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DESIGN OF 12-12V PHASE MODULATED SERIES RESONANT DC-DC CONVERTER

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ABSTRACT

Full bridge DC-DC converter topology is applied for high power applications and aims at high efficiency with power density and lower Electromagnetic interference. To achieve soft switching, Zero Voltage Switching has been used to minimize the losses and to increase the efficiency of the system. This paper analyses and presents Phase modulated series resonant converter.

This paper aims at designing and implementation of Phase modulated series resonant converter. The input of 12 Volts is applied on the source side and expected to get regulated 12 Volts as the output. This converter consists of Pulse generation control, control circuit and resonant tank circuit. The converter uses PWM controller SG3525 with switching frequency of 100kHz. Simulation is carried out using ORCAD CAPTURE software tool and expected result is obtained.

Keywords-Full bridge converter, Phase modulated topology, Phase modulated series resonant converter, Series resonant converter

I. INTRODUCTION

For high power applications and power conversions series resonant converter plays very important role. By adding a capacitor in series with leakage inductance of the transformer a resonant circuit is formed. Instead of varying switching frequency, the duty ratio is varied and this results in Phase modulated series resonant converter (PMSRC).

Soft switching can be achieved by operating converter above the resonant frequency. This concept can be extended for higher wattage applications using similar design and different specifications.

A. Concept of Phase Modulated Converter

Phase Shifted Pulse Width Modulated Converter is a Phase Modulated Converter (PMC) with full bridge topology. Basic principle of operation of PMC is as follows:-

Lossless switching is possible in converters like double ended converter, push-pull, half bridge, full bridge etc, if duty ratio is kept fixed. To control the input with duty ratio fixed schemes other than variation of duty ratio have to be employed. For a full bridge converter, phase modulation can be implemented. Phase modulation refers to varying phase difference between two legs of the bridge, i.e. phase difference between VA and VB. Phase difference is varied by introducing phase lag or time delay in switching of Phase Modulated Converter(PMC).

Switching is performed in a way such that it produces proper phase difference between two legs to obtain desired output.

By keeping output voltage constant, the input voltage can be varied by varying phase difference of PMC by introducing time delay in switching [1].

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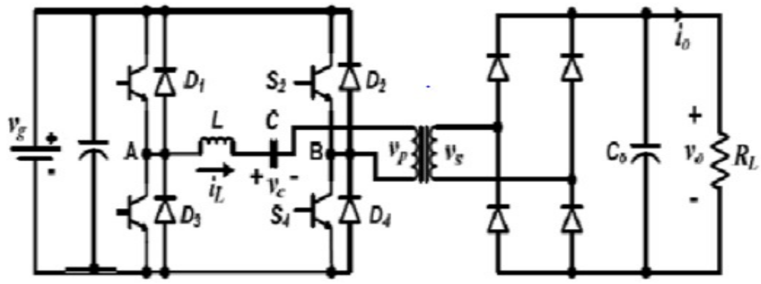

Fig. 1: Full bridge SRC converter topology

The full bridge series resonant converter circuit implemented in the present paper is shown in fig. 1. It consists of four switches with a resonant tank on the primary side of the high frequency transformer. On the secondary side, there exists a diode bridge to convert AC signals to DC. A capacitor is used on the output side to remove the ripple content present in the output DC voltage.

Schematic of Phase modulated converter and the input ac waveform to the transformer having phase difference of 90º is shown in fig. 2

