ISSN(Online): 2320-9801
ISSN (Print): 2320-9798

International Journal of Innovative Research in Computer and Communication Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijircce.com

Vol. 5, Issue 4, April 2017

Design and Analysis of Full-Bridge Phase-Shift Soft-Switching DC-DC Converter

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ABSTRACT: In this paper, effective method of controlling the lagging leg conduction and oscillating voltage spikes are proposed. The comparison between conventional converter and proposed converter is presented. Specific problems of Full Bridge Phase shift soft switching DC-DC converter is overcome by the use of clamp switch on secondary to remove voltage spikes and by the use of resonant capacitor for lagging leg conduction problem. The simulation is done for both conventional converter and proposed converter using MATLAB/SIMULINK. The efficiency of both the converters is calculated and Total Harmonic Distortion is analysed (THD). The converter is designed for 360V input, 230±10V output, 3.7KW output power and 100 KHz switching frequency.

KEYWORDS: Full-Bridge, Phase-shift, Soft-Switching, Oscillating Voltage spikes, lagging leg conduction, Clamp switch

I. INTRODUCTION

In Power Electronics, Switch Mode Power Supplies (SMPS) hard switching is the simplest method of switching. This uses static switches for its operation. It requires less number of inductor and capacitors for circuit which results in less cost and complexity. These static switches require finite turn-on and turn-off time. The power dissipation is more in hard switching strategy due to transition between on and off of the switches. Power dissipation is proportional to switching frequency i.e if the switching frequency is increased consequently power dissipation in the switches increases.

The Phase shift modulation technique is used for switching each MOSFET. Soft switching has two types i.e Zero Voltage Switching (ZVS) and Zero Current Switching (ZCS) technique. Here ZVS technique is used in the proposed converter. It is possible to have high efficiency system and can be used for higher frequency ranges.

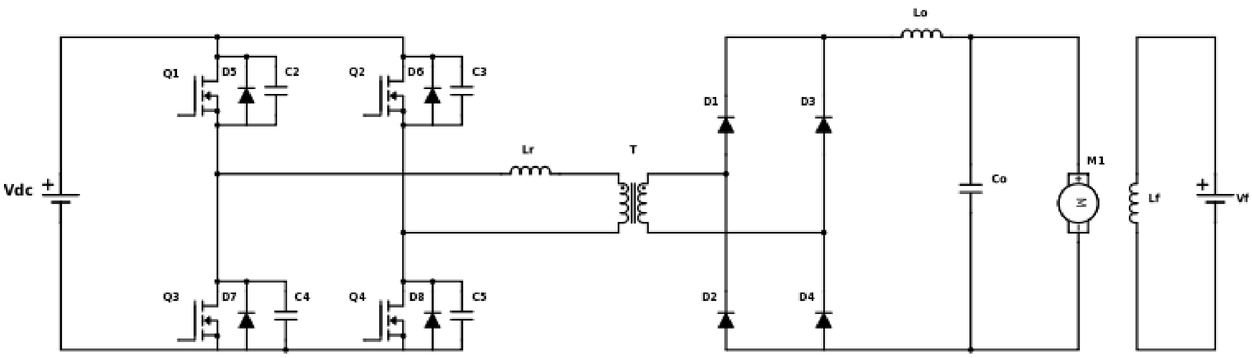

Figure.1 Conventional circuit of Full-Bridge Phase-Shift Soft-Switching DC-DC converter

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Figure.1 shows the converter, assume Q_1 and Q_3 are leading legs and Q_2 and Q_4 are lagging legs. Current flowing can make the stray capacitance of Q_1 and Q_3 to turn on and discharge until the body diode is forward biased. So it realises ZVS. Because of smaller inductor value current cannot make stray capacitance discharge until body diode forward bias and turns on. By increasing the value of inductor it is possible to have lagging leg ZVS but there may be chances of duty cycle loss.

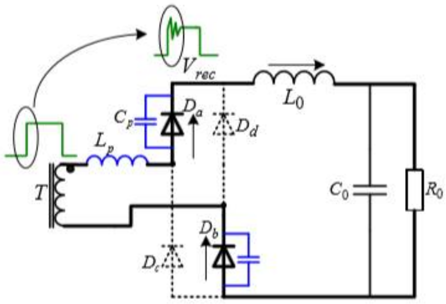

Figure.2 Oscillation in the transformer secondary rectifier

Diodes normally will have small stray capacitances which are neglected in analysis. But these stray capacitance and transformer leakage inductance causes oscillations shown in Figure.2.

