AC to DC Bridgeless Boost Converter for Ultra Low Input Energy Harvesting

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Abstract. This paper presents design of circuit which converts low input AC voltage to a higher output DC voltage. A buck-boost topology and boost topology are combined to condition cycle of an AC input voltage. the unique integration of a combining circuit of buck-boost and boost circuit have been proposed in order to introduce a new direct ac-dc power converter topology without conventional diode bridge rectifier. The converter achieved to convert a milli-volt scale of input AC voltage into a volt scale of output DC voltages which is from 400mV to 3.3V.

1. Introduction

In the current era of our technology, the supplies of fossil fuel are decreasing in a skyrocketing of energy generation costs, so the development of more advance methods in exploiting renewable energy sources are increasing. In a conventional way, power plant or battery are being used in supplying electricity which required electrical wiring and battery replacement. On the other hand, Energy harvesting is a technology that converts freely available energy in the environment into electrical energy which can be further used in low power electronics. The requirement for electronic devices has decreased because of semiconductor devices which lead to the development of technology like electronic devices, wireless sensors, medical implants etc. There are various sources for energy harvesting [1] such as solar, organic, vibration, thermal, near-field electromagnetic and far-field electromagnetic or Radio Frequency RF. Energy harvesting, or energy scavenging is a process where energy is captured from surrounding system's environments and extracted into useable electrical energy [2]. If there is an energy lost occur, the energy will be lost in form of heat, light, sound, vibration or movement. Energy harvesting are the greatest advancement in the power microelectronics technology which it can replace batteries for small and low power electronic devices.

This research mainly focuses on the development on the simulation of AC-DC boost converter for ultra-low input low energy harvesting to investigate it`s ability and developing the cost effective and environmentally friendly prototype. The design was simulated using power electronic simulation software (PSIM) to determine total energy converted from the power converter. The ability of the AC-DC converter was analyzed by the voltage and current output produced.

2. Methodology

2.1. Basic principle of AC-DC converter

AC-DC converters serve as a rectifier. A rectifier is an electrical devices that converts alternating current into direct current which periodically in reverse direction or polarity in a one direction [4]. It is called as rectification process. This rectifier has many applications such as component of power supplies and as the radio signal detectors. There are two basic concept of rectification which are full wave rectification and half wave rectification as shown in Figure 1. The function of diode is to clamp the negative side of the input voltage in both cases. For half wave rectification, only a single diode is used to clamp the negative side of input ac voltage to form a half positive side of waveform. Whereas, for the full bridge rectification, there is four combining diode that structured like a bridge. The diode then, will inverts the negative side of waveform and turns it into positive side and the result of the full wave is direct current.
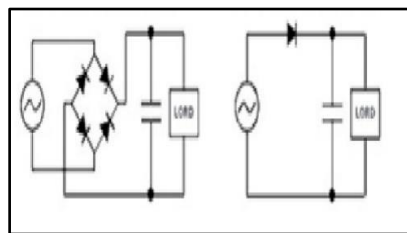

Figure 1: Operation of the rectification

After the conversion of direct current, the capacitor smoothed the waveform. The ripple of the waveform remained and as for the ripple voltage, it changed as a function of the of the capacitor and the load.

2.2. Buck-boost converter

Buck boost converter is a type of switched of mode power source that combine two type of converter which is buck and boost in a similar circuit. The circuit included in the category of non-isolated DC-DC converter which provides a regulated DC output voltage from either an AC or DC input voltage. In this case, the electronic switch used are MOSFET, which are opened and closed periodically by the converter. Furthermore, the circuit needs to operate in continuous current mode (CCM) because of the inductor never goes to zero and continuously supply the current for the output. Based on the duty cycle of the switching transistor, the output voltage was modifiable, and the polarity of the output voltage was inverse to the AC voltage input. Circuit diagram of buck-boost converter as shown in Figure 2[6].
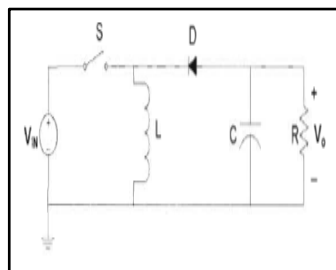

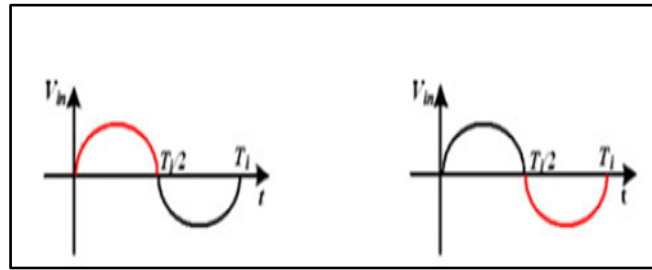**Figure 2.** Circuit diagram of buck-boost converter

Figure 3. The positive and negative half cycle [7]

There are 2 modes of operation for buck-boost converter:

Mode 1: when switch is turned ON, the diode will be in a reverse biased state. During this state, the inductor gets charged and the inductor current increased.

