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DESIGN AND ANALYSIS OF CONVENTIONAL BOOST CONVERTER FOR WIPER MOTOR

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Abstract

Window cleaning devices in automobiles, commonly referred to as "wiper" are powered by an electric motor of approximately 50W at 24V. To fulfil the requirements, there is a need to step up the voltage from the available 12V battery source to 24V. The Conventional Boost Converter is the most basic setup that can be used for the purpose. The Power circuit includes an inductor, a switch, a diode and a capacitor. This paper deals with the analysis the conventional DC-DC converter taking into consideration the various losses due to the components. The results are verified with a 50W prototype.

Introduction

The classical boost converter is the most fundamental block of most boost-derived topologies, hence, the minimum amount of losses occurring in those topologies is fixed for a given duty ratio. Restricting the power to a particular value i.e. for aparticular application, a reference can be set which can be referred to while figuring the best circuit with the highest efficiency.

Circuit description

Power circuit:

The power circuit consists of an inductor L, capacitor C, a switch M1 and Diode D1 as shown in fig 1:

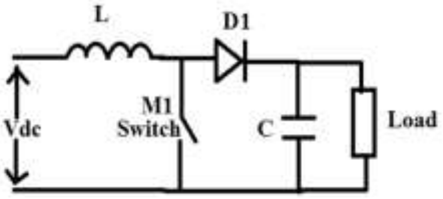

Figure 1. Conventional Boost Converter

The efficiency and the gain expression for a conventional boost converter is given by 1 and 2.
Substituting value of Vo and Io from 1 in 2:
$\%\eta = 100\%$
Ideally there should be no losses, but practically there are losses that are to be accounted for. In this paper, the losses due to various passive elements are considered in designing, analysing and verifying the circuit design.

Modes of operation

The circuit works in 2 modes of Operation.
Mode 1: Switch is off.

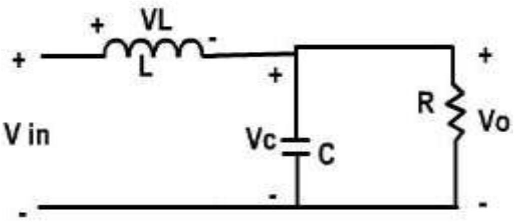

Figure. 2 Mode 1-M 1 is OFF.

The switch being off, the diode is forward biased and the energy stored in the inductor plus that from the voltage source flows through the inductor and charges the output capacitor.

Mode 2: Switch is on and the capacitor is initially charged.

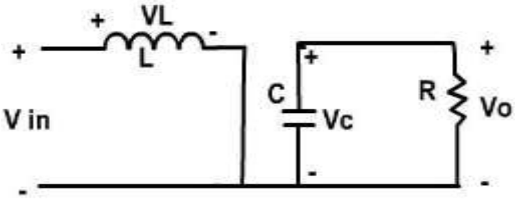

Figure 3 Mode 2-M 1 is ON

Now, as the capacitor is charged, and the switch is on, the inductor starts charging up again through the input voltage source and correspondingly the energy stored in the capacitor flows through the load.

Design & discussion

$$G(D)=\frac{Iin}{Io}=\frac{Vo}{Vin}=\frac{1}{1-D} \tag{1}$$

$$\eta=\frac{Vo*Io}{Vin*Iin} \tag{2}$$

$$Vl(off)=Vo-Vin \tag{3}$$

$$Ic(off)=Il-\frac{Vo}{R} \tag{4}$$

$$Vl(on)=Vin \tag{5}$$

$$Ic(on)=-\frac{Vo}{R} \tag{6}$$

Applying Volt Second Balance over one period, and assuming the switching ripples to be minimum, we get:

$$\frac{Vl(on)T(on)}{T}=\frac{Vl(off)T(off)}{T} \tag{7}$$

We know

$$D=\frac{T(on)}{T}$$

$$D^{'}=\frac{T(off)}{T}=1-D,$$

Substituting values of $Vl(on)$ and $Vl(off)$ from 3 and 5 to 7. We get,

$$Vo=\frac{1}{1-D}Vin$$

$$\frac{Vo}{Vin}=G(D) \tag{8}$$

Similarly in an ideal transformer model,

$$\frac{Vo}{Vin}=N \tag{9}$$

Where N= ratio of Number of turns (Primary to secondary)

From 8 and 9, we can say:

$$G(D)=N$$

Similarly, using capacitor current balance and equation's 4 and 6,

$$\frac{Iin}{Io}=N=G(D)$$

Therefore, the conventional boost converter operating in continuous conduction mode can be modelled as an ideal DC transformer with a turns ratio of 1:G(D).

