DESIGN A STRAY MAGNETIC FIELD ENERGY HARVESTER DEVICE

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DESIGN A STRAY MAGNETIC FIELD ENERGY HARVESTER DEVICE

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DECLARATION

I declare that this thesis entitled *"Design a Stray Magnetic Field Energy Harvester Device"* is the result of my own research except as cited in references. The thesis has not been accepted for any degree and is not concurrently in candidature of any other degree.

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APPROVAL

"I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in term of scope and quality for it complies the partial fulfilment for awarding the award of the degree of Bachelor of Electrical Engineering with Honor"

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Date : JULY 2021

DEDICATION

This thesis is dedicated to my family members especially my beloved mother and my late father. This one is for you, Ayah.

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In preparing this, I was aided by many around me. First, I would like to pay my gratitude and appreciation to my supervisor, Dr. Fairul Azhar Abdul Shukor who helped me a lot with finishing this PSM thesis especially during this pandemic. He guided me a lot on how to run the experiment and gave me ideas on to improve the experiment. He also aided me by supplying electrical parts for my project which I am very grateful for. Without his assisting, finishing this project would be far from easy.

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ABSTRACT

Nowadays, energy harvesting has been a great initiative to use an energy conservation as an act to store the energy for further use in every power line and power grid. This study focuses on developing an energy harvester by using stray magnetic field which is an energy created by electric current that flows along power line of a power distribution system. This study will further the chance for supplying energy for low-power device especially sensor. The methods used in this project is the used of ferrite-core magnet of different size and demonstrated with several number of turns focusing on harvesting power device. The basic focus of ferromagnetic materials was on the theory of the magnetic field to obtain energy for small electronic devices to provide electricity. Using magnetic field theory, the first step defines the magnetic field around the current carrying cable. After winding the ferrite-core with various turns, tests the proposed harvester by seeing the output voltage emf. The last step compares among the core winding which produces the best results which for ferrite-core A with 150 turns give maximum output voltage of 0.2289V at current equals 0.5A, while for ferrite-core B with 150 turns give maximum output voltage of 0.01493V at current equals 0.5A. In conclusion, ferrite-core A produced the best result overall with higher voltage produced.

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ABSTRAK

Pada masa kini, penuaian tenaga merupakan sebuah inisiatif yang bijak bagi menjadikan penjimatan tenaga sebagai satu kaedah menyimpan tenaga untuk kegunaan jangka panjang bagi talian kuasa dan grid kuasa. Kajian ini memberi fokus terhadap cara bagi memperkembangkan penuaian tenaga dengan menggunakan medan magnet terbiar, ia merupakan tenaga yang dicipta daripada arus elektrik yang mengalir menerusi talian kuasa di dalam sistem pengagihan kuasa. Kajian ini juga dapat meningkatkan peluang untuk membekalkan tenaga bagi peranti berkuasa rendah terutamanya sensor. Kaedah yang digunakan di dalam kajian ini ialah penggunaan magnet teras ferit dalam pelbagai saiz dan di demonstrasikan dengan pelbagai bilangan lilitan yang memfokuskan kepada peranti penuaian tenaga. Fokus utama ialah dengan menggunakan bahan feromagnetik berdasarkan teori elektromagnetik bagi penerimaan kuasa untuk peranti kecil elektronik sebagai penjanaan kuasa. Dengan menggunakan teori medan magnet, syarat pertama ialah dengan membuktikan kewujudan medan magnet pembawa arus di sekililing kabel. Selepas menggulung wayar di magnet teras ferit dengan sebilangan lilitan, peranti penuaian tenaga itu di uji untuk melihat hasil keluaran voltan emf. Akhirnya, prestasi penuaian tenaga yang dibangunkan akan dibandingkan dengan mengambilkira keluaran yang tertinggi di mana untuk teras-ferit A dengan 150 gegelung telah memberikan nilai keluaran voltan maksima sebanyak 0.2289V pada arus 0.5A, manakala untuk teras-ferit B dengan 150 gegelung telah memberikan nilai keluaran voltan maksima sebanyak 0.01493V pada arus 0.5A. Konklusinya, teras-ferit A telah menghasilkan pengeluaran terbaik keseluruhannya dengan memberikan nilai voltan tertinggi.