Mode 2: when the switch is turned OFF, the diode be in a forward biased state as it allows the current to flow from output to input. The energy stored in inductor directed to the load side and the inductor current now will drop until the switch get turned ON again in the next cycle.

2.3. Basic principle of the proposed circuit
The proposed bridgeless boost converter topology is a unique integration of boost and buck-boost converter. The boost converter is the common power conditioning interface due to its simple structure, voltage step-up capability and its high efficiency. While for the buck-boost converter, it literally has an ability to step up the voltage input with a reverse polarity for an instance, the converter managed to condition the negative cycle of the circuit. The advantages of this proposed circuit are both of the buck-boost and boost circuit shared the same single inductor and capacitor, this may led to the reduction of circuit size where it meet the weight and size requirement for this project. Secondly, for the very low voltage micro-generators, the output voltage is so small that its rectification is feasible by the use of MOSFET in the proposed circuit compared with the use of conventional diode which are not feasible at all. 0.4 V as an input voltage with 100 Hertz of frequency sinusoidal AC voltage is adopted to simulate the output.

2.4. Modes of operations
The proposed converter containing six modes of operation which divided into two half cycles, positive half cycle and negative half cycle. The circuit operates in positive half cycle from mode 1 until mode 3 whereas for the circuit to operates in negative half cycle is from mode 4 until mode 6. When the input voltage is in the positive half cycle, S1 is turned ON while the diode D1 is reverse biased, and the circuit operated in boost modes. When the input voltages are in negative half cycle, S2 is turned ON while the diode D2 is reverse biased and the circuit operated in buck-boost modes.

Mode 1: Switch S2 is in ON state at t0, at this state, the inductor is energized by the AC voltage input. As for load, it will be powered by output filter capacitor which had stored energy. Zero Current Switching also occur at this state in order to reduce the switching losses.

Mode 2: Switch S2 is turned OFF, the energy which had been stored in the inductor earlier in mode 1 will energized the load side.

Mode 3: When there is no more energy in the inductor, the inductor current will drop to zero. As soon as this happen, diode, D2 will be in the OFF state automatically. Then, here comes the capacitor to power up the load by using stored in it. The converter will return to mode 1 as soon as switch S2 is turned ON and still in positive half cycle.

Mode 4: Switch S1 is turned ON in this mode, the inductor again will be charged by the AC voltage input. Meanwhile, the energy stored in capacitor will feed the load.

Mode 5: Switch S1 is in OFF condition while on this mode. The energy stored in inductor during mode 4 will be used to feed load side. As the inductor current drop to zero, the diode D1 will turn ON automatically. In this mode, there is an occurrence of switching losses.

Mode 6: When diode D1 is in OFF state, it means that the inductor current had already reach zero. But, the capacitor will continue to power up the load side using the stored left in it. The converter will return to mode 4 if switch S1 is turned ON again and if it still in negative cycle.
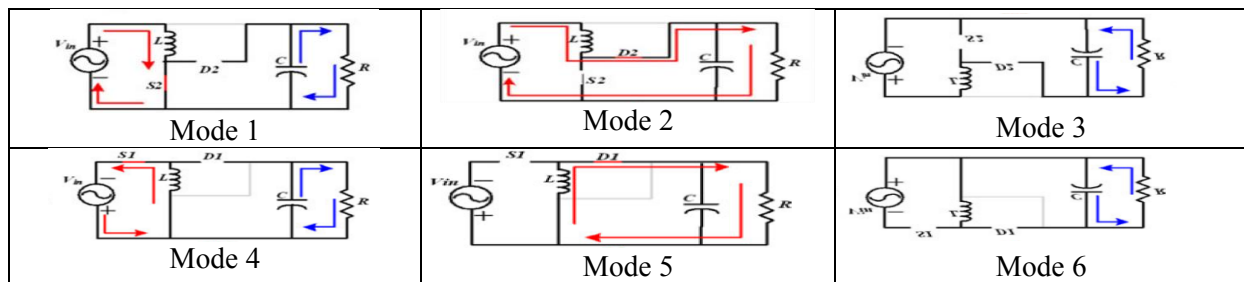

