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Topology selection, design and simulation of 300W resonant DC-DC converter

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ABSTRACT : Due to higher efficiency, lower electromagnetic interference and reduction in higher switching losses resulting from a higher frequency operation of PWM converters, resonant converter topologies are popular in research. This paper is concerned with comparison of load resonant converters for front-end DC-DC converter applications. Three topologies; series-resonant, parallel-resonant and series-parallel resonant converters are discussed. The relative advantages and drawbacks of each converter are also discussed.

Keywords : Series Resonant converter, MOSFET, zero voltage switching

I. INTRODUCTION

To perform the power conversion with high efficiency and to reduce the size of transformer and filter components, high frequency operation of the converter is desirable. An attractive alternative for a high frequency dc-to-dc converter is the use of a resonant converter. These converters typically employ the use of high frequency resonant (LC) circuits. These circuits may be operated either at switching frequency below/above the resonant frequency. The operation above resonance is preferred compared to below resonance for any type regarding to the fact of a basic resonance principle that the operation above resonance is in the lagging power factor region of the basic resonance curve. The performance of three resonant topologies in medium voltage DC-DC converter application is discussed in this paper for a converter rating of 300W. How higher efficiency can be achievable by reducing switching losses (turn on and off) is also presented in this paper. The simulation results are verified with the theoretical aspects [1] [2].

II. TOPOLOGY SELECTION FROM THREE TRADITIONAL LOAD RESONANT CONVERTER TOPOLOGIES

In resonant topologies, Series Resonant Converter (SRC), Parallel Resonant Converter (PRC) and Series Parallel Resonant Converter (SPRC) also called LCC resonant converter) are the three main topologies. The analyses of these topologies have been studied and most popular topology for medium voltage low current front-end DC-DC converter is investigated.

Series Resonant converter-An overview :

Fig.1. shows configuration of a SRC in a class D version with its most usable application; continuous conduction in which switching frequency is above resonant frequency, a square wave voltage VAB with 50% of duty cycle of switching can be applied to the resonant tank circuit.

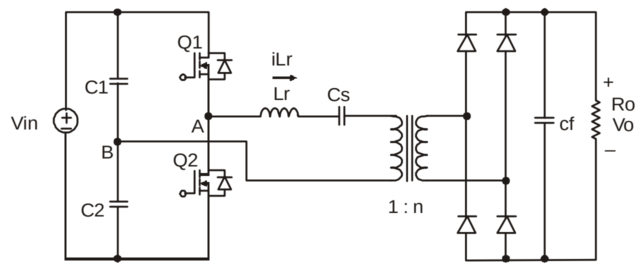


Fig.1. Configuration of SRC.

Due to filtering action of the LC tank, it selects only a fundamental component although the tank circuit is supplied by a square wave. The operation above resonance shows the fact that the resonant circuit current i_{Lr} lags the voltage applied to the resonant tank V_{AB}. And due to this fact the switches turn on at zero voltage (ZVS) and turn on switching losses are practically zero. The use of power MOSFET as switch, antiparallel diodes with fast reverse recovery are not required, as its inverse parasitic diode is of sufficient speed to be used even at higher frequency operation. The result is that at the operation above resonance there are no turn on and diode switching losses [2] [3]. By changing the frequency of input voltage $V_{AB,}$ the impedance of resonant tank will change and output voltage can be regulated. So for series resonant converter, the maximum gain happens at resonant frequency and this can be proved from DC gain characteristics (Fig.2) also [3].

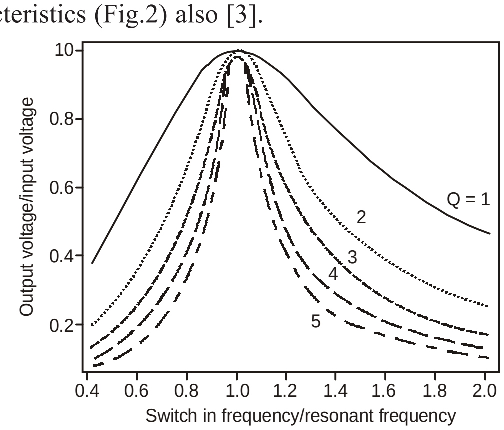


Fig.2. DC gain characteristics of SRC.

