

## **AC to DC Converter for Low Voltage Small Scale Generator**

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**Abstract :** AC-DC single-stage converters are attractive because of their simplicity. The conventional power electronics converters used for such application have two stages, a diode bridge rectifier at the front end followed by a dc-dc boost converter. However, the extremely low output voltage of electromagnetic micro-generator does not allow diode bridge rectification. Even if possible, the losses in the front and diode bridge make the conventional power electronic interfaces quite inefficient. The proposed single stage converter directly boosts the micro-generator low ac voltage to usable dc voltage level, and hence, achieves higher efficiency. The main objective of this study is to minimize the cost, output ripple and minimize use of the dc power sources which makes converter circuit inefficient in the field of various electronic devices.

**Keywords -** Small scale generator, energy harvesting, AC to DC Converter, boost converter, pulse wide modulation (PWM), doublers discontinuous conduction mode (DCM).

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### **I. Introduction**

Energy harvesting is the process which captures energy from different sources, like, radio waves, traffic induced vibration and so on. Small scale generator or Micro generator is one of the most significant inventions of our rapidly developed electronic system. It has recently attracted various applications such as wireless sensor nodes (WSN) including remote environmental monitoring, homeland security, automotive sensors and biomedical implement etc. [1] [2]. There are different types of micro generator or small scale generator such as piezoelectric, electromagnetic, and electrostatic. The output voltage of micro generator is ac type, but almost all the electronic loads require DC voltage for further operation. Power processing system is another important thing, because micro generator produces very low ac voltage but we need DC voltage for most of the sensor applications. There are different kinds of power processing systems, but all are not efficient and cost effective.

Now-a-days, all the portable electronic devices use battery as a power source. Energy harvesting can be an effective alternative [3]. Some of the studies have designed the power processing circuits, but most of them are not cost effective. They have used different specific components, such as, polarity detector, comparator, PI controller, flip-flop, low pass filter, and feedback controller etc.. A few studies have discussed the charge pump circuit for the boost converter [1]-[8].

The proposed converter presents a dual polarity boost converter as an energy harvesting system. In this study, Section II presents the background of study, Sections III discusses the proposed converter, mathematical derivation is presented in Section IV and simulation is presented in section V. A new methodology is proposed for producing duty cycle which completely depends on power processing circuit of the input voltage.

### **II. Background**

This paper developed a converter of energy harvesting for the small scale generator or micro generator. A schematic diagram of micro generator is shown in Fig.1. We find out a method of using voltage multiplier for the low voltage converter. Furthermore the concept is utilized to design a new converter at low cost.

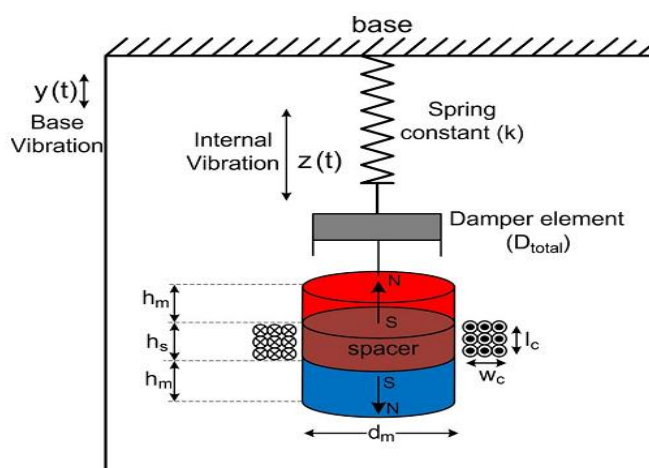


Fig 1: Small scale generator [1].

### A. Buck-boost converter

The Buck boost converter (Fig.2) can operate in four modes. Modes (1, 2) are operating for positive half cycle and Modes (3, 4) for negative half cycle of input sinusoidal voltage [5]. The main advantage of the buck boost converter is that it works in both cycles and reduces the problem of dual polarity boost converter.

MODE 1: When supply voltage is positive, switch S1 will be ON and inductor gets energy through switch S1.

