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Improvement of Power in Piezoelectric Energy Harvesting Systems Using the Synchronized Switch Harvesting Inductor (SSHI) Technique

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ABSTRACT

Energy needs have always been a problem that must be solved, the utilization of fossil energy sources is a solution that is widely used, but this energy source can run out at any time. The idea to create an energy producer that utilizes mechanical energy from the motion of objects, creating a tool in the form of a floor that can produce electrical energy by utilizing piezoelectricity as a harvester with SSHI technique as an optimizer. Piezoelectric is a sensor that can react when given vibration or pressure. The energy harvesting floor is made using piezoelectrics arranged in series of 16 pieces, this harvesting tool is assisted by standard energy harvesting (SEH) and syncronized swiych harvesting inductor (SSHI) techniques this technique combines several components namely, MOSFET IRF530N, Inductor, reactifier, capacitor. This floor can produce 5V AC energy in a few steps, and produce 2V - 2.5V DC after entering the rectifier, after being given a load in the form of a capacitor and LED the voltage generated per beat is 0.03V - 0.06V, this study compares the harvesting circuit using SSHI and not using SSHI, getting the conclusion SSHI as a harvesting stabilizer dampens the resulting power surge.

1. Introduction

Energy needs have always been a problem that must be resolved, the use of fossil energy sources is a solution that is widely used but this energy source is temporary and can run out at any time over time [1]. The idea of creating energy producers from wasted energy arises such as energy harvesting floors that utilize mechanical energy from the motion of objects that we do not realize are around us and are wasted for free [2], one of which is energy that exists in living things and can even be created by human tools, namely mechanical energy in the form of vibrations generated by human footsteps, vibrations from running vehicles [3]. Low-power energy harvesting can be utilized and is very interesting to develop. This research is a solution in generating energy, creating a tool in the form of a floor that can convert electrical energy by utilizing piezoelectricity as a harvester [4].

If the crystal gets energy from one direction, then the electric charge will change places in the crystal itself, so that the crystal will be divided into two parts, namely the natural part and the part that loses the electric charge. This process was proven by a French physicist named Madame Currie (1880), and is now known as the piezoelectric effect [5].

The piezoelectric effect has two characteristics, namely converting pressure into electrical energy and changing the shape of the piezoelectric material by applying an electric voltage to the piezoelectric. Piezoelectric material is a material that can produce an electric field when given mechanical power. If done otherwise the piezoelectric will get a strain so as to create mechanical energy [6]. The ability of one piezoelectric chip is around 5 µA for the current released and 5 V_{ac} for the voltage issued. The combination of many piezoelectric can be a single unit of energy generation [7].

To get a stable harvesting result, the combination of piezoelectric and synchronized switch harvesting inductor (SSHI) method [8] connected based on standard energy harvesting (SEH), SEH technique provides a simple and reliable solution to harvest ambient vibration energy but its harvesting ability is difficult to be improved further [9]. Proposed SSHI technique to improve energy conversion efficiency, The principle of synchronization switching is similar to vibration control with state-switched piezoelectric materials, The SSHI interface circuit reverses the voltage across the piezoelectric element at the time of transition from short circuit to open circuit. SSHI consists of several components namely MOSFET IRF530N and Inductor [10].

2. Methods

This research is conducted by designing a power optimization system on the harvester using the SSHI method connected to the piezoelectric harvester. In order for the system design to be carried out properly, sufficient information and collection of theories related to the process of designing this research system are needed.

2.1. SSHI

The SSHI circuit is composed of several components that are interconnected so that they can affect every time the current entering the SSHI circuit stabilizes its wave, as for the supporting components in this SSHI circuit, namely MOSFET IRF530N, Arduino UNO, potentio, inductor winding / coil. SSHI schematic is found in Fig. 1. SSHI consists of several components, namely MOSFET IRF530N and Inductor.

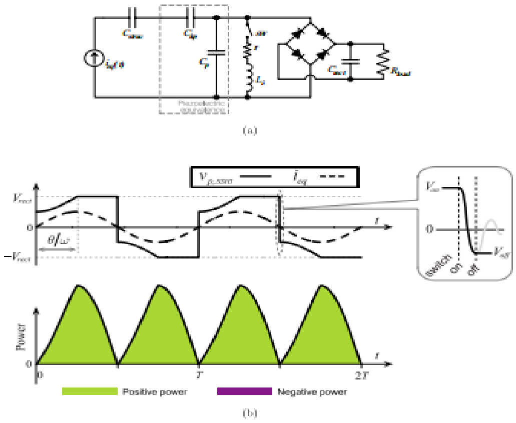

Fig. 1. SSHI interface circuit, (a) Circuit topology and (b) Typical waveform

The switch takes action to invert the voltage across the piezoelectric capacitance by a factor where V_{on} and V_{off} are the voltages before and after inversion, respectively; Q is the quality factor of the $r - Li - Cp$ switching circuit. One of the switching processes is magnified and shown in Fig. 1(b). This switching action makes the symbol vp change to ieq. Therefore, the synchronized switching action makes vp in phase with ieq, which ensures that the power entering the electrical part is always positive. In addition, the magnitude of vp is also increased by applying SSHI, which indicates that more energy is extracted from the source [11].

