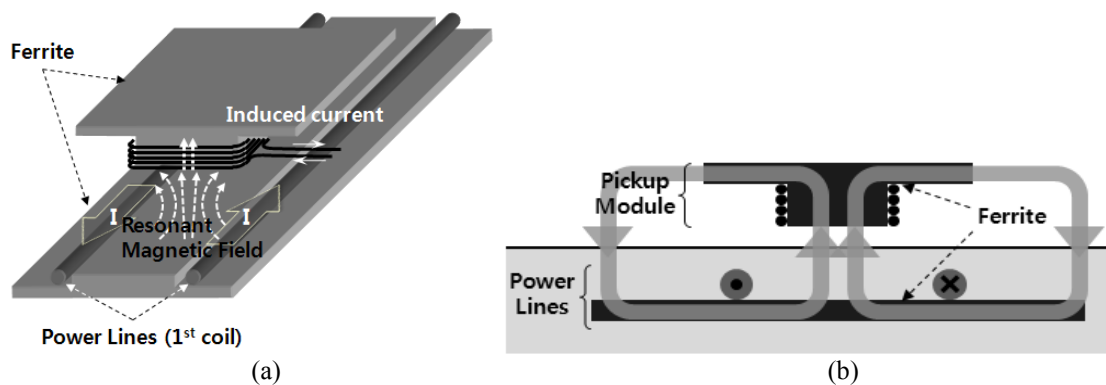


Figure 3: Power lines and pickup coils pair and the generated magnetic flux path for OLEV.

From the simplified equivalent circuit model of the wireless power transfer system with two series resonant coils as shown in Figure 4, the power (P_L) at the load R_L is calculated to be proportional to the frequency, mutual inductance, and magnitude of source current assuming that the system is operating at the resonance frequency as shown in (1). The power transfer efficiency is also an important factor for commercialization and it should be reasonably high compared with the efficiency of other types of vehicles.

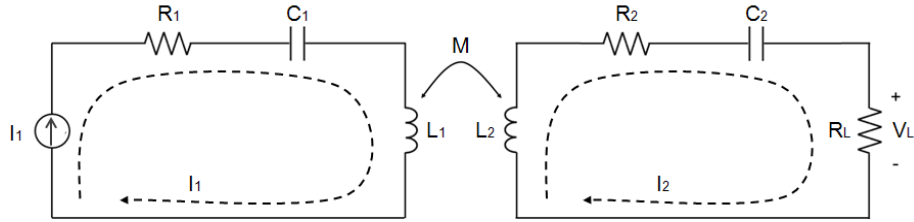


Figure 4: Simplified equivalent circuit model of power transfer system

$$P_L \cong \frac{\omega^2 M^2}{(R_2 + R_L)^2 + \left(\omega L_2 - \frac{1}{\omega C_2} \right)^2} I_1^2 R_L \cong \frac{\omega^2 M^2}{R_L} I_1^2 \quad (1)$$

$$K \cong \frac{\omega^2 M^2 R_L}{R_1 (R_2 + R_L)^2 + \omega^2 M^2 (R_2 + R_L)} \cong \frac{1}{1 + \frac{R_1 R_L}{\omega^2 M^2}} \quad (2)$$

3. Electromagnetic Compatibility

3.1 Electromagnetic Field (EMF)

The design of electromagnetic field distribution is also a significant factor in wireless power transfer system especially in the high power transport system. The magnetic flux more than tens of thousands μT from current of thousands of ampere-turn is generated between power lines and pickup coils, and the magnetic flux density can exceed the regulation suggested by ICNIRP [2]. Therefore, it is very significant to control the leakage magnetic flux for wireless power transfer system in automotive application because of the high current in the system.

