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Design and implementation of current fed DC-DC converter for PHEV application using renewable source

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Abstract. As the fossil fuels are depleting day by day, the use of renewable energy sources came into existence and they evolved a lot lately. To increase efficiency and productivity in the hybrid vehicles, the existence less efficient petroleum and diesel IC engines need to be replaced with the new and efficient converters with renewable energy sources. This has to be done in such a way that impacts three factors mainly: cost, efficiency and reliability. The PHEVs that have been launched and the upcoming PHEVs using converters with voltage range around 380V to 400V generated with power ranges between 2.4KW to 2.8KW. The basic motto of this paper is to design a prolific converter while considering the factor such as cost and size. In this paper, a two stage DC-DC converter is proposed and the proposed DC-DC converter is utilized to endeavour voltage from 24V (photovoltaic source) to a yield voltage of 400V and to meet the power demand of 250W, since only one panel is being used for this proposed paper. This paper discuss in detail about why and how the current fed DC-DC converter is utilized along with a voltage doubler, thus reducing transformer turns and thereby reducing overall size of the product. Simulation and hardware results have been presented along with calculations for duty cycle required for firing sequence for different values of transformer turns.

1. Introduction

The growth rate of technology is much faster in last few years. Also Renewable energy is key for future thus various products are producing based on such technology that renewable energy is use in it somehow. In other hand with current rate of use of fossil fuels, they will wash out in next 50 years or so. Thus there arises need to use renewable energy for future development need. Here comes the need of more and more efficient converters using power electronics devices so as to maximise output power i.e. minimise losses. Many companies are come forward to design PHEV's vehicles as technology advances day by day and tax exemption is there for renewable work.

These vehicles are classified into

1.1. Hybrid electric vehicle

Two types of energy sources are use in this vehicle viz. conventional fuel as main source and electricity as back up source. Battery charges using regenerative power. Hence less fuel is save compare to remaining two types.



1.2. Battery operated electric vehicle.

Only battery is use in such type of vehicle. The advantage is that no conventional fuel use hence no bad environmental impact. Disadvantage is that no back up energy so battery may drain completely result in breakdown of vehicle. Also torque production is less hence can't use in hilly areas.

1.3. Plug- In Hybrid Electric vehicle.

PHEV is combination of advantage of first two types i.e. most of time battery is use (primary source battery) and present of conventional fuel as back up so no problem when battery fails to provide enough power. Climate change effect on this type is less compare to other two. Cost of battery, converter and charging framework will decide overall achievement of PHEVs.

The objective is to design a converter which is efficient as well as reliable and can fulfil PHEV vehicle requirement. Thus a current fed DC-DC converter is design which meets the criteria. Conventional DC-DC converter can't give very high output require by PHEV vehicle with great efficiency which the proposed converter can. The new converter is interleaved type hence transformer is use in between two stages in order to increase the voltage.

Primary side is with transformer and overlapped switching thus act as boost whereas secondary side is voltage doubler circuit hence voltage is further increased. The input inductor is use as to protect Solar panel from short circuit as well as to do boost action by saving energy during overlap period. Input inductors blocks transformer leakage reactance to flow to solar panel, if inductor is not there life of source may get reduce due to flow of current into the panel. Absence of input inductance may be decreases total size n cost but transformation ratio may increase hence input inductor is best solution.

The additional advantage of proposed converter is high conversion ratio of voltage ad very less losses across the switch. In planed model the first stage of converter which acts as inverter generates output voltage of 200 V at transformer secondary with 24 V dc input from solar. Second stage is of voltage doubler which produces dc output with voltage of 400 V. Delton's voltage doubler circuit is used at second stage. Transformer is use to boost the voltage to 200 V from 66.66 V. Double fault protection is another objective of isolation transformer. Also such transformer helps in maintance as isolation increases user safety further more.

