IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

A Bridgeless Boost Rectifier for Energy Harvesting Applications

Rahul [*1], H C Sharad Darshan [2]
[*1,2] Dept of EEE, Dr. AIT Bangalore, India
Rahulhs.dsce@yahoo.com

Abstract

The proposed design compares a single-stage AC–DC power electronic converter to efficiently manage the energy harvested from electromagnetic micro and meso scale generators with low-voltage outputs. This topology combines a boost converter and a buck-boost converter to condition the positive and negative half portions of the input AC voltage, respectively. Only one inductor and capacitor are used in both circuits to reduce the size of the converter.

Generally bridge rectifier is very complicated in design structure and also increases the size of converter, it will require a more number of inductor and capacitor, diodes this will increases the power losses.

By using this bridgeless rectifier we can step up the input voltage efficiently and also reduces the losses, increases the efficiency of the converter.

Keywords: AC/DC conversion, boost, bridgeless, buck-boost, energy harvesting, low-voltage rectification.

Introductions

Kinetic energy harvesters convert mechanical energy present in the environment into electrical energy. The past decade has seen an increasing focus in the research community on kinetic energy harvesting devices[1]. Typically, kinetic energy is converted into electrical energy using electromagnetic, piezoelectric, or electrostatic transduction mechanisms. In comparison to electrostatic and piezoelectric transducers, electromagnetic transducers outperform in terms of efficiency and power density[2]. In this project, electromagnetic energy harvesters are considered for further study.

A general diagram of an electromagnetic generator is demonstrated in Fig. 1, where k is spring stiffness constant; m is the proof-mass; DE and DP represent electrical and parasitic dampers, respectively. Essentially, the energy harvesting system consists of a spring, a proof mass, and an electrical damper. The extrinsic vibrations excite the internal oscillation between the proof mass (magnet) and electrical damper (coils). The internal oscillation produces a periodically variable Magnetic flux in the coil, which induces a corresponding alternating output voltage.

Literature Survey

In energy harvesting systems, power electronic circuit forms the key interface between transducer and electronic load, which might include a battery[3]. The electrical and physical characteristics of the power conditioning interfaces determine the functionality, efficiency, and the size of the integrated systems. The power electronic circuits are employed to

1) Regulate the power delivered to the load, and
2) Actively manage the electrical

Damping of the transducers so that maximum power could be transferred to the load. The output voltage level of the micro and meso scale energy harvesting devices is usually in the order of a few hundred milli volts depending on the topology of device. The output AC voltage should be rectified, boosted, and regulated by power converters to fulfill the voltage requirement of the loads. Nonetheless, miniature energy harvesting systems have rigid requirement on the size and weight of power electronic interfaces.

Conventional AC-DC converters for energy harvesting and conditioning usually consists of two stages. A diode bridge rectifier typically forms the first stage, while the second stage is a DC-DC converter to regulate the rectified AC voltage to a DC voltage (see Fig. 1). However, the diode bridge would incur considerable voltage drop, making the low-voltage rectification infeasible.

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 1.852

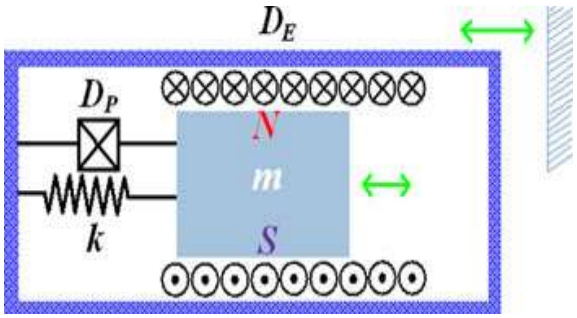


Fig. 1 General diagram of an electromagnetic micro generator.

