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A self-starting AC-to-DC step-up converter for energy harvesting applications

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Abstract

This paper presents the design and implementation of a self-starting direct AC-to-DC step-up converter for energy harvesting applications. The proposed circuit employs a power efficient buck-boost converter with a diode voltage multiplier as a start-up circuit. The overall AC-to-DC converter can start and run autonomously from an audio signal generator, such as an audio jack. Experimental results showed that the prototype converter could achieve a power conversion efficiency of 45% when applying a 5-kHz input signal.

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Keywords: AC/DC conversion, bridgeless, boost, buck-boost, Active rectifier, Direct AC-to-DC Step-Up Converter ;

1. Introduction

Recently, there has been a significant research and development on power converters for energy harvesting applications. Traditionally, a power converter consists of a diode bridge rectifier followed by a buck or boost DC-DC converter. However, using the diode bridge rectifier typically results in considerable power losses and low power conversion efficiency. To achieve high power conversion efficiency, a direct AC-to-DC converter can be employed [1], [2]. Previous work on direct AC-to-DC converters showed that higher power conversion efficiency can be obtained. However, prior power converter circuits require battery or supplementary power source to start the power conversion system. This can be inconvenience or impractical for some applications. This paper proposes a self-starting AC-to-DC converter, which can achieve high-efficiency power conversion without the need of a battery or supplementary power source.

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2. Circuit Design and Realization

Fig. 1 shows the proposed AC-to-DC step-up converter circuit. It consists of a direct AC-to-DC bridgeless boost converter, a diode voltage multiplier, and a controller. The operation of the circuit can be explained as follow. Initially, when the input voltage signal is applied, the switch Φ1 is turned on and the diode voltage multiplier will rectify the AC input signal and provide a higher output DC voltage to the load capacitor (C1). When the voltage across C1 is sufficiently large, the controller will start to operate and turn off Φ1 and turn on the bridgeless boost converter.

The bridgeless boost converter, in Fig. 2, is controlled by the controller to function as both a boost converter and an inverting buck-boost converter. During positive input cycles, the circuit operates as a boost converter as illustrated by the dotted line in Fig. 2. During negative input cycles the circuit operates as an inverting buck-boost as illustrated by the solid line in Fig. 2.

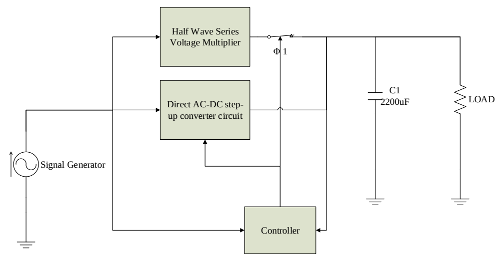

Fig. 1 The proposed self-starting AC-to-DC converter

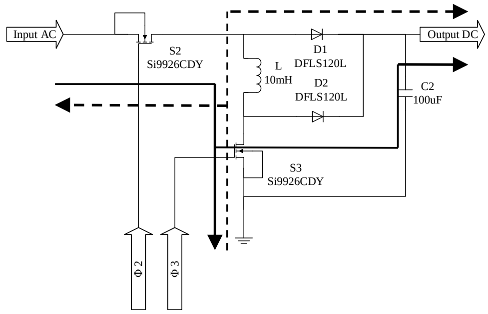

Fig. 2 Bridgeless boost converter

Fig. 3 shows the simplified circuit diagram of the controller. An ultra-low power 8-bit microcontroller from ST Microelectronics (STM8L) was selected for this work. The main functions of the controller are to control the operation of the bridgeless boost converter and to regulate the output voltage across the load according to system requirements. The output voltage is regulated by feeding back the output voltage via a voltage divider and a filter to an analog-to-digital converter inside the controller. The front-end part of the controller consists an amplifier and a comparator which function as an input polarity detector to distinguish between positive and negative input cycles. The output of the polarity detector is used to control the function of the bridgeless boost converter.

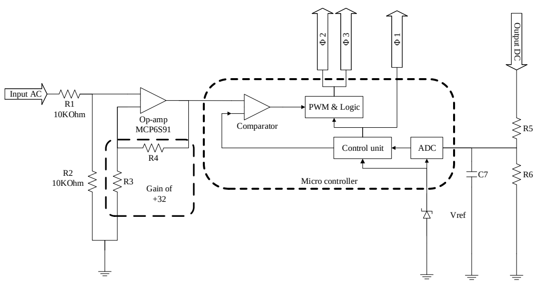

Fig. 3 Circuit diagram of the controller

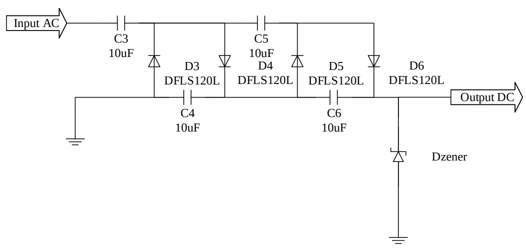

Fig. 4 Diode voltage multiplier

Figure 4 shows the simplified circuit diagram of the diode voltage multiplier used in this work. It is the simple two-stage half-wave Cockcroft-Walton multiplier [5]. A Zener diode is used for over voltage protection at the output.