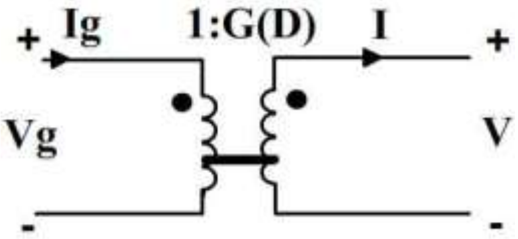

Figure 4. DC-Transformer Model

A transformer can also be modelled as a combination of a voltage source and a current source respectively.

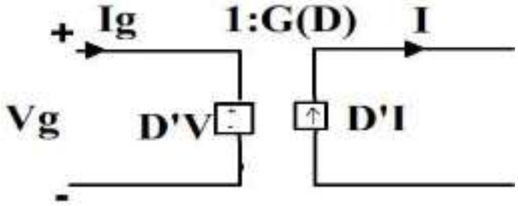

Figure 5

Similarly, Including the inductor copper loss, Diode loss and switch loss in the circuit, we get the following model:

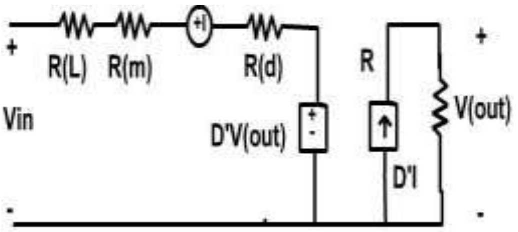

Figure 6 Circuit Diagram with loss compensator components

Now applying Volt Second balance and Capacitor Current balance, we get the expression for gain and efficiency for the circuit as:

$$G(D)=\frac{1}{D'}(1-\frac{D'V_d}{V_g})(\frac{1}{1+\frac{R_l+DR_{on}+D'R_d}{D'^2 R}}) \qquad (10)$$

$$\eta=\left(1-\frac{D^{'}(V_d)}{V_g}\right)\left(\frac{1}{1+\frac{R_l+DR_{on}+D^{'}R_d}{D^{'2}R}}\right) \qquad (11)$$

For practical implementation, the design equations for the passive elements in the DC-DC converter are shown below:
The current and Voltage ripple can be expressed by :

$$\Delta I=\frac{V_{in}D}{FL} \qquad (12)$$

$$\Delta V=\frac{I_{out}D}{FC} \qquad (13)$$

The critical values of L and C are given by:

$$L_c>\frac{D(1-D)r}{2f} \qquad (14)$$

$$C_c > \frac{D}{2fr} \tag{15}$$

The switch stress can be expressed by :

$$V_m = V_o \tag{16}$$

Calculation

For simulation and theoretical calculation, to account for the inductor loss, a resistance of the value 0.088Ω as measured is included. Similarly, for the On-state resistance of the switch (R_{on}), an external resistance with the value of 0.075Ω is included.
To account for diode loss, Forward characteristics are plotted experimentally and as per the graph, a resistance of 0.85Ω is included with a voltage drop of 0.8V.

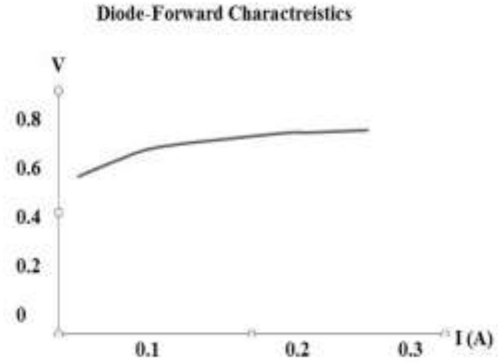

Figure 7.

D is the Duty ratio of the switch which is chosen to be 0.5 for the set value of gain to be 2 respectively.

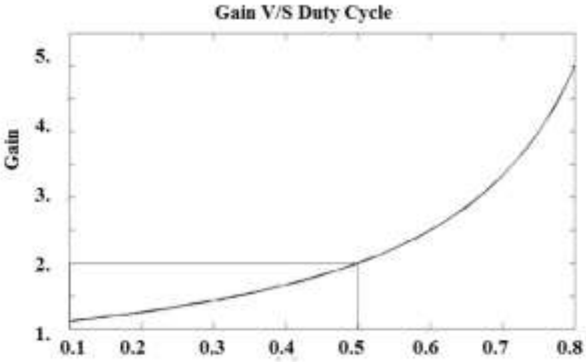

Figure 8

Voltage=14V, Output Voltage=28V, Power=50W, Operating Frequency=50KHz and using the equation 14 and 15, the values of inductor and capacitor used for implementation of the circuit are L=50µH, C=47µF.