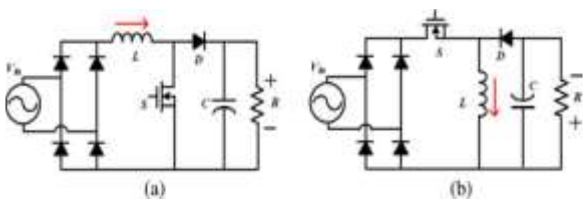
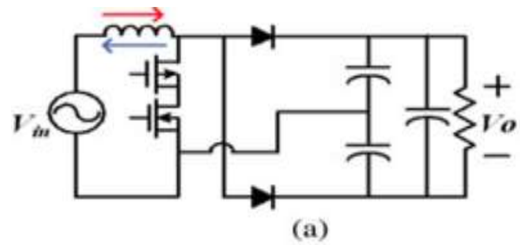


Fig. 2.Conventional two-stage diode-bridge ac–dc converters .(a)Boost rectifier. (b) Buck-boost rectifier.

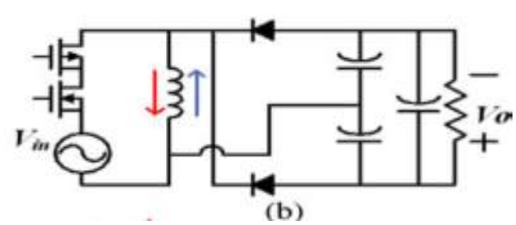
To overcome these drawbacks, CMOS diodes with low voltage drops are investigated in the bridge rectifiers, to substitute conventional p-n junction diodes. Such reported diodes include 1) diode-connected passive MOSFET, which adopts threshold voltage cancellation techniques and 2) MOSFET, which is actively controlled by a comparator. In either case, the low-voltage-drop diode techniques require either additional bias networks or external comparators. Thus, both the complexity and the power loss of the circuitry would increase. Some converters reported in the literature use transformers as the first stage boosters to overcome the voltage drop in semiconductor devices .However, the size of the transformer could be unacceptably large in low frequency energy harvesting applications.

Another approach to maximize the conversion efficiency in low-voltage rectification is to use bridgeless direct AC-DC converters .Those topologies both use bidirectional switches and split capacitors, or two parallel DC-DC converters to condition positive and negative input voltages separately. For the split-capacitor topologies [see Fig. 3(a)–(c)], due to the low operation frequency of specified micro generators, the capacitors have to be large enough to suppress the voltage ripple under a desired level. The increased size and number of energy storage components make those topologies impractical due to the size limitation of energy harvesters. On the other hand, the split capacitors could be eliminated by using two synchronous MOSFETs [see Fig. 3(d)]. However, the additional switches would incur extra switch loss and driving circuit dissipations.

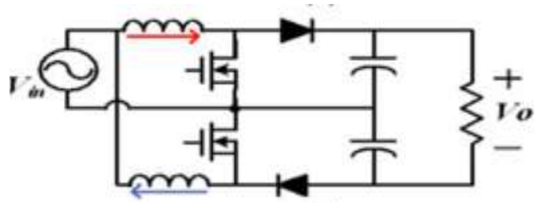


To overcome these drawbacks, CMOS diodes with low voltage drops are investigated in the bridge rectifiers, to substitute conventional p-n junction diodes. Such reported diodes include 1) diode-connected passive MOSFET, which adopts threshold voltage cancellation techniques and 2) MOSFET, which is actively controlled by a comparator. In either case, the low-voltage-drop diode techniques require either additional bias networks or external comparators. Thus, both the complexity and the power loss of the circuitry would increase. Some converters reported in the literature use transformers as the first stage boosters to overcome the voltage drop in semiconductor devices .However, the size of the transformer could be unacceptably large in low frequency energy harvesting applications.

Another approach to maximize the conversion efficiency in low-voltage rectification is to use bridgeless direct AC-DC converters .Those topologies either use bidirectional switches and split capacitors, or two parallel DC-DC converters to condition positive and negative input voltages separately. For the split-capacitor topologies [see Fig. 3(a)–(c)], due to the low operation frequency of specified micro generators, the capacitors have to be large enough to suppress the voltage ripple under a desired level. The increased size and number of energy storage components make those topologies impractical due to the size limitation of energy harvesters. On the other hand, the split capacitors could be eliminated by using two synchronous MOSFETs [see Fig. 3(d)]. However, the additional switches would incur extra switch loss and driving circuit dissipations.



