SEMARAK ILMU
PUBLISHING
202103268166(003316878-P)

Journal of Advanced Research in Applied
Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Review of Active Circuit and Passive Circuit Techniques to Improve the Performance of Highly Efficient Energy Harvesting Systems

Liew Hui Fang[1,*], Rosemizi Abd Rahim[2], Muhammad Izuan Fahmi[1], Junita Mohd Nordin[2], Aini Syuhada Md Zain[2]

[1] Electric Vehicle Energy Storage System (eVess) Group, Centre of Excellence for Renewable Energy (CERE), Faculty of Electrical Engineering & Technology, Universiti Malaysia Perlis, Sungai Chuchuh, 02100, Padang Besar, Perlis, Malaysia
[2] Faculty of Electronics Engineering & Technology, Universiti Malaysia Perlis, Pauh Putra Campus, 02600, Arau, Perlis, Malaysia

ARTICLE INFO

Article history:
Received 14 January 2023
Received in revised form 28 May 2023
Accepted 5 June 2023
Available online 21 June 2023

Keywords:
Energy harvesting; passive circuit; active circuit; power electronics; power scavenging; piezoelectric

ABSTRACT

In piezoelectric energy harvesting systems, energy harvesting circuits are the interface between piezoelectric devices and electrical loads. The conventional view of this interface is based on the concept of impedance matching. In fact, in the power supply circuit can also apply as an electrical boundary conditions, such as voltage and charge, to piezoelectric devices for each energy conversion cycle. The major drawback of piezoelectric power harvesting have low-power relationships in systems within (in the range of μW to mW), then system also have significantly reduced any potential losses in circuits that make up the EH system, whereas other condition into careful selection of circuits and components can enhanced the energy harvesting performance and electricity consumption. In the study of energy harvesting systems, it is an energy harvesting system approach that using active and passive electronic circuit to control voltage and or charge on piezoelectric devices as proposed and review to mechanical inputs for optimized energy conversion. Several factors in the practical limitation of active and passive energy consumption, due to device limitations and the power efficiency of electronic circuits, will be introduced and have played an important role into to enhance optimum and increase efficiency of energy harvesting system.

1. Introduction

The most fundamental and ideal solution is one that can effectively collect energy from the surrounding environment and convert it to electricity using piezoelectric materials as a means of gathering energy from the environment that can be efficiently collected, the need to use means of storing the energy generated is generally required. Consequently, energy-harvesting technology that can effectively harvest human motion energy is necessary. Without accumulating a significant quantity of energy, the energy harvesting system would be ineffective as a power source for the majority of electronic devices. However, energy harvesting systems typically operate at low voltage (below 1.0 V) and very low power (below 1.0 mW), which is lower than the power of the majority of

---

[*] *Corresponding author.*
E-mail address: hfliew@unimap.edu.my

https://doi.org/10.37934/araset.31.1.271290

electronic applications [1-3]. Therefore, a few proficient passive or active interface circuits are suggested and have been predicted as ac-dc harvesting circuit sources for the purpose of harvesting high power from piezoelectric energy harvesters.

The evolution of piezoelectric harvesting circuitry from passive multiplication to active multiplication techniques used in piezoelectric energy harvesting systems will be reviewed in chronological order. Current literature [2-4] has demonstrated an interest in enhancing the efficiency of circuitry by incorporating various harvesting circuit techniques. These techniques can be classified as passive [6-7] and active harvesting circuitry [8-10] rectification and multiplication techniques, respectively. The voltage multiplier circuit is an alternative technique for multiplying voltage supply [11-13]. By combining the stages of the Villard and Dickson circuits, it is possible to multiply the supply voltage. In 2012, Anil and Ravi [14] studied a variety of multiplier circuits, including the function of a multi-stage circuit utilising a charge-switching transistor. Studies comparing the efficacy of DC multiplier circuits and DC boost converters were conducted to establish their suitability [15-16].

In addition, energy harvesting systems have become increasingly popular in recent years due to their ability to convert ambient energy sources, such as solar, thermal, and mechanical energy, into usable electrical energy. However, these systems often suffer from low efficiency and limited power output, which can be a major challenge in practical applications. Secondly, to improve the performance of energy harvesting systems, circuit techniques are employed to optimize the energy conversion process, increase the efficiency of the system, and enhance the power output. There are two main types of circuit techniques: passive and active. Passive circuit techniques rely on passive components such as resistors, capacitors, and inductors to enhance the performance of the system. Active circuit techniques, on the other hand, use active components such as transistors, amplifiers, and voltage regulators to increase the efficiency of the system. Therefore, this project is important because it aims to review and compare the different circuit techniques used to improve the performance of energy harvesting systems. By doing so, this research studies can identify the most effective techniques for enhancing the efficiency and power output of these systems. Ultimately, this can lead to the development of more reliable and efficient energy harvesting systems, which can have a significant impact on various fields, such as renewable energy, wireless sensor networks, and Internet of Things (IoT) devices.

2. Review of Passive and Active AC-DC Rectification Techniques

In this study, the choice between a "passive" or "active" solution for correction is examined and tabulated. Several researchers in recent studies [17-19] focused on the implementation of self-powered circuits for power management. In some of them, the problem of reusing the energy collected in the reservoir to power the circuit has been solved [20]. Thus, the majority of extant energy harvesting circuits, such as conventional diode rectifier with voltage doubler, are primarily passive [21-23]. For full-wave conductors in practical energy harvesting systems, however, the possibility of a full-powered circuit is a crucial factor to consider [24-27]. The first is typically a diode bridge, whereas the second is a toggling power converter [28-29]. Piezoelectric micropower generators with modified power conversion circuits [30-32] include a half-wave synchronous rectifier with a voltage doubler, a full-wave synchronous rectifier, and a passive full-wave rectifier circuit.

Passive circuit techniques typically have a very low power harvesting capability deficiency [33-35]. Therefore, in order to increase the harvested energy, the active technique and its components, including MOSFET, thyristor, and transistor, have been recommended, proposed, and depending on the type, the energy harvesting interface circuit has been suggested [36-37]. Therefore, the designed interface circuits comprise of a piezoelectric element with an input vibration source, an AC-DC thyristor double rectifier circuit, and a DC-DC boost converter employing a thyristor with a storage device [38-41]. In comparison to conventional diode rectifier circuits, these passive and active rectifier circuits exhibit significant advancements. In general, synchronous rectification techniques fabricated using the complementary metal-oxide-semiconductor (CMOS) process are based on active rectifiers and have a high output power efficiency when coupled with a piezoelectric micro-power generator. It provides the utmost efficiency for active rectification circuits at the micropower level in active rectifiers. This active rectification technique entails greater complexity and the highest cost, but it is particularly attractive because it provides the opportunity to harvest energy and, indirectly, surmount the weakness of passive solutions.

3. Passive AC-DC Rectification

A passive circuit is a type of energy harvesting circuit. It is made up of capacitive and inductive parts, and the rapid power transfer is always from the device to the electrical circuit. Conventional electrical interfaces, like passive energy gathering, focus on power conditioning ideas, which often include AC-DC rectification and voltage regulation. Most popular and simple AC-DC rectification circuits are full-wave rectifiers and voltage multipliers [42–45]. The full bridge diode rectifier (FBDR) circuit topology [46–48] is made up of four passive p-n diodes. Voltage multipliers are another type of AC-DC design that can produce a higher output voltage than half-wave or full-wave AC-DC converters.

Figure 1 shows the harvesting circuits, which are made up of a full-wave rectifier with an output capacitor, an electrochemical battery, and a switch-mode DC-DC converter that handles the energy transfer into the battery [49–51]. To put the optimal power transfer theory into practise and get the most power out of the battery, adaptive control methods must be used continuously.

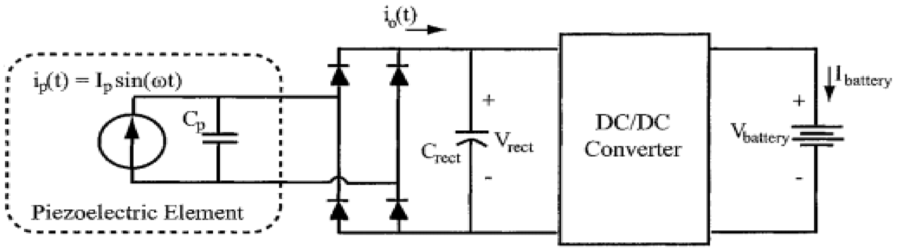

Fig. 1. AC-DC rectifier and load into piezoelectric model [52]

It has been found what the relationship is between the output voltage of the interface, the open-circuit voltage of the piezoelectric element, and the load. An FBDR circuit and a filter capacitor are what make up the interface circuit. As shown in [53–55], complete bridge diode rectifier and voltage double are the most popular interface circuits for piezoelectric energy harvesters. Researchers have also found many ways to change rectifier circuits, such as the switch-only rectifier [56–59] and the bias-flip rectifier [60–61]. To make a synchronous rectifier circuit, diode-connected transistors are changed with full bridge active diode circuits [62–64], active voltage double [65–66], or cross-coupled MOSFETs [67–69]. High reverse current usually hurts low-voltage Schottky diodes, but it doesn't kill low-voltage low-power energy gathering circuits. Also, MOSFET-based rectifying diodes have replaced Schottky diodes. They are easy to use and work with CMOS manufacturing methods, which makes them good for low power supplies. But the input voltages of these MOSFET-based full wave rectifiers are limited by the cut-off voltages of the transistors. Table 1 gives an overview of passive

AC-DC rectification methods, and Table 2 gives an overview of passive rectification techniques to compare their features and performance evaluations based on current research.

Table 1
Summary of passive AC-DC rectification technique for harvesting circuit

Authors and Year	Technique	Efficiency
In 2006, Le *et al.,* [70]	Full wave rectifier	66%
In 2008, Torah *et al.,* [71]	Five stage Dickson multiplier circuit using Schottky diode	65%
In 2013, Gleeson *et al.,* [72]		
In 2013, Roscoe *et al.,* [73]	Cockcroft Walton doubler circuit using Schottky diode	63%
In 2015, Ud Din *et al.,* [74]	Full wave rectifier	53.4%
In 2014, Kushino *et al.,* [75]	Voltage double circuit	19% higher than in output power compared to standard full bridge rectifier
In 2016, Mostafa *et al.,* [76]		57 mW
In 2013, Baby *et al.,* [77]	Full wave rectifier	38.08%

Table 2
Summary of passive rectification techniques in energy harvesting circuitry

Passive Rectification technique	Features and Performances Evaluation
Standard FBDR circuit	Simple circuit configuration, no external supply, higher loss from diodes, low efficiency, less compatible for low voltage application
Voltage Doubler circuit	Simple circuit configuration, less diode in circuit configuration, improve efficiency again FBDR, high DC voltage output, no external supply

3.1 Review of Transformer as Passive Circuits Technique

Transformers are considered as an alternative to buck-boost converters for boosting the AC voltage produced by piezoelectric transducers. In this investigation, the performance of piezoelectric transducer inputs connected to each medium frequency low voltage transformer will be evaluated. The signal voltage will be amplified by transformers connected to the input of each piezoelectric. The amplified signal voltages are then connected to a rectifier circuit, which converts the AC signal to a DC signal and regulates the signal's level in order to generate a higher voltage output.

