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An Energy Transfer System Design Using Wireless Power on Different Cross-Section Types

Nurmasyithah[1], Hamdani[2], Solly Aryza[3]
[1,2,3]Universitas Pembangunan Panca Budi, Medan, North Sumatera, Indonesia

Article Info	ABSTRACT
Keywords: Design, System, Energy Transfer, Wireless Power, Cross-section.	Wireless power transfer (WPT) technology has emerged as a transformative solu-tion for delivering electrical energy without the need for physical connections. This study investigates the design and performance optimization of an energy transfer system em-ploying WPT across different cross-section types of transmission coils, including circular, rectangular, and elliptical geometries. The objective is to analyze the impact of coil shape and configuration on power transfer efficiency, coupling strength, and electromagnetic field distribution. Using finite element analysis (FEA) and experimental validation, the study evaluates key parameters such as coil alignment, resonant frequency, and load var-iations under different cross-sectional designs. The results demonstrate that the geome-try of the coils significantly influences the system's power transfer efficiency, with circu-lar cross-sections exhibiting superior performance in terms of coupling factor and power density. However, rectangular and elliptical cross-sections offer distinct advantages in specific scenarios, such as space-constrained environments and non-uniform load distri-butions. This research provides a comprehensive framework for designing and optimiz-ing WPT systems tailored to diverse application requirements, including electric vehicles, medical devices, and consumer electronics. The findings contribute to advancing the ver-satility and efficiency of wireless energy transfer technologies, paving the way for more adaptable and reliable energy solutions in modern engineering applications.
	Corresponding Author: Nurmasyithah Universitas Pembangunan Panca Budi, Medan, North Sumatera, Indonesia nurmasyithah@gmail.com

INTRODUCTION

In 1899 Tesla was able to light a light bulb that had a distance between the source and the load (in this case the light bulb) of 25 miles without using a cable medium [1]. But at that time, to light a lamp 25 miles away using copper wire was cheaper than the cost of building a power plant that could transmit energy without wires as required by Tesla. So this discovery gradually tended to be forgotten for decades.

But research on wireless electrical energy delivery does not stop there. Development efforts related to this research continue to be developed by researchers around the world. Until in 2007 by researchers from MIT or the Massachusetts Institute of Technology, one of

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whom was named Marin Soljajic, stated that the process of transferring electrical energy can be done by resonant magnetic coupling.

Based on this background, the principle of Wireless Power Transfer is expected to be a solution in the field of electricity in terms of the use of less effective cables. So that it can send electrical energy from the sender to the receiver without using a cable conductor as a transmission medium.

Wireless power transfer (WPT) is one of the technological innovations that is increasingly gaining attention in various modern applications, such as charging electronic devices, electric vehicles, and medical devices. This technology allows the transfer of electrical energy without the need for a physical connection, thus offering advantages in terms of efficiency, safety, and ease of use.

In a WPT system, one of the factors that determines performance is the design of the coil used to transfer energy. The geometry and type of coil cross-section play an important role in influencing the efficiency of power transfer, coupling factor, and electromagnetic field distribution. Common cross-sections include circular, rectangular, and elliptical shapes, each of which has unique characteristics under various operating conditions.

This study aims to evaluate and analyze the effect of the coil cross-section shape on the efficiency of the WPT system. With a simulation approach based on finite element analysis (FEA) and experimental testing, this study will identify key parameters that affect power transfer performance, such as resonance frequency, coil alignment position, and load variation.

Through this study, it is expected to produce optimal WPT system design guidelines based on specific application needs. The results of this research are expected to contribute to the development of more efficient, flexible, and reliable wireless power transfer technology to support various needs in the fields of modern engineering and technology.

Literature Review

Electromagnetic Field

The experiment of James Clerk Maxwell (1831–1879) a British (Scotland) scientist stated that if there are changes in voltage in the PQ wire, both in magnitude and direction, then in the PQ wire the electrons move back and forth, in other words, there are electrical vibrations in the PQ wire. Changes in voltage cause changes in the electric field in the room around the wire, while changes in electric current cause changes in the magnetic field. The process of changing the electric field will cause a changing magnetic field and the changes in the magnetic field that occur will re-create the electric field.