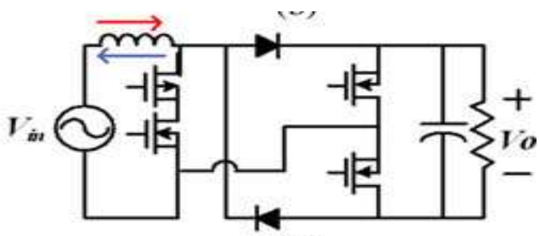
ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 1.852



(c)

Fig. 3 Bridgeless ac–dc converters

(a) Split capacitor boost converter. (b) Split capacitor buck-boost converter. (c) Dual polarity boost converter. (d) Boost converter with secondary switches.



(d)

The boost converter is the common power conditioning interface due to its simple structure, voltage step-up capability, and high efficiency. The buck-boost converter has ability to step up the input voltage with a reverse polarity; hence, it is an appropriate candidate to condition the negative voltage cycle. Besides, the boost and buck-boost topologies could share the same inductor and capacitor to meet the miniature size and weight requirements.

[1] Advances in low power VLSI design, along with the potentially low duty cycle of wireless sensor nodes open up the possibility of powering small wireless computing devices from scavenged ambient power. A broad review of potential power scavenging technologies and Conventional energy sources is first presented. Low-level vibrations occurring in common household and office environments as a potential power source. The main objective is not to suggest that the conversion of vibrations is the best or most versatile method to scavenge ambient power, but to study its potential as a viable power source for applications where vibrations are present. Different conversion mechanisms are investigated and evaluated leading to specific optimized designs for both capacitive Micro Electro Mechanical Systems (MEMS) and piezoelectric converters. Simulations show that the potential power density from piezoelectric conversion is significantly higher. Experiments using an off-the-shelf PZT piezoelectric bimorph verify the accuracy of the models for piezoelectric converters. A power density of 70mW/cm^3 has been demonstrated with the PZT bimorph. Simulations show that an optimized design would be capable of 250 mW/cm^3 from a vibration source with an acceleration amplitude of 2.5 m/s^2 at 120 Hz.

[2]Vibration energy harvesting is receiving a considerable amount of interest as a means for powering wireless sensor nodes. This project presents a small (component volume 0.1 cm^3, practical volume 0.15 cm^3) electromagnetic generator utilizing discrete components and optimized for a low ambient vibration level based upon real application data. The generator uses four magnets arranged on an etched cantilever with a wound coil located within the moving magnetic field. Magnet size and coil properties were optimized, with the final device producing 46 μW in a resistive load of 4 kΩ from just 0.59 m s^2 acceleration levels at its resonant frequency of 52 Hz. A voltage of 428 m Vrms was obtained from the generator with a 2300 turn coil which has proved sufficient for subsequent rectification and voltage step-up circuitry. The generator delivers 30% of the power supplied from the environment to useful electrical power in the load. This generator compares very favorably with other demonstrated examples in the literature, both in terms of normalized power density and efficiency.

[3] A summary of published techniques for power conditioning within energy harvesting systems is presented. The focus is on low-power systems, e.g, <;10mW, for kinetic energy harvesting. Published concepts are grouped according to functionality and results contrasted. The various techniques described are considered in terms of complexity, efficiency, quiescent power consumption, startup behavior, and utilization of the harvester compared to an optimum load. This paper concludes with an overview of power management techniques that aim to maximize the extracted power and the utilization of the energy harvester.

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 1.852

Block diagram

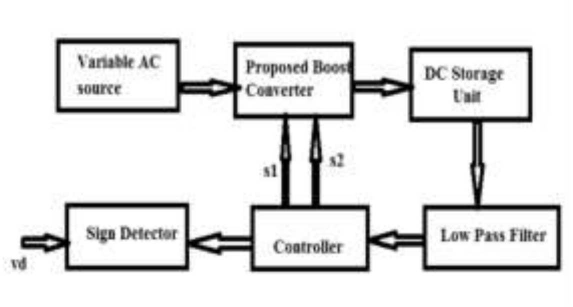


Fig.3 Block diagram of a proposed Boost converter

Proposed Boost Converter Method

A new bridgeless boost rectifier, shown in Fig. 4 which is a unique integration of boost and buck-boost converters, is proposed in this paper. When the input voltage is positive, S1 is turned ON and D1 is reverse biased, the circuitry operates in the boost mode. As soon as the input voltage becomes negative, the buck-boost mode starts with turning ON S2 and reverse biasing D2.MOSFETs with bidirectional conduction capability.

