DESIGN OF FERRITE CORE BASED ON DYNAMIC WIRELESS POWER TRANSFER IN EV

BY

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ABSTRACT

Electric vehicle (EV) is leading to green future transportation. Instead of it helps to reduce gas emission to the environment, EV technology cut the cost of petrol prices. However, consumers are still suffering from the range anxiety and refuelling time. The range anxiety is the limited driving range. This is due to the limited numbers of EV charging stations available throughout Malaysia cause a big problem for consumers to travel across city if they are running out of battery. The long charging time for a full battery charge also is another factor. The standard charging time for a full battery is about 12 to 30 minutes. Thus, wireless charging is an alternative recharging option. Wireless charging is the contactless connection between grid and vehicle which can be established in a few seconds. Static wireless charging allows recharging process to take place once the vehicles is located at the above charging plate and must be in static. Whilst, dynamic wireless charging is better for recharging process where recharging the battery pack is done in motion. However, the biggest elements that must be tolerated with the dynamic wireless charging system is the airgap and misalignment. Even though many studies show the effectiveness of wireless pad design using ferrite core, they rarely proposed an effective method to solve the problems by varying the geometric shape of ferrite shape. Therefore, this thesis will propose a few combinations of ferrite core shapes on wireless power transfer (WPT) system on EV. This works is divided into three technical tests. The first and second tests will be on simulation analysis. The third test is on experimental work. The design that improves the coil coupling is the main contribution of this study. From the simulation and experiment analysis, ferrite pair that have high magnetic flux density delivered more power transfer.

خلاصة البحث

المركبة الكهربائية (EV) تقود إلى النقل المستقبلي الخالي من انبعاث الغازات الضارة. بدلًا من المساعدة في خفض انبعاثات الغازات على البيئة، بتكنولوجيا المركبة الكهربائية وتخفيض تكلفة البترول. ومع ذلك، لا يزال طائفة من المستهلكون يعانون من الشعور بالقلق عند إعادة التزويد بالوقود. نتيجة الشعور بالقلق من قبل السائقين وذلك يرجع إلى العدد المحدود من محطات الشحن الكهربائي المتاحة في أنحاء ماليزيا الذي يسبب مشكلة كبيرة للمستهلكين الدين يرغبون للسفر على الي البلدات الاخري من مشكلة نفاذ البطارية. كذلك المدة طويلة لشحن البطارية بالكامل أيضًا احد العوامل ألاخرى. في العادة البطارية بحاجة من ١٢ إلى ٣٠ دقيقة لشحنها بالكامل. لذلك، الشاحن اللاسلكي سيكون البديل لإعادة الشحن. حاليًا نستخدم الشاحن المكون الإضافي بسبب انه أكثر ملاءمة. الشاحن اللاسلكي هي عبارة عن عدم وجود اتصال بين الشبكة والمركبة التي يمكن تأسيسها في بضعة ثواني. الشاحن اللاسلكي الثابت يمكن إجراء عملية شحن فورِيّة بشرط وقوف المركبات على صفيحة الشحن ويجب أن تكون المركبة مرصوفة بطريقة صحيحة. بينما، حيوية الشاحن اللاسلكي الديناميكي أفضل في عملية شحنه بحيث إعادة شحن البطارية يتم في الحركة. ومع ذلك، فإن أكبر العناصر التي يجب التغاضي عنها باستخدام حيوية الشاحن اللاسلكي الديناميكي هي الفجوة الهوائية وعدم رصف المركبة بطريقة صحيحية. على الرغم من الدراسات السابقة تبين أن فعالية تصميم دفتر اللاسلكية باستعمال الفريت المغناطيسي نادرا ما اقترح وسيلة فعالة لحل المشكلات من خلال تغيير الأشكال الهندسية للفريت. وبناء عليه، هذه الأطروحة سوف تقترح بعض تركيبات لأشكال الفريت المغناطيسي على نقل الطاقة اللاسلكي (WPT) على المركبة الكهربائية. هذا العمل مقسم إلى ثلاث اختبارات فنية. اختبارا الأول والثاني سوف يكون في تحليل المحاكاة. وأما الاختبار الثالث على التجربة العملية. تتمثّل المساهمة الرئيسية في هذه الدراسة هو التصميم الذي يحسن الملف الكهربائي. من تحليا المحاكاة و التجبة فان طريقة الفريت المغناطيسي عندها قوة مغناطيسية عالية تعطي قوة عالية للنقل .

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science (Communication Engineering).

