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Proposed Dynamic Contactless Power Transfer System

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Abstract

Since EV has the subject that a vehicles price with the long charging time with short mileage is high, it has not resulted in full-scale spread. The dynamic contactless power transfer system which performs an electric power supply on the vehicles under drive is expected as a means to solve the subject of EV. There are some problems resulting from the loop coil being used for the dynamic contactless power transfer system. The first problem is that it is incompatible with the stationary contactless power transfer system. In the stationary contactless power transfer system, since the ground coil of a different type from a loop coil is adopted, the vehicles must install two coils, under parking and driving. The space reservation for installing a coil by passenger car is difficult, and is not practical. The second problem is that the leakage flux and the radiation noise become large. The third problem is that a construction period and a repair period become long. In this paper, the dynamic contactless power transfer system which has the following features is proposed and a simulation and an experimental result show the validity. The feature of the system to propose is as follows. The ground coil of a proposal system is the same as that of the stationary contactless power transfer system, and electric supply becomes possible also while parking also driving. The proposal system consists of same ground side coil as the stationary contactless power transfer system, and a vehicles side coil, and leakage flux and a radiation noise are small. Since a proposal system vacates an interval and installs a ground coil, construction period shortening and price reduction of a system of it are attained.

Keywords: Contactless power transfer system, Dynamic, EV

1 Introduction

The electric vehicles (EVs) currently on the market have a short cruising range of around 100 km per charge, which makes them inappropriate for long-distance drives. Rechargeable batteries generally have low energy density and are costly. Thus, there is a limit to increasing the capacity of the battery just to extend the cruising range. Although fast-chargers are being installed at various places in order to enhance the convenience of EVs, there are problems regarding location and charging time. To alleviate these problems, technologies for charging the battery of an EV without requiring a connection cable have been explored and field trials have been conducted overseas.

The present study examined the need for developing a contactless power transfer system that charges traveling EVs and the specifications of an assumed system as their usage becomes widespread.

An outline of our proposed contactless power transfer system (CPTS) for charging moving EVs is also reported.

2 Need for Developing the CPTS for Charging Moving EVs

2.1 Number of Fast-Chargers Required at 10% EV Penetration

Under the assumption that 10% of the vehicles traveling on the major highways in Japan such as the Tomei Expressway (between Tokyo and Nagoya) and the Meishin Expressway (between Aichi and Hyogo) are EVs, the required number of fast-chargers was estimated. The estimation was based on Equation (1), which is used to calculate the number of parking spaces at highway rest areas.

Number of Fast-Chargers Required

$$= DT \times PR \times RHR / Turnover \tag{1}$$

where

DT : Design Traffic

PR : Parking Rate

= Number of vehicles parked / Main road-traffic

RHR : Rush-Hour Rate

= Number of vehicles parked during rush-hour / Number of vehicles parked

Turnover = 1/Average Parking Time

Assuming that the total daily traffic for the Tomei and Meishin Expressways on both inbound and outbound lanes is 50,000 vehicles, the daily EV traffic at 10% penetration on either lane (inbound or outbound) is 2,500. As the traveling range per charge is about 100 km, each EV needs to be charged every 100 km, based on which the number of fast-chargers required at each rest area is estimated. The parking rate is 50% because EVs park every 100 km and the rush-hour rate is 0.1 because 10% of the vehicles on the highway are EVs. Since it takes 30 minutes to charge each EV, the turnover is 0.5.

Therefore, approximately 60 fast-chargers need to be installed at each rest area. However, as the rest areas are located every 60 km and there are two parking areas in between, 20 fast-chargers are required at each rest area or parking area.

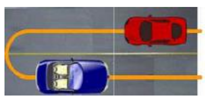
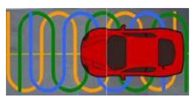
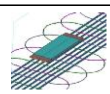
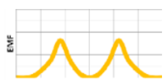
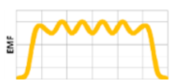
Considering the capacity of the power receiving equipment (1,250 kW) at each rest area or parking area, the cost of introducing a fast-charger, the maintenance cost, and a charging time of 30 minutes, the spread of EVs dependent on the stationary charging system is not promising.