Circuit Diagram

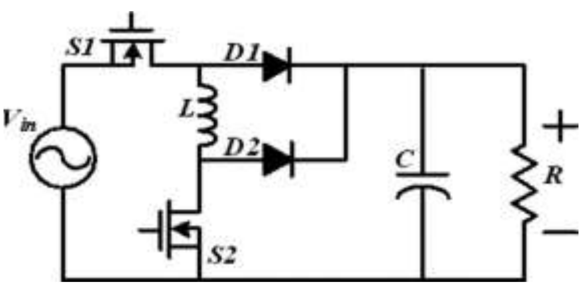


Fig.4 Proposed bridgeless boost rectifier for low-voltage energy harvesting.

Work as two-quadrant switches to ensure the circuitry functionality in both positive and negative voltage cycles. This topology was introduced in for piezoelectric energy harvesting applications.

Fig. 5 Operating modes of the proposed boost rectifier.

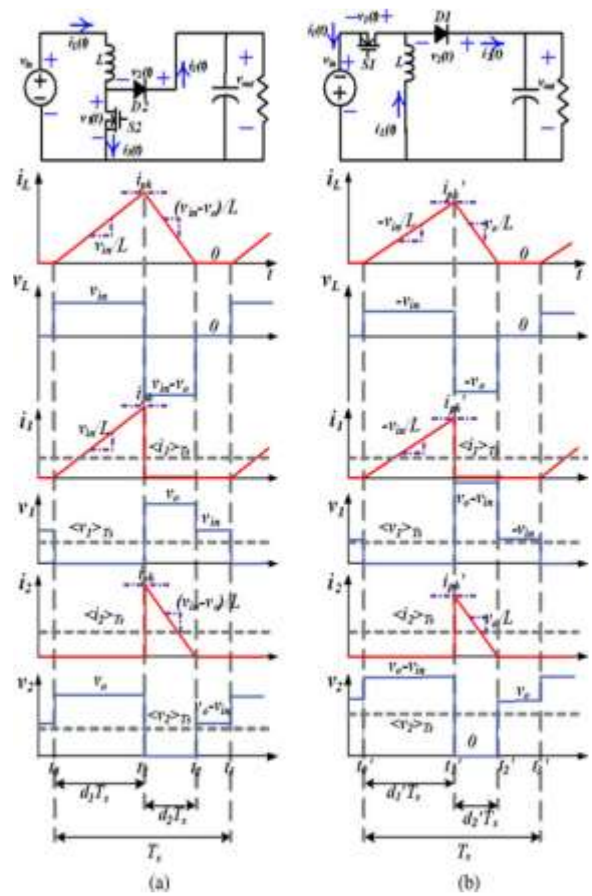
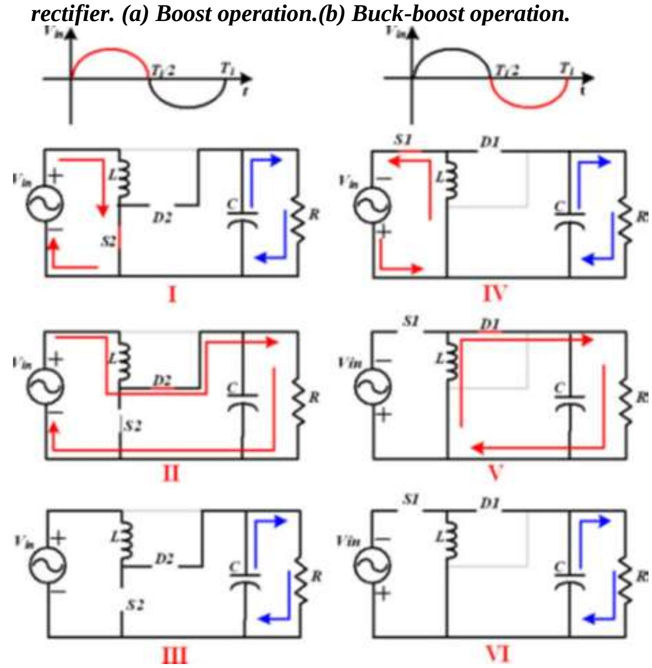


Fig.6 Waveforms of the proposed boost/buck-boost rectifier. (a) Boost operation.(b) Buck-boost operation.



ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 1.852

The DCM operating modes of the proposed boost rectifier are shown in Fig. 4. Each cycle of the input ac voltage can be divided into six operation modes. Modes I–III illustrate the circuit operation during positive input cycle, where S1 is turned ON while D1 is reverse biased. The converter operates as a boost circuit during Modes I–III, while switching S2 and D2. The operation during negative input cycle is demonstrated in Modes IV–VI, where S2 is turned ON while D2 is reverse biased. In these modes, the converter operates similar to a buckboost circuit.

Mode I: This mode begins when S2 is turned ON at t0. The inductor current is zero at t0 . The turn on of S2 is achieved through zero current switching (ZCS) to reduce switching loss. Inductor L is energized by the input voltage as both S1 and S2 are conducting. Both diodes are reverse biased. The load is powered by the energy stored in the output filter capacitor C.

Mode II: S2 is turned OFF at t1, where t1 − t0 = d1Ts ,d1 is the duty cycle of the boost operation, and Tsis the switching period. The energy stored in the inductor during Mode I is transferred to the load. The inductor current decreases linearly. During this mode, switching loss occurs during the turn on of diodeD2.

Mode III: D2 is automatically turned OFF as soon as the inductor current becomes zero at
t2 (t2 − t1 = d2Ts). This avoids the reverse recovery loss of diode. The load is again powered by the stored energy in the capacitor. The converter would return to Mode I as soon as S2 is turned ON, if the input voltage is still in positive cycle.

Mode IV: During the negative input cycle, Mode IV starts as soon as S1 is turned ON at t_ 0 . ZCS condition can also be achieved by ensuring the converter operation in DCM. The energy is transferred to the inductor L again, while the output filter capacitor C feeds the load.

Mode V: At t_ 1 , S1 is turned OFF, where t_ 1 − t_ 0 = d_ 1 Ts, d_ 1 is the duty cycle of the buck-boost operation. The energy stored in the inductor during Mode IV is transferred to the load. The inductor current decreases linearly. During this mode, switching loss occurs during the turn on of the diode D1. Mode VI: When the inductor current decreases to zero at
t_ 2 (t_ 2 − t_ 1 = d_ 2Ts), D1 is turned OFF at zero current. The load is continuously powered by the charge stored in the output capacitor. The converter would return to Mode IV as soon as S1 is turned ON, if the input voltage is still negative.

According to the analyses of operation modes, the switches are turned ON with ZCS and the diodes are turned OFF with ZCS. Due to the DCM operation, the input current sensor can be eliminated and switching loss can be reduced. Moreover, the control scheme of DCM operation is relatively simpler. Since the circuit size can be reduced and the efficiency can be enhanced, DCM operation is more suitable than continuous conduction mode (CCM) operation.

Control circuit for the proposed converter

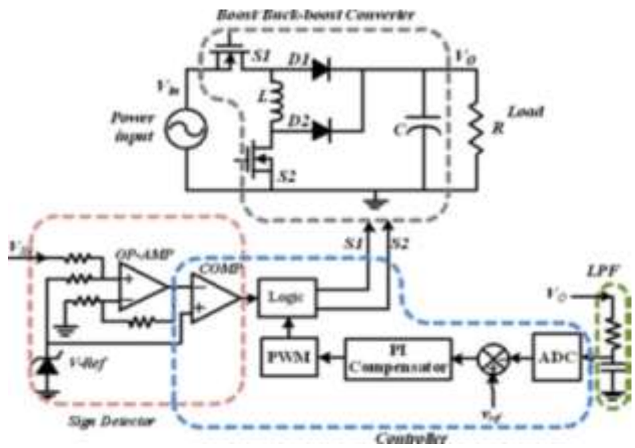


Fig.7 control circuit for the proposed converter.

Sign detector

A sign detector is used to determine the input voltage polarity. The sign detector is composed of a voltage reference, an op -amp, and the on-chip analog comparator. The op-amp operates as an analog adder, where a DC bias (voltage reference) is added to the input voltage. The signal summation is compared with the voltage reference to detect the polarity.

Controller

This paper proposed a new topology, which has the maximum power point tracking (MPPT) capability. However, the main objective of this paper is to introduce the circuit topology, which is capable of satisfying the voltage requirement (3.3 V) of an electronic load. Thus, a voltage feedback control loop is utilized to regulate the load voltage.

The converter is designed to operate in DCM. The output voltage is filtered by a passive low-pass filter and then fed to the analog-to-digital converter (ADC) of the controller.
The difference between the ADC output and the desired voltage is calculated and compensated through the PI algorithm to generate an adjustable

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 1.852

duty cycle signal. The switching signals of S1 and S2 are dependent on the polarity of the input voltage. A sign detector is used to determine the input voltage polarity.

Matlab simulation and result

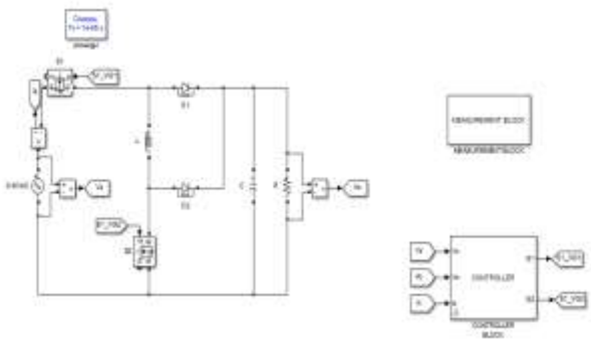


Fig.8 Proposed Simulink model

Design procedure

If the voltage gain is much larger than unity, according to (17) and (18), the boost and buck-boost operations share the same duty cycle D, which is determined by the boost ratio (Vo /Vm), the inductance of the inductor L, and the switching frequency fs. Equation (1) defines the commutation relationship of the duty cycle of the proposed boost/buck-boost converter

$$D = d1 = d'1 = 2Vo/Vm\sqrt{Lfs/R} \qquad (1)$$

The boost ratio is defined according to the specific application, while the load resistance R is dependent on the output power level. With the specified power and voltage demands, the inductance is designed according to the desired range of duty cycle and switching frequency. The larger the switching frequency is, the smaller the inductance would be. In order to design a smaller inductor with purpose of obtaining smaller size and weight, a higher switching frequency is preferred. However, the higher the switching frequency is, the higher the switching loss would be. A tradeoff between the size of inductor and the switching loss should be taken into account in the design process.

$$\Delta iL = vin\,(t)DTs/L \qquad (2)$$

The maximum current ripple corresponds to the peak input
voltage. According to previous analyses, the inductor, diodes, and MOSFETs share the same value of current ripple, which is defined in the following equation:

$$\Delta iL,max = VmDTs/L \qquad (3)$$

The voltage ratings of the MOSFETs and diodes are normally chosen higher than Vo with an appropriate margin for safe operation. The turn-on resistances of MOSFETs and the forward voltage drop of diodes are the major components, which impact the efficiency.

Control strategy

For a dynamic EM energy harvester system, if the external excitation frequency is different from the intrinsic resonance frequency, the PEI should be able to match its input impedance with the internal impedance of the harvester so that maximum power point (MPP) could be tracked. This paper proposed a new topology, which has the maximum power point tracking (MPPT) capability. However, the main objective of this paper is to introduce the circuit topology, which is capable of satisfying the voltage requirement (3.3 V) of an electronic load. Thus, a voltage feedback control loop is utilized to regulate the load voltage.

The simplified scheme of the controller and power stage is illustrated in Fig. 7. The converter is designed to operate in DCM. The output voltage is filtered by a passive low-pass filter and then fed to the analog-to-digital converter (ADC) of the controller.

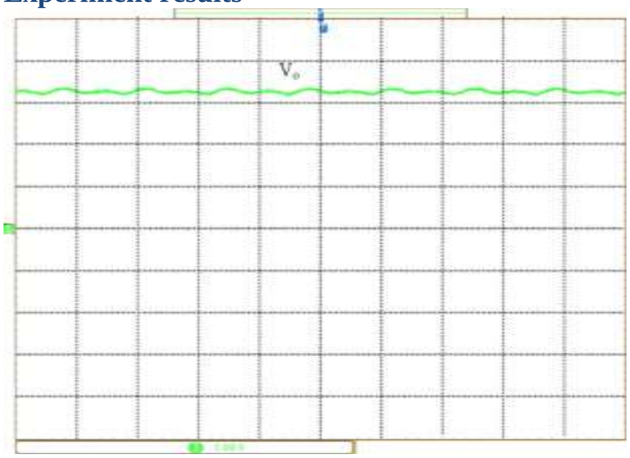
The difference between the ADC output and the desired voltage is calculated and compensated through the PI algorithm to generate an adjustable duty cycle signal. The switching signals of S1 and S2 are dependent on the polarity of the input voltage.

A sign detector is used to determine the input voltage polarity. The Atmel Mega 16 A is selected as the controller in this paper, which has both on-chip analog comparator and integrated ADC and can be integrated with the sign detector.

The sign detector is composed of a voltage reference, an opamp, and the on-chip analog comparator. The op-amp operateas an analog adder, where a dc bias (voltage reference) is added to the input voltage. The signal summation is compared with the voltage reference to detect the polarity.

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 1.852

Experiment results



The above fig.9 shows the required output of the proposed converter. In which the output voltage is increases up to 3.3V DC.

Conclusion

A single stage ac–dc topology for low-voltage low-power energy harvesting applications is proposed in this paper. The topology uniquely combines a boost converter and a buck-boost converter to condition the positive input cycles and negative input cycles, respectively. Only one inductor and one filter capacitor are required in this topology. A compact 2 cm×2 cm, 3.34-g prototype is fabricated and tested at 54.5 mW. This prototype successfully boosts the 0.4-V, 100-Hz ac to 3.3-V dc. Output voltage is tightly regulated at 3.3 V through closed-loop voltage control. The measured conversion efficiency is 71% at 54.5mW. In comparison to state-of-the-art low-voltage bridgeless rectifiers, this study employs the minimum number of passive energy storage components, and achieves the maximum conversion efficiency. The future research will be focused on investigating and designing integrated three-phase power electronic interfaces for electromagnetic energy harvesting.

References

1. *S. Roundy, P. K. Wright, and J. Rabaey, "A study of low level vibrations as a power source for wireless sensor nodes," Comput. Commun., vol. 26, no. 11, pp. 1131–1144, Jul. 2003.*
2. *M. El-hami, P. Glynne-Jones, N. M. White, M. Hill, S. Beeby, E. James, A. D. Brown, and J. N. Ross, "Design and fabrication of a new vibrationbased electromechanical power generator," Sens. Actuators A: Phys., vol. 92, no. 1 3, pp. 335–342, Aug. 2001.*
3. *S. P. Beeby, R. N. Torah, M. J. Tudor, P. Glynne-Jones, T. O'Donnell, C. R. Saha, and S. Roy, "A micro electromagnetic generator for vibration energy harvesting," J. Micromech. Microeng., vol. 17, no. 7, pp. 1257–1265, Jul. 2007.*
4. *R. Vullers, R. van Schaijk, and I. Doms, "Micropower energy harvesting," Solid-State Electron., vol. 53, no. 7, pp. 684–693, Jul. 2009*