Figure 4. Operation Modes of Converter

2.5. Circuit Design
The proposed circuit contained a buck-boost circuit and boost circuit was simulated using PSIM software [5]. The proposed circuit is modelled and simulated in a closed loop operation. For the simulation in PSIM, the output of the proposed converter was around 3.4V direct current which are then is compared to a reference voltage of 3.3V and the error signal is given to a PI controller. The saturation blocks functions were to produce a hysteresis control that can limit the output of PI controller which mean, it can control the PI output to stay in the certain limits or range. Meanwhile, the saw-tooth waveform from signal generator were used to compared with the control voltage in order for gate pulses to detect the positive and negative peak in the cycle from the converter switches. The electromagnetic microgenerator represented by the sinusoidal AC voltage source in PSIM software to obtain a 3.3V DC as an output voltage. The simulation parameters are as shown below:

Table 1. Simulation parameter

Parameter	Specification
Input voltage	400mV, 100Hz
Switching Frequency	10KHz
Inductor	$4.7\mu H$
Capacitor	$1000\mu F$
Load resistance	200Ω

With the simulation parameter, the proposed circuit is now completed and successful. The circuit is simulated using PSIM software and being implemented in a closed loop control as shown in Figure 5.
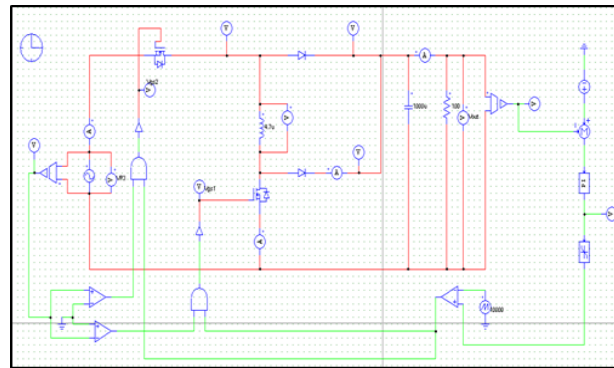
Figure 5. Bridgeless Boost Converter Circuit

3. Results and Discussion

Figure 6 shows the waveform generated for the converter circuit. The figure showed the input voltage is 400mV and the sinusoidal waveform tells that the input is AC voltage from the electromagnetic microgenerators. The figure also shows that the inductor operates during positive and negative half of cycle for the voltage input. The inductor is fully operated when the negative and positive half cycle are being conditioned by the input voltage. The AC voltage of the micro generator is being given to the proposed AC-DC step up converter which rectifies and boosts the AC voltage to a DC voltage of constant magnitude which is found to settle at 3.35V and 0.0166A. The waveform of a sawtooth voltage and PI controller act as a control voltage. The function of both of this voltage are to provide a gate pulses to be given to both switches where the PI controller voltage will cut the sawtooth voltage.
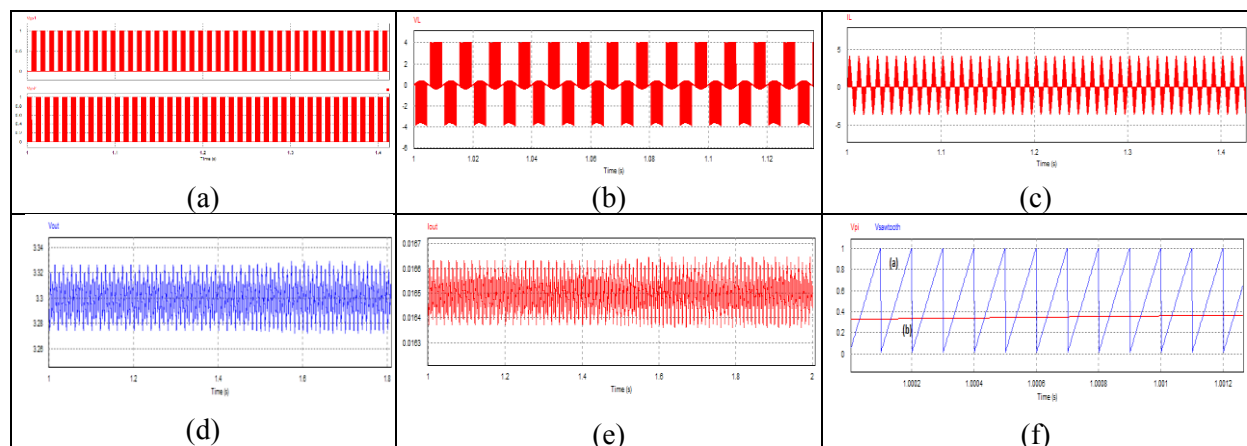