According to Camarda *et al.,* [78], the energy harvesting capability of a piezoelectric transformer (PT) in 2014 is 74 mV for the input minimal activation voltage and 106.4 kHz for the measured oscillation frequency. Ahola *et al.,* [79] studied the energy harvesting efficacy of a switch mode power supply with a current transformer in 2008. Energy harvesting is possible with the current transformer, which can be manufactured with low-cost materials and is a viable option for powering electronic components affixed to an electric motor.

In 2015, Macrelli *et al.,* [80] proposed a circuit with a low-voltage step-up oscillator with a step-up transformer in battery-less micropower operating at low-voltages and examined the use of bond wire micromagnetic in energy harvesting applications. Figure 2 depicts the toroidal structure of a step-up transformer with a minimum starting input voltage of 100 mV. The primary coil has n_1 turns and the secondary coil has n_2 turns.

This section intends to review, analyze, categorize, and classify various step-up or step-down transformers based on their characteristics, specifications, and voltage-boosting techniques in order to demonstrate a clear configuration and construction of the working principle and framework of the development of step-up transformers used in energy harvesting systems. Finally, a comparison of the various transformer design methods and a summary of the comparative study of various voltage-boosting techniques are presented in Table 3.

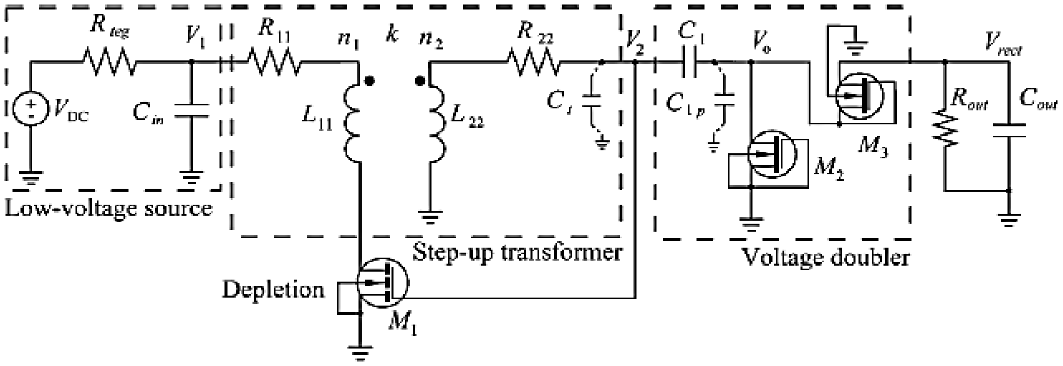

Fig. 2. Schematic of the designed low-voltage step-up oscillator with a step-up transformer and parasitic capacitances [80]

Table 3
Summary of the reviewed transformer design in energy harvesting system

Reference/Techniques	Input voltage and frequency	Output voltage
In 2014, Camarda *et al.,* [78]	73 mV	1.83 V
Start-up oscillator and n-channel JFETs with a piezoelectric transformer	104.6 kHz	
In 2008, Ahola *et al.,* [79]	1.50 V	3.0 V
Switch mode power supply ultilizing current transformer	50 Hz	
In 2015, Macrelli *et al.,* [80, 143]	100 mV, ≈	-
The bond wire micromagnetic low-voltage step-up oscillator is composed of the step-up transformer and a depletion n-type MOSFET, IC MOSFET in STMicroelectronics 0.32 µm technology	2.88 MHz	
In 2014, Teh *et al.,* [81]	21 mV	1 V
The oscillator is composed of the step-up transformer and a thin-film thermoelectric generators (TEG) in STMicroelectronics 0.13 µm technology	55 kHz	2 mW 74%
In 2015, Camarda *et al.,* [82]	69 mV	-
Piezoelectric transformer with thermoelectric generators (TEGs) and on JFET and MOSFET	106.814 kHz	
In 2016, Martinez *et al.,* [83]	12 mV	1 V
Armstrong oscillator with a piezoelectric transformer and a normally on MOSFET	55 kHz	

3.2 Active AC-DC Rectification

Active rectification techniques can also be defined as the replacement of standard diodes with active diodes. On the other hand, an active diode is shown that can be built to work like an ideal diode and has the potential to solve the forward-bias voltage drop problem. In the same way, the active produces a bidirectional switch-mode converter to control or change the voltage or charge on the piezoelectric device electrodes. Also, the piezoelectric device's voltage or current patterns are easier to control. At the same time, active-diode-based AC-DC rectifiers, also called synchronous rectifiers, were widely reported, including by [84] to improve efficiency by reducing conduction loss. The active diode method could have very low turn-on voltages and minimum reverse leakage. But active diodes have a major drawback in that the comparison needs an external power source. Recent energy-scavenging systems, which are also called "energy harvesting," need a constant source of energy and rely on their own mechanism for self-starting (boot-strapping) from a state of being completely depleted.

Despite the fact that the comparator requires external power sources, such as batteries the amount of power it uses is usually quite low and depends on how much current is going through the switch device. (i.e. MOSFET). Since the on-resistance of a switch MOSFET is usually a lot lower than the corresponding resistance of a passive diode, an active diode can provide more efficient rectification [85-86]. Recent studies [87-88] have suggested the synchronous switch harvesting on inductor (SSHI), which is made using CMOS technology. By adding a digital switch and an inductor to a piezoelectric element in series (S-SSHI) [89–93] or parallel (P-SSHI) [94–99], the SSHI method becomes one of the most important nonlinear electronic interfaces. Figure 3(a) [100-101] shows the case of a normal circuit, while Figure 3(b) [100-101] shows an SSHI parallel circuit. (b). Adding a switch in combination with the piezoelectric structure is needed. At extreme amounts of mass displacement, an electronic switch turns on. Figure 3(c) shows the series-SSHI interface, which is a different version of the SSHI interface. This series-SSHI circuit is made by connecting a switching device in series to the piezoelectric structure.

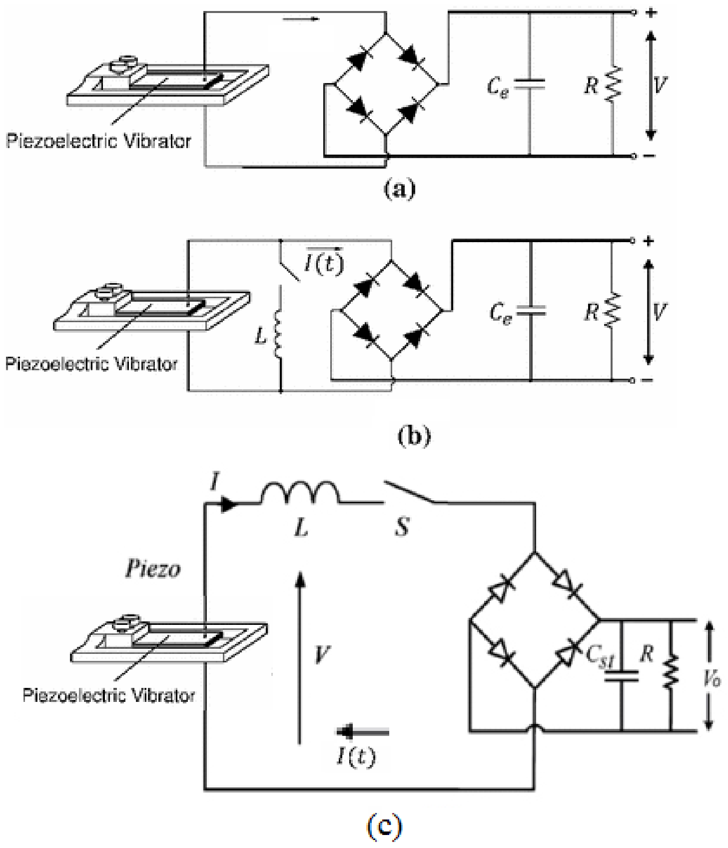

Fig. 3. (a) A standard harvesting circuit (b) A parallel-SSHI harvesting circuit (c) A series-SSHI harvesting circuit [102]

In similar studies [103-108], double synchronised switch harvesting (DSSH) was devised by adding a buck-boost converter to the parallel-SSHI concept. Figure 4 illustrates this general circuit demonstrating the DSSH technique's fundamentals.

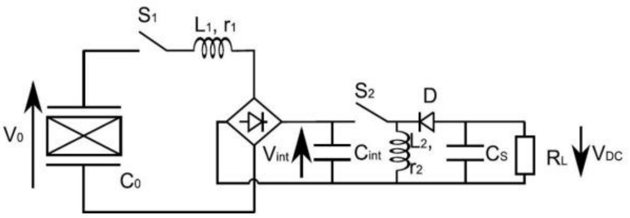

Fig. 4. Energy harvesting double synchronized switch harvesting (DSSH) [109]

The effects of using DC-DC converters with control algorithms as self-powered adaptive circuits to maximise the power output of piezoelectric elements have been studied in [110-112]. Using their adaptive circuit, Ottman et al. [113] discovered in 2002 that the rate of energy extraction was four times that of direct charging without converters. As shown in Figure 5, the DC-DC converter is situated between the rectifier's output and the battery for optimal voltage performance at the rectifier's output.

