An Efficient AC-DC Step up Converter for Low voltage Harvesting Applications

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Abstract: 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 acto- dc power converter that 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. Detailed analysis of the converter is carried out to obtain relations between the power, circuit parameters, and duty cycle of the converter. Based on the analysis, control schemes are proposed to operate the converter. Design guidelines are presented for selecting the converter component and control parameters. A self-starting circuit is proposed for independent operation of the converter. Detailed loss calculation of the converter is carried out. Simulation and experimental results are presented to validate the proposed converter topology and control schemes.

***Index Terms*: AC–DC conversion, boost converter, energy harvesting, low power, low voltage, power**

INTRODUCTION:

Self-powered devices harvest the ambient energies by micro generators and can perform their operations without any continuous external power supply. Many types of micro generators, used in the self-powered devices, are reported in the literature for harvesting different forms of ambient energies.

The inertial micro generators, which harvest mechanical energy from the ambient vibrations, are currently the focus of many research groups [2-6], [8-13], [16-21]. The power level of the inertial micro generators is normally very low, ranging from few microwatts to tens of mill watts. Based on the energy conversion principle, the inertial micro generators can be classified mainly into three types: electromagnetic, piezoelectric, and electrostatic. Among them, the electromagnetic micro generators have the highest energy density [8, 9, and 20]. In this research, the electromagnetic micro generators are considered for further study.

The electromagnetic generators are typically spring-mass damper-based resonance systems (see Fig.1.1) in which the small amplitude ambient mechanical vibrations are amplified into larger amplitude translational movements and the mechanical energy of the motion is converted to electrical energy by electromagnetic coupling [9]. The output voltage of an electromagnetic micro generator is ac type, but the electronic loads require dc voltage for their operation. Therefore, the ac voltage of the electromagnetic micro generator output has to be processed by a suitable power converter to produce the required dc voltage for the load.

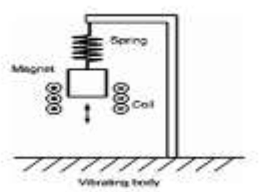


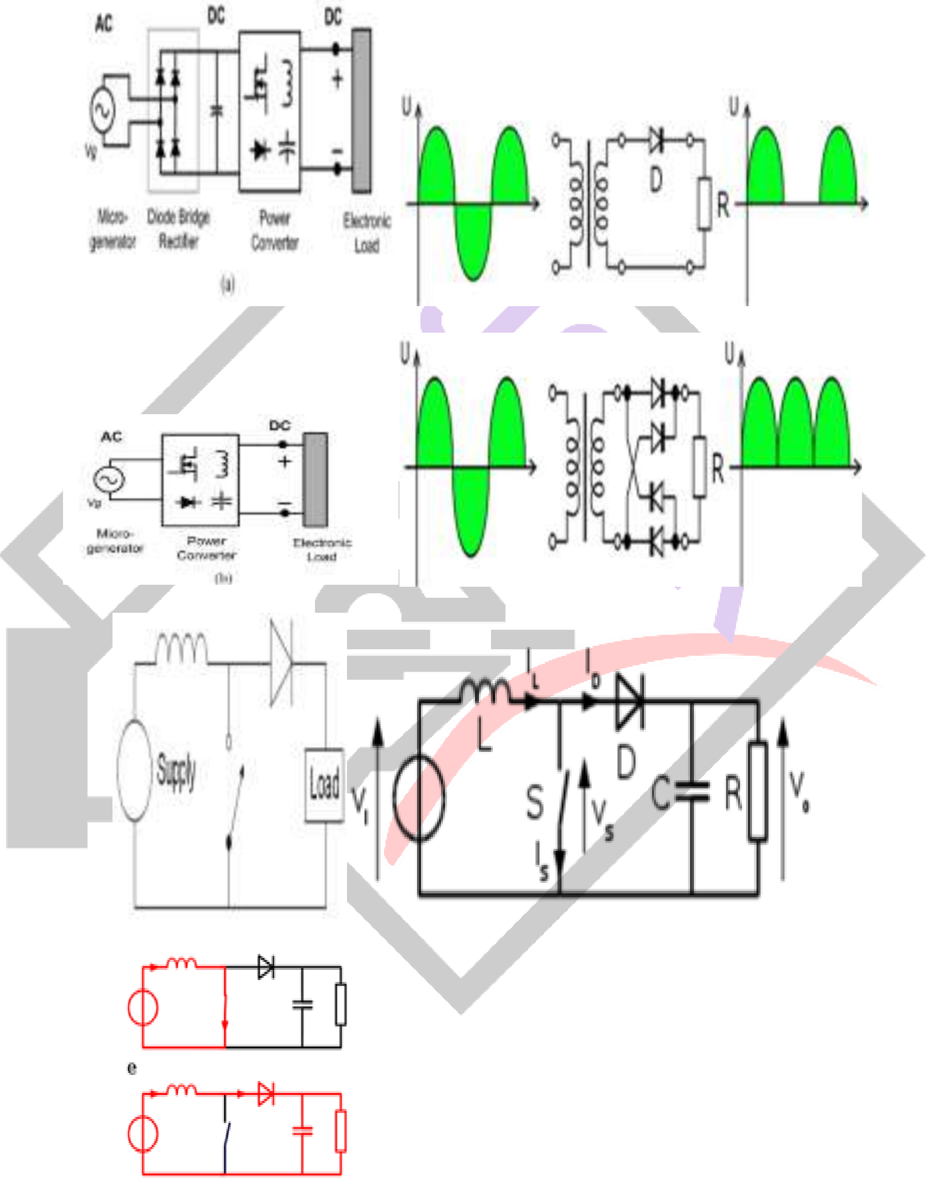
Fig. 1.1 Schematic diagram of a resonance inertialmicro generator.

