Introduction of a Novel Application in On Line Electric Vehicle

Hyung-Wook Shim, Jong-Woo Kim, Dong-Ho Cho

Abstract
In this paper, we study on the optimized SMFIR(Shaped Magnetic Field In Resonance) structure to reduce OLEV’s(On-Line Electric Vehicle) power variance. It is hard to locate the vehicle on a road exactly in which the power line is placed under the road. This is the main reason why the power variance would occur dramatically since the shape of magnetic fields which are absorbed on pick-ups doesn't match between power line and pick-ups. As to this problem, OLEV should be designed to compensate unmatched magnetic fields by optimizing the structure. In addition, it is important to limit EMF, generated from high frequency current, within ANSI standard. As safety is verified, OLEV will be stepped forward to commercialization. Therefore, we analyze the factors that affect to power increase and decrease from SMFIR structure. Furthermore, we suggest the optimized SMFIR structure which is safer and have higher performance.

Keywords: Power Exchange, IPT, SMFIR, On-Line Electric Vehicle

1 Introduction
For replacing fossil fuel to eco-friendly resources, many types of vehicle recently have been introduced in transportation industry. OLEV(On Line Electric Vehicle) is one of the vehicle developed in KAIST(Korea Advanced Institute of Science and Technology) since 2009. Although it have a few hinders regarding power transfer efficiency and heavy cost, it is obvious that, if these are solved, OLEV will bring out ripple effect to vehicle trend for convenient charging and various applications. With the property of structures, collector and feeder, the most remarkable advantages of OLEV are changing formation of magnetic fields and transferring power bi-directionally. It is consequently possible to increase power transfer efficiency and be used emergency power source similar to V2G(Vehicle to Grid). In addition, there is another issue about vehicle’s mileages. Normally, EV(Electric Vehicle) can be drove for lower than 200km with a charge, whereas OLEV is independent to mileage because of energy exchanging application. Only to park a particular space, energy exchanging is simply operated. Therefore, it would be OLEV’s distinctive strong point compared to others. In the point of view above, we suggest a novel design of power line for power exchange. From this research we expect that this application will be powerful added value, which make it come to the fore OLEV commercialization.
2 Application Technology in OLEV

Improve practicality for various applications are now the most important issue in EV industry. Especially, as battery capacity keep decreased naturally, we have to find the way to use surplus power. In this regard, utilize characteristics of wireless power transfer technology, OLEV have developed useful application. The one is bidirectional power transfer and another is power exchange. Not only both technologies based on the SMFIR(Shaped Magnetic Field in Resonance), it is also applied inductive power transfer method.

2.1 Overview of OLEV

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OLEV have many advantages of reduced battery capacity and driving charging compared to EV which is highly dependent on the battery. In addition to these, many applications have been developed since it doesn’t need power cables which are connected between vehicle and electrical outlet. For instance, a SMFIR technology which forms particular magnetic fields was developed for increasing power transfer efficiency. We can have any formations and performance only to vary material and structure of core. On top of that, V2G system, reversal mechanism compared to vehicle charging, is a promising application. As OLEV uses the wireless method, only to control inverter output frequency, it is possible to apply the application. Thus, without economic burden, surplus energy in batteries would be utilized to assistance sources[1].

2.2 Shaped Magnetic Field in Resonance

There are three properties, shown in Fig 2, representing of interaction of magnetic field and substance. The basis of this phenomenon is explained by changing line’s path. From this principle, we can make any paths with particular formations what we need.

![Interaction of magnetic field and substance](image1)

Figure 2: Interaction of magnetic field and substance

In case of wireless power transfer technology, it is essential to use this method to design optimistic feeder and collector structures. That is because not only increasing power transfer efficiency, it is also critical to reduce and control diffraction magnetic fields heading passengers within designated quantity[2].

