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Modelling and simulation of current fed dc to dc converter for PHEV applications using renewable source

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Abstract: With the current rate of depletion of the fossil fuel the need to switch on to the renewable energy sources is the need of the hour. Thus the need for new and efficient converters arises so as to replace the existing less efficient diesel and petroleum IC engines with renewable energy sources. The PHEVs, which have been launched in the market, and Upcoming PHEVs have converters around 380V to 400V generated with a power range between 2KW to 2.8KW. The fundamental target of this paper is to plan a productive converter keeping in mind cost and size restriction. In this paper, a two-stage dc-dc converter is proposed. The proposed converter is utilized to venture up a voltage from 24V (photovoltaic source) to a yield voltage of 400V to take care of a power demand of 2.4kW for a plug-in hybrid electric vehicle (PHEV) application considering the real time scenario of PHEV. This paper talks about in detail why the current fed converter is utilized alongside a voltage doubler thus minimizing the transformer turns thereby reducing the overall size of the final product. Simulation results along with calculation for the duty cycle of the firing sequence for different value of transformer turns are presented for a prototype unit.

1. Introduction

The world of today moves at a much larger phase and so is the technology. With each new advancement in technology, the need to develop efficient products with more features becomes the present need of the hour. With the current consumption of energy trend, it is estimated to fulfill the old prophecy of depletion of the fossil fuels within 50 years or so [1]. Probably it will take a couple of thousands of years to replenish the amount of fossil fuel that we have used in last few decades. Thus there arises the need to switch on to alternate energy sources for sustainable development that simultaneously considers economic growth without compromising with the environment. The renewable source being not only replenish-able but also environment-friendly acts as an excellent alternative to the conventional power sources [2,3]. Here comes the role of power electronics in designing more and more efficient converters, so as to minimize the losses and maximize the output power. As the technology advances with more breakthroughs in highly efficient converters along with international tax exemption, many companies have come forward with modular vehicle design with higher efficiency [5,6]. Such vehicles are termed as hybrids and can be classified into three.

1.1. Hybrid electric vehicle

These types of vehicles have two boarded energy sources, typically conventional fuel as primary source and electricity as the range extender. The battery charges itself by utilizing the regenerative power hence it saves less fuel while compared to the other two types.

1.2. Battery operated electric vehicle
This type of vehicles has only onboard energy stored in the battery. EV has the advantage of low running cost, battery to wheel efficiency of 76%, no noise pollution, the absence of gear assembly along with being environment-friendly. The disadvantages include short driving range and the absence of backup source in case the battery runs out of charge and low torque production that obstruct their use in tough inclined roads.

1.3. Plug- In Hybrid Electric Vehicle
The concept of PHEVs may be able to kill fuel utilization altogether for everyday vehicle trips. It consists of a renewable source as the primary source and IC engine as the secondary source acting as a range extender. Thus combining the advantages of EV such as better efficiency, low noise cheaper and easy maintenance along with smooth and easy control. Also in the case of PHEVs, the effect of climate on the range is negligible when compared to other types of vehicle.


2. Objective
The main objective of this paper is to design a low-cost efficient and reliable converter, thus designed a current fed dc-dc converter, which meets the required criteria.A conventional dc-dc converter converts without inversion thus it fails to convert low voltage to very high voltage. Thus, a new current fed dc-dc converter put forward, which comprises of two stages viz. current fed converter followed by voltage doubler.

The presence of inductor at the source side of the current fed converter protects the renewable source from short circuit current when all the four switches are operating at a duty cycle D greater than 50%. Input side inductor also protects the source from transformer leakage reactance, which in case of a voltage fed converter reduces the life of the renewable source even in a LC filter introduced at the input of voltage fed converter it may substantially decrease the overall power efficiency. Absence of load inductance in case of current fed converter reduces the size of the product but transformation ratio may increase substantially this drawback is dealt by using a voltage doubler circuit.