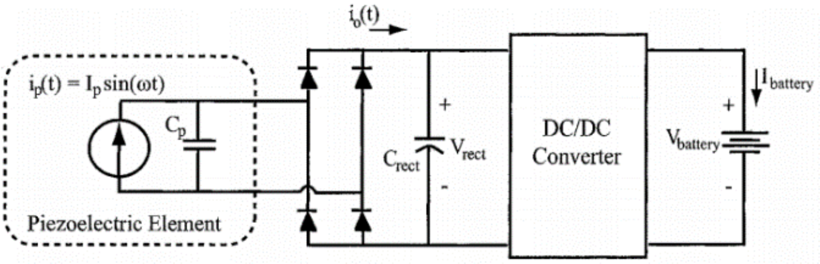

Fig. 5. Adaptive energy harvesting circuit [113]

The electrical equivalent circuit and fundamental block diagram of the piezoelectric power harvesting system are depicted in Figure 6(a). It includes piezoelectric generators, DC-DC converters, rectifiers, energy storage and charging devices [114]. To enhance the performance of the system, each block can be designed with distinct strategies. In 2009, Balpande *et al.,* [115] devised an effective power harvesting model utilising PZT as an alternative power source for active RFID tags. Using dynamic threshold MOS technology and supercapacitors as storage devices, this model employs the Villard 6-stage voltage multiplier circuit shown in Figure 6(b) along with supercapacitors as storage devices. This circuit is used to multiply and rectify the input voltage using a diode and capacitor, as well as to model a voltage multiplier circuit with DTMOS. The input voltage of 200 mV$_{p-p}$ was utilised and the output of 1.2 V$_{dc}$ was detected.

In general, active AC-DC rectification utilised techniques such as synchronous rectifier circuits, synchronous rectifier switching circuits, self-powered switching circuits, and self-powered adaptive circuits. In an active rectifier circuit, a transistor is used in lieu of a passive diode to reduce the diode's conduction loss. Since the majority of transistors exhibit low resistance, the use of active rectifier circuits has been strongly recommended. Table 4 is a summary of the active rectifier circuit used in piezoelectric harvesting circuitry, with a focus on the operation principle or method and the efficacy of these circuits.

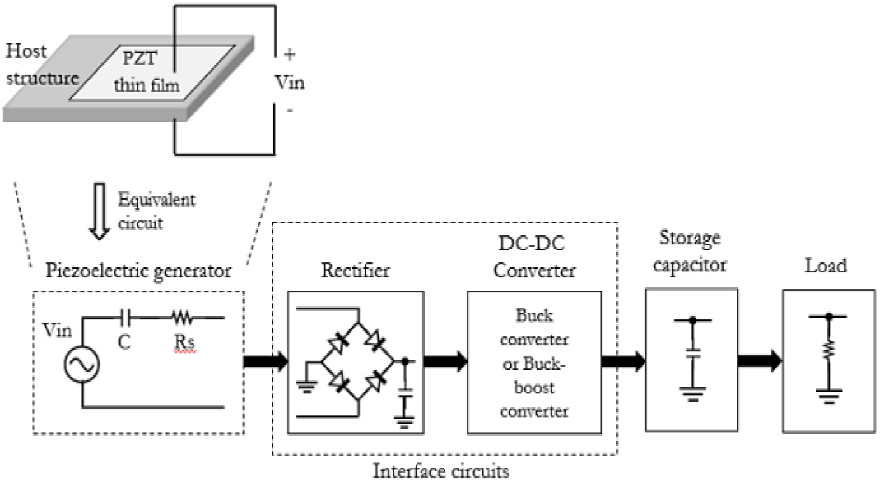

Fig. 6. (a) Basic block diagram of piezoelectric energy harvesting [115]

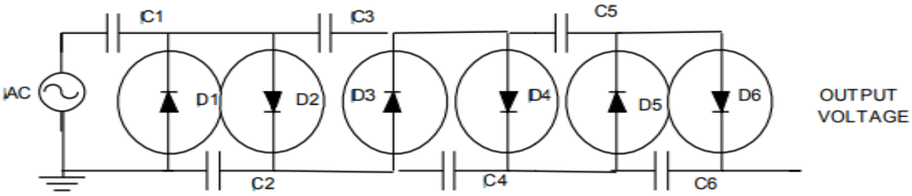

Fig. 6. (b) Villard six-stage voltage multiplier circuit [115]

Table 4
Summary of several active AC-DC rectification technique for harvesting circuit

Synchronous rectifier circuit	
Author and Techniques	Efficiency
In Ulusan, [55] -Active voltage doubler, -MOSFET based switching, -90 nm CMOS technology	67%
In Le *et al.,* [70] recommended -Active full bridge rectifier, -MOSFET based switching, -0.35 µm CMOS technology	86%
In Ud Din *et al.,* [74], -Active full bridge rectifier, -0.18 µm CMOS rectifier using symmetric flipping technique	80%
In Baby *et al.,* [77], -Active full bridge rectifier with switch control, -Four MOSFET based rectifying diodes	93.3%
In Han *et al.,* [116] proposed, -Active full bridge rectifier with comparator, -Four MOSFET based rectifying diodes, -Four stage charge pump	A maximum output power of 18.8 µW can be extracted from a single piezoelectric MPG, with 92% efficiency in the rectifier stage
In Dallago *et al.,* [117] suggested , -Active voltage double with AC-DC converter, -Two MOSFET based rectifying diodes, -switches are driven by two comparators, -diffused in the BCD6s technology with 0.35µm	91%
In Dallago et al. [118] introduced, -Active voltage doubler, -0.35 µm CMOS technology, -MOSFET based switching	94%
In Cheng *et al.,* [119] presented , -Active voltage doubler, -MOSFET based switching	>80%

Yang *et al.,* [120] presented, -Cross-coupled active full bridge rectifier, -NMOS based switching, -0.18 µm CMOS technology	91%
In Sun *et al.,* [121], -Active full bridge rectifier, -MOSFET based switching -0.18 µm CMOS technology	90%
In Rao *et al.,* [122], -Active voltage doubler, -0.5 µm CMOS technology	87%
Synchronous rectifier switching circuit	
Lallart *et al.,* [109], -Double synchronized switch harvesting (DSSH), -Externally battery powered	-Power extraction efficiency 500% higher than of a standard FBDR circuit
Guyomar *et al.,* [123], -Parallel –SSHI, -Two comparator use to detect polarity change of piezoelectric devices, -Externally powered	-Power extraction efficiency 5.8 times higher than of a standard FBDR circuit
Becker *et al.,* [124], -Synchronized switching interface circuit, -Direct energy injection technique without addition energy storage element	-There results show that an efficiency benefit by a factor of 3, compared to standard devices can be achieved by the presented device [76]
Do *et al.,* [125], -Parallel –SSHI integrated with active full bridge rectifier, -PMOS and NMOS base rectifying diode, -Externally battery powered	-92.6% power efficiency -Power extraction 4.5 times higher than of a standard FBDR circuit
Singh *et al.,* [126], -Parallel –SSHI, -Externally battery powered	-Power extraction efficiency 4.72 over the standard FBDR circuit
Wu *et al.,* and Hsieh *et al.,*[127-128], -Parallel –SSHI retifier -0.25 µm CMOS technology, -SSHI switching control, -Externally battery powered	-The circuit extracts 336% more power compared with the full bridge rectifier -Output power can reach up to 43.42 µW at 120 Hz
Chen *et al.,* [129], -Series-SSHI-phi interface circuit, -With a 0.25 µm CMOS HV process	60%
Self-powered switching circuit	
Shen *et al.,* [130], -Enhanced SSHI, -Modification of DSSHI technique	-Power extraction efficiency by 300% higher than of a standard rectifier -71% of power efficiency
Chen *et al.,* [131] -Velocity control SSHI (VSSHI) -MOSFET switch	-Power extraction efficiency by 200% higher than of a standard FBDR circuit
Kong *et al.,* [132] -Discontinuous conduction mode (DCM) flyback converter	72%
Chen *et al.,* [133] -SSDI technique with velocity sensing	86%
Darmayuda *et al.,* [134] -Buck-boost converter	54%
Self-Powered Adaptive Circuit	
Ottman *et al.,* [113] -Adaptive control technique full bridge and dc–dc converter	-Adaptive dc–dc converter increases power transfer by over 400% as compared to without the dc–dc converter
Tabesh *et al.,* [135] -Adaptive energy-harvesting circuit with open-loop voltage-doubler rectifier, a step-down switching converter, and an analog controller	-Power extraction efficiency 60% -Output power 0.5 mW with 250 Hz
Alvarez-Carulla *et al.,* [136]	-Max power transfer 140 µW

Adaptive control technique Analog Control Unit with full bridge and a capacitor	
Chew *et al.,* [137] -Adaptive circuit include full bridge (FB) rectifier, buck converter, analogue MPPT controller, and energy aware interface (EAI) -batteryless	-Power extraction efficiency 66%
Chew *et al.,* [138] -Adaptive circuit include full bridge (FB) rectifier, buck converter, analogue MPPT controller, and energy aware interface (EAI) -Full analogue Power management circuit (PMM) with adaptive circuit	-Energy transfer efficiency at 70 to 80%
Li *et al.,* [139] -Closed loop control method based on the voltage doubler interface circuit -DC-DC input voltage as the feed-forward signal to adjust the switching duration -Adaptive Self-powered stand-alone system	-Harvested power was only 0.78 mW with the efficiency of 16% by using this control strategy.

Table 5 provides an overview of active rectification techniques for comparing feature and performance evaluation based on current research analyses.

Table 5
Summary of active rectification techniques in energy harvesting circuitry

Active Rectification technique	Features and Performances Evaluation
Synchronous rectifier circuit	Replace diode with MOSFET transistor, power conversion efficiency > 80%, requires external supply, compatible for low voltage application
Synchronous rectifier switching circuit	Improve power extraction efficiency, use peak detector, use controlled-switch and inductor, high power extraction efficiency >90%, requires external supply, complex circuit configuration, compatible for low voltage configuration

4. Summary of Literature Review on Passive and Active Rectification Energy Harvesting

The passive diode-rectifier circuit is therefore the simplest technology with the lowest efficiency [135-139]. In a semi-active circuit, the output voltage can be processed nonlinearly by a switched control (MOS field effect transistor and inductor) circuit to increase its magnitude and change its phase based on the construction synchronised switching damping principle, but at the expense of complexity and high-energy consumption. In the active circuit [140-142], the system is not dependent on an external power supply or external comparators; however, an appropriate set of electrical boundary conditions applied to the piezoelectric element can drive the extracted energy to the limits of the piezoelectric harvester [143,144]. The characteristics of vibration-based energy harvesting system interfaces, efficiencies, and features are compared in Table 6.