The design of the device is needed so that the harvester looks neat and its performance becomes good, this design is arranged with the beginning of a floor mounted piezoelectric with a size of 35mm [12] in series in each harvester circuit and then connected to an optimizer circuit named synchronize switch harvesting inductor (SSHI) as a research focus frame, so that the utilization of the tool can be realized, the harvester circuit is connected to the rectifier as an AC-DC converter [13] so that it can be utilized and stored in temporary storage such as capacitors [14].

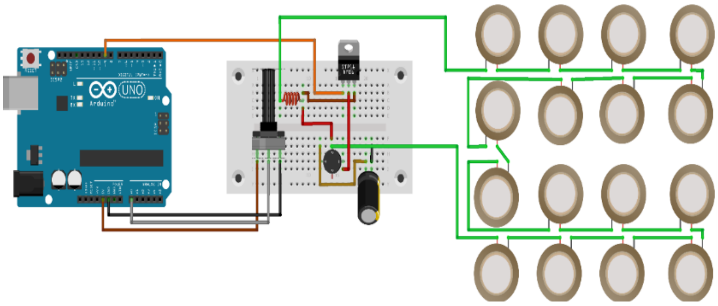

Fig. 2. Floor Connected Harvester SSHI circuit

To control the SSHI circuit using the utilization of Arduino UNO as a PWM regulator brain for MOSFET as a switch that will make energy harvesting more regular compared to the harvester floor circuit without SSHI connected, the pin function on Arduino UNO can be seen in Table 1 [15]. Fig. 3 is a system block diagram of the energy harvesting process interface using a floor harvester connected to SSHI, in the figure it can be seen that the input from the block diagram process above is human footsteps which will enter into the conversion process stage by piezoelectric sensors so that mechanical energy turns into electrical energy in the form of AC, The converted energy enters the SSHI circuit through the IRF530N mosfet which has been controlled using PWM with the help of Arduino UNO and potentios, the energy flow that enters the SSHI circuit will continue in the rectifier circuit which aims to convert AC electricity to DC and then enter the capacitor as storage.

Table 1. Pin function on Arduino UNO

NO	PIN Arduino UNO	Description
1	5V	Foot potentio input 1 on resistive carbon
2	GND	Leg 3 potentio input on resistive carbon
3	Analog 0	Rotary shaft potentio output
3	Digital 9	Feedback output on gate leg mosfet

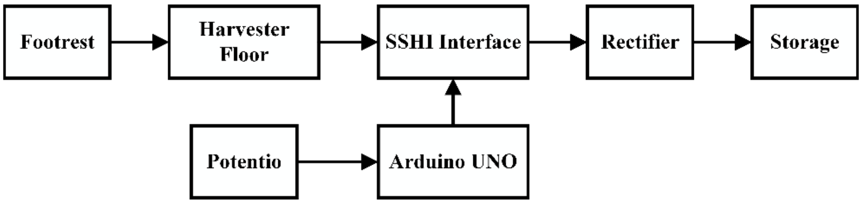

Fig. 3. Block Diagram of SSHI Connected Harvester System.

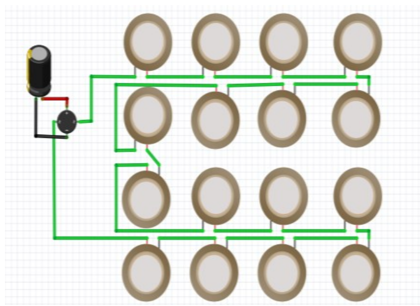

Fig. 4. Piezoelectric Circuit On Harvester Beach Not Connected SSHI Circuit

Fig. 5 is a system block diagram of the energy harvesting process interface using a harvester floor without connecting to SSHI, in the figure it can be seen that the input from the block diagram process above is the human footsteps which will enter the conversion process stage by piezoelectric sensors so that mechanical energy turns into electrical energy in the form of AC, the converted energy enters the rectifier circuit aims to convert AC electricity into DC and then enters the capacitor as storage.