2.3 Bidirectional Power Transfer

The method of generating induced electromotive force by magnetic fields in feeder is the same as it in collector in OLEV. Accordingly, we don’t need to consider compatibility of connection vehicle to vehicle. Only to operate feeder and collector system inversely, they can transfer power bidirectionally[3].

![Bidirectional power transfer configuration](image2)

Figure 3: Bidirectional power transfer configuration
3 Application Technology in OLEV

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3.1 Principle and Properties

From the both of applications what we discussed, exchanging power technology can be now embodied in OLEV. The reasons why this application is introduced are that utilizing long time restored energy in battery, increasing mileage of vehicle.

![Diagram of Power Line](image1)

Figure 4: Power exchange method

For power exchange among vehicles, it is key factor to design feeder and collector’s ferrite core considering bidirectional power transfer. In addition, charging station except to area placed vehicles has to be released a few EMF. Thus, feeder and collector system should be designed considering optimized structure and safety.

3.2 Feeder

The feeder consists of a power line, ferrite cores and PCU(Power Conditioning Unit). Firstly, power line has particular shape in order to transform magnetic fields by which is caused. It is very critical in that strength of magnetic fields and extent of magnetic flux passing through are factors generating electromotive force. The power line shaped suggesting in this paper is shown in Fig. 5. As it is seen, it has a charging section and a non-charging section. In the charging section, parallel lines are placed. To maximize magnetic flux, each of lines has opposite current vector. In the non-charging section, on the other hand, magnetic fluxes are just harmful factor to passengers owing to EMF(Electric and Magnetic Fields). Therefore, as we introducing crossed power lines, EMF could be minimized near area.

![Diagram of Power Line](image2)

Figure 5: Power Line

Theoretical values of magnetic fields in both sections are induced below.

In Fig. 6, magnetic field in P can be calculated from (1) to (5). I is a current and z is a distance from line to measuring point. Also, l is a finite line length.

![Diagram of Power Line](image3)

Figure 6: Power Line

\[
B = \frac{\mu_0 I}{4\pi} \cdot \int \frac{dl \times \hat{n}}{\eta^2} \cdot dl 
\]

(1)

\[
dl \times \hat{n} = dl \cdot \cos\theta
\]

(2)

\[
l = z \cdot \tan\theta, \quad dl = \frac{z}{\cos^2\theta} \cdot d\theta
\]

(3)

\[
B = \frac{\mu_0 I}{4\pi} \cdot \int \left( \frac{\cos^2\theta}{z^2} \right) \cdot \left( \frac{z}{\cos^2\theta} \right) \cdot \cos\theta \cdot d\theta
\]

(4)

\[
B = \frac{\mu_0 I}{4\pi z} \cdot (\sin\theta_2 - \sin\theta_1)
\]

From (5), magnetic fields in the middle of section
1 and 2 can be expressed to (6). Direction of magnetic fields doesn’t display, since it is induced by alternative current.

\[ B \approx \frac{\mu_0 I}{\pi Z} \cdot (\sin\theta_2 - \sin\theta_1) \quad (6) \]

In the section 3, it can be expressed to (7).

\[ B \approx \frac{\mu_0 I}{4\pi Z} \cdot (\sin\theta_2 - \sin\theta_1) - \frac{\mu_0 I}{4\pi Z} \cdot (\sin\theta_3 - \sin\theta_1) \quad (7) \]

In addition, as shown in Fig. 7, distribution of magnetic fields strength is simulated using MAXWELL tool.

![Figure 7: Distribution of magnetic fields strength](image)

Secondly, ferrite cores which transform magnetic field shape are proposed in Fig. 8. As it was studied in chapter 2.2, we focus on increasing magnetic flux heading collector directly and decreasing magnetic flux heading outside of collector using concentration, deviation and repulsion. Compared to the established OLEV structure which was designed for vehicle charging only, feeder and collector have a same shape of core which available bidirectional power transfer.