Table 6
Comparing the features of different piezoelectric energy harvesters

Method	Features and performance evaluation
Synchronized rectifier (full bridge or voltage double) [70]	Improve efficiency (37% higher), but the efficiency is still low since the circuit is not adaptive; stand-alone operation; single supply voltage, sensorless; implemented and demonstrates as a CMOS micro-chip
Optimized energy harvester for a full bridge rectifier using step-down converter [101]	Non-adaptive; stand-alone (for P_{in}> 10 mW and V_{oc}> 30 V);no external sensor; multi-supply voltage; efficiency(<20% for P_{in}<50 mW, 60% for P_{in}>10 mW); fairly compatible for micro-scale integration
Adaptive energy harvester for a full bridge rectifier using step-down converter [113, 140]	External sensor (current); adaptive; non-stand alone; need multi supply voltage (for sensing circuit); efficiency and the total circuits power losses have not been reported; fairly compatible for micro-scale integration
Simple passive rectifier (standard full bridge rectifier) [135]	Low efficiency, non-adaptive; stand-alone operation; sensorless; no external supply required; highly compatible for micro-scale integration
Synchronized switch harvesting [123, 141]	External sensor (to determine switching time with respect to displacement); non-adaptive; stand-alone; possibly needs multi supply voltage (for sensing circuit, details of circuitry has not been provided); efficiency 70% (peak power 300 mW; circuit consumes 5% of extracted power (Max power loss 15 mW)); fairly compatible for micro-scale integration
Adaptive energy harvesting using voltage doubler rectifier [135]	Stand-alone (P_{in}>0.5 mW and V_{oc}> 8 V); adaptive; non-external sensor; single supply voltage; efficiency 60% for P_{in}>0.5 mW (independent of load and piezoelectric parameters); fairly compatible for micro-scale integration
Buck-boost sensorless energy harvester [142-143]	Sensorless; non-adaptive; stand-alone; single supply voltage; efficiency; above 84% for the power range 0.2-1.5 mW (for a given load and piezoelectric parameters); fairly compatible for micro-scale integration [142]

5. Current Challenges and Future Direction of Energy Harvesting

There are several current challenges related to improving the performance of energy harvesting systems using active and passive circuit techniques, as well as several potential future directions for research and development in this field. First, one of the major challenges facing energy harvesting systems is limited power output, which can limit their practical applications. Increasing the power output of energy harvesting systems is a major research focus. Secondly, energy harvesting systems need to be adaptable to various energy sources and environmental conditions. Developing systems that can adapt to different energy sources and environmental conditions is another research direction. Despite significant advances in circuit techniques, energy harvesting systems still suffer from low efficiency. Therefore, review of several active and passive circuit is producing ideas for researchers. improving the efficiency of these systems. Lastly, the cost and size of develop energy harvesting systems can be a limiting factor in practical applications. Developing cost-effective and compact energy harvesting systems is a major challenge.

The potential future direction of energy harvesting is implementation of multiple energy sources for harvesting energy is bring a lot of advantages compare to single source energy harvesting which is a promising direction for the development of energy harvesting systems. This approach can increase the power output and efficiency of the systems. Hybrid techniques which involved combining active and passive circuit techniques to enhance the performance of energy harvesting systems is another research direction. Thus, by developing effective energy storage systems is critical for energy harvesting systems. Research on new energy storage technologies is a promising direction for future development and design of wireless power transfer is aims promising approach for powering low-power devices using energy harvesting. Developing efficient wireless power transfer systems is a promising future direction for this field as well. In summary, the current challenges and future directions related to improving the performance of energy harvesting systems using active and passive circuit techniques include addressing power output, efficiency, adaptability, cost, and size limitations, as well as exploring multi-source harvesting, hybrid techniques, energy storage, and wireless power transfer.

6. Conclusions

In conclusion regarding the review of the current piezoelectric energy harvesting technique, the majority of researchers are concentrating on active devices, resulting in a dearth of research into passive devices. The piezoelectric power harvesters have limited power, so the efficacy of AC-DC converter devices must be enhanced by optimising the power harvesting at all levels. The maximal power transfer in either mechanical or electrical energy is dependent on the physical properties of the piezoelectric material and other operating conditions. Passive techniques that incorporate filtering levels consisting of inductors and/or capacitors to reduce the amplitude of low-frequency signals are intriguing due to their simple design structure, small size, and increased dependability. On the other hand, the active techniques proposed to date are partially adequate, but the design complexity and cost of additional circuits are frequently insufficient for low-power applications. In current research, the use of self-powered circuits has successfully overcome the disadvantages of external power source problems, but the circuit configuration is complex and entails high overheads, such as controller circuits and switching devices, without significant improvements in circuit efficiency.

The standard FBDR circuit has a flaw in that the load resistor and the supply source do not share a point that can be earthed. When a minor voltage needs to be rectified, the circuit is unsuitable. Similarly, the recommendation of a transformer to supplant an active rectifier circuit necessitates an external power supply in order for the active diodes to function. Even the low resistance characteristics of the active diode contribute to the circuit's decreased conduction losses. This research lacuna convinces the author to conduct a thorough investigation of passive devices. This method has the benefit of requiring no additional energy sources for energy conversion. It is to ensure an original study has been conducted after all possible comparable studies have been examined. Indeed, it is evident from prior research that the use of piezoelectric materials for energy harvesting systems in the process of energy extraction from sources of ambient vibration is natural. Piezoelectric can convert mechanical force into an electric charge without the need for additional power.

Acknowledgement

The author would like to acknowledge the support from the Fundamental Research Grant Scheme (FRGS) under a grant number of FRGS/1/2020/TK0/UNIMAP/02/57 from the Ministry of Higher Education Malaysia.

References

[1] Eguchi, Kei, Akira Shibata, Kyoka Kuwahara, and Takaaki Ishibashi. "Design of an inductor-less step-up ac/dc converter for 0.3 V@ 1 MHz vibration energy harvesting." *Energy Reports* 6 (2020): 159-165. https://doi.org/10.1016/j.egyr.2019.11.057

[2] Singh, Geetanjali, and Sudip Kundu. "An efficient DC-DC boost converter for thermoelectric energy harvesting." *AEU-International Journal of Electronics and Communications* 118 (2020): 153132. https://doi.org/10.1016/j.aeue.2020.153132

[3] Li, Teng, Yunxin Zhang, and Xinlai Geng. "An Adaptive Self-powered Piezoelectric Energy Harvesting Circuit and Its Application on Bridge Condition Monitoring." (2017). https://doi:10.20944/preprints201701.0062.v1

[4] Tapia-Hernandez, Alejandro, Mario Ponce-Silva, and Victor H. Olivares-Peregrino. "Techniques used to synchronize multi-phase AC-DC converters for energy harvesting applications, a review." *Renewable and Sustainable Energy Reviews* 69 (2017): 123-128. https://doi.org/10.1016/j.rser.2016.11.148

[5] Sarker, Mahidur R., Sabariah Julai, Mohd Faizul Mohd Sabri, Suhana Mohd Said, Md Mainul Islam, and Muhammad Tahir. "Review of piezoelectric energy harvesting system and application of optimization techniques to enhance the performance of the harvesting system." *Sensors and Actuators A: Physical* 300 (2019): 111634. https://doi.org/10.1016/j.sna.2019.111634

[6] Asthana, Prateek, and Gargi Khanna. "Power amplification interface circuit for broadband piezoelectric energy harvester." *Microelectronics Journal* 98 (2020): 104734. https://doi.org/10.1016/j.mejo.2020.104734

[7] Lan, Chunbo, Lihua Tang, and Ryan L. Harne. "Comparative methods to assess harmonic response of nonlinear piezoelectric energy harvesters interfaced with AC and DC circuits." *Journal of Sound and Vibration* 421 (2018): 61-78. https://doi.org/10.1016/j.jsv.2017.11.019

[8] Balato, Marco, Luigi Costanzo, Alessandro Lo Schiavo, and Massimo Vitelli. "Optimization of both perturb & observe and open circuit voltage MPPT techniques for resonant piezoelectric vibration harvesters feeding bridge rectifiers." *Sensors and Actuators A: Physical* 278 (2018): 85-97. https://doi.org/10.1016/j.sna.2018.05.017

[9] Mohamad, Tengku Norliza Tengku, Jahariah Sampe, and Dilla Duryha Berhanuddin. "Architecture of micro energy harvesting using hybrid input of RF, thermal and vibration for semi-active RFID tag." *Engineering Journal* 21, no. 2 (2017): 183-197. https://doi.org/10.4186/ej.2017.21.2.183

[10] McCullagh, James. "An active diode full-wave charge pump for low acceleration infrastructure-based non-periodic vibration energy harvesting." *IEEE Transactions on Circuits and Systems I: Regular Papers* 65, no. 5 (2017): 1758-1770. https://doi.org/10.1109/TCSI.2017.2764878

[11] Abidin, Nik Ahmad Kamil Zainal, Norkharziana Mohd Nayan, Muhammad Mokhzaini Azizan, and Azuwa Ali. "Analysis of voltage multiplier circuit simulation for rain energy harvesting using circular piezoelectric." *Mechanical Systems and Signal Processing* 101 (2018): 211-218. https://doi.org/10.1016/j.ymssp.2017.08.019

[12] Chouhan, Shailesh Singh, Marko Nurmi, and Kari Halonen. "Efficiency enhanced voltage multiplier circuit for RF energy harvesting." *Microelectronics journal* 48 (2016): 95-102. https://doi.org/10.1016/j.mejo.2015.11.012

[13] Machado, Marcio Bender, Franciele Nornberg, Mohamad Sawan, Carlos Galup-Montoro, and Marcio Cherem Schneider. "Analysis and design of the Dickson charge pump for sub-50 mV energy harvesting." *Microelectronics Journal* 90 (2019): 253-259. https://doi.org/10.1016/j.mejo.2019.06.009

[14] Anil, Aamna, and Ravi Kumar Sharma. "A high efficiency charge pump for low voltage devices." *International Journal of VLSI Design & Communication Systems* 3, no. 3 (2012): 43. https://doi.org/10.5121/vlsic.2012.3305

[15] Kordetoodeshki, Elham, and Alireza Hassanzadeh. "An ultra-low power, low voltage DC-DC converter circuit for energy harvesting applications." *AEU-International Journal of Electronics and Communications* 98 (2019): 8-18. https://doi.org/10.1016/j.aeue.2018.10.029

[16] Shirazi, N. Cheraghi, A. Jannesari, and P. Torkzadeh. "Self-start-up fully integrated DC-DC step-up converter using body biasing technique for energy harvesting applications." *AEU-International Journal of Electronics and Communications* 95 (2018): 24-35. https://doi.org/10.1016/j.aeue.2018.07.033

[17] Zhao, Liya, and Yaowen Yang. "Comparison of four electrical interfacing circuits in wind energy harvesting." *Sensors and Actuators A: Physical* 261 (2017): 117-129.https://doi.org/10.1016/j.sna.2017.04.035