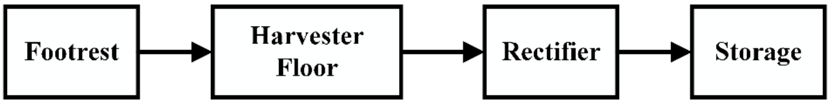

Fig. 5. Block Diagram of SSHI-Free Harvesting System

2.2. Software Design

Software design focuses on designing program listings using the Arduino IDE for making controller designs in the form of program listings using pin A0 as input and output using pin 9 which is connected to the Arduino UNO as a controller for the SSHI optimizer circuit in order to control the switch in the optimizer circuit through PWM connected to the potentio.

3. Results and Discussion

The data collection method uses a comparison method, namely comparing the harvester floor circuit connected to SSHI and the harvester circuit without SSHI by varying the stepping method, namely the number of steps and successive steps can be seen in Fig. 6.

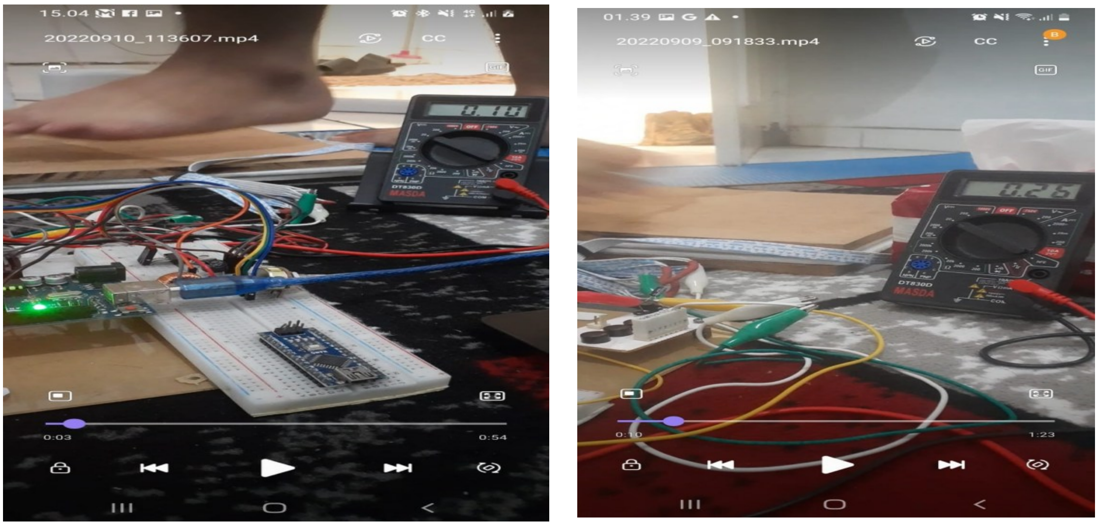

Fig. 6. Data retrieval using SSHI and without SSHI

3.1. Data Collection Based on The Number of Footholds

The data presented is a comparison of voltage and current in experiment 1 and experiment 2 connected to SSHI and without SSHI with the method of taking data based on the number of footholds with a range of 1 to 10 footholds with the aim of knowing the magnitude of the increase in voltage and current generated at each increase in footing, this can be seen in the comparison in Table 2.

In the data of Table 2 and Table 3, the comparison of voltage and current in the experiment without using SSHI, the first experiment obtained a peak value at the 8th step of 0.24 V and in the 2nd experiment obtained a peak value of 0.27 V at each additional foothold there was a spike and a derivative that looked unstable, this can be seen in the 3rd step in the 1st experiment getting a value of 0.15 V and in the 4th step getting the voltage down to 0.09 V as well as the 2nd experiment at the 8th step getting a voltage of 0.27 V at the 9th step down to 0.13 V. The comparison in the SSHI connected circuit gets a peak value in the 1st experiment of 0.19 V and in the 2nd experiment of 0.27 V each at the 10th step, in the SSHI connected table the voltage value produced is more stable than the voltage produced at the 10th step. Comparison in the SSHI connected circuit gets a peak value in experiment 1 of 0.19 V and in experiment 2 of 0.27 V each at the 10th step, in the SSHI connected table the voltage value produced is more stable compared to the voltage produced by the circuit without SSHI connected. For the current obtained following the voltage, the greater the voltage the smaller the current obtained. Data retrieval based on sequential steps.