2. Modes of operation

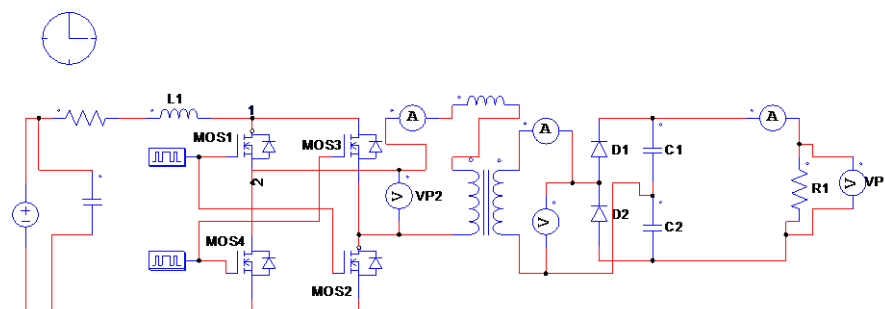


Figure 1. A Current Fed DC-DC Converter topology with voltage doubler rectifier in the output

Figure 1 Show the proposed dc-dc Current Fed Converter topology. In total Four MOSFETs are used before transformer primary side which act as inverter. MOSFETs are considered as switch since the cost of MOSFET is less than IGBT and it can work on Very high switching frequency, this is beneficial for reducing switching losses and simultaneous decreases component size. For very high

boosting purpose the duty is higher than usual. Parasitic capacitors are connected in parallel with each switch to reduce the losses. Two stages of circuit are connected by means of isolated transformer which steps up the voltage of primary side.

In Figure 2 switching pattern is shown for current fed converter. Switches' Switching pattern decides the four modes of operation of converter. D is notation for Duty cycle whereas D_c denotes overall overlapping period. Two overlapping happens in one cycle hence each overlapping has value of $\frac{D_c}{2}$.

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

The relation between overlapping period and the duty cycle is given by

$$D = 0.5 + \frac{D_c}{2} \tag{2}$$

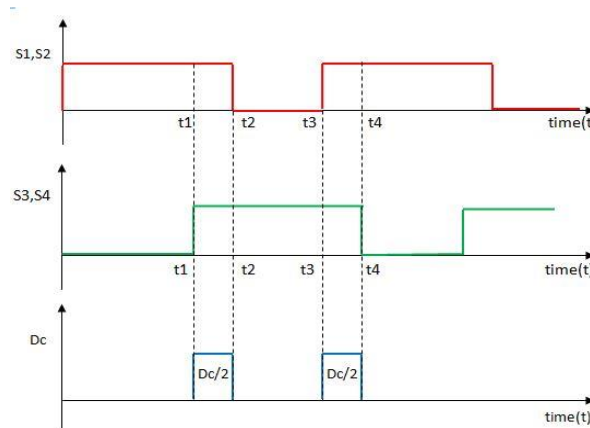


Figure 2. Switching pattern

2.1. Mode 1

Switch S_1 and Switch S_2 are triggered i.e. turn on and - Switch S_3 and Switch S_4 are OFF which can be seen in Figure 3. The direction of the current flow can be shown in Figure 3.

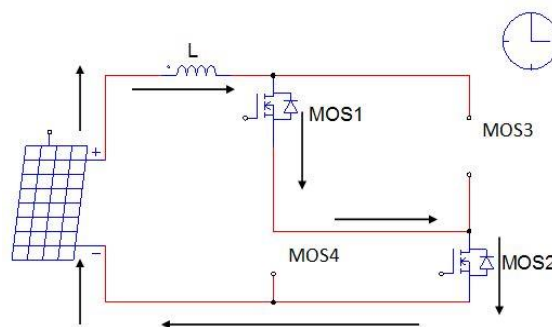


Figure 3. Mode 1 operation

2.2. Mode 2

As shown in figure2 the first overlapping $\frac{D_c}{2}$ decides time period of this mode. All the Four switches are ON during whole time period thus short circuit condition happens across transformer's primary side which shown by figure4. In this mode Inductor charges as voltage across primary is zero until ne

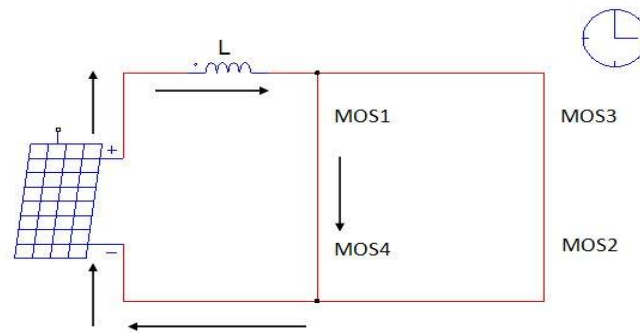


Figure 4. Mode 2 operation

2.3. Mode 3

Figure5 shows this mode and it can be understand easily that its contradictory to first mode, here switch S_3 and switch S_4 are ON whereas switch S_1 and switch S_2 are OFF. The voltage stored in inductor along with voltage from solar thus increasing total voltage at transformer's primary reducing transformers turn ratio and also losses along with it. The size of overall product is also decreases.

