DC-DC Circuit Analysis for Harvesting Energy Using Piezoelectric and Electromagnetic Micro-Generators

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Abstract—**Inline with the advancement of low power circuit design, it has reduced the power requirements of electronic devices to the level of microwatts. As power demand decreases, the possibility of using energy harvesting systems as an alternative to batteries increases. However, for low power electronic application, the consistency of minimum voltage and current supply to the electronic devices is an important issue to be considered. This paper presents an outcome of DC-to DC step down IC MC34063A for harvesting energy using piezoelectric and electromagnetic. The simulation results of the circuit shows an output voltage of 3.3V with an input voltage of 5V from the micro-generators.**

Keywords—Energy Harvesting, Piezoelectric, Micro generator, Hybrid, DC-DC Converter.

I. Introduction

The use of energy harvesting technique has attracted the attention of researchers in ensuring effectiveness in powering the electronic devices. This technique extracts energy derived from ambient environment such as light, temperature gradient, vibration, radio frequency and converts into consumable electrical energy.[1, 2, 3]

Vibration source is selected in this project because it widely exits everywhere around us and produce relatively high acceleration level which is useful for electrical power generation even from household appliance such as blender and stand fan, vehicles and machineries as reported in .[4, 5]

There are three main transduction mechanisms employed to extract kinetic energy from vibration to electrical energy. These transduction mechanisms are piezoelectric, electromagnetic and electrostatic.[1, 4, 6] The focus of this project is using piezoelectric and electromagnetic micro-generator to convert the ambient vibration into useful electrical energy.

A. Piezoelectric

The research of energy harvester using piezoelectric received the great attention for the past decade due to its relatively high voltage generation.[7, 8, 9, 10].Typically, power source for small electronic device require a dc voltage of 3.3V.[11, 12] which is not an issue for piezoelectric, but the current generated is small therefore is not sufficient to maintain the operation of electronic devices, therefore a buck converter is needed to increase the current output.[5]

Generally, piezoelectric is used for converting mechanical energy derived from vibration, pressure or force into electrical energy.[1, 7] Piezoelectric material generates electrical charges when a proportional mechanical load is applied. In piezoelectric harvesting system as shown in Figure.1, piezoelectric extract energy from the vibration source usually from ambient environment and transform in to electrical energy and store in storage circuit, usually using the supercapacitor, which can be used for powering external load.
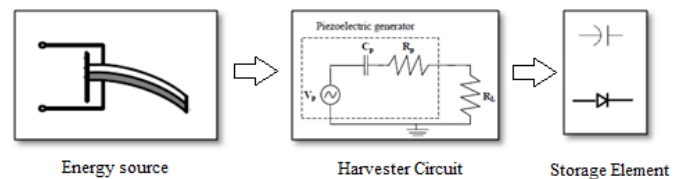

Figure 1: Piezoelectric harvesting system

B. Electromagnetic Micro-generator

Electromagnetic based micro generator is popular due to its simplicity in construction without the need of high-end fabrication facility. The essential of this micro generator is just consists of permanent magnets and magnetic coil.[11, 9].Electromagnetic micro-generators induce enable EMF on the coil from the movement of the permanent magnet based on Faraday's law.[11, 13].

The advantage of electromagnetic micro-generator is its relatively high current generation as a compensation of its output voltage[1, 9].

C. Hybrid

Hybrid energy harvesting system combining piezoelectric and electromagnetic (EMT) micro-generators is a solution for both of the micro-generators as low power sources [8, 7, 15]

because the micro-generators, when operate individually produce a limited electrical power which may not be enough to meet the minimum requirement of powering small electronic devices.[16]

In this research, the piezoelectric and electromagnetic are constructed in same housing but with two separated energy harvesting circuit entities to power up the same device in the systems as shown in Figure 2. The advantage of piezoelectric is able to generate relatively high voltage output which can compliment lower voltage output electromagnetic generator but with relative high current output. This is to optimize the performance of the energy harvesting system.

The Figure.3 shows a block diagram of the hybrid harvesting system using PZT and EMT. They are coupled together to work as a different system that present as an efficient output power.
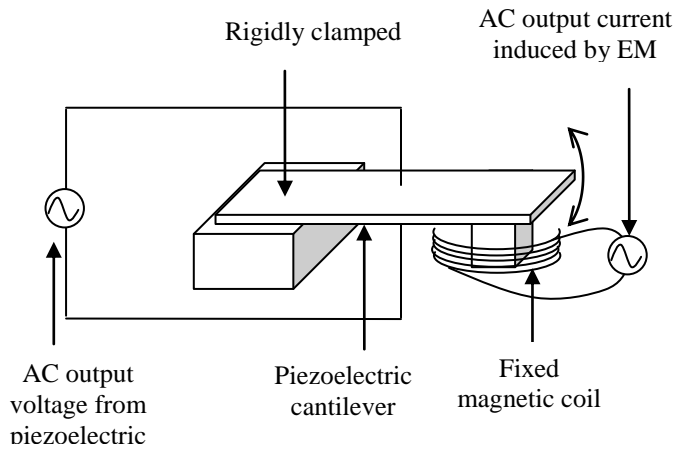

