

Review of Inductive Power Transfer

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ABSTRACT

Inductive Power Transfer (IPT) technology has been gaining popularity all around the world for the last few decades. It is gradually becoming an indispensable part of people’s lives. This paper will evaluate IPT technology from two general aspects: current development statement and future development tendencies. After reviewing a large amount of literature, it can be concluded that many researchers have made their efforts and some valuable outcomes have already been accomplished. It turned out that at the current stage, two main applications of this technology are studied most, including the charging of Electric Vehicles (EVs) and Electrical Unmanned Aerial Vehicles (UAVs) by using IPT systems. Additionally, uncontrolled power loss, leakage of magnetic field and relative coil position problems are bothering people. Different studies have been carried out in order to solve these problems with this technology in different situations. Different solutions will be presented through a literature review. In the future, efficiency and volume problems will likely be the research tendency according to the literature review.

Keywords: Inductive power transfer, current statement, problems, future development

1. INTRODUCTION

Wireless Power Transfer (WPT) has been examined around the world for decades. Tremendous achievements have been made. Inductive Power Transfer (IPT), as a topology of WPT has grown to be an important topology in various applications. It was originally a fledgling technological base in 1995 [1]. However, it has become an indispensable part of modern technology. Figure 1 presents the typical IPT structure.

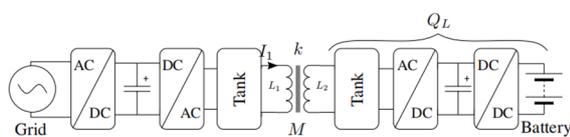


Fig.1. Typical IPT structure [2]

Here the tank part is used as a compensation circuit (resonant tank). The M sign represents the mutual inductance between the primary side and the secondary side. The L1 is the transmitter inductance and the L2 is the receiver inductance. K is the coupling factor that can be infected due to the material of the medium. QL is the load quality factor [2]. The inductors can be used as filters. This picture generally covers the necessary parts of the technology, other components can also be added as an improvement. The aim of this paper is to present a

general evaluation of IPT technology. The current development state and main problems faced with this technology will be analysed and the direction of future research will also be suggested according to the literature review. This research is important, since it provides a relatively comprehensive knowledge about the rough conditions of IPT technology.

2. CURRENT DEVELOPMENT STATE AND PROBLEMS TO BE SOLVED

2.1. The current development state

The most popular applications of IPT technology are concentrated in the areas of Electric Vehicles (EVs) and drones. Here, this paper will analyse them separately.

2.1.1. The application related to EVs

It is evident that EVs have been gaining popularity around the world for decades. They are not only environmental-friendly, but also efficient. As the research goes deeper, the battery charging system becomes a vital part. Firstly, like all electronic devices, the method of charging by wire is applied. However, the efficiency was low and the cost was high [3]. Thus, wireless charging is taken into consideration, since it is user-friendly and safe.

Different topologies are applied to charging EVs including: resonant inductive power transfer methods [3], different compensation topologies such as Series-Series (SS), Double-sided Inductor-capacitor-capacitor (LCC-LCC) and Double-sided Capacitor capacitor (CC-CC) topologies [4], and many other topologies. The basic structure described above is certain to be adaptable to all topologies; only the specific components must be changed.

It is obvious that in order to charge faster, sometimes high power is required. There are also two different charging situations: static and dynamic charging [3]. The resonant inductive power transfer can achieve high efficient high power charging under both situations according to the research of professor Mohammad and his research team [3]. Additionally, choosing a proper compensation topology can also be of great importance, since it would affect the efficiency and power transfer capability of the whole system [4]. According to the research conducted by Korea Electric Power

Corporation (KEPCO), the three topologies including SS, LCC-LCC, CC-CC above showed good efficiency and good capability.

