



Faculty of Electronic Engineering and Computer Engineering

DESIGN AND DEVELOPMENT OF POWER CONDITIONING CIRCUIT FOR IMPACT-BASED PIEZOELECTRIC ENERGY HARVESTER

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**DESIGN AND DEVELOPMENT OF POWER CONDITIONING CIRCUIT FOR
IMPACT-BASED PIEZOELECTRIC ENERGY HARVESTER**

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

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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DECLARATION

I declare that this thesis entitled “Design and Development of Power Conditioning Circuit for Impact-based Piezoelectric Energy Harvester” 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 husband, mother, father and adorable son

ABSTRACT

Harvesting ambient energies from the surrounding can be realized by using piezoelectric mechanical transducer. This type of energy offering a prospect of powering low power electronic devices such as wireless sensor nodes which replacing the uses of batteries as the primary sources. Numerous studies have shown that the power densities of energy harvesting devices is around hundreds of microwatts. However, the power requirements for most electronic devices are in the range of micro to milliwatts. Furthermore, piezoelectric transducer generates high magnitude of output voltage; can reach up to hundreds Volts, but very low in term of current. This is the key challenge in developing an efficient power conditioning circuits that can offers an adequate output power for an optimum power transfer. In this project, a power conditioning circuits was developed for managing the power conversion process of a vibrational-based impact mode piezoelectric energy harvester. The proposed circuit should be able to enhance the generated output power from the piezoelectric by using a three conditioning units. It consists of an AC/DC rectifying circuits, step-down DC/DC buck converter and a storage capacitive bank. The power generator was implanted on the electrodynamic shaker with the acceleration level of 0.7 g at the resonant frequency of 42 Hz. Few power enhancement methods have been investigated in term of mechanical structural design and also on the proposed power conditioning circuitry itself. The generated output voltage from the harvester can be increased by 16.7% by using a proposed supporting base with a booster hole of 30 mm in diameter in order to increase the transducer's strain displacement further. The analysis was conducted part by part before fully integrating them in a whole unit. For the first stage, the efficiency of the circuit can be enhanced by reducing the value of the parasitic components of the rectifying components; forward voltage drops of the diode, V_f and the capacitativity. The constructions of the rectifying circuits also affect the power conversion of the harvester system. It is found that full-wave Schottky bridge rectifier is the most efficient conversion circuit for piezoelectric energy harvester compared to the full-wave bridge MOSFET rectifier and specialized voltage doubler rectifier with 35.6% differences of 3.77 mW output power. Next, the system gets integrated with a regulated conversion circuit that has been designed to regulate at 3.3V with a hysteretic voltage mode control feedback system. As a conclusion, the proposed circuits managed to increase the regulated output current by 51.93% with the power conversion efficiency of 70.43% and 330 μW output power. A practical evaluation was conducted by employing an RF transmitter as the application load. It has been isolated first by using a push button during the capacitive charging process. It requires about 7.3 minutes to fully charge a 13.2 mF storage capacitor and able to transmit the encoded signal to the receiver in 16.03 s. For further improvement, the designs can be modified by employing the usage of supercapacitor as energy storage to increase the extracted output power of the harvester.