Results

Theoretical results:

In Ideal Case, The efficiency and gain as calculated using 1 and 2 come out to be 100% and 2.
In Non-Ideal Case where the loss compensator components are considered to match the practical scenario:
For Vg=14V, Vd=0.8V, Rd=2.1Ω, Rl=0.088Ω, D=0.5 ,R=11.52Ω , Ron=0.075Ω.Using equation 16,The value of switch stress calculated is 28V.Using equations 10 and 11,The value of gain calculated is 1.63 and the efficiency comes out to be 81.55%.

Simulation results:

Ideal case: Figure 10 shows the output power and output voltage for the conventional circuit without considering losses with the output voltage observed as Vo=26.75V. Figure 11 depicts the output current in this case with output current being Io=2.3A. Figure 12 shows the ripple difference between the input and the output current and their respective values with I in= 4.5A. From the observed values, the gain and efficiency are calculated using 1 and 2 equation to be 1.91 and 87.89% respectively.

Non-ideal case: Considering the losses, Figure 13 shows the output voltage to be Vout=22.25V with figure 14 depicting outputCurrent Io=1.94A with gain= 1.589 , and an efficiency of 79.701% calculated respectively using 1 and 2 equation.

Hardware results*:*
A 50 W prototype is simulated and built to validate the circuit.
A PIC 18F45K20 flash microcontroller was used to generate the gate pulse in an open loop structure at a switching frequency of 50 kHz at a duty cycle of 0.5.
The input voltage of 14V was supplied from a battery. The switch used was a Power MOSFET IRFP250M and the diode being used was MUR460. The circuit was tested with a resistive load.
Using the above stated components, Output voltage (Vout)=22.0V,Output current (Io)=2.07 A. The value of gain comes out to be 1.57 and the value of efficiency is 72.12%.