Only a fundamental component is considered for the analysis so equivalent ac resistance is; [3]

$$\text{Rac} = \frac{8}{\Pi^2} R_L \quad ...(1)$$

Where, R_L= Load resistance

For SRC advantages are lower switching loss and EMI through ZVS so improved efficiency and magnetic components size reduced by high frequency operation. Drawbacks with this type are not suitable with wide range of input voltage and can not regulate the output at light and no load condition [4,5].

In PRC Advantage with this type is at light load, the frequency doesn't need to change too much to keep output voltage regulated. Thus light load regulation problem doesn't exist in PRC. Disadvantage is that the circulating energy (overlapping of switch voltage and current) is very high even at light load results in more losses and due to high circulating energy higher turn off current so not suitable choice in DC-DC conversion [6][7].

For SPRC advantages are it combines the good characteristic of PRC and SRC. It has narrow switching frequency range with load change compare with SRC and the circulating energy is reduced compare with PRC. The big problem with SPRC is that with wide input range, the conduction loss and switching loss will increase and switching loss is similar to that of PWM converter at high input voltage and so not preferred solution for DC-DC conversion [6][7].

After analysis and comparing all topologies the conclusion is that SRC with MOSFET as a power switch is much easier to design because it only needs to design on a single resonant point with soft switching to the converter. It is possible to reduce higher switching losses and over all size of the converter at higher switching frequency operation. Series Resonant Converter is the simplest and most understood topology with higher part load efficiency and that's why it is selected for a medium power front end DC-DC conversion [8].

III. SIMULATION OF THE SCHEME

For front-end DC/DC application, a half-bridge SRC is designed to meet the specifications with following parameters :

Design equations :

Resonant frequency :

$$fr = \frac{1}{2\Pi\sqrt{LC}} \quad ...(2)$$

Where,

L = Inductor of a resonant tank and

C = Capacitor of a resonant tank

Characteristic impedance :

$$Z_c = \sqrt{\frac{L}{C}} \quad ...(3)$$

Solving Equ. (2) and (3) tank circuit parameters can be found.

Quality factor of the series resonant circuit :

$$Q = \frac{WrL}{R_L} = \frac{Z_c}{R_L} \quad ...(4)$$

$$Wr = 2\Pi fr \quad ...(5)$$

As component stresses are directly a function of Q, so value of Q should be chosen as low as possible (here 0.2) [7].

Medium voltage DC-DC converter data :

(*i*) Input voltage : 325 V DC

(*ii*) Switching frequency : 50 kHz

(*iii*) Ratio of switching frequency to resonant frequency (*fs*/*fr*) : 1.1

(*iv*) Transformer turns ratio: 1 : 4.15

(*v*) Resonant inductance (Lr) : 0.743mH,

(*vi*) Resonant capacitance (Cr) : 16.5nF.

(*vii*) Output voltage : 600V DC

(*viii*) Output power : 300W

(*ix*) Power switches : MOSFETs

Fig.3 shows the simulation scheme for a medium voltage front end DC-DC converter in PSIM 6.0. In this simulation scheme the MOSFETs of half bridge inverter is gated with a square wave voltage waveform with a 50% of duty cycle providing a dead time of 0.35µ sec between the transition of the two switches to avoid a cross conduction of the two switches. The simulation is done for the total time of 0.02 sec.

