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Boost Rectifier for Energy Harvesting Applications

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Abstract

Energy Harvesting is a method by which the energy is captured and stored so that it can be conditioned and used later. For energy harvesting many devices like electrostatic, piezoelectric and electromagnetic transducers are used. The output from transducers in the range of millivolt is to be rectified, boosted and regulated. So a new boost rectifier topology is designed for energy harvesting applications. This rectifier integrates both boost and buck-boost converters for conditioning the output. The rectifier is designed for an input voltage of 12 V (RMS) AC and an output voltage of 30 V (DC).

Keywords: Energy harvesting, boost rectifier, boost converter, buck boost converter, AC/DC conversion, bridgeless topology.

1. Introduction

Energy harvesting means it is a process of capturing and converting energy from sources like vibrations, piezoelectric devices, solar power, thermal energy, wind energy, salinity gradients, kinetic energy etc. into electrical energy . This energy is conditioned either for direct use or accumulated and stored for small wireless autonomous devices like wireless sensors, walkie talkie etc. This provides an alternative source of power for applications in locations where there is no grid power. The harvested energy is low and it cannot be used to power a device.

Most of the low-power electronics devices like remote sensors etc. are powered using batteries. However, these batteries must be replaced after few years. The replacements will be costly if there are a number of sensors in remote locations. Most energy harvesting applications are designed to be self-sustaining, cost effective and require only little servicing.

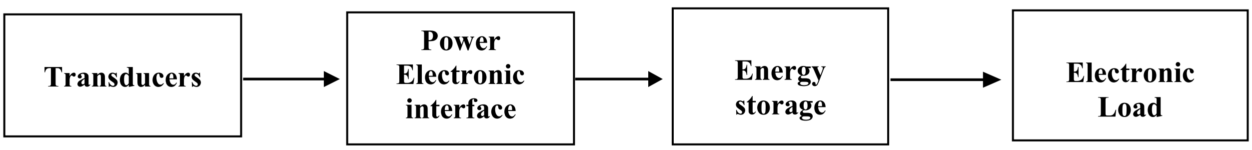

Fig 1- Block Diagram of Energy Harvesting system

In energy harvesting systems, power electronic devices are the key interface between transducer and electronic load. In certain vibration powered electrical generators, AC is produced which is to be converted to DC to feed the electronic load. These power conditioners regulate the power delivered to the load. Since the energy harvesting circuits provide an output of few millivolts, this is needed to be rectified and boosted in order to deliver it to the electronic load.

Conventional AC/DC converters mainly consist of two stages: A diode bridge rectifier and a DC-DC converter which regulates the rectified AC voltage. The voltage drop produced by the diode bridge rectifier due to the conduction of diodes is considerably high when it is used for low voltage applications. Later instead of Silicon diodes, CMOS diodes with low voltage drops were used. But these diodes also had drawbacks. In certain converters transformers were used to boost the voltage. However the size of transformer required for low frequency range is large. The new approach in the energy harvesting system is to use AC-DC bridgeless converters. Here the boost converter topology and buck converter topology is integrated to form bridgeless boost rectifier. The boost converter is a commonly used power conditioning circuit with simple circuit, voltage step-up capability, and high efficiency. The buck-boost converter has an ability to step up the input voltage with a reverse polarity and it would be useful to condition negative half-cycle. Here, both the converter topologies uses a common inductor and capacitor. Bridgeless boost converter consists of two switches S1 and S2, two diodes D1 and D2, one inductor L and capacitor C.

2. Modes of Operation

When the input voltage is positive, the circuit operates in boost mode. When the input is negative, the circuit operates in buck boost mode. The circuit operates in Discontinuous Conduction Mode (DCM). There are six modes of operation for the converter. During modes 1 to 3 the circuit operates in boost mode and during modes 4 to 6 the circuit operates in buck boost mode.

