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Closed Loop Control of an Efficient AC-DC Step up Converter

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Abstract

Efficient ac/dc rectification of low voltages is critical for the realization of fully-functional vibrational energy harvesting systems. The conventional two stage power converters with bridge rectifiers are inefficient and may not be practical for the low voltage micro generators. This paper presents an efficient ac-to-dc power converter which avoids the bridge rectification and directly converts the low ac input voltage to the required high dc output voltage at a higher efficiency. The proposed converter consists of a boost converter in parallel with a buck-boost converter; which are operated in the positive half cycle and negative half cycle, respectively. Based on the analysis control schemes are proposed to operate the converter. Simulation results are presented to validate the proposed converter topology and control schemes.

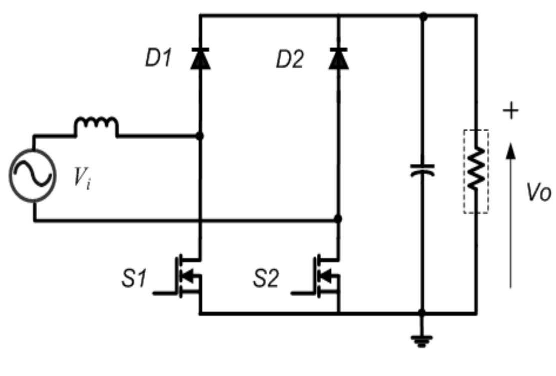
Keywords: Ac-dc conversion, boost converter, power converter control, low power.

Introduction

Semiconductor diodes available today are close to ``ideal" devices, they have severe limitations in low level applications. The active power factor correction (PFC) circuits are widely used to effectively draw the energy from the mains via an AC to DC converter. One of the challenges with the electromagnetic micro generators is that, due to the practical size limitations, the output voltage level of the generators is very low (few hundreds of mille volts), whereas the electronic loads require much higher dc voltage (3.3 V). The conventional power converters, re-ported for energy harvesting mostly consist of two stages: a diode bridge rectifier and a standard buck or boost dc-to-dc converter. However, there are major disadvantages in using the two-stage power converters to condition the outputs of the electromagnetic micro generators. First, for very low-voltage electromagnetic micro generators, rectification is not feasible by the use of conventional diodes. Second, if the diode bridge rectification is feasible, the forward voltage drops in the diodes will cause a large amount of losses and make the power conversion very inefficient.

Proposed AC – DC Converter

To address the problems of the conventional two stage converters, direct ac-to-dc converters are proposed. In these converters, bridge rectification is avoided and the micro generator power is processed only in a single stage boost type power converter. A dual polarity boost converter topology for direct ac-to-dc power converter is reported in [1]. In this converter, the output dc bus is split into two series connected capacitors and each of these capacitors is charged only for one half cycle of the micro generator output voltage. As the time periods of the resonance based micro generators output voltages are normally in the order of milliseconds, very large voltage drops will occur in the capacitors during the half cycles when they are not charged by the converter. Extremely large capacitors will be required to achieve acceptable voltage ripple at the output dc bus. This is not practical due to the size limitations of the micro generators. A direct ac-to-dc converter is proposed by the authors in [2]. The proposed converter, as shown in Fig.01, consists of a boost converter (inductor, L1, switch S1, and diode, D1) in parallel with a buck-boost converter (inductor, L2, switch, S2, and diode, D2). In this converter, the negative output to input voltage gain of a buck-boost converter is utilized to step-up the negative half input voltage of the micro generator to a positive high DC output voltage. The output dc bus is realized by using a single capacitor. The output capacitor is charged by the boost converter in the positive half-cycle and by the buck-boost converter in the negative half-cycle. Therefore, it resolves the problems present in a dual polarity boost converter.