The other advantages of using a current fed converter include high voltage conversion ratio and low losses across the switch. In the proposed model a current fed converter which act as an inverter produces an output voltage of 200 V which is later rectified and doubled using Delon's doubler circuit to get an output voltage of 400 V. An isolation transformer is used in between current-fed converter and voltage doubler circuit. A main aim of using isolation transformer is it protects user from double fault. An isolation transformer helps during maintenance of converters increasing the user safety further more.


3. Circuit Diagram and Operating Modes
The proposed Current Fed DC-DC Converter topology is illustrated as in Figure.1. there are four MOSFET used as switches in the primary side of the circuit which acts as inverter. MOSFETs are used as switches because of higher switching frequency which is beneficial for decreasing circuit components size and decreasing switching losses. Since, it does the boost operation the duty ratio is greater than 50%. Four capacitors connected across each MOSFET minimizes switching losses and improves ripple. The isolated transformer connecting the two stages of the circuit step-up the primary side voltage.
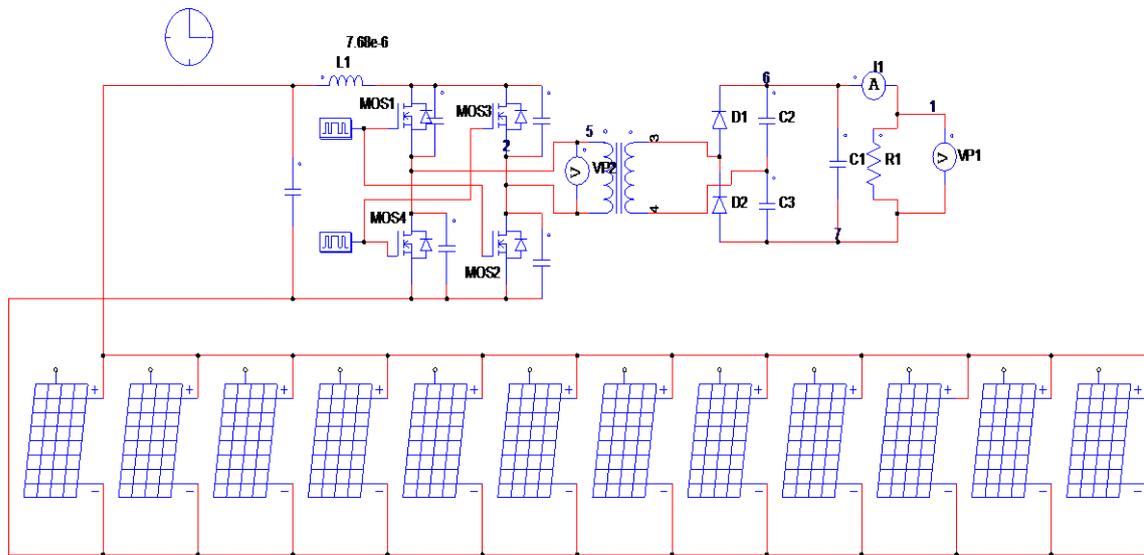
Figure 1. A Current Fed DC-DC Converter topology with voltage doubler rectifier in the output