2.2 CPTS for Charging Moving EVs Developed both in the world

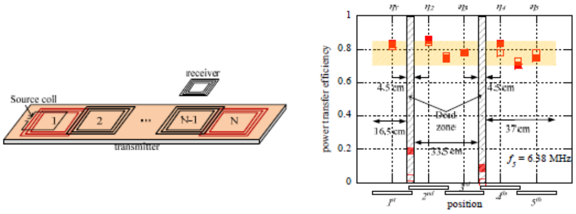
Two types of CPTS for charging moving EVs have been proposed: the electromagnetic induction method by KAIST in South Korea and Bombardier Inc. in Canada, and the magnetic resonance method by KERI in Korea. As shown in Table 1, the electromagnetic induction method is further divided into the system with loop coils and a power receiving coil developed by Showa Aircraft Industry Co., Ltd., and that with an S-shaped loop coil and a power receiving coil by Bombardier Inc. in Canada. The former system has an issue regarding significant changes in transfer power with misalignment along the width of the vehicle. The latter system also has a problem with power fluctuations due to misalignment along the vehicle width and in the front-and-back direction.

In addition, these loop systems are different from the contactless power transfer system for charging parked EVs for which international standardization is ongoing, and it is difficult for them to achieve high-efficiency power transfer. With the system for charging moving EVs and the system for charging parked EVs, it is difficult to share the same equipment. Moreover, it is necessary to lay loop coils in the entire areas to be served. The cost for construction and maintenance is also high[1][2].

Table 1. Electromagnetic induction type CPTS for Charging Moving EVs

	Conductor loop & pickup coil	S-shaped loop & pickup coil
Ground side		
Vehicle side	 Vertical type Horizontal type	
EMF		

The magnetic resonance system proposed by KERI in South Korea has a structure in which the ends of the transmission coils overlap as indicated in Figure 1(a). The coil between the excitation point and the receiving point serves as a relay coil. This system is reported to have a technical problem regarding significant reductions in power transfer efficiency at the overlaps as shown in Figure 1(b) (3).



(a) System schematic (b) Efficiency

Fig. 1. Magnetic resonance type dynamic WPT.

3 Specifications of the CPTS for Charging Moving EVs

The transfer power and power transfer section length required for a contactless power transfer system for charging moving EVs were estimated using Equation (2). The first term indicates the power consumption in the power transfer section, and the second term the power consumption in the contactless power transfer section.

$$l = \frac{v_c\left(\frac{L}{v_h}\cdot p_h - Q\right)}{c - \left(p_c - \frac{v_c}{v_h}\right)} \qquad (2)$$

where

l [km] : Length of the contactless power transfer

L [km] : Length of the cruise section

c [kW] : Contactless transfer power

v_c [km/h] : Vehicle speed in the contactless power transfer section

v_h [km/h] : Vehicle speed outside the contactless power transfer section

p_c [kW] : Power consumption during the cruise in the contactless power transfer section

p_h [kW] : Power consumption during cruising outside the contactless power transfer section

Q [kWh] : Available battery power supply

Under the assumption of traveling on highways and in urban areas, the required ratio of the power transfer sections to the entire traveling sections for the specified transfer power was estimated. It was also assumed that all energy required for traveling is supplied by power transfer while traveling. In other words, the SOC of the battery on the EV does not decrease.

3.1. Highways

The estimation for highways assumes an average passenger car with a normal travel speed of 90 km/h. During power transfer, two cases were calculated: The speed is reduced to 50 km/h and kept the same at 90 km/h. The power consumption at 50 km/h was assumed to be 5 kW and at 90 km/h to be 9 kW. Figure 2 shows the results. On the condition that the amount of contactless power transfer is 25 kW, which is half the output of the fast-charger, the ratio of the contactless power transfer sections is approximately 20% of the entire travelling sections for a travelling speed of 50 km/h in the contactless power transfer sections and 40% for a travelling speed of 90 km/h, if the vehicle is to travel without losing battery capacity.

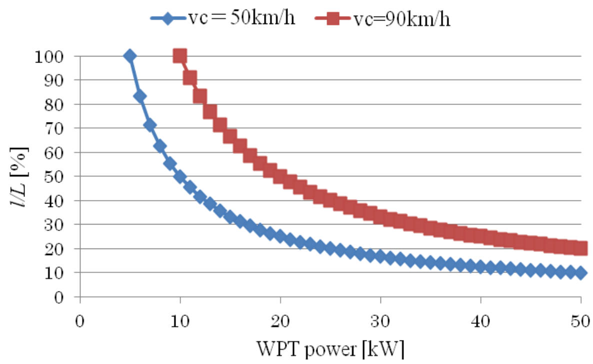


Fig. 2. Simulation results in the case of highways.

3.2. Urban Roads

The calculation for travelling in urban areas was made for a regular route bus as well as a passenger car. The vehicle speed in the contactless power transfer sections and outside the contactless power transfer sections was assumed to be 25 km/h. The power consumption of a passenger car travelling at 25 km/h was assumed to be 2.5 kW and the regular route bus to be 7.5 kW. Figure 3 shows the results. Even for the regular route bus, if the transfer power is 25 kW, which is the same as for the highway, it can travel without losing battery capacity by providing contactless power transfer sections in approximately 30% of the total.

