STUDY AND ANALYSIS OF IMPACT-BASED PIEZOELECTRIC ENERGY HARVESTER FOR WIDEBAND OUTPUT

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MASTER OF SCIENCE IN
ELECTRONIC ENGINEERING

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Faculty of Electronic and Computer Engineering

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NG XUE YAN

A thesis submitted
in fulfillment of the requirements for the degree of
Master of Science in Electronic Engineering

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2019

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DECLARATION

I declare that this thesis entitled “Study and Analysis of Impact-Based Piezoelectric Energy Harvester for Wideband Output” 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 : ....

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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. AMAT AMIR BIN BASARI

Date : ....

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DEDICATION

Special dedication to my beloved parents

Ng Kek Seng and Ong Guat Cheng

Their encouragement and guidance have always be an inspiration to me along this journey of education.

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ABSTRACT

The piezoelectric energy harvester (PEH) is the piezoelectric materials that are used to produce charges when the piezoelectric transducer is either bent, compressed or stretch. It has been widely developed because it is easier to be used and has higher power density compares with electrostatic and electromagnetic energy harvester. However, due to the frequency of the ambient vibration sources is changeable and also, the frequency generated from the impact will provide a sharp peak and a narrow bandwidth which making it not ideal to efficiently operates the applications devices in real life. As the piezoelectric transducer has a high Q-factor, the operating frequency bandwidth of the piezoelectric transducer is narrowed and limited. The yielded output power of the piezoelectric transducer only can be harvested within the narrowed operating frequency bandwidth. Thereupon, the motivation of this research is to widen the operating frequency bandwidth of the vibration-based impact mode PEH so that it can be applied on self-powered RF system and operated at the ambient vibration sources' frequency which is between 10Hz to 300Hz. For the laboratory setup, the continuous vibration impact mode experiment is conducted to characterize the performance and output efficiency of the piezoelectric disc. The additional of the interfaced plate is analyzed and included as it can enhance the output efficiency of the piezoelectric disc. Moreover, the frequency response of the piezoelectric disc is characterized by altering the proof mass and vibrating beam's width and thickness of the designed piezoelectric power generator. The highest performance of the piezoelectric disc with the interfaced plate and vibrating beam is selected to be applied on the new design piezoelectric power generator. Three different designs of power generator are devised and different connections of combining the multiple piezoelectric discs are analyzed. Furthermore, a buck converter of LTC 3588 is applied for the purpose of stepping up the current while stepping down the harvested output voltage. This is because of the current of the PEH is not high sufficient to drive the self-powered RF system. The piezoelectric discs of P-DL piezoelectric power generator that are connected in DCTC SSP connection can harvest 0.41mW of output power with 1 g-level of the acceleration level. The self-powered RF system with DCTC SSP connection can be operated with the ambient frequency from 30Hz to 280Hz (250Hz bandwidth) which is wider about 1.56 times compared to the CTDC connections. Moreover, the charging time of the DCTC SSP connection is 71 seconds, which is shorter compares to the charging time of CTDC connections that are more than 251 seconds. The overall result justifies that this research can be applied for the electronic device such as self-powered piezoelectric based RF system in wide ambient frequency sources and appliances. A hybrid system or an incrementation of an acceleration level will be included for the future work for the purpose of enhancing the performance of the designed power generator to drive and apply on the Internet of Things (IoT) monitoring system.