MODE 2: When switch S1 will be OFF and diode D1 will be forward biased, the stored energy of the inductor will be delivered to the load. After that, inductor current will decrease to zero.

MODE 3: The buck-boost converter operates in negative half cycle, then the switch will be ON and inductor preserves the current. The capacitor discharges through the load.

MODE 4: In this mode switch S2 is OFF and diode D2 will be forward biased. Inductor current will be discharged through the load and capacitor will be charged.

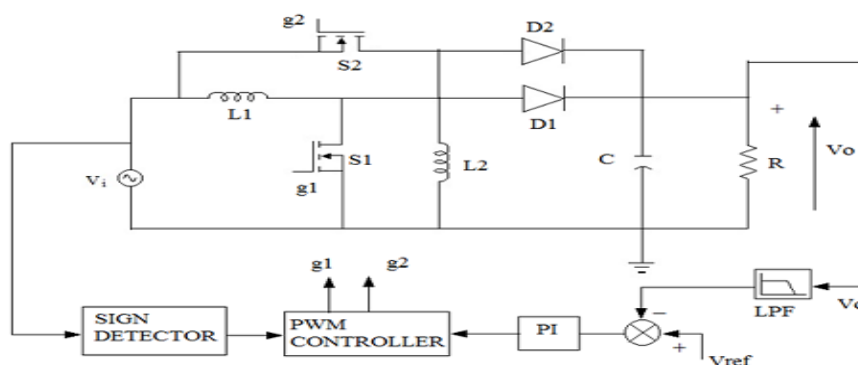


Fig. 2: Buck-boost converter [3].

## III. Proposed Converter

### A. Proposed Dual Polarity Boost Converter

The proposed converter separately processes the positive and negative half cycles of the generated voltage. Diode rectification will be replaced by alternate activation of one of two voltage boost circuits. This is a form of synchronous rectification which avoids a series connection of separate rectifier and voltage converters.

To limit the step-up ratio, the two circuits will provide half of the output voltage each. The target output voltage is 4.16V. When the generator voltage is positive, upper half of the output voltage is produced. Similarly, lower half of the output voltage is generated, when the input voltage is negative. In order to prevent conduction in the negative polarity boost converter when the generator voltage is positive, it is sufficient to hold off the MOSFET of the negative polarity converter. This gate voltage of the two converters needs to be synchronized to the generator voltage. Synchronous rectification has been integrated in the boost converter so as to avoid series connection of separate rectifier and boost stages. The proposed converter operates the boost converters in discontinuous conduction mode to avoid turn-on power loss in the MOSFET and reverses recovery effects in the diode. Several other benefits follow from this choice: relatively small passive components can be

added to the output side to manage the device parasitic capacitance etc. Schottky diodes have been used in this simple example, but synchronously switched MOSFETs could be used instead.

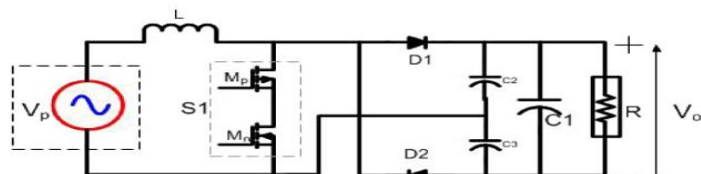


Fig 3: Dual polarity boost converter [2].

**B. Startup circuit:**

A startup circuit provides dc supply to the controller and gate driver circuit. The node voltage Vdc+ and Vdc- are providing positive and negative DC voltage. Batteries E1 and E2 provide the charge for the capacitor C1 and C2 through the diode D2 and D3 forward bias and reverse bias respectively. Battery E1 is charging through the DaR1 and E2 is charging through the DaR2 [2].