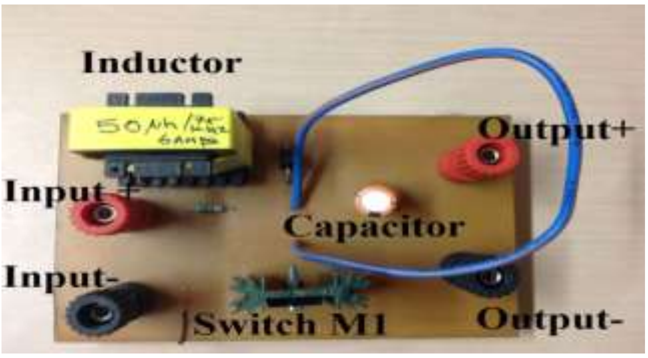

Figure 9: Experimental Circuit

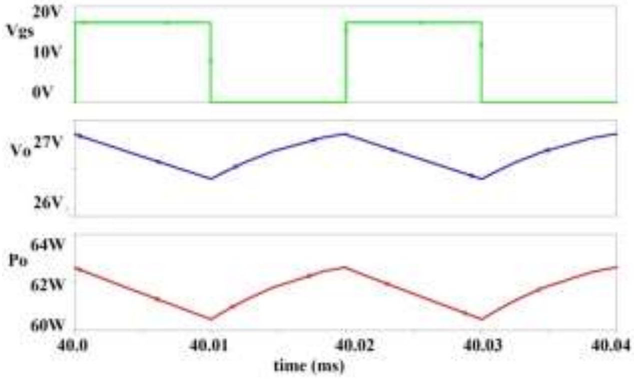

Figure 10 Gate Pulse, Output Voltage, Output Power

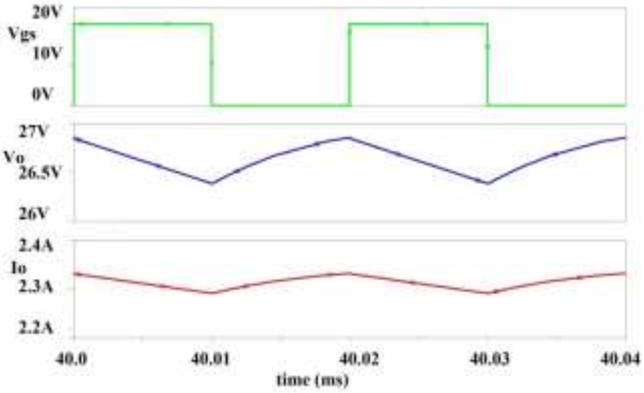

Figure 11 Gate Pulse, Output Voltage, Output Current

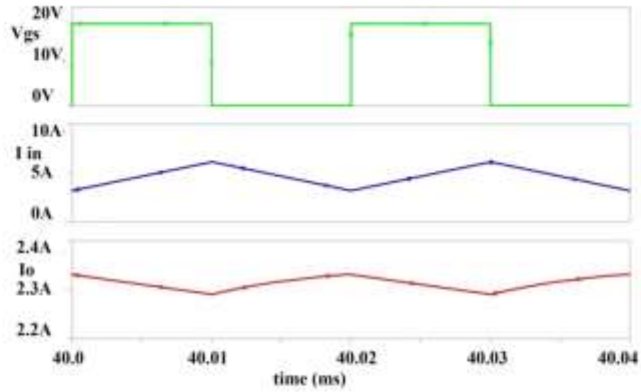

Figure 12 Gate Pulse, Input Current, Output Current

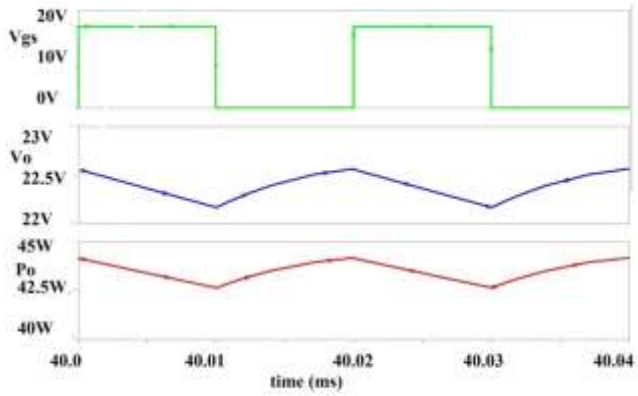

Figure 13Gate Pulse, Output Voltage, Output Power

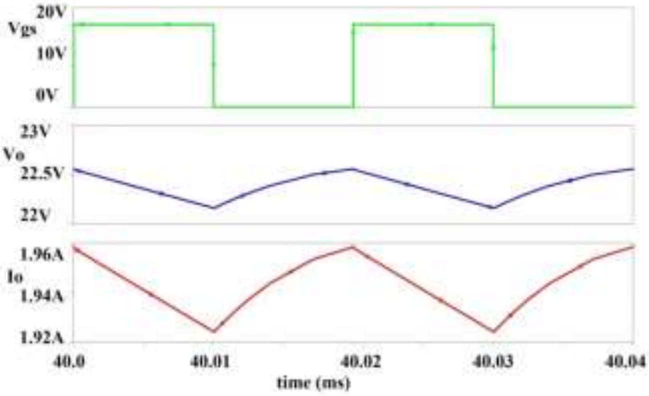

Figure 14Gate Pulse, Output Voltage, Output Current

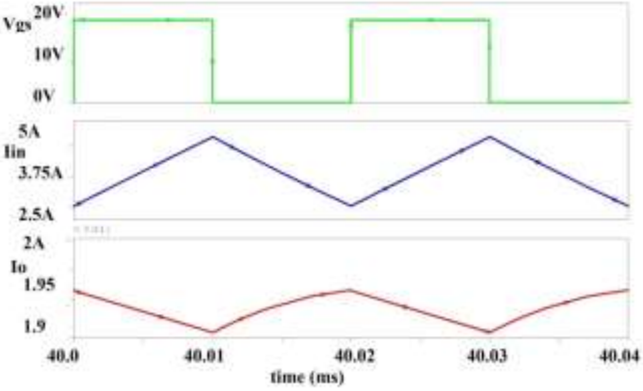

Figure 15Gate Pulse, Input Current, Output Current

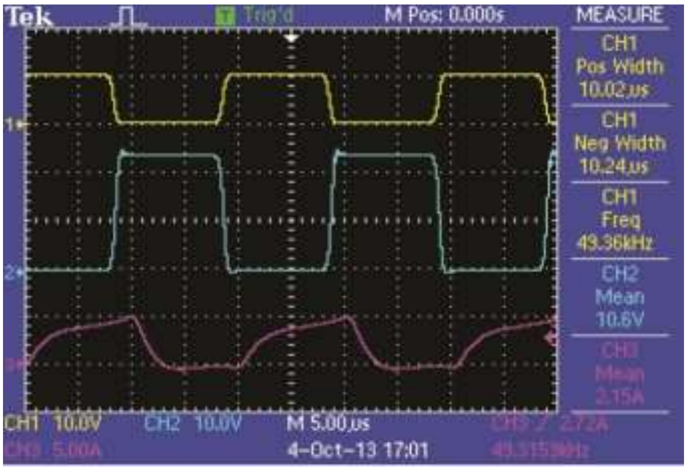

Figure 16 Gate Pulse, input voltage, inductor current

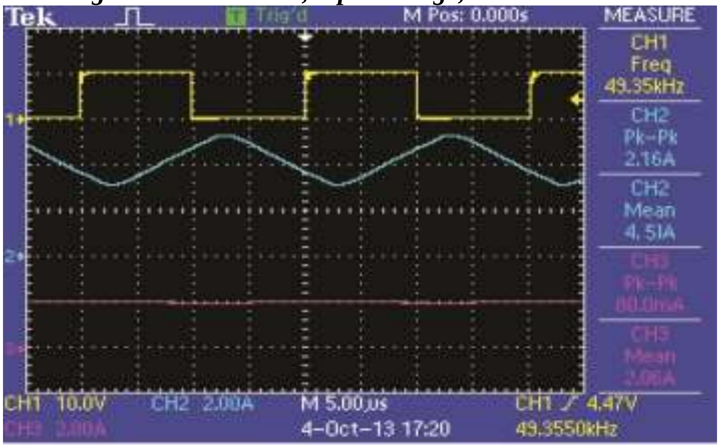

Figure 17 Gate pulse, Input Current, Output Current

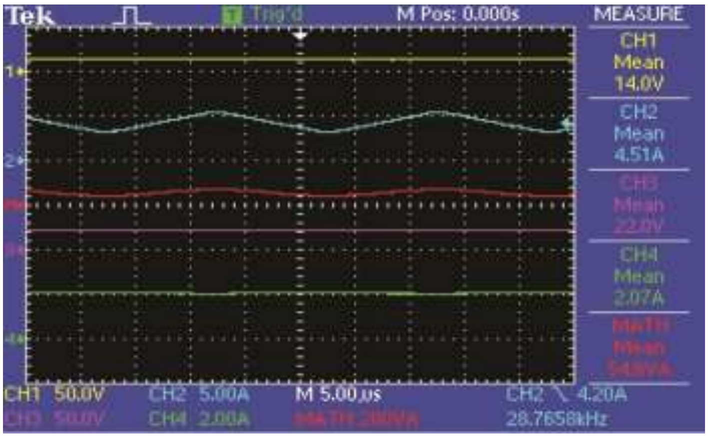

Figure 18, Input Voltage, Input Current, Output Voltage, Output Current, Input Power