II. Related work

To solve the Problems of conventional circuit solutions are provided in many literatures. Solutions for problem like lagging leg conduction can use saturable inductors rather than normal inductors to overcome this problem given in [2]. This ensures lagging leg ZVS soft switching because saturable inductors with small current can enter to saturation mode. Due to saturable inductors lagging leg switching can be achieved for a wide range . This method will have more losses due to inductor heating but still it works great in practice.

In [3] to [6] method of using auxiliary network to achieve the lagging leg soft switching is given. Advantage of this method is it can be used to achieve lagging leg switching for wide range. Disadvantages are like addition of extra passive elements, complications in designs and it is not practically acceptable. In this method condenser stops working causing accelerated energy transfer of the inductor. So it is not adopted.

Passive absorption method [7] using saturable reactor and active clamping method [8] by the use of active switches are the several solutions for secondary rectifier bridge oscillation problem. The method of using passive absorption is not good and causes energy loss. But the use of clamping switches is considered better.

III. Proposed methodology

This paper presents Full-bridge Phase shift soft switching DC-DC converter of 3.7KW. The input voltage is 360V and output is 230±10VDC. The proposed circuit topology is shown in Figure.3

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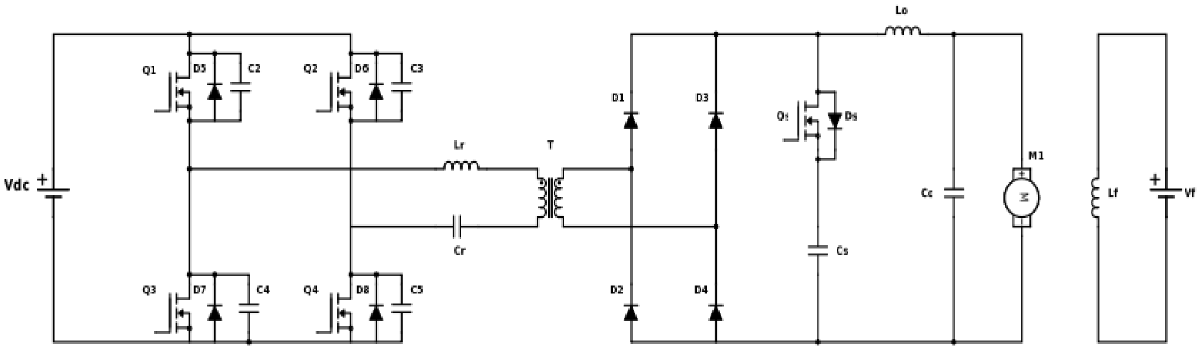

Figure.3 The proposed circuit topology of Full-Bridge Phase-shift Soft switching DC-DC converter

The increase in value of inductor can lighten the problem of lagging leg problem but duty cycle losses become more. By use of saturable inductor this problem can be overcome but it saturates for small amount of current. The inductance will be decreased. The leakage inductance of transformer is the only inductive device in resonant circuit that helps to reduce duty cycle loss. The energy stored in the saturable inductor will help stray capacitance charging and discharging and body diode is forward biased to realize soft switching.

The oscillating voltage spikes may damage the bridge rectifier and in this proposed circuit it uses clamp circuit to suppress the oscillation. The active clamp has Q_s, D_s and C_s whose function is to clamp the rectified voltage of secondary bridge rectifier circuit V_{rec}.

At the time of voltage step, transformer with leakage inductance and clamp switch capacitor will participate in the resonance network. The output filter inductance is equivalent to constant current source and will not take part in resonance. According to the KCL rule, current of leakage inductance in transformer is sum of inductor current and resonance current.

