Faculty of Electronics and Computer Engineering

ENERGY HARVESTING SYSTEM BASED ON ROAD PAVEMENT INCORPORATED WITH THERMOELECTRIC GENERATOR SYSTEM

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DECLARATION

I declare that this thesis entitled “Energy Harvesting System Based on Road Pavement Incorporated with Thermoelectric Generator 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 : Muhammad Syadza bin Sharuddin

Date : 21 June 2021

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	:	DR. AZDIANA MD YUSOP
Date	:	21/06/2021

DEDICATION

To my beloved mother and father.

ABSTRACT

Thermal energy harvesting (TEH) is an exciting subject due to its advantage of being easily procured, whether from natural sources or waste heat. Asphalt road is one of the examples of waste heat sources that can be easily collected due to its availability almost everywhere on earth. A thermoelectric generator (TEG), which operates based on the Seebeck effect, can be utilized to harvest thermal energy from the road. The Seebeck effect produces potential differences when there is a temperature gradient between two dissimilar electrical conductors. This research aims to develop an energy harvesting system on road pavement using TEG device. An energy management system is also designed and analyzed for the road thermal energy harvesting system. The improvement of the system is evaluated based on behavior and characteristic of the temperature difference across the TEG surface, output voltage, and efficiency. Experiments were performed on pavement samples installed with aluminium and copper plates under three different conditions. Firstly, the experimental result shows that the best type of metal plate is copper plate. Secondly, increasing the number and length of metal plates can produce a higher yield. Thirdly, the TEG's thermal connection test indicated that stacking TEG on top of each other (2x2 and 1x4) increases the output voltage and efficiency. The best cooling method is water tank cooling, where it generates the highest temperature gradient and output voltage compared to ambient and heatsink cooling. The energy management experiment results presented that DC1587A can charge supercapacitors faster than ECT310 because DC1587A has MPPT (maximum power point tracking) capability. TEH from asphalt pavement is green, sustainable, and at less cost. The potential of this technology is very promising and it can help supply extra energy from excess heat anywhere.

SISTEM PENUAIAN TENAGA BERASASKAN RANGKUMAN TURAPAN JALAN DENGAN SISTEM PENJANA TERMOELEKTRIK

ABSTRAK

Penuaian tenaga termal (TEH) adalah subjek yang menarik kerana kelebihannya yang mudah diperoleh, sama ada dari sumber semula jadi atau haba buangan. Jalan asfalt adalah salah satu contoh sumber haba buangan yang dapat dikumpulkan dengan mudah kerana ketersediaannya di hampir semua tempat di muka bumi. Penjana termoelektrik (TEG), yang beroperasi berdasarkan kesan Seebeck, dapat digunakan untuk menuai tenaga termal dari jalan. Kesan Seebeck menghasilkan voltan apabila terdapat perbezaan suhu antara dua konduktor elektrik yang tidak sama. Penyelidikan ini bertujuan untuk menghasilkan sistem penuaian tenaga di turapan jalan menggunakan alat TEG. Sistem pengurusan tenaga juga direka bentuk dan dianalisis untuk sistem penuaian tenaga termal jalan. Penambahbaikan sistem dinilai berdasarkan tingkah laku dan ciri perbezaan suhu di antara permukaan TEG, voltan keluaran, dan kecekapan. Ujikaji dilakukan pada sampel turapan yang dipasang dengan plat aluminium dan tembaga dengan tiga keadaan yang berbeza. Pertama, hasil eksperimen menunjukkan bahawa jenis plat logam yang terbaik ialah plat tembaga. Kedua, meningkatkan bilangan dan panjang plat logam dapat menghasilkan keluaran yang lebih tinggi. Ketiga, ujian konfigurasi TEG menunjukkan bahawa meletakkan TEG di atas satu sama lain (2x2 dan 1x4) meningkatkan voltan dan kecekapan. Kaedah penyejukan terbaik adalah penyejukan tangki air, di mana ia menghasilkan perbezaan suhu dan voltan keluaran tertinggi berbanding dengan penyejukan ambien dan penyejukan sinki haba. Hasil eksperimen pengurusan tenaga menunjukkan bahawa DC1587A dapat mengecas kapasitor lebih cepat daripada ECT310 kerana DC1587A mempunyai kemampuan MPPT (pengesanan titik maksimum). TEH dari turapan asfalt adalah teknologi hijau, lestari dan murah. Potensi teknologi ini sangat baik dan ia dapat membantu membekalkan tenaga tambahan dari haba buangan di mana sahaja.

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LIST OF ABBREVIATIONS

BEM	-	Building Energy Management
DTEHR	-	Dynamic Thermal Energy Harvesting Reusing
HFI	-	High-Frequency Injection
MEMS	-	Micro-scale Electromechanical Systems
MPPT	-	Maximum Power Point Tracking
MSCs	-	Micro-Supercapacitors
PMC	-	Power Management Circuit
PZTs	-	Piezoelectric Transducers
RTGS	-	Road Thermoelectric Generator System
SEPIC	-	Single-Ended Primary-Inductor Converter
TEC	-	Thermoelectric Cooler
VCO	-	Voltage Controlled Oscillator
WSNs	-	Wireless Sensor Networks

LIST OF SYMBOLS

V	-	Potential difference
W	-	Power
^{O}C	-	Temperature in Celsius
F	-	SI unit for capacitance
Z	-	TEG Figure of merit
M	-	Conversion unit formula
ΔT	-	Temperature difference
Ω	-	Electrical resistance
J	-	Unit of work
η_{ideal}	-	Ideal efficiency
η_{opt}	-	Optimum efficiency

LIST OF APPENDICES

LIST OF PUBLICATIONS

1. M.S. Sharuddin, A.M. Yusop, A.S.M. Isira, K.N. Khamil, 2020. Effect of Different Condition on Voltage Generation and Thermal Gradient from Road Pavement using Thermoelectric Generator. *Jurnal Kejuruteraan*, 32(3), pp. 59-66.