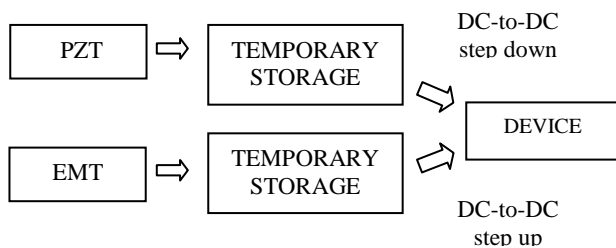Figure 2: Schematic diagram of hybrid piezoelectric and electromagnetic micro-generators

Figure 3: Block diagram of DC-to-DC circuit of the hybrid micro-generator

In order to obtain an efficient output power, it required both the high voltage and high current output. From $P=VI$, the voltage and current affect the power output. Since the current induced by EMT is relatively large at the range of a few mA but at low output voltage at the range of a few mV, therefore the power output is in the range of a few micro Watts. This is similar to power generated by piezoelectric generate relatively

large voltage at the range of a few Volt but at very low output current at a range of a few µA, therefore the output power is in the range of a micro Watts. A hybrid micro-generator generates total power as a summation of the power generated by individual micro-generator as in equation (1).

$$P_T = P_{EMT} + P_{PZT} \qquad (1)$$

II. DC-DC Converter

A. Buck Converter

Buck converter model which is known as a dc to dc step down converter is used to increase current output at the expense of the voltage output from the piezoelectric.

The basic buck converter shown Figure.4 consists of inductor and capacitor to store current and to smoothen the output voltage, with a MOSFET or BJT. The diode in the circuit is to ensure that the flow of the inductor current is in one direction and to discharge the capacitor through the load when the circuit is in "open" state. The voltage at the inductor equal to output voltage, $V_L = -V_o$.

When the switch is close, the diode becomes reverse biased and no current flow through. Positive voltage across the inductor is generated, $V_L = V_i - V_o$. The current through the inductor increase and charging the capacitor.
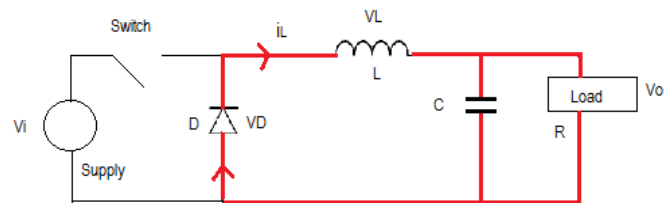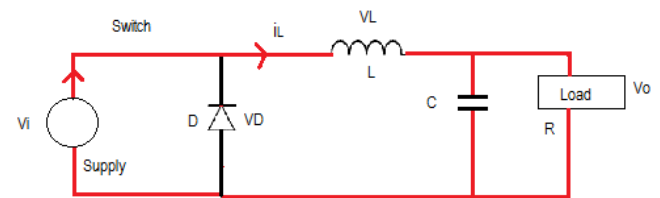

Figure 4: Buck converter in "open" state

Figure 5: Buck converter in "close" state

B. Boost Converter

Since the output voltage from the electromagnetic micro-generator is very small in the range of a few milivolt, therefore the boost converter is necessary to increase the voltage to a

useful level such as 3.3V or 5V, which is the minimum voltage requirement to power up small electronic device

In a boost converter the output voltage is always higher than the input voltage. The boost converter circuit usually contains a diode and a semiconductor switch. The capacitor and inductor in the boost converter is used as energy storage element. To reduce the output voltage ripple, usually capacitor and inductor is added to the output circuit [17].

In close state as shown in Figure 6, current flows through the inductor and switch. Inductor current starts to increase linearly. Diode in this state is reversed biased and energy is store in the inductor. When in open state as shown in Figure 7, diode become forward biased. Inductor current flows through the diode, capacitor and resistor, thus results in low current output.
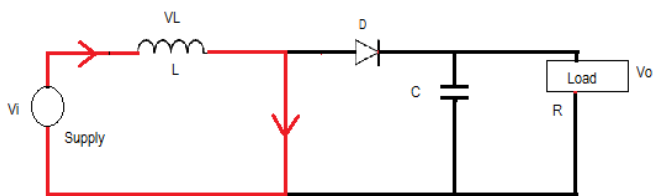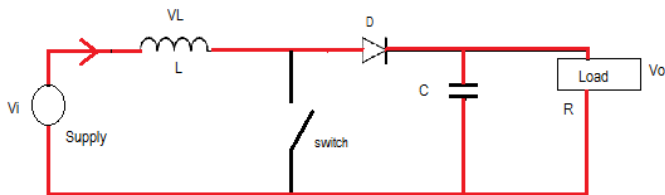

Figure 6: Boost converter "close" state.

Figure 7: Boost converter "open" state.