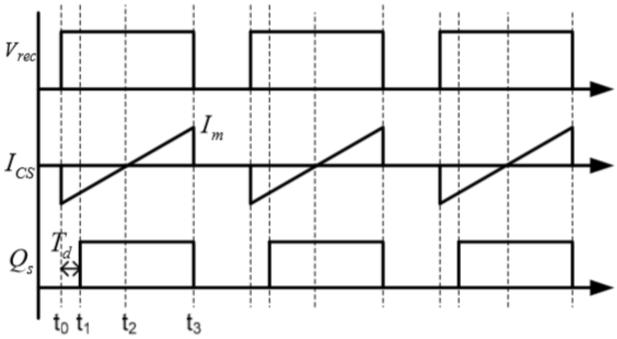

Figure.4 the waveforms of rectifier voltage, clamping capacitor current and drive voltage of clamper

Figure.4 shows the waveform of rectifier output voltage, clamping current and MOSFET driving voltage. From the figure we can say that from time t_0 to t_1 there is a period of dead time for MOSFET switch where voltage is zero but capacitor current starts to discharge, at this time voltage from the rectifier will be available. During period t_1 to t_2 the MOSFET will be switched on, capacitor completely discharges. During period t_2 to t_3 MOSFET will be on but capacitor starts to charge. At t_3, MOSFET will be switched off and capacitor starts to discharge during this period. The maximum current level reached by capacitor is denoted as I_M.

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IV. SIMULATION RESULTS

Figure.5 shows the simulation of conventional Full Bridge phase shift DC-DC converter and Figure.6 shows proposed converter model in MATLAB/SIMULINK. It also shows the Transformer primary side, secondary side waveforms for both converters, Speed and armature current curves associated with circuit and THD analysis.