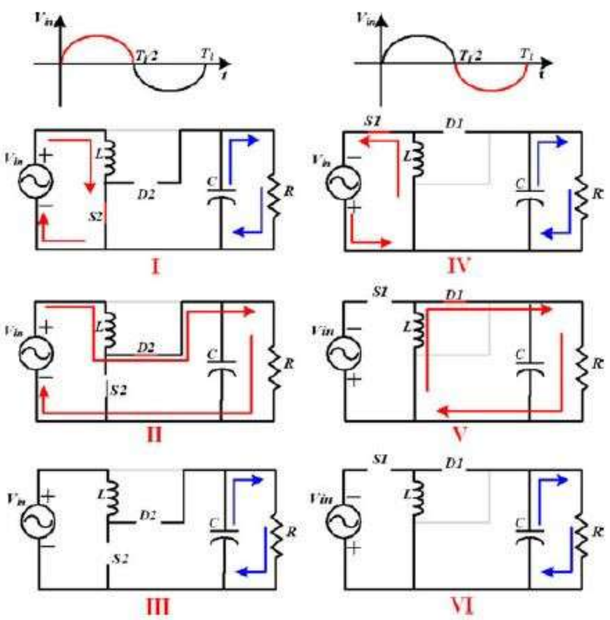

Fig.2-Modes of Operation

1. **Mode 1**: The switch S2 is turned ON at t0. The inductor current is zero at that time. The turn on is achieved through Zero Current Switching scheme (ZCS). Since S1 and S2 are conducting, inductor L is energised by the input voltage. Both diodes are reverse biased. The load is powered by the energy stored in the output filter capacitor C
.

2. **Mode 2**: S2 is turned OFF at t1, where $t1 - t0 = d1Ts$, d1 is the duty cycle of the boost operation, and Ts is 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 diode D2.

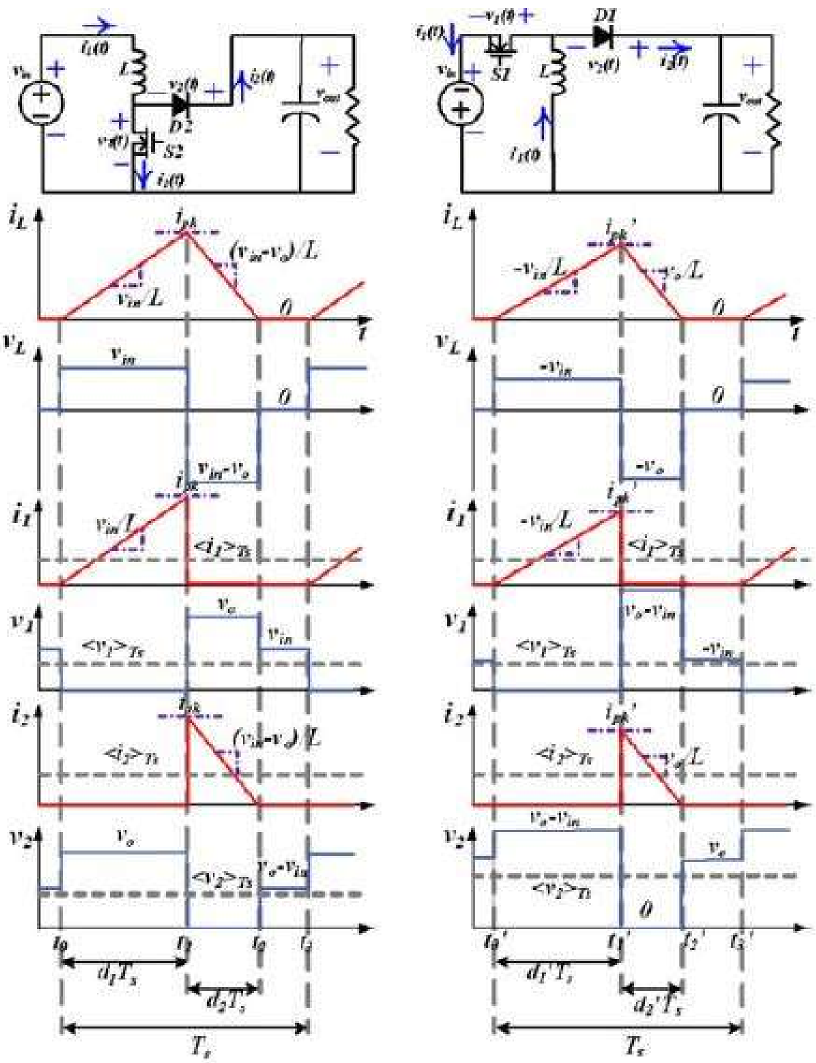

Fig.3 -Typical waveforms of Rectifier

3. **Mode 3:** 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.