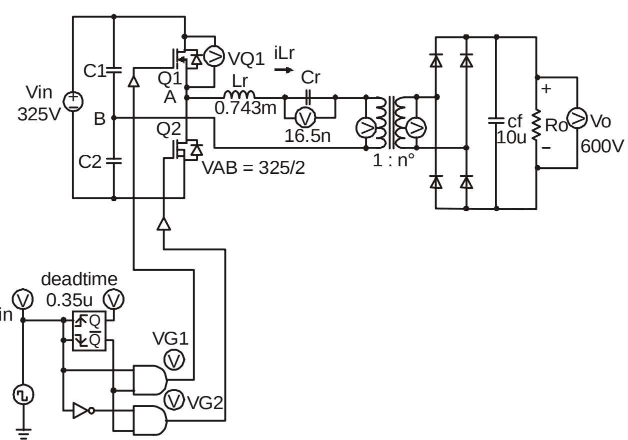
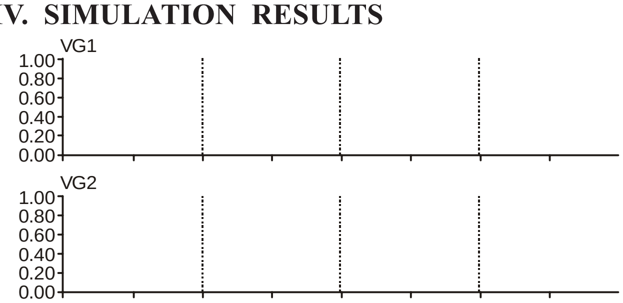


Fig.3. Simulation circuit for front end DC-DC conversion.

IV. SIMULATION RESULTS



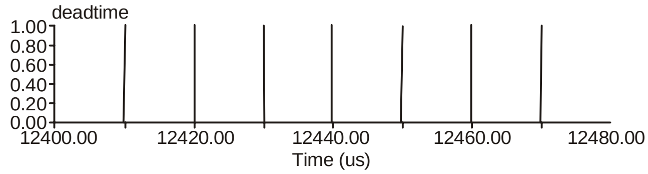


Fig.4(a). Gate pulses for power switches (MOSFETs).

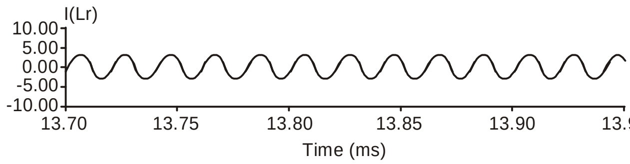


Fig.4(b). Inductor current.

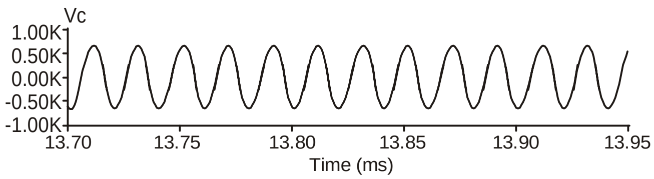


Fig.4(c). capacitor voltage.

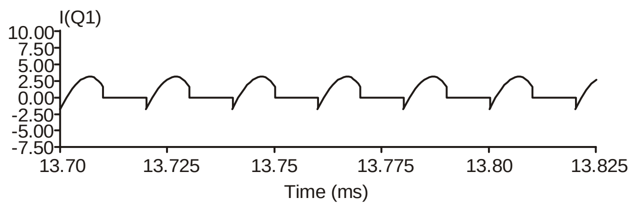


Fig.4(d). Switch (MOSFET) current.

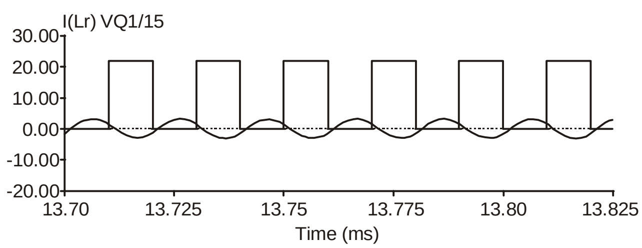


Fig.4(e). Switch voltage and inductor current.

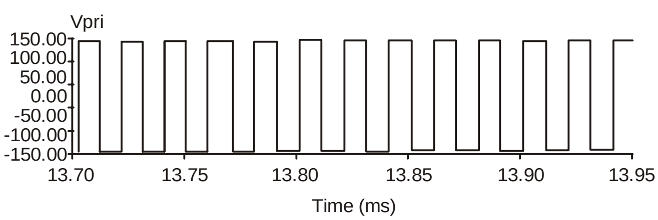


Fig.4(f). Output voltage of a resonant inverter.