In Table 4 and Table 5 discuss the comparison of the circuit connected to SSHI and without SSHI connected by taking voltage and current data based on successive footing. In the circuit data without connected SSI in experiment 1 get a voltage peak point at the 40-time footing of 0.46V and in experiment 2 get a peak point at the 20-time and 40-time footing of 0.37 V, in the circuit data without SSHI it can be seen that the voltage harvesting is not stable in experiment 1 10x footing of 0.26 V on the next footing to 0.21 V on the 20-time footing of 0.31 V on the 25-time footing of 0.27 V. It can be concluded that there are spikes up and down in voltage on some additional footing. In the SSHI circuit connected voltage data, experiment 1 gets a peak value of 0.79 V and in experiment 2 gets a peak value of 0.48 V, in the SSHI connected circuit the resulting voltage increases as the number of footholds increases. For the current obtained following the voltage, the greater the voltage the smaller the current obtained.

Table 2. Stress comparison based on number of footings

Stress by number of footings				
Number of Footings	**Without SSHI**		**With SSHI**	
	Trial 1(V)	**Trial 2(V)**	**Trial 1(V)**	**Trial 2(V)**
1 footing	0.06	0.08	0.06	0.05
2 footing	0.08	0.04	0.1	0.09
3 footing	0.15	0.09	0.13	0.11
4 footing	0.09	0.11	0.11	0.13
5 footing	0.14	0.12	0.11	0.11
6 footing	0.17	0.11	0.12	0.15
7 footing	0.19	0.08	0.13	0.2
8 footing	0.24	0.27	0.16	0.24
9 footing	0.21	0.13	0.16	0.27
10 footing	0.13	0.15	0.19	0.27
∑	**1.46**	**1.18**	**1.27**	**1.62**
Average	**0.146**	**0.118**	**0.127**	**0.162**

Table 3. Flow comparison based on number of footholds

Flow by number of footholds				
Number of Footings	**Without SSHI**		**With SSHI**	
	Trial 1(A)	**Trial 2(A)**	**Trial 1(A)**	**Trial 2(A)**
1 footing	0.567	0.425	0.567	0.68
2 footing	0.425	0.85	0.34	0.378
3 footing	0.227	0.378	0.262	0.309
4 footing	0.378	0.309	0.309	0.262
5 footing	0.243	0.283	0.309	0.309
6 footing	0.2	0.309	0.283	0.227
7 footing	0.179	0.425	0.262	0.17
8 footing	0.142	0.126	0.213	0.142
9 footing	0.162	0.262	0.213	0.126
10 footing	0.262	0.227	0.179	0.126

Table 4. Comparison of voltage based on successive steps

Current based on number of steps				
Number of Footings (time)	**Number of Footings**		**Number of Footings**	
	Trial 1(V)	**Trial 2(V)**	**Trial 1(V)**	**Trial 2(V)**
10	0.26	0.19	0.57	0.24
15	0.21	0.21	0.63	0.24
20	0.31	0.23	0.68	0.3
25	0.27	0.37	0.77	0.44
30	0.08	0.22	0.7	0.46
35	0.14	0.35	0.79	0.47
40	0.46	0.37	0.79	0.48
∑	**1.73**	**1.94**	**4.93**	**2.63**
Average	**0.247142857**	**0.277142857**	**0.704285714**	**0.375714286**

Table 5. Comparison of current based on successive steps

Current based on number of steps				
Number of Footings (time)	Number of Footings		Number of Footings	
	Trial 1(V)	Trial 2(V)	Trial 1(V)	Trial 2(V)
10	0.131	0.179	0.06	0.142
15	0.162	0.162	0.054	0.142
20	0.11	0.148	0.05	0.113
25	0.126	0.092	0.044	0.077
30	0.425	0.155	0.049	0.074
35	0.243	0.097	0.043	0.072
40	0.074	0.092	0.043	0.071