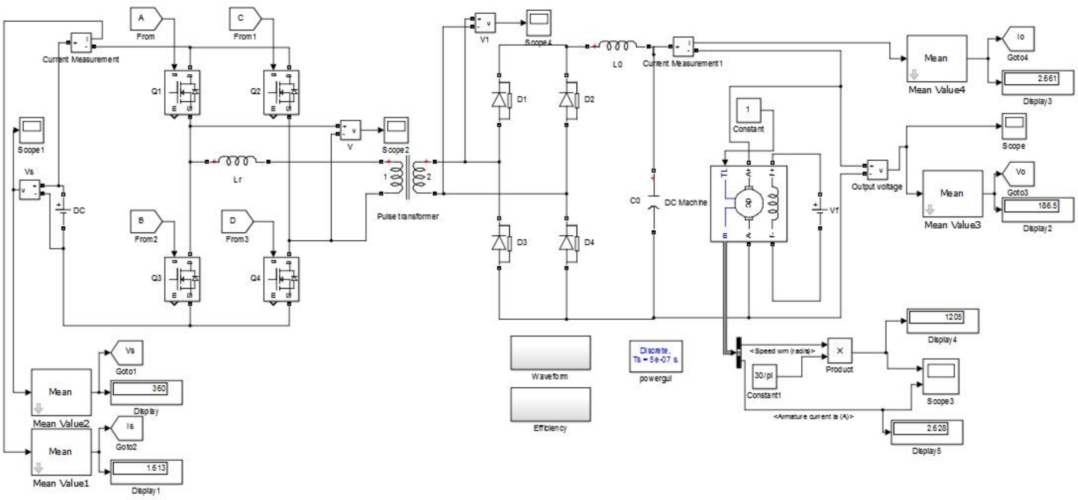

Figure.5 Simulation of Conventional Phase shift DC-DC converter

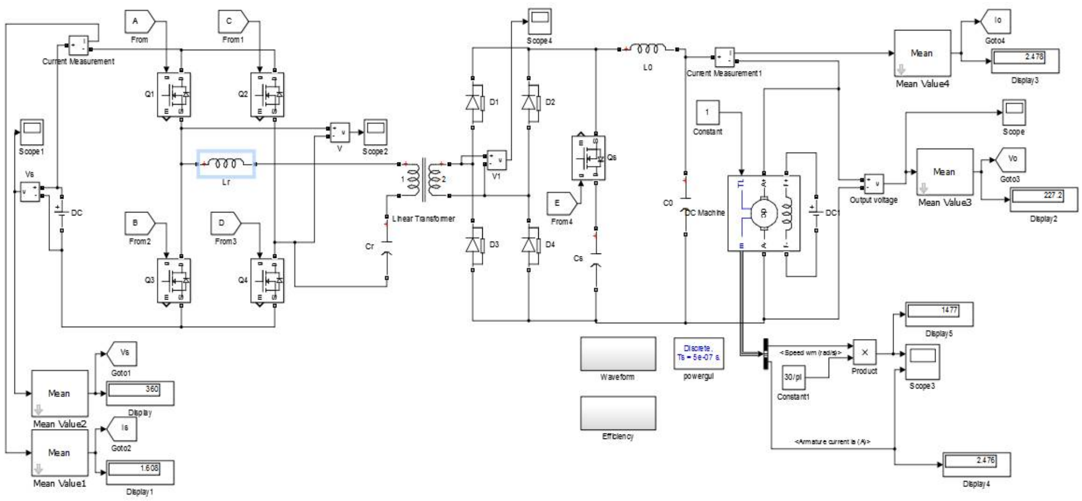

Figure.6 Simulation of Proposed Phase shift DC-DC Converter

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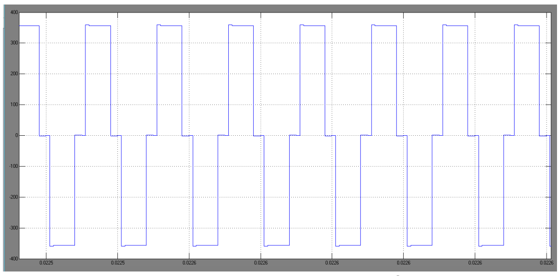
Figure.5a Conventional circuit transformer primery side

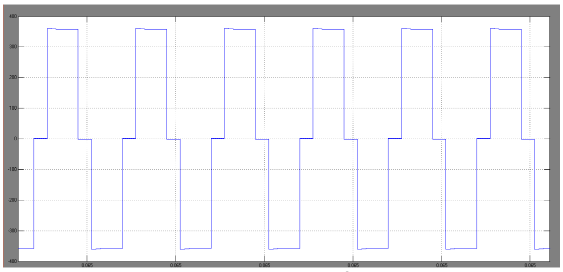
Figure.6a Proposed circuit transformer primery side

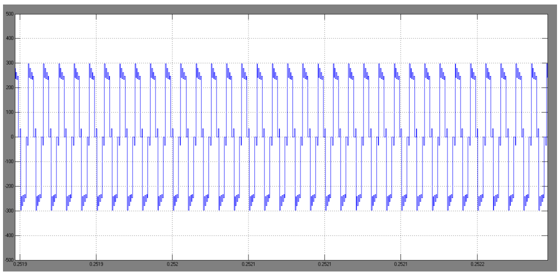
Figure.5b Conventional circuit secondary side

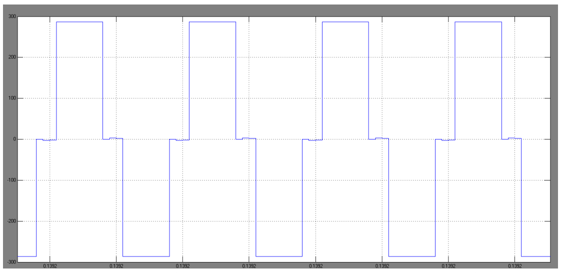
Figure.6b Transformer secondary side waveform

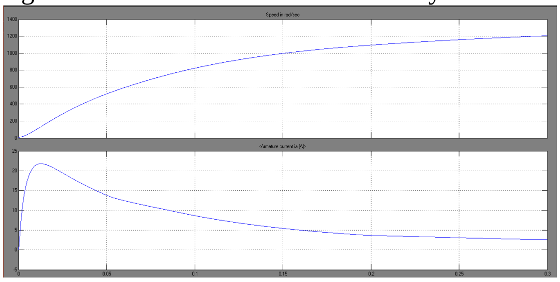
Figure.5c Speed and armature current of motor

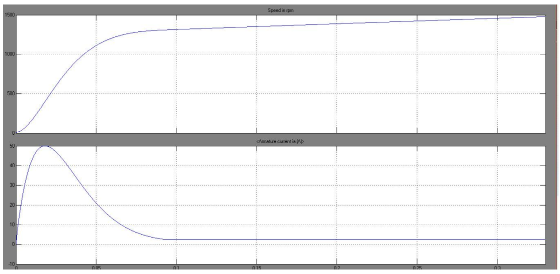
Figure.6c Speed and armature current of motor

Figure.5a shows the tranformer primary side waveform. Its peak voltage is 360V, Figure.5b shows transformer secondary side waveform. Its peak voltage is nearly 300V with voltage spikes and Figure.5c shows speed-armature current waveform of conventional converter in which speed reached is 1205rpm and correspondig armature current is 2.5A. Figure 6a shows the transformer primery side. Its peak voltage is 360V , Figure 6b shows transformer secondary side of proposed converter. Its peak voltage is nearly 300V with pure square waveform and Figure 6c shows speed-armature current waveforms of proposed converter with speed as 1477rpm and corresponding armature current as 2.47A.

