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Superconductors in Improving the Efficiency of the Power Transfer System

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Abstract- **The principle theory behind contactless power transfer is mutual induction. The leakage inductance of contactless power transfer system is very high where as its magnetizing inductance is very low. This reduces its coupling coefficient. Superconductors have the special ability to expel the magnetic field. This property is incorporated with contactless power transfer system, which increases its magnetic coupling coefficient. This paper shows analysis and measurement results of a novel contactless power transfer system comprising of a ferrite core enveloped with layers of superconducting tapes.**

Index Terms- Electromagnetics, Inductive Power Transfer System, Superconductors.

INTRODUCTION

Contactless Power Transfer was presented by Nikola Tesla. In his Tesla coil, the voltage rating and frequency was very high, but ampere rating was low. The coupling was done through the air. Hence the efficiency was very poor.

The principle of contactless power transfer system is that electricity is transmitted from one circuit to other without using conductive wires.It has large air gap, long primary wire and multiple secondary wires. This increases the leakage inductance and reduces the magnetizing inductance. Therefore, large magnetizing current flows through the primary loop due to small magnetizing inductance. This reduced the overall system efficiency. There are different methods to transfer energy. It includes: inductive CPT, capacitive CPT and radiant CPT.

INDUCTIVE CONTACTLESS POWER TRANSFER

Inductive contactless power transfer system is the most efficient way of energy transfer. This system uses alternating magnetic field to transfer the energy from the primary coil (power source) to the secondary loop which is called pick-up (power sink). The primary conductor loop and the secondary pick-up are magnetically coupled to transfer the energy from the power source to the power sink. The total system acts similar to a single phase transformer which has large stray inductivities (especially on the primary side) and a large magnetization current due to the large air gap between the primary side and the secondary side of the inductive system. The magnetic coupling between primary and secondary is usually gained by the use of ferromagnetic material.

The electric power which can be transferred by such kind of system can be calculated as follows:

$P = I_p V_p \cos\varphi = I_p.\omega.B_{fe}.A_{fe} \cos\varphi$

Where P : transferred power
Ip : primary current
Vp : generated voltage
Bfe : flux density
Afe : area of the core
cos φ : phase angle

Its efficiency peaks to 90%.It has a wide range of application which ranges from mobile phones to super speed vehicles. Possible applications of contactless inductive power transfer are in automotive industry, transportation systems, elevators, storage systems and cranes.

The major advantages of this technology includes maintenance-free operation, no sparkling effects due to contact problems, complete isolation of primary and secondary circuits, less pollution and ruggedness against dust and environmental conditions.

The other side of the coin, i.e. the disadvantages is complex technology multiple power conversion and high investment costs.

In this method, the magnetic power is transferred primarily between two coils, thus reducing the effect of the magnetic field on the surroundings. However, oscillating magnetic fields with high frequency generate powerful electromagnetic radiation, which is harmful to people. This poses a problem in high power applications of inductive system, such as electric vehicles.

Another limitation of this system is that efficiency of the power transfer depends on both the magnetic resonance frequency and physical alignment of the magnetic coils.

SUPERCONDUCTORS

Superconductors are materials with zero electrical resistance. This means that transportation of electrons takes without any resistance. So they can conduct electricity without losing energy in the form of heat, sound or any other form of energy. The material becomes superconductive when it has reached "critical temperature" (T_c). However, most materials must be cooled down to extremely low temperatures (near the absolute zero, -273ºC). Recent researches develop compounds that become superconductive at higher temperatures.

Superconductors come in two different flavors: type I and type II.

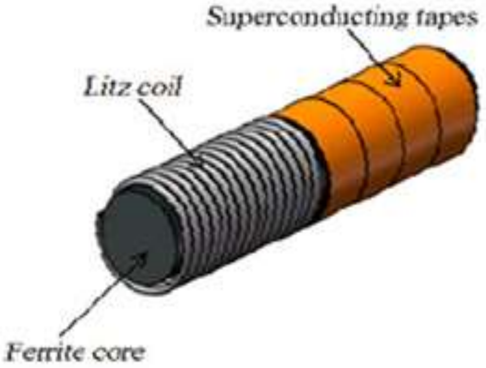
Type I Superconductors consists of basic conductive elements that are used in electrical wiring to computer microchips.

Type II Superconductors is composed of metallic compounds such as copper or lead. They reach a superconductive state at much higher temperatures when compared to type I superconductors.