2.1.2. The applications related to drones

Electrical Unmanned Aerial Vehicles (UAVs), also known as drones, have been applied to various areas during their development, including social infrastructure monitoring for industrial purpose, precision agriculture, and many other aspects [5]. Among all these applications, most of them would require efficient and substantial energy supply according to the literature review. Thus, initially, huge batteries with capacities of 600Wh to 2800Wh were used to supply the power according to Obayashi and his team. However, the weight of the battery is too high, so the efficiency of the battery is restricted by its own weight [5]. Although recently, lithium ion battery has been applied to the charging process, the problem of weight remains. Thus, wireless charging using IPT technology was applied naturally. The basic charging process is as follows:

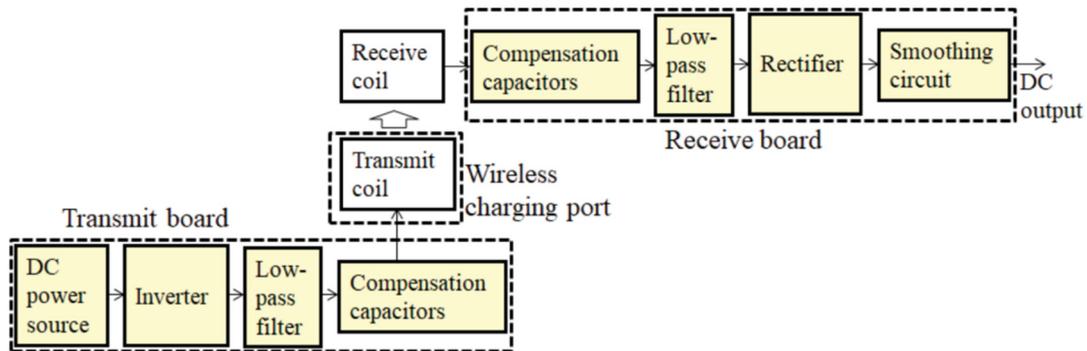


Fig2. The process of charging UAVs by using IPT technology [5]

According to this basic structure, various specific internal structures are used. For example, Obayashi and his team [5] developed a fast wireless FRP frustum charging port for an 85-kHz band 50-V 10-A inductive power transfer system. The capacity and efficiency of the charging process are greatly improved. Nonetheless, this model can only be applied to limited situations. It is for sure that under different circumstances, different topologies should be applied.

2.2. The problem to be solved

Through decades of development, various problems are raised under different situations. Some have been solved while others can only be improved. Here, three meaningful problems are discussed according to the literature review.

The first problem would be the power loss during the transfer process. This is a problem that can not be erased completely due to the fact that most IPT systems work in complex environments where many factors could cause the power loss such as temperature. In fact, many applications including the EVs and UAVs mentioned above demand a high density and highly efficient power transfer environment. However, thermal impact on the components may greatly interrupt the process [6]. Some people have made efforts to improve the problem. For instance, professor Alexander [6] from Germany developed a design procedure for power loss shifted inductive energy transfer systems, which can be used to reduce the power loss on both the primary side and the secondary side. His experiment suggested that the model is adaptable to many applications. The specific circuit looks as follows:

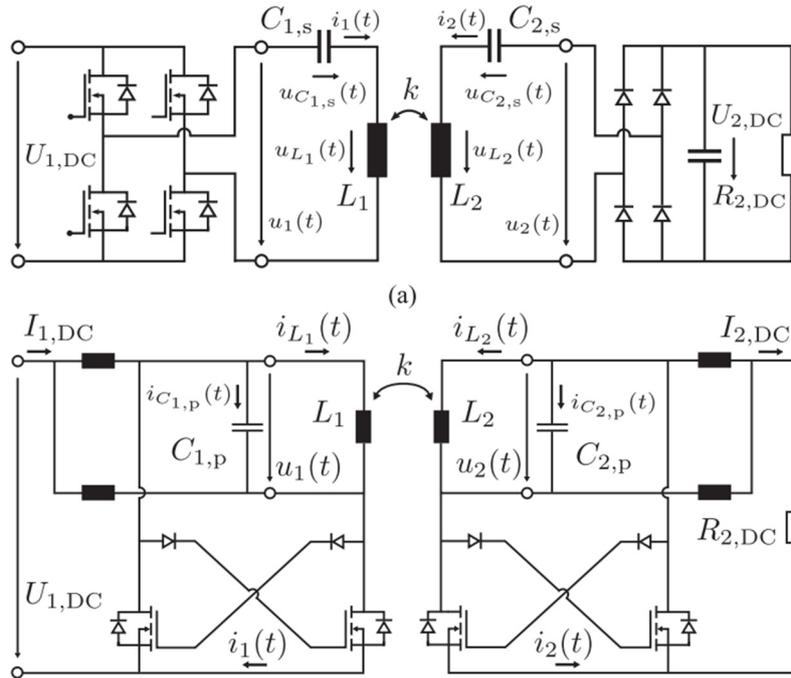


Fig.3. The circuit for reducing power loss [6]

However, his experiment data also suggests that the model is far from perfect. Power loss dependent on the load is still detected [6]. This problem has existed since the beginning of this technology, and the solutions are still improvable.

The second problem is the leakage of magnetic fields. It is certain that the coils of IPT systems are surrounded by Electromagnetic fields (EMFs). Since most systems do not work in a isolated free space, thus there would be interference from other EMFs on the working system. Besides, the working components in the system are not perfect. These factors could cause the magnetic field leakage. A research team from XJTU [7] developed a model which contains a structure called hemicylinder-cylinder joint structure. This design can reduce the level of leakage magnetic fields (LMFs). It

can also maintain the transmit efficiency at 97.91% according to their experiment [7]. However, magnetic leakage still exists.

The third question would be the coil offset problem. In various kinds of WPT systems, sudden changes in the relative position between the receiving and transmitting coils could happen, which would change the parameters of the system and cause overshoot and undershoot as well as ringing in the voltages and currents [8]. Thus, it is important to figure out how to reduce the impact of this problem. Professor Li [8] and his crew raised a concept called “coupling coefficient susceptibility” to measure the stability of any system [8]. They also built a model to investigate the relative position transient (RPT) problem:

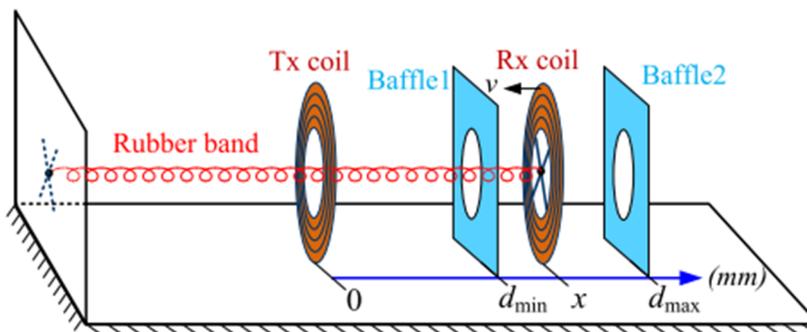


Fig.4. The model used to investigate RPT problem [8]

According to their experiment data, many systems have low efficiency. Thus, this problem remains to be improved.

3. FUTURE DEVELOPMENT

In this part, some future development tendency will be examined according to the literature review.

Since the application of IPT technology becomes wider, as mentioned above, there will be some situations where the space is strictly constrained. Thus, the volume of the components should be reduced to some degree. According to the analysis above, it can be concluded the first development tendency will reduce the size of different applications of IPT technologies. Currently various researches are being carried out simultaneously. Some studies have already made huge progresses. For instance, the State Key Laboratory of Analog and Mixed-Signal VLSI, Institute of Microelectronics and University of Macau [9] worked together and figured out a methodology of Asymmetrical Coils Design,

which can solve the problem for space-constrained applications. It is common sense that the transmitting and receiving side of the IPT technology should be designed in symmetry so that a better coupling coefficient can be obtained. With the coils not being symmetry any more, it is hard to keep the efficiency and output of the system unchanged [9]. However, they figured out a model for Series-Series Inductive Power Transfer (SSIPT) that can achieve an asymmetrical coil with a similar transfer efficiency and the same load independent current (LIC) output [9]. The design flowchart is shown below:

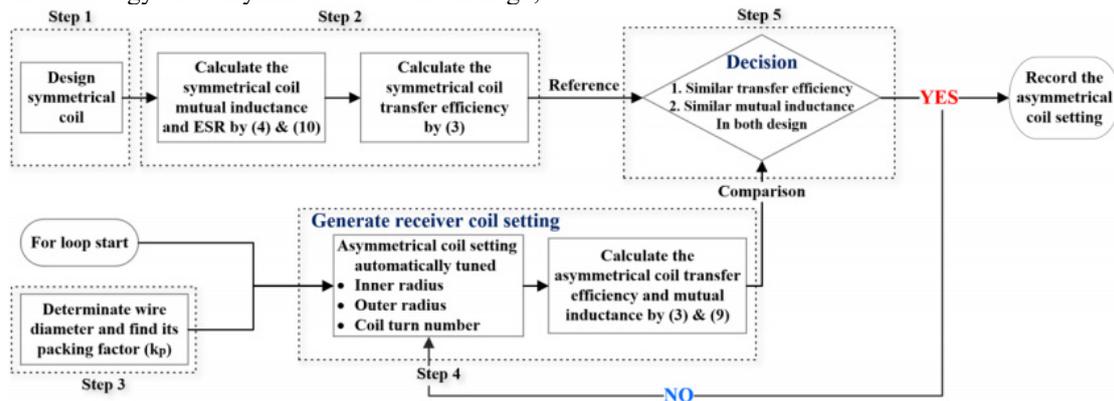


Fig.5. The flow chart of designing IPT systems with asymmetrical coils [9]

According to their experiment data, this technology efficiently decreases the volume of coils but can still be improved [9].

The second development tendency will improve the efficiency of different IPT systems. As is mentioned above, due to various uncontrolled factors such as temperature, the efficiency of the system can never be 100% for practical applications. However, people can try to improve the efficiency to a relatively higher value. The first method will change the material of the components. Professor Long [10] suggested that the intrinsic brittleness and low flux density saturation point of ferrite used by IPT systems would cause the the reliability and performance of the systems to be reduced. Thus, in his experiment, nanocrystalline-ribbon-based magnetic cores were suggested to be applied to IPT systems to bring higher efficiency [10]. He also designed a model with a 11.1 kw pad to achieve higher efficiency and power density [11]. Additionally, FEM simulations and experimental results were applied to justify the suggestion [12]. In conclusion, core miniaturization can be effectively achieved at the cost of 20% higher core losses [12]. Thus, further improvements can be made.

4. CONCLUSION

To summarize, this paper generally evaluated the IPT technology from two sides: current development situation and future development tendency. Various

experimental data were presented to prove the validity of the theories.

In terms of the current development state, two main applications were mentioned: EVs and UAVs. Charging EVs or UAVs with IPT technology would be both environmental-friendly and efficient. For charging EVs, resonant inductive power transfer methods and three compensation topologies including series-series (SS), Double-sided Inductor-capacitor-capacitor (LCC-LCC) and Double-sided Capacitor (CC-CC) topologies were covered. The performance of these technologies under different situations was evaluated according to the literature review. For charging UAVs, the basic process of charging was analyzed and a fast wireless FRP frustum charging port for an 85-kHz band 50-V 10-A IPT system was also mentioned.

When it comes to the problems to be solved, three popular problems were raised including: power loss problem, magnetic field leakage problem and coil offset problem. For the power loss problem, a design procedure for the power loss shifted IPT systems was presented. A hemicylinder-cylinder joint structure was presented to solve the magnetic field leakage problem and a concept called “coupling coefficient susceptibility” was raised to stabilize the coils.

In the future development analysis part, two general tendencies were presented: reducing the volume and improving the efficiency of the problem. In the aspect of reducing the volume of IPT systems, a model for SSIPT

was presented, and relative experiment data was presented too. For efficiency improvement, it is suggested that different material based cores called nanocrystalline-ribbon-based magnetic cores should be applied. Relative experiment data was also presented to prove the validity of the assumption.

Due to the restriction of material and time, this paper is far from complete. Further researches and reports are expected in the future study.

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