Figure 2. shows the switching pattern of the current-fed converter. The four modes of operations are decided by the switching pattern of the switches. Duty cycle is denoted by D and total overlapping period is given by Dc presence of two Overlapping period during one cycle results in each having a value of $\frac{Dc}{2}$.
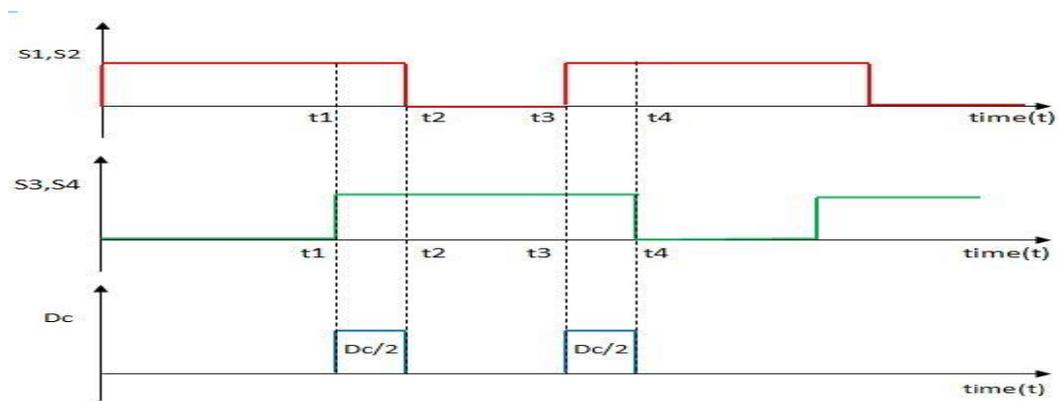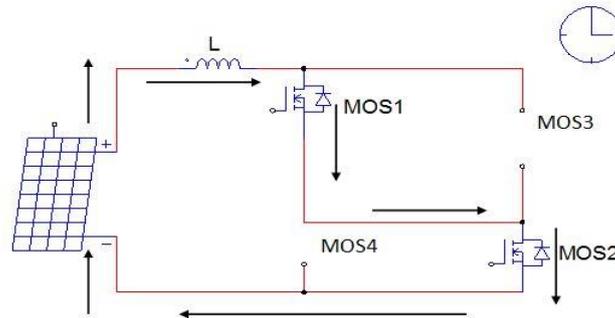

Figure 2. Switching pattern

The relationship between the overlapping period and duty cycle is given by
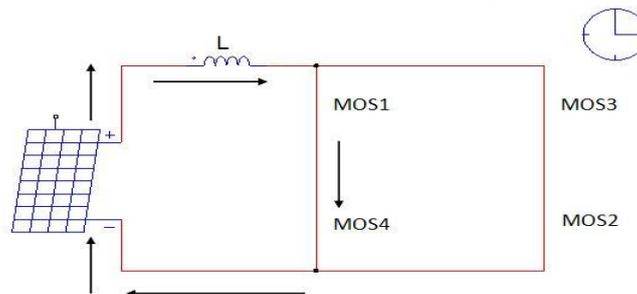
$$D = 0.5 + \frac{D_c}{2} \tag{1}$$

3.1. Mode 1
In this mode, the switches S_1 and S_2 gets turned on and the switches S_3 and S_4 are in OFF state as shown in Figure 3. the current flow direction is as shown in the Figure 3.
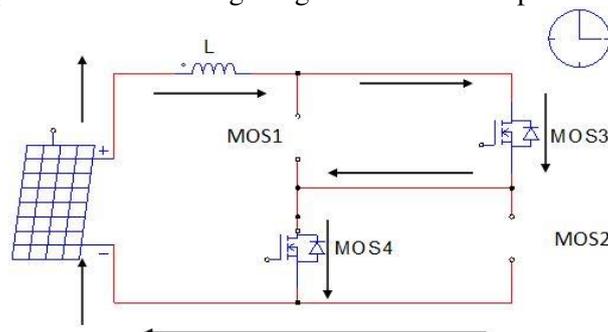
Figure 3. Mode 1 operation

3.2. Mode 2

In this mode, all the switches are in ON condition resulting in a short circuit as shown in Figure 4 it is at this time period that the voltage across the primary of transformer is zero and the Inductor starts charging until the switches S_1 and S_2 gets turned OFF. This time period is denoted by $\frac{D_c}{2}$

Figure 4. Mode 2 operation

3.3. Mode 3

In this mode the switches S_3 and S_4 gets turned ON and the switches S_1 and S_2 are in OFF state as shown in Figure 5.The inductor starts discharging all the charge stored in the previous state in addition with the supply voltage as a result the input side voltage is increased thus reducing the number of transformation ratio required and decreasing the general size of the product.