III. Simulation and Experimental Results

For piezoelectric application, MC34063A monolithic control IC is used for current limiting and output voltage adjustable. The functional block of MC34063A is shown in Figure 8 [18].

MC34063A consists of an internal temperature-compensated reference, a comparator, an oscillator, a PWM controller with active current limiting, a driver and a high-current input switch.MC34063A is containing all primary circuit therefore, is easy to use.

Protues ISIS Profesional software is used to simulate the step down circuit using MC34063A. The circuit for buck converter circuit with MC34063A is presented in Figure 9. An

oscillation AC input is used in this simulation circuit to represent either the piezoelectric or EMT generator.
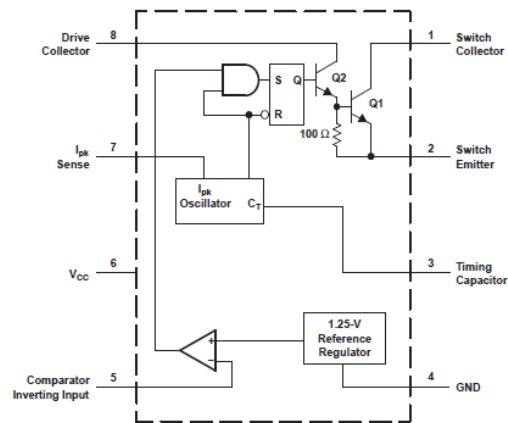
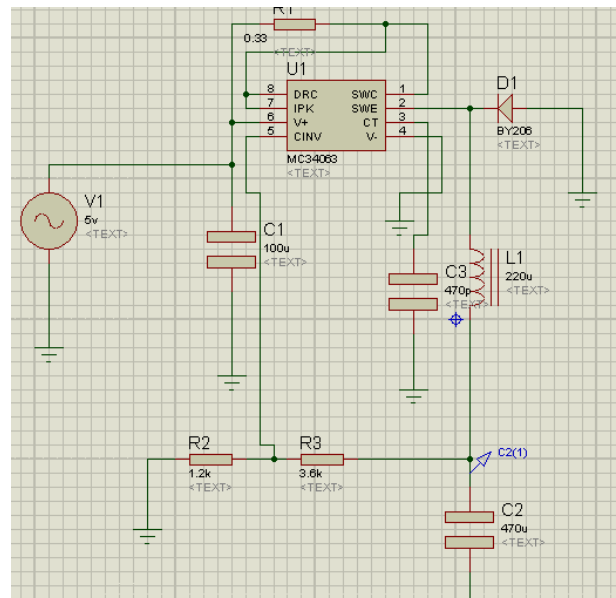

Figure 8: Block diagram of MC34063A

Figure 9: Circuit simulation of MC34063A

In order to prove that MC34063A is effective as a switching power supply, the output voltage should be at the level as desire. The value of inductor, L_1, capacitor, C_1, C_2 and C_3 and resistor R_1, R_2 and R_3 need to be considered. Value of R_2 and R_3 was chosen to design the control circuit by using equation (2).

$$Vout = Vref\,[(R3/R2)+1] \qquad (2)$$

For the simulation V_{ref} is chosen as 1.25V, where the *Vout* is the desired output voltage. The input capacitor C_1 is fixed at 100uF.

For the LC output filter, the inductor, L_1 is fixed at 220μH and capacitor, C_2=470pF.The voltage output level at desirable values 3.3 V is commensurate with 5 V of input voltage, and 5 V output voltage is commensurate with 10 V input voltage as shown in Figure 10.
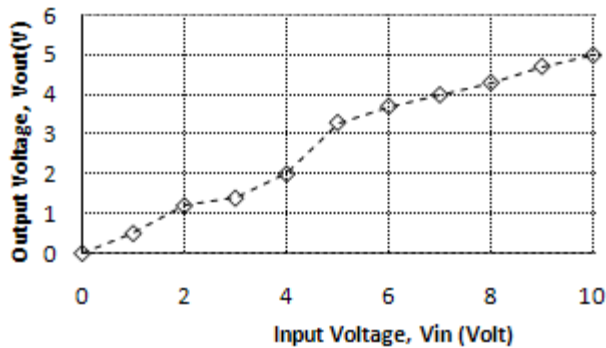

Figure 10: Output voltage Vs Input Voltage for experimental results using MC34063 A.

Theoretically, the piezoelectric output voltage is capping near to 5V, by using the MC34063A.It can be fixed at 3.3V, for most of the electronic applications, with proper design of the parameter of the discrete components which can be used to power up small electronic devices.

IV. Conclusion

DC-to-DC converter circuit is crucial for energy harvesting application due to unpredictive level of voltage and current generated. From the simulation results in this paper, it shows that MC34063A IC is effective in regulating the voltage output to the desirable level 3.3 V. The properly design of energy harvester circuit is important to deliver reliable and efficient voltage supply to electronic system from energy harvested through both piezoelectric and electromagnetic.

Acknowledgment

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