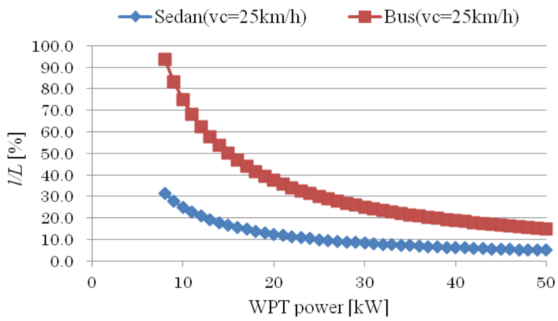


Fig. 3. Simulation results in the case of urban areas.

4 Proposed CPTS for Charging Moving EVs

4.1. System Configuration and Outline of Power Transfer

It is preferable that the contactless power transfer system for charging moving EVs is compatible with the contactless power transfer system for parked EVs for which international standardization is under way. Figure 4 shows the proposed system. The ground several coils should be connected to one power source in series or in parallel. When several coils are connected to a power source, the coil which does not form coupling with the secondary coil shows lower impedance than the one with coupling. Taking this into account, primary coils are connected to power source in series. This connection allows the total impedance of the load of the power source to be the sum of each coil's impedance. Owing to this, the system can protect the inverter and coils from high current caused by small input impedance of load, as long as there is a primary coil forming coupling with the secondary coil.

This system uses ground coils that conform to the future international standard so that vehicles with a vehicle coil for the contactless power transfer system for parked EVs can also receive power while travelling. In addition, ground coils are located with spacing in between rather than in contact with each other. The purpose of this layout is to facilitate installation and reduce the cost of the ground facility.

When the vehicle coil is directly above a ground coil, power is transferred through that ground coil. When the vehicle coil is between ground coils, power is transferred through the two ground coils. Therefore, as Figure 5 indicates, the power transfer concept of the proposed system enables continuous transfer with some fluctuations. The range of fluctuations is largely determined by the interval between the coils, an example of which is given later.

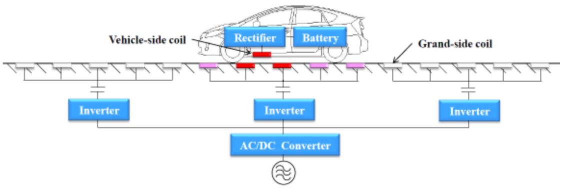


Fig. 4. Proposed system comcept.

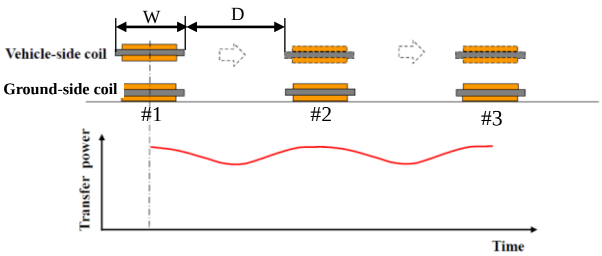


Fig. 5. Power transfer concept of the proposed system.

4.2. Power Transfer Characteristics

As a technical review of the proposed system, the power transfer characteristics, which are a type of basic performance, were evaluated. As shown in Table 2, the evaluation system consists of three ground coils and one vehicle coil. The ground coils and the vehicle coil are H-shaped solenoid coil which is shown in Fig.6. The evaluation circuit and evaluation system are shown in Fig.7 and Fig.8. The ground coils interval (D) was changed from the core width of the ground coil (W) to twice the width. As Figure 5 indicates, the power received with the vehicle coil was measured with the vehicle coil initially directly above a ground coil without misalignment and then while moving.

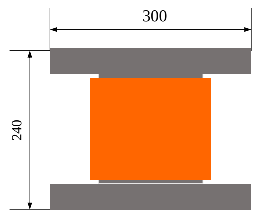


Fig. 6. Outline of the H-shaped solenoid coil

Table 2. Specifications of evaluation system.

Output power		3 kW
Gap [mm]		70±30 mm
Resonance type		SS
Coil type		H-shaped solenoid
Frequency [kHz]		85
Size [mm]	Ground-side	240×305×25
	Vehicle-side	240×305×20
Winding	Ground-side	20T×2p
	Vehicle-side	14T×2p
Number of coils	Ground-side	3
	Vehicle-side	1

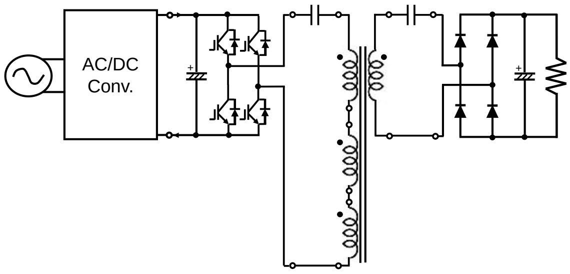


Fig. 7. Evaluation circuit.