Electromagnetic induction is the event of the emergence of EMF (Electromotive Force) in a conductor or coil due to changes in magnetic lines of force (magnetic flux). According to Michael Faraday's experiment, a magnetic field with changing flux values can produce electric current. Faraday concluded that a constant magnetic field cannot produce current, but changes in magnetic field flux in a circuit of conducting materials will cause an induced voltage in the circuit (Faraday's law). [5]

The emergence of inductance due to the presence of a magnetic field caused by an electric current (explained by the Biot-Savart law). The Biot-Savart law states that electromotive force will be produced by an electric current flowing in a conductor located between a magnetic field. In order for an electronic circuit to have an inductance value, a component called an inductor is used in the circuit. An inductor is a passive two-terminal electronic component that stores energy in a magnetic field

1. Self-inductance
   Self-inductance is the emergence of an electric voltage in a coil when a change in current occurs. If a conducting wire intersects a magnetic field, there will be a voltage in the wire.
2. Mutual Inductance
   Mutual inductance consists of two coils (N1 and N2) or inductor windings that are close to each other. The process of mutual inductance occurs when the coil N1 is flowed by current, then magnetic flux will arise. The magnetic flux in the coil N1 will propagate to the coil N2 and cause magnetic field induction in the coil N2. The magnetic field flux in the coil N2 will produce an induced electromotive force in the N2 coil circuit.

Mutual induction voltage is defined when current (i) flows through the coil, then around the coil there will be magnetic flux (φ). Based on Faraday's law, a coil that experiences a change in magnetic field will produce an induced voltage of V which is proportional to the multiplication of the number of turns N by the change in flux (φ) per time.

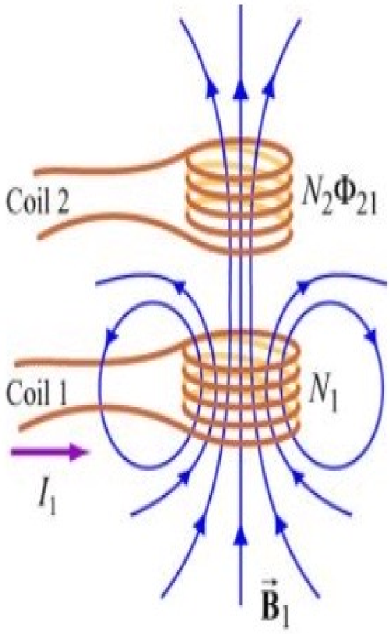

Figure 1. Inductance in Coils

Wireless Energy

Wireless energy delivery system uses the principle of electromagnetic resonance induction, consisting of a transmitter circuit and a receiver circuit of the system. In the transmitter circuit, the alternating current power source is first rectified with a DC module, then enters the LC circuit, in this case the Inductor (L) and capacitor (C), to create a non-radiative alternating magnetic field signal generator. On the receiving circuit side, there is also an LC circuit, where L and C function to produce resonance from the magnetic field produced by the transmitter circuit to receive electrical power.

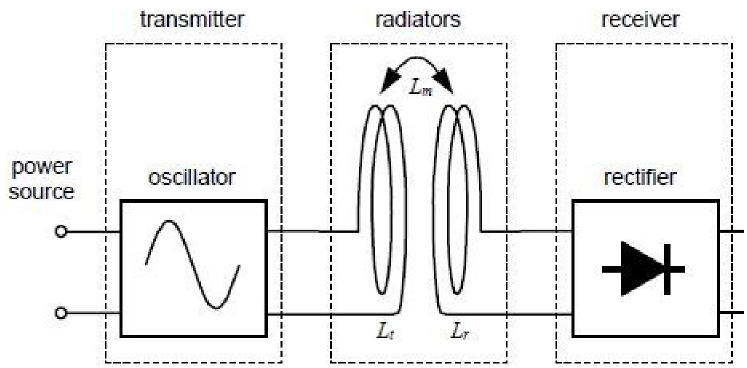

Figure 1. System Block Diagram

The basic principle of electromagnetic induction is when alternating current passes through a coil, a magnetic field will be generated around the coil. If in this condition another coil is placed near the coil, then the magnetic field from the first coil will also arise around the second coil. This is the reason why wireless energy transmission can occur between the two coils.

Wireless energy transfer is a process in which electrical energy is transmitted from a power source to a load without using cables (wireless). Based on the work of Michael Faraday (1830), James C. Maxwell (1864) and Heinrich R. Hertz (1888), Tesla demonstrated an experiment in wireless energy transfer in 1893. Nicola Tesla created a method in which energy could be transmitted remotely wirelessly, by building the Wardenclyffe Tower in Shoreham, Long Island which functions as a means of wireless telecommunications and electrical power transmission. Tesla managed to transmit electrical energy as far as 47 meters to light an incandescent lamp.

In 1985 Guglielmo Marconi demonstrated radio transmission over 1.5 miles[6]. The theory that Marconi used was the relationship between antenna height and maximum transmission distance based on empirical theory. In 1904 at the St. Louis World's Fair an airplane was flown approximately 100 feet (30 meters) using energy transmitted through space with a 0.1 Hp (75 watt) motor[7].

