OPTIMISED DESIGN OF THERMOELECTRIC ENERGY HARVESTING SYSTEM FOR POWERING RADIO FREQUENCY SWITCH

GOH SIEW YUN

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A thesis submitted
in fulfilment of the requirements for the degree of
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DECLARATION

I declare that this thesis entitled "Optimised Design of Thermoelectric Energy Harvesting System for Powering Radio Frequency Switch System" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : ....

Date : ....

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Electronic Engineering.

Signature : ....

Supervisor Name : ....

Date : ....

DEDICATION

To my beloved mother and family. Thank you for giving me mentally and moral support during the master program.

ABSTRACT

Thermoelectric generator (TEG) is an energy harvester that converts heat energy into electrical energy. The motivation of this research project to use TEG to harvest energy from heat that dissipated from infrared sunlight, and prove that the electrical energy from TEG is useful for powering electronic device. This research work proposes a self-powered wireless application by using IR light to simulate sunlight spectrum. A PV cell is more common compared to TEG in converting sunlight to electrical energy. However, by complementing PV cell with TEG, it would be more effective in generating useful electrical energy. Another problem is the difficulty of concentration of radiated heat on hot surface of a TEG, which was solved by using heat absorber attached on the hot surface of TEG. Moreover, due to insufficient electrical energy from TEG to power up electronic device, DC to DC convertor is used to boost up voltage output. One of the objectives in this research work is complementary of electrical energy between TEG and PV cell. Moreover, optimisation of electrical energy TEG output for powering wireless devices is also an important objective. In the laboratory setup, an IR light bulb was used to simulate the infrared wavelength of sunlight spectrum that produces heat. Different types of heat absorbers were used to concentrate the radiation heat from IR light bulb to optimize the electrical output from TEG. A DC to DC converter was designed to boost up the electrical voltage generated from the TEG. In this project, two integrated circuits were investigated for comparison, they were LTC 3105 which is with a maximum power point controller and LTC 3108 with is with a power manager. These two circuits were connected to the RF transmitter and compared in term of charging time, discharging time, and electrical output. The TEG and PV cell were placed under the sunlight in open air from 9:00am to 5:00pm to prove that both harvesters complemental with each other. The result showed that the power outputs of TEG with heat absorber and TEG without heat absorber were 407.55uW and 52.99uW, respectively. This proved that the heat absorber optimised the performance of TEG. For the RF transmitter, the signal transmissions using LTC 3108 and LTC 3105 were 0.25s and 1.25s, respectively. This proved that LTC 3105 can handle longer duration of signal transmitting. Lastly, the TEG contributed about 15% electrical output to complemental the PV cell with the same size when exposed to sunlight. The overall result proved that the electrical energy of TEG can be optimised, which is useful for powering low-power electronic devices.

ABSTRAK

Penjana termoelektrik (TEG) adalah penuai tenaga yang menukar tenaga haba menjadi tenaga elektrik. Motivasi projek penyelidikan ini adalah menggunakan TEG untuk menuai tenaga daripada inframerah dari cahaya matahari dan membuktikan tenaga daripada TEG adalah berguna untuk menghidupkan peranti elektronik. Pengajian projek ini mencadangkan aplikasi tanpa wayar kuasa sendiri yang mengguna lampu inframerah untuk mensimulasikan spektrum matahari. PV lebih biasa berbanding dengan TEG dalam menuai tenaga solar. Walau bagaimanapun, pelengkap antara PV dan TEG akan lebih berkesan dalam menghasilkan tenaga electrik. Selain itu, sinaran haba susah tumpu pada permukaan panas TEG. Masalah ini boleh diselesaikan melalui pemasangan penyerap haba pada permukaan panas TEG. Di samping itu, penukar DC ke DC direka untuk meningkatkan voltan TEG kerana elektrik dari TEG tidak cukup untuk menghidupkan peranti elektronik. Salah satu objektif kerja kajian ini adalah melengkapkan kuasa elektrik antara TEG dan sel PV. Di samping itu, mengoptimumkan kuasa elektrik TEG untuk menghidupkan peranti tanpa wayar adalah objektif yang penting juga. Dalam ujikaji makmal, lampu inframerah digunakan untuk mensimulasi panjang gelombang inframerah spektrum cahaya matahari yang menghasilkan haba. Pelbagai jenis penyerap haba digunakan untuk mengumpulkan haba daripada inframerah lampu untuk TEG. Selepas itu, penyerap haba yang mendapat keluaran elektrik yang tertinggi telah dipilih untuk dipasang pada TEG. Kemudian, dua jenis IC iaitu LTC 3105 yang pengawal takat kuasa maksimum dan LTC 3108 yang mengurus kuasa digunakan untuk membina penukar DC ke DC. Dua IC tersebut dibandingkan untuk memilih penukar DC ke DC yang sesuai untuk penghantar RF, ia dibanding dalam masa pengecas, masa mengeluarkan cas, dan keluaran elektrikal. TEG dan sel PV diletakkan di bawah mahatari dari 9:00 pagi sehingga 5:00 petang untuk membuktikan bahawa TEG adalah satu alternatif yang dapat meningkatkan penghasilkan tenaga elektrik. Keputusan projek ini menunjukkan keluaran tenaga TEG dengan penyerap haba ialah 407.55uW dan keluaran tenaga TEG tanpa penyerap haba ialah 52.99uW. Keputusan tersebut membuktikan penyerap haba dapat mengoptimumkan keluaran elektrik TEG. Untuk pengunaan penghantar RF, LTC 3108 berupaya menghantar isyarat RF selama 0.25 saat manakala LTC 3108 berkuasa menghantar isyarat RF lebih lama selama 1.25 saat. Ini membuktikan LTC 3105 boleh menghantar isyarat yang lebih panjang. Di samping itu, TEG telah menyumbang voltan litar lebih kurang 15% kepada sel PV dengan saiz yang sama apabila menggunakan matahari sebagai punca haba. Hasil keseluruhan projek ini telah membuktikan tenaga elektrik TEG boleh dioptimumkan di mana ia berguna untuk peranti elektronik kuasa rendah.

