DESIGN AND DEVELOPMENT OF HIGH EFFICIENCY WIRELESS PHOTOVOLTAIC POWER TRANSFER SYSTEM

by

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A thesis submitted in fulfillment of the requirements for the degree of Doctor of Philosophy

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2021

ACKNOWLEDGMENT

I have taken efforts of this thesis, but it would not have been possible without the kind support, assistance and help of many individual and organization. Moreover, if would like to extended my sincere thanks to all of them.

I would like to thanks to my dissertation supervisor, Dr. Leong Jenn Hwai, and Co-supervisor, Dr. Muhammad Irwanto, whose expertise is very valuable in this matter formulating researcher topic and particular methodologies.

Thanks to my friends, Reza Juliangga, Dr. Mahrizal Masri, my wife, my children and my grandchildren, for giving supporting and giving some ideas to help myself to finish this thesis. Without them, it is so hard for me to complete this thesis.

Thank you.

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LIST OF ABBREVIATIONS

DC	Direct Current
AC	Alternating Current
PV	Photovoltaic
WPVPT	Wireless Photovoltaic Power Transfer
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
WPT	Wireless Power Transfer
LED	Lightning Emitting Diode
SS	Series-Series
SP	Series Parallel
PS	Parallel Series
PP	Parallel-Parallel
STC	Standard Test Condition
SISO	Single Input Single Output
SIMO	Single Input Multiple Output
MISO	Multiple Input Single Output
MIMO	Multiple Input Multiple Output
PCB	Printed Circuit Board
PWM	Pulsa Width Modulation

LIST OF SYMBOLS

a	Radius of the solenoid
B	Magnetic flux density
B_t	Magnetic flux density on transmitter coil
C	Capacitance of capacitor
C_r	Capacitance of capacitor on receiver side
C_t	Capacitance of capacitor on transmitter side
d	Coil diameter of solenoid
d_{tr}	Distance between transmitter and receiver coil (meter)
d_w	Diameter of wire
e_{tr}	Induced voltage on receiver coil by transmitter coil
f	Frequency
H	Magnetic field intensity
I	Current generated by PV module
I_L	Load current
I_M	Current of circuit module
l	Coil length
L	Inductance of inductor
I_o	Current generated by PV module related to current density
I_r	Receiver coil current
I_{SC}	Short circuit current
I_{SCM}	Short circuit current module
I_t	Transmitter coil current
M_{tr}	Mutual inductance between transmitter and receiver coil

N	Turn number of wire
N_r	Turn number of receiver coil
N_t	Turn number of transmitter coil
N_S	Number of solar cell is connected in series
N_P	Number of solar cell is connected in parallel
P_{inDC}	DC input power of main DC source
P_{inrec}	DC output power of rectifier
P_{outAC}	AC output power of inverter circuit
P_{outrec}	DC output power of rectifier
P_r	AC power on the receiver coil
P_t	AC power on the transmitter coil
R_s	Series resistance of PV module
R_{sh}	Shunt resistance of PV module
r_t	Radius of transmitter coil
r_r	Radius of receiver coil
V	PV module voltage
V_M	Voltage module
V_{SC}	Short circuit voltage
V_{OC}	Open circuit voltage
V_{SCM}	Short circuit voltage module
V_T	Diode thermal voltage
V_{ocM}	Open circuit voltage module
Z	Flux direction
Φ_r	Magnetic flux on receiver coil

Φ_t	Magnetic flux on transmitter coil
Φ_{tr}	Mutual flux of transmitter and receiver coil
μ_O	Permeability
ß	Magnetic flux
$ß_t$	Magnetic flux density
η_{inv}	Efficiency of inverter circuit
η_{tr}	Efficiency of transmitter and receiver coil
η_{rec}	Eficiency of rectifier circuit
η_{wpt}	Total efficiency of WPT system

Rekabentuk dan Pembangunan Sistem Pindah Kuasa Fotovoltan Tanpa Wayar Dengan Kecekapan Yang Tinggi

