SOFT COMMUTATED THREE-PHASE DC-DC CONVERTER

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Abstract - High efficient DC-DC Converters find its application in electric power generation, transmission, distribution and Uninterruptable power supplies (UPS). Three phase converter system as compared with single phase converter system increases power density with reduced switching stresses, efficient usage of the transformer magnetic core and smaller filter design as the frequency of the system is higher. Inorder to make use of the above mentioned advantages a ZVS-PWM three-phase current-fed push-pull dc-dc converter with active clamping was developed. This converter topology allows the reuse of the energy from the leakage inductances and reduces the electromagnetic interferences (EMI). The topology was designed and simulated using MATLAB/SIMULINK. The input supply voltage used for the converter is 120V DC.

Keywords – Active clamping, DC-DC Converter, Soft commutation.

I. INTRODUCTION

Three-phase current fed dc-dc converters are widely used in the industrial as well as in power generation, and distribution system. Rectifiers and inverters with PWM technique and soft switching results in high speed conversion process in various applications. The renewable energy source utilizes dc-dc converters in the processing stage, without the use of external circuitry for soft commutation high efficiency is achieved for dc-dc converters.

The comparison of the three phase current-fed dc-dc converter with other existing topologies is included in the section II. In Section III the circuit description of soft commutated three-phase current fed dc-dc converter. The operation stage of the topology is presented in Section IV. Design and simulation result of the converter topology is given in section V. In section VI the conclusion of the topology is presented.

In the future, this converter topology could be applied as a high efficiency alternative to many applications such as the energy processing of photovoltaic arrays and fuel cell systems or automotive devices and fuel cell powered vehicles, where the three phase dc-dc conversion is already showing its benefits.

II. COMPARISON WITH TOPOLOGIES

A. Single-phase topology

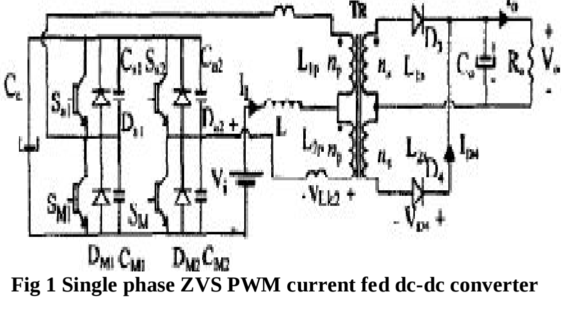


Fig 1 Single phase ZVS PWM current fed dc-dc converter

Due the unbalance in the conduction times of the main switches, energy is stored in the leakage inductances of the transformer. Clamping techniques are used to provide a path for the stored energy in order to avoid the damage of the switches due to severe voltage overshoots. The problems like low power density, large transformer and filter size reduces the use of single phase topology in power generation and distribution.

B. Conventional three-phase topology

Three phase current fed converter providing a high frequency three phase transformer, the losses are better distributed than in a single phase topology, and the chopping frequencies of the input current and output voltage are three times higher than the switching frequency, which reduces the size requirements for the filter. Better active clamping and efficient soft commutation technique is not implemented in this topology.

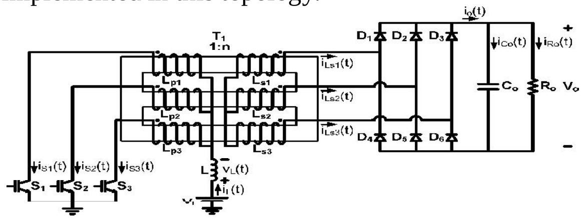


Fig. 2 Three phase current fed dc-dc converter

III. CIRCUIT EXPLANATION OF ZVS-PWM THREE-PHASE CURRENT FED DC-DC CONVERTER.

A. Circuit explanation and simplified circuit

The switches S_1',S_2' and the capacitor C_g ,C_a in Fig. 3, operates for achieving active clamping. The inductances L_{d1},L_{d2},L_{d3} performs three functions as listed:

a) Maintaining current during the commutation intervals.

b) Represents the sum of leakage inductances of the transformer and the external inductances for each phase.

Soft commutation is provided by the addition of capacitors C_1',C_2',C_a' ,C_1,C_2,C_a and appropriate dead time between main and complimentary gate signals. The simplified circuit in Fig. 4, is used to explain the different operation stages and is a non-isolated equivalent version of the converter with input as current source and output as voltage source. A coupled three-phase reactor is used as substitute for transformer.

B. Operation regions and Duty Cycle

Depending on the duty cycle the converter is capable of operating in three operation regions as in Table I. The converter presented in operates in region R_2 and R_3 never operates in region R_1 due to the absence of demagnetizing path for the inductor. The topology presented in this paper operates in region R_1 and R_2 it is the most efficient operation region.