[18] Chew, Zheng Jun, and Meiling Zhu. "Low power adaptive power management with energy aware interface for wireless sensor nodes powered using piezoelectric energy harvesting." In *2015 IEEE SENSORS*, pp. 1-4. IEEE, 2015. https://doi.org/10.1109/ICSENS.2015.7370663

[19] Kosunalp, Selahattin. "An energy prediction algorithm for wind-powered wireless sensor networks with energy harvesting." *Energy* 139 (2017): 1275-1280. https://doi.org/10.1016/j.energy.2017.05.175

[20] Yoon, Eun-Jung, and Chong-Gun Yu. "Power management circuits for self-powered systems based on micro-scale solar energy harvesting." *International Journal of Electronics* 103, no. 3 (2016): 516-529.https://doi.org/10.1080/00207217.2015.1036802

[22] Kuang, Yang, Tingwen Ruan, Zheng Jun Chew, and Meiling Zhu. "Energy harvesting during human walking to power a wireless sensor node." *Sensors and Actuators A: Physical* 254 (2017): 69-77.https://doi.org/10.1016/j.sna.2016.11.035

[23] Khan, Muhammad Bilawal, Dong Hyun Kim, Jae Hyun Han, Hassan Saif, Hyeonji Lee, Yongmin Lee, Minsun Kim et al. "Performance improvement of flexible piezoelectric energy harvester for irregular human motion with energy extraction enhancement circuit." *Nano Energy* 58 (2019): 211-219. https://doi.org/10.1016/j.nanoen.2019.01.049

[24] Wang, Zhiyu, Weike Zhang, Xuelian Li, and Lizhen Gao. "Recent progress in flexible energy storage materials for lithium-ion batteries and electrochemical capacitors: A review." *Journal of Materials Research* 31, no. 12 (2016): 1648-1664. https://doi.org/10.1557/jmr.2016.195

[25] Lallart, Mickaël. "Nonlinear technique and self-powered circuit for efficient piezoelectric energy harvesting under unloaded cases." *Energy Conversion and Management* 133 (2017): 444-457.https://doi.org/10.1016/j.enconman.2016.10.065

[26] Satpathy, Priya Ranjan, and Renu Sharma. "RETRACTED: Power recovery and equalization in partially shaded photovoltaic strings by an efficient switched capacitor converter." (2020). https://doi.org/10.1016/j.enconman.2019.112258

[27] Qiu, Chunkai, Fan Wu, Chengkuo Lee, and Mehmet Rasit Yuce. "Self-powered control interface based on Gray code with hybrid triboelectric and photovoltaics energy harvesting for IoT smart home and access control applications." *Nano Energy* 70 (2020): 104456. https://doi.org/10.1016/j.nanoen.2020.104456

[28] Xu, Cuidong, and Ka Wai Eric Cheng. "A switched capacitor based AC/DC resonant converter for high frequency AC power generation." *Energies* 8, no. 10 (2015): 10842-10860. https://doi.org/10.3390/en81010842

[29] Kwon, Seong-Cheol, Junjiro Onoda, and Hyun-Ung Oh. "Performance evaluation of a novel piezoelectric-based high-frequency surge-inducing synchronized switching strategy for micro-scale energy harvesting." *Mechanical Systems and Signal Processing* 117 (2019): 361-382. https://doi.org/10.1016/j.ymssp.2018.08.030

[30] Kwon, Seong-Cheol, Junjiro Onoda, and Hyun-Ung Oh. "Improvement of micro-jitter energy harvesting efficiency of piezoelectric-based surge-inducing optimal switching strategy." *Sensors and Actuators A: Physical* 281 (2018): 55-66. https://doi.org/10.1016/j.sna.2018.08.043

[31] Du, Sijun, Yu Jia, Chun Zhao, Shao-Tuan Chen, and Ashwin A. Seshia. "Real-world evaluation of a self-startup SSHI rectifier for piezoelectric vibration energy harvesting." *Sensors and Actuators A: physical* 264 (2017): 180-187. https://doi.org/10.1016/j.sna.2017.07.050

[32] Wu, Liao, Chenrui Guo, Miaomiao Guo, and Ying Long. "A triple-bias parallel SSHI rectifier for piezoelectric energy harvesting." *IEICE Electronics Express* 16, no. 4 (2019): 20190025-20190025. https://doi.org/10.1587/elex.16.20190025

[33] De Giuseppe, Gianluigi, Alfonso Centuori, and Angelo Malvasi. "An improved PZT cantilever SPICE model for practical energy harvesting circuits simulations and measurements." *Measurement* 98 (2017): 374-383.https://doi.org/10.1016/j.measurement.2016.09.038

[34] Wang, Weiyin, Hei Wong, and Yan Han. "A high-efficiency full-wave CMOS rectifying charge pump for RF energy harvesting applications." *Microelectronics Journal* 46, no. 12 (2015): 1447-1452. https://doi.org/10.1016/j.mejo.2015.08.001

[35] Ganesh, R. Jai, S. Kodeeswaran, M. Kavitha, and T. Ramkumar. "Performance analysis of piezoelectric energy harvesting system employing bridgeless power factor correction boost rectifier." *Materials Today: Proceedings* 45 (2021): 486-494. https://doi.org/10.1016/j.matpr.2020.02.085

[36] Chen, Joy Iong-Zong. "The Implementation of a High Efficiency Full-Bridge Converter." *Engineering* 3, no. 4 (2011): 331. https://doi.org/10.4236/eng.2011.34038

[37] Dhayabarasivam, S. S., and K. Jayanthi. "Energy Harvesting Circuit Utilizing MOSFET Based Bridge Rectifier." In *2018 IEEE International Conference on System, Computation, Automation and Networking (ICSCA)*, pp. 1-5. IEEE, 2018. https://doi.org/10.1109/ICSCAN.2018.8541201

[38] Jabbar, Hamid, Hyun Jun Jung, Nan Chen, Dae Heung Cho, and Tae Hyun Sung. "Piezoelectric energy harvester impedance matching using a piezoelectric transformer." *Sensors and Actuators A: Physical* 264 (2017): 141-150. https://doi.org/10.1016/j.sna.2017.07.036

[39] Camarda, Antonio, Aldo Romani, Enrico Macrelli, and Marco Tartagni. "A 32 mV/69 mV input voltage booster based on a piezoelectric transformer for energy harvesting applications." *Sensors and Actuators A: Physical* 232 (2015): 341-352. https://doi.org/10.1016/j.sna.2015.05.014

[40] Wang, Junlei, Linfeng Geng, Lin Ding, Hongjun Zhu, and Daniil Yurchenko. "The state-of-the-art review on energy harvesting from flow-induced vibrations." *Applied Energy* 267 (2020): 114902. https://doi.org/10.1016/j.apenergy.2020.114902

[41] Wahbah, Maisam, Mohammad Alhawari, Baker Mohammad, Hani Saleh, and Mohammed Ismail. "An AC–DC converter for human body-based vibration energy harvesting." *Microelectronics journal* 55 (2016): 1-7. https://doi.org/10.1016/j.mejo.2016.06.006

[42] Hara, Yushin, Kensuke Saito, and Kanjuro Makihara. "Compact, digital and self-powered piezoelectric vibration energy harvester with generation control using voltage measurement circuit." *Sensors and Actuators A: Physical* 299 (2019): 111609. https://doi.org/10.1016/j.sna.2019.111609

[43] Sah, Dipak K., and Tarachand Amgoth. "Renewable energy harvesting schemes in wireless sensor networks: A survey." *Information Fusion* 63 (2020): 223-247.https://doi.org/10.1016/j.inffus.2020.07.005

[44] Liu, Yiran, and Yuji Suzuki. "Self-powered SSHI for electret energy harvester." In *Journal of Physics: Conference Series*, vol. 1052, no. 1, p. 012022. IOP Publishing, 2018. https://doi.org/10.1088/1742-6596/1052/1/012022

[45] Álvarez-Carulla, Albert, Jordi Colomer-Farrarons, Jaime López-Sánchez, and Pere Miribel-Català. "Piezoelectric Harvester-based structural health monitoring that uses a self-powered adaptive circuit." In *2015 IEEE Metrology for Aerospace (MetroAeroSpace)*, pp. 531-535. IEEE, 2015. https://doi.org/10.1109/MetroAeroSpace.2015.7180713

[46] Chaour, Issam, Ahmed Fakhfakh, and Olfa Kanoun. "Enhanced passive RF-DC converter circuit efficiency for low RF energy harvesting." *Sensors* 17, no. 3 (2017): 546.https://doi.org/10.3390/s17030546

[47] Chen, Zhongsheng, Yemei Xia, Jing He, Yeping Xiong, and Gang Wang. "Elastic-electro-mechanical modeling and analysis of piezoelectric metamaterial plate with a self-powered synchronized charge extraction circuit for vibration energy harvesting." *Mechanical Systems and Signal Processing* 143 (2020): 106824. https://doi.org/10.1016/j.ymssp.2020.106824

[48] Brenes, A., Adrien Morel, D. Gibus, C-S. Yoo, P. Gasnier, E. Lefeuvre, and A. Badel. "Large-bandwidth piezoelectric energy harvesting with frequency-tuning synchronized electric charge extraction." *Sensors and Actuators A: Physical* 302 (2020): 111759. https://doi.org/10.1016/j.sna.2019.111759

[49] Saman, R., Nader, K., & Faramarz, H. (2022). Energy Harvesting Materials: Overview, Encyclopedia of Smart Materials. *Elsevier*, 230-241; https://doi.org/10.1016/b978-0-12-803581-8.12112-5

[50] Liu, Weiqun, Gang Qin, Qiao Zhu, and Guangdi Hu. "Synchronous extraction circuit with self-adaptive peak-detection mechanical switches design for piezoelectric energy harvesting." *Applied Energy* 230 (2018): 1292-1303. https://doi.org/10.1016/j.apenergy.2018.09.051

[51] Lan, Chunbo, Lihua Tang, and Ryan L. Harne. "Comparative methods to assess harmonic response of nonlinear piezoelectric energy harvesters interfaced with AC and DC circuits." *Journal of Sound and Vibration* 421 (2018): 61-78. https://doi.org/10.1016/j.jsv.2017.11.019

[52] Jayakrishnan, E. P., and Jaseena Sayed. "Piezoelectric Energy Harvesting: A Review on Power Conditioning." *Advances in Control Instrumentation Systems: Select Proceedings of CISCON 2019* (2020): 1-8. https://doi.org/10.1007/978-981-15-4676-1_1

[53] Chen, Y-Y., Dejan Vasic, François Costa, W-J. Wu, and C-K. Lee. "A self-powered switching circuit for piezoelectric energy harvesting with velocity control." *The European Physical Journal Applied Physics* 57, no. 3 (2012): 30903. https://doi.org/10.1051/epjap/2012110355