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 mill volts), whereas the electronic loads require much higher dc voltage (3.3V) [9].The conventional power converters, reported for energy harvesting ,[2-7],[10,11],[14-18],[20],[22], mostly consist of two stages: a diode bridge rectifier and a standard buck or boost dc-to-dc converter [see Fig.1.2 (a)]. 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.

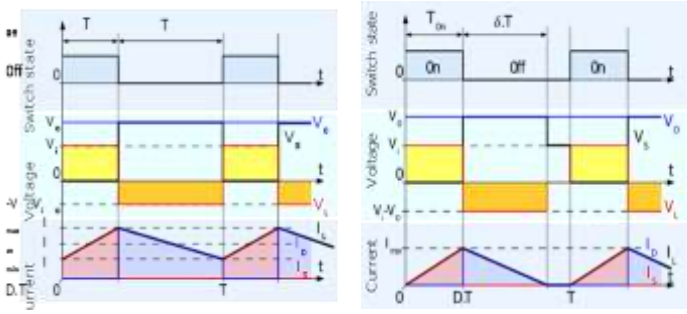
To address the problems of the conventional two-stage converters, direct ac-to-dc converters are proposed [10, 13, and 15]. In these converters, bridge rectification is avoided and the micro generator power is processed only in a single-stage boost-type power converter [see Fig. 1.2(b)]. A dual-polarity boost converter topology for direct ac-to-dc power converter is reported in [10]. 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

OPERATION:

FIGURES:



CONTINUOUS MODE: DISCONTINUOUS MODE:



SPECIFIC STRUCTURES:

Synchronous rectification:

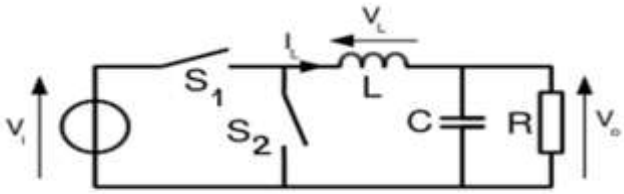


Fig: 5.6 Simplified schematic of a synchronous converter, in which D is replaced by a second switch, S2

A synchronous buck converter is a modified version of the basic buck converter circuit topology in which the diode, D, is replaced by a second switch, S2. This modification is a tradeoff between increased cost and improved efficiency.

In a standard buck converter, the freewheeling diode turns on, on its own, shortly after the switch turns off, as a result of the rising voltage across the diode. This voltage drop across the diode results in a power loss which is equal to

$PD = VD(1 - D)Io$

Where:

VD is the voltage drop across the diode at the load current Io,D is the duty cycle, and Io is the load current.

By replacing diode D with switch S2, which is advantageously selected for low losses, the converter efficiency can be improved. For example, a MOSFET with very low RDSON might be selected for S2, providing power loss on switch 2 which is

$Ps2 = I20\ RDSON(1 - D)$

By comparing these equations the reader will note that in both cases, power loss is strongly dependent on the duty cycle, D. It stands to reason that the power loss on the freewheeling diode or lower switch will be proportional to its on-time. Therefore, systems designed for low duty cycle operation will suffer from higher losses in the freewheeling diode or lower switch, and for such systems it is advantageous to consider a synchronous buck converter design.