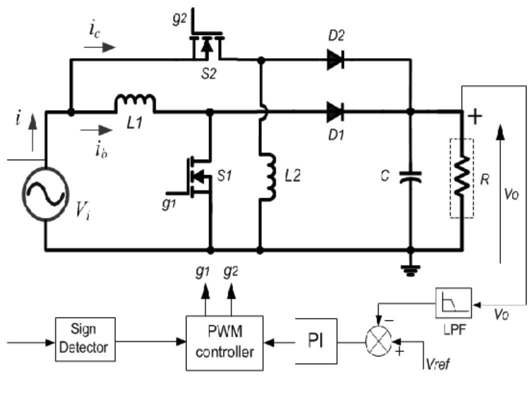


Fig.01: Proposed direct ac-to-dc converter. **Fig.02:** Conventional converter

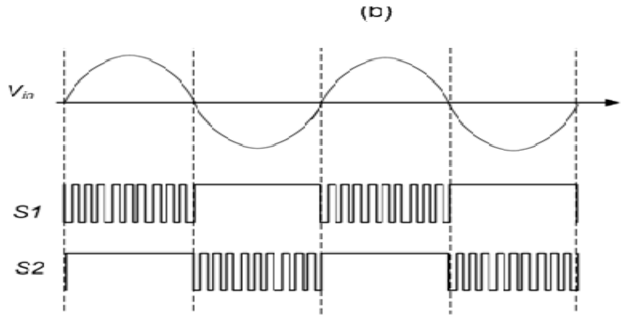


Fig.03: Input voltage and the gate drive pulsed to the lower switches (*S1* and *S2*).

The standard 4-switch H-bridge converter, as shown in Fig.02 respectively, can be used for the direct ac-to-dc boost conversion [3]. It can be noted that to achieve the boost operation, the lower switches (S1 and S2) of these two converters should be able to conduct in both the directions. In this case, without increasing the number of devices, the bidirectional conduction capability of the two MOSFETs (S1and S2) can be used to achieve the boost operation. The control gate pulses for these two switches are shown in Fig.03. It can be seen that during the positive half-cycle of the input voltage, S2 is kept ON for the entire half-cycle and the gate pulse to S1 is controlled to achieve the boost operation. Likewise, in the negative half-cycle, S1 is kept ON for the entire half-cycle and S2 is controlled. To achieve the boost operation, these two topologies use single inductor compared to the two inductors used in the proposed converter in this work (Fig.01). However, there are several disadvantages in these two H-bridge converters. Firstly, in these converters, there are two devices in the conduction path during charge or discharge of the boost inductor. In the proposed converter, only a single device conducts during the charge or discharge of the inductors. In the converter, proposed in this work, any MOSFET is operated only for a half-cycle of the input ac voltage. Whereas, in the H-bridge type converters the MOSFETs, used for the boost operation (S1 and S2), are operated for the entire cycle of the input ac-voltage. Therefore, the device conduction losses in the proposed converter are reduced by more than a factor of two. In energy harvesting applications as the power level is very low, these losses are significant compared to the total output power. Secondly, as the MOSFETs are designed for forward conduction, in the reverse conduction mode they offer higher ON state resistance. This further increases the conduction losses in the H-bridge topologies. In the third place, the input voltage polarity has to be sensed to control S1 and S2. But in the H-bridge topologies the input voltage source is floating with respect to the output voltage ground. Therefore the implementation of the control circuit is difficult. This can be easily implemented in the proposed converter. Furthermore, it can be mentioned that although the proposed converter uses two inductors (L1 and L2) they do not operate in the same half cycle. Therefore, their total losses are almost equal to the losses of the single inductor used in the H-bridge converters[5]. A converter is designed based on the analysis. Simulations are carried out for the verification of the proposed control schemes.

Simulation Analysis

Simulation has become a very powerful tool on the industry application as well as in academics, nowadays. The Simulation analysis is carried out using Matlab simulink. The conventional converter is shown in Fig.04. Here MOSFET is selected to realize the switches, S1 and S2, the forward voltage of the selected MOSFET body diode is higher than the peak of the input voltage. The corresponding input wave form is shown in Fig.05 and output voltage waveform is shown in Fig.06. Here the bridge rectification is needed and increases the conduction loss.