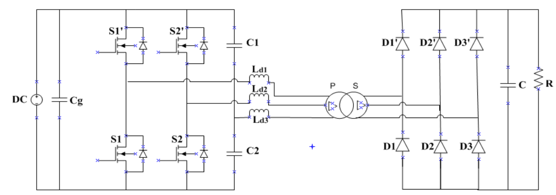


Fig.3 Soft commutated three phase current fed dc-dc converter

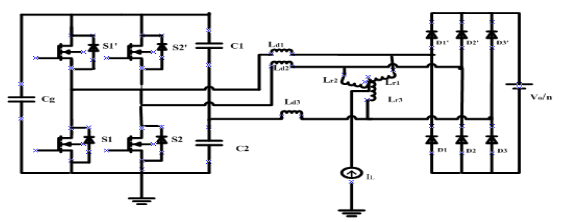


Fig. 4 Simplified circuit of the three- phase dc-dc converter

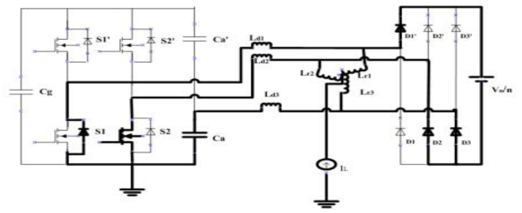
TABLE I
OPERATION REGIONS

Region	Duty cycle	Switches simultaneous ON
R_1	$0 \le D \le 1/3$	None
R_2	$1/3 \le D \le 2/3$	Up to two
R_3	$2/3 \le D \le 1$	Up to three

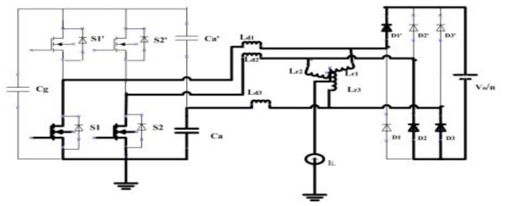
IV. OPERATION STAGES

Soft commutated three -phase current-fed dc-dc converter topology has nine operation stages per switching period in region R_2 and can be described as follows.

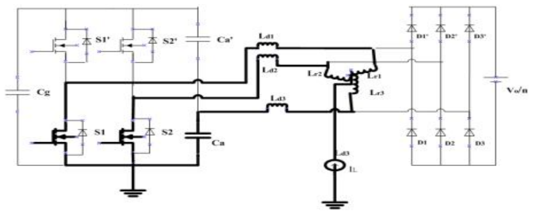
First stage (t_0 , t_1) – The switches S_1',S_2 were conducting and capacitor C_g was delivering energy before this stage starts. The capacitor C_a charges. During this stage no energy transfer from the source to the load. The current through the inductor $L_{d1}(i_{d1}(t))$, increases linearly through the intrinsic diode of S_1 and reaches $I_L/3$ Fig. 5(a). The current $i_{d2}(t)$ and $i_{d3}(t)$ decreases linearly from $2I_L/3$ to $I_L/3$ through the switch S_2 and capacitor C_a respectively as shown in Fig. 5(b). The load receives energy from the commutation inductances through diodes D_1,D_5,D_6.



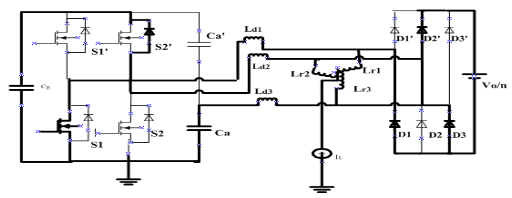
(a)



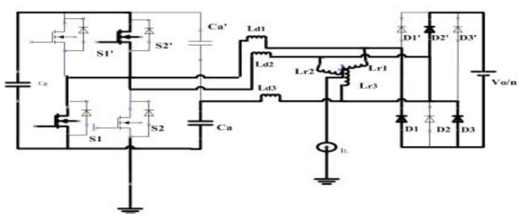
(b)



(c)



(d)



(e)

Fig . 5 Region R_2 operation stages (a) First stage – part 1 (b) First stage – part 2 (c) Second stage(d) Third stage – part 1 (e) Third stage – part 2

Second stage (t_1, t_2) – At the beginning of this stage, Fig. 5(b),the currents $i_{Ld1}(t)$,$i_{Ld2}(t)$,and $i_{Ld3}(t)$ is at a value $I_L/3$ and remains at this value. The diodes of the rectifier bridge remains off. There is no energy transfer from source to load.

Third stage (t_2, t_3) – This stage begins when the switch S_2 is off. The current $i_{Ld2}(t)$ decreases linearly through the intrinsic diode of S_2' and becomes zero and then increases to $–I_L/3$ Fig. 5(d). Capacitor C_g

charges and discharges during this stage. The current $i_{Ld1}(t)$ and $i_{Ld3}(t)$ increases linearly and reaches $2I_L/3$ as in Fig. 5(e). Through the diodes D_2, D_4, and D_6 the load receives energy.

The fourth and seventh operational stages are similar to the first stage, the fifth and eighth operational stages are similar to the second stage, and the sixth and ninth stages are similar to the third stage. The only difference is that other switches are on. After the ninth stage, the switching period is complete, and a new period starts with the first stage. The main theoretical waveforms for region R3 are shown in Fig. 6.

