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A BOOST RECTIFIER FOR LOW-VOLTAGE ENERGY HARVESTING APPLICATIONS VISHNU PRASAD

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ABSTRACT

In this paper, a single-stage ac–dc power electronic converter is proposed to efficiently manage the energy harvested from electromagnetic micro scale and mesoscale generators with low-voltage outputs. The proposed 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 circuitries to reduce the size of the converter. A 2 cm × 2 cm, 3.34-g prototype has been designed and tested at 50-kHz switching frequency, which demonstrate 71% efficiency at 54.5 mW. The input ac voltage with 0.4-V amplitude is rectified and stepped up to 3.3-V dc. Detailed design guidelines are provided with the purpose of minimizing the size, weight, and power losses. The theoretical analyses are validated by the experiment results.

INTRODUCTION

Dynamic Energy gatherers change over mechanical vitality present in nature into electrical vitality. The previous decade has seen an expanding centre in the exploration group on dynamic vitality collecting gadgets [1]. Regularly, active vitality is changed over into electrical vitality utilizing electromagnetic, piezoelectric, or electrostatic transduction components [2]. In correlation to electrostatic and piezoelectric transducers, electromagnetic transducers beat regarding effectiveness and force thickness [3]. In this study, electromagnetic vitality collectors are considered for further study. A general chart of an electromagnetic generator is shown in Fig. 1, where k is spring firmness consistent; m is the verification mass; DE and DP speak to electrical and parasitic dampers, separately. Basically, the vitality reaping framework comprises of a spring, a proof mass, and an electrical damper [4], [5]. The extraneous vibrations energize the inner wavering between the evidence mass (magnet) and electrical damper (curls). The inside wavering creates an intermittently variable attractive flux in the curl, which affects a comparing exchanging yield voltage. In vitality gathering frameworks, power electronic circuit shapes the key interface in the middle of transducer and electronic burden, which may incorporate a battery [6].

The electrical and physical characteristicsof the power molding interfaces decide the usefulness, effectiveness, and the extent of the coordinated frameworks [7]. The power electronic circuits are utilized to

1) manage the power conveyed to the heap, and
2) effectively deal with the electrical damping of the transducers so most extreme power could be exchanged to

the heap [8], [9]. The yield voltage level of the microscale and mesoscale vitality reaping gadgets is for the most part in the request of a couple of hundred millivolts relying upon the topology of gadget [10], [11]. The yield air conditioning voltage ought to be redressed, supported, and managed by power converters to satisfy the voltage prerequisite of the heaps. In any case, small scale vitality reaping frameworks have inflexible necessity on the size and weight of power electronic interfaces.

Traditional ac–dc converters for vitality collecting and molding for the most part comprises of two stages [12]–[14]. A diode span rectifier regularly shapes the first stage, while the second stage is a dc–dc converter to direct the corrected air conditioning voltage to a dc voltage.

CIRCUIT CONFIGURATION AND PRINCIPLE

In electromagnetic energy harvesters, the internal oscillation between coils and magnet produces a periodically variable magnetic flux in the coil, which induces a corresponding output voltage. The power electronics interface (PEI) is employed to supply constant voltage and to deliver power to the load. In order to facilitate and simplify analyses, it is assumed that the input impedance of the PEI is significantly larger than the internal impedance of energy harvesting device. The induced voltage could be assumed to be a low amplitude sinusoidal ac voltage source. As the frequency of vibration source and induced voltage (usually less than 100 Hz) is much less in comparison to that of the switching frequency (around tens of kHz), the induced ac voltage can be assumed as a constant voltage source in each switching period. In this paper, a 0.4-V, 100-Hz sinusoidal ac voltage source is adopted to emulate the output of the electromagnetic energy harvester. The DCM operating modes of the proposed boost rectifier are shown in Fig. 5. 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 buck-boost 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*.

