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A Bridgeless Boost Converter Using Boostand Buck-Boost Strategyfor Low Voltage Energy Harvesting Applications

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ABSTRACT:The output voltage range of micro and mesoscale energy harvesting equipment is normally equal to some hundred millivolts based on topology of the system. The AC output voltage should first rectified next boosted and then regulated by power electronic converters to meet load voltage requirements. Miniature voltage energy harvesting system necessitates fixed requirement of size and shape for interfacing of power electronic devices. In conventional energy harvesting AC-DC converters it consists of two stages; first stage is diode bridge rectifier for AC-DC conversion and second stage is DC-DC converter which regulates the rectified output but in this conventional converters the major drawback is large voltage drop which makes the low-voltage rectification with lower output and higher losses. The proposed “bridgeless boost rectifier” combines boost and buck-boost converters which has bidirectional conduction capability for AC-DC conversion and it is single stage converter. In this paper input AC 0.4v is rectified and stepped up to 3.3v DC. The size of the converter is made compact by using single inductor and capacitor. The results are verified by using MATLAB simulation.

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

I. INTRODUCTION

Kinetic energy harvester converts mechanical to electrical energy. Generally kinetic energy is converted into electrical energy by using piezoelectric, electromagnetic or electrostatic transducer mechanism [1]. In comparison to electrostatic and piezoelectric transducers, electromagnetic transducers performs in terms of efficiency and power density [2]. By this study, electromagnetic energy harvester is considered for future analysis.The key interface in energy harvesting systems is power electronic circuits [3]. The power electronic circuits are employed to control the power delivered to the load and manages the electrical oscillations of the transducer for maximum power transferring to the load. For output voltage rectification and boosting of electrical output of energy harvester the bridgeless boost converter is used.

Conventional AC-DC converters for energy harvesting commonly consists 2 stages. A diode bridge rectifier typically forms the first stage and the second stage is a DC-DC converter to regulate the rectified AC voltage to a DC voltage (fig. 1). But, diode bridge rectifier subject voltage drop and makes the rectification infeasible [4].

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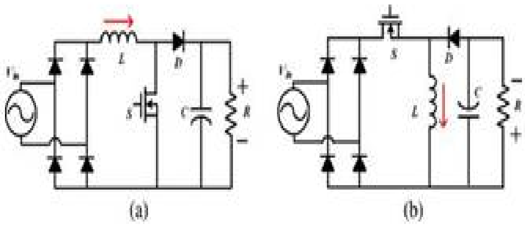


(a) (b)

Fig. 1: Conventional two-stage diode bridge AC-DC converters.

A new bridgeless boost rectifier, shown in fig. 2, it is integration of boost and buck-boost converters, which is proposed in this paper. When the input voltage is positive S1 is turned ON and D1 is reverse biased then the circuitry operates in the boost mode [5]. As soon as the input voltage becomes negative, the buck-boost mode starts with turning ON S2 and reverse biasing D2 [6].

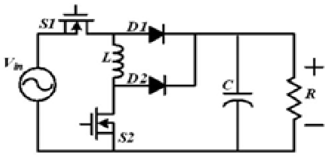


Fig.2: Proposed bridgeless boost rectifier for low-voltage energy harvesting.

II. PRINCIPLE OF OPERATION

In this paper , a 0.4V, 100Hz sinusoidal ac voltage source is taken to build the output of the electromagnetic energy harvester. The circuit operates in discontinuous mode and the operation modes of the proposed boost converter are shown in fig. 3. Each cycle of input ac voltage can be divided into 6 operation modes. Modes I–III gives the circuit operation during positive half cycle, where S1 is turned ON while D1 is reverse biased and converter operates as boost converter during Modes I–III, while switching S2 and D2. The operation during negative half cycle is shown in Modes IV–VI, where S2 is turned ON and D2 is reverse biased. In these modes, the converter operates as buck-boost circuit [7].

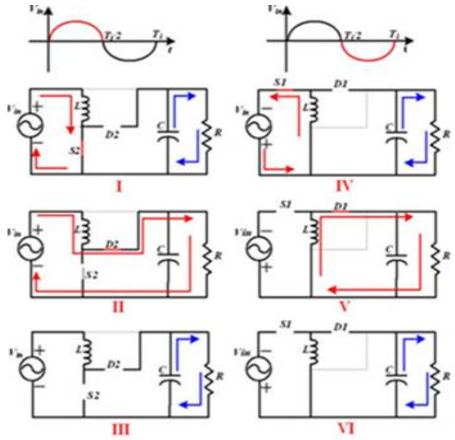


Fig.3: Modes of operation of proposed converter.