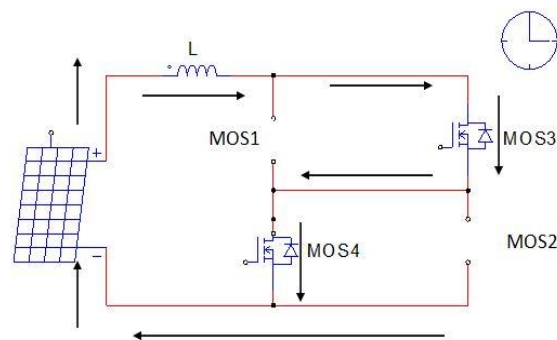


Figure 5. Mode 3 operation

2.4 Mode 4

This mode is same as 2nd mode, swithes are simultaneously on thus iductor charges. This mode only differ from 2nd mode as next cycle will be S_1 and S_2 ON i.e. mode 1 starts and this repeats all the time.

3. Steady state analysis

In this segment the steady state operation of the proposed converter has been accounted.

3.1. Inductance

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. In mathematical form, charging current is given by

$$\Delta i_c = \frac{V_g D_c T}{2L} \quad (3)$$

Moreover, discharging current is calculated by

$$\Delta i_d = \left(V_g - \frac{V_o}{n} \right) * \frac{1-D_c}{L} \quad (4)$$

Since the current through inductor is zero we get

$$V_g * D_c + \left\{ V_g - \left(\frac{V_o}{2n} \right) \right\} (1 - D_c) = 0 \quad (5)$$

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

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

$$I_L = \frac{n^2 V_g}{(1-D)^2 R} \quad (6)$$

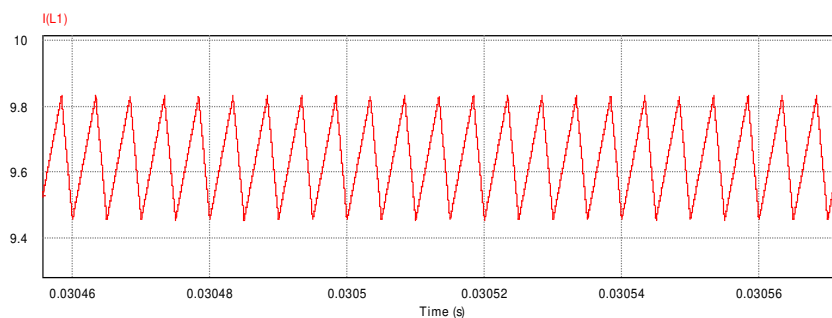


Figure 6. Inductor Current

$$L = \frac{V_g D_c}{\Delta I_L} \quad (7)$$

3.2 Transformer

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

$$D = 1 - (0.06 * n) \quad (8)$$

Table 1. Calculating 'd' for different value of 'n'

For n = 3	For n = 4
Duty cycle, D = 0.82	Duty cycle, D = 0.76
$D_c = 0.64$	$D_c = 0.56$
$T_{on} = 8.2 \mu s$	$T_{on} = 7.6 \mu s$
$T_{off} = 1.8 \mu s$	$T_{off} = 2.4 \mu s$

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

3.3 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.