By comparing the Figure.5b and Figure.6b we can say that conventional converter voltage spikes are more on the secondary side of the transformer which has been overcome in proposed converter by the use of resonant capacitor with combination of resonant inductor.Speed-armature current is also improved in proposed circuit as compared to conventional circuit.

Figure.7a and Figure.7b shows the Total Harmonic Distortion (THD) analysis done on both the converters. Due to the presence of voltage spikes oscillations the THD of conventional converter is more i.e 95.67% hence in proposed circuit it is reduced to 27.91%.

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By refering to Table.1 efficiency of the system can be calculated as follows

$$\eta = \frac{Po}{Pin} \times 100$$

$$Po = Vo \times Io$$
$$Pin = Vin \times Iin$$

Therefore

$$\eta = \frac{Vo \times Io}{Vin \times Iin} \times 100$$

For conventional converter,

$$\eta = \frac{186.5 \times 2.66}{360 \times 1.613} \times 100 = 85.4\%$$

For proposed converter,

$$\eta = \frac{227 \times 2.478}{360 \times 1.608} \times 100 = 97.2\%$$

Motor selected in this is of 5HP i.e

$$KW = \frac{HP \times 746}{1000}$$

$$Power\ in\ KW = \frac{5 \times 746}{1000} = 3.7KW$$

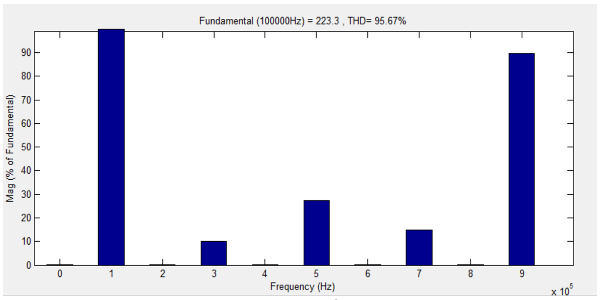

Figure.7a THD analysis of conventional converter

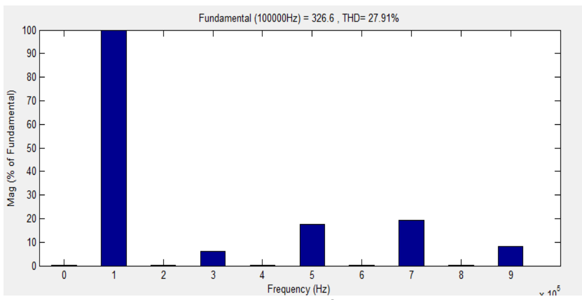

Figure.7b THD analysis of proposed converter

Conventional Converter		Proposed converter	
Parameter	Value	Parameter	Value
Input voltage, Vin	360V	Input voltage, Vin	360V
Input current, Iin	1.613A	Input current, Iin	1.608A
Output voltage,Vo	186.5V	Output voltage,Vo	227V
Output current, Io	2.66A	Output current, Io	2.478A
Speed of the motor, N	1205rpm	Speed of the motor, N	1477rpm
Armature current, Ia	2.5A	Armature current, Ia	2.476A
Efficiency, η	85.45%	Efficiency, η	97.23%
THD on Primery side of transformer	28.14%	THD on Primery side of transformer	28.11%
THD on secondary side of transformer	95.67%	THD on secondary side of transformer	27.91%

Table.1 Parameters and Values of converters

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V. CONCLUSION

In this paper comparision is done between conventional and proposed Full-Bridge Phase-Shift Soft-Switching DC-DC converter along with DC motor as a load.Then the performance is analysed with THD and Efficiency of the converter. THD of the proposed Converter is reduced by the use of resonant capacitor and inductor combination.Efficiency is boosted to 97.23% from 85.45%. Hence the proposed converter is more efficient and can be used in the applications like PV cells, Electric vehicles, Battery charge circuit, HEV, Micro grids etc based on the requirements.

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