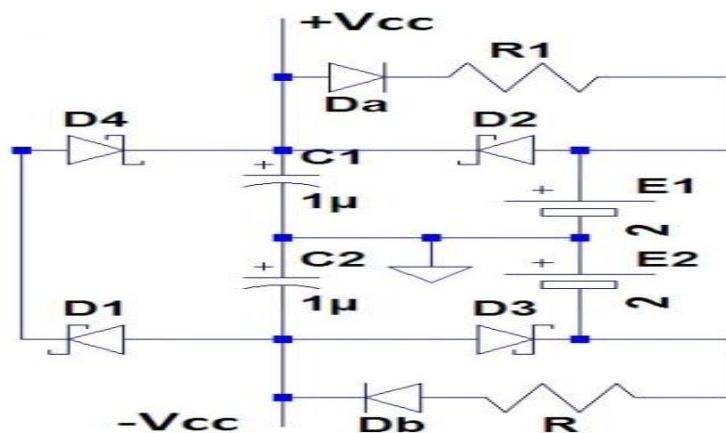


Fig 4: Start-up Circuit [2].

**C. Voltage doubler**

Voltage multipliers are AC-to-DC power conversion devices, comprised of diodes and capacitors that produces a high potential DC voltage from a lower voltage AC source [9]. Multipliers are made up of multiple stages. Each stage is comprised of one diode and one capacitor. Two staged multiplier is called voltage doubler. Voltage doubler consists of two diodes and two capacitors as presented in Fig.5.

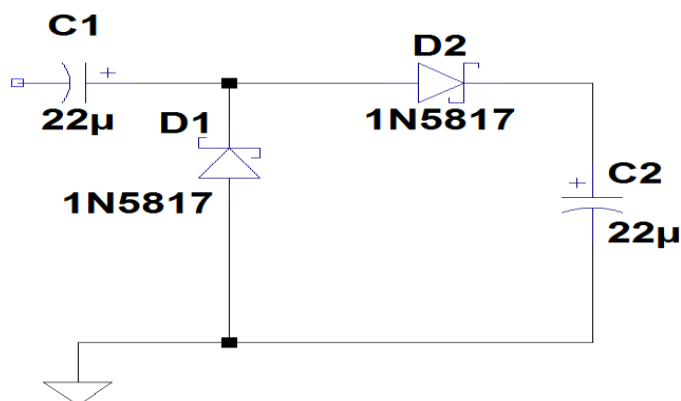


Fig 5 Half wave voltage doublers [4].

During the negative half cycle of AC input voltage (Fig. 5) diode D1 is forward biased and diode D2 is reverse biased. Therefore, C1 will be charged until the voltage across it becomes equal to the peak value of the source voltage. During the positive half cycle of AC input voltage, D1 is reverse biased and D2 is forward biased. Hence C1 (charged to Vs) and C2 will be charged with the sum of series peak voltage, i.e. 2Vs. Hence doubler circuit passes to the duty voltage (Vduty).

### IV. Mathematical derivation

When the input peak voltage  $V_p$  with frequency is  $f_i$ , the input power of the circuit is as below[1]:

$$P_i = \frac{V_p^2 D^2}{4 f_s L} \beta \tag{1}$$

$$\beta = 2 \int_0^{2\pi} \sin^2 \theta \left[ 1 - \frac{\sin \theta}{V_o/V_p} \right]^{-1} dt \tag{2}$$

Here,  $\beta$  is close to the unity ( $V_o \gg V_p$ ) and  $L$  is the inductor and  $\theta = 2\pi \cdot \frac{t}{T_i}$ . Output power of the circuit depends on its switching loss and component loss.

$$P_{output} = P_{in} - P_{loss\_c} - P_{sw\_M1,2} \tag{3}$$

The switching loss can be estimated as:

$$P_{sw\_M1,2} = \frac{V_p^2 \tau}{2 T_s L} \tag{4}$$

$\tau$  is the switching transistor time.

Total component loss can be calculated by following equation

$$P_{loss\_c} = I_{i(rms)}^2 R_{ind} + I_{sw(rms)}^2 R_{ds-on} + 4 V_f I_{diode(av)} \tag{5}$$

Where,

$I_i$ ,  $I_{sw}$  and  $I_{(diode)}$  are input current, switching frequency and diode current respectively.