At last, as shown in Fig. 9, PCU consist of rectifier, DC-DC converter and inverter. Rectifier is a three phase full-wave rectifier and converter is a two phase buck converter. Finally, inverter is a full bridge inverter. The arrow line express established PCU configuration and the dotted arrow line show the new PCU configuration for exchanging power. The reason why power line is connected to rectifier is to compensate the voltage sag and swell caused by power variance of battery during power exchanging [1]-[3].

![Figure 9: PCU configuration](image)

### 3.3 Collector

The collector, as shown in Fig. 10, consists of a pick-up, rectifier and regulator.

![Figure 10: Collector configuration](image)

Firstly, pick-up is classified to ferrite core and winding. Windings are tied up with ferrite core, which has particular shape to maximize magnetic flux density in pick-up, and this combination is attached to bottom of vehicle. As it is mentioned, collector’s ferrite core has same structure with feeder except that which is wound with windings as shown in Fig. 11.

![Figure 11: Collector’s ferrite core](image)

The rectifier is a single-phase SCR(Silicon Controlled Rectifier) operated by phase controlled method. The regulator is a boost DC-DC converter.
4 Simulation

4.1 Condition
To demonstrate performance of the system, we analyze an induced electromotive force in feeder and collector. It is simulated by MAXWELL program with particular conditions which is shown in Table 1.

<table>
<thead>
<tr>
<th>Item</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solution Type</td>
<td>Transient, Eddy Current</td>
</tr>
<tr>
<td>Mesh</td>
<td>10mm</td>
</tr>
<tr>
<td>Resonance Frequency</td>
<td>5kHz</td>
</tr>
<tr>
<td>Battery Capacity</td>
<td>20kWh</td>
</tr>
<tr>
<td>Charging Time</td>
<td>10min</td>
</tr>
<tr>
<td>Number of Windings</td>
<td>Collector: 32, Feeder: 10</td>
</tr>
<tr>
<td>Air gap</td>
<td>20, 30cm</td>
</tr>
</tbody>
</table>

4.2 Results
To get performance more than 50% of power efficiency, when the energy exchange is occurred in two vehicles, the vehicle, which gives the power, transfers the controlled power to induce 100A/5kHz current in the power line.

In the Fig. 12, the induced electromotive force in to be charged vehicle is about AC 466V at 30cm air gap. Suppose it has as same as an established OLEV structure, total power transferred is about 8.7kW. If the vehicle is charged for 10 minutes, total charge quantity is about 1.3kWh.

In the Fig. 13, the induced electromotive force in to be charged vehicle is about AC 650V. Suppose it has as same as an established OLEV structure, total power transferred is about 16kW. If the vehicle is charged for 10 minutes, total charge quantity is about 2.6kWh.

To demonstrate the safety about limiting exposure to time-varying electric, magnetic, and electromagnetic fields, EMF is measured to follow ICNIRP guidelines. Also, the measuring method is follower by IEC 62110 in Fig. 14[4-5].

As shown in Fig. 15, EMF is measured at three points, since it is important to verify the differences the point near the vehicle and the point where the vehicle doesn’t be placed.

From the Fig. 16-18, the points of A and B have higher EMF value than the point of middle, X and X respectively. In addition, the EMF value at
middle is very low at 5mG average compared to the ICNIRP guidelines; 62.5mG. According to this, the energy exchange configuration is acceptable for safety regulation.

From the results of simulation, it is possible to charge a vehicle with 0.8C-rate maximum. Also, charging infrastructure is having EMF value below the ICNIRP guidelines. Especially, there are rarely EMF value above the power line where is no a vehicle.

5 Conclusion

In this paper, the novel application of OLEV is introduced to develop its utilization. From the results, energy exchange between vehicles is operated with prominent performance and safety. It shows the possibility of applicability of the energy exchanging technology. However, the power efficiency is still low by which the property of wireless power transfer compared to plug-in charging method. If the structure for energy exchange would be optimized, it should not only be improved its performance but also be more practical by extension.

References


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