ABSTRAK

Pindah kuasa tanpa wayar (PKW) merupakan satu peranti elektronik yang menukar kuasa arus terus (AT) menjadi kuasa arus ulang-alik (AU) pada gegelung penghantar dengan menggunakan satu litar penyongsang dan menghantarnya tanpa wayar ke gegelung penerima berasas gagasan gandingan beraruhan. Normalnya, masa pensuisan dari litar penyongsang dihubungkan dengan pemasa analog dan komponen-komponen pensuisan transistor dwikutub. Ianya menyebabkan frekuensi yang diinginkan dari isyarat pensuisan sukar diset untuk satu pemacu yang sesuai untuk memacu pangkalan pemacu dari komponen-komponen pesuisan, jugaaras voltan dan arus dari komponen-komponen pesuisan ialah rendah. Satu nilai kearuhan yang tidak sesuai pada gegelung penghantar dan penerima boleh menyebabkan frekuensi yang tidak padanan. Masalah ini menyebabkan satu kuasa yang dihantar rendah, kecekapan rendah dan jarak penghantaran dekat. Amnya, bateri ialah sebagai punca voltan AT utama pada sistem PKW, tetapi ianya sesuai untuk kenaan kawasan bergerak. Ini dikeranakan bateri menghendaki untuk dicas sepanjang atau setelah beroperasi. Modul fotovoltan (FV) ialah sesuai menggantikan bateri untuk keadaan ini. Prestasi modul FV bergantung pada sinaran surya dan ianya berbeza pada satu kawasan dengan kawasan lainnya. Dengan demikian, satu kajian yang dihubungkan dengan prestasi modul FV dan keamatan medan magnet dari gegelung penghantar ialah mustahak pada sistem pindahan kuasa fotovoltan tanpa wayar (PKFVW). Tujuan dari tesis ini ialah untuk mereka bentuk, menyelaku, dan menganalisis sistem PKW dengan mikropengawal digit dan kuasa MOSFETs untuk memperbaiki prestasinya dengan jarak penghantaran yang lebih panjang. Tujuan lainnya ialah untuk menyelaku dan menganalisis sinaran surya yang dihubungkan dengan prestasi modul FV dan keamatan medan magnet dari solenoid pada sistem PKFVW. Reka bentuk sistem PKW dihubungkan dengan menghitung nilai kearuhan dan membina gegelung penghantar dan penerima untuk diameter 16.6 cm dan 47.5 cm dengan sistem frekuensi 2.5 kHz. Pembangunan litar penyongsang dan litar penerus juga dihubungkan untuk tepi penghantar dan penerima sistem PKW. Ujikaji dan penyelakuan sistem PKW dihubungkan untuk mengesahkan prestasinya untuk punca voltan AT yang diperlukan dan jarak antara gegelung penghantar dan penerima. Data sinaran surya untuk tahun 2015 dianalisis dan dihubungkan dengan prestasi modul FV dan keamatan medan magnet yang dijanakan oleh gegelung penghantar. Satu ujikaji dan penyelakuan sistem PKFVW juga dihubungkan untuk mengesahkan prestasinya untuk keadaan yang berbeza dari sinaran surya dan presatasi modul FV. Hasil-hasil menunjukkan bahawa prestasi sistem PKW ialah sah untuk hasil-hasil ujikaji dan penyelakuan berasaskan peratusan ralat. Kuasa AT pada tepi penerima dari sistem PKW akan disusutkan dengan satu jarak yang lebih panjang antara gegelung penghantar dan penerima. Hasil penyelakuan keamatan medan magnet pada gegelung penghantar menunjukkan bahawa keamatan medan magnet dipengaruhi oleh magnitud arus AU yang mengalir melalui gegelung penghantar untuk nombor pusingan pemalar dari gegelung penghantar dan panjang gegelung penghantar. Magnitud arus AU yang mengalir melalui gegelung penghantar bersandar pada aras punca voltan AT atau voltan modul FV. Kenaikan punca voltan AT atau voltan modul FV menyebabkan kenaikkan arus AU dan keamatan medan magnet pada gegelung penerima. Ujikaji dan penyelakuan prestasi PKFVW ialah juga sah untuk keadaan yang berbeza dari sinaran surya dan presatasi modul FV.