ABSTRAK

Penuaian tenaga ambien daripada sekeliling boleh direalisasikan dengan menggunakan pemindaharuh mekanikal piezoelektrik. Tenaga jenis ini menawarkan prospek yang dapat menghidupkan peranti elektronik berkuasa rendah seperti nod-nod sensor tanpa wayar yang mampu menggantikan penggunaan bateri sebagai sumber kuasa utama. Banyak kajian menunjukkan bahawa ketumpatan kuasa peranti penuaian tenaga adalah sekitar ratusan mikrowatt. Bagaimanapun, kuasa yang diperlukan untuk kebanyakan peranti elektronik ini berada dalam lingkungan mikro hingga ke miliwatt. Walaupun pemindaharuh piezoelektrik mampu menghasilkan tenaga voltan yang tinggi hingga mencecah ratusan voltan, tetapi penghasilan tenaga arusnya sangat rendah. Ini adalah cabaran utama dalam membangunkan litar penyesuaian kuasa yang boleh dipercayai dan menawarkan kuasa keluaran yang mencukupi untuk pemindahan kuasa yang optimum. Dalam projek ini, litar penyesuaian kuasa telah dibangunkan untuk menguruskan proses penukaran kuasa getaran penjana kuasa piezoelektrik berdasarkan impak. Litar tersebut perlulah berjaya meningkatkan kuasa keluaran menggunakan tiga penyesuaian unit. Ia terdiri daripada litar penerusan AC/DC, penurun tenaga DC/DC dan sebuah bank simpanan kapasitif. Penjana kuasa tersebut telah diimplan pada penggongcang elektrodinamik pada tahap pemecutan 0.7 g di frekuensi resonan 42 Hz. Kaedah penambahbaikan kuasa telah dijalankan dari segi rekabentuk struktur mekanikal dan juga pada litar penyesuaian kuasa itu sendiri. Voltan keluaran yang dihasilkan dari penjana kuasa mampu ditingkatkan sebanyak 16.7% dengan menggunakan asas sokongan yang mempunyai lubang pendorong berdiameter 30 mm, berfungsi untuk meningkatkan anjakan terikan pemindaharuh. Analisis dijalankan bahagian demi bahagian sebelum diintegrasikan sepenuhnya dalam satu unit. Pada peringkat pertama, kecekapan litar ditingkatkan dengan mengurangkan nilai komponen berparasit; kehilangan voltan hadapan diod, V_f dan kapasitiviti. Teknik pembinaan litar penerusan juga mempengaruhi penukaran kuasa sistem penjana tenaga tersebut. Penilaian mendapati bahawa litar jambatan gelombang penuh Schottky adalah litar yang paling cekap bagi sebuah penjana tenaga piezoelektrik berbanding dengan litar jambatan gelombang penuh MOSFET dan litar penggandaan khusus penerus voltan dengan perbezaan sebanyak 35.6% dan 3.77 mW tenaga keluaran. Seterusnya, sistem disambungkan dengan litar penukaran yang berfungsi untuk mengawal selia arus voltan pada 3.3V dengan sistem maklum balas kawalan mod voltan heteretik. Konklusinya, litar tersebut berjaya meningkatkan arus keluaran terkawal sebanyak 51.93% dengan kecekapan penukaran kuasa sebanyak 70.43% untuk kuasa keluaran 330 μ W. Penilaian praktikal telah dilakukan dengan menggunakan pemancar RF sebagai beban aplikasi yang terdahulunya telah diasingkan daripada litar dengan menggunakan punat tekan semasa proses pengecasan kapasitif. Ia memerlukan 7.3 minit untuk cas penuh sebuah 13.2 mF storan kapasitor dan mampu menghantar kod isyarat kepada penerima dalam 16.03 s. Untuk penambahbaikan, rekabentuk litar boleh diubah suai dengan menggunakan sebuah pemuat lampau sebagai penyimpan tenaga untuk meningkatkan penyarian tenaga keluaran daripada penuai.

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TABLE OF CONTENTS

	PAGE
DECLARATION	
APPROVAL	
DEDICATION	
ABSTRACT	i
ABSTRAK	ii
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	vii
LIST OF FIGURES	x
LIST OF ABBREVIATIONS	xvii
LIST OF SYMBOLS	xviii
LIST OF PUBLICATIONS	xix
CHAPTER	
1. INTRODUCTION	1
1.1 Research background	1
1.2 Problem statement	4
1.3 Research objectives	6
1.4 Scope of the research	6
1.5 Thesis organization	9
2. LITERATURE REVIEW	11
2.1 Overview	11
2.2 Power requirements of electronic devices and systems	11
2.3 Ambient energy sources and energy harvesting	12
2.4 Piezoelectric energy harvesting	16
2.4.1 Discovery of piezoelectric	16
2.4.2 Piezoelectric materials	17
2.4.3 Piezoelectric effect	17
2.5 Piezoelectric equivalent circuit	18
2.6 Piezoelectric energy harvester	19
2.7 Power conditioning circuit	25
2.8 Power electronic converter	35
2.8.1 Passive AC/DC conversion	35
2.8.1.1 Hall-wave rectifier	36
2.8.1.2 Full-wave rectifier	39
2.8.1.3 Passive full-wave MOSFET rectifier	41
2.8.1.4 Voltage doubler rectifier	42
2.8.2 SMPS step-down buck DC/DC converter	44
2.8.2.1 Basic buck converter (open-loop)	45
2.8.2.2 SMPS feedback buck converter	50
2.8.2.3 Chipset	52
2.9 Energy storage unit	54