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ABSTRAK

Jentuai tenaga piezoelektrik (PEH) adalah bahan piezoelektrik yang digunakan untuk menghasilkan cas semasa pemindaharuh piezoelektrik ketika dibengkokkan, dimampatkan atau diregang. Ia telah berkembang secara meluas kerana ia lebih mudah untuk digunakan dan mempunyai ketumpatan kuasa yang lebih tinggi berbanding dengan jentuai tenaga elektrostatik dan elektromagnet. Walau bagaimanapun, disebabkan frekuensi punca getaran ambien sering bertukar dan frekuensi yang dijana hentaman akan memberikan hasil pengeluaran jalur lebar yang sempit dan terhad, ia mungkin tidak dapat beroperasi dengan cekap untuk penggunaan aplikasi peranti dalam kehidupan yang sebenar. Ini disebabkan pemindaharuh piezoelektrik mempunyai Q-faktor yang tinggi boleh menyebabkan hasil keluaran kuasa pemindaharuh piezoelektrik hanya boleh dituai dalam linkungan kendalian frekuensi jalur lebar yang sempit. Oleh itu, motif penyelidikan ini adalah untuk memperluaskan jalur lebar frekuensi kendalian PEH berasaskan getaran secara hentaman ragam supaya ia boleh diaplikasi pada sistem RF yang berkuasa-diri dan dapat beroperasi dalam linkungan frekuensi sumber getaran ambien 10Hz hingga 300Hz. Ujikaji berasaskan getaran berterusan secara hentaman ragam dijalankan untuk mengenalpasti ciri-ciri prestasi dan kecekapan pengeluaran yang dihasilkan oleh cakera piezoelektrik. Penambahan plat yang diselaraskan turut dianalisis kerana ia dapat meningkatkan kecekapan pengeluaran cakera piezoelektrik. Selain itu, tindak balas frekuensi cakera piezoelektrik dikenalpasti dan dicirikan dengan mengubah jisim hujung dan kelebaran dan ketebalan papan besi penggetar penjana kuasa piezoelektrik yang telah direka. Prestasi tertinggi yang dicapai oleh cakera piezoelektrik bersama plat yang diselaraskan dan papan besi penggetar akan dipilih untuk digunakan pada rekabentuk penjana kuasa piezoelektrik yang baru. Analisis dan ujikaji telah dijalankan pada tiga rekabentuk penjana kuasa yang telah direka secara berbeza dan masing-masing mempunyai sambungan litar yang berbeza untuk menyambungkan beberapa cakera piezoelektrik. Selain itu, penukar buck LTC 3588 digunakan untuk meningkatkan kadar arus dan pada masa yang sama, ia akan menurunkan kadar voltan yang dituai. Hal ini adalah disebabkan oleh arus PEH yang tidak mencukupi untuk memacu sistem RF yang berkuasa-diri. Cakera P-DL piezoelektrik penjana tenaga yang disambungkan pada sambungan SSP DCTC boleh menghasilkan kuasa keluaran setinggi 0.41mW pada tahap pecutan skala 1g. Sistem RF yang berkuasa-diri dengan sambungan SSP DCTC boleh beroperasi dalam linkungan frekuensi ambien 30Hz hingga 280Hz (250Hz kelebaran). Ia adalah 1.56 kali ganda lebih lebar berbanding dengan sambungan CTDC. Seterusnya, masa pengecasan sambungan SSP DCTC ialah 71 saat dan ia adalah lebih cepat daripada masa pengecasan sambungan CTDC yang memerlukan lebih daripada 251 saat. Hasil keseluruhan kajian ini mendapati bahawa penyelidikan ini boleh diaplikasi pada peranti elektronik yang berkuasa-diri seperti sistem RF berasaskan piezoelektrik pada kelebaran frekuensi ambien. Sistem hibrid atau peningkatan tahap pecutan akan dijelaskan pada masa depan untuk meningkatkan prestasi penjana tenaga yang direka untuk diaplikasi pada sistem pengawasan IoT.

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LIST OF ABBREVIATIONS

AC – Alternating Current

COPS – Compliant Orthoplanar Spring

CP – Central Position

CT – Multiple Outputs of the Piezoelectric Discs are Combined into a Single Output

CTD – The Single Output is Connected to a Rectifier

CTDC – The Rectified Output is Connected to a Capacitor

CTP – Combined the Outputs of the Piezoelectric Discs Directly

DC – Direct Current

DCTC – The Rectified Outputs of the Piezoelectric Discs are Interfaced to Their Own Capacitors Then Combined Together into a Single Output

DTC – The Outputs of the Piezoelectric Discs Are Connected to Their Own Rectifiers Then Combined into a Single Output

DTP – Combined the Rectified Outputs of the Piezoelectric Discs

EEH – Electrostatic Energy Harvester

EH – Energy Harvester

EMEH – Electromagnetic Energy Harvester

Emf – Electromotive Force

EP – End Position

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FUC – Frequency Up-Converting
G-force – Acceleration Level
I-DL – I-shaped Different Length
IEH – Impact Energy Harvester
IoT – Internet of Things
IPEH – Impact-based Piezoelectric Energy Harvester
I-SL – I-Shaped Same Length
KE – Kinetic Energy
LED – Light-Emitting Diode
MEMS – Micro-Electro-Mechanical Systems
MP – Middle Position
NIEH – Non-Impact Energy Harvester
PAP – Parallel with Alternating Polarities
P-DL – Plus-Shaped Different Length
PE – Potential Energy
PEH – Piezoelectric Energy Harvester
PMN–PT – Lead Magnesium Niobite-Lead Titanate
PSP – Parallel with Same Polarity
PV – Photovoltaic
PVDF – Polyvinylidene Difluoride
PVEH – Piezoelectric Vibration Energy Harvester
PZT – Lead Zirconate Titanate
Q-factor – Quality Factor
RF – Radio Frequency
SAP – Series with Alternating Polarities

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SDOF – Single-Degree-of-Freedom

SSP – Series with Same Polarity

TEG – Thermoelectric Generator

THUNDER – Thin Layer Unimorph Driver transducer

Tx/Rx – Transmitter/Receiver

U-PVEH – U-shaped Piezoelectric Vibration Energy Harvester

VIPEH – Vibration-Based Impact Mode Piezoelectric Energy Harvester

WSN – Wireless Sensor Network

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LIST OF SYMBOLS

$\varepsilon_k = \varepsilon$ - Strain

D_i - Dielectric displacement

E_{absip1} - Impact Energy Absorbed by Interfaced Plate at First Cycle Frequency

E_{absip2} - Impact Energy Absorbed by Interfaced Plate at Second Cycle Frequency

E_{el} - Energy Stored in Elastic Strain Energy of Piezoelectric Disc

E_{imp} - Impact Energy

E_j - Applied Electric Field

Q_{total} - Overall Q-factor

S_{km}^{E} - Elastic Compliance Matrix

c_1 - Damping Constant

d_{im}^{d} - Piezoelectric Coefficients

d_{jk}^{c} - Piezoelectric Constants

e_{ij}^{σ} - Dielectric Permittivity

f_a - Anti-Resonant Frequency

f_m - Minimum Impedance Frequency

f_n - Natural Frequency

f_{new} - New Natural Frequency

f_p - Maximum Impedance Frequency

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