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# Development & Implementation of Electric Tram System with Wireless Charging Technology

**DongHo Cho*, GuHo Jung*, Uooyeol Yoon* and Byungsong Lee**

*Wireless Power Transfer Research Center(WPTRC), KAIST, 291 Daehak-ro, Yuseong-gu, Daejeon, Korea
** Korea Railroad Research Institute(KRRI), Korea

## Abstract

In this paper, an electric tram system with a wireless power transfer system based on SMFIR technology is presented. The detailed technology of power-line infra, regulator, and pick-up device is described for train application, respectively. Furthermore, implementation and experimental results for wireless power transfer electric tram are presented

## I. Introduction

Studies for applying wireless inductive power technology to vehicle system have been being made [1]..[5]. From a few years ago, KAIST also has developed and commercialized On-Line Electric Vehicle(OLEV) system using wireless magnetic resonance technologies to reduce weight, volume and cost of battery in conventional battery powered electric vehicles[2]..[5].

For the first time, the main target for our study focused on on-line electric bus system because bus moves on a regular route and the optimal length of road embedded rail can be calculated considering bus speed, number of bus stops and stoppage time. After that, we applied the developed OLEV technology to train. Fig. 1 shows the overview of a proposed OLEV tram system.

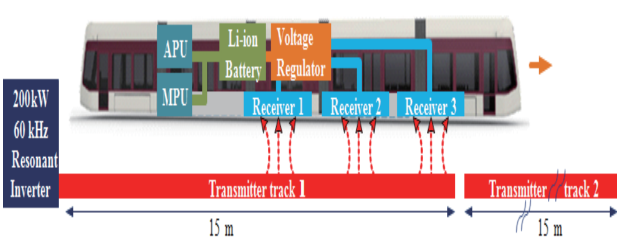


**Fig. 1.** Overview of proposed OLEV tram system..

As shown in Fig. 1, this system consists of four components, that is, three-phase power inverter, road embedded power line module, pickup module with rectifier and regulator. The power inverter supplies 60kHz high frequency current to the power line module which is composed of high frequency cable and magnetic core. In case that power inverter supplies high frequency current to the cable, the power line module generates a high frequency magnetic field through power cable and core, and pickup module with rectifier converts this magnetic field to low DC voltage. And power line consists of two 15m power tracks and the regulator outputs high DC voltage appropriate for battery inside tram using this low DC voltage.

## II. Overall System

The rated power of motor for electric tram is 180kW, which is very high compared to a small electric car. And an airgap, that is, a distance between power line module and bottom side of the pickup module should be about 70mm for protecting collisions with obstacles on the rail. From this, target development requirements of our OLEV tram system were determined as shown in Table. I

**Table. I.** Target development requirements and basic spec. for OLEV tram system

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* **Corresponding Author** E-mail: dhcho@kaist.ac.kr, Tel: +82-42-350-3467



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| Items | Values | Comments |
|---|---|---|
| Airgap | About 70mm | Distance between power line module and bottom side of pickup module |
| Inverter switching frequency | 60kHz | |
| Rated power of regulator | 180kW | |
| Total power transfer efficiency | Upto 90% | Power efficiency from three phase input of power inverter to regulator DC output |

Fig. 2 shows an overall block diagram and the power circuits of wireless charging system for a proposed OLEV tram system. As illustrated in the internal circuit of power inverter in Fig. 2, three-phase AC or DC voltage is rectified and controlled as a variable DC-link voltage by phase controlled rectifier or DC/DC converter. This DC-link voltage is converted as an isolated single-phase voltage source by single-phase inverter and high-frequency transformer, where DC blocking capacitor Cb exists for protecting the saturation of transformer and the turn-ratio of for this transformer varies according to the current of power cable flowing inside the power line module.