2.10	Summary	55
3.	METHODOLOGY	56
3.1	Overview	56
3.2	Introduction	56
3.3	Piezoelectric transducer	58
3.4	Weight-drop analysis	59
3.4.1	Impact force of the object acceleration due to gravity	59
3.4.2	Configuration of the harvester setting base	61
3.4.3	Experimental setup	64
3.4.3.1	Evaluating the effect of changing the piezoelectric strain displacement	64
3.4.3.2	Evaluating the performances of AC/DC conversion circuit on the piezoelectric	65
3.5	Vibrational-based impact mode analysis	68
3.5.1	The design of the stand generator structure prototype	68
3.5.2	Acceleration level	71
3.5.3	Resonant frequency	71
3.5.4	Experimental setup for vibrational-based impact mode analysis	72
3.6	Harvester circuitry	75
3.7	AC/DC conversion simulation	76
3.7.1	Simulation of full-wave rectifier	78
3.7.1.1	Discussion and analysis for conventional rectifiers	81
3.7.2	Simulation of specialized voltage doubler	84
3.7.2.1	Discussion and analysis	86
3.7.3	Summarization on the AC/DC converter simulation	88
3.8	Simulation of the designed circuit of step-down DC/DC converter	89
3.8.1	Basic buck converter	89
3.8.1.1	Calculation and simulation analysis	90
3.8.2	Feedback buck converter	95
3.8.3	Summarization on the DC/DC Simulation	100
3.9	Summary	102
4.	RESULT AND DISCUSSION	103
4.1	Overview	103
4.2	Weight-drop analysis	103
4.2.1	Output result from the piezoelectric mechanical transducer	104
4.2.2	Effect of changing the strain displacement of the piezoelectric	105
4.2.3	Harvester characterization for weight-drop analysis	106
4.2.4	Rectification	108
4.2.4.1	Evaluation on the diode's forward voltage drop, V_f	109
4.2.4.2	Evaluation on the different rectifier topologies for weight-drop analysis	113
4.3	Piezoelectric power generator analysis	116
4.3.1	Harvester characterization for vibrational-based impact mode analysis	117
4.3.1.1	Resonant frequency	117
4.3.1.2	Impedance matching	118

4.3.2	Passive AC/DC conversion	121
4.3.2.1	Evaluation on the diode's forward voltage drop, V_f	121
4.3.2.2	Evaluation on the different rectifier topologies	126
4.3.3	SMPS step-down buck DC/DC converter	129
4.3.3.1	Evaluation on the voltage and power performances	132
4.3.4	Storage system	136
4.3.5	Implementation of the develop system on RF communication module	138
4.4	Summary	141
5.	CONCLUSION AND FUTURE WORK	143
5.1	Overview	143
5.2	Conclusion	143
5.3	Recommendations for future research	145
REFERENCES		146

LIST OF TABLES

TABLE	TITLE	PAGE
1.1	List of the environmental wasted energy that exist naturally from daily activities	3
1.2	Parameter specification for the experimental setup	8
2.1	Power densities for typical energy sources (Valenzuela and Adrian, 2009)	13
2.2	Specific harvester convertor for typical ambient energy sources	13
2.3	Advantages and disadvantages of typical energy harvester system	14
2.4	A comparison on the advantage and disadvantage of the three main vibration conversion methods	15
2.5	Summary for piezoelectric energy harvester	25
2.6	Summary for power conditioning circuit	34
3.1	Specification of the piezoelectric transducer (Piezoelectric Sound Components, 2012)	58
3.2	Experimental parameters for weight-drop analysis	67
3.3	Specifications of the proposed designed structure of the power generator stand	68
3.4	The details of the equipment used	73
3.5	Experimental parameters for vibrational-based impact mode analysis	75
3.6	Diode's forward voltage drop	76