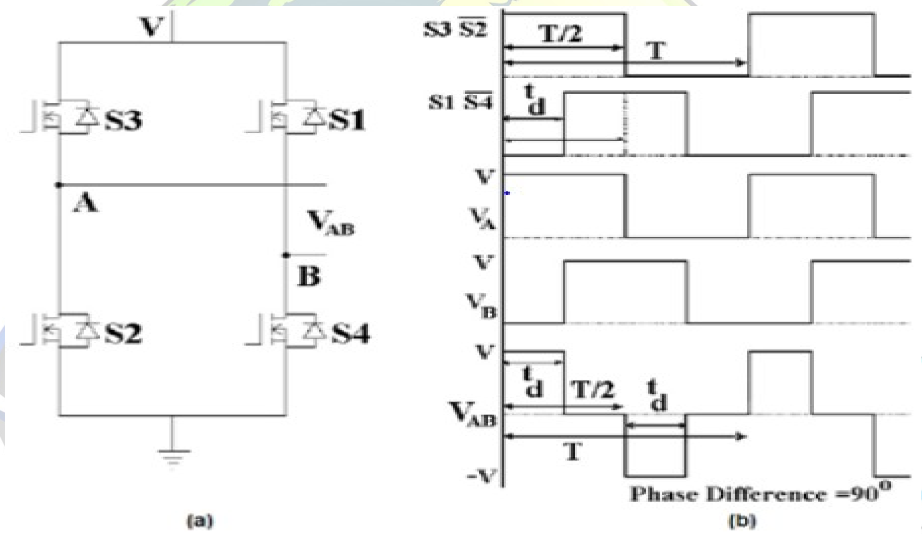

Fig. 2:(a) Schematic of Phase modulated converter (b)Waveform with phase difference of 90º

In fig. 2(b), t_d is time delay (in seconds) in switching two legs and T is switching time period (in seconds).
High power densities can be achieved by switching at high frequencies in the range of a few kHz or MHz. Because of the increase in switching losses, the conventional hard switching converters are not suitable at such high frequencies. Soft switching can be achieved with either Zero Current Switching [ZCS] or Zero Voltage Switching [ZVS].

Just prior to the turn-off in the ZCS converters, the current through the device is made zero by external means, thus eliminating the turn-off losses. In the ZVS converters, turn-on losses are eliminated by making the voltage zero across the device. Resonant converters & Resonant Switch converters add extra resonating LC tank circuit to achieve soft switching by making the device current or the voltage sinusoidal, and switching at the zero crossing instants of the current or the voltage. Also, the variable frequency operation of these converters results in sub-optimal utilization of the components. Resonant Transition converterscombine the low switching loss characteristics of the resonant converters and the low conduction loss and constant frequency characteristics of the PWM converters. The Phase modulated converter presented in this paper offers ZVS transitions.
The operation is identical to the square wave PWM full bridge converter. These features make Phase modulated converter as the preferred topology for high voltage and high frequency applications. Operation principle of this converter is explained in section II.

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II. PRINCIPLE OF OPERATION

The basic operation principle of the phase modulated converter is brought out by the following three points
* In any converter, like the push-pull, half-bridge, full-bridge etc., it is possible to design for Zero Voltage switching, if the duty ratio is kept fixed.
* To control the output, duty ratio has to be fixed. In a full bridge converter, Phase Modulationis the simplest alternative scheme. Phase Modulation refers to varying the phase difference between the two arms, i.e., the phase difference between Va, and Vb.
* The output capacitance should be significant, especially for high voltage and high frequency applications. This imposes to obtain ZVS.

To turn-off MOSFET and to turn-on the complimentary MOSFET, a definite dead-time T_{delay}, has to be allowed in the same arm. Enough energy has to be stored in the parasitic inductances of the power transformer, to fully discharge the output junction capacitance of the MOSFETS'. Next section discusses the factors affecting ZVS.

III. FACTORS AFFECTING ZVS

The discharge current tothe transformer primary is done by turn-on of a MOSFET to get ZVS. The primary current should maintain the proper polarity till the capacitance is fully discharged. To obtain ZVS, it is clear that large magnetizing current and leakage inductance should have desired polarity. The dead time that affects ZVS is considered as the major factor. Total primary current reversesat heavy loads. Hence T_{delay} has to be smaller at heavy loads. Ideally, T_{delay} should be load dependent. The parameters affecting ZVS are magnetizing current that aids ZVS but if it increases, it may lead to higher stress and conduction losses. Section IV discusses about Series Resonant Converter.

IV. SERIES RESONANT CONVERTER

The SRC aids in intrinsic low switching losses that allows operating at higher switching frequencies and taking advantage of inevitable parasitic inductances as a part of resonant tank, lower electromagnetic interference (EMI) levels, higher power density, a single capacitor as output filter.

The following assumptions are considered for the analysis:
1) The converter switching frequency is constant and greater than the resonant frequency.
2) The converter uses the phase-shift modulation scheme and has settled in steady-state operation.
3) Output capacitor is large and output voltage is constant with no ripple. The variation range of Vout is from zero to Vin .