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DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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"In the name of Allah, the Most Gracious and the Most Merciful"

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LIST OF SYMBOLS

B	Magnetic Field Density units Tesla or Wb/m^2
∇ x	Curl (Measure of the strength of B)
μ_0	Permeability of the Medium
J	Current Density
$\mathcal{E}_0$	Electricity Permittivity of Free Space
E	Electric Field
μ_r	Permeability of the Magnet of Free Space
N	Number of Coil Turns
l	Length of Coil
ω	Resonance Frequency
M	Mutual Inductance
Ip	Primary Current
Is	Secondary Current
L1=Lp	Primary Inductance
L2=Ls	Secondary Inductance
Vp	Primary Voltage
RL	Load Resistance
k	Coupling Coefficient
Cp	Primary Capacitance
Cs	Secondary Capacitance
Rp	Primary Resistance
Rs	Secondary Resistance
η	Efficiency

LIST OF ABBREVIATIONS

EV	Electric vehicle
SWC	Static Wireless Charging
UHF	Ultra-High Frequency
DC	Direct Current
WPT	Wireless Power Transfer
CO_2	Carbon dioxide
WIPT	Wireless Inductive Power Transfer
ASEAN	Association of Southeast Asian Nations
M*t*Co2e	Millions tons of Carbon dioxide equivalent
MESTECC	Ministry of Energy, Science, Technology, Environment and Climate Change
METSCE	Kementerian Tenaga, Sains, Teknologi, Alam Sekitar dan Perubahan Iklim
GreenTech Malaysia	Malaysian Green Technology
TNB	Tenaga Nasional Berhad
EMB	Electric Mobility Blueprint
KeTTHA	Kementerian Tenaga, Teknology Hijau dan Air
MITI	Ministry of International Trade and Industry
CPT	Capacitive Power Transfer
IPT	Inductive Power Transfer
AC	Alternating Current
SS Topology	Series-Series Topology

SP Topology	Series-Parallel Topology
PS Topology	Parallel-Series Topology
PP Topology	Parallel-Parallel Topology
RIPT	Resonance Inductive Power Transfer
FEA	Finite Element Analysis
FEM	Finite Element Method
CST EM Studio	Computer Simulation Technology ElectroMagnetic Studio
JMAG FEA	JMAG Finite Element Analysis
NI Multisim	National Instrument Multisim
PCB	Printed Circuit Board
RMS	Root Mean Square

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Electric vehicle (EV) is an automobile vehicle which operate completely on electricity without emission of gases like conventional car. The working principle is very simple in nature and plays a role in preventing environmental degradation. EV can be associated with the use of electric motor for propulsion and powered by electricity either by plug in, battery or solar panels. This vehicle is not a new concept but instead was developed since mid-18th century. However, during the 20^{th} century EV became obsolete because of its limited driving range and high price as compared to gasoline powered vehicle. It is expected that by 2050, the number of vehicles on the road is expected to reach up to 2.5 billion (KUMAR, 2018).

With regards to the future transport significance, EV is considered as the likely replacement for internal combustion engine driven vehicle. Electric vehicle can possibly lessen carbon discharges by reducing the CO_2 emission, air pollution and reliance on imported fuel (Tian, Li, & Tian, n.d.). Due to this, the EV technology has captured the world's attention and many researches have realize the significant of EV thus intense studies have been reported on this technology.

EV has rechargeable battery on-board as shown in Figure 1.1. The source of power is not from the oil or gas emission anymore since EV is 100% electrical transportation. Instead its source of power comes from the battery pack, this battery pack is charge using the wireless power transfer method where the primary transmitter coil acts as transmitter to transmit the power from primary to secondary. Whilst, the vehicle picks up coil acts as the receiver or also known as secondary in order to charge the battery pack. Referring to Figure 1.1, the fully charged battery pack acts as energy source to drive the traction motor inside the vehicle. Same with the gas emission transportations, battery pack of an electric vehicle need to be recharged first.

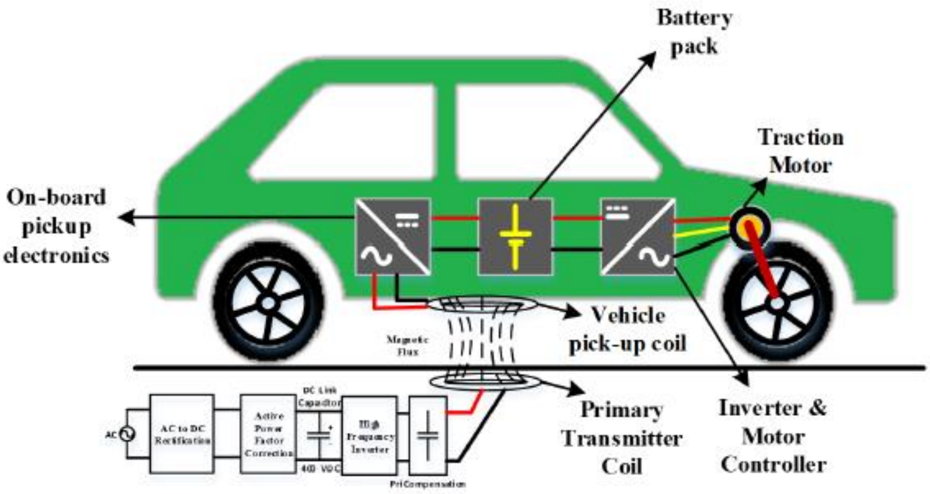

Figure 1.1: Electric Vehicle System Model (Pathipati, Azeez, Williamson, Dohmeier & Boting, 2016)

Battery recharging for EV can done in three different modes as stated by (Ahmad, Alam, Member, & Chabaan, 2018). These three modes are further discussed in Chapter 2:

1) static charging;

2) quasi-dynamic charging;

3) dynamic charging.