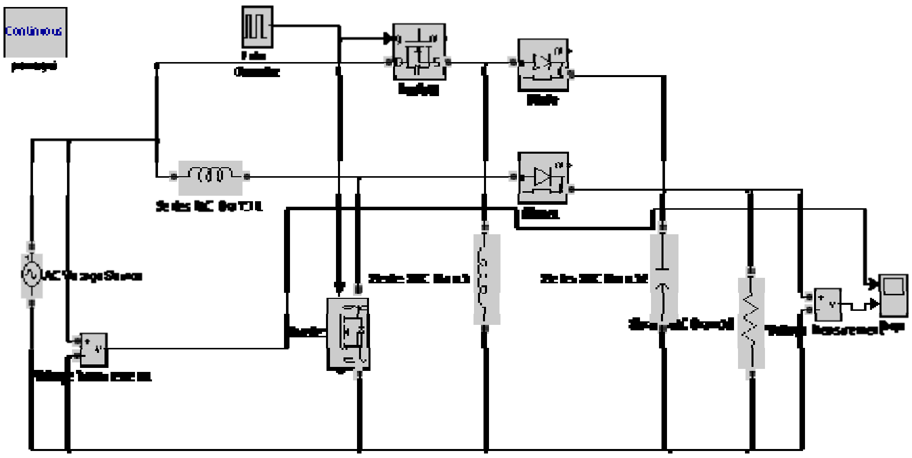
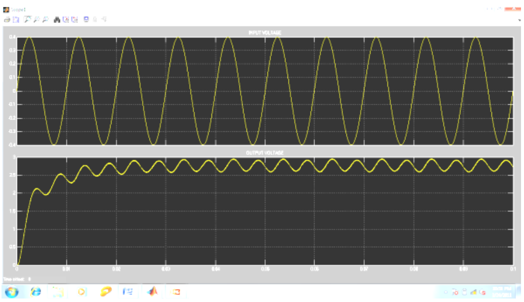


Fig.04: Simulation of conventional converter



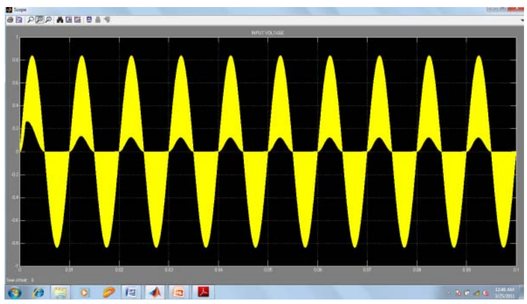


Fig.05: Input voltage **Fig.06:** Input voltage and output voltage.

Proposed closed loop system is shown in Fig.07. Output voltage is sensed and it is compared with a reference voltage. The error is processed through a PI controller. Step rise in input voltage for closed loop system is shown in Fig.08. The corresponding input current is shown in Fig.09.The switching operation of the MOSFET's is shown in Fig.10. The output of the pulse generator controls the output voltage till it reaches the set value. It can be seen that the DC voltage reaches the set value as shown in Fig.11. From the output waveform it is seen that the negative gain of the buck-boost converter is utilized to boost the voltage of the negative half-cycle of the micro generator to positive dc voltage. The converter is successfully operated to directly step up the low ac voltage 0.4 volts to a high dc voltage 3.8 volt.