In 1945, Leon Theremin invented a spy device for the Soviet Union, which retransmitted incident radio waves with audio information[8]. This device is considered a precursor to RFID (Radio Frequency Identification) technology. RFID is a technology that uses radio waves to automatically identify or tag objects.

In 1964, a miniature helicopter was demonstrated that was powered by microwave power [9]. Microwave is an electromagnetic wave with super high frequency (SHF), which is above 3 GHz (3x109 Hz). The first demonstration of RFID tag signal reflection was carried out by Steven Depp, Alfred Koelle and Robert Freyman at the Los Almos National Laboratory in 1973[9]. Hidetsugu Yagi, a researcher from Japan, also conducted research on microwave energy transfer by designing a directional array antenna [10]. In 1975, researchers at Goldstone (California) made a discovery that could transfer energy reaching kilowatts using microwave transmission with a distance of up to one kilometer[12].

Wireless energy transfer research conducted by Marrin Soljacic from MIT whose project was named WiTricity in 2007[2]. During the energy transfer research, Marrin Soljacic combined the theory of resonance and inductive coupling or called resonance inductive coupling (RIC). The function of resonance is to increase the efficiency of the magnetic field line distance and expand the distance of energy transfer to the sender side (RX) with the same frequency. Marrin Soljack is able to send energy up to 2 meters with an efficiency of 40% using a frequency between 1MHz-10 MHz.

Energy transfer research by Mandip Jung Sibakoti and Joey Hambleton is based on the work of MIT published in 2007. The main objective of Mandip Jung Sibakot's research is to transfer energy (in watts) to the RX receiver circuit from isolated AC waves to DC voltage as its output. Mandip Jung Sibakoti uses radio frequencies between 1 MHz - 20 MHz[12].

Working Principle of Wireless Energy Transfer

The working principle of wireless electrical energy transfer is almost the same as the working principle of a transformer. The process of energy transfer occurs when the voltage source supplies alternating current to the TX coil circuit (electrical energy sending circuit), then the TX coil circuit will produce a magnetic field around the coil. The magnetic field in the coil will create magnetic field lines of force. The TX coil that produces a magnetic field, then induces (mutual induction) the RX coil (electrical energy receiving circuit) on the condition that the RX coil must be in the area of the magnetic field lines of the RX coil. The results of mutual induction produce a magnetic field in the RX coil.

In the TX circuit, there is a change in the voltage value, causing a change in the electric field flowing in the TX circuit. Changes in the electric field over time will cause changes in the magnetic field flux around the TX coil. Changes in the magnetic field value in the TX coil create changes in the induced field in the RX coil. These changes result in changes in the magnetic field in the TX coil. The magnetic field in the RX coil that changes over time will produce an electric field and cause induced voltage in the RX coil circuit.

Inductive Resonance of Electromagnetic Fields

The use of inductive resonance of electromagnetic fields to increase the bandwidth of electromagnetic field waves by using the same frequency between the sender signal and the receiver signal, so that the distance of wireless electrical energy transmission becomes further with higher power efficiency[19]. The frequency used uses a high frequency using an oscillator circuit (variations and combinations of capacitor, inductor, and transistor components).

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METHOD

The Power Supply referred to in this Final Assignment is an adapter circuit. A DC Power Supply or Adapter basically has 4 main parts in order to produce a stable DC current. The four main parts include Transformer, Rectifier, Filter and Voltage Regulator as shown in Figure 2.

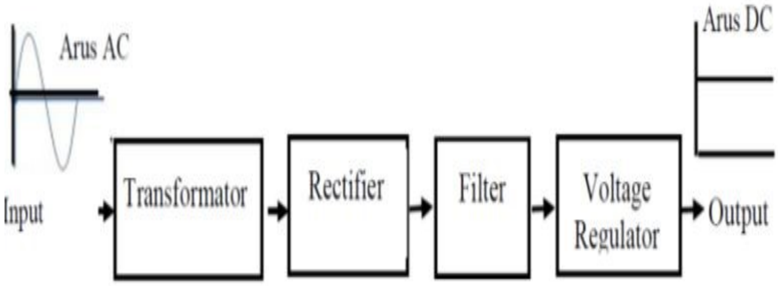

Figure 2. Block Diagram of DC Power Supply

The working process of this wireless electrical energy delivery system can be seen through the flow diagram in Figure 3.