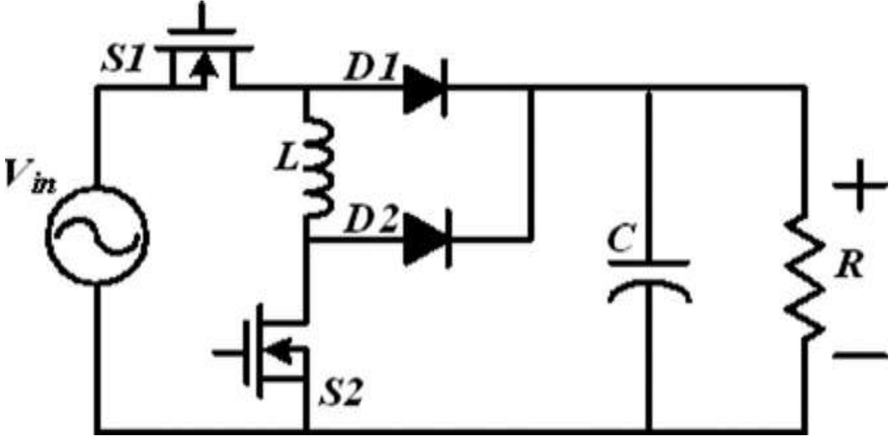

Fig. 1. Proposed bridgeless boost rectifier for low-voltage energy harvesting

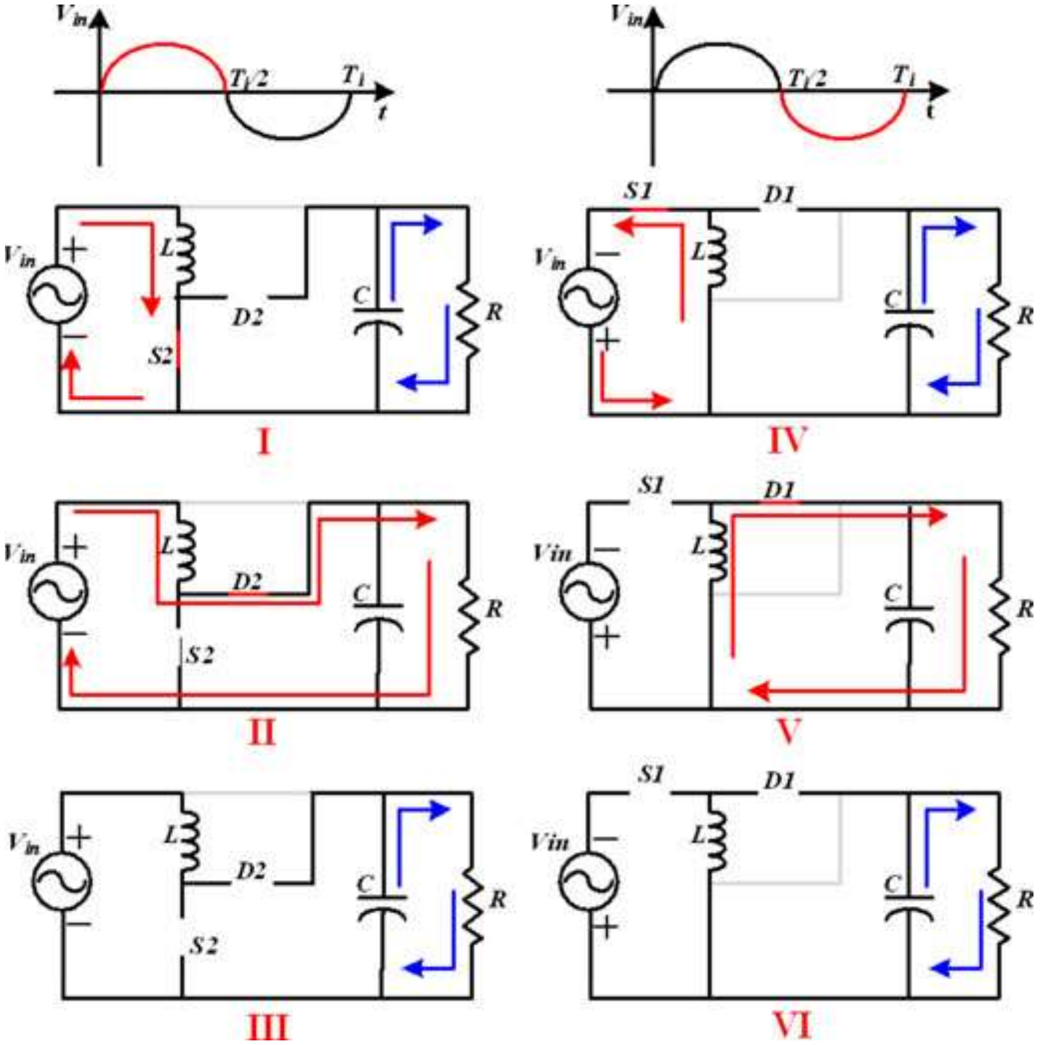

Fig. 2. Operating modes of the proposed boost rectifier.

Mode II: *S*2 is turned OFF at *t*1, where $t1 - t0 = d1Ts$, *d*1 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 *D*2.

Mode III: *D*2 is automatically turned OFF as soon as the inductor current becomes zero at *t*2 ($t2 - t1 = d2Ts$). 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 *S*2 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 *S*1 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, *S*1 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 *D*1.