Mode I: This mode starts when S2 is ON at t_0 and at t_0 the current through the inductor is zero. The S2 is turned ON by ZCS for reduction of switching losses. When S1 and S2 starts conducting inductor L will get energized by input voltage. Here both diodes were reversed biased. The load is supplied by the energy stored in the output filter capacitor C.

ModeII: Here S2 is turned OFF at t_1, where t_1-t_0=d_1T_s, where d_1 is the duty cycle of boost operation, $T_s$is the switching period. The load is supplied by the energy stored in the inductor during mode I.

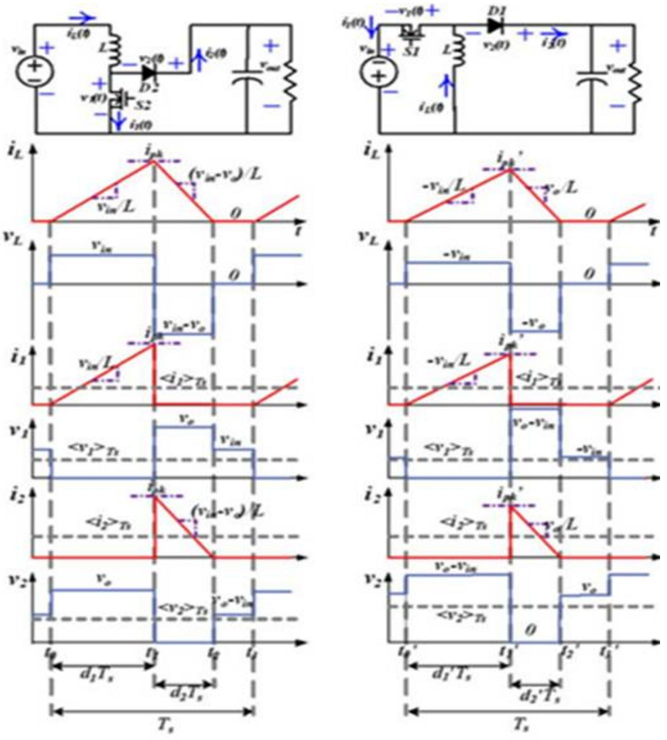
Mode III: D2 turned OFF by itself when the current through inductor become equal to zero at t2 (t2-t1 = d2TS). The load is supplied by the energy stored in the capacitor. The converter will put back to mode I if the input0voltage is still0in positive half cycle.

Mode IV: The buck-boost operation is preferred for negative half cycle. During negative half cycle of input voltage, this mode starts when S1 is ON at t`0. The input voltage supplied will energizes the inductor and the load is supplied by the energy stored in the capacitor.

Mode V: At t`1, S1 is turned0OFF, where t`1 – t`0 = d`1 Ts, where d`1 is the0duty cycle of0buck-boost converter. The load is transferred by the energy stored in the inductor during mode IV.

Mode VI: When current through0inductor decreased to0zero at t`2, D1 turns OFF at zero0current. The load is supplied by the energy stored in the output capacitor. Mode IV to mode VI operation will be done when input voltage is still negative [8].

Here discontinuous operation is preferred than continuous operation.



(a) (b)

Fig. 3: Waveforms of proposed converter (a) Boost operation (b) Buck-boost0operation.

III. DESIGN PROCEDURE

The duty cycle of the proposed boost or buck-boost converter is,

$$D = d_1 = \grave{d}_1 = \frac{2V_0}{V_m}\sqrt{\frac{Lf_s}{R}}$$

The load resistance depend upon the output power level. Based on the power and voltage levels inductor is designed in accordance to the switching frequency and duty cycle. The inductance will be small for large switching frequency. For small size and weight requirement the inductance is maintained at small value with large switching frequency. But higher the switching frequency the losses will also become high so a tradeoff between the switching and size of the inductor should took for design [9].