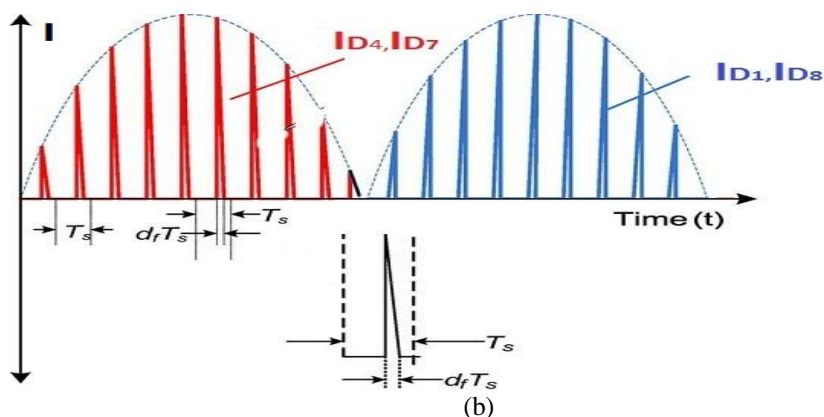
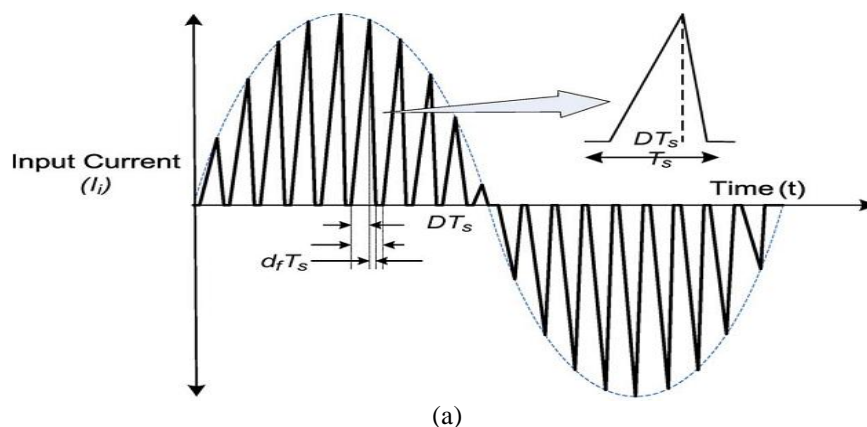


Fig:6 (a) Input current and (b) diode current [1].

The peak of the input current can be defined as:

$$i_p = V_i D T_s / L \tag{6}$$

Where

$$V_i = V_p (\sin 2\pi T_s / T_i)$$

The rise time of input current is

$$DT_s = i_p L / V_i \tag{7}$$

And the fall time of input current is

$$d_f T_s = i_p L / (V_0 - V_i) \tag{8}$$

Since the input current has a triangular shape Fig. 7(a), its rms value over a switching cycle can be derived as [1]:

$$I_i^2 (rms) = \frac{1}{T_s} \int_0^{T_s} I_i^2 (t) . dt = \frac{1}{3} i_p^2 (D + d_f) \tag{9}$$

Using above equation (6), (7), (8) and (9), we can write-

$$I_{(rms)}^2 = \frac{1}{3} \cdot \frac{D^3 T_s^2 V_i^2}{L^2} \cdot \frac{1}{1 - V_i / V_0} \tag{10}$$

The total number of switching cycles in a line cycle can be defined as  $N = T_s / T_i$ . Since the converter is being operated for a high step-up ratio ( $V_i / V_0 \ll 1$ ), for a large value of N, the summation can be approximated as integration over the line cycle. Therefore,

$$I_{sw(rms)}^2 = \frac{D^3 T_s^2 V_p^2}{6L^2} \beta \tag{11}$$

The switch current and the diode currents can be calculated as :

$$I_{sw(rms)}^2 = \frac{D^3 T_s^2 V_p^2}{6L^2} \tag{12}$$

And

$$I_{diode(avg)} = \frac{D^2 T_s V_p^2}{4LV_0} \tag{13}$$

Hence, the Capacitor current is Equal to the diode current.

$$I_{diode(avg)} = I_{c3} = I_{c4}$$

Hence,  $T = \frac{1}{f_i}$ ,

where, T=input voltage time

$$V_{c3} = \frac{1}{2C_3} \int_0^{T/2} I_{c3} dt \tag{14}$$

And similarly,

$$V_{c4} = \frac{1}{2C_4} \int_{T/2}^T I_{c4} dt \tag{15}$$

Output Current across the load resistance is,

$$I_0 = \frac{V_{C3} + V_{C4}}{2R} \tag{16}$$

### V. Simulation and Result

The proposed design is simulated by LTspice software. The converter is shown in Fig. 7. The value of parameters is given in the table.