Figure 5. Mode 3 operation

4

3.4. Mode 4

It is similar to mode 2 operation that is all the switches are in ON condition and the inductor charges. Only difference is after this switches S_1 and S_2 starts conducting that is the cycle repeats (mode 1 starts).

4. Mathematical Design

4.1. Inductor

The inductor functions to store the charge during the overlapping period (time period during which all switches are operating) and dissipates the stored charge in addition to supply. The value of charging current and discharging current are calculated by volt-second balance equation [4]. Since the current through inductor is zero we get

$$V_g * D_c + \left\{ V_g - \left(\frac{V_o}{2n} \right) \right\} (1 - D_c) = 0 \tag{2}$$

From power balance equation $P_{in} = P_{out}$

Assuming the ripple current ΔI_L is 10% of the inductor current for calculation

$$I_L = \frac{n^2 V_g}{(1-D)^2 R} \tag{3}$$

4.2. Transformer

Thus the correlation between D and the number of turns n is given by

$$D = 1-(0.06n) \tag{4}$$

Table 1. Calculating 'D' for Different Value of 'n'

Parameters	Value
For n=3	For n=4
Duty cycle, D = 0.82	Duty cycle, D = 0.76
Dc = 0.64	Dc = 0.56
Ton = 8.2 µs	Ton= 7.6µs
Toff = 1.8 µs	Toff = 2.4 µs

Since T_{off} = 1.8 µs which gives sufficient time for reverse recovery of the diode and the primary target include compact size so the product is designed for n=3

4.3. Load Capacitance

The significance of load Capacitance is to reduce the output ripple there are only fixed values of capacitance available in market using trial and error method load capacitance. From the Figure 7 capacitor output voltage is nearly same as desired output

4.4. Voltage Doubler

Delon circuit is incorporated to reduce the product size.

$$C_3 = \frac{I_L T}{\Delta V_c} \tag{5}$$

For an output ripple of 1% allowing 5% due to discharge of C_3 and 5% due to discharge of C_2
$\therefore \Delta V_c = 0.5 * V_o$

$$\tag{6}$$

$$C_3 = C_2 \qquad\qquad\qquad (7)$$

4.5. Design specifications

Table 2. Design parameter

| Parameters	Values
Input voltage, V_g	24 V
Output voltage, V_o	400 V
Switching frequency, F	100 kHz
Maximum output power, P_{out}	2.4 KW
Inductor current, I_L	100 A
Input current ripple, $\Delta I_L = 10\% \, I_L$	10 A
Output voltage ripple	1% of 400 V
Ripple across voltage doubler capacitance, ΔV_c	5% of Vo
Load capacitance, C_1	10 μF
Voltage doubler capacitance, $C_2 = C_3$	14.9 μF
Inductor, L	7.68 μH
Transformer turns, n	3

