Static Contactless Charging System Using Inductive Coupling Method

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Abstract—In this paper, static contactless charging system is demonstrated by using the method of inductive coupling. Although conductive charging technology has been widely used in many electrical industries such as mobile phones, electric toothbrushes, battery-used electric devices till today, inductive charging technology is going to be another option to choose for consumers in not very far time. It is because inductive charging can give more reliable and flexible benefits since it can be used without a charging cord to plug-in. In this project, oscillator circuit converts DC energy to AC energy in order to transmit magnetic field from transmitter coil to receiver coil by passing frequency and then mutual induction (inductive coupling) occurs between the two coils without any core material except air medium. This system is based on coupling magnetic field, then designed and constructed as two parts. There are two parts in this system and they are transmitter part and receiver part. The transmitter coil (transmitter part) transmits coupling magnetic field to receiver coil (receiver part) by passing frequency at about 30 kHz. The system is safe for users and neighboring electronic devices. This paper outlines the proposed development of a contactless inductive charging system for small electrical device such as mobile phone, small battery car, etc. The project aims to develop contactless charging technology and it is also intended to give a message that how useful the static contactless charging is by creating a proof of concept for inductive charging.

Index Terms—Inductive coupling, oscillator, receiver, transmitter

1) INTRODUCTION

Contactless power transfer (CPT) technology is a new kind of power transmission technology which based on Faraday-Lenz electromagnetic induction principle, and it can solve the problem of mobile devices wireless and flexible power supply (2). This technology is safer, more reliable and flexible than traditional technology. And broader application prospects than traditional power transmission technology (1). It was demonstrated firstly by MIT using inductive coupling during the summer 2007 (6, 7). In 2008, Intel also achieved contactless power through inductive coupling. This project can be charged several different handheld devices, such as battery-used small electronic devices, toothbrushes, cellular phones and MP3 player (like 5V charging adapter) (3, 4, 5). It can be charged on the surface of the transmitter coil by putting receiving coil at the device. Contactless power transfer means the power supply is not plugged into the device being charged (close proximity or physical contact) (8).

In this project, power supply 12V DC drives oscillator circuit as push-pull driver to operate transmitter coil. Then, the transmitter coil transmits coupling magnetic field by passing frequency at about 30 kHz. In this state, the receiver coil receives coupling magnetic field as AC voltage. DC level stabilizer converts AC to DC voltage again to charge the battery of device (small-power electric car).

![Block diagram of static contactless power transfer system](image)

2) THEORETICAL BACKGROUND

ICPT technology is a new kind of power transmission technology which based on Faraday-Lenz’s electromagnetic induction principle, and it can solve the problem of electric devices’ principle wireless and flexible power supply.

A. Laws of Electromagnetic Induction

(i) Faraday’s Law of Electromagnetic Induction

Electromagnetic induction is the process by which a current can be induced to flow due to a changing magnetic field. According to the Faraday’s law of electromagnetic induction, the magnitude of induced EMF is directly
proportional to the rate of change of magnetic flux linked with a conductor or coil. This can be stated mathematically as:

\[ \varepsilon = \frac{d\phi}{dt} \text{ (Volts)} \]  

(1)

(ii) Lenz’s Law of Electromagnetic Induction

While Faraday’s law tell us the magnitude of the EMF produced, Lenz’s law tell us the direction that current will flow.

Lenz’s law is typically incorporated into Faraday’s law with a minus sign, the inclusion of which allows the same coordinate system to be used for both the flux and EMF.

\[ \varepsilon = -\frac{d\phi}{dt} \text{ (Volts)} \]  

(2)

(iii) Faraday-Lenz’s law of Electromagnetic Induction

In practice, it is often considered that deals with magnetic induction in multiple coils of wire, each of which contributes the same EMF. For this cause, an additional term \( N \) representing the number of turns, is often included, i.e.,

\[ \varepsilon = -N \frac{d\phi}{dt} \text{ (Volts)} \]  

(3)

Where,

\* \( \varepsilon \) is the electromotive force (EMF),
\* \( N \) is the number of turns,
\* \( \frac{d\phi}{dt} \) is the rate of change of magnetic flux with time.