In SRCs, the transformers are usually designed to have minimum losses and this requires selecting the maximum flux density of the magnetic core in the linear region of the *B–H* curve. Also, for a proper transformer a tight coupling between primary and secondary windings, is required. Thus, the magnetizing current can be safely neglected as far as the voltage gain and soft-switching aspects are concerned. In practice, the specifications of an output-voltage-regulated DC–DC converter usually designed such that regulation must be less than 1% for the maximum peak-to-peak voltage ripple at the output terminal. In a SRC, the output capacitor provides the low impedance path for the AC component of the rectified current after the diode bridge. This requires the output capacitor to have a low equivalent resistance and reactance at double the switching frequency. Because of the large magnetization inductance of the transformer, there is only one possibility for the resonant current to flow, i.e., through the rectifier bridge. Therefore, the SRC is operational only if the condition$V$in $\geq nV$out [2].

This paper deals with the Phase Modulated Series Resonant Converter (PM-SRC) which is a SRC operating at a fixed switching frequency and is duty ratio controlled. Steady state analysis of the PM-SRC operating above resonant frequency is carried out. The PM-SRCis also referred to as the phase Modulated SRC or pulse width modulated SRC [3].

It consists of a full bridge inverter feeding a series resonant tank. The tank current is rectified and filtered using a capacitive filter to produce the required DC voltage. This method can be implemented for high voltages. High voltage is obtained using a step up transformer and voltagemultiplier circuits. Low voltage on the secondary side can be obtained from high voltage using a step down transformer. Control is achieved through

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phase modulation. Conduction of switches on the leading leg of the inverter is phase shifted with respect to the conduction of switches on the lagging legresulting in a quasi-square excitation voltage.

Parasitic inductance of the transformer becomes part of the resonant inductance *Lr.* By including the resonant capacitor *Cr* and exciting the tank with a voltage waveform *V,* having frequency close to the tank resonant frequency, the effective impedance offered by the parasitic inductance to power flow is reduced. The circuit offers ZVS when operated above resonant frequency; this is preferred for a MOSFET based inverter [4].

Discrete time domain modeling can be used to derive a linearized small-signal phase-shift to output voltage transfer function for the PM-SRC. This can be used for linear closed loop PI control design for the stable operation [5].

Design of the converter is as follows,

In the proposed paper, the converter input voltage is 12V with the expected output of 12V having the regulation of ±1%. The open loop simulations are carried out using PSpice software and the expected output is obtained as per the calculations.

Input voltage (Vi) = 12V, Output Voltage (Vo) = 12V. For the experimental purpose the load applied is 0.26watts. This can be extended to higher wattage ratings upto few kilowatts and can be implemented with proper design. The operating frequency considered in the proposed model is 100 kHz. Section V shows the simulation results.

V.SIMULATION RESULTS

The simulation is carried out using PSpsice software package. Fig. 3 shows the proposed simulated circuit considering the open loop operation.