Figure 6. Waveform for the Buck-Boost Converter. (a) Positive & negative half cycle of both switches, (b) Inductor`s voltage, (c) the inductor`s current, (d) Output voltage, (e) Output current, (f) sawtooth voltage and voltage of PI controller

The simulation had been conducted to determine the DC output voltage and current waveform for low energy harvesting devices. Here, to get the desired of DC output voltage, the actual voltage was being compared to 3.3V which are the reference voltage. This is because the input voltage of the proposed circuit is connected to a transducer which getting its energy by converting mechanical energy to electrical energy. The converting process is done by electromagnetic coupling and the transducer used for this experiment are electromagnetic micro-generators which build from mass-spring damper based arrangement. As for the method used in this project, the buck-boost topology was combined with the boost topology. The reason why both topologies were combined together are

because buck-boost converter can operate the input voltage in a reverse polarity. So, it is the perfect candidate for the proposed converter to condition the negative half cycle of the switch. A performance`s comparison between the proposed bridgeless converter with the other low energy harvesting converter are depicted in Table 2. For a feedforward and feedback DC-DC PWM boost converter topology is proposed as in table. The system is designed to produce 35mW, but the system does not work well for low input voltages. As for the dual polarity boost converter system, the system works well for low input voltage, but the output power produced is only 23mW and the output voltages is 4.16V. It is not the desired output voltage for the low power converter energy harvesting project.

Table 2. The performance`s comparison of energy harvesting converters

Type of energy harvesting converters	Input voltage (V_{in})	Output voltage (V_{out})	Output power (P_o)
Feed-forward and feedback DC-DC PWM boost converter [9]	0.4V – 1.4V	3.3V	35mW
Dual polarity boost converter [10]	0.4V	4.16V	23mW
This work (bridgeless boost converter)	0.4V	3.3V	55mW

4. Conclusion

In this paper, the unique integration of a combining circuit of buck-boost and boost circuit have been proposed to introduce a new direct ac-dc power converter topology without conventional diode bridge rectifier. The feasibility of a new ultra-low input voltage power management circuit that act as the proposed circuit for micro-energy harvesting system has been demonstrated and simulated in the PSIM software. The proposed power converter circuit supplied by an AC sinusoidal voltage input are about 400mV had generated a boosted output voltage such as 3.35V will be successfully drives the low electronic load such as wireless sensors, low electronic devices and medical implants.

5. Acknowledgement

References

[1] J. M. Conrad, "A survey of energy harvesting sources for embedded systems," in *IEEE SoutheastCon* 2008, 2008, pp. 442-447.

[2] Wischke, M., Masur, M., Kroener, M., & Woias, P. Vibrating Harvesting In Traffic Tunnels To Power Wireless Sensors. *Smart Material and Structures*, pp. 1-8. 2011

[3] A. Sriramulu, B. Madhu. and A. Nachiappan, "Implementation of an efficient AC-DC converter for low voltage energy harvesting," *Engineering Education: Innovative Practices and Future Trends* (AICERA), 2012 IEEE International Conference on, Kottayam, 2012, pp. 1-6.

[4] M.N.M.Hussain, N. Ismail, "*Power Electronics* power semiconductors,conveters and applications", pp.51, 2010.

[5] Hemant Mehar, "The Case Study of Simulation of Power Converter Circuits Using PSIM Software in Teaching", pp.1-6. 2013

[6]   F. Saleemi, "Analysis and Design of Multiphase Multi-Interleave DC-DC Converter with Input-Output Bypass Capacitor," no. September, p. 119, 2008.

[7]   H. Wang, Y. Tang, and A. Khaligh, "A bridgeless boost rectifier for low-voltage energy harvesting applications," IEEE Trans. Power Electron., vol. 28, no. 11, pp. 5206–5214, 2013.

[8]   V. J. Abu, P. E. Sebastian, and P. R. P. Thomas, "A Comparative Study of Various AC-DC Converters for Low Voltage Energy Harvesting," vol. 3, no. 3, pp. 50–55, 2016.

[9]   X. Cao, W. J. Chiang, Y. C. King, and Y. K. Lee, "Electromagnetic energy harvesting circuit with feedforward and feedback dc-dc PWM boost converter for vibration power generator system," IEEE Trans. Power Electron., vol. 22, no. 2, pp. 679–685, 2007.

[10] M. M. Rahman, A. Riduan, M. Foisal, and A. Gafur, "AC to DC Converter for Low Voltage Small Scale Generator," *IOSR J. Electron. Commun. Eng. Ver. I*, vol. 10, no. 5, pp. 2278–2834, 2015.