Inductor current ripple for both buck and buck-boost operation is same,

$$\Delta i_L = \frac{V_{in}(t)DT_s}{L}$$

The maximum current ripple corresponds to the peak input voltage is,

$$\Delta i_{Lmax} = \frac{V_m DT_s}{L}$$

IV. CONTROL STRATEGY

The simplified controller scheme for proposed converter is shown in fig. 4. The converter is designed for DCM operation. The passive low-pass filter is used for the output voltage filtering and this is fed to ADC of the controller. The difference between desired output and ADC output is calculated and compensated by the PI controller to generate the suitable duty cycle [10].

To determine the input voltage polarity a sign detector is used. The switching signals S1 and S2 are dependent on the polarity of the input voltage. The sign detector is composed of a voltage reference, an op-amp and on-chip analog comparator.

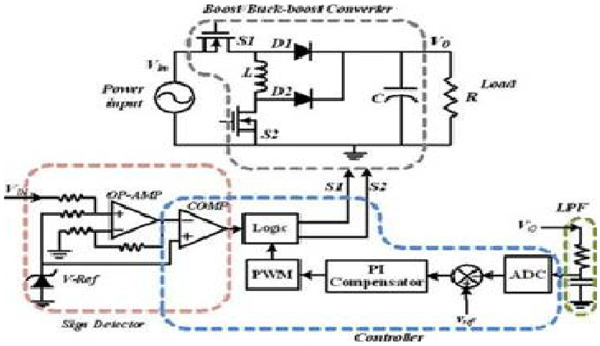


Fig. 4: Control circuit0for proposed converter

V. RESULTS AND DISCUSSION

5.1 Modelling of closed loop bridgeless boost rectifier using MATLAB:

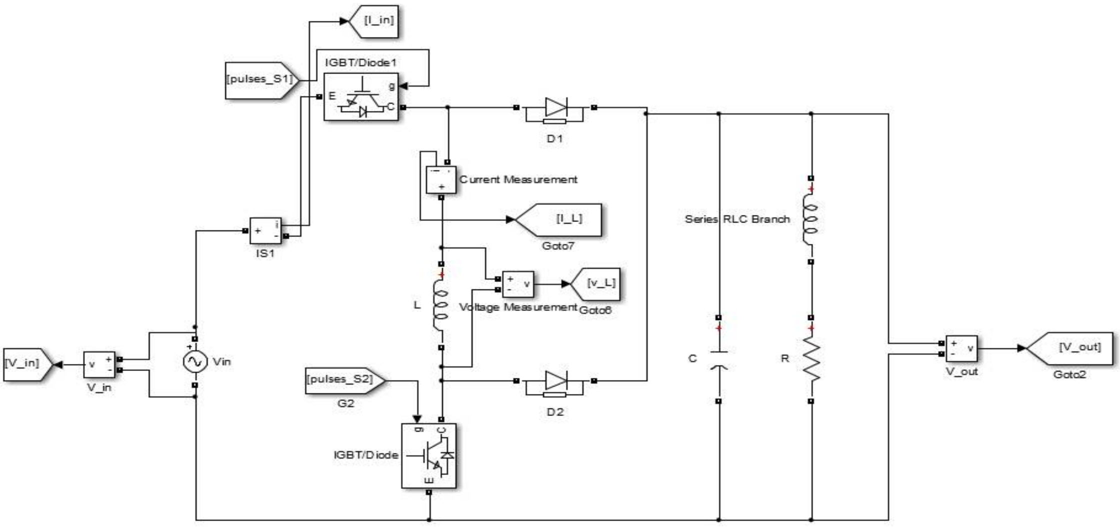


Fig.5: proposed closed loop model of bridgeless boost converter.

Fig. 5shows the closed loop simulation model of proposed bridgeless boost converter. Here the input voltage is 0.4V AC with 100 Hz input frequency. Which is rectified and boosted to 3.3V DC voltage through bridgeless boost converter. Here the voltage drop is very less. The load resistance used here is 200ohms.