3.7	Simulation setup parameters for rectifying unit	77
3.8	Simulated results of the performances of different rectifier configurations	83
3.9	Simulated results of the performances of different type of voltage doubler	88
3.10	The setting parameters for the open-loop basic buck converter	90
3.11	Specification parameters for the basic buck converter	92
3.12	The output results for the open-loop basic buck converter	100
3.13	The output results for the closed-loop feedback buck converter	100
4.1	Relationship on the displacement of the fall with the resulted velocity and time	107
4.2	Diode's characteristic (Incorporated, 2014; Semiconductors, 2015)	110
4.3	Results of the performances of rectified over different Vf characteristic	112
4.4	Results of the performances of different rectifier topologies	116
4.5	Results of the impedance matching at the optimum peak	120
4.6	Harvester resonant frequency and max. output voltage of different rectifier	123
4.7	Results on performances of rectifier on different Vf characteristic at optimum	125
4.8	Results of the performances of different rectifier topologies	128
4.9	The time taken to reach 3.3 V for each circuits configuration	132
4.10	Results of the proposed power conditioning circuits on the resistive load	134
4.11	The efficiency of the proposed circuits	134
4.12	Comparison on the design performances benchmark	135

4.13	Charging time for storage capacitor to reach 3.3 V	138
4.14	Time taken for discharging the storage capacitor	141

LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	General block diagram of the proposed energy harvester system	7
2.1	Overview on the power requirements of electronic devices including energy harvesting power range (Ünlü, Wawrla and Diaz, 2018)	12
2.2	Piezoelectric equivalent schematic diagram (a) Norton and (b) Thevenin	18
2.3	Piezoelectric materials operating modulus: (a) d33 -mode (impact) and (b) d31 -mode (bending) (Kumar, Chaturvedi and Jejurikar, 2014; Xu et al., 2017)	19
2.4	3D model of the housing for piezoelectric bending mechanism (Abdal-Kadhim and Leong, 2016)	21
2.5	Power generator structure of vibration-based impact mode piezoelectric power generation (Basari et al., 2015)	24
2.6	Full-bridge rectifier circuits employed with inductance matching in between the harvester (Kim et al., 2015)	27
2.7	Electric power harvester using (a) Full-wave bridge rectifier (b) specialized Full-wave Voltage Doubler rectifier (Kashiwao et al., 2016)	28
2.8	Basic DC/DC converter (a) buck, (b) boost, (c) buck-boost	28
2.9	Simplified schematic of energy harvesting circuitry introduced by Ottman, Hofmann and Lesieutre (2002)	29

2.10	Schematic diagram of a DC/DC converter interfaced with (a) Full-wave bridge rectifier, (b) AC/DC Voltage doubler rectifier (Tabesh and Frechette, 2010)	30
2.11	Circuit diagram of a voltage doubler and bridgeless boost rectifier (Sarker, Mohamed and Mohamed, 2016)	30
2.12	Schematic diagram of the proposed circuit system by Amirnudin et al. (2017)	31
2.13	Bridgeless buck AC/DC converter with a control circuit (Kizu, Okano and Koizumi, 2016)	32
2.14	Architecture of a the proposed power conditioning circuit by Lee et al. (2017)	33
2.15	Half-wave rectifier circuit diagram	36
2.16	Half-wave rectifier outputs in ideal diode condition	37
2.17	Half-wave rectifier outputs in the real diode condition	37
2.18	Full-wave rectifier circuit diagram	39
2.19	Wave forms of the alternating input voltage (top) and the rectified output voltage (bottom) of the full-wave rectifier	40
2.20	Full-wave MOSFET rectifier circuit diagram	41
2.21	Specialized Voltage Doubler (a) Half-wave Voltage Doubler and (b) Full-wave Voltage Doubler	42
2.22	Wave forms of the alternating input voltage (top) and the rectified voltage doubler output voltage (bottom)	43
2.23	Basic step-down buck converter	45
2.24	Inductor current, i_L waveform of buck converter (a) CCM and (b) DCM (Hart, 2011)	46