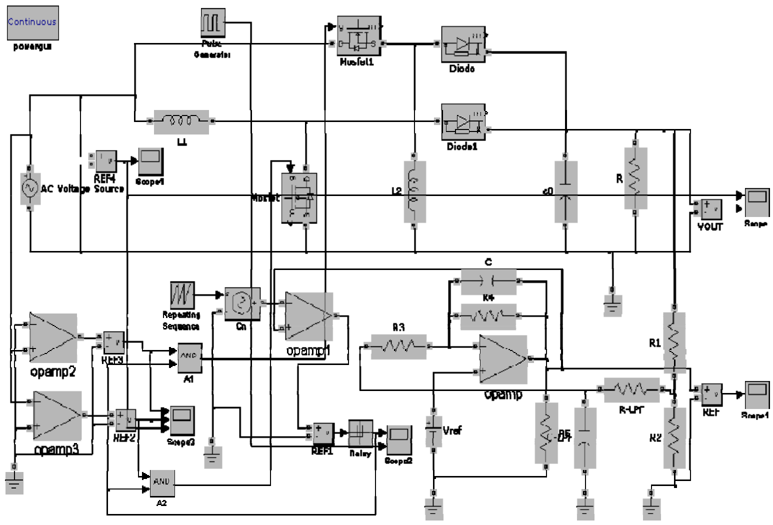


Fig.07: Proposed closed loop system

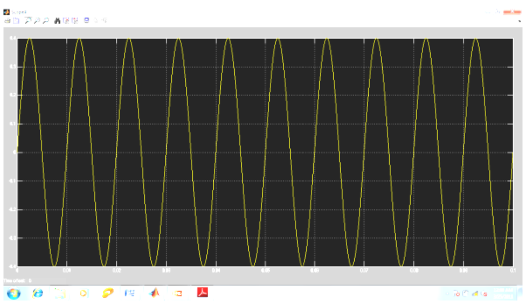


Fig.08: Input AC Voltage

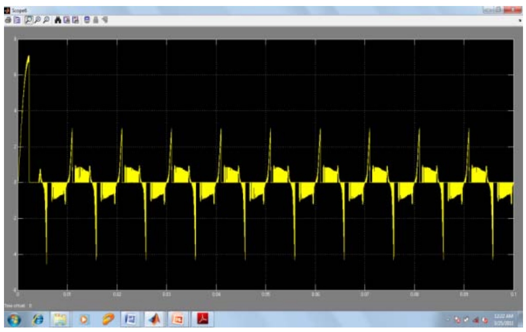


Fig.09: Input AC current

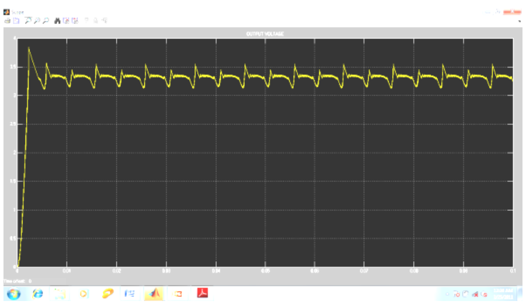


Fig.10: switch operation of Mosfet’s

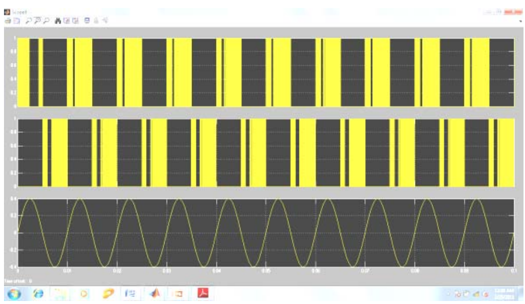


Fig.11: Output DC Voltage

Conclusion

The proposed direct ac-to-dc low voltage energy harvesting converter avoids the conventional bridge rectification and achieves higher efficiency. The proposed converter consists of a boost converter in parallel with a buck-boost converter. The negative gain of the buck-boost converter is utilized to boost the voltage of the negative half-cycle of the micro generator to positive dc voltage. Detailed analysis of the converter for direct ac-to-dc power conversion is carried out. Simulation of the converter is successfully operated to step up the low ac voltage to a high dc voltage and measured efficiency of the converter is 61%, which is higher than the reported converters.

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