5.Results

It is observed that the input to the primary side of transformer is 66.56 V and for transformation ratio of 3 the output voltage is 199.8 V ≈ 200 V. Which is approximately similar to the output waveform.
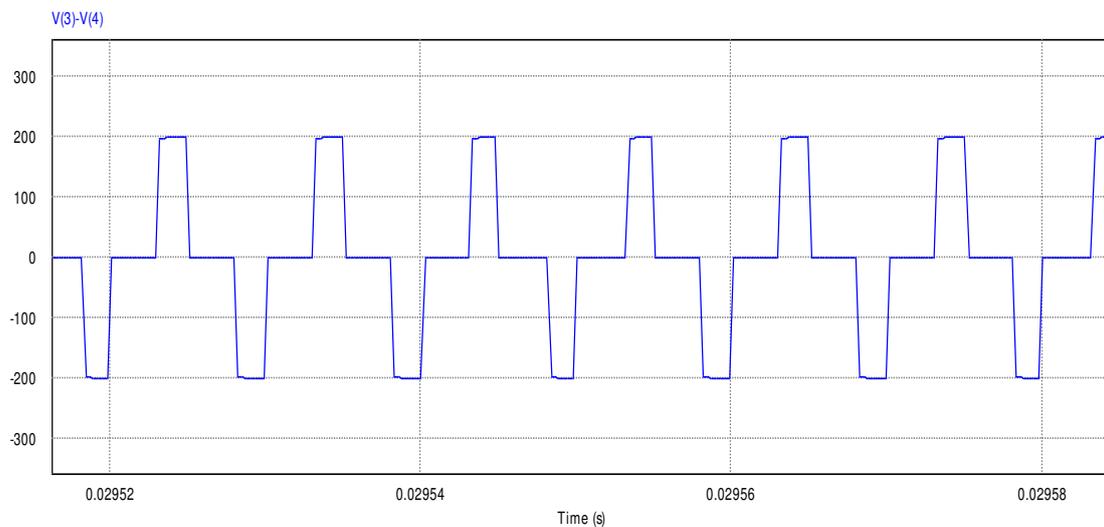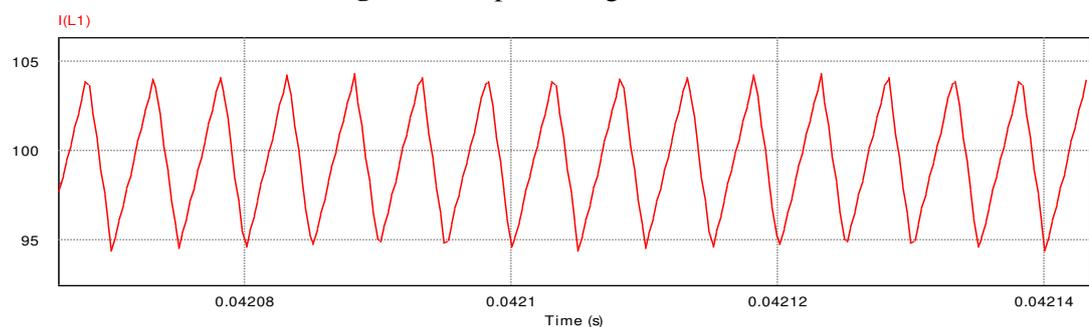

Figure 6. Output voltage at transformers secondary terminal

The output waveform across the load is shown with ripple voltage of 1% which is same as that shown in the Figure 7.
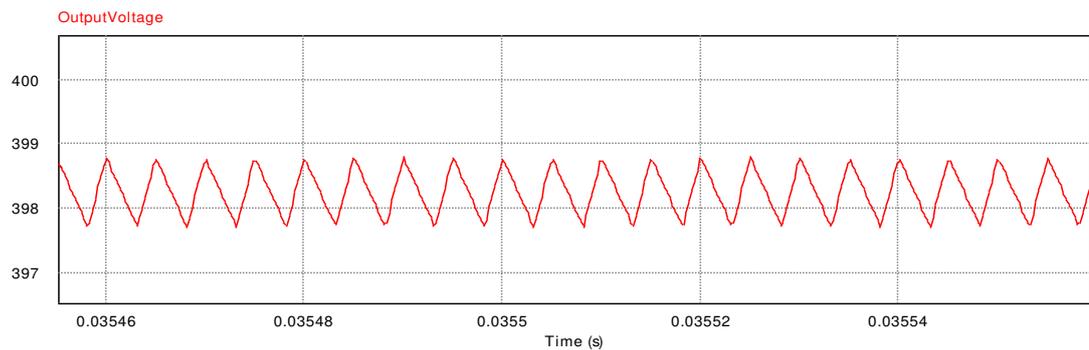
Figure 7. Output Voltage

Figure 8. Inductor Current

6. Conclusion

A new topology, isolated current fed dc-dc converter is designed and analyzed in this paper the power converter is necessary in order to utilize renewable energy as main power source for PHEV application. The main features of the discussed converter are signal input inductor isolation, high frequency switching and less output ripple. Duty cycle of the switches are controlled in order to manage efficient used of stored energy in inductor. The simulation result suggest that the designed converter is suitable for PHEVs application.

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