The converter operates at a switching frequency of 50 kHz. In practical cases micro generator did not give the input voltage which is an ideal sinusoid. But here the simulation is done with a pure sinusoidal waveform [1]. It can be seen that the converter operates in DCM. The input current over a few switching cycles is along with positive gate signals. The converter operates in DCM to reduce switching losses. It can be seen that the gate voltage of them-MOSFET ( $V_{gn}$ ) is positive when the p-MOSFET gate voltage ( $V_{gp}$ ) is negative. Therefore, both the MOSFET are turned ON at the same instance.

Parameter	Value
Switching Frequency	50kHz
Input Voltage	400mV,100Hz
Output Voltage	4.16V
Capacitor(C1 and C2)	1uF
Capacitor(C3 and C4)	4.7uF
Inductor(L)	10uH
Filter capacitor	100uF
Capacitor (C5, C6, C7)	22uF
MOSFET and OPAM	AO6407,AO6408 and LTC6247

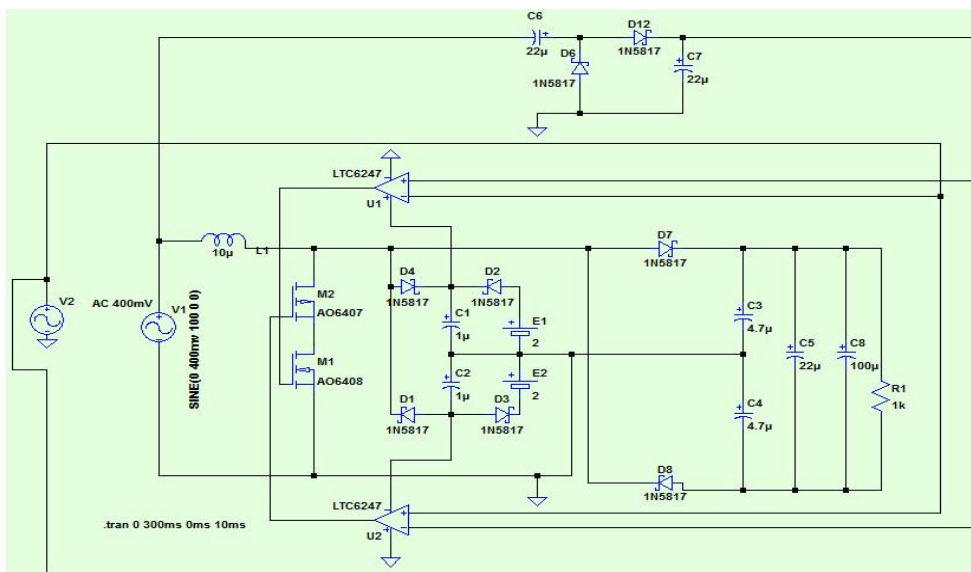
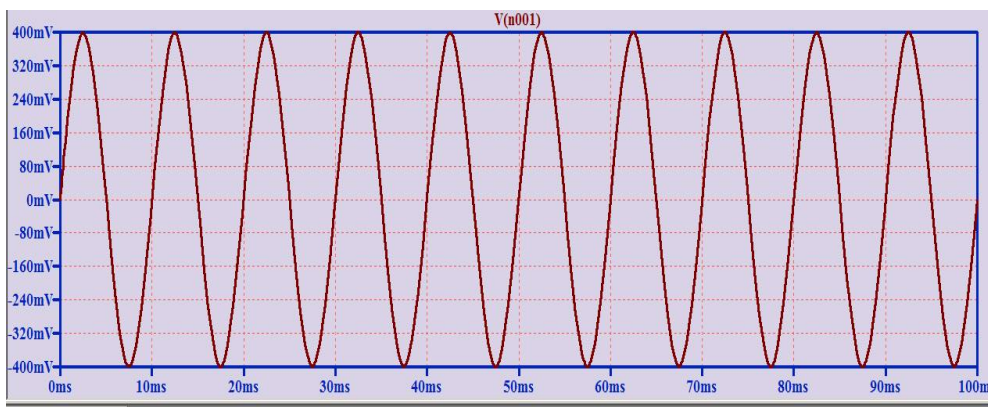
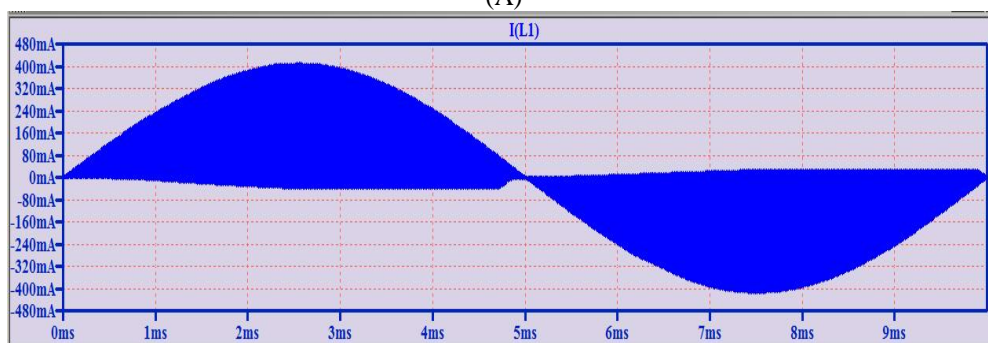