Contact less charging or wireless charging is a new technology for EV power transfer. Charging is done using wireless power transmitter and receiver to supply continuous power to the EV.

On 2009 before, EV only deals with Static Wireless Charging (SWC) in which the vehicle needs to stay at charging area during recharging time. The problem or limitation in this technology is that the vehicle can only be charged when the vehicle is parked or in stationary modes such as in car parks, garages or at traffic lights (Panchal, Stegen, & Lu, 2018). The major issues in public acceptance correlate to EV is attributed to its high battery cost and limited driving range.

The Lithium-Ion battery is widely used as the primary power source for the EV's drivetrain due to its high specific energy (100-265 W/kg) and specific power density (250-340 W/kg) compared to other battery technology. Despite its superior characteristics, it still adds considerable weight and size to the vehicle. For example, Nissan Leaf's 24 kWh battery pack weighs around 200 kg. In addition to high weight and size, the estimated price for EV are about double of a gasoline counterpart with nearly half of the cost for the battery itself (Aditya & Williamson, 2019).

The limited driving range is an even greater obstacle to the market penetration of EV than their higher cost. For example, gasoline vehicles can go over 500 km before refueling which takes about 2-3 minutes at a filling station which are located every few kilometers. On the other hand, most EV can only go about 100-200 km before it requires another round of recharging about 30 minutes or more than 12 hours (“How long it takes to fully charge an electric car,” 2016). Besides this, charging stations are not as readily available as fuel stations. These limitations of static charging EV has open up the researcher door to new dynamic charging method.

One of the studies (Aditya, Sood, Fellow, Williamson, & Member, 2017) found that the limitations of EV can be overcome by introducing the new dynamic charging technology for EV which provides the following advantages over conventional wired charging:

a. *Safety and convenience*

Wireless charging provides galvanic isolation between load and source. Therefore, it eliminates the disadvantages of plug-in charging technology such as: risk of electrocution, especially in wet and hostile environment from aging wiring and bad connections; failure to plug in; trip hazard from a long connecting wire; poor visual appeal due to hanging cords; contactor wear caused by excessive use and thermal cycling.

b. *Battery volume reduction*

Due to the scope of opportunity charging, charging can take place more frequently. Therefore, EV can travel the same distance with a reduced number of battery pack. Hence, it can lower the price of EV and make the EV more efficient due to the reduced weight.

c. *Weather Proof*

In a wireless charger, power transfer takes place due to an electromagnetic link, therefore charging is not affected by the weather. Besides, a transmitter is embedded underground, therefore, is safe from extreme weather condition and requires less frequent maintenance or replacement than a plug-in charger would require.

The application of wireless dynamic charging in Malaysia is still a new concept but now a mobile phone can be charged wirelessly in static mode. From the google research (NST Business, 2018) mentioned that in early 2021, sales of electric vehicles in Malaysia are expected to breach three million units globally from 700,000 units in 2016.

1.1.1 History of Wireless Power Transfer

In 1826, Andrie-Marie conducted an experiment to see the relationship between electric current and magnetic field. In 1831, Faraday's Law explained that the electromagnetic force could be induced by varying magnetic flux (Shadid, Noghanian, & Nejadpak, 2016). In 1865, Maxwell's theory of electromagnetism was published. It mentioned that electromagnetic waves speed is the same as speed of light. In 1886, Heinrich Hertz demonstrated a successful experiment on wireless energy transfer he also created an apparatus that can detect microwaves in the UHF region ("The History of Wireless Power Transmission," 2014).

In 1899 based on work done by Hertz, Nicola Tesla has managed to improve the experiment on wireless power transfer. He demonstrated it by powering fluorescent lamps 25 miles away from the power source without using wires. However, his hard work didn't attract enough attention due to the expensive cost of building the wireless power transmitter and receiver (Shadid et al., 2016). William C.Brown in 1964 contributes to the modern development of microwave power transmission. He invented a powering helicopter on microwave transmission using a rectenna which directly converts microwaves to DC current (Shadid et al., 2016). Recently, wireless power transfer has managed to attract many researches due to the scope of the technology has been extended to many different areas. A Table 1.1 below summarize the advantages and disadvantages of the wireless power transfer technology (WPT).

Table 1.1: The Advantages and Disadvantage of WPT

Advantages	Disadvantages
1) No cables, hence all the cable related electric hazards are mitigated. 2) Using wireless power transfer, more than one device can be charged in the secondary. 3) No worries about the charging interruption and theft as there is no plugging of cables involved. 4) Can be used even in the harsh environmental conditions. 5) Low maintenance due to no connectors or cables.	1) When inductive power transfer is used, magnetic shielding is required to avoid magnetic radiation and its hazardous effects. 2) Expensive compared to the conductive charging. 3) Distance of separation or airgap is a big concern, it is not efficient or feasible for very large airgaps. 4) Cannot be used for fast charging as the magnetic radiation in inductive power transfer and voltage between the power