2. Muhammad Syadza Sharuddin, Azdiana Md. Yusop, Ahmad Sadhiqin Mohd Isira, N.F. Kamaruddin, Khairun Nisa Khamil, 2019. Evaluation of Voltage Generation and Thermal Distribution from Road using Thermoelectric Technology. *International Journal of Engineering and Advanced Technology (IJEAT)*, 8(6), pp. 4603-4608.

3. M.S. Sharuddin, A.M. Yusop, A.S.M. Isira, K.N. Khamil, 2019. Performance analysis of DC-DC converters for road pavement thermoelectric system. *Proceedings of Mechanical Engineering Research Day 2019*, pp. 214-215.

4. K.N. Khamil, M.F.M. Sabri, A.M. Yusop, M.S. Sharuddin, 2019. Finite element analysis of the thermal response test for road thermoelectric energy harvesting system (RTEHs). *Proceedings of Mechanical Engineering Research Day 2019*, pp. 193-195.

CHAPTER 1

INTRODUCTION

1.1 Background of research

The world is heavily dependent on fossil fuels for electrical energy generation, which is very vital for public or private consumption in our daily life. As stated by World Energy Council 2016, the majority of the world's energy consumption source is oil (32.9 %), which is mainly utilized for transport, followed by coal with 29.2 % where it is used to generate electricity (World Energy Council, 2016). The reserves of fossil fuels and coal will soon be depleted since they are categorized as limited and non-renewable energy sources. Moreover, fossil fuels and coal burning are not environmentally friendly as they produce harmful byproducts such as carbon dioxide (CO_2) and sulfur dioxide (SO_2), consequently encouraging global warming and other damaging environmental effects. This problem can be overcome by using renewable sources of energy. The use of renewable energy has been a widely topic to discuss due to its sustainability, in which the energy sources can replenish themselves naturally without being exhausted and produce no excess product, which may harm the environment. There are many sources of renewable energy, including bioenergy, hydropower, thermal energy, solar energy, wind energy, and wave energy (Owusu and Asumadu-Sarkodie, 2016). Solar energy comes from the sun, which radiates its energy in our solar system. Solar from the sun consists of light energy and thermal energy. The sun generates energy from its internal core from a phenomenon called nuclear fusion. Even though only a small amount of solar energy emits from the sun that reaches the Earth, it is more than sufficient to supply all our energy needs (NEED, 2017).

Asphalt road is broadly utilized for land transportation between places and helps people and goods travel all over the world (Tahami et al., 2019). Road pavement can be really hot during the day due to solar energy from the sun radiates to the pavement structure and causes them to absorb and store solar power in the form of thermal energy. This thermal energy stored in the road pavement can be harvested using a thermoelectric generator or TEG to provide an alternative source of electrical energy. TEG is a device that converts the thermal gradient into electrical energy. The TEG operates based on the Seebeck effect; when there is a temperature difference between two dissimilar conductors, a potential difference will be generated. TEG is known to be environmentally friendly and does not have any mechanical parts (Yu et al., 2010). TEG produces no byproduct and does not need any maintenance. However, the renewable energy source is known to be unstable. Hence, the electrical energy obtained from the TEG must be managed carefully by developing an energy management system that can help boost and store electrical energy into a storage device such as a battery or supercapacitor. The idea of thermal energy harvesting from road pavement does not only offer a clean and renewable source of energy, but also can save costs. For example, the government does not have to build electricity poles along the road just to power up road lamps and traffic lights, which can cost a fortune.

1.2 Problem statement

The thermal energy harvesting using a TEG is one of the energy harvestings prospective methods that can be implemented in road pavement, which is suitable for Malaysia's climate due to the location of Malaysia which is situated along the earth equator, as a result, the country received maximum solar energy every day throughout the year. The thermal energy harvesting system based on temperature difference across asphalt road is a novel idea, which means there is a limited amount of work and study that explains or

describes the attempt using laboratory experiments and simulations, thus research on this topic can be very valuable. Asphalt road is made up of aggregates (stone, sand, and gravel) and asphalt cement, which makes the surface rough or not smooth, and this can be a problem for TEG to harvest thermal energy if the idea is to install the TEG to the asphalt pavement surface directly. Moreover, poor design of thermal energy harvesting for road systems also can compromise the TEG structure and longevity. The installation of TEG inside the road is not recommended because the pressure from the weight of vehicles that uses the road can crush the TEG.

As stated by Su et al., the conversion efficiency of TEG can be improved by reducing the temperature of the thermoelectric cold side (Su et al., 2017). Therefore, this shows that the total power generated from thermoelectricity is predominantly defined by the temperature gradient between the cold side and the hot side of TEG. Thus, increasing the temperature difference between the TEG surfaces would be the key idea to enhance the TEG's yield and increase efficiency. Parameters or aspects that can improve the thermal gradient of TEG's surface should be considered in the research to produce a high yield.

Just like other power generator systems, TEG needs an energy management scheme that can improve output power performance. Generally known, renewable source of energy is not steady or inconsistent and produces a low output voltage; thus, it needed to be boosted and regulated. Additionally, in a renewable power generation system, sometimes power generated is used directly for electronic application usage without the presence of any storage device, but when the application is not used, power may still be generated, consequently wasting the generated electrical energy.