4. **Mode 4:** During the negative input cycle, Mode IV starts as soon as S1 turned ON at t0'. 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

5. **Mode 5**: At t1', S1 is turned OFF, where t1' − t0' = d1Ts, d1 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..

6. **Mode 6:** When the inductor current decreases to zero at t2' (t2' − t1' = d2'Ts), 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.

3. Simulation Results

The boost rectifier is designed as a scaled up version of the power electronic interface which is actually used in energy harvesting applications. The boost rectifier works at an input voltage of 12 V (RMS) AC and at an output voltage of 25 V DC. The performance of the converter was first tested and evaluated by using the software MATLAB/Simulink version 2015a. The sampling used is discrete and the toolboxes used are Simscape and Sim-power system. A sampling time of 0.1 µs was given.

Table 1- System Specifications

Sl. No	System Parameters	Specifications
1.	Input Voltage	12 V (RMS) AC
2.	Output Voltage	25 V DC
3.	Switching Frequency	20 kHz
4.	Inductor	26 µH
5.	Capacitor	1000 µF
6.	Duty ratio 1	0.8
7.	Duty ratio 2	0.2

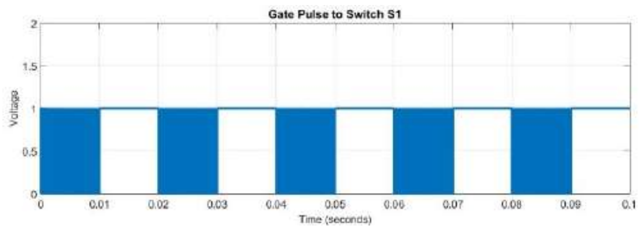

Fig. 4- Gate Pulse to S1

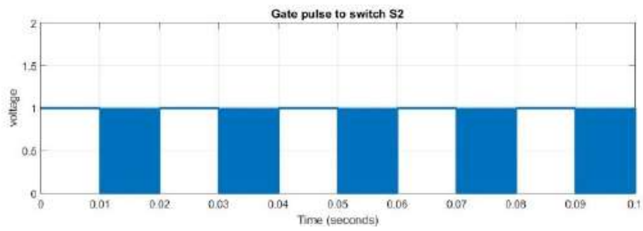

Fig 5-Gate Pulse to S2

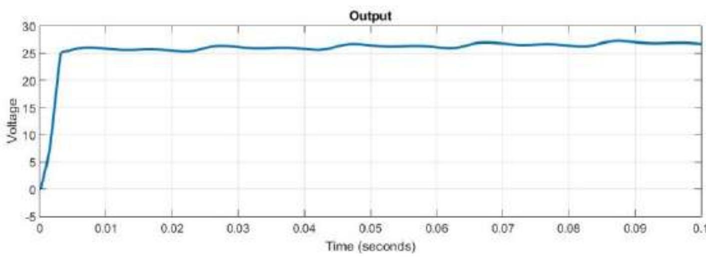

Fig 6- Output Voltage Waveform

4. Comparison with Conventional Energy Harvesting Systems

The boost rectifier and conventional energy harvesting system was simulated with the same constraints. The settling time of output voltage is more for conventional system when compared to that of bridgeless boost rectifier. Also the boosting action for the conventional system is less. Moreover the boost rectifier produces higher voltage than the conventional system because of its duty ratio. By using duty ratio the output voltage of the boost rectifier can be controlled whereas the output voltage of the conventional system cannot be controlled. Fig.7 and fig.8 shows the comparative analysis.