V. DESIGN AND SIMULATION RESULTS

A. Specifications

The specifications to simulate the converter were tabulated as below:

TABLE II
DESIGN SPECIFICATION

Input Voltage (V_i)	120 V
Output Voltage (V_o)	467 V
Output Power (P_o)	4KW
Switching frequency (f_s)	40KHz
Input current ripple (ΔI_L)	$0.08I_L$

Duty Cycle $$D = 1 - \frac{V_i}{V_{cg}} \quad (1)$$

Using the above equation the duty cycle can be calculated, the clamping voltage is choosen as 350V.

C. Turns Ratio Of The Transformer And Commutation Inductance

The turns ratio can be calculated to achieve the desired output voltage considering the effective duty cycle reduction of 5% is choosen.

$$n = \frac{V_O}{V_i}(1 - D + nI'_O) \quad (2)$$

The commutation inductance is calculated as,

$$L_d = {nI'_OV_i}/{F_snI_O} \quad (3)$$

D. Duration of operation stages

The duration of the operation stages can be calculated as

$$\Delta t_1 = \frac{n\,L_dI_L}{V_i} \quad (4)$$

$$\Delta t_2 = \frac{T_s}{3} - \Delta t_1 - \Delta t_3 \quad (5)$$

$$\Delta t_3 = (1 - D)T_s \quad (6)$$

E. Boost Inductance

Operation in region R3, the boost inductance can be calculated as

$$L = \frac{V_i}{\Delta I_L f_s}\left(D - \frac{2}{3}\right) \quad (7)$$

F. Peak Output Current

$$I_{O-MAX} = \frac{\frac{2}{3}I_O}{(1-D)+NI'_O} \quad (8)$$

G. RMS Value of the Current Through the Output Capacitor

$$I_O\sqrt{\frac{4/9}{(1-D)+NI'_O} - 1} \quad (9)$$

H. External Commutation Capacitance

The maximum commutation capacitance is

$$C_{ext} \leq \frac{0.4I_L\Delta t}{6V_{cg}} - C_{oss} \quad (10)$$

Parameters for the simulation design is tabulated as below:

TABLE III
DESIGN PARAMETERS

Sl no	Description	Value
1	Duty Cycle (D)	0.657
2	Turns Ratio (n)	1.06
3	Commutation Inductance (L_d)	14.15µH
4	Δt_1	1.325µs
5	Δt_2	6.675 µs
6	Δt_3	333.33ns
7	Boost Inductance (L)	70µH
8	Peak Output Current (I_{o-max})	21.03 A
9	RMS value of current (I_{Coef})	6.34A
10	External Commutation Capacitance	3.1nF

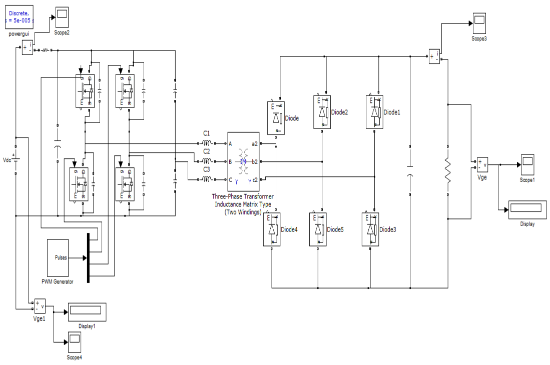


Fig. 7 Simulation of soft commutated three phase dc-dc converter.

I. Simulation Results

The ZVS – PWM three phase current fed push-pull dc-dc converters were simulated using MATLAB/SIMULINK and the waveforms of input voltage and current, output voltage and current are as shown.

CONCLUSION

The ZVS-PWM three-phase current fed push-pull dc-dc converter topology presented in this paper shows a competitive efficiency of about 93%. This technique can be utilized as processing stage for many renewable sources. The switching losses can be reduced significantly and electromagnetic interferences can be minimized by achieving soft commutation (ZVS). An output voltage of 467V can be obtained from an input voltage of 120V.

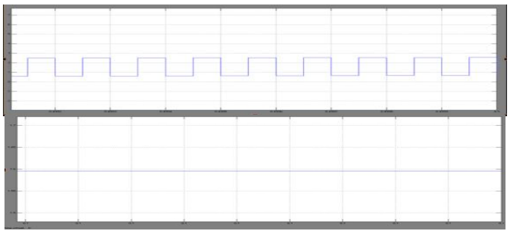


Fig.8 Input voltage and current waveform of Soft commutated three phase dc-dc converter.

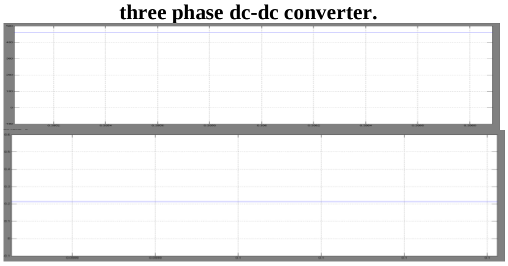


Fig. 9 Output voltage and current waveforms of Soft commutated three phase dc-dc converter

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