Self Powered Buck-Boost Converter for Low-Voltage Energy Applications

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***Abstract*—With electronic circuits now capable of operating at microwatt levels, it is feasible for them to be powered using non-traditional sources. This has led to energy harvesting, which provides the power to charge, supplement, or replace batteries in systems where battery use is inconvenient, impractical, expensive or dangerous. It can also be used for data transmission as well Energy harvesting can power smart wireless sensor nodes, to monitor and optimize complex industrial processes, remote field installations. Which uses its input as the wasted energy from combustion engines, industrial processes. Key to energy harvesting is a power converter that can operate with ultra-low-voltage inputs. The basic converter topology used here is the Buck-Boost Converter**

***Index Terms*—Energy Harvesting, Buck-Boost Converters**

I.INTRODUCTION

Conventional AC-DC converters for energy harvesting consist of two-stages, full bridge diode rectifier and DC-DC converter. However the diode-bridge would incur considerable voltage drop, making the low-voltage rectification infeasible [1]. Much primitive structures uses transformers in the booster stage to overcome diode voltage drops but that also creates noises. Latest topologies uses bidirectional switches and split capacitors, but due to the low- operating frequency range the value of the capacitors have to be large enough to suppress the voltage ripple under the desired level. Conduction losses and losses due to parasitic capacitances contribute 31%- 37% of total losses [2]. Why we are going for Buck-Boost topology rather than Boost topology alone is because this converter has the ability to set up the input voltage with a reverse polarity, hence it is an appropriate candidate to condition the negative voltage cycle[3]. Buck and Boost also shares the common capacitor and inductor hence reduction in no. of components can be achieved. Buck- Boost structures using linear regulators are in use but these were changed when switching converters came in to play. Switching converters are particularly useful in submilliwatt applications because the generated energy will be in the milliwatt operating range [4]. Also linear voltage regulators cant synthesize optimum load impedances. The input is given from a electromagnetic microgenerator. Microgenerators are of three types, 1) Piezoelectric 2)Electrostatic 3) Electromagnetic in which electromagnetic source has the potential to drive an electronic load rather than any other source. Rather than solar, wind, hydro, thermal this paper mainly focuses on vibrational energy as input, reason because with all the other sources independent modules have been developed. In the physical realization of the circuit conventional diodes cannot be used since it causes considerable voltage drop therefore Schottky diodes have to be used which drops only some millivolts. In this paper a Buck- Boost topology have been proposed which performs the unique action of boost converter in the positive cycle and buck- boost converter in the reverse cycle thus obtaining the required result.

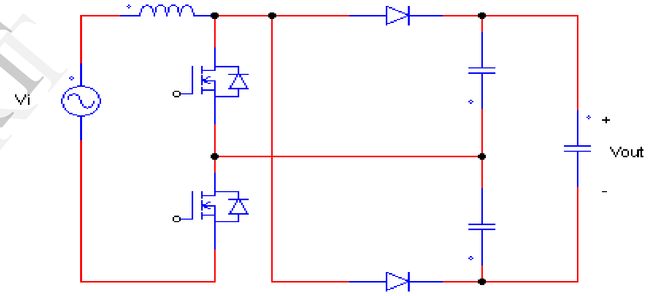

Fig.1.Conventional topology using bidirectional switch and split capacitor.

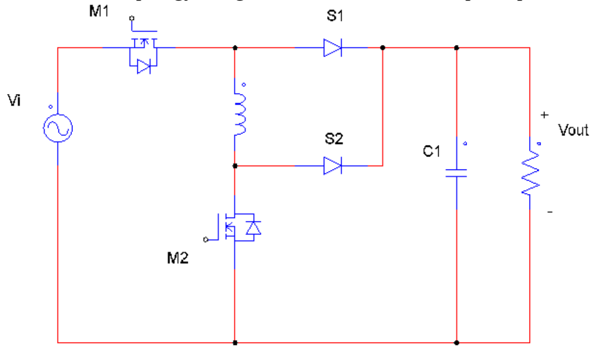

Fig.2.Classical Buck-Boost Converter

The operation of the basic configuration [3] is as follows, when the input is positive,M1 is turned on and the circuit operates in boost mode with diode S1 in reverse biased condition, when the input supply become negative, M2 conducts reverse biasing S2, the circuit now operates in Buck-Boost mode.

