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On 26th & 27th March 2015

Closed Loop Control of Soft-Switched Single Switch Resonant Converter

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ABSTRACT: In this paper, a single switch ZVS resonant converter with closed loop PI control is proposed. This resonant converter has several advantages such as simple construction, small size, and easy to apply soft switching techniques in order to withstand voltage or current stresses. It provides zero voltage switching (ZVS) for the active switch(S) and zero current switching (ZCS) for the energy blocking diode (D). The energy blocking diode is provided to filter the output stage of the converter. To reduce the cost of switches and the switching losses, only one switch is provided to the resonant converter. For output voltage stabilization a closed loop circuit with PI control is provided. So, when the load changes the output voltage is kept constant. A closed loop control has high reliability, easy implementation and output short circuit and overload protection. Simulation is done using PSIM and the simulation results that show zero voltage switching for switch and zero current switching for energy blocking diode is attained. And also if the output voltage changes with the load changes, the closed loop control provide a required stable output voltage.

KEYWORDS*:* Resonant converter, Zero voltage switching (ZVS), Zero current switching (ZCS), PI control

I.INTRODUCTION

DC-DC converters have been of great importance in power electronics because of its simple circuits and efficient control schemes. Using this, the output voltage can be varied steplessly by controlling the duty ratio of the semiconductor device used in chopper. The conventional boost converter is difficult to realize high step-up conversion ratio and voltage stabilization. It leads to serious reverse recovery problem of output diode and increases the voltage or current rating of all components [1]. It can be simply achieved by using couple-inductor structure, cascade topology.[2] But the leakage inductor of the couple-inductor creates the voltage spike on the switching devices and reverse recovery problem on the output diode.

When compared with other dc-dc converter resonant converter have high efficiency and small size. For small size, the switching frequency has to be high. Therefore components size will reduces. But high switching frequency cause high stress on the switch. If soft switching techniques have been used these switching stress can be avoided [3]-[7].

Resonant converter can be classified into several converter types. They are converter with more number of switches and converter with bulky transformer. The Leakage inductors of the transformer and resonant capacitors help to achieve ZCS for rectifier diodes to overcome the reverse recovery problem [10]. However, these transformers and switches increases losses in the circuit and reduce the efficiency of the converter. There are some topologies which reduces these losses by reducing the number of switches [8]-[10] else by removing the transformer.

A single-stage quasi-resonant converter is proposed in [8] with the advantages of single switch and two diodes without any output inductor and utilizing the transformer in forward mode. But, soft switching is not achieved at switch turn OFF instant. In [9] the topology, it uses a smaller transformer like forward converter and not require the bulky output inductor of forward topologies. But this converter require trigger circuit to trigger the switch.

If the transformer is avoided[13], the overall size of the power supply size can be reduced. Converter With Hard-Switching Auxiliary Circuit [16] is introduced. In that, the converter has low conduction loss, but the auxiliary switch has hard turn-off.

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In this paper a voltage mode control of soft-switched single switch resonant converter have been introduced. For high efficiency and small size, high switching frequency is provided. And also a single switch, soft switching techniques are used to reduce the switch stress. A voltage mode control with PI control was used [17], to regulate the output voltage to the required value, when the load and line values are changes.

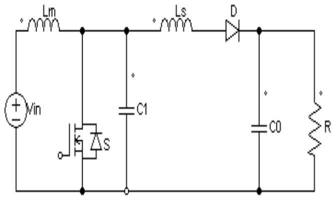

Fig.1. proposed soft-switched single switch resonant converter

In Section II, the proposed converter is introduced and its various operating modes are explained. Design considerations are described in Section III. To verify the theoretical analysis, the simulation results are presented in Section IV and a conclusion is provided in Section V.

II.PROPOSED CONVERTER

In this section, the proposed converter is introduced and its operating modes are discussed. The proposed converter shown in Fig.1 and the equivalent circuit of each operating mode is shown in Fig. 2

A. Circuit Operating Principles

The soft-switched single-switch resonant power converter is analyzed using the following assumptions.

1) The switching elements of the converter are ideal, so that in the ON state the drop in forward voltage across the resistance of the power switch is negligible.

2) The equivalent series resistance of the capacitance and Stray capacitance is negligible.

3) The filter capacitance *Co* at the output terminal is very large; the output voltage across capacitor *Co* can be an ideal dc voltage in each switching cycle.

4) The choke inductance *Lm* at the input terminal of the converter is large. Therefore, the input current through the inductor *Lm* can be idealized dc current in each switching cycle.

One switching cycle is divided into six modes, which are described as follows.