2.25	Buck converter during (a) ON state, (b) OFF state	46
2.26	Buck converter waveforms in CCM mode (a) Inductor voltage, (b) Inductor current, (c) Capacitor current and (d) Switch current (Hart, 2011)	47
2.27	The proposed schematic of the SMPS voltage-mode hysteretic step down buck converter	51
2.28	Integrated circuit design from MAXIM for buck converter MAX638	53
3.1	Flowchart of overall project methodology	57
3.2	The 7BB-35-3 piezoelectric disc, Murata Manufacturing Co., Ltd	58
3.3	Application of conservation of energy to a free-falling object	59
3.4	The conservation of energy in free-fall phenomenon	61
3.5	Different characteristic of the landing surfaces stiffness (a) soft ground, (b) semi-hard ground and (c) rigid ground	61
3.6	The illustration of piezoelectric strain displacement (a) when piezoelectric is detained by a flat surface and (b) when piezoelectric has a hole beneath it	63
3.7	Cross-sectional view of the setting base (a) top and side view, (b) dimetric view	63
3.8	Setting base with ø30 mm booster hole	63
3.9	Experimental setup for weight-drop analysis (a) detained setting base, (b) booster setting base	65
3.10	Overall weight-drop experimental setup block diagram	66
3.11	Weigh-drop analysis experimental setup	66
3.12	Schematic drawing of the proposed structure (a) setting base, (b) vibrating beam and (c) spacer beam	69

3.13	The proposed prototype schematic diagram of piezoelectric power generator	70
3.14	The actual prototype of piezoelectric power generator	70
3.15	(a) Top view, (b) bottom view of the piezoelectric power generator prototype	70
3.16	Piezoelectric power generator (a) schematic diagram, (b) experimental setup for vibrational-based impact mode analysis	73
3.17	Overall vibrational impact-based piezoelectric energy harvester block diagram	74
3.18	Vibrational impact-based piezoelectric energy harvester experimental setup	74
3.19	Full-wave bridge Silicon rectifier schematic diagram	78
3.20	Simulated input V_{in} and output $V_{silicon}$ waveform of full-wave bridge silicon rectifier, $V_{in} = 20 \text{ V}$, $RL = 1 \text{ k}\Omega$ and $f = 24 \text{ Hz}$	78
3.21	Full-wave bridge Schottky rectifier schematic diagram	79
3.22	Simulated input V_{in} and output $V_{schottky}$ waveform of full-wave bridge Schottky rectifier, $V_{in} = 20 \text{ V}$, $RL = 1 \text{ k}\Omega$ and $f = 24 \text{ Hz}$	79
3.23	Full-wave bridge MOSFET rectifier schematic diagram	80
3.24	Simulated input V_{in} and output V_{MOSFET} waveform of full-wave bridge MOSFET rectifier, $V_{in} = 20 \text{ V}$, $RL = 1 \text{ k}\Omega$ and $f = 24 \text{ Hz}$	80
3.25	Comparison graph for the input and output waveform of the V_{in} , $V_{silicon}$, $V_{schottky}$ and V_{MOSFET}	81
3.26	Half-wave specialized voltage doubler schematic diagram	84
3.27	Simulated input V_{in} and output V_{hwout} waveform of half-wave specialized voltage doubler, $V_{in} = 20 \text{ V}$, $RL = 1 \text{ k}\Omega$ and $f = 24 \text{ Hz}$	85

3.28	Full-wave specialized voltage doubler schematic diagram	85
3.29	Simulated input V_{in} and output V_{fwout} waveform of full-wave specialized voltage doubler, $V_{in} = 20$ V, $RL = 1$ k Ω and $f = 24$ Hz	86
3.30	Comparison graph for the input and output waveform of the V_{in} , V_{hwout} and V_{fwout}	87
3.31	Open-loop basic buck converter schematic diagram	91
3.32	Simulated diode voltage V_{d1} and gate-source voltage V_{gs} waveform of open-loop basic buck converter	93
3.33	Average inductor current IL_1	94
3.34	Simulated diode voltage V_{d1} and inductor current IL_1 waveform of open-loop basic buck converter	94
3.35	Simulated output voltage V_{basic} and output current I_{load} waveform of open-loop basic buck converter	95
3.36	Closed-loop feedback buck converter schematic diagram	96
3.37	Simulated waveform of the gate voltage V_{gate} and the source gate V_{source} of the MOSFET	97
3.38	Simulated waveform of the gate voltage V_{gate} and the output current of the positive feedback capacitor IC_2	98
3.39	Simulated waveform of the buck output voltage $V_{feedback}$	99
3.40	Combination of the output voltage of the open-loop basic buck converter, V_{basic} and the closed-loop feedback buck converter, $V_{feedback}$	101
4.1	Generated AC output voltage of piezoelectric transducer without the disk's setting base	104