3.4 Voltage doubler

Delon circuit is incorporated to reduce the product size.

$$C_3 = \frac{I_L T}{\Delta V_c} \quad (9)$$

For an output ripple of 1% allowing 5% due to discharge of C_3 and 5% due to discharge of C_2

$$\therefore \Delta V_c = 0.5 * V_o \quad (10)$$

$$C_3 = C_2 \quad (11)$$

Table 2. Component selection

Parameters	Values
Load capacitance C_1	10 μF
Voltage doubler capacitance $C_2 = C_3$	14.9 μF
Inductor L	7.68 μH
Transformer turns ratio n	3

Table 3. Design specifications

Parameters	Values
Input voltage V_g	24 V
Output voltage V_o	400 V
Switching frequency f	100 kHz
Maximum output power P_o	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 V_o

It is observed that the input to the primary side of transformer is 66.56V and for transformation ratio of 3 the output voltage is

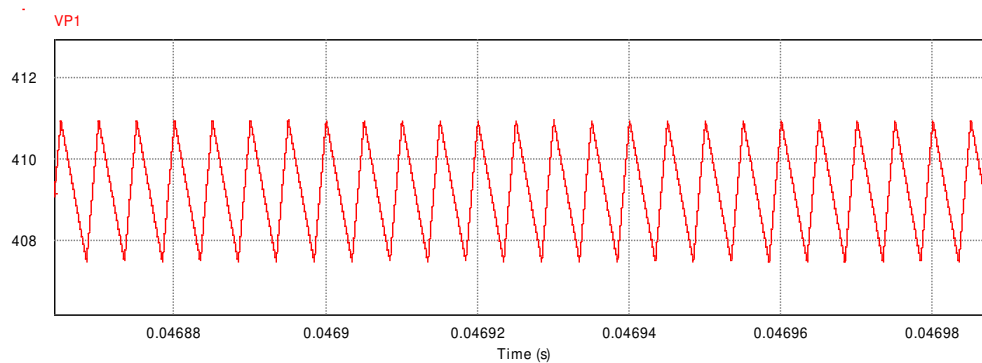


Figure 7. Output voltage across load

$199.8V \approx 200V$. Which is approximately similar to the output waveform.

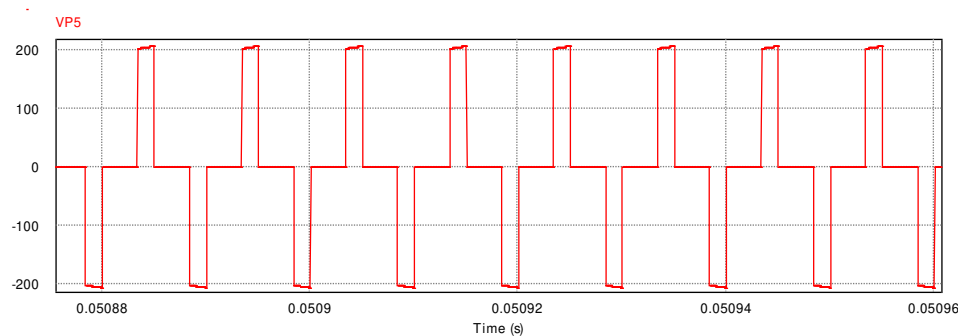


Figure 8. Output voltage at transformers secondary terminal

The output waveform across the load is shown with ripple voltage of 1% which is same as that shown in the figure8.

4. Pulse generation in d-space

Using MATLAB mathematical model is designed and the required pulses are generated. Initially, the MATLAB model is designed using constant blocks. In d-space we have two output ports. Slave I/O and Master I/O ports. Using Slave I/O PWM port in dSpace, we connect the MATLAB model with the external circuit. Slave I/O PWM has four channels and each channel is connected to individual pins. The channel 1 is given to pin no.5, channel 2 is given to pin no.10, channel 3 is given to pin no.29 and channel 4 is given to pin no.11. Pin no 5 and pin no.10 gives two individual pulses and pin no.29 and pin no.11 are connected externally with OR gate. The MATLAB model for duty cycle designing and the generated pulses are as shown in Figure 9 and Figure 10 respectively.