Mode VI: When the inductor current decreases to zero at *t*_ 2 (*t*_ 2 − *t*_ 1 = *d*_ 2*Ts*), *D*1 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 *S*1 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

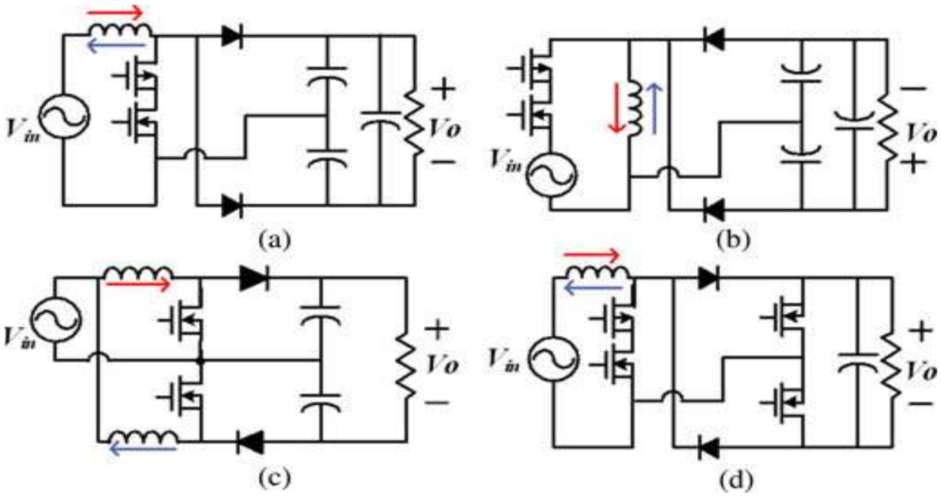

Fig. 3. Bridgeless ac–dc converters [6]. (a) Split capacitor boost converter. (b) Split capacitor buck-boost converter. (c) Dual polarity boost converter. (d) Boost converter with secondary switches.

DCM operation is more suitable than continuous conduction mode (CCM) operation diodes include 1) diode-connected passive MOSFET, which adopts threshold voltage cancellation techniques [15], [16], and 2) MOSFET, which is actively controlled by a comparator [6], [17]–[21]. 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 [22], [23]. 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 [24]. 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. 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. 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 work as two-quadrant switches to ensure the circuitry functionality in both positive and negative voltage cycles.

SIMULATION DIAGRAM & RESULTS

Simulation circuit for a buck-buck-boost converter with input voltage 230V rms and output voltage of 80V DC is shown in Figure 4.