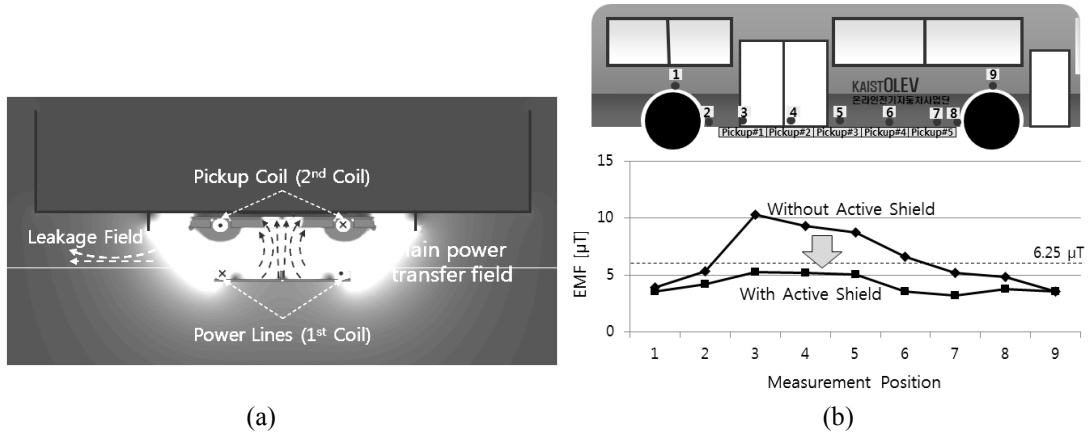


Figure 5: Electromagnetic field (EMF) generated from OLEV (a) Field distribution (b) Measured EMF reduction using active shield

The OLEV system achieved a human exposure level of EMF below the international guideline or requirement published by ICNIRP, of which the suggested value is $6.25 \mu\text{T}$ at 20 kHz, by minimizing the leakage magnetic field in the magnetic energy transfer path through the introduction of the passive shielding devices and the active field cancellation method. A maximum efficiency of 83% was achieved with a power capacity in the 100 kW range. In the measurement of EMF, the IEC 62110 standard was applied.

3.2 Electromagnetic Interference

The electromagnetic interference (EMI) is also a traditional regulation to protect electronic devices and human body from the generated electromagnetic field. Although the electromagnetic

interference regulation and measurement standard of automotive industry have been established, they should be improved or updated according to the new upcoming technologies such as electric vehicle and wireless power transfer technology. Under these circumstances, the EMI test of OLEV has been performed by Korea Automobile Testing & Research Institute (KATRI) with current gasoline vehicle test procedure. As shown in Figure 6, the generated EMI from OLEV fully satisfied the regulation in all frequencies. Now the Radio Research Agency in Korea is establishing the new standard of EMI test for electric vehicles, and the verification of the EMI from OLEV for this new standard is being performed. As the frequency range of current radiation regulation starts from 30 MHz, the EMI regulation could include the kHz range in the future.

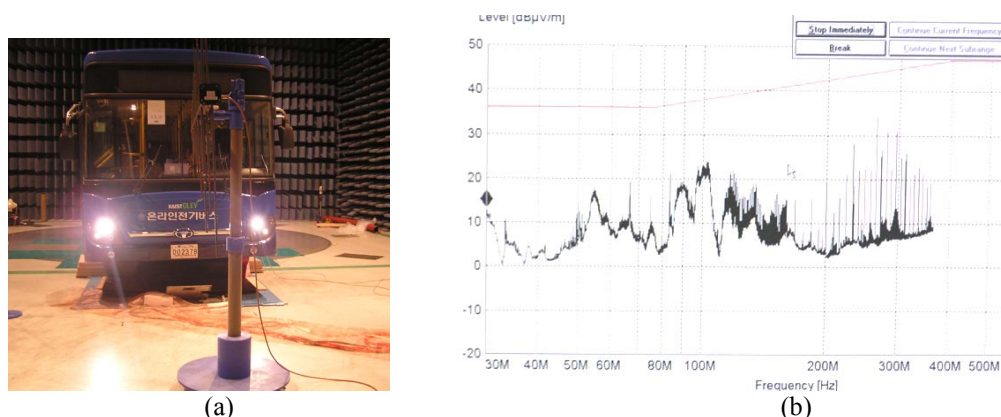


Figure 6: Electromagnetic interference test for OLEV (a) Test environment (b) Test result

4. Conclusions

We introduced the concept of OLEV system and its non-contact power transfer mechanism. The design of electromagnetic field is necessary not only for maximization of power transfer capacity and efficiency but also for minimization of EMF and EMI. With the optimization of power lines and pickup coils, we could successfully achieve the power transfer capacity of 100 kW with maximum efficiency of 83% satisfying the international guideline published by ICNIRP.

Acknowledgments

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