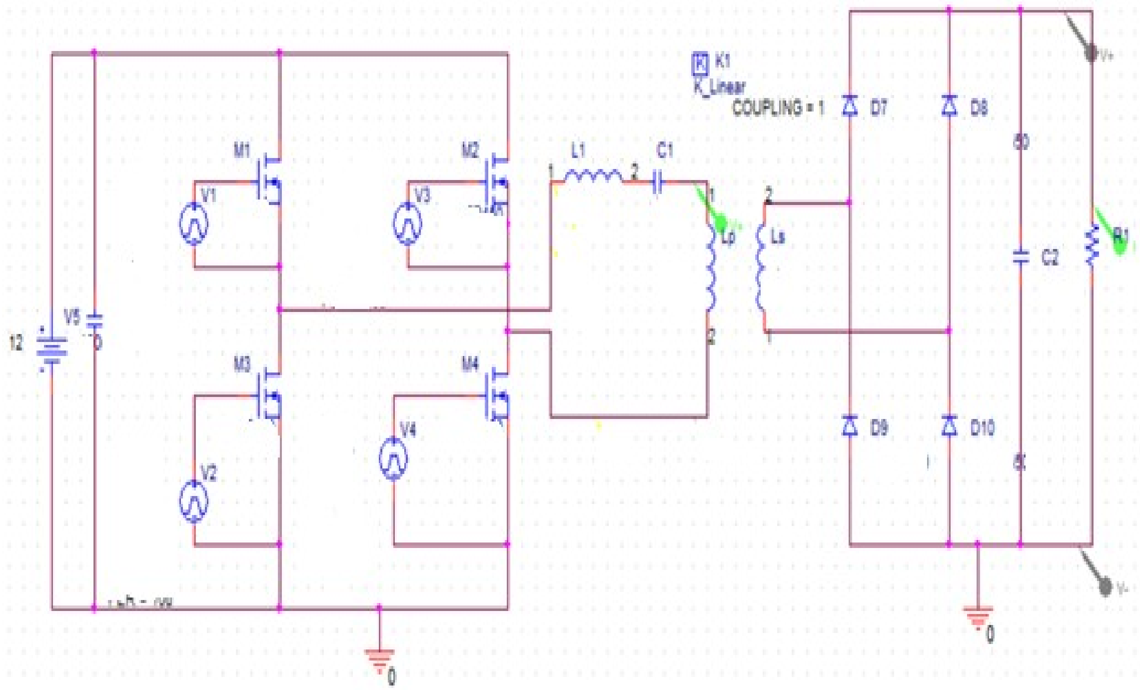

Fig. 3: Circuit simulated using PSpice

Fig. 4 shows the simulated waveform of primary bridge voltage

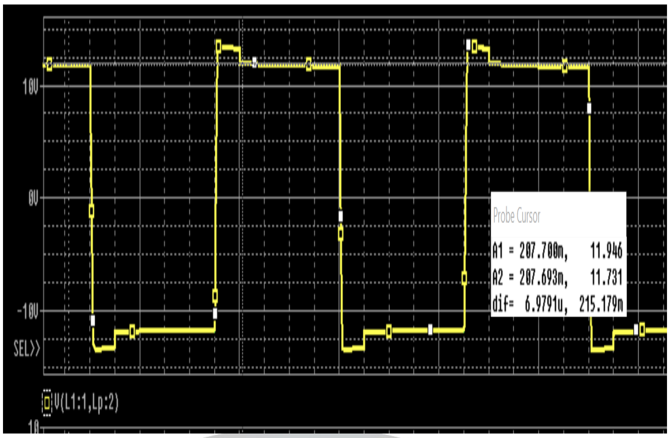

Fig. 4: Primary side bridge voltage – 11.94V

Fig. 5 shows simulated waveform of the resonant tank current which is aiding ZVS operation.

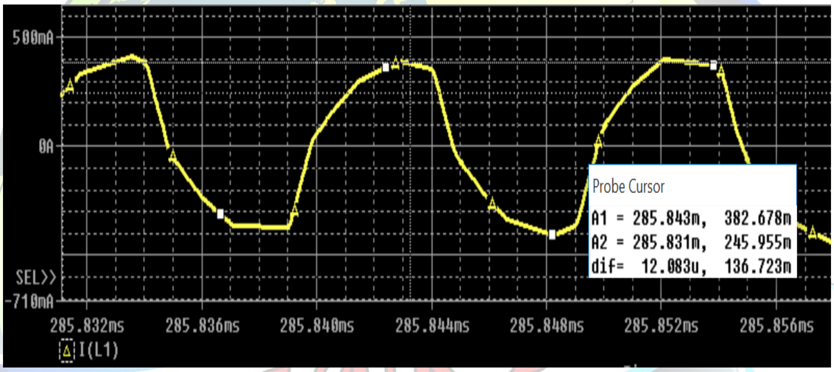

Fig. 5: Resonant tank current – 382.67mA

The simulated output voltage of the converter at the load is shown in fig. 6 for the open loop operation.