Without actual numbers the reader will find the usefulness of this substitution to be unclear. Consider a computer power supply, where the input is 5 V, the output is 3.3 V, and the load current is 10A. In this case, the duty cycle will be 66% and the diode would be on for 34% of the time. A typical diode with forward voltage of 0.7 V would suffer a power loss of 2.38 W. A well-selected MOSFET with RDSON of 0.015 Ω, however, would waste only 0.51 W in conduction loss. This translates to improved efficiency and reduced heat loss.

Another advantage of the synchronous converter is that it is bi-directional, which lends itself to applications requiring regenerative braking. When power is transferred in the "reverse" direction, it acts much like a boost converter.

The advantages of the synchronous buck converter do not come without cost. First, the lower switch typically costs more than the freewheeling diode. Second, the complexity of the converter is vastly increased due to the need for a complementary-output switch driver.

Such a driver must prevent both switches from being turned on at the same time, a fault known as "shoot through." The simplest technique for avoiding shoot through is a time delay between the turn-off of S1 to the turn-on of S2, and vice versa. However, setting this time delay long enough to ensure that S1 and S2 are never both on will itself result in excess power loss. An improved technique for preventing this condition is known as adaptive "non-overlap" protection, in which the voltage at the switch node (the point where S1, S2 and L are joined) is sensed to determine its state. When the switch node voltage passes a preset threshold, the time delay is started. The driver can thus adjust to many types of switches without the excessive power loss this flexibility would cause with a fixed non-overlap time.

Finally, the current can be measured at the input. Voltage can be measured lossless, across the upper switch, or using a power resistor, to approximate the current being drawn. This approach is technically more challenging, since switching noise cannot be easily filtered out. However, it is less expensive than emplacing a sense resistor for each phase.

EFFICIENCY FACTORS:

Conduction losses that depend on load:

- Resistance when the transistor or MOSFET switch is conducting.
- Diode forward voltage drop (usually 0.7 V or 0.4 V for schottky diode)
- Inductor winding resistance
- Capacitor equivalent series resistance

Switching losses:

- Voltage-Ampere overlap loss
- Frequency switch*CV2 loss
- Reverse latence loss

Losses due drivingMOSFET gate and controller consumption. Transistor leakage current losses and controller standby consumption.

5.8 IMPEDANCE MATCHING:

A buck converter can be used to maximize the power transfer through the use of impedance matching. An application of this is in a "maximum power point tracker" commonly used in photovoltaic systems.

By the equation for electric power:

$V0I0 = \eta Vi$

Where:

Vo is the output voltage

Io is the output current

η is the power efficiency (ranging from 0 to 1)

Vi is the input voltage

Ii is the input current

By Ohm'sLaw:

$I0=V0/Z0$

$Ii=Vi/Zi$

Where:

Zo is the output impedance

Zi is the input impedance

Substituting these expressions for Io and Ii into the power equation yields:

$V2o/Zo=\eta Vi2/Zi$

As was previously shown for the continuous mode, (where $IL > 0$):

where: D is the duty cycle

Substituting this equation for Vo into the previous equation, yields:

$(DV_i)^2/Z_0 = \eta V_i^2/Z_i$

which reduce to:

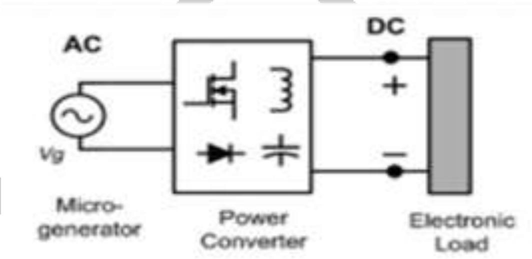
$D^2/Z_0 = \eta/Z_i$

and finally:

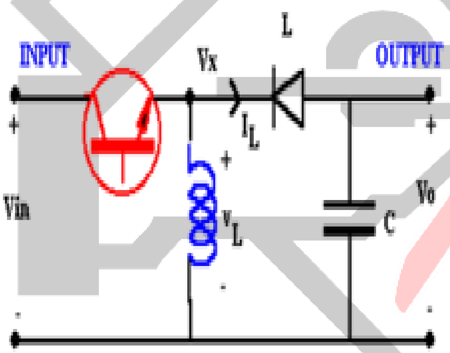
$D = \sqrt{\eta Z_o/Z_i}$

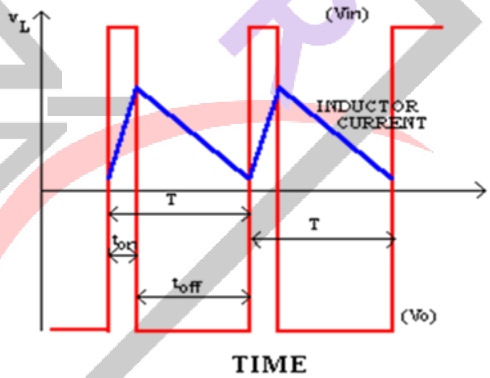
This shows that it is possible to adjust the impedance ratio by adjusting the duty cycle. This is particularly useful in applications where the impedance(s) are dynamically changing.

DIRECT AC-TO-DC POWER CONVERSION:

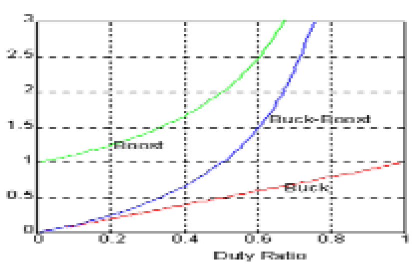


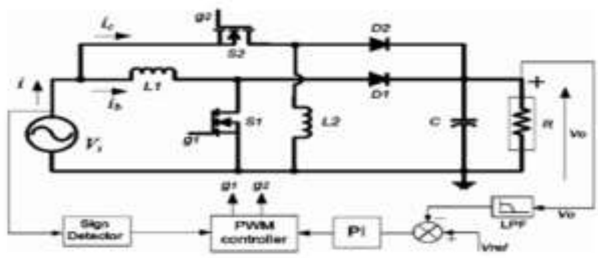
BUCK-BOOST CONVERTER: Waveforms:



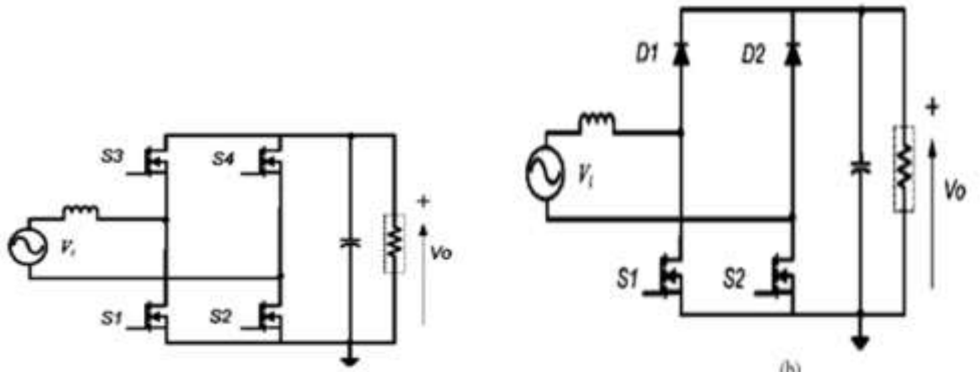


CONVERTER COMPARISON:PROPOSED DIRECT AC-TO-DC CONVERTER:



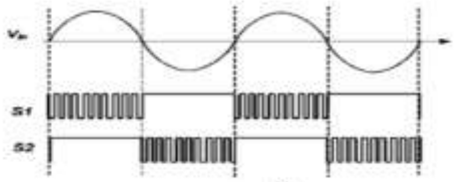


MODES OF OPERATION:



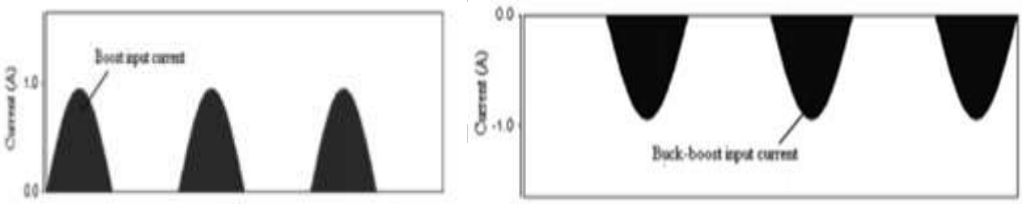
(a) (b)