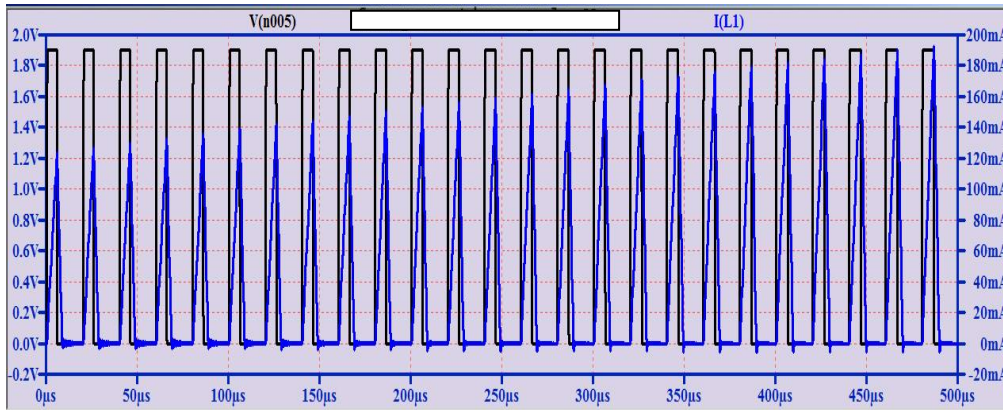
Fig 7: Proposed Converter Circuit.



(A)



(B)



(C)  
Fig 8: (A) Input Voltage (B) Input Current(c). Input Gate Current (Mn) for positive cycle