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LIST OF SYMBOLS

Ω	-	ohm
B	-	flux density
H	-	magnetic field intensity
J	-	current density
μ	-	magnetic permeability
Δ	-	differential
τ	-	time constant

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CHAPTER 1

INTRODUCTION

1.1 Background

Generally, it is not an unfamiliarity to harvest energy from the environment, for a quick, it has been centuries of civilization to use solar and wind energy. Even then, these days the voicing energy harvesting has been used to define the process of keeping very small amounts of energy from one or more of natural-occurring energy sources (e.g solar thermal, wind, kinetic, etc.), collecting and piling them for powering low-energy electrical appliances. There are plenty of other sources besides solar and wind energy, such as vibrations and thermal, which exist in the environment and can be used as an energy harvest system. Vehicles that travel over a bridge will create such vibrations that produced kinetic energy and later can be used to generate electricity [1].

In this era of global urbanization along with the rapid evolution of big cities, it shows that the request for electric energy will continue to grow in the coming years. It is a huge obstacle to provide this enormous energy from power plants to end customers, as the existing power distribution systems may reach to their thermal constraints. Wireless sensors are regarded to be most likable tools for collecting data such as current, voltage, and temperature because of their low power utilization, fast deployment and cheap in price. However, the limited life cycle of the batteries which capable in sensing the system is tailback as it is costly to renew these batteries regularly. Thus, the energy harvesting technology is an alluring solution to make wireless sensors self-dependent [2].

On the recent events, the growth of low-power appliances and needs for wireless sensors together give on to the evolution of little measure of precisely available energy in the environmental atmosphere into operational electrical energy. It is also implemented for straight application as well as rummage and keep for later operation. This gives an adequate cause of energy for utilizations where there is no network power and it is not satisfactory to introduce other renewable energy sources like wind and solar. Furthermore, the energy harvesting is free in maintenance and appealing internationally. On top of that, harvesting energy is being appreciated environmentally for sole purpose of giving gadgets with battery-less or in another way a unified battery charger device.

In applications such as remote corrosion monitoring systems, implantable devices and remote patient monitoring, structural monitoring, Internet of Things (IoT), and equipment monitoring. The energy harvester is a device that creates energy from the external sources. At certain times, the energy from harvested sources can be non-uniform and compact, so it is the most crucial that the systems design should be methodical to harvest and reserve the power. Energy harvesting system that is based on stray magnetic induction is getting fundamental care; while it is also suitable to dictate the variables in network lines [3]. Energy harvesting can supply energy autonomy to wireless sensors, a key engineering qualification for looming sensing technologies, on condition that a suitable environmental source is available at the sensor locality [4].

In few places, mains power is available at all time and the installation suits the time and money needed in order to connect the device to the mains. Battery power might be perfectly tolerable, while in other mains power is not very so. Thus, changing of batteries would become an intolerable maintenance overhead. There are some other form of energy in these locations is freely accessible and in theory it should be possible to generate a useful electrical from harvesting and converting the energy. In examples are wind, solar power, thermal difference, vibration and electromagnetic coupling (both capacitive and inductive). Every each one of these powers have its own eccentricity, hence could be useful in different kind of situations. However, the only energy that is available throughout the supply network is electromagnetic energy, whereas the others are only available at definite places [5].

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A voltage is induced in a conductor loop if it is subjected to a time-varying magnetic flux, according to Faraday's law. If there is a closed passage, a current will flow in the conductor. In fact, all eddy-current devices are founded on this fundamental idea. When a huge conducting substance is exposed to a time-varying magnetic field, the same phenomena occurs instead of a conductor loop, which can be seen as a filament. The body could be made of magnetic or nonmagnetic material. In this body, voltages are produced once more, causing currents to circulate in the proper channels [6].