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II.PROPOSED TOPOLGY

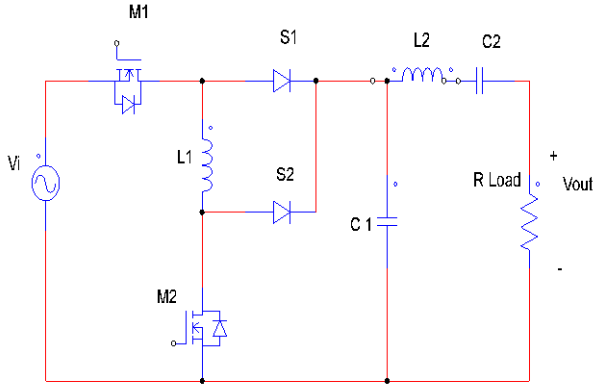

Fig.3.The proposed Topology

In this topology an additional inductor and a capacitor is provided L_2 &C_2 .This filter will stabilize the output voltage without using a output voltage control OPAMP or any linear regulators.

A. Modes Of Operation

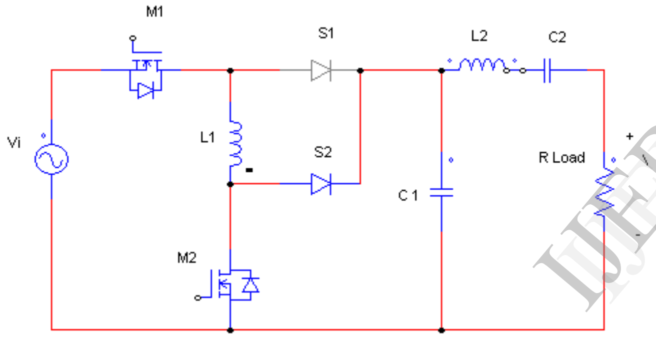

Fig.4. Mode 1 operation

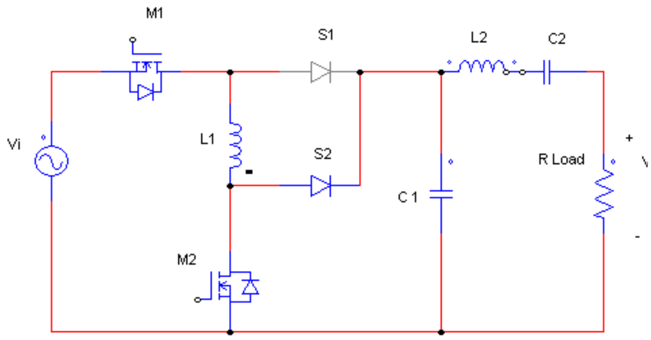

Fig.5.Mode 2 Operation

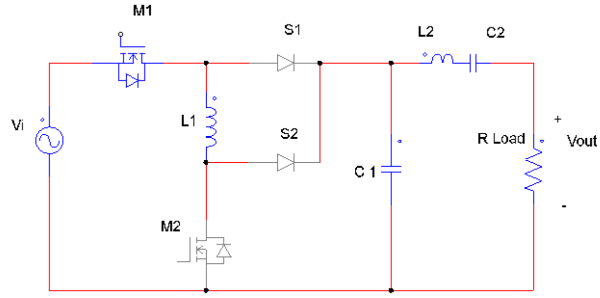

Fig.6. Mode 3 Operation

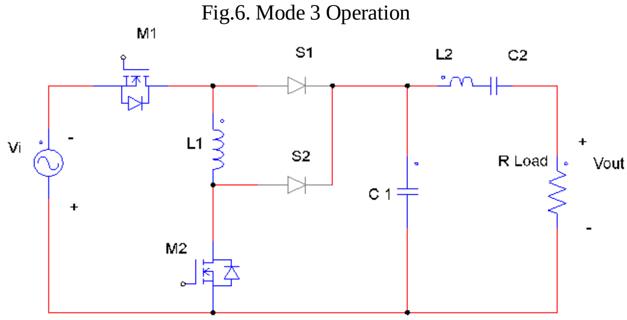

Fig.7. Mode -4 Operation

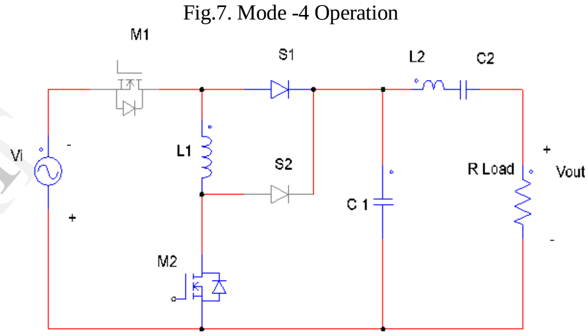

Fig.8. Mode-5 Operation

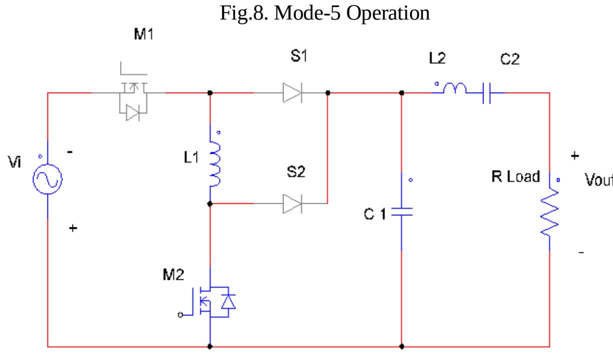

Fig.9. Mode-6 Operation

Mode I (Fig.4) - During the positive half cycle,M_1 is turned ON, S_2 is forward biased. The circuit operates as Boost circuit. The output is supplied from the capacitor C_1 to the load thus non-interrupting the flow of output power

Mode II (Fig.5) -The operation is same but the only difference is that the inductor L_1 which was charging previously during the mode-1 operation discharges through

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the diode S_2 thus increasing the power output. Also at this point the capacitor C_1 charges to its peak value.

Mode III (Fig. 6) - As the energy stored in the inductor has been completely dissipated, diode S_2 gets reverse biased, M_2 is also turned OFF but the capacitor C_1 is providing the output continuously from the stored charge. Therfore the powerflow remains unidirectional

Mode IV (Fig.7) -Here the input reverses two MOSFETS are turned ON and the two diodes OFF as it is reverse biased but the current circulates in the reverse direction at the input but at the output the capacitor is keeping the current flow unidirectional. Thus it is observing Buck-Boost operation.At this mode the function of L_2 and C_2 is expressive, L_2 will operate together with C_1 as a tank circuit thus parallel resonance operation can be observed.

Mode V (Fig.8) -In this mode M_I MOSFET turned OFF because of the current reversal owing to natural commutation/line commutation. But as the inductor L_1 discharges the power flow is still maintained and it also charges the capacitor.

Mode VI (Fig.9) - As the inductor discharges completely the entire stored energy, the diode S_1 gets reverse biased. But the capacitor discharges and the power flow is maintained as such.

III. ANALYSIS AND DESIGN

For the steady-state analysis several assumptions are taken in to account [8].

1. The output capacitor C_1 is assumed to be very high so that it filters out the voltage ripple
2. The input voltage for simulation is assumed to be sinusoidal
3. The switching frequency of M_1 and M_2 is assumed to be much larger than the input supply frequency.
4. Internal resistances and diode drops are neglected for simplification of analysis