[54] Mouapi, Alex. "Performance analysis of multistage voltage doubler rectifier for RF energy harvesting." In *2019 IEEE International Conference on Environment and Electrical Engineering and 2019 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe)*, pp. 1-4. IEEE, 2019. https://doi.org/10.1109/EEEIC.2019.8783871

[55] Tayyab, Umais, and Hussain A. Alzaher. "A Self-Biased Active Voltage Doubler for Energy Harvesting Systems." *Active and Passive Electronic Components* 2017 (2017). https://doi.org/10.1155/2017/1650161

[56] Uluşan, H., K. Gharehbaghi, Ö. Zorlu, A. Muhtaroğlu, and Haluk Külah. "A self-powered hybrid energy scavenging system utilizing RF and vibration based electromagnetic harvesters." In *Journal of Physics: Conference Series*, vol. 660, no. 1, p. 012023. IOP Publishing, 2015. https://doi.org/10.1088/1742-6596/660/1/012023

[57] Wu, Wan-Ling, Yong-Zheng Wang, and Ching-Yuan Yang. "Flipping Rectifiers for Piezoelectric Vibration Energy Harvesting." In *2019 International SoC Design Conference (ISOCC)*, pp. 198-199. IEEE, 2019. https://doi.org/10.1109/ISOCC47750.2019.9027758

[58] Vinko, Davor. "Minimizing switching time of energy harvesting management circuit." In *2018 41st International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)*, pp. 0099-0102. IEEE, 2018. https://doi.org/10.23919/MIPRO.2018.8400019

[59] Fan, Shiquan, Zhongming Xue, Zhuoqi Guo, Wei Gou, Xu Yang, and Li Geng. "An ultra-low power (ULP) zero-current-detector (ZCD) circuit for switching inductor converter applied in energy harvesting system." In *2017 IEEE Electrical Design of Advanced Packaging and Systems Symposium (EDAPS)*, pp. 1-3. IEEE, 2017.https://doi.org/10.1109/EDAPS.2017.8276949

[60] Singh, Vikash, Roshan Kumar, and Zhao Wei. "Adaptive time-switching and power-splitting protocols for energy harvesting sensor networks with multiple relays." *Computer Networks* 179 (2020): 107341.https://doi.org/10.1016/j.comnet.2020.107341

[61] Khan, Muhammad Bilawal, Hassan Saif, and Yoonmyung Lee. "A Piezoelectric Harvesting Interface with Capacitive Partial Electric Charge Extraction for Energy Harvesting from Irregular High-Voltage Input." *Energies* 13, no. 8 (2020): 1939. https://doi.org/10.3390/en13081939

[62] Kathol, Paul Brian. "An Improved Synchronous Charge Extraction Rectifier for Piezoelectric Energy Harvesting from Low-Amplitude Vibrations." Master's thesis, Schulich School of Engineering, 2019. http://hdl.handle.net/1880/111044

[63] Belal, Ehab, Hassan Mostafa, and M. Sameh Said. "Comparison between active AC-DC converters for low power energy harvesting systems." In *2015 27th International Conference on Microelectronics (ICM)*, pp. 253-256. IEEE, 2015. https://doi.org/10.1109/ICM.2015.7438036

[64] Zhou, Xing, Yi-Die Ye, and Hua-Kang Xia. "An active rectifier with P-SSHI for piezoelectric energy harvesting system." In *2018 14th IEEE International Conference on Solid-State and Integrated Circuit Technology (ICSICT)*, pp. 1-3. IEEE, 2018.https://doi.org/10.1109/ICSICT.2018.8565693

[65] Lipski, Mark, Yin Li, Manjusri Misra, and Stefano Gregori. "A low forward bias active diode circuit for electrostatic energy harvesters." In *2018 IEEE International Symposium on Circuits and Systems (ISCAS)*, pp. 1-5. IEEE, 2018. https://doi.org/10.1109/ISCAS.2018.8351218

[66] Harrasi, S., and A. S. Holmes. "Synchronous voltage doubler for electromagnetic harvesters." *PowerMEMS, Atlanta, GA* 2012 (2012): 68-71. https://nanopdf.com/download/synchronous-voltage-doubler-for-electromagnetic-harvesters_pdf

[67] Meng, Miao, Dixiong Wang, Binh Duc Truong, Susan Trolier-McKinstry, Shad Roundy, and Mehdi Kiani. "A multi-beam shared-inductor reconfigurable voltage/SECE mode piezoelectric energy harvesting interface circuit." *IEEE transactions on biomedical circuits and systems* 13, no. 6 (2019): 1277-1287.https://doi.org/10.1109/TBCAS.2019.2942261

[68] Chen, Nan, Hyun Jun Jung, Hamid Jabbar, Tae Hyun Sung, and Tingcun Wei. "A piezoelectric impact-induced vibration cantilever energy harvester from speed bump with a low-power power management circuit." *Sensors and Actuators A: Physical* 254 (2017): 134-144. https://doi.org/10.1016/j.sna.2016.12.006

[69] Das, Pratima. "Maximum power tracking based open circuit voltage method for PV system." *Energy Procedia* 90 (2016): 2-13. https://doi.org/10.1016/j.egypro.2016.11.165

[70] Shen, Hui, Hongli Ji, Jinhao Qiu, Yixiang Bian, and Dawei Liu. "Adaptive synchronized switch harvesting: A new piezoelectric energy harvesting scheme for wideband vibrations." *Sensors and Actuators A: Physical* 226 (2015): 21-36.https://doi.org/10.1016/j.sna.2015.02.008

[71] Le, Triet T., Jifeng Han, Annette Von Jouanne, Kartikeya Mayaram, and Terri S. Fiez. "Piezoelectric micro-power generation interface circuits." *IEEE journal of solid-state circuits* 41, no. 6 (2006): 1411-1420. https://doi.org/10.1109/JSSC.2006.874286

[72] Torah, Russel, Peter Glynne-Jones, M. Tudor, T. O'donnell, S. Roy, and Steve Beeby. "Self-powered autonomous wireless sensor node using vibration energy harvesting." *Measurement science and technology* 19, no. 12 (2008): 125202. https://doi.org/10.1088/0957-0233/19/12/125202

[73] Gleeson, R., Michaël Kraft, and N. M. White. "Design and analysis of an SOI MEMS voltage step-up converter." *Journal of Micromechanics and Microengineering* 23, no. 11 (2013): 114017. https://doi.org/10.1088/0960-1317/23/11/114017

[74] Roscoe, Nina M., and Martin D. Judd. "Harvesting energy from magnetic fields to power condition monitoring sensors." *IEEE Sensors Journal* 13, no. 6 (2013): 2263-2270.https://doi.org/10.1109/JSEN.2013.2251625

[75] ud Din, Amad, Doyoung Chung, Dasom Park, Hyunsik Lee, and Jong Wook Lee. "A high energy extraction self-controllable CMOS resonant rectifier circuit for piezoelectric energy scavenging system." In *2014 International SoC Design Conference (ISOCC)*, pp. 40-41. IEEE, 2014. https://doi.org/10.1109/ISOCC.2014.7087584

[76] Kushino, Yukito, and Hirotaka Koizumi. "Piezoelectric energy harvesting circuit using full-wave voltage doubler rectifier and switched inductor." In *2014 IEEE Energy Conversion Congress and Exposition (ECCE)*, pp. 2310-2315. IEEE, 2014. https://doi.org/10.1109/ECCE.2014.6953711

[77] Mustapha, Ain Atiqa, K. Leong, and Noraini Mat Ali. "Piezoelectric energy harvesting rectifying circuits comparison." *ARPN J. Eng. Appl. Sci* 11, no. 10 (2016): 6361-6365.

[78] Baby, Shynela SP, Rajan S. Edward, and Clarence Asis A. Allwyn. "Performance analysis of an efficient active rectifier for powering LEDs using piezoelectric energy harvesting systems." In *2013 International Conference on Circuits, Power and Computing Technologies (ICCPCT)*, pp. 376-380. IEEE, 2013. https://doi.org/10.1109/ICCPCT.2013.6528844

[79] Camarda, Antonio, Aldo Romani, and Marco Tartagni. "Piezoelectric transformers for ultra-low voltage energy harvesting applications." *Procedia Engineering* 87 (2014): 1521-1524. https://doi.org/10.1016/j.proeng.2014.11.588

[80] Ahola, J., T. Ahonen, V. Sarkimaki, A. Kosonen, J. Tamminen, R. Tiainen, and T. Lindh. "Design considerations for current transformer based energy harvesting for electronics attached to electric motor." In *2008 international symposium on power electronics, electrical drives, automation and motion*, pp. 901-905. IEEE, 2008.https://doi.org/10.1109/SPEEDHAM.2008.4581191

[81] Macrelli, Enrico, Aldo Romani, Rudi Paolo Paganelli, Antonio Camarda, and Marco Tartagni. "Design of low-voltage integrated step-up oscillators with microtransformers for energy harvesting applications." *IEEE Transactions on Circuits and Systems I: Regular Papers* 62, no. 7 (2015): 1747-1756. https://doi.org/10.1109/TCSI.2015.2423796

[81] Teh, Ying-Khai, and Philip KT Mok. "Design of transformer-based boost converter for high internal resistance energy harvesting sources with 21 mV self-startup voltage and 74% power efficiency." *IEEE Journal of Solid-State Circuits* 49, no. 11 (2014): 2694-2704. https://doi.org/10.1109/JSSC.2014.2354645

[82] Camarda, Antonio, Aldo Romani, Enrico Macrelli, and Marco Tartagni. "A 32 mV/69 mV input voltage booster based on a piezoelectric transformer for energy harvesting applications." *Sensors and Actuators A: Physical* 232 (2015): 341-352.https://doi.org/10.1016/j.sna.2015.05.014

[82] Martinez, T., Gaël Pillonnet, and F. Costa. "A 12 mV start-up converter using piezoelectric transformer for energy harvesting applications." In *Journal of Physics: Conference Series*, vol. 773, no. 1, p. 012028. IOP Publishing, 2016. https://doi.org/10.1088/1742-6596/773/1/012028

[83] Belal, Ehab, Hassan Mostafa, Yehea Ismail, and M. Sameh Said. "A voltage multiplying AC/DC converter for energy harvesting applications." In *2016 28th International Conference on Microelectronics (ICM)*, pp. 229-232. IEEE, 2016. https://doi.org/10.1109/ICM.2016.7847857