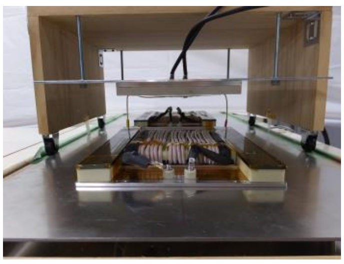


Fig. 8. Evaluation system.

Figure 9 shows the characteristics of power transfer with change ground coil interval. The position of the vehicle coil was normalized with the core width of the ground coil (W) and the power received by the vehicle coil was normalized with the power received at the position immediately above a ground coil. The results demonstrate stable power transfer with fluctuations of receiving power within 10% for an interval between ground coils of W and 20% for an interval of 1.5 W.

Figure 10 indicates the power transfer efficiency between the ground side coil and the vehicle side coil of the proposed system. Even if the vehicle side coil moves, the system to propose shows that an electricity supply efficient decline can be done small.

When the vehicle side coil moves between 2 ground side coils, an electricity supply efficient fluctuation will be small by sharing transfer of power to the vehicle side coil by both ground coils. Even if the vehicle side coil moves, the system to propose shows that a mutual inductance fluctuation between the ground sides coil and the vehicle side coil can be done small.

A decline of the maximum power transfer efficiency of the proposed system is caused by resistance increase of the ground side coil. The device which won't be resistance increase of the ground side coil becomes important.

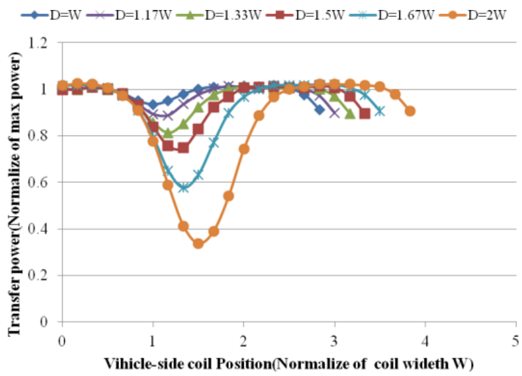


Fig. 9. Characteristics of power transfer with change ground coil interval.

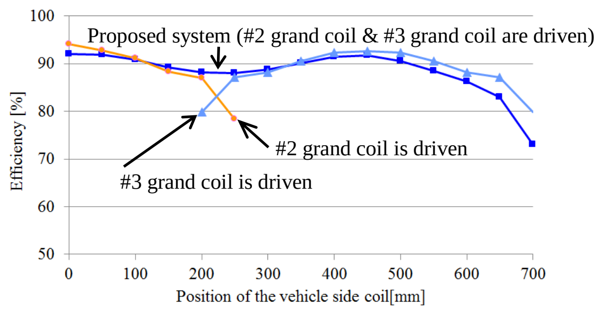


Fig. 10 Power transfer efficiency between the coil (In case of D=W).

5 Conclusion

This study demonstrated the need for a contactless power transfer system for charging moving EVs based on the calculation of the number of fast-chargers required to be installed along the highways when EV penetration has reached 10%. The simulation for traveling on highways and in urban areas clarified the required specifications for the contactless power transfer system for charging moving EVs that guarantees the traveling of EVs with the current performance without having to stop for charging.

Assuming that the speed of passing contactless power transmission sections is the lowest allowable speed on highways (50 km/h), the ratio of the length of the contactless power transmission sections to the total length needs to be only 20%, which is a practical number.

We have resolved the technical issues of the conventional system, proposed a contactless power transfer system for charging moving EVs that can also service vehicles with vehicle coils for the contactless power transfer system for charging parked EVs and demonstrated its technological significance through experiments. The contactless power transfer system for charging moving EVs has the following advantages:

- Long-distance drives are possible without concerns about charging.
- Users do not have to wait while their EVs are being charged.
- Reducing the fluctuations in the SOC of the vehicle battery alleviates the degradation of the cells.
- The reduction in the capacity of the vehicle battery reduces the vehicle cost.

The contactless power transfer system for charging moving EVs with the above features has the potential to make a significant contribution to the spread of EVs.

6 Future Plans

In addition to resolving the technical problems of the conventional systems, we are planning to study the following on our proposed system:

- Optimization of the ground-side coil connection (series or parallel) and a resonance circuit (SS or SP).
- Power transfer characteristic analysis to more than one vehicles.
- Development of the 25kW contactless power transfer system for charging moving EVs.

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