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LIST OF ABBREVIATIONS

ΔT	-	Temperature Gradient
A0	-	Analogue Pin 0
A1	-	Analogue Pin 1
d	-	Distance between IR light bulb with DUT
DC	-	Direct Current
DUT	-	Device Under Test
Ephoton	-	Photon Energy
Egap	-	Bandgap Energy
I	-	Current Output
Ic	-	Capacitor Current
IC	-	Integrated Circuit
IL	-	Current Load Output
IR	-	Infrared
LED	-	Light Emitting Diodes
LTC 3105	-	Step-up DC/DC Converter
LTC 3108	-	Ultralow voltage step-up Converter
MCPCB	-	Metal Core Printed Circuit Board
PCB	-	Printed Circuit Board
PE foam	-	Polyethylene Foam
Pout	-	Power Output

P_{peak}	-	Peak Power Output
PV	-	Photovoltaic
RF	-	Radio Frequency
RTC	-	Real Time Clock
Rx	-	RF Receiver
STEG	-	Solar Thermoelectric Generator
TC 54	-	Voltage detector
TEG	-	Thermoelectric Generator
Tx	-	RF Transmitter
UV	-	Ultraviolet
Voc	-	Open Circuit Voltage Output

LIST OF SYMBOLS

ε	-	Electric field
α	-	Seebeck coefficient
ΔT	-	Temperature Gradient
T_h	-	Hot surface temperature of TEG
T_c	-	Cold surface temperature of TEG
P_o	-	Power output
I_o	-	Current output
R_L	-	Load resistance
E	-	Photon energy
h	-	Planck constant
v	-	frequency
c	-	speed of light
λ	-	wavelength
Q	-	charge of electron
V	-	voltage

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CHAPTER 1

INTRODUCTION

1.1 Overview

Electrical energy undeniably an important role in our daily modern life because it can be transformed into other forms of energy for household application, transportation, manufacture industries, and so on. However, some energy is lost during the energy transform, leading to higher energy consumption and wastage of energy. The law of energy conservation states that the energy cannot be created or destroyed, but it can transform from one form into another form of energy. Energy harvester is one of the devices that can convert wasted energy into useful electrical energy. Various energy sources such as solar, vibration, thermal, radio frequency are available in our surrounding environment for harvest. Therefore, energy harvesting is potential from conversion, storage, accumulation and boosting wasted energy into useful electrical energy.

Energy harvesting is generation of electrical energy by conversions, such as mechanical, chemical, solar, radio frequency, and thermal energy into electrical energy. Solar to electrical energy is the best choice among all the energy conversion processes above and is used widely in products such as solar power bank, calculator, and in-house implementation. The most common harvester used to convert solar energy into electrical energy is photovoltaic (PV) cell. However, sole PV cell is incapable to fully utilize solar energy from the sunlight spectrum, especially from infrared light, because infrared light does not have enough photon energy to break through the band gap of PV cell. Neverthless, the temperature radiation from the infrared light can still be harvested using thermoelectric generator (TEG).

The conversion of heat energy into electrical energy is based on the effect discovered by Thomas Seebeck in 1821. The Seebeck effect defines that electrical energy is generated from the temperature gradient applied on a pair of dissimilar semiconductor junction. TEG is a combination of many pairs of dissimilar semiconductor junction, connect it electrically in series and thermally in parallel. TEG has two surfaces, which are hot surface and cold surface. The hot surface absorbs the heat from source to the TEG hot surface, while the cold surface releases the heat from the TEG. Electric energy is generated when the temperature gradient is applied on both surfaces of TEG.

This thesis proposes the application of TEG to harvest heat energy from infrared light, for conversion into useful electrical power. This application begins by using infrared light bulb to simulate the heat energy from the infrared sunlight spectrum. The operation of TEG also involves interchange of heat and electric effect, thus can be used to generate electrical energy from infrared light bulb. Heat absorber is used to concentrate the heat, and then distribute the heat on the surface of TEG uniformly in order to obtain optimised output from the TEG. Various heat absorbers had been investigated in this study for comparison of optimum electrical energy output.

Then, the TEG and PV cell were placed under the sunlight to study the voltage output of both harvesters. The voltage outputs of both harvesters were compared by unity-based normalization to investigate the feasibility of complements of these two harvesters.

Last, the self-powered RF switch system was initiated using the TEG as a power generator for the system. A DC to DC converter circuit was employed to boost up and charge the electrical output from TEG, to ensure enough energy to power up the RF switching circuit. Two DC to DC converters had been utilized for comparison to choose the better