COMPUTER ANALYSIS OF MAGNETIC FLUX DISTRIBUTION IN WIRELESS POWER TRANSFER SYSTEMS

Desislav Iliev[1], Nikolay Madzharov[2]
[1] Technical University of Gabrovo, BG
[2] Technical University of Gabrovo, BG

Abstract
This paper presents a computer simulations of the distribution of the magnetic field density in a model of an inductive-resonant wireless power transfer system with a passive resonant circuit. The utility of the passive resonant circuit and its influence the field distribution on the individual windings in the system is visually demonstrated. For comparison of the obtained results, a model of the same system without passive resonance circuit is presented. The advantage of an additional passive resonant circuit in the contactless charging systems for electric vehicles has been proved.

Keywords: Wireless Power Transfer, magnetic resonance, efficiency, coupling coefficient, simulation.

INTRODUCTION

Rapid development in the field of Wireless Power Transfer System (WPT) has been observed over the past few decades. Devices of this type have long been available to the average consumer – contactless chargers for mobile phones, laptops, tablets, etc. Studies and practical trials are carried out in many other areas of WPT systems - for charging electric vehicles, for transmitting energy and direct power supply of aircraft, Unmanned Aerial Vehicle (UAV) and even to spaceship. In medicine, there is a particular interest in these systems, because they allow charging of rechargeable batteries of implants without connecting wires.

EXPOSE

I. TIPES OF WPT SISTEM

Basically, WPT system can be divided into two groups: for long-distance energy transmission with electromagnetic radiation (radiative) (microwave and laser) and for the transmission of energy over small distances without electromagnetic radiation (non-radiative), (capacitive, inductive and inductive resonance) (Table 1).

Table 1
Average values of WPT systems

Method	Transmission distance	Efficiency	Power	Frequency	Influence on living objects
Capacitive	up to 3 mm	up to 60%	up to 10 W	up to 1 MHz	Low
Inductive	up to 30 cm	up to 90%	up to 300 kW	up to 100 kHz	Low
Inductive resonance	up to 2 m	up to 80%	up to 50 kW	up to 5 MHz	Moderately
Microwave	up to 50 km	up to 60%	up to 100 kW	up to 300 GHz	Dangerous
Laser	up to 100 km	up to 50%	up to 1 MW	over 1 THz	Dangerous

The first group is utilized to transfer energy over a greater distance, from a few tens of centimeters to tens of kilometers or even hundreds of kilometers. The second group is utilized in the transfer of energy over a small and a medium-range distances, from a several millimeters to a several tens of centimeters.

Microwave Power Transfer (MPT). It is a method using electromagnetic radiation. This method is the oldest, if you take into account the radio communication, which began as early as the 19th century, because it is essentially a transfer of energy. In the early 1960s, W. Brown in laboratory conditions was able to transfer energy using a frequency of 2.45 GHz, using magnetrons and clystrons with special horn antennas as an antenna, and for receivers using a rectifying antenna ("rectenna") created for receivers. In 1975, he was able to transferred

495W of energy at a distance of 170.2 cm with 54% efficiency. In the same year, he transferred 30 kW of power at a distance of 1640 meters.

Laser Power Transfer. This method also uses electromagnetic radiation with a frequency greater than 1 THz. Energy transfer can take place over very long distances reaching tens of kilometres in the presence of direct visibility between the transmitter and the receiver, as the energy is concentrated in a narrow beam and dissipates very little upon distance. Different types of lasers can be used as a transmitter. Photovoltaic elements are used as a receivers, which is also associated with one of the main limitations of its application, and their low efficiency, usually about 12 %.

Capacitive Power Transfer. It belongs to the group of non-radiative methods. So far, this method has found almost no practical application. This is mainly due to the fact that in order to transfer energy, an equivalent capacitor (or capacitors) is created in order to carry out the two main schemes in the practical realization of this method – bipolar capacitive connection and unipolar capacitive connection. The amount of energy transferred from the source to the load, which reaches several tens of watts, is determined by the size of the plates of the equivalent capacitors, the distance between them and the operating frequency. This method does not allow reduction of the overall dimensions of the devices and an increase in the distance at which energy can be transferred through it. However, in 2011 Toyota Central R & D Labs., Inc. and Toyohashi University of Technology conducted research to perform WPT of a car while driving using this method. Their aim is to avoid the problem of accurate positioning of the vehicle during movement, because the plates of the equivalent capacitors worked in the road surface can be made with a sufficiently large width.