[84] Kashiwao, Tomoaki, Iman Izadgoshasb, Yee Yan Lim, and Mikio Deguchi. "Optimization of rectifier circuits for a vibration energy harvesting system using a macro-fiber composite piezoelectric element." *Microelectronics Journal* 54 (2016): 109-115. https://doi.org/10.1016/j.mejo.2016.05.013

[85] Lubieniecki, Michał, and Tadeusz Uhl. "Integration of thermal energy harvesting in semi-active piezoelectric shunt-damping systems." *Journal of electronic materials* 44 (2015): 341-347. https://doi.org/10.1007/s11664-014-3194-2

[86] Rojas, Rafael A., and Antonio Carcaterra. "An approach to optimal semi-active control of vibration energy harvesting based on MEMS." *Mechanical Systems and Signal Processing* 107 (2018): 291-316. https://doi.org/10.1016/j.ymssp.2017.11.005

[87] Lallart, Mickaël, and Giulia Lombardi. "Synchronized Switch Harvesting on ElectroMagnetic System: a nonlinear technique for hybrid energy harvesting based on active inductance." *Energy conversion and management* 203 (2020): 112135. https://doi.org/10.1016/j.enconman.2019.112135

[88] Ochi, Yoshki, and Hirotaka Koizumi. "Piezoelectric energy harvesting circuit using full-wave voltage doubling rectifier type series-synchronized switch harvesting on inductor." In *IECON 2017-43rd Annual Conference of the IEEE Industrial Electronics Society*, pp. 1417-1422. IEEE, 2017. https://doi.org/10.1109/IECON.2017.8216241

[89] Xia, Huakang, Yinshui Xia, Ge Shi, Yidie Ye, Xiudeng Wang, Zhidong Chen, and Qian Jiang. "A self-powered S-SSHI and SECE hybrid rectifier for PE energy harvesters: analysis and experiment." *IEEE Transactions on Power Electronics* 36, no. 2 (2020): 1680-1692. https://doi.org/10.1109/TPEL.2020.3007694

[90] Alaei, Zohreh. "Power Enhancement in Piezoelectric Energy Harvesting." (2016): 1-6. http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-188956

[91] Zhang, Jinxiao, Haili Liu, and Ya Wang. "Synchronized Switch Harvesting on Inductor Interface to Promote Piezoelectric Stack Energy Harvesting From Human Walking." In *Smart Materials, Adaptive Structures and Intelligent Systems*, vol. 50497, p. V002T07A016. American Society of Mechanical Engineers, 2016. https://doi.org/10.1115/SMASIS2016-9297

[92] Xu, Zhuo, Zhengbao Yang, and Jean Zu. "Impedance matching circuit for synchronous switch harvesting on inductor interface." In *2015 IEEE International Conference on Mechatronics and Automation (ICMA)*, pp. 341-345. IEEE, 2015. https://doi.org/10.1109/ICMA.2015.7237508

[93] Li, Shuo, Abhishek Roy, and Benton H. Calhoun. "A piezoelectric energy-harvesting system with parallel-SSHI rectifier and integrated maximum-power-point tracking." *IEEE Solid-State Circuits Letters* 2, no. 12 (2019): 301-304. https://doi.org/10.1109/LSSC.2019.2951394

[94] Hsu, Hao-Hsiang, and Ching-Yuan Yang. "A Parallel-SSHI Rectifier for Piezoelectric Energy Harvesting." In *2018 IEEE International Conference on Consumer Electronics-Taiwan (ICCE-TW)*, pp. 1-2. IEEE, 2018. https://doi.org/10.1109/ICCE-China.2018.8448404

[95] Yu, Jiaqi, Wensi Wang, Lu Jin, and Xu Liu. "Power Management IC Design for Microwatts Vibration Piezoelectric Energy Harvesting Based on Parallel-SSHI." In *2018 IEEE 3rd International Conference on Integrated Circuits and Microsystems (ICICM)*, pp. 178-183. IEEE, 2018. https://doi.org/10.1109/ICAM.2018.8596592

[96] Cheng, Xin, Bo Cheng, Zechen Tang, Yongqiang Zhang, and Zhang Zhang. "A Single-Input Multi-Output Piezoelectric Energy Harvesting System Combining with P-SSHI and Cold Startup Circuit." In *2019 IEEE Asia Pacific Conference on Circuits and Systems (APCCAS)*, pp. 65-68. IEEE, 2019. https://doi.org/10.1109/APCCAS47518.2019.8953081

[97] Zouari, Manel, Slim Naifar, Martin Götz, Nabil Derbel, and Olfa Kanoun. "An optimized self-powered P-SSHI circuit for piezoelectric energy harvesting." In *2017 IEEE International Instrumentation and Measurement Technology Conference (I2MTC)*, pp. 1-6. IEEE, 2017.https://doi.org/10.1109/I2MTC.2017.7969755

[98] Zhao, Kang, Junrui Liang, and Chen Chen. "Parallel synchronized septuple bias-flip circuit for piezoelectric energy harvesting enhancement." In *IECON 2017-43rd Annual Conference of the IEEE Industrial Electronics Society*, pp. 2629-2634. IEEE, 2017. https://doi.org/10.1109/IECON.2017.8216442

[99] Liang, Junrui. "Synchronized bias-flip interface circuits for piezoelectric energy harvesting enhancement: A general model and prospects." *Journal of Intelligent Material Systems and Structures* 28, no. 3 (2017): 339-356. https://doi.org/10.1177/1045389X16642535

[100] Ottman, Geffrey K., Heath F. Hofmann, and George A. Lesieutre. "Optimized piezoelectric energy harvesting circuit using step-down converter in discontinuous conduction mode." *IEEE Transactions on power electronics* 18, no. 2 (2003): 696-703. https://doi.org/10.1109/TPEL.2003.809379

[101] Lien, I. C., Y. C. Shu, W. J. Wu, S. M. Shiu, and H. C. Lin. "Revisit of series-SSHI with comparisons to other interfacing circuits in piezoelectric energy harvesting." *Smart Materials and Structures* 19, no. 12 (2010): 125009. https://doi.org/10.1088/0964-1726/19/12/125009

[102] Zhao, Kang, Junrui Liang, and Haoyu Wang. "Series synchronized triple bias-flip (S-S3BF) interface circuit for piezoelectric energy harvesting." In *2019 IEEE International Symposium on Circuits and Systems (ISCAS)*, pp. 1-5. IEEE, 2019. https://doi.org/10.1109/ISCAS.2019.8702617

[103] Sidharthan, Vishnu, M. Udaya Bhasker, Srikanth Korla, and M. S. Chandrasekhar. "Energy Harvesting of Synchronized Switch Harvesting On Inductor." In *2018 International Conference on Recent Innovations in Electrical, Electronics & Communication Engineering (ICRIEECE)*, pp. 2882-2887. IEEE, 2018. https://doi.org/10.1109/ICRIEECE44171.2018.9009273

[104] Wang, Xu. "A study of harvested power and energy harvesting efficiency using frequency response analyses of power variables." *Mechanical Systems and Signal Processing* 133 (2019): 106277. https://doi.org/10.1016/j.ymssp.2019.106277

[105] Brenes, A., Adrien Morel, D. Gibus, C-S. Yoo, P. Gasnier, E. Lefeuvre, and A. Badel. "Large-bandwidth piezoelectric energy harvesting with frequency-tuning synchronized electric charge extraction." *Sensors and Actuators A: Physical* 302 (2020): 111759. https://doi.org/10.1016/j.sna.2019.111759

[106] Zhu, Hongjun, Ying Zhao, and Jie Hu. "Performance of a novel energy harvester for energy self-sufficiency as well as a vortex-induced vibration suppressor." *Journal of Fluids and Structures* 91 (2019): 102736. https://doi.org/10.1016/j.jfluidstructs.2019.102736

[107] Ouanes, MA Ben, Hatem Samaali, D. Galayko, Philippe Basset, and Fehmi Najar. "A new type of triboelectric nanogenerator with self-actuated series-to-parallel electrical interface based on self-synchronized mechanical switches for exponential charge accumulation in a capacitor." *Nano Energy* 62 (2019): 465-474. https://doi.org/10.1016/j.nanoen.2019.05.049

[108] Lallart, Mickaël, Lauric Garbuio, Lionel Petit, Claude Richard, and Daniel Guyomar. "Double synchronized switch harvesting (DSSH): A new energy harvesting scheme for efficient energy extraction." *IEEE transactions on ultrasonics, ferroelectrics, and frequency control* 55, no. 10 (2008): 2119-2130. https://doi.org/10.1109/TUFFC.912

[109] Sharma, Himanshu, Madhav Sharma, Chetan Sharma, Ahteshamul Haque, and Zainul Abdin Jaffery. "Performance analysis of solar powered DC-DC buck converter for energy harvesting IoT nodes." In *2018 3rd International Innovative Applications of Computational Intelligence on Power, Energy and Controls with their Impact on Humanity (CIPECH)*, pp. 26-29. IEEE, 2018. https://doi.org/10.1109/CIPECH.2018.8724183

[110] Twaha, Ssennoga, Jie Zhu, Yuying Yan, Bo Li, and Kuo Huang. "Performance analysis of thermoelectric generator using dc-dc converter with incremental conductance based maximum power point tracking." *Energy for Sustainable Development* 37 (2017): 86-98. https://doi.org/10.1016/j.esd.2017.01.003

[111] Garcia-Valverde, Rafael, José A. Villarejo, Markus Hösel, Morten V. Madsen, Roar R. Søndergaard, Mikkel Jørgensen, and Frederik C. Krebs. "Scalable single point power extraction for compact mobile and stand-alone solar harvesting power sources based on fully printed organic photovoltaic modules and efficient high voltage DC/DC conversion." *Solar Energy Materials and Solar Cells* 144 (2016): 48-54.https://doi.org/10.1016/j.solmat.2015.08.020

[112] Ottman, Geffrey K., Heath F. Hofmann, Archin C. Bhatt, and George A. Lesieutre. "Adaptive piezoelectric energy harvesting circuit for wireless remote power supply." *IEEE Transactions on power electronics* 17, no. 5 (2002): 669-676. https://doi.org/10.1109/TPEL.2002.80219

[113] Mohamad, Tengku Norliza Tengku, Jahariah Sampe, and Dilla Duryha Berhanuddin. "Architecture of micro energy harvesting using hybrid input of RF, thermal and vibration for semi-active RFID tag." *Engineering Journal* 21, no. 2 (2017): 183-197. https://doi.org/10.4186/ej.2017.21.2.183

[114] Balpande, Suresh S., Sudhir B. Lande, Umesh Akare, and Laxman Thakre. "Modeling of cantilever based power harvester as an innovative power source for RFID Tag." In *2009 Second International Conference on Emerging Trends in Engineering & Technology*, pp. 13-18. IEEE, 2009. https://doi.org/10.1109/ICETET.2009.152

[115] Han, Jifeng, Annette von Jouanne, Triet Le, K. Mayaram, and T. S. Fiez. "Novel power conditioning circuits for piezoelectric micropower generators." In *Nineteenth Annual IEEE Applied Power Electronics Conference and Exposition, 2004. APEC'04.*, vol. 3, pp. 1541-1546. IEEE, 2004. doi: 10.1109/APEC.2004.1296069.