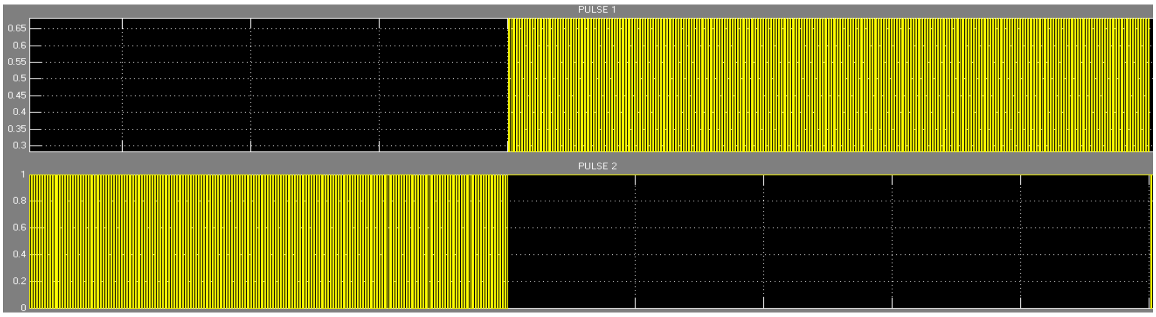


Fig. 6: Gate pulses of proposed closed loop bridgeless boost converter.

Fig. 6 shows the simulated model of gate pulse generation for proposed bridgeless boost converter. Here the switching frequency is 50K Hz. Pulses are generated with the help of closed loop model by using PI controller. The generated controlled output from the PI controller is input to the gate pulse generation model.

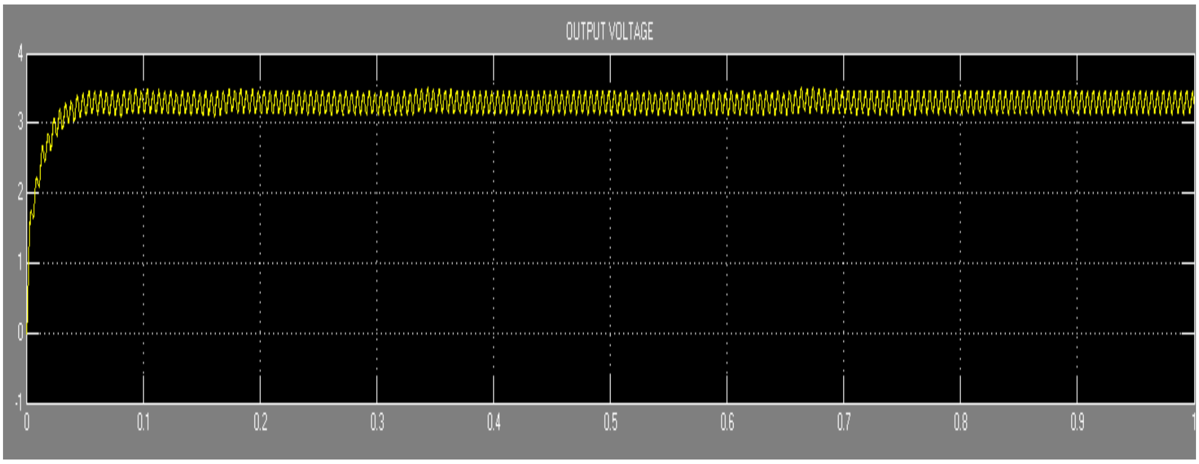


Fig.7: Output voltage of the proposed closed loop bridgeless boost converter

.Fig. 7 shows the output voltage of proposed closed loop bridgeless boost converter. Here the output voltage is 3.3V DC which remain constant for the input 0.4V to 3.3V AC input voltage so this can be used as the variable input device for low voltage constant energy output.