ABSTRACT

Wireless power transfer (WPT) is an electronic device that converts direct current (DC) power to be alternating current (AC) power on the transmitter coil using an inverter circuit and transmits it without wire to the receiver coil based on the concept of inductive coupling. Normally, the switching time of the inverter circuit is conducted by an analog timer and the switching components are bipolar transistor. It causes a desired frequency of the switching signal is difficult to be set for a suitable driver to drive the driving terminal of the switching components, also the voltage and current level of the switching components are low. An unsuitable value of inductance of transmitter and receiver coil can cause an unmatching frequency. These problems cause a low transmitted power, low efficiency and short transferring distance. Generally, battery is as main DC voltage source of WPT system, but it is not suitable to be applied in the moving area. It is due to that the battery needs to be charged during or after operating. The photovoltaic (PV) module is suitable to replace the battery for this condition. The performance PV module depends on solar irradiance and it is different in one area to the other area. Thus, a study of solar irradiance related to the PV module performance and the magnetic field intensity of the transmitter coil are important on the wireless photovoltaic power transfer (WPVPT) system. The objectives of this thesis are to designs, simulates and analyses a WPT system with digital microcontroller and power MOSFETs for improving its performance with a longer transferring distance. The other objective is to simulate and analyse solar irradiance related to the PV module performance and the magnetic field intensity of solenoid in the WPVPT system. The design of WPT system is conducted by calculating the inductance value and constructing the transmitter and receiver coil for the diameter of 16.6 cm and 47.5 cm with the frequency system of 2.5 kHz. The development of inverter circuit and rectifier circuit are also conducted for the transmitter and receiver sides of WPT system. An experimental and simulation of WPT system are conducted to validate its performance for a required DC voltage source and distance between the transmitter and receiver coil. The data of solar irradiance for the year of 2015 is analysed and related to the performance of PV module and magnetic field intensity generated by the transmitter coil. An experimental and simulation of WPVPT system are also conducted to validate its performance for the different condition of solar irradiance and PV module performance. The results show that the performances of WPT system are valid for the experimental and simulation results based on the error percentage. The DC power on the receiver side of WPT system will be decreased with a longer distance between the transmitter and receiver coil. The simulation result of magnetic field density on the transmitter coil shows that the magnetic field density is affected by the magnitude of AC current that flows through the transmitter coil for the constant turn number of transmitter coil and the constant coil length. The magnitude of AC current that flows through the transmitter coil depends on the level of DC voltage source or PV module voltage. The increasing of DC voltage source or PV module voltage causes the increasing of AC current and magnetic field density on the transmitter coil and increasing the capability of arriving magnetic field on the receiver coil. The experimental and simulation of WPVPT performance are also valid for the different condition of solar irradiance and PV module performance.

CHAPTER 1: INTRODUCTION

1.1 Introduction

Generally, the electrical energy is sent from the electrical power plant to the customer loads using the transmission and distribution line with a high electrical power capacity and a sending distance until hundred kilometres. The transmission and distribution line uses wire to flow the current and it is suitable to be applied in an open space area. In the specific area, where a limitation of wire placement or installation, thus a wireless power transfer (WPT) is suitable to be applied for the transferring distance around some centimetres to some meters.

The WPT system converts the DC power to be AC power using an inverter circuit and it is transferred through the transmitter and receiver coil. The AC power on the receiver coil needs to be rectified using a rectifier circuit if it is applied to the DC loads. The WPT system has been designed with the different topology and analysed by the previews researches in term of power, efficiency and transferring distance. The magnetic resonant coupling-wireless power transfer (MRC-WPT) system has been designed by Kusuma, (2012) and John, (2017) with very low power for LED light and low transmission distance of only 5 cm and 8 cm, respectively. The concept of electromagnetic inductive-wireless power transfer (EI-WPT) system with photovoltaic (PV) module as DC voltage source has been designed and analysed by Fareq et al., 2014 which it is connected to a 0.15 W 5mm red LED lamp, thus the maximum efficiency is only 3% for the transmission distance of 5 cm and by Namin et. al., (2018) with maximum efficiency of 6% for the transmission distance of 26 cm.

The previews researchers have been designed the WPT system successfully, but their efficiencies are still low and the capabilities of transferring distance are also still short. It is due to that the capability of power generated by the inverter and transmitted by the transmitter coil to the receiver coil are affected by the suitable choice of frequency and type of switching component on the inverter circuit. The size and construction of transmitter and receiver coil also takes an important role in the transferring distance. A choice of electronic device is important to generate a required frequency and match it to the inductance of transmitter and receiver coil, thus it has good performance in the high power and efficiency of WPT system. A choice of high voltage and current switching component is also needed to be able to increase the high power and efficiency of WPT system, it is due to that magnetic field generated on the transmitter coil is proportional to the AC current which flows through the coil. Therefore, a high efficiency WPT system is suitable to be designed and developed in this thesis.