Mode I— The power switch *S* is off. To avoid switching losses, The power switch must be turned on only at zero voltage. Otherwise, the capacitor voltage will dissipated through the switch. To avoid this situation, anti-parallel diode of the switch must conduct before the switch turn on. Thus ZVS and ZCS for the switch is obtained. When the capacitor voltage v_C falls to zero, the switch can be turn-on. Since, $i_{Lm} - i_{Ls}$ is negative is the reason for the diode conduction. I_{+Ls0} is the initial condition of the inductor current *iLs* .

When $i_{Lm} - i_{Ls}$ becomes positive, anti-parallel diode of switch reverse biases, and the mode will ends.

Mode II— switch S is turn on. The line voltage is applied to the choke inductor L_m, and i_{Lm} increases continuously. The resonant current i_{Ls} passes through the energy-blocking diode *D*. This mode ends when the inductor current i_{Ls} falls to zero.

Mode III—switch is continuously conducting. The inductor current i_{Ls} falls to zero, and negative going is prevented by diode D. Inductor L_m is continuously charging and it is discharged when the switch is off. Then mode ends.

Mode IV— After switch turn off, the capacitor current i_C become i_{Lm} . Then capacitor voltage V_C increases from zero to finite value. For ZVS, at zero voltage the switch S turns off. From the input voltage capacitor C is charging. Here, supply to the load is supplied by output capacitor C_0. When diode forward biased this mode ends.

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Mode V— Switch remains of state. The inductor current i_{Ls} is positive and the diode D is turn on, hence resonance occur between L_s and C. The capacitor current i_C is positive and V_c increases to the its peak value. When i_C resonates to zero this mode ends.

Mode VI— The capacitor current Ic becomes zero and capacitor voltage V_c resonates from negative to zero. At $\omega_t = 2\pi$ switch S turn on to eliminate the switching losses. To provide ZCS condition to the diode, before the resonance of Ls stops, the switch kept off and providing a positive current to flows through the diode D.
When gate signal for the switch is again provided this mode will ends and the cycle repeats.

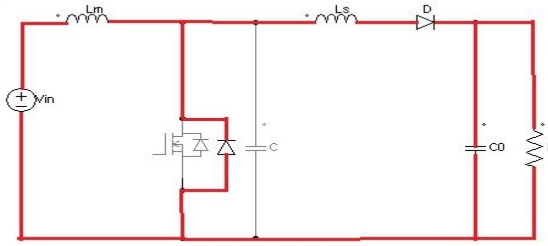

Fig.2. Mode 1

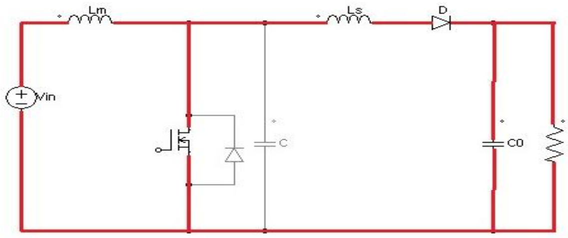

Fig.3. Mode 2

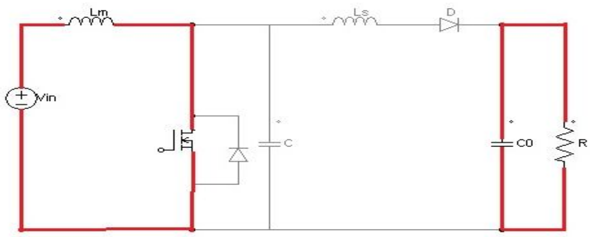

Fig.4. Mode 3

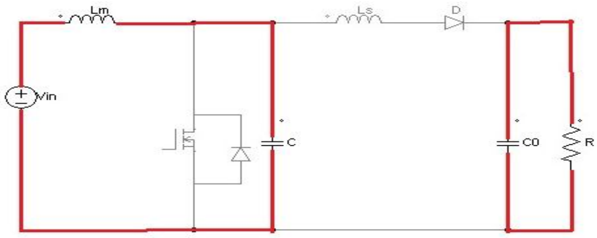

Fig.5. Mode 4

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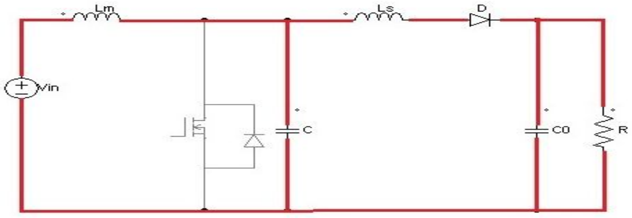

Fig.6. Mode 5

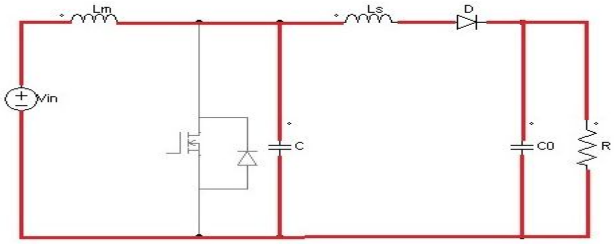

Fig.7. Mode

III.DESIGN CONSIDERATION

To simplify the operating characteristics of the soft-switched single switch resonant converter. It is assumed that the load circuit is a voltage sink type. And the output capacitor is kept at large value to get a constant output. As a result, depending on whether the inductor current enters or leaves the energy-blocking diode, the link voltage has constant positive and negative amplitudes, respectively.