1.2 Problem Statement

As stated in previous sub-section, it can be said that there are so many types of harvesting energy. Energy harvester main purpose is to scavenge and stored for later utilization. When there is no network power or it is not suitable to introduce other renewable energy sources like wind and solar, that is when energy harvesting based on magnetic induction come in handy [3]. Although, it is not a naturally occurring energy source, it is squandered to the climate and could be exploited for a diversity of application, in example, monitoring physical parameters around the lines, as temperature, humidity, wind movement. In [2], it is said that the limited life span of batteries could become a barrier as it can be high-priced to regularly changing the batteries. Thus, it is a very enticing solution to make wireless sensors- based applications self-sustainable by energy harvesting.

In previous work of Yuan and Huang, [7] they discussed that the suitable energy source near any appliance that carries sufficient currents is the magnetic field energy, since it is well grounded and technically easy to garner. There are two kinds of magnetic field energy harvesters functioning for different occasions which are the cable-clamped energy harvester and free-standing energy harvester. Furthermore, for the first type a toroid is mounted on a power cable. As the coil can fully enclose the current conductor, making the power density of this kind of energy harvester particularly high. Next, unlike the cable-clamped type, the second type energy harvester can be positioned in any spot as long as there is an alternating magnetic field. This is because the harvesting coil is capable of powering various sensors due to of its great flexibility. As proposed in [8], a magnetic induction-based energy harvesting system is relied on the basic concept of the electrical transformer.

On top of that, some experiments were conducted that have the result shown that the ferrite-based energy harvesting system is more flexible compared to nanocrystalline core and iron powder core [9]. The experimental method of this study used an electromagnetic energy harvesting using stray magnetic field generated by electric current around a single-phase power cord of a distribution system that can be utilized to provide the more energy for the small power energy management circuit in low-power device.

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1.3 Research Objectives

This study represents the way of an energy harvesting system using stray magnetic energy to provide energy for low-power devices. The objectives of this study are stated below:

i. To fabricate ferrite-core based energy harvesting module by considering different dimension and winding turns.
ii. To measure output voltage of the harvesting device on different line current and load, output voltage and RL characteristic of the ferrite-core magnets.
iii. To analyse and compare the performance of the harvesting device under different structure setting and experiment parameters.

1.4 Scope

This study focuses on developing a device that can be used to harvest energy from stray magnetic field by applying the concept of electromagnetic energy and transformer. The same concept can be seen from smart-grid application energy harvesting and powerhead lines as it is suitable for scavenge and storing energy for sensors application. To be able to create an energy harvester that is capable to replace battery function is an advantage for low-power device. Limitations due to this study can be the variety number of coil-turns (e.g. 50, 100, 150) to get the most accurate and suitable result. The amount of time spent to winding the coil could also be considered as minor limitation that occurred along the process since two different size of ferrite core is being used to observe effect of ferrite core diameter to the EMF voltage. Line current range is from 0.1A to 0.5A. The range will be revised according to the available load in laboratory. Performance parameters measure are EMF voltage, output current, induced current, and induced emf.

1.5 Motivation

What can be said from this project is that it is a project that could be developing further. As example, Sustainable Development Goals (SDG) by United Nation did mentioned about the state of renewable energy in one of its goals which is Goal 7 or SDG 7. In the modernized era today, working towards increasing the global percentage of renewable energy could be the best initiative in *ensuring access to affordable, reliable, sustainable and modern energy for all*.