According to the boost operation, shown in modes 1-3, the average voltage across the switch can be expressed as

$$V(t) = (1-D_1-D_2) ViT_s + D_2T_sV_{0ut} \quad (1)$$

$$\text{Where } V_i=V_m\sin\omega t \quad (2)$$

The average switch current during the switching period

$$I_1(t) = D_1^2T_sV_{in}/2L \quad (3)$$

Since the waveform for the inductor current is triangular in shape as seen in the simulation result (fig. 15) The average diode voltage and current can be expressed as :

$$V_2(t) = D_1T_sV_{0ut} +[(1-D_1-D_2) (V_{out}-V_{in})] \quad (4)$$

$$I_2(t) = \frac{D_2^2T_s(V_{out}-V_i)}{2L} \quad (5)$$

Applying Voltage second balance rule ie. Energy across the inductor is equal to zero. We get

$$D_2= D_1\frac{V_i}{(V_{out}-V_i)} \quad (6)$$

In Boost operation the instantaneous power dissipated in the entire circuit is

$$P_d = \frac{V_{in}^2}{R} = \frac{V_m^2\sin^2\omega t}{R} \quad (7)$$

The instantaneous current flowing through the load resistor is

$$I = \frac{P}{(V_{out}-V_i)} = \frac{V_m^2\sin^2\omega t}{R\,[V_{out}-V_m\sin\omega t]} \quad (8)$$

The instantaneous power delivered to the load

$$P_o = V_0 * I \quad (9)$$

$$= V_o\frac{V_m^2\sin^2\omega t}{R\,[V_{out}-V_m\sin\omega t]} \quad (10)$$

Therefore the total energy delivered to the load

$$E_o = \int_0^{\frac{T}{2}} P_o\,dt \quad (11)$$

The total energy consumed by the circuit

$$E_d = \int_0^{\frac{T}{2}} P_d\,dt \quad (12)$$

According to the energy conservation principle energy supplied must be equal to the energy delivered. As a result equating (11) & (12)

$$\frac{V_0^2T}{2R} = \frac{V_m^2D_1^2T_sT_i}{8L} \quad (13)$$

The inductance L and switching frequency f_s is used to determine the duty ratio D, from (13) the equation can be determined as

$$D = \frac{2V_0}{V_m}\sqrt{\frac{Lfs}{R}} \quad (14)$$

DESIGN

The design was carried out based on the requirement the inputs and outputs required are Vin =400mV,f = 100Hz, fs= 50000Hz Iin=0.8A

Applying Buck-Boost Operation Equation,

$$\frac{V_0}{V_{in}} = \frac{D}{1-D} \quad (15)$$

From this we will get the value of D (duty ratio). The average inductor current may be obtained from the average source current and the equation is:

$$I_g = \frac{DI_o}{1-D} \quad (16)$$

Supposing Discontinuous Conduction Mode

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$$\frac{V_0}{V_d} = \frac{D}{\Delta_1} \qquad (17)$$

From this obtain the value of discontinuous conduction interval Δ_1 then the value of inductance can be found out as

$$L = \frac{V_d}{2I_l} D\, T_s (D+\Delta_1) \qquad (18)$$

From the obtained value of L findout the commercially available inductor then recalculate the average currents inorder to obtain the actual values of the same. Again calculate the value of load resistor or the limit of load resistance,

$$\frac{\delta I_l}{I_l} = \frac{(1-D)^2 R T_s}{L} \qquad (19)$$

The charging and discharging currents of the capacitor decides the voltage ripple. Consider that the entire AC part of the inductor current flows in to the capacitor. This relation gives the value of capacitance.

$$\frac{\delta V_0}{V_0} = \frac{DT_s}{RC} \qquad (20)$$

Choose the value of the capacitance appropriately . The validity of this assumptions can be checked by using the two given equalities.

Ts << RC

$$\frac{DT_s}{RC} << 1 \qquad (21)$$

Since the required power and voltage limit is specified the inductance value have to be designed from the given parameters .If the switching frequency increases, the size of the inductor decreases. But we cannot increase the switching frequency above a specified limit because the switching loss will increase considerably. Therefore the actual size of the inductor should compensate the loss incurred. In the efficiency calculation the forward voltage drop and ON state drop of MOSFET plays an important role. The duty ratio for the Boost and Buck- Boost operation is taken as D itself.