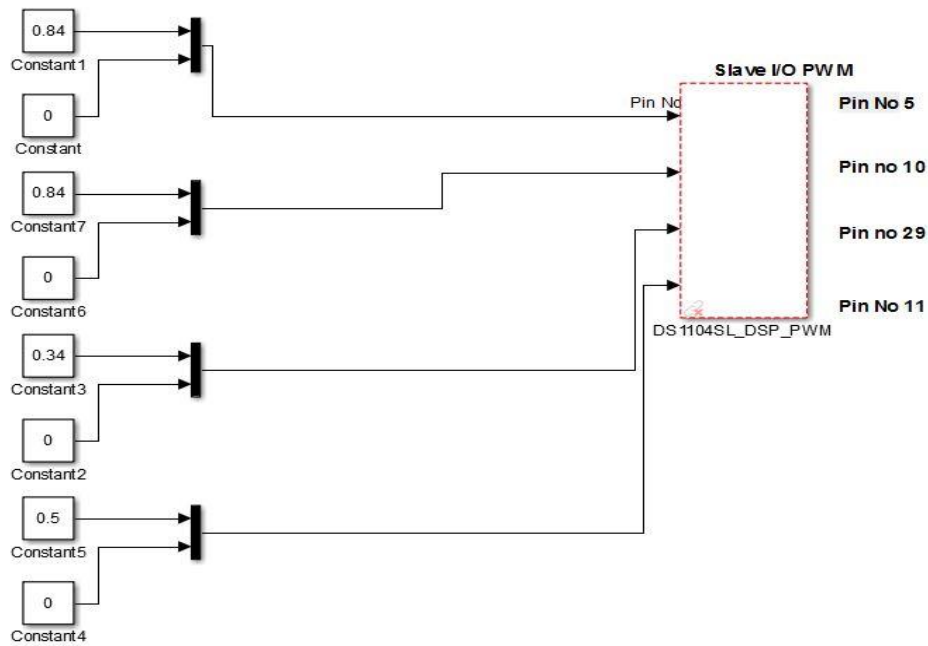


Figure 9. MATLAB model for duty cycle

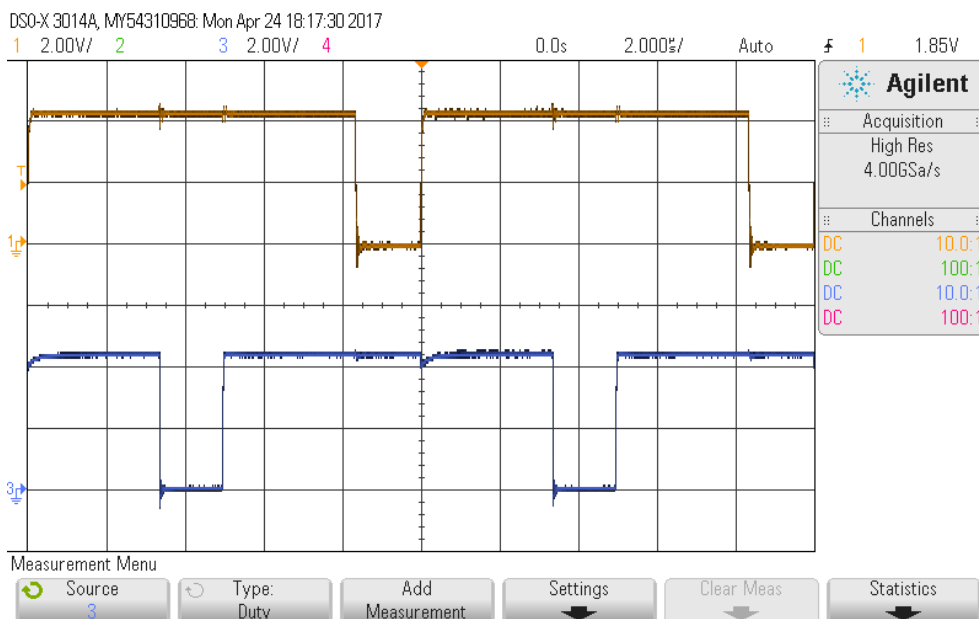


Figure 10. Pulse generation using d-space

5. Conclusion

New Methodology of dc-dc conversion is presented in this paper as isolated current fed dc-dc converter. It is designed using PSIM and also practically implemented in lab. Overlapping pulses are generated using DSPACE. Renewable energy is used in order to save fossil fuel and make vehicles go green i.e. PHEV application. Thus main features include superfast switching, signal input inductor

and less output ripple. To use energy storage elements efficiently the duty cycle and overlapping is controlled. The simulation results and hardware testing is appropriate for PHEV's application.

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