Figure 1-1 SDG 7/ Goal 7 promotional poster

For a developing country such as Malaysia, this project could be a stepping-stone in creating much better energy harvester in renewable energy. With energy harvesting, those powered transmission line would get enough energy and sufficed without wasting any of it (energy). The battery will be rechargeable easily, not having to change the battery regularly in a year.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Energy harvesting is winning purchase as a concept for more and more gadgets are getting connected to the Internet. The Internet of Things (IoT) is the Internet for physical objects, exposing and exchanging data. Sensor of some sort is a typical type connected device. Often put up at a place where it needs to gather up data and transfer it up to the cloud for analysis. Battery technology is still advancing as of today, but there is always a room for improvement. After a while, the battery will be used up with a growing number of gadgets, replacing batteries will become a bottleneck. Thus, energy harvesting devices would be able to power themselves up. There is no requirement for physical attractions at all. Also, there are numbers of sources from which power can be harvested. However, not all power can be strong, some of these can be considered very weak power, which defines devices in addition still need to be very power efficient. Even so, enhancing it to work on minimal power which can be instinctively collected is a major advantage and worth experimenting. Alternating current that flows in a conductor creates magnetic fields. In theory, as the frequency getting faster and the current becoming higher, the field will become stronger. These magnetic fields would not produce any losses unless harvested, but with accurate equipment they can be used to transmit power from the conductor to a receiver system. Just the same concept as transformer, only a lot less suitable. Transformer surrounds the field it is using within a high permeability core and manage to provide power with very little losses [10].

2.2 Electromagnetism

2.2.1 Electromagnetic Force

Electromagnetic force (EMF) is a kind of physical interactivity that take place among electrically charged atoms. It reacts between charged atoms and is the mixture of all magnetic and electrical forces. The EMF can both be attractive and repulsive.

Lorentz force is another name for electromagnetic force. It is called EMF for a reason since it contains the formerly distinct electric force and the magnetic force; both forces are really from the same essential forces. Even when the particles are static or moving, the electric force will act among all charged particles. This basically means that there is electric field in every charged particle, whether it is moving or not. In example, in electric current there are moving charged particles that give off magnetic fields [11].

2.2.2 Magnetostatics

Immobilized particles create unchanged electric fields, and stable (i.e., non-time-varying) currents create unchanged magnetic fields. When $\partial/\partial t = 0$, the magnetic fields in a form with magnetic permeability μ are controlled by the second set of Maxwell's equations.

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$$\nabla \cdot \mathbf{B} = 0, \qquad (2.1)$$

$$\nabla \times \mathbf{H} = \mathbf{J}, \qquad (2.2)$$

J is the current density. Both magnetic flux density **B** and the magnetic field intensity **H** are affiliated by

$$\mathbf{B} = \mu\mathbf{H}. \qquad (2.3)$$

Based on Fawwaz and Ulaby, Fundamentals of applied electrostatics [12], on the sub-section of The Biot-Savart Law, they were dealing with the magnetic field ferocity **H** instead. They promptly said that for the majority of substances the flux and field are precisely connected by $\mathbf{B} = \mu\mathbf{H}$, consequently understanding of one inferred understanding of the other (presume that μ is known). Based on Hans Oersted's experiments on the divergence of compass needles by current-carrying wires, he acknowledged that currents create magnetic fields that form hoops with the wires. Resuscitate from Oersted's outcomes, Jean Biot and Felix Savart comes to a statement that articulates the magnetic field **H** at whichever point in space to the current *I* that precipitates **H**. In Biot-Savart law, it is known that the differential magnetic field *d***H** induced by a steady current *I* passing through a differential length vector *d***l** is

$$d\mathbf{H} = \frac{I}{4\pi}\frac{d\mathbf{l}\times\hat{\mathbf{R}}}{R^2} \quad \text{(A/m)}, \qquad \mathbf{(2.4)}$$

Where $\boldsymbol{R} = R\hat{\mathbf{R}}$ is the length vector between *d***l** and the scrutiny point P shown in Fig. 1. $\text{Ampere}.\frac{\text{m}}{m^2}$ = (A/m) is the SI unit for **H**. Assuming that *d***l** is along the path of the current *I* and the unit vector.

