Research on SECE interface circuit for micro wind harvesting system with piezoelectric structure

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Abstract. Micro wind harvesting system with piezoelectric structure is an attractive method to power micro electric devices in outdoor field work. Interface circuit is one of the keys to improve the efficiency of harvested energy. A SECE interface circuit is design with microcontroller, which monitors the voltage and generates pulse signal. A simulation is performed in Multisim software to validate the proposed circuit. Results show that the maximum output power of classic interface circuit is 128.118μW at 110KΩ, and it increases to 390μW with proposed SECE interface circuit. It indicates that the efficiency of harvested energy is improved by 200%.

1. Introduction

With the development of global economic, energy crisis is a growing problem for mankind. More and more researchers focus on the wind energy, vibration energy, mechanical energy and solar energy, which can be harvested from environment \cite{1}. Due to the advantages of clean, small size, and economical, wind energy harvesting with piezoelectric material is more attractive to power micro electric devices.

Piezoelectric structure converts the wind energy into vibration energy, and the electric energy is harvested by piezoelectric effect. Micro wind harvesting system with piezoelectric structure is suitable for low-power devices, such as wireless sensor node, Remote monitoring. Comparing with classic battery, it is friendlier to the environment, and do not need frequently replacement. A major limitation of its application is low efficiency of harvested energy, especially the interface circuit \cite{2-3}. Erturk designed a piezoelectric wind to harvest wind energy, and its output power achieves 10.7mW at wind speed of 9.3m/s \cite{4}. Bryant and Garcia proposed a wind energy harvester which output 2.2mW at 7m/s \cite{6}. Akaydin developed wind-induced vibration energy collector, the maximum power is 0.1mW at 1.192m/s wind speed \cite{5}.

In this paper, a SECE (Synchronous Electric Charge Extraction) interface circuit is designed to improve efficiency of micro wind harvesting system. With theoretical analysis, the proposed SECE interface circuit is simulated in Proteus and Multisim software. Results show that the efficiency of proposed SECE interface circuit is improved by 200% than classic interface circuit.

2. Controller design

2.1. Experimental setup
Test Results and Discussions The piezoelectric structure for micro wind harvesting is shown in Fig.1. When the wind blows through the block m, the aerodynamic force will push and vibrate the block. Then the piezoelectric patch is excited and electric charge is generated by piezoelectric effect. With proposed SECE interface circuit, the electric energy can be harvested and stored.

As shown in Fig.2, the proposed SECE interface circuit consists of 5 diodes, an inductor, and a capacitor. The four diodes in the left is similar with the classic interface circuit, work as a rectifier bridge. The right part with switch, inductor and capacitor is similar with classic Buck-Boost circuit. In some meaning, the proposed SECE interface circuit is a modified Buck-Boost circuit specially for application of micro wind harvesting system.

![Fig.1 Experimental setup](image1)

![Fig.2 Circuit diagram of micro energy harvesting system](image2)

![Fig.3 Waveform of voltage and current](image3)
The switch S is off for most of the time, and it will be turned on to on for a limited time span only when the block achieves a displacement maximum, as shown in Fig. 3. At time $t_0$, the block vibration reaches its maximum displacement and piezoelectric patch outputs its maximum voltage. The switch S turns on at time $t_0$, and electrical resonance will appear with the capacitor of piezoelectric patch and inductor L. The voltage on piezoelectric patch is zero after a quarter of the resonance period. That is, the energy on piezoelectric patch has been transferred to inductor L at the time $t_1$. The parallel resistor RL will consume the energy from inductor L and capacitor C1. The switch S turns off at the time $t_1$, and the above process repeats when the block reaches the opposite displacement.

In the time span $[t_1, t_0 + \frac{T}{2}]$, the displacement $u$ and voltage $V_{C0}$ on capacitor $C_0$ satisfy the following equation,

$$\alpha \dot{u} = C_0 \dot{V}_{C0}$$  \hspace{1cm} (1)

Integrate the above equation,

$$V_M = \frac{2\alpha U_M}{C_0}$$  \hspace{1cm} (2)

where $U_M$ is the maximum displacement of block $m$, $V_M$ is the maximum voltage on piezoelectric patch. Because the power loss on inductor L and switch S is very small, it can be ignored in theoretical derivation, then the output power is

$$P = \frac{1}{2} \frac{C_0 V_M^2}{\pi / \omega} = \frac{2\alpha^2 \omega U_M^2}{\pi C_0}$$  \hspace{1cm} (3)

where $\omega$ is frequency of wind induced vibration. Equation (3) indicates that the output power of SECE interface circuit will not change with the load.

### 2.2. Peak detection

In the proposed SECE interface circuit, a pulse signal is necessary for switch control at the time that voltage reaches its peak. Because frequency of piezoelectric structure vibration ranges from 5Hz to 10Hz, the test signal for peak detection modular is set to be 5Hz and 10Hz. The simulation of 5Hz sine wave is shown in Fig.4, microcontroller type MSP430F249 was chosen for the computing. When the voltage to port P6.0 reaches its peak, a pulse will be generated and sent out via port P2.0. A standard 5V voltage was connected to port AVCC, and port AVSS was grounded during the experiment. With IAR Embedded Workbench software, the hex file was downloaded to microcontroller and the result waveform is displayed in Fig.5. It indicates that the microcontroller can monitor the voltage of port P6.0. A pulse signal is generated in port P2.0 at the time port P6.0 monitor the voltage peak.
3. Circuit simulation

3.1. Classic interface circuit for micro wind harvesting system

Piezoelectric patch vibrated by wind was modelled by current source of 126μA, 10Hz and a 242nF parallel capacitor as shown in Fig.6. The rectifier bridge consists of four diodes type 1BH62, and the
capacitor C2 filter the high frequent noise to stabilize output voltage. Fig.7 that the maximum output power is 128.118μW at the load of 110kΩ.

![Simulation result of classic interface circuit](image)

**Fig.7 Simulation result of classic interface circuit**

### 3.2. SECE interface circuit for micro wind harvesting system

The SECE interface circuit for micro wind harvesting system is simulated in Multisim as shown in Fig.8. The four diodes and capacitor were the same as classic circuit, and inductor is 100mH. The period of switch S1 is 50ms, and its on-time is a quarter of the resonance period, that is, 276μs. Diode D5 of type 1BH62 can avoid the electric energy back to inductor L1.

![Simulation of SECE interface circuit](image)

**Fig.8 Simulation of SECE interface circuit**
The result of theoretical calculation and simulation is shown Fig.9. The output power of theoretical calculation is higher than the simulation, because the diode loss is ignored in theory. The power fluctuates slightly, when the load increases from 100kΩ to 300kΩ. This because the filter capacitor C2 is too small to remove voltage ripple. The power is stabilized at 390μW, when the load larger than 300kΩ.

4. Conclusion
A SECE interface circuit is design with microcontroller, which monitors the voltage and generates pulse signal. A simulation is performed in Multisim software to validate the proposed circuit. Results show that the maximum output power of classic interface circuit is 128.118μW at 110KΩ, and it increases to 390μW with proposed SECE interface circuit. It indicates that the efficiency of harvested energy is improved by 200%.

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