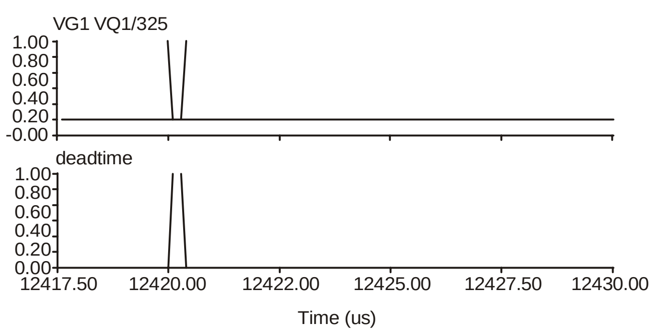


Fig.4(g). ZVS/ZCS turn on and dead time.

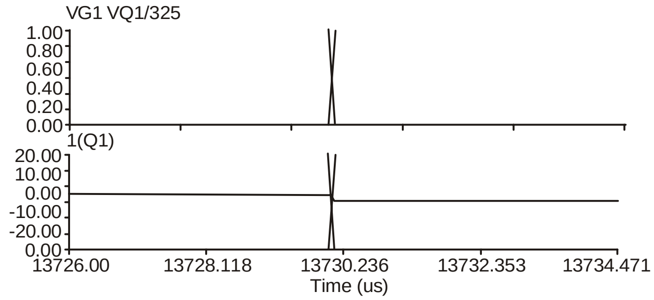


Fig.4(h). Low current turn off.

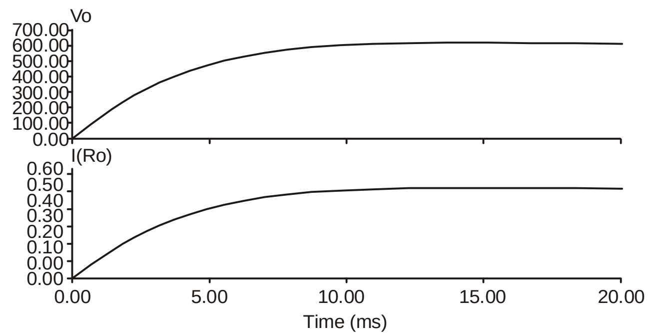


Fig.4(i). DC output voltage and output current.

Fig.4(a) shows gate pulses to the power switches *Q*1 and *Q*2 having 50% of duty cycle and 0.35 isec of dead time between the transisition of two switches. Fig.4(b) and 4(c) shows resonant inductor current and capacitor voltage, it is clear that filtering action of resonant tank is strong and so sine waveforms are there even square wave is applied as an input. Due oscillating nature of current the overlapping region between current and voltage is reduced compared to conventional PWM waveforms so circulating energy is reduced and resonant switching is resulted into the soft switching of the converter. Fig 4(d) shows MOSFET current, as during the dead time MOSFET's parasitic diode carries the current so it is possible to achieve ZCS condition at turn on. Fig 4(e) shows converter waveforms at full load, as it is possible to get converter operation in lagging power factor region for the entire load range. Fig 4(f) shows output of resonant inverter. From Fig 4(g) it is clear that ZVS turn on is achieved due to the operation above resonance. Fig 4(h) shows low voltage/low current turn off of the switch. Turning off of one MOSFET caused opposite MOSFET's parasitic diode to be turned on and energy is returned back to the DC source, this is results in low turn off losses. As turn off time of the MOSFET is very low so these losses are not affecting much so from the simulated waveforms of Fig 4(g) and 4(h) it is clear that switching losses are negligible which can improve the overall efficiency of the converter. Fig 4(i) shows DC output voltage and current of the converter. Due to filtering action of resonant tank amount of ripple is very less and value of secondary side filter capacitor is also decreased.

V. CONCLUSION

By comparative analysis of SRC, PRC and SPRC it can be concluded that SRC is a good choice for a medium power front-end DC-DC conversion due to easy design procedure and most understood topology with a higher efficiency. With SRC combined with a MOSFET as a power switch it is easy to achieve ZVS/ZCS naturally at turn on by operating the converter above resonant frequency and low current turn off is also achieved which results in reduction of switching, size of magnetic and filter components and overall size of the converter. These can be analyzed and verified from simulation results also. As no load regulation is difficult with SRC so some another method should be used to regulate output voltage at no load.

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