Inductive Power Transfer (IPT). This method is non-radiative. Until now, it has found the most widespread practical application. Capacities up to a few dozen kilowatts at a distance of up to a few tens of centimeters and even meters can be transmitted through it. The principle of energy transfer in this method resembles the work of a transformer, the primary and secondary coils of which are separated by a large air gap and lack a core (if used, it is also separated by the gap). An AC current flows through the primary (transmission) coil, which creates an AC field, which in turn creates an AC current in the secondary (receiving) winding. As the distance between them increases, the electromagnetic connection coefficient reduces the overall EFFICIENCY of the system. At a distance bigger than one quarter of the diameter of the coils (D), the magnetic coupling coefficient (k) decreases a lot and reaches a value below 0,17 [1]. To avoid this problem are done and continue to do research in this direction, but they are not completed.

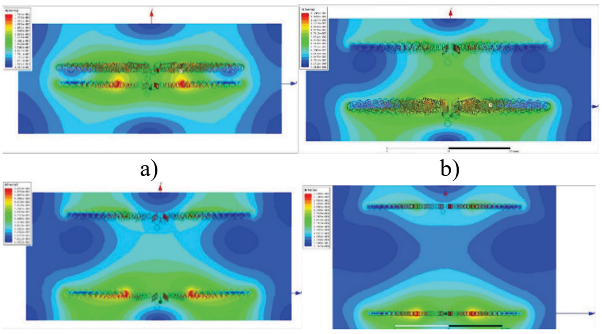
Inductive-resonant Power Transfer (IRPT). To avoid the disadvantage of the IPT, in 2007 [2], researchers from MIT introduced an additional resonance circuit (or circuits) that allows increasing the distance of WPT, at efficiency up to 80%. Resonance circuits are consistently related inductance and capacitor. When the operating frequency increases, resonance can also be obtained without the use of consistently connected capacity and inductance, but the capacity of inductances involved in the system can also be used. When the distance increases, the magnetic coupling coefficient (k) decreases rapidly, but its compensation can be done with the increasинг the quality factor (Q) of the circuits.

The above advantages of this method relative to the inductive method make it very promising in its use in a lifestile – for charging different mobile devices, as well as for directly powering those with low power consumption – TV sets, radio receivers, etc. It can be used in medicine to charge rechargeable batteries to medical implants, thereby eliminating the need for connecting wires or surgical intervention for the replacement of devices, which reduces patients' discomfort. In the automotive industry and in general in transport, this method provides the ability to charge the batteries of electric vehicles by reducing the need for accurate positioning and giving advantages in charging them while driving. In these cases, the receiving part is incorporated into the frame of the electric vehicle and this predetermines a relatively large distance to the roadway where the transmitter coil is built.

II. SIMULATION RESULTS OF INDUCTIVE POWER TRANSFER SISTEM WITHOUT AND WITH RESONANT CIRCUIT

For output data for computer analysis of magnetic flux density in IRPT system, a model of an inductive resonance energy transfer system [3], consisting of a transmiter and reciver coil and a passive resonance circuit shall be used. The parameters are – a three equal coils of 60 mm external diameter (D), made of ten turns of copper wire (litz wire) with a diameter of 2 mm. The operating frequency of the system is 30 kHz and power of 500W.

Initially, the magnetic flux density of the system without a resonant circuit is simulated, at a distance between transmitter and receiver coil of 5, 15, 25, 40 millimeters (Fig.1) to serve as a subsequent comparison of the results.