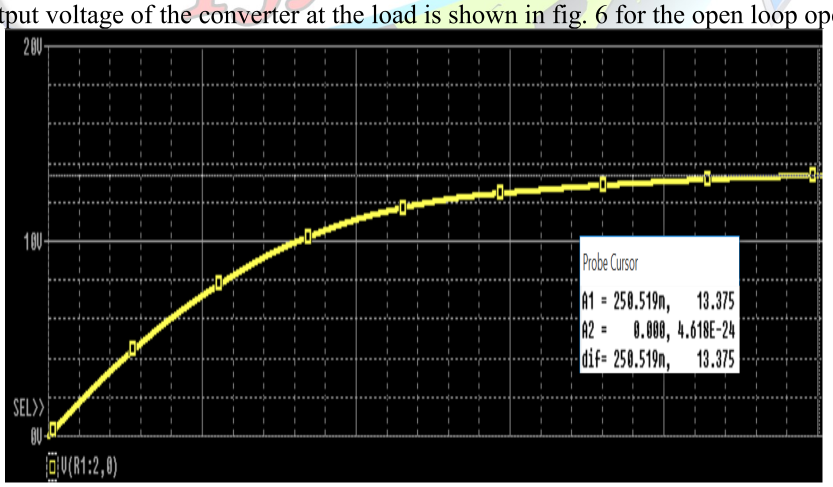

Fig. 6: Open loop output voltage – 13V

The practical hardware circuit of the proposed Phase modulated series resonant converter is shown in figs.7, 8 and 9.

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Fig. 7: MOSFET and transformer circuit-Primary side

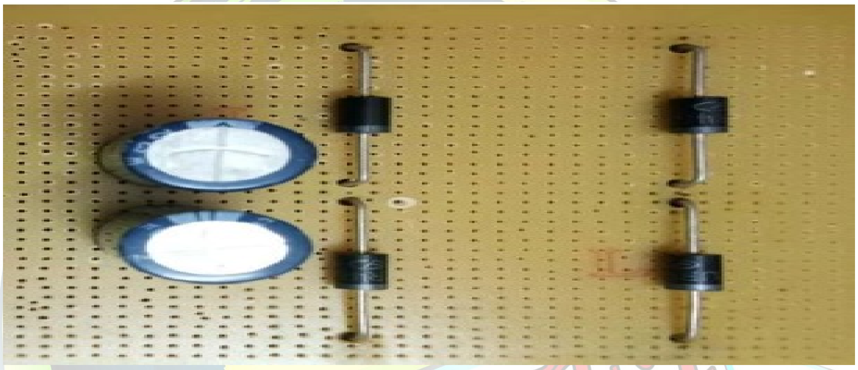

Fig.8: Secondary side diode bridge

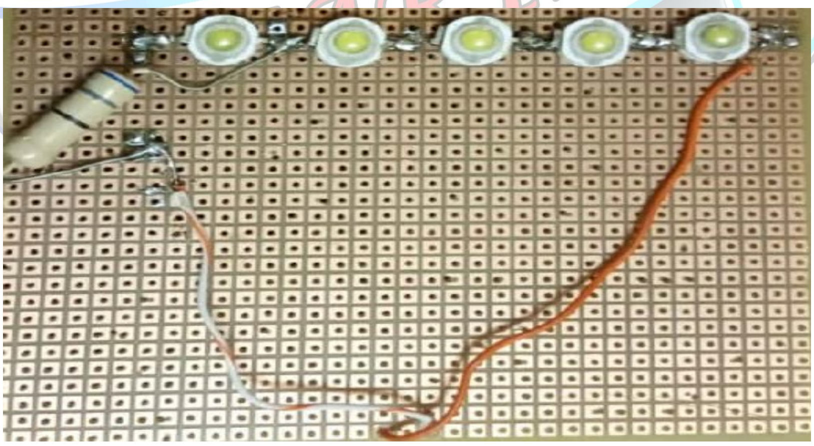

Fig. 9: LED load

The measured values in the hardware circuit is similar to the results obtained in the simulation.
This section is followed by the conclusion.

VI. CONCLUSION

The full bridge Phase modulated series resonant converter is designed and implemented.The converter is designed for the input voltage of 12Volts with the tollerance upto ±5% to obtain constant output voltage of

12Volts with the regulation of ±1% for the full load output power. The converter designed works within the given limits satisfactorily maintaining constant regulated output voltage. The converter is simulated using the PSpice software package. The relavant waveforms are obtained. The hardware is implemented and expected results are obtained satisfactorily. These results are accurately matching with the simulation results. More stable operation can be achieved by implementing closed loop design with PI controller.

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