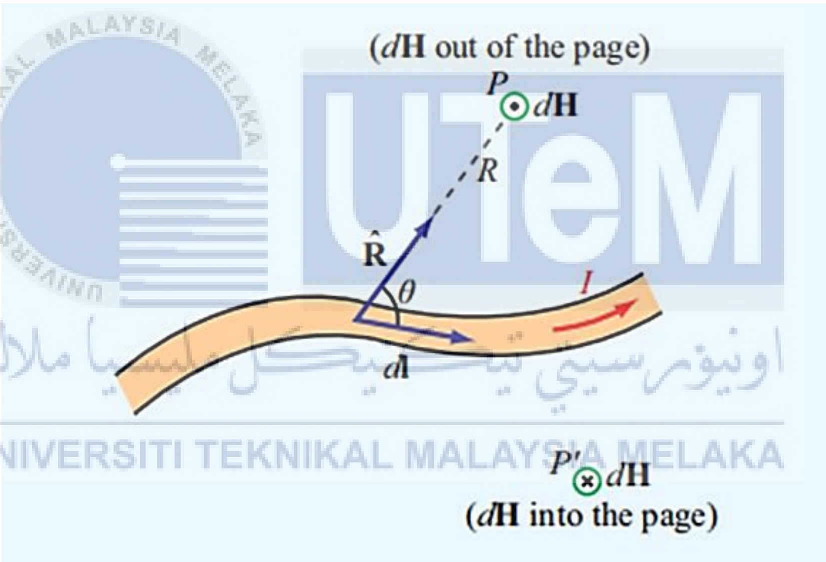

Figure 2-1 Magnetic field dH generated by a current element I dl

To figure out the sum magnetic field H entitled to a conductor of limited size, due to all the current essentials that are concocting the conductor, the contributions need to be added up. Thus, the Biot-Savart law becomes

$$\mathbf{H} = \frac{I}{4\pi}\int_l \frac{d\mathbf{l}\times\hat{\mathbf{R}}}{R^2} \quad \text{(A/m)}, \qquad \mathbf{(2.5)}$$

where *l* is the line direction along where *I* occurs.

2.3 Magnetic field inside a toroidal coil

Toroidal coil, also called a torus or toroid is a core with a ring-shaped structure sheathed within a close spaced twirls of wire Figure 2-2. In precision, it showed the turns in the figure as separated wide apart, but in study they are looped in a compactly spaced disposition to produce fundamentally orbicular loops.

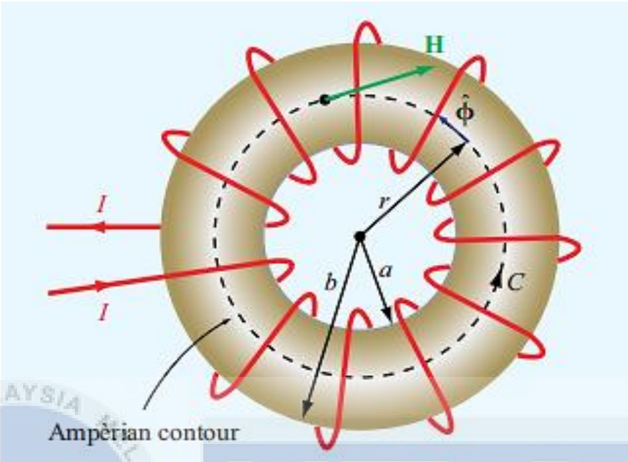

Figure 2-2 Toroidal with inner radius a, and outer radius b. The wire loops usually are much compact within each other than shown in figure

The function of toroid is to attract numbers of circuits by magnetically couple and to calculate the magnetic behaviors of resources, as pictured in Figure 2-3. From uniformity, it is straightforward that H is unvarying in the azimuthal path. If orbicular Amperian contour is built with center at the start and radius $r < a$, there is no flowing of current along the exterior of the contour, and thus

$$\mathbf{H} = 0 \qquad \text{for } r<a.$$

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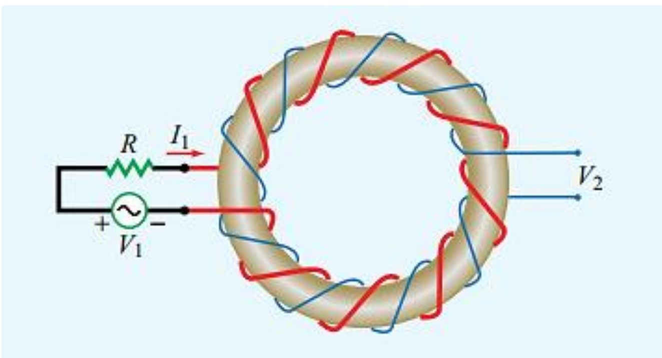