The minus sign shows that, the direction of the induced EMF and the direction of change in magnetic fields have opposite signs.

B. Magnetic Field

Magnetic fields are produced by electric currents, which can be macroscopic currents in wires, or microscopic currents associated with electrons in atomic orbits. Magnetic fields occur whenever charge is in motion. As more charge is put in more motion, the strength of a magnetic field increases.

Except along the axis, the magnetic field of a circular coil cannot be expressed in closed form. Along the coil axis, if the origin of the coordinates is taken at the center of the coil and if the \( z \) axis is taken along the coil axis, the magnitude of the magnetic field \( B \), which points in the \( z \) direction, is given by

\[ B = \frac{\mu_0 N a^2 I}{2(a^2 + z^2)^{3/2}} \]  

(4)

Where,

\* \( N \) is the number of turns of the field coil,
\* \( I \) is the magnitude of the electric current (Ampere, A),
\* \( a \) is the radius of the coil (meter, m),
\* \( z \) is the axial distance from the center of the coil (meter, m),
\* SI unit of \( B \) is the Tesla (T),
\* \( \mu_0 = 4\pi \times 10^{-7} \) is the permeability of free space (Tm/A).

C. Magnetic Flux

Magnetic flux is a measurement of the total magnetic field which passes through a given area. The magnetic field through a loop can be changed either by changing the magnitude of the field or changing the area of the loop.

For a loop of area \( A \) in the presence of a uniform magnetic field \( B \), the magnetic flux is defined as

\[ \phi = NBA \cos \theta \]  

(5)

Where,

\* \( \phi \) is the angle between \( B \) and the normal to \( A \),
\* \( A \) is the area of the loop,
\* \( B \) is the magnetic field,
\* SI unit of \( \phi \) is the Weber (Wb).

D. Strength of Magnetic Flux

The strength of magnetic flux mainly depends on the distance and the position of the receiver coil. Figure 2 shows the three different position of the receiver coil.
Power Supply 12V battery (DC voltage) is used in this project and it supplies 12 V to operate the control circuit. The DC power source provides a constant DC voltage to the input of the transmitter circuit. By using 12V battery, circuit diagram receives stable voltage and current. Therefore, it is suitable for the circuit of wireless charging system by using inductive coupling.

The transmitter coil, energized by the high frequency AC current, produces an alternating magnetic field. In this project, wire gauge 18 is used and the number of turns of the transmitter coil is eight turns.

Transmitter circuit receives a constant DC voltage from the DC power supply. There, this DC power is converted to a high frequency AC power and is supplied to the transmitter coil. Components of the transmitter circuit are Field Effect Transistor, Diodes, Inductor, Capacitor and Resistors. Figure.5 shows the transmitter circuit with the transmitter coil.

In transmission section, oscillation circuit operates as push-pull devices to transmit magnetic field to the receiving coil. The system uses coupled magnetic fields as a frequency to transfer electromagnetic energy from the transmitter coil to receiver coil. Fig.4 shows the transmitter circuit.

A. Transmission section

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A. Receiving Section

In the receiver coil, it receives magnetic field induced from the transmitter coil. In this state, it is AC level and it needs to convert DC level for charging the battery of electric device. The wire gauge and turns of the coil are the same as the transmitter coil.
Fig. 6 Circuit diagram of receiving section

When the battery car is in the motion over the inductive charging surface, the transmitter coil induced the magnetic field to the receiver coil. The rectifier rectifies the induced voltage from AC to DC level. When the green LED (charging LED) is on, the battery of the device is started to charge.

In this project, DC 6 volts battery is used to drive the motor of small battery car. The battery receives the power from the receiver coil.