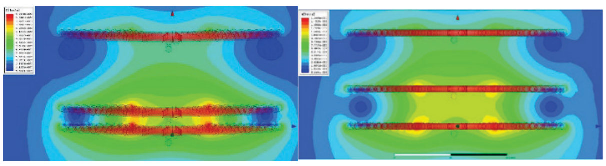


a) b) c) d)

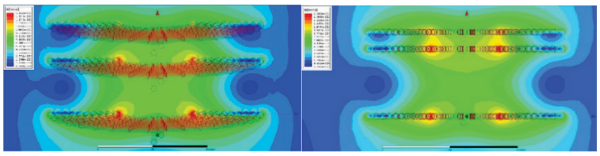
Fig.1 *WPT system without resonant circuit. Distance between transmitter and receiver are: a)- 5mm, b)- 15mm, c)- 25mm, d)- 40mm.*

From the presented results it can be seen how the field strength, which completely envelops the receiving winding, decreases with increasing distance, as at 5 millimeters it is $6{,}4.e^{-3}$T, then it becomes $5.3.e^{-3}$T, $4{,}3.e^{-3}$T and at a distance of 40 millimeters it has dropped to $3{,}7.e^{-3}$T.

The second simulation was made at a distance between the transmitter and receiver coils of 25 mm, but with a passive resonance circle introduced, successively placed at a distance of 5, 10, 15 and 20 millimeters from the transmiter coil (Fig. 2).



a) b)

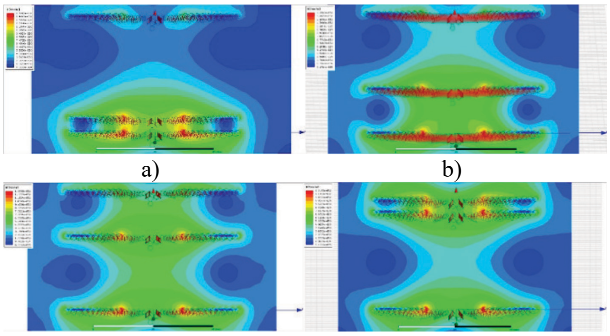


c) d)

Fig.2 *WPT system with resonant circuit and distance between transmitter and receiver 25 mm. Distance between transmitter end resonant coil are: a)- 5mm, b)- 10mm, c)- 15mm and d)-20 mm.*

It can be seen how the field strength around receiver coil gradually increases, starting from $4{,}35.e^{-3}$T and passing through $4{,}8.e^{-3}$T, $5{,}5.e^{-3}$T and reaching $6{,}1.e^{-3}$T (at maximum approach of the resonant circuit to the receiver coil).

The third simulation was made at a distance of 40 millimeters between the receiver and transmitter. The resonant circuit is located at a distance of 5, 15, 25 and 35 millimeters from the transmitter, respectively (Fig. 3).



a) b) c) d)

Fig.3 *WPT system with resonant circuit and distance between transmitter and receiver 40 mm. Distance between transmitter end resonant coil are: a)- 5mm, b)- 15mm, c)- 25mm and d)- 35 mm.*

The field intensity values around receiver coil are: $4{,}0.e^{-3}$T, $4{,}2.e^{-3}$T, $4{,}7.e^{-3}$T and $5.3.e^{-3}$T. And in this case, the values increase.

CONCLUSION

1. As evidenced by the results obtained, when increasing the distance between the transmitter and receiver coil above 1/4 D (15 mm) and using a resonance circuit, the magnetic flux density around receiver coil can be maintained within very good limits. Thus, a high efficiency of the whole system can be achieved with a correctly selected position of the additional resonance circuit and correct adjustment. In both cases (Fig.2 and Fig.3), a good distribution of the magnetic flux density

around the receiver coil is obtained at maximum approach of the resonant coil to it.

2. At a distance of 15 mm (1/4D) between the transmiter and receiver coil without resonance circuit, the field intensity shall be $5{,}3.e^{-3}T$. At a distance of 25 mm between the transmiter and receiver coil with a resonance circuit, increase to $6{,}1.e^{-3}$T. But at a distance of 40 mm between the transmiter and receiver coil with resonant circuit the field density is $5{,}3.e^{-3}T$. The magnetic flux density remains the same, while the energy transfer distance increases 2.66 times (from 15 millimeters to 40 millimeters), while the whole efficiency of the system preserves.

3. In the presented configuration, the receiver and resonant coils are located very close. It is suitable for WPT charging of electric vehicles due to the fact that these two coils can be deployed in the vehicle. With different placement of the resonant coil can be obtained better transmission efficiency regardless of the clearance of the vehicle.

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