[116] Dallago, Enrico, Daniele Miatton, Giuseppe Venchi, Giovanni Frattini, and Giulio Ricotti. "Self-supplied integrable active high-efficiency AC-DC converter for piezoelectric energy scavenging systems." In *2007 IEEE International Symposium on Circuits and Systems*, pp. 1633-1636. IEEE, 2007. doi: 10.1109/ISCAS.2007.378832.

[117] Dallago, Enrico, Daniele Miatton, Giuseppe Venchi, Valeria Bottarel, Giovanni Frattini, Giulio Ricotti, and Monica Schipani. "Active self supplied AC-DC converter for piezoelectric energy scavenging systems with supply independent bias." In *2008 IEEE International Symposium on Circuits and Systems*, pp. 1448-1451. IEEE, 2008. doi: 10.1109/ISCAS.2008.4541701.

[118] Xu, Cuidong, and Ka Wai Eric Cheng. "A switched capacitor based AC/DC resonant converter for high frequency AC power generation." *Energies* 8, no. 10 (2015): 10842-10860. doi: 10.1109/ISCAS.2008.4541701.

[119] Sun, Yang, In-young Lee, Chang-jin Jeong, Seok-kyun Han, and Sang-gug Lee. "An comparator based active rectifier for vibration energy harvesting systems." In *13th International Conference on Advanced Communication Technology (ICACT2011)*, pp. 1404-1408. IEEE, 2011.

[120] Sun, Yang, Nguyen Huy Hieu, Chang-Jin Jeong, and Sang-Gug Lee. "An integrated high-performance active rectifier for piezoelectric vibration energy harvesting systems." *IEEE Transactions on Power Electronics* 27, no. 2 (2011): 623-627. doi: 10.1109/TPEL.2011.2162078.

[121] Rao, Yuan, and David P. Arnold. "An AC/DC voltage doubler with configurable power supply schemes for vibrational energy harvesting." In *2013 Twenty-Eighth Annual IEEE Applied Power Electronics Conference and Exposition (APEC)*, pp. 2844-2851. IEEE, 2013. doi: 10.1109/APEC.2013.6520701.

[122] Guyomar, Daniel, Adrien Badel, Elie Lefeuvre, and Claude Richard. "Toward energy harvesting using active materials and conversion improvement by nonlinear processing." *IEEE transactions on ultrasonics, ferroelectrics, and frequency control* 52, no. 4 (2005): 584-595. doi: 10.1109/TUFFC.2005.1428041.

[123] Becker, Philipp, Erwin Hymon, Bernd Folkmer, and Yiannos Manoli. "High efficiency piezoelectric energy harvester with synchronized switching interface circuit." *Sensors and Actuators A: Physical* 202 (2013): 155-161.https://doi.org/10.1016/j.sna.2013.04.030

[124] Do, Xuan-Dien, Huy-Hieu Nguyen, Seok-Kyun Han, Dong Sam Ha, and Sang-Gug Lee. "A self-powered high-efficiency rectifier with automatic resetting of transducer capacitance in piezoelectric energy harvesting systems." *IEEE Transactions on Very Large Scale Integration (VLSI) Systems* 23, no. 3 (2014): 444-453. doi: 10.1109/TVLSI.2014.2312532.

[125] Singh, Kanishka Aman, Ratnesh Kumar, and Robert J. Weber. "A broadband bistable piezoelectric energy harvester with nonlinear high-power extraction." *IEEE Transactions on Power Electronics* 30, no. 12 (2015): 6763-6774. doi: 10.1109/TPEL.2015.2394392.

[126] Wu, Liao, Jishun Kuang, Zhiqiang You, Peng Liu, and Shuo Cai. "A parallel-SSHI rectifier for ultra-low-voltage piezoelectric vibration energy harvesting." *IEICE Electronics Express* 13, no. 17 (2016): 20160539-20160539. doi: 10.1587/elex.13.20160539

[127] Hsieh, Y. C., J. J. Chen, H. S. Chen, and W. J. Wu. "An integrated circuit design of high efficiency parallel-SSHI rectifier for piezoelectric energy harvesting." In *Journal of Physics: Conference Series*, vol. 773, no. 1, p. 012029. IOP Publishing, 2016. https://doi.org/10.1088/1742-6596/773/1/012029

[128] Chen, Chi-Huan, Hung-Chen Chen, Yu-Shyang Huang, Ping-Hsuan Hsieh, Ping-Hsien Wu, and Yi-Chung Shu. "A series-SSHI-Phi interface circuit for piezoelectric energy harvesting with 163% improvement in extracted power at off- resonance." In *2016 IEEE Asian Solid-State Circuits Conference (A-SSCC)*, pp. 29-32. IEEE, 2016. https://doi.org/10.1109/ASSCC.2016.7844127

[129] Shen, Hui, Jinhao Qiu, Hongli Ji, Kongjun Zhu, and Marco Balsi. "Enhanced synchronized switch harvesting: a new energy harvesting scheme for efficient energy extraction." *Smart Materials and Structures* 19, no. 11 (2010): 115017.https://doi.org/10.1088/0964-1726/19/11/115017

[130] Chen, Y-Y., Dejan Vasic, François Costa, W-J. Wu, and C-K. Lee. "A self-powered switching circuit for piezoelectric energy harvesting with velocity control." *The European Physical Journal Applied Physics* 57, no. 3 (2012): 30903.https://doi.org/10.1051/epjap/2012110355

[131] Kong, Na, and Dong Sam Ha. "Low-power design of a self-powered piezoelectric energy harvesting system with maximum power point tracking." *IEEE Transactions on power electronics* 27, no. 5 (2011): 2298-2308. https://doi.org/10.1109/TPEL.2011.2172960

[132] Chen, Yu-Yin, Dejan Vasic, François Costa, Chih-Kung Lee, and Wen-Jong Wu. "Self-powered semi-passive piezoelectric structural damping based on zero-velocity crossing detection." *Smart Materials and Structures* 22, no. 2 (2013): 025029. https://doi.org/10.1088/0964-1726/22/2/025029

[133] Darmayuda, I. Made, Chai Tshun Chuan Kevin, and Je Minkyu. "Modified Buck Boost Circuit for Linear and Non-Linear Piezoelectric Energy Harvesting." *International Journal of Electronics and Communication Engineering* 7, no. 9 (2013): 1173-1177. doi.org/10.5281/zenodo.1087682

[134] Tabesh, Ahmadreza, and Luc G. Fréchette. "A low-power stand-alone adaptive circuit for harvesting energy from a piezoelectric micropower generator." *IEEE Transactions on Industrial Electronics* 57, no. 3 (2009): 840-849.https://doi.org/10.1109/TIE.2009.2037648

[135] Álvarez-Carulla, Albert, Jordi Colomer-Farrarons, Jaime López-Sánchez, and Pere Miribel-Català. "Piezoelectric Harvester-based structural health monitoring that uses a self-powered adaptive circuit." In *2015 IEEE Metrology for Aerospace (MetroAeroSpace)*, pp. 531-535. IEEE, 2015.https://doi.org/10.1109/MetroAeroSpace.2015.7180713

[136] Chew, Zheng Jun, and Meiling Zhu. "Low power adaptive power management with energy aware interface for wireless sensor nodes powered using piezoelectric energy harvesting." In *2015 IEEE SENSORS*, pp. 1-4. IEEE, 2015. https://doi.org/10.1109/ICSENS.2015.7370663

[137] Chew, Zheng Jun, Tingwen Ruan, and Meiling Zhu. "Strain energy harvesting powered wireless sensor node for aircraft structural health monitoring." *Procedia Engineering* 168 (2016): 1717-1720. https://doi.org/10.1016/j.proeng.2016.11.498

[138] Li, Teng, Yunxin Zhang, and Xinlai Geng. "An Adaptive Self-powered Piezoelectric Energy Harvesting Circuit and Its Application on Bridge Condition Monitoring." (2017). doi: 10.20944/preprints201701.0062.v1

[139] Ammar, Yasser, Aurélien Buhrig, Marcin Marzencki, Benoît Charlot, Skandar Basrour, Karine Matou, and Marc Renaudin. "Wireless sensor network node with asynchronous architecture and vibration harvesting micro power generator." In *Proceedings of the 2005 joint conference on Smart objects and ambient intelligence: innovative context-aware services: usages and technologies*, pp. 287-292. 2005. https://doi.org/10.1145/1107548.1107618

[140] Lefeuvre, Elie, Adrien Badel, Claude Richard, Lionel Petit, and Daniel Guyomar. "A comparison between several vibration-powered piezoelectric generators for standalone systems." *Sensors and Actuators A: Physical* 126, no. 2 (2006): 405-416. https://doi.org/10.1016/j.sna.2005.10.043

[141] Lefeuvre, Elie, David Audigier, Claude Richard, and Daniel Guyomar. "Buck-boost converter for sensorless power optimization of piezoelectric energy harvester." *IEEE Transactions on Power Electronics* 22, no. 5 (2007): 2018-2025.https://doi.org/10.1109/TPEL.2007.904230

[142] Forouzesh, Mojtaba, Yam P. Siwakoti, Saman A. Gorji, Frede Blaabjerg, and Brad Lehman. "Step-up DC–DC converters: a comprehensive review of voltage-boosting techniques, topologies, and applications." *IEEE transactions on power electronics* 32, no. 12 (2017):9143-9178. https://doi.org/10.1109/TPEL.2017.26

[143] Adnan, N. F., Lee, K. Q., Kang, H. S., Wong, K. Y., & Tan, H. Y. (2022). Preliminary investigation on the energy harvesting of vortex-induced vibration with the use of magnet. Progress in Energy and Environment, 21, 1-7. https://doi.org/10.37934/progee.21.1.17

[144] Nordin, N. F., Lee, K. Q., & Kang, H. S. (2019). Energy Harvesting of Daily Human Life Activities using a Self-Made Piezoelectric System. *Progress in Energy and Environment*, *10*, 1-5.