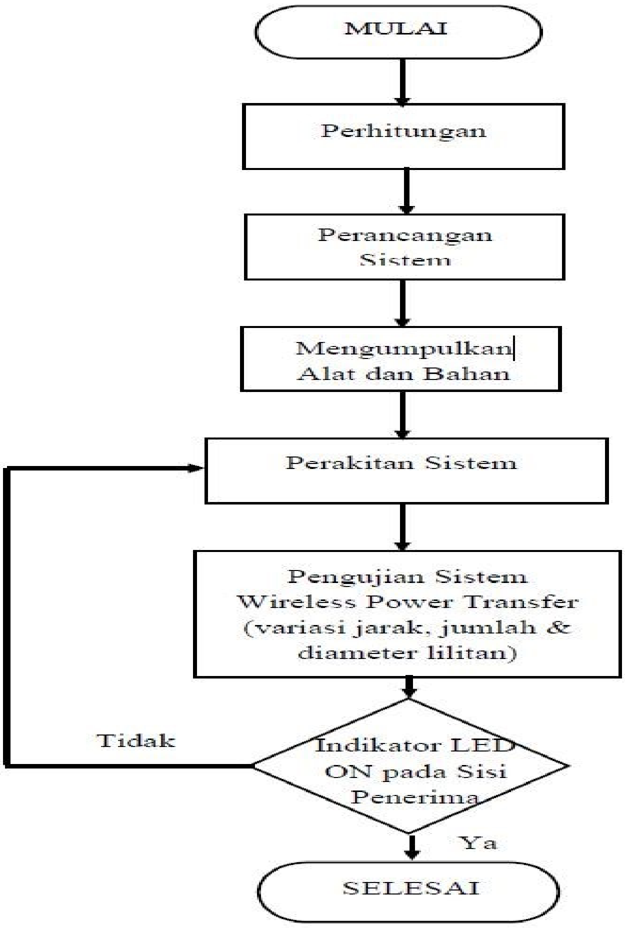

Figure 3. Research Flow Diagram

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RESULTS

The first test was conducted on a coil of 30 turns, the diameter of the loop is 3.5 cm with a copper wire diameter of 0.3 mm. The first process was given a source voltage of 6 volts and successfully transferred power at a voltage of 5.53 volts to the receiver side, as evidenced by the voltage received on the receiver side of 2.6 volts as shown in Table 1.

Table 1. Test Data with 6 Volt Voltage Source

No	distance (cm)	V receiver (Volt)	I Transmitter (A)	I Receiver (A)	led indicator
	0,5	2.5	0.055	0.016	Me on
	1	2.4	0.050	0.014	Me on
	1,5	2.3	0.044	0.012	Me on
	2	2.1	0.042	0.005	Matt i

The next experiment of the wireless power transfer system was by changing the transmitter loop and receiver loop with a larger copper loop diameter than the previous one, namely 0.6 mm as shown in Table 2.

Table 2. Test Data of 0.6mm Loop Cross Section

Tension n Source (V)	Distance (cm)	V receiver (Volt)	I Transmitter (A)	I Receiver (A)	Indicator r Led
	2	2.6	0.06	0.19	Light up
8	2,	2.5	0.58	0.18	Light up
	3	2	0.45	0.07	Dead
	2	2.5	0.08	0.05	Light up
12	2.5	2.6	0.075	0.03	Light up
	3	2.3	0.05	0.01	Light up
	3.5	2	0.04	0.05	Dead
	2	2.8	0.11	0.04	Light up
	2.5	2.7	0.12	0.03	Light up
15	3	2.6	0.13	0.005	Light up
	3.5	2.5	0.11	0.004	Light up
	4	2.4	0.1	0.003	Light up
	4.5	2	0.8	0.002	Dead

For data on testing the transmit and receive power on a 6 volt voltage source, see Table 3.

Table 3. Test Data with 6 Volt Voltage Source

		Distance		P	P	
o	(cm)		Send		accept	
		0.5		0,3	0.16	
			3			,47
		1		0,	0.14	
			28			,43
		1.5		0,	0.1	
			25			,42
		2		0,	0.08	
			21			,38

CONCLUSION

This study successfully analyzed the effect of coil cross-sectional shape on the performance of the Wireless Power Transfer (WPT) system. Based on the results of simulations and experiments that have been carried out, several conclusions were obtained as follows: The coil cross-sectional shape has a significant effect on power transfer efficiency. Coils with circular cross-sections show the highest power transfer efficiency because they have better coupling factors and more even electromagnetic field distribution. Rectangular cross-sections are more suitable for applications with limited horizontal space because their shape allows flexible dimension adjustments. The elliptical cross-section offers more stable performance under non-uniform load conditions or varying power transfer distances, although its efficiency is slightly lower than that of circular cross-sections. The coupling factor, resonant frequency, and distance between coils are the parameters that most influence WPT performance, with varying effects depending on the type of coil cross-section. Optimal adjustment of these parameters can improve the overall system efficiency. The design of coils with cross-sectional shapes that are adjusted to application needs can improve the flexibility and efficiency of the WPT system. For example, medical device applications require a compact design with high efficiency, while electric vehicle applications require a design that can adjust the coil position with large tolerances.

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