4.2	Generated AC output voltage of piezoelectric transducer with the disk's booster setting base	105
4.3	Comparison on the generated output voltage with different height and mass	108
4.4	Rectified output voltage of the conventional bridge rectifier	109
4.5	Instantaneous peak voltage of full-wave bridge rectifier with different type of diodes	111
4.6	Generated output power of the rectifier against the resistive load	112
4.7	Instantaneous output voltage of different rectifier topologies	114
4.8	The performances of power on different rectifier topologies	115
4.9	Comparison on piezoelectric output voltage at different excitation frequency at 0.7 g and 1.0 g	118
4.10	Resistive piezoelectric output voltage at 42 Hz	119
4.11	Resistive piezoelectric output power at 42 Hz	120
4.12	Fabricated PCB of (a) Half-wave voltage doubler, (b) Full-wave voltage doubler, (c) Full-wave bridge rectifier and (d) Full-wave MOSFET rectifier	122
4.13	Comparison on the performance of different types of rectifiers with different operating frequencies	123
4.14	Voltage performance of full-wave bridge rectifiers with different type of diodes at 42 Hz	124
4.15	Power performances of Full-wave bridge rectifiers with different types of diodes at 42 Hz	124
4.16	Voltage performances of different rectifier configuration over resistive load	126

4.17	Power performances of different rectifier configuration over resistive load	128
4.18	Fabricated PCB of (a) Feedback buck converter, (b) chipset MAX638 buck converter and (c) basic buck converter	129
4.19	Prototype of the power conditioning circuit system	130
4.20	Block diagram on the circuit configurations of evaluating the performances of the proposed circuits	130
4.21	Open-circuit voltage (Voc) performances of different buck architecture over time in seconds	131
4.22	Voltage performances of different buck architecture over resistive load	133
4.23	Power performances of different buck architecture over resistive load	133
4.24	From left: 10 μ F, 100 μ F, 1000 μ F and 13.2 mF storage capacitor	137
4.25	The charging time (a) 10 μ F, (b) 100 μ F , (c) 1000 μ F and (d) 13.2 mF	137
4.26	Applied system (a) RF transmitter and (b) RF receiver	139
4.27	Testing application device operating voltage	139
4.28	The discharging time (a) 10 μ F, (b) 100 μ F , (c) 1000 μ F and (d) 13.2 mF	140

LIST OF ABBREVIATIONS

AC	-	Alternating Current
BJT	-	Bipolar Junction Transistor
CCM	-	Continuous Conduction Mode
CMOS	-	Complementary Metal-oxide Semiconductor
DC	-	Direct Current
DCM	-	Discontinuous Conduction Mode
IC	-	Integrated Circuit
IoT	-	Internet of Things
IR	-	Infrared
LEDs	-	Light-emitting Diodes
MFC	-	Micro-fibre Composite
MOSFET	-	Metal Oxide Semiconductor Field-effect Transistor
PV	-	Photovoltaic
PWM	-	Pulse-width Modulation
PZT	-	Lead Zirconate Titanate
RF	-	Radio Frequency
SMPS	-	Switch-mode Power Supplies
ULP	-	Ultra Low Power
WSN	-	Wireless Sensor Network

LIST OF SYMBOLS

<i>g</i>	-	gravitational acceleration
<i>g</i>	-	gram
Hz	-	operational frequency
mm	-	millimeter
<i>v</i>	-	velocity
V	-	Voltage
A		Ampere
N	-	Newton
\vec{D}	-	electric displacement
d_{31}	-	piezoelectric charge coefficients,
$\vec{\sigma}$	-	mechanical stress
ε^σ	-	permittivity at constant stress
\vec{E}		electric field
\vec{S}		mechanical strain
s^E		mechanical compliance
V_f		forward voltage drop
D		duty cycle
<i>D</i>		diode

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- 1 Nawir, N. A. A., Basari, A. A. and Yan, N. X., 2019, Experimental studies on the performances of AC/DC rectifier circuit on impact-based piezoelectric energy harvester. *Journal of Engineering and Applied Sciences, ARPN Journals*, vol. 14, No. 9, pp. 1657-1668.
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