Figure 2-3 Toroidal with coil two windings used as a transformer

Likewise, for an Amperian contour with radius $r > b$, the net current that flows through its veneer is equals to zero since an equivalent value of current coils cross the façade in both paths; therefore,

$$\mathbf{H} = 0 \qquad \text{for } r > b \text{ (region exterior to the toroid coil)}$$

A path of radius *r* is being construct for the zone inside the core in Figure 2-2. In every loop, we understand that the field **H** at the origin of the circular points along the alliance of the loop, which for this situation is the $\emptyset$ direction, and in prospect of the path of the current I pictured in Figure 2-2, based on right-hand rule, **H** need to be in the $-\emptyset$ direction. Therefore, $\mathbf{H} = -\hat{\emptyset}H$. The sum current confluence the veneer of the contour with radius *r* is $N\,I$ and its course is into the page. There is a right-hand rule that affiliated with Ampere's Law, if the current is positive and it crosses the surface of the contour in the route of the four fingers of the right hand when the thumb is directing along the path of the contour C. Thus, the current through the veneer bridged by the contour is $-N\,I$. Ampere's Law being applied then gives

$$\oint_C \boldsymbol{H}.d\mathbf{l} = \oint_0^{2\pi}(-\hat{\emptyset}H)\cdot\hat{\emptyset}r\,d\emptyset = -2\pi rH = -N\,I$$

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Therefore, $H = NI/(2\pi r)$ and

$$\mathbf{H} = -\hat{\emptyset}H = -\hat{\emptyset}\frac{NI}{2\pi r} \qquad \text{(for } a < r < b\text{).} \qquad \mathbf{(2.6)}$$

2.4 Magnetic Permeability

Relationship of $\mathbf{B} = \mu_0 \mathbf{H}$ in free space is altered to

$$\mathbf{B} = \mu_0 \mathbf{H} + \mu_0 \mathbf{M} = \mu_0 (\mathbf{H} + \mathbf{M}), \qquad \textbf{(2.7)}$$

$$\mathbf{D} = \epsilon_0 \mathbf{E},$$

$$\mathbf{D} = \epsilon_0 \mathbf{E} + \mathbf{P} \qquad \textbf{(2.8)}$$

Where the magnetization vector M is declared as the vector total of the magnetic dipole moments of the particles comprised in a unit volume of the material. Ignoring the scale factors, the impression of **B**, **H**, and **M** in Eq. (2.7) are reflections of **D**, **E**, and **P** in Eq. (2.8). Furthermore, like most of dielectrics P and E are directly related, in various magnetic materials

$$\mathbf{M} = \chi_m \mathbf{H}, \qquad \textbf{(2.9)}$$

Where $\varkappa_m$ is dimensionless quantum known as the magnetic susceptibility of the material. For ferromagnetic materials; the correlation between M and H is not linear. Not only that, it also relies on the origin of substance. Remember the fact that, Eq. (2.7) could be combined with Eq. (2.9) to achieve

$$\mathbf{B} = \mu_0 (\mathbf{H} + \chi_m \mathbf{H}) = \mu_0 (1 + \chi_m) \mathbf{H}, \qquad \textbf{(2.10)}$$

or

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$$\mathbf{B} = \mu \mathbf{H}, \qquad \textbf{(2.11)}$$

where μ, the material's magnetic permeability, leans to χ_m as

$$\mu = \mu_0 (1 + \chi_m) \qquad \text{(H/m).} \qquad \textbf{(2.12)}$$

Sometimes, it is simple to interpret the magnetic behaviors of a material in *relative permeability* μ_r terms:

$$\mu_r = \frac{\mu}{\mu_0} = 1 + \chi_m \qquad \textbf{(2.13)}$$