In superconductors below the transition temperature, electrons form cooper pairs, to synchronize their motion with the ions. Superconductors show the phenomenon of perfect diamagnetism characterized by the complete absence of magnetic permeability and the exclusion of the interior magnetic field.

INDUCTIVE CPT WITH SUPERCONDUCTORS

The new structure of the contactless power transfer system coupler relies on the diamagnetic feature of superconductor, to enhance the magnetic coupling between the primary coil and the pickup coil. The primary structure of the coupler is composed of ferrite core, Litz coil, and superconducting tapes. The superconducting tapes are placed perpendicularly to the axis of the cylinder on one side of the ferrite core, and each tape is covered by Kapton to ensure the insulation between others. The tapes are not soldered together to prevent the inverse magnetic field generated by induced current loop in tapes. The other side of the ferrite core is wrapped with Litz wire.

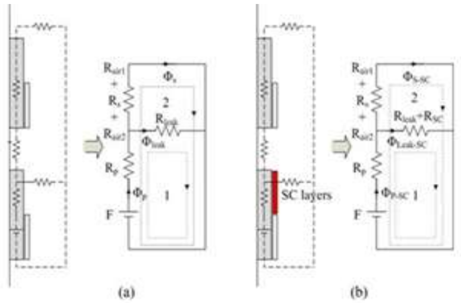


The coupling coefficient (K) of the system is defined as

$$K = \frac{\Phi_S}{\Phi_P} = \frac{\psi_S/N_2}{\psi_P/N_1} = \frac{d\psi_S/N_2 \cdot dt}{d\psi_P/N_1 \cdot dt} = \frac{U_2/N_2}{U_1/N_1} \left.\begin{matrix} \\ \\ \end{matrix}\right\} \Rightarrow K = \frac{U_2}{U_1} \quad (1)$$
$$N_1 = N_2 = N$$

Where φp and φs are, respectively, the magnetic flux through primary coil and secondary coil, N1 and N2 represent turns of primary and secondary windings, respectively, ψp and ψ*s* the magnetic linkage of primary coil and secondary coil, respectively, and U1 and U2 are the voltage of the power source and pickup coil, respectively.

Magnetic circuit model of the system is shown below.



Equivalent magnetic circuit of the system (a) without SC and (b) with SC.

The magnetic flux through the primary core is given by the following equation.

$$\Phi_P = \frac{F}{R_P + \dfrac{(R_{\text{air2}} + R_S + R_{\text{air1}})R_{\text{leak}}}{R_{\text{air2}} + R_S + R_{\text{air1}} + R_{\text{leak}}}}, \qquad (2)$$

$$\Phi_{P-SC} = \frac{F}{R_P + \dfrac{(R_{\text{air2}} + R_S + R_{\text{air1}})(R_{\text{leak}} + R_{sc})}{R_{\text{air2}} + R_S + R_{\text{air1}} + R_{\text{leak}} + R_{sc}}} \qquad (3)$$

Where F is the magneto motive force, φp and φp-sc are magnetic flux through primary core without and with SC layers. Rp , Rleak, Rair2 + Rs + Rair1 and Rsc represent, respectively, the reluctance of primary core, leakage from primary core, air gap plus secondary core, and SC layers. The only difference between the two magnetic circuits is the increase of reluctance in loop 2 because of the diamagnetic feature of the SC layers, which makes the magnetic flux through primary core (φp-sc) decrease by comparing (2) and(3). On the other hand, the decrease of φp-sc leads to the increase of φs-sc, which can be derived from

$$\Phi_S = \frac{F - \Phi_P R_P}{R_{\text{air2}} + R_S + R_{\text{air1}}} \tag{4}$$

$$\Phi_{S-\text{SC}} = \frac{F - \Phi_{P-\text{SC}} R_P}{R_{\text{air2}} + R_S + R_{\text{air1}}} \tag{5}$$

Where φs and φs-sc are the magnetic flux through secondary core without and with superconducting layers. In conclusion, we can infer from (1) to (5) that the coupling coefficient of such structure would increase for the changes of magnetic flux caused by SC layers.

CONCLUSION

In this paper, we have discussed about inductive contactless power transfer system, magnetic shielding of superconductors, and diamagnetic property of superconductors in power transfer system. A novel structure is introduced which has superconducting tapes on primary side which decreases the flux through primary coil and thereby increasing the flux through the secondary coil. This changes the flux ratio and hence the efficiency of the contactless power transfer system.

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