The soft-switched single-switch resonant converter consists of a choke inductor *Lm*, which generates a ripple-free constant current source, a MOSFET that is anti-parallel with a body diode *DE*, a resonant capacitor *C* that is connected in parallel with the body diode, a resonant inductor *Ls*, an energy-blocking diode *D* that is connected in series with the parallel combination of the body diode and the capacitor, and a first-order low-pass output filter $Co - R$. The main feature of this converter is that the body diode junction capacitance is absorbed into the resonance capacitance *C* and some lead inductances are absorbed into the resonant inductance *Ls*.

For operating below resonance is preferred because the active power switch turns on at zero current and zero voltage; thus, the freewheeling diode does not need to have very fast reverse-recovery characteristics. The energy blocking diode turnoff by zero current switching by reducing the current through it zero.

To attain ZVS operation for the switch, the turn on signal of the active power switch *S* should be applied while its body diode is conducting. For discontinuous mode of operation $fs < fo$. Thus, the converter must satisfy the condition,

$$f_s \leq f_o = \frac{1}{2\pi\sqrt{LsC}} \qquad (1)$$

Load resistance,

$$R \leq \sqrt{(Ls/C)} \qquad (2)$$

And also, $R = (P0/V0)$ (3)

Assume , C = 0.18µF

Then L_s =19µH

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IV.CONTROL STRATEGIES

The single switch resonant converter topology along with closed loop PI control is shown in fig.8. The control signal for the single switch of the resonant converter is provided by, sensing the output voltage of the converter by a voltage sensor. This output voltage is compared with the reference voltage. The error output coming from the comparator is given to the PI controller. The PI controller output is compared with carrier signal. It produces a PWM signal, which provided as the gate signal for the single switch of the resonant converter.

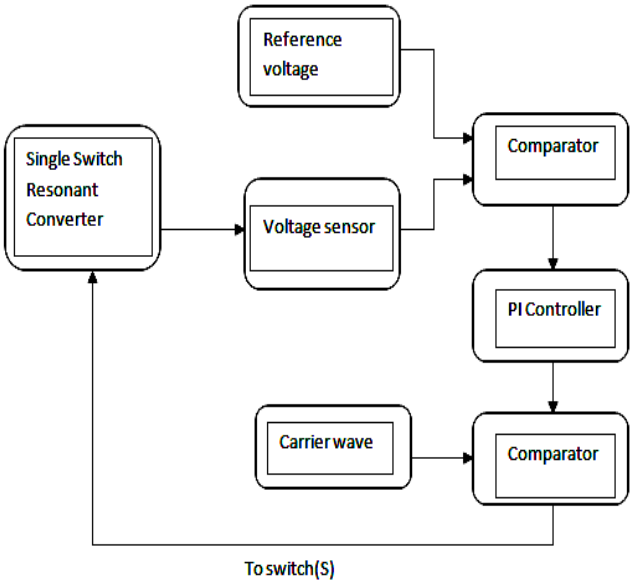

Fig.8. control method

V. SIMULATION RESULT

The output voltage of a switch mode power supply is kept constant with the help of closed loop control. The value of the output voltage (actual value) is compared with a reference voltage (nominal voltage). The difference between actual and nominal value controls the duty cycle of the transistor drive. The function of the control loop is to regulate the variation of the mains and of the change of the output current. This is called line regulation and load regulation. There are two different methods of regulation: voltage-mode and current-mode control. The voltage-mode control is the "traditional" method of regulation. Voltage sensing is easier than current sensing: Less noise, less power loss, Less cost, More resolution. Single feedback path is easier to design. To get load regulated output voltage, 15V DC input is used.

Table.1. components specifications

Parameter	Value
Input voltage (Vin)	15V
Output voltage (Vo)	18V
Output power (Po)	32 W
Switching frequency (f_s)	70kHz
Resonant frequency (f_o)	86kHz
Duty cycle (D)	0.35
Resonant capacitance(C)	0.18µF

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Resonance inductance (Ls)	19mHμH