3. Experimental Results

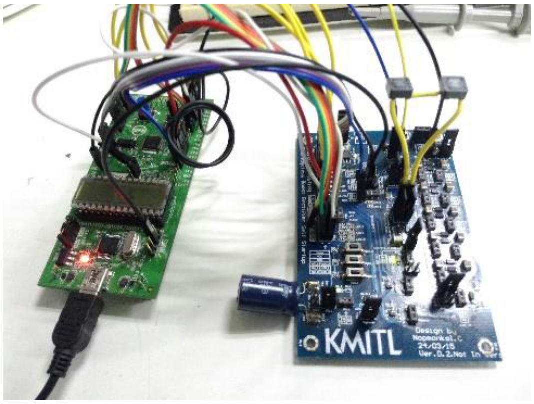

Fig. 5 The prototype self-starting AC-to-DC converter

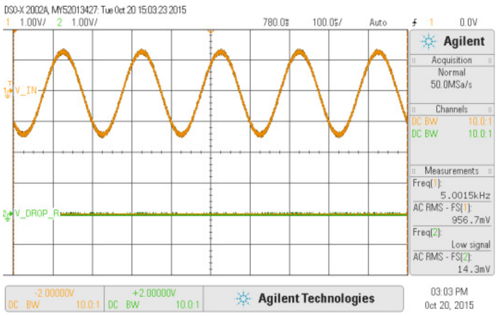

Fig. 6 Waveforms of output of signal generator

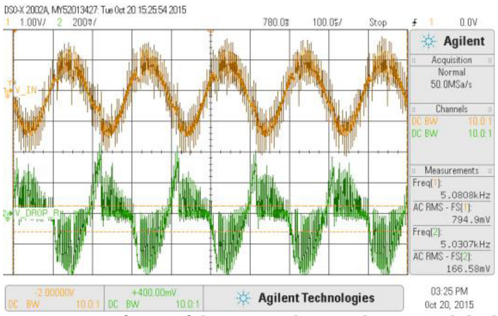

Fig. 7 Waveforms of the input voltage and current while the bridgeless boost converter is in operation

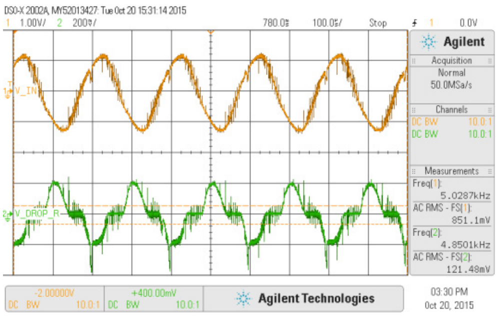

Fig. 8 Waveforms of the input voltage and current while the voltage multiplier is in operation

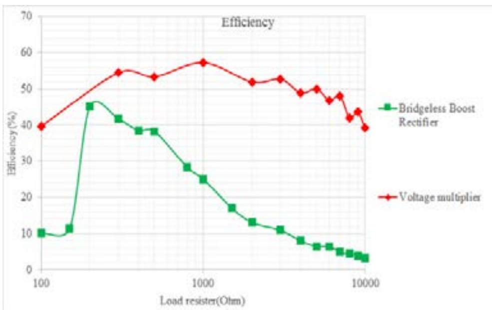

Fig. 9 Measured power efficiency

In this prototype, the maximum overall power conversion efficiency is approximately 45% when the load resistor is about 200 Ohm. There are a few ways to improve the power conversion efficiency. Firstly, we can increase the power efficiency of the bridgeless boost converter during the transition by turning off the switch between boost mode and buck-boost mode or buck-boost mode and boost mode. Thus the inductor current becomes zero and, as a result, this avoids the reverse recovery loss of diodes. Secondly, we can reduce the on-resistance of the MOSFET switches by using larger gate. Table 1 summarizes the measured performance of the prototype converter and compares them with prior research works.

4. Conclusion

The design and implementation of a self-starting direct AC-to-DC step-up converter for energy harvesting applications were described. The overall AC-to-DC converter can start and run autonomously from an audio signal generator. Experimental results, the prototype converter achieve a power conversion efficiency of 45% when applying a 5-kHz input signal.

Table 1 Performance summary and comparison

Ref.	η	Fin	Pin	Vin (p-p)	Pout	Vout	Iout	RLoad	Structure	Start-up	Year
[1]	55	108 Hz	-	2 V	10 mW	3.3V	-	1k	Direct AC/DC Converter	Battery	2010
[2]	71	100 Hz	-	800 mV	54.5 mW	3.3V	-	200	Direct AC/DC Converter	Battery	2013
[3]	94.2	200 Hz	-	2 V	-	1V	30 uA	50k	Active AC/DC Converter	-	2013
[4]	45	868 MHz	-14 dBm	-	-	2V	-	-	Voltage multiplier	self	2012
This work	45.1	5 KHz	80 mW	800 mV	36.1 mW	2.6V	13.9 mA	200	Direct AC/DC Converter	Voltage multiply	2015

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