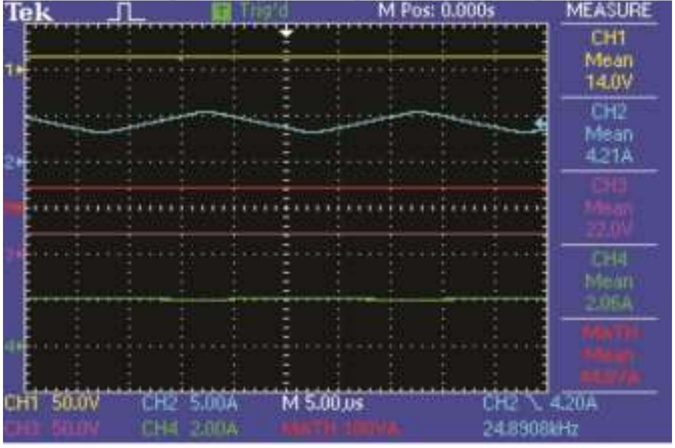

Figure 19 Input Voltage, Input Current, Output Voltage, Output Current, Output Power

The figure 15,16,17 and 18 depict the practical behavior shown by the circuit. It is observed that the circuitoperates at the designed parameters successfully and matches the results obtained by simulating the circuit and theoretical calculations.

Conclusion

The proposed converter has been designed, simulated and validated for a 50W load. The converter is operated at a duty cycle of 0.5. A voltage gain of 2 was obtained without using a transformer. The converter was designed to supply a load of 50W at 24V. The simulation and practical calculations are in accordance with the experimental values and the design equations.The output waveforms obtained from the practical and simulation confirm the performance of the proposed converter.

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