WAVEFORMS:



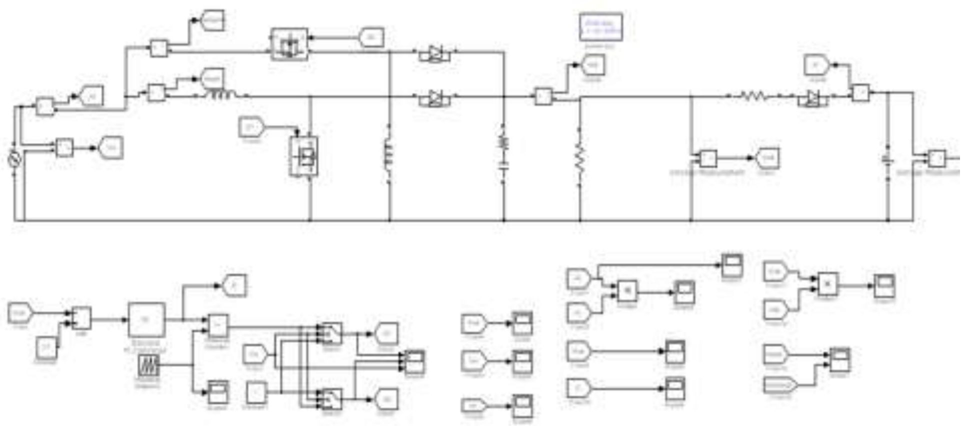
(c)

SIMULATION RESULTS

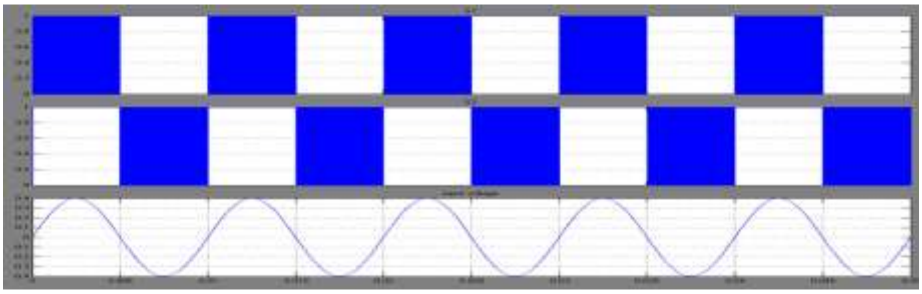


(a) (b)

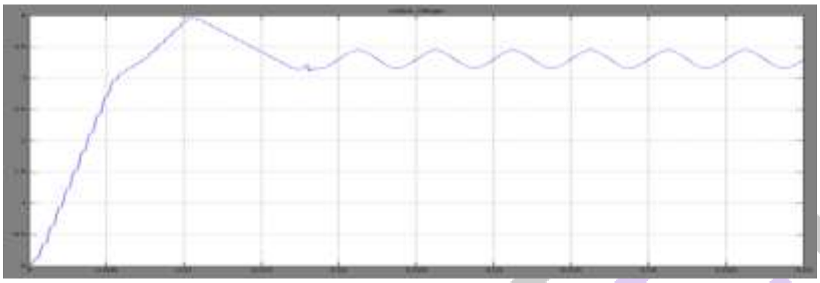
SIMULINK MODEL OF PROPOSED DIRECT AC-TO-DC CONVERTER



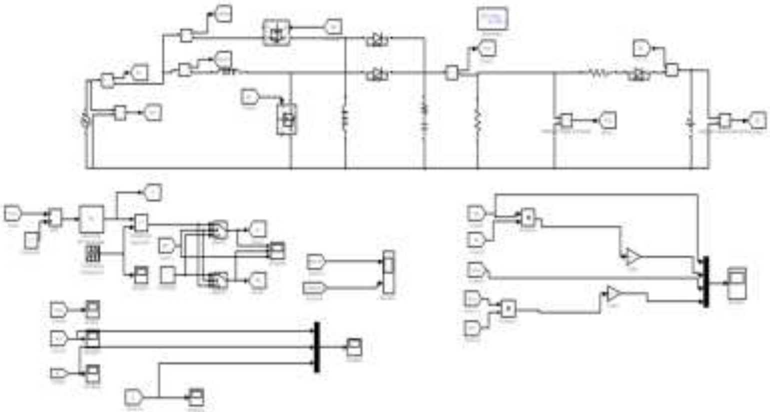
RESUTS:



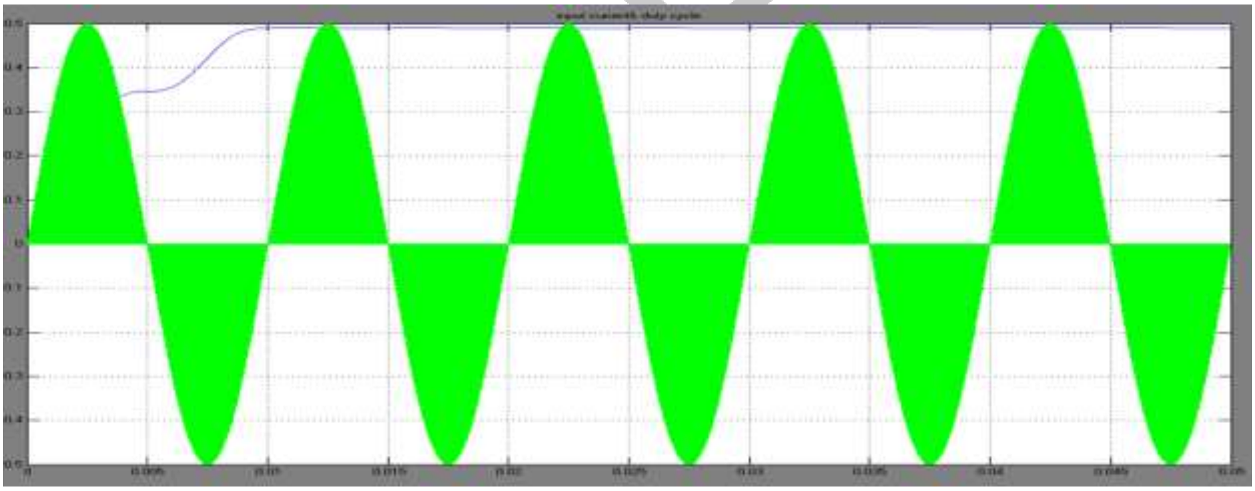
OUTPUT WAVE FORM:



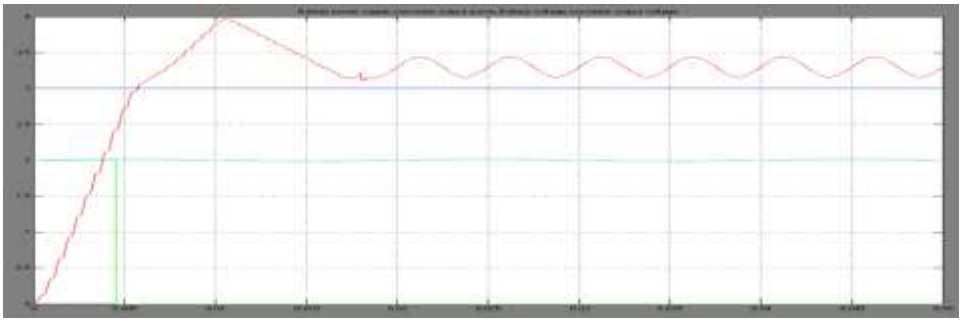
SIMMULATION DIAGRAM FOR COMBINED OUTPUT:



10 INPUT CURRENT INPUT VOLTAGE AND DUTY CYCLE:



COMBINED RESULT:



CONCLUSION

The presented 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 and the relations between various converter circuit parameters and control parameters are obtained. Based on the analysis, a simplified control scheme is proposed for high-voltage step-up application. Design guidelines are presented for selecting values of the key components and control parameters of the converter. A self-startup circuit, using a battery only during the beginning of the converter operation, is proposed for the energy-harvesting converter. Operation and the implementation of the self-startup circuit and the control circuit of the converter are presented in details.

Based on the analysis and the design guidelines, a prototype of the converter is developed.The proposed control scheme with the self-startup circuit is implemented and the converter is successfully operated to directly step-up the low ac voltage to a high dc voltage. The loss components of the converter are estimated. The measured efficiency of the converter is 61%, which is higher than the reported converters.

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