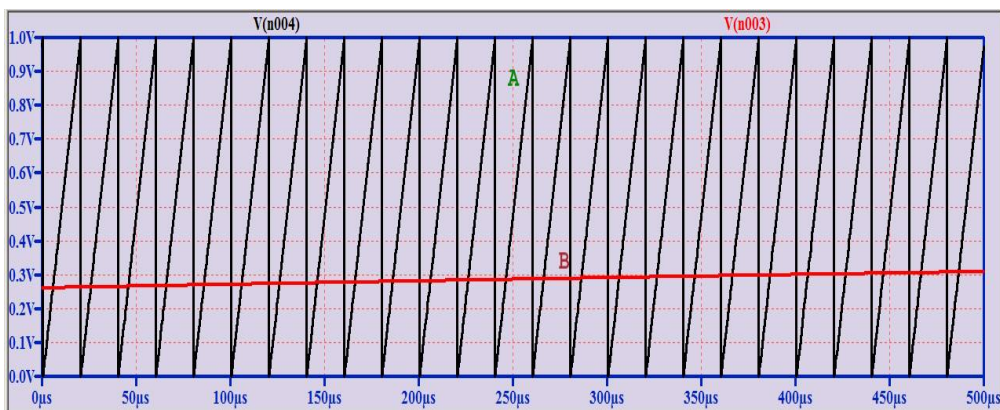


Fig 9: Sawtooth waveform & Duty cycle.

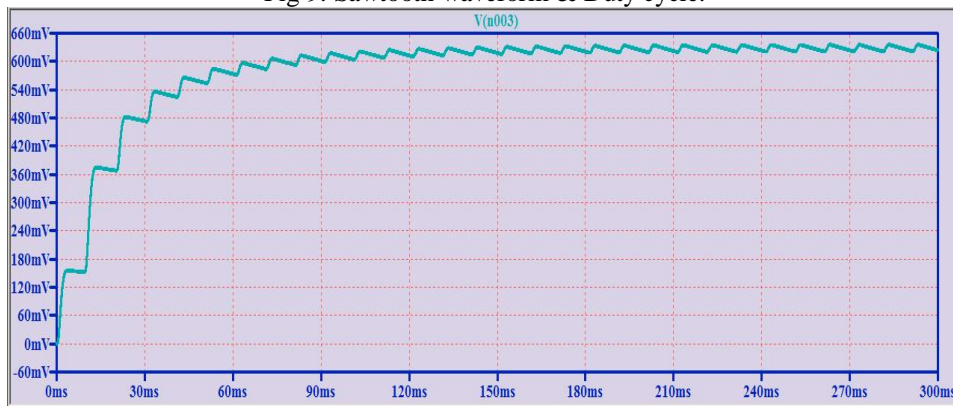


Fig 10: Doubler circuit output.

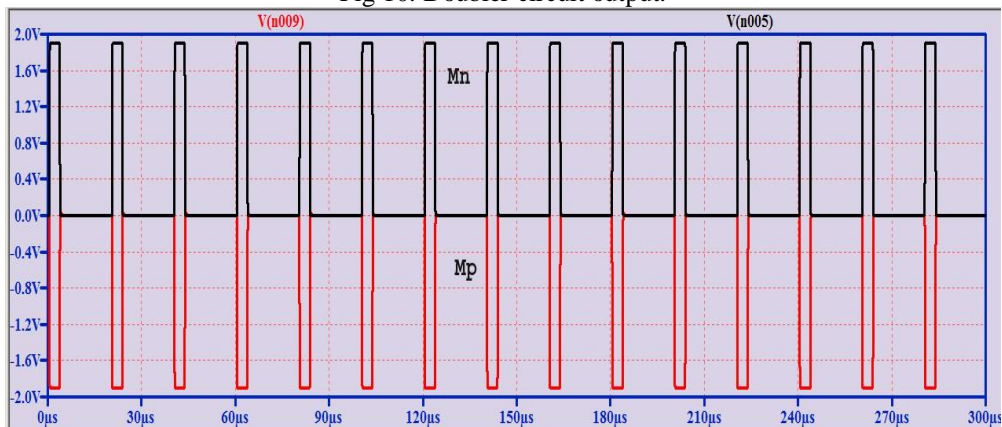


Fig 11: PWM waveform for MOSFET.