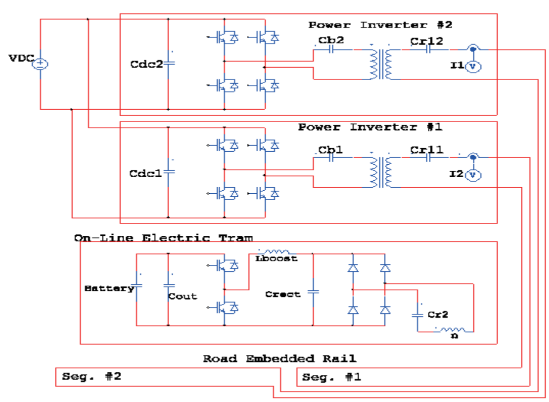


**Fig. 2.** Overall block diagram and power circuits of proposed system for electric tram.

## III. Wireless Power Transfer Structure

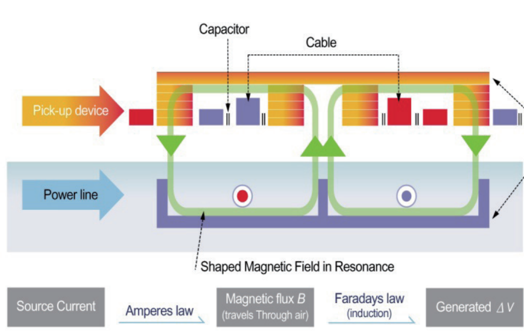


**Fig.3.** Shaped magnetic field in resonance(SMFIR) technology

Wireless power transfer of simple inductive coupling technology is realized with two coupled coils. Two coils are mutually coupled with the same resonant frequency and are placed within a very short distance to obtain sufficient efficiency of transferring power. When two coils become more distant each other, transfer efficiency is decreased since magnetic flux generated by primary coil cannot reach a secondary coil, resulting in a decrease of mutual coupling. The trace of magnetic flux has to be modified in order to obtain higher transfer efficiency. An appropriate way is to place material with high permeability, especially ferrite core. Magnetic fluxes tend to be absorbed in the ferrite core, and are radiated at the edge as shown in Fig. 3. In designing these core structures, primary module width is minimized to reduce the cost of power line module construction, and the thickness of pickup is minimized to reduce the weight of the pickup modules. The designs were supported by theory, finite-element method based computer simulations, and practical experiments. In the power line module, the ferrite cores are not continuous but separated at regular distances. This reduces the cost of the power line module embedded within the rail.

## IV. Design of Power Transfer Infrastructure

As shown in the secondary part of transformer, equivalent inductance Lr1 is measured by power cable and core in the power line module, whose value varies with length of rail and is about 60 uH in case of 15 m track length and is higher uH in longer length of track.  In case of the power line module shown in Fig. 2, it is divided into two tracks, that is, #1, #2. Because this power infrastructure has two tracks and power inverter can supply current to each track, the common cable is used. In our system, each track consists of 6 turns of high frequency power cables with internal ritz wires and dual-rail type(E-type) ferrite core.

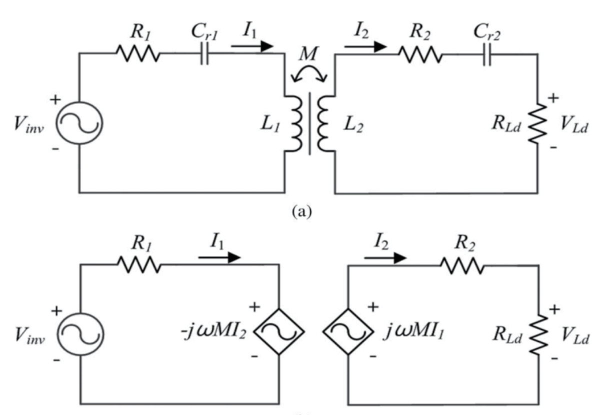


**Fig.4.** Equivalent circuits of proposed wireless power transfer system: (a) Actual equivalent circuit and (b) Ideal equivalent circuit in perfect resonance.