This thesis designs and develops a 2.5 kHz WPT system for powering direct current and alternating current. It is constructed by microcontroller PIC16F628A for generating a performance required frequency and MOSFET IRF460 with high voltage and current. The inductance of transmitter and receiver are found and constructed for matching the frequency system. It is supplied directly by PV module. Since the WPVPT system is to be installed and used in Perlis, Malaysia, the solar irradiance in Perlis, is studied and analysed to evaluate the power generation potential of the WPVPT system. A simulation of WPT system is also conducted to validate the measurement result of WPT performance.

1.2 Problem Statement

In this thesis, the problem statements are stated as below:

a. Conventionally, an analog frequency generator (e.g. 555 timer) is used to generate switching signal in the wireless power transfer (WPT) system. The desired frequency of the switching signal is difficult to set using the analog timer. Another disadvantage of conventional WPT system is the use of bipolar transistor that only allows low voltage and current level, thus the power transmitted and received by transmitter coil and receiver coil are low and it also causes higher losses. The WPT system also transmits the power for the distance between the transmitter and receiver coil with very low efficiency. Therefore, a method to generate and set frequency using microcontroller and to obtain the higher voltage and current level using power MOSFET are desired to improve the performance of a WPT system.

b. Basically, the AC voltage generated by the transmitter coil comes from the DC voltage source that it is converted by inverter circuit. The DC voltage source can come from a battery for the WPT application in a static area. But the battery has a discharging time during it is applied into the WPT system and it will be empty if there is no charging source to the battery. It means that the battery is not suitable to be applied in to the WPT system in a specific area, for example in the moving devices (robot, car or aerospace vehicles). In this case, PV module is suitable to change the battery as a main DC voltage source of wireless photovoltaic power transfer (WPVPT) system. It is due to the PV module operates based on the solar irradiance in one area, and the structure of earth surface is different in one area to the other area, thus a study of solar irradiance related to the PV module is important as DC voltage source of the WPVPT system.

The magnetic field produced in the solenoid of WPVPT transmitter and receiver coils depend on the current flow in the solenoid winding. It also depend on the turn number, diameter of transmitter and receiver coils and the distance between the transmitter and receiver coils. To ensure optimal performance of the WPVPT system, it is therefore essential to analyse and formulate the relation between the PV module output current and the magnetic field intensity in the transmitter and receiver coil.

1.3 Thesis Objective

The main objective of this thesis is to design, develop and analyse a wireless power transfer (WPT) and a wireless photovoltaic power transfer (WPVPT) system. The output power of PV module is in DC and it is dependent on the solar irradiance and ambient temperature. A 2.5 kHz alternating current (AC) voltage waveform is derived from the PV output DC voltage and the AC power is transferred from the transmitter coil to the receiver coil of WPVPT system. The WPVPT system operates in according to the electromagnetic induction principle in which the solenoid of transmitter coil produces a changing magnetic field that induces a voltage across the terminals of receiver coil. The main and secondary objectives of this thesis are summarized as follows:

a. To design, simulate and analyse a WPT system with digital microcontroller and power MOSFETs for improving its performance with a longer transferring distance.
b. To simulate and analyse solar irradiance related to the PV module performance and the magnetic field intensity of solenoid in the WPT system.
c. To observe, simulate and analyse the performance of WPVPT system.

1.4 Thesis Scope

The scopes of thesis are as follows:

a. Since the PV module operation is dependent on the solar irradiance at a specific location, the solar irradiance data in Perlis, Malaysia throughout the year 2015 is analysed to determine the power generation potential for the WPVPT system.

b. Two different PV modules are employed to evaluate the performance of the WPVPT system. The first one is type is Yingli YL75 PV module (75 W, 21.5 V), which is used in a 2.5 kHz WPVPT system with the transmitter and receiver coil diameter of 16.6 cm. The second one Kaneka G-SA060 amorphous silicon (a-Si) PV module (60 W, 91.8 V), which is used in a 2.5 kHz WPVPT system with the transmitter and receiver coil diameter of 47.5 cm.

c. The effect of turn number of transmitter and receiver coil, diameter of solenoid of transmitter and receiver coil and the distance between transmitter and receiver coil on the performance of WPVPT system are studied and analysed.

1.5 Thesis Outlines

This thesis is organized into five main chapters as follows

Chapter 1 introduces the background, problem statement, objectives and organization of this thesis.