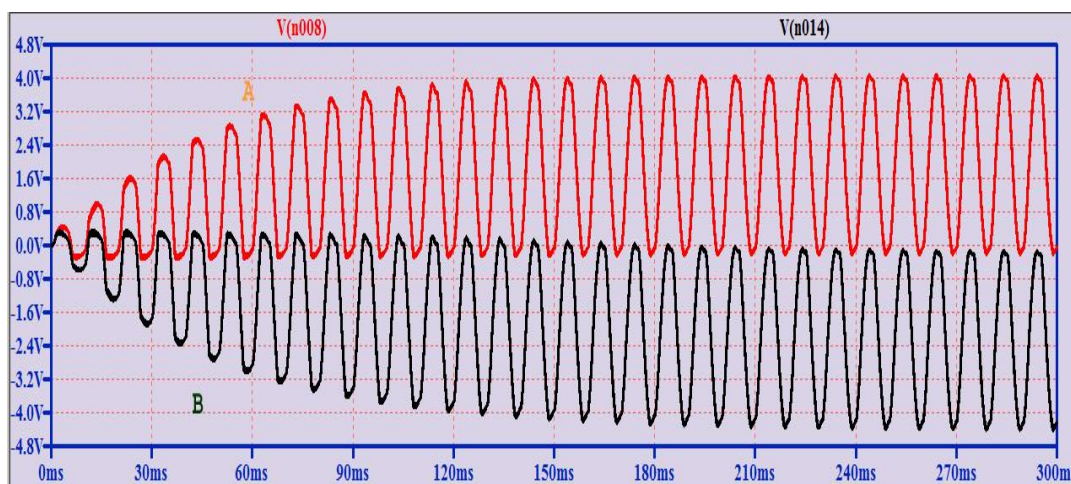


Fig 12: Voltage across capacitor C3 &amp; C4.

Secondary voltages are used for first time triggering gate voltage of the MOSFET. The circuit is working autonomously. Fig 12 shows the output voltage across the capacitors C3&C4. Each capacitor works as a charge storage for every half cycle.

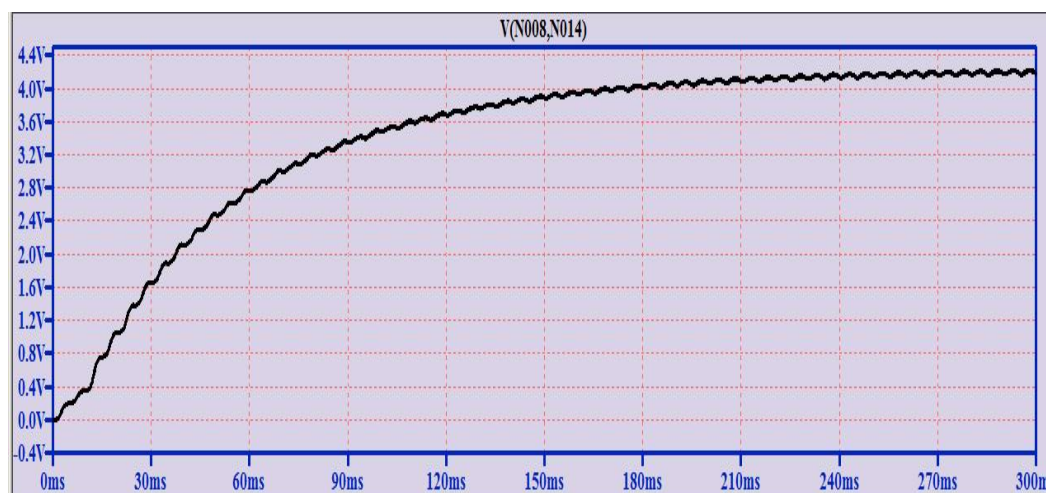


Fig 13: Final output voltage

Hence, the output voltage of the converter is 4.16V, duty voltage is 0.613V, steady state time is 150 millisecond, and 70mV is the output voltage ripple.

## VI. Conclusion

In this paper, we have designed a new method for producing duty cycle and minimized the secondary battery sources for power processing circuit. In most of the previous circuits, duty cycle depends on the battery of primary stage. But, the proposed circuit removes this disadvantage. The duty cycle of our circuit completely depends on its input. Another specification of this circuit is that, we can control the duty cycle. For instance, if we use a silicon diode bridge rectifier then it gives 0.18 duty cycle and Tripler gives 0.9 duty cycle. Our proposed circuit input power is estimated to be around 30mW. If duty cycle is 0.18 and 0.9, input power is estimated 26mW and 65mW respectively. Power consumption of the circuit is 7mW and output power is 23mW.

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