IV. CONTROL STRATEGY

The SinePWM control strategy can be used for the pulse generation in the physical implementation as well as simulation because it produces perfect square pulses for triggering that will limit the output waveform distortion. To make output voltage constant we can use a comparator or P/PI/PID compensator.

V. SIMULATION RESULTS

The simulation was carried out for designed values of inductance and capacitance for an output voltage of 3.3V from 400mV,100Hz input sinusoidal supply. The values of parameters are tabulated as below:

TABLE 1

PARAMETER DESCRIPTION

Sl.No	PARAMETERS	VALUES
1	Input Supply	0.4V,100Hz
2	Output Voltage	3.3V
3	Switching Frequency	50kHz

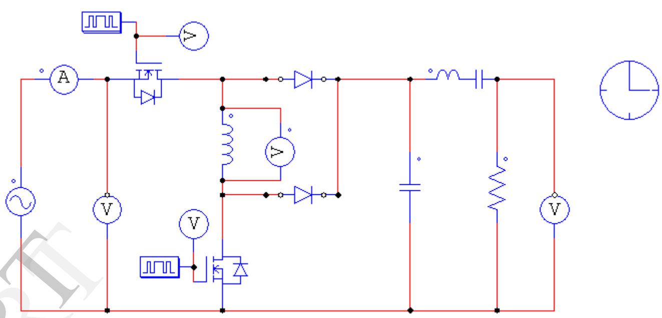

Fig.10. Open loop Simulation Setup of the Proposed topology

WAVEFORMS OBTAINED

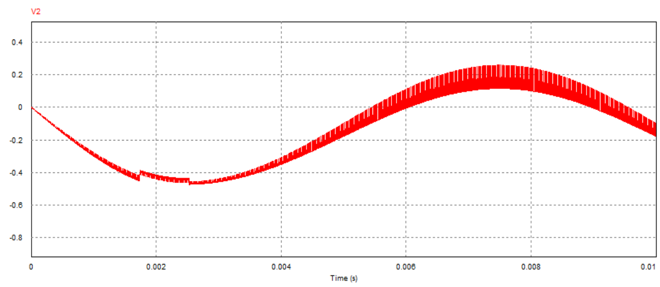

Fig.11. Input Voltage

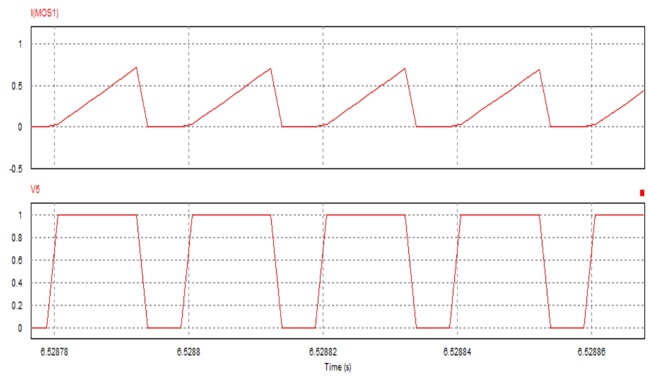

Fig.12. Gate Current and Voltage of M1

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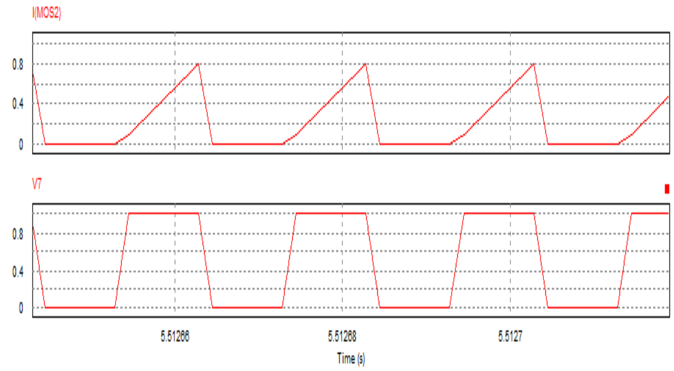