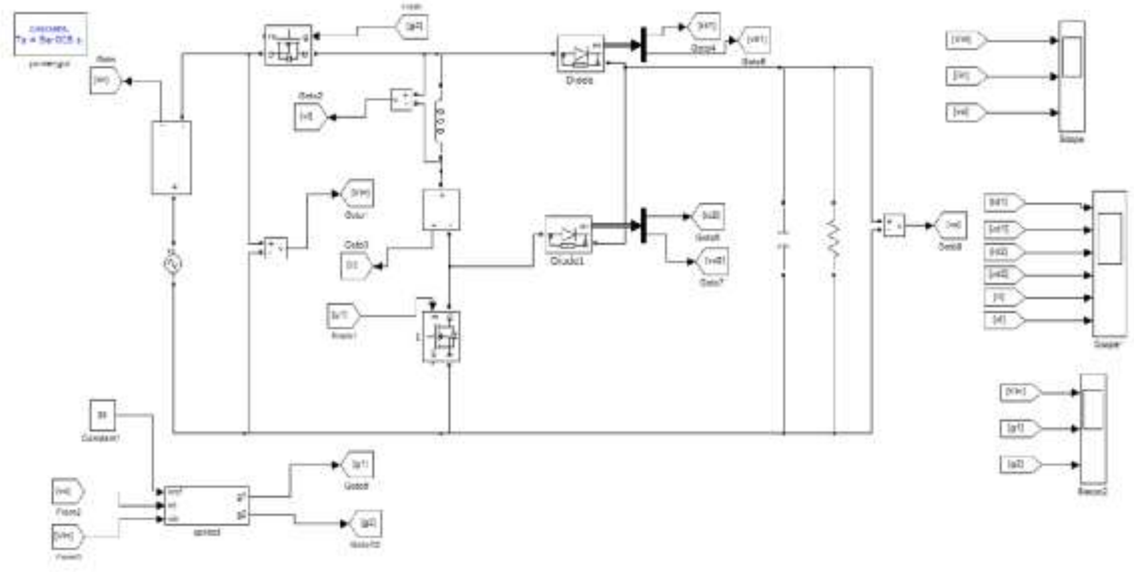

Fig 4: Proposed bridgeless boost rectifier for low-voltage energy harvesting

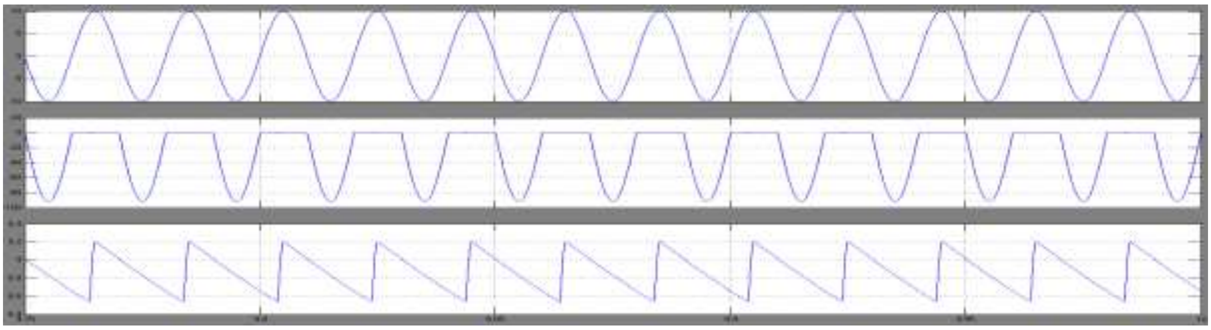

Fig 5: Simulation Results for output voltage and current

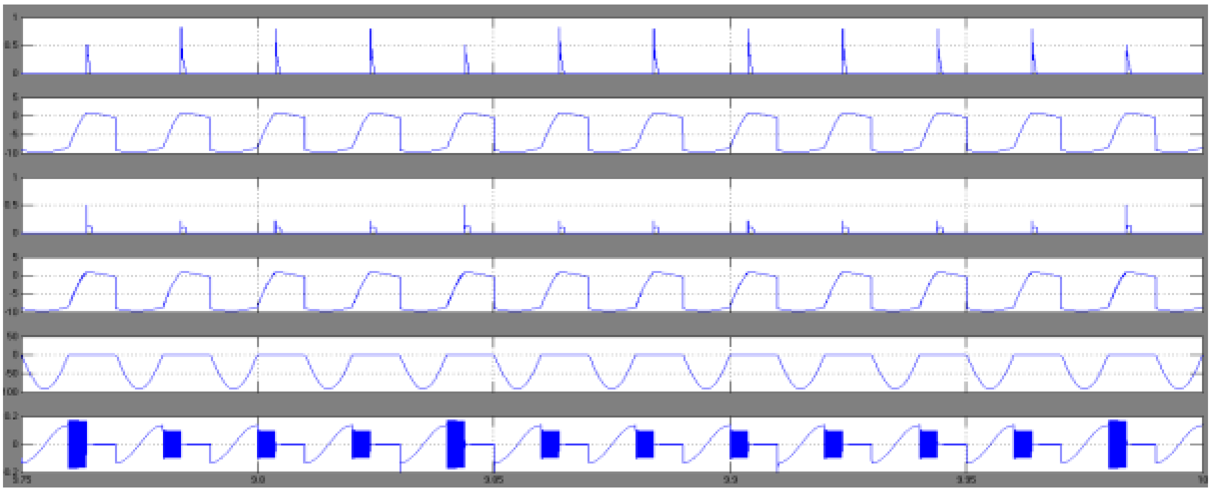

Fig 6: Simulation Results for converter voltages and energy storage

CONCLUSION

A single stage ac–dc topology for low-voltage low-power energy harvesting applications is proposed in this paper. The topology interestingly joins a help converter and a buck-support converter to condition the positive information cycles and negative data cycles, individually. Stand out inductor and one channel capacitor are required in this topology. A minimal 2 cm×2 cm, 3.34-g model is manufactured and tried at 54.5 mW. This model effectively helps the 0.4-V, 100-Hz air conditioning to 3.3-V dc. Yield voltage is firmly directed at 3.3 V through shut circle voltage control. The deliberate transformation proficiency is 71% at 54.5mW. In correlation to best in class low-voltage bridgeless rectifiers, this study utilizes the base number of uninvolved energy stockpiling segments, and accomplishes the most extreme transformation proficiency. The future examination will be centred on researching and outlining incorporated three-stage power electronic interfaces for electromagnetic energy harvesting.

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