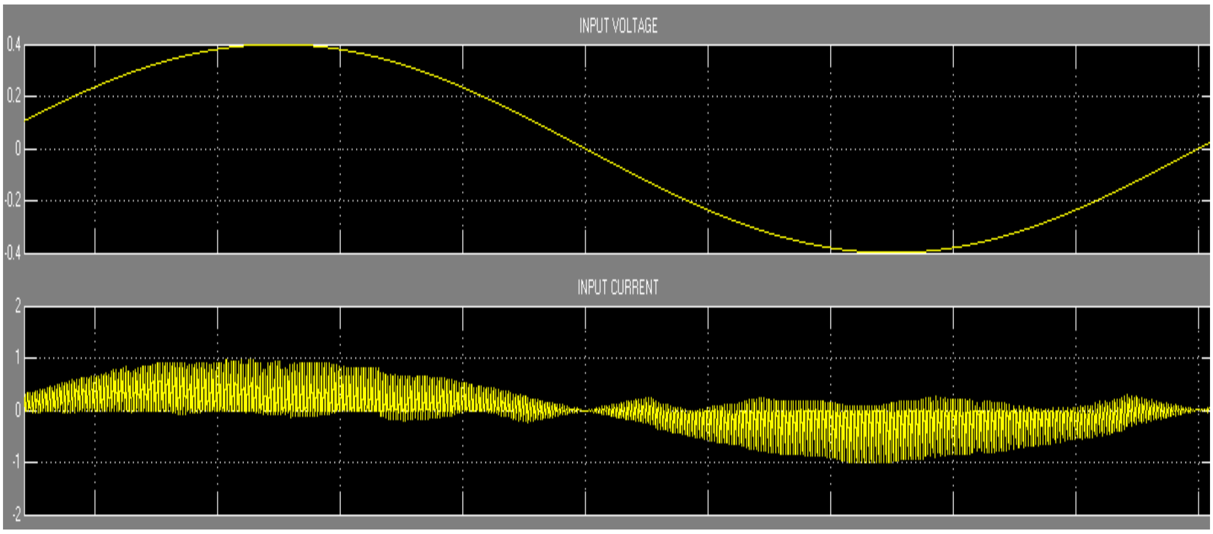


Fig.8: Input voltage and input current of the proposed closed loop bridgeless boost converter.

Fig.8 shows the input voltage and input current of the proposed bridgeless boost converter. The input voltage is 0.4V AC.

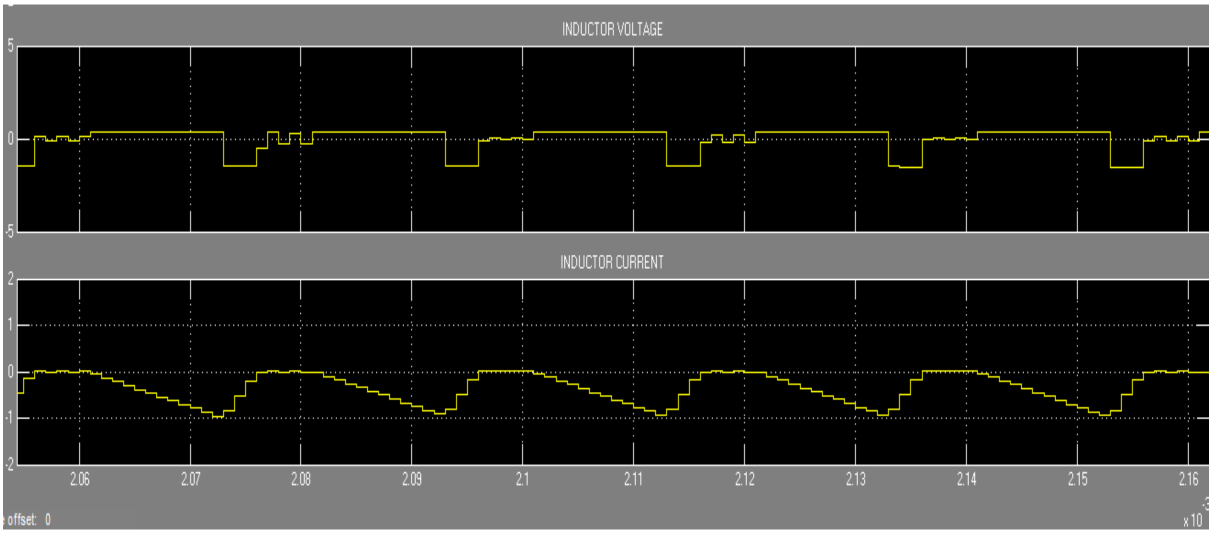


Fig.9: Inductor voltage and inductor current of the proposed closed loop bridgeless boost converter.

Fig. 9 shows the inductor current and inductor voltage of proposed converter.

V. CONCLUSION

For low power and low voltage energy harvesting purpose a single stage AC-DC bridgeless boost converter is proposed in this paper. This combines boost and buck-boost converters in operation. One inductor and a only filter capacitor reduces the circuit size. In this paper an input of 0.4V AC voltage and 100Hz frequency is successfully rectified and boosted to 3.3V DC by using closed loop MATLAB simulation.

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