Fig.13.Gate Current and Voltage of M2

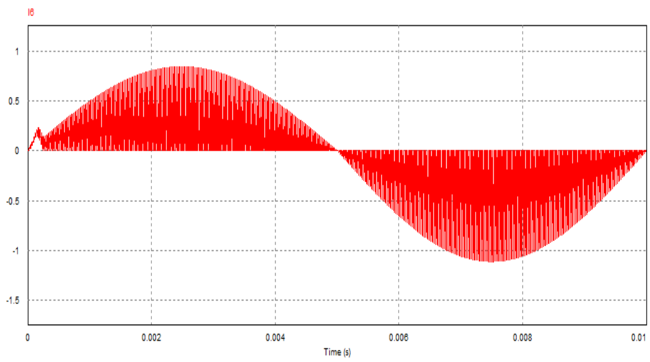

Fig.14. Input Current

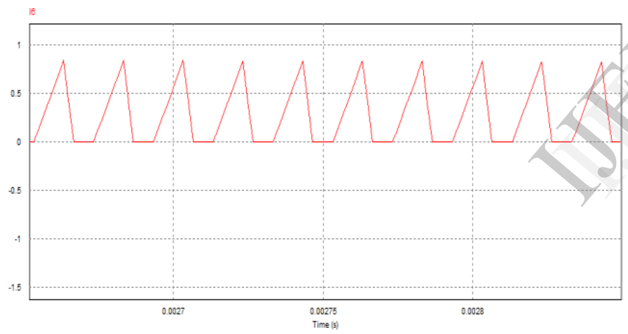

Fig.15. Inductor current waveform during Boost operation

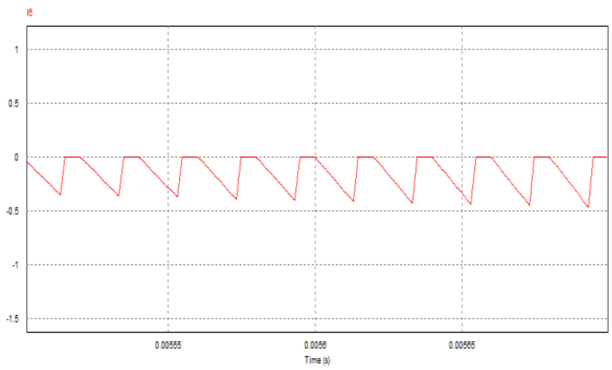

Fig.16. Inductor current during Buck-Boost Operation

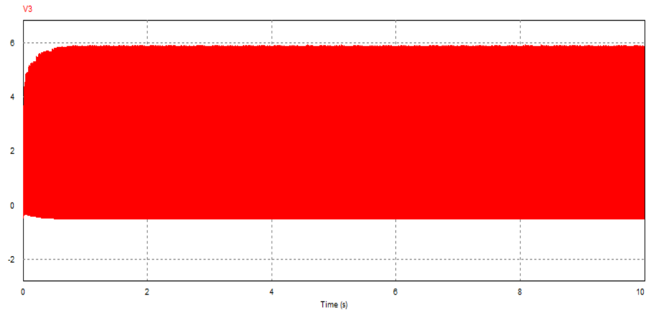

Fig.17. Output Voltage using LC filter at the output stage

VI. CONCLUSION

A unique combination of Buck and Buck- Boost Converter is presented in this paper which can produce a constant output voltage .The design was carried out for an output voltage of 3.3V, from an input supply of 400mV ,this potential can drive an LED or it can be used for battery charging purpose provided current gain is optimum. Further expansion can be brought about by providing an active feedback circuit and using instrumentation amplifier at the booster stage. The instrumentation amplifier have to be provided with an input supply as V_{cc} for driving it this will incur the use of a backup. But providing an active feedback circuitary with minimal losses makes the circuit completely self reliable and we can operate the given circuit without any backup supply that is why the paper is titled as Self Powered Buck-Boost Converter. Since Infrared Data Transmission is also using the same converters at the receiver stage by widening the output range, the industrial relevance of this converter can also be widened.

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VII.REFERENCE

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