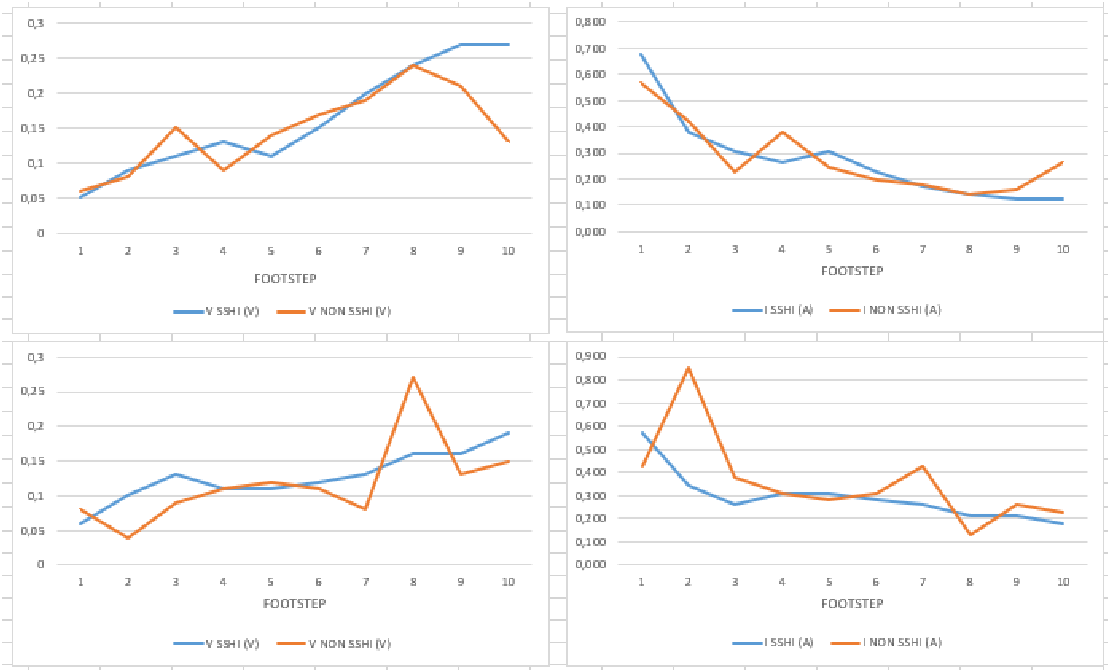

Fig. 7. Comparison Chart of Voltage and current based on the number of footings

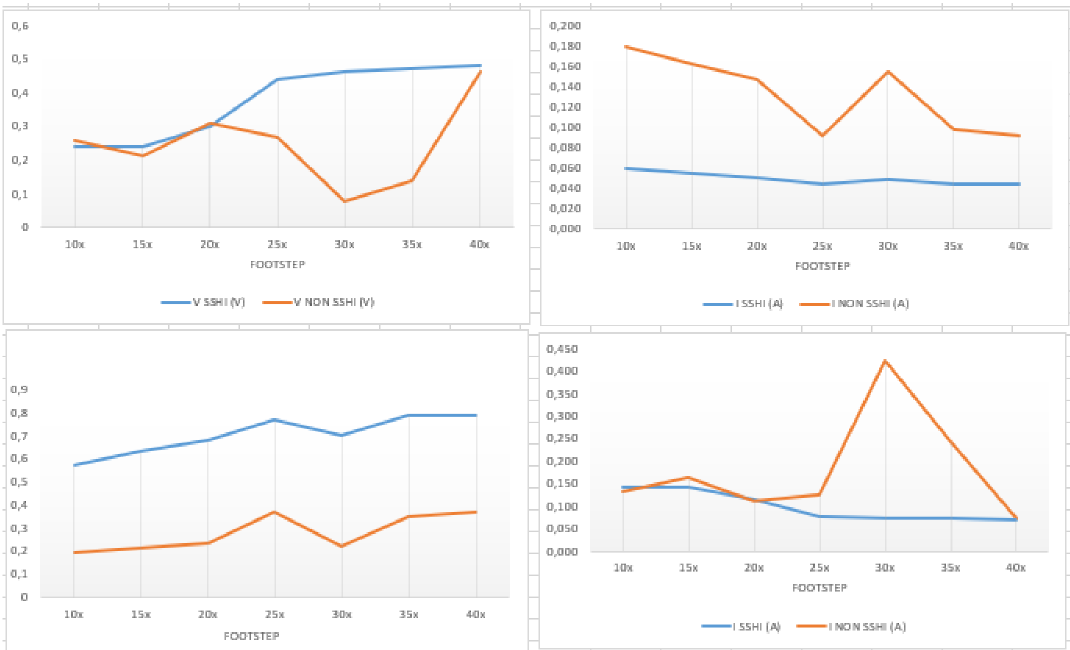

Fig. 8. Comparison Chart of Voltage and current based on continuous footing

4. Conclusion

Based on functional testing of energy harvesting devices with the synchronize switch harvesting inductor (SSHI) method, it can be concluded that energy harvesting on the harvesting floor by applying mechanical pressure which will be converted by piezoelectric into electrical energy. The harvester floor circuit coupled with the SSHI circuit makes the harvesting results more stable, each additional step will increase the voltage generated, successive steps accelerate energy harvesting. The first step will produce more power than the next step, in the test results the ability of the harvester to produce energy is 0.02 V - 0.06 V with a current of 0.04 A - 0.6 A.

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