4) CALCULATIONS OF THE SYSTEM DESIGN

A. Calculation of Magnetic Field (B)

From equation (4),

\[ B = \frac{\mu_0 N a^2 I}{2(a^2 + z^2)^{3/2}} \]

Where, \( a = 101.6 \text{ mm} = 0.1016 \text{ m} \), 
\( z = 5 \text{ cm} = 0.05 \text{ m} \),
\( I = 1.13 \text{ A} \),
\( \mu_0 = 4\pi \times 10^{-7} \text{T m/A} \),
\( N = 8 \text{ turns} \).

Then, \( B = 40.38 \times 10^{-6} \text{T} = 40.38 \text{ } \mu\text{T} \).

B. Calculation of Magnetic Flux (\( \phi \))

From equation (5),

\[ \phi = NBA \cos \theta \]

Where, \( N = 8 \text{turns} \),

\[ B = 40.38 \text{ } \mu\text{T} \],
\[ r = 0.1016 \text{ m} \],
\[ A = \pi r^2 = 0.032 \text{ m}^2 \],
\[ \theta = 0^\circ, 45^\circ, 90^\circ, \ldots \]

At \( \theta = 0^\circ \) position, \( \phi = 10.47 \text{ } \mu\text{Tm}^2 \).
At \( \theta = 45^\circ \) position, \( \phi = 5.503 \text{ } \mu\text{Tm}^2 \).
At \( \theta = 90^\circ \) position, \( \phi = 0 \text{ Tm}^2 \).

C. Calculation by Digital Oscilloscope

Fig. 7 Waveform of the two coils testing by oscilloscope

Fig. 8 Waveform of primary coil (channel-2, yellow color) 
\( V_p = 14 \text{V}, \text{time } T = 35\mu\text{s}, \text{frequency } f = 1/T \approx 28.571 \text{kHz} \)

Fig. 9 Waveform of secondary coil (channel-1, red color) 
\( V_s = 8.4 \text{V}, \text{time } T = 35\mu\text{s}, \text{frequency } f = 1/T \approx 28.571 \text{kHz} \)
Fig. 10 DC voltage of secondary coil (8.4V)

D. Calculation by Digital Voltmeter

Fig. 11 DC Voltage and Ampere of Transmission Section
(Distance between transmitter and receiver = 5 cm)

\[ P = VI = 12.801 \times 9.869 = 126.333 \text{ W} \]

Fig. 12 DC Voltage and Ampere of Receiving Section
(Distance between transmitter and receiver = 5 cm)

\[ P = VI = 8.473 \times 1.3788 = 11.683 \text{ W} \]

E. Calculation of System Efficiency

Efficiency is defined as

\[ \eta = \left( \frac{P_{\text{receiving}}}{P_{\text{transmitting}}} \right) \times 100 \]

(6)

Then, efficiency, \( \eta = 0.0925 = 9.25\% \)

5) Simulation and Test Results
6) CONCLUSION

In this paper, contactless charging system by using inductive coupling method is designed and constructed. There are many kinds of methods in contactless charging system such as Inductive Coupling, Magnetic Resonance Coupling, Microwave Radiation, Radio Frequency Energy Harvesting and Laser power beaming. Among them, inductive coupling method is chosen to use in this paper. Contactless charging system by using inductive coupling method is safety and more efficiency than other methods of contactless power transfer. Contactless charging method can increase efficiency by changing the design of coil and the circuit design.

Moreover, we can add to use solar energy via photovoltaic (PV) panels in this current project. Solar energy is one of the top-rank renewable energy resources which cannot be harmful to the natural environment. And also, we can do dynamic contactless charging which is more-advanced technology than the static contactless charging since the battery car has to be charged while moving on the road. However, it is harder to construct, the infrastructure used in the construction are too much expensive, and the cost and gain effects are not fair. Therefore, static contactless charging system is the suitable and reliable technology for consumers who like to use contactless charging technology till today even though dynamic charging system is more-advanced.

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REFERENCES