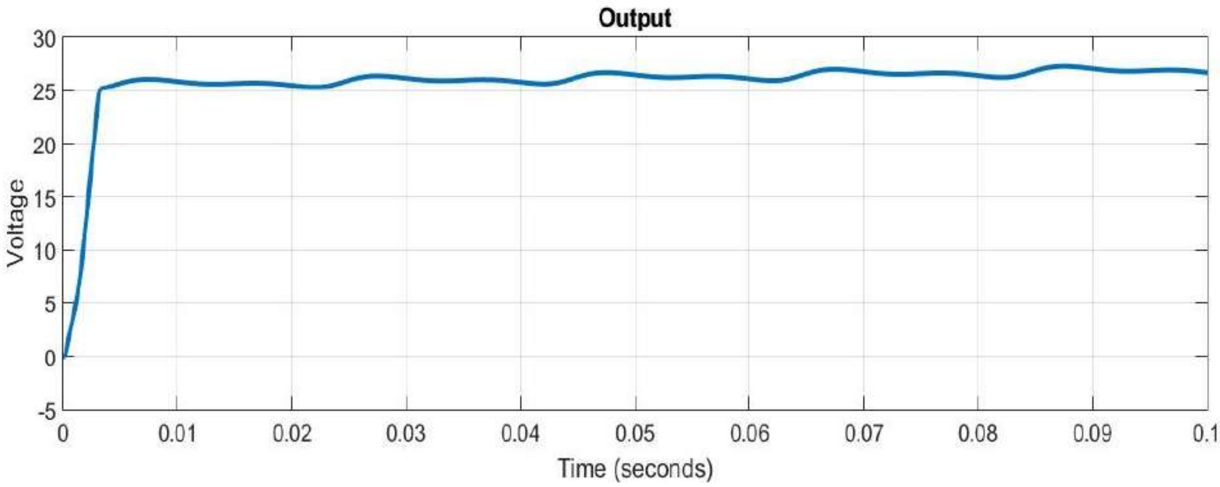

Fig.7-Output voltage of bridgeless boost rectifier

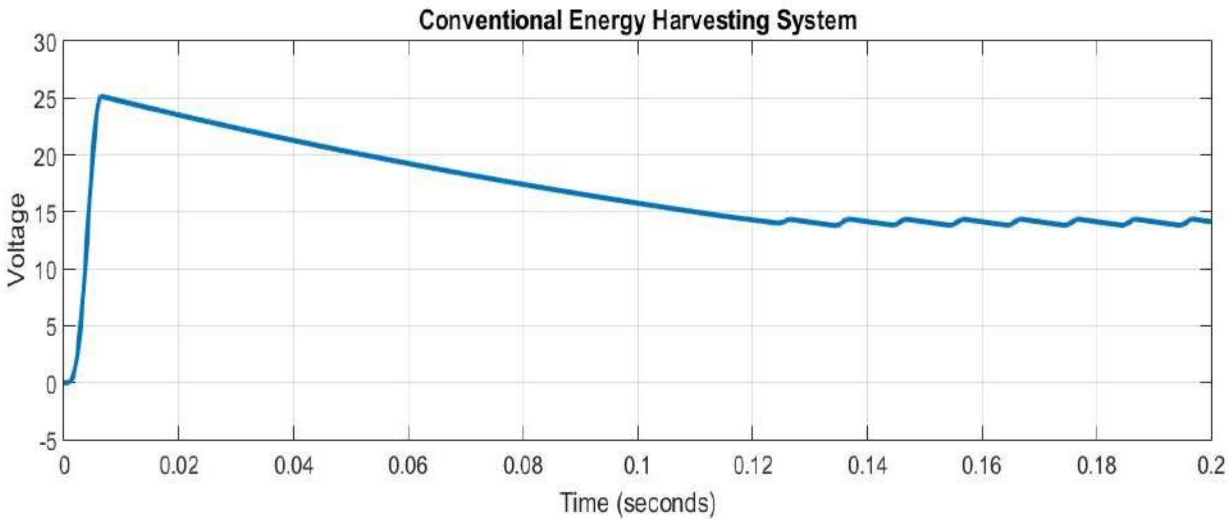

Fig.8-Output voltage of conventional energy harvesting system

5. Conclusion

The rectifier integrates both boost and buck-boost converters. In the positive half cycle, the circuit acts as a boost converter and in the negative half cycle the circuit acts as a buck-boost converter. The circuit is operated in discontinuous conduction mode (DCM) so that the switching losses can be reduced and control circuitry for DCM is simple. The conversion efficiency is more when compared to that of conventional rectifiers. Conduction losses are less. The disadvantage is that the rectifier has switching losses. When compared to the conventional energy harvesting systems this rectifier shows better performance in boosting the output obtained from harvesters. This type of rectifier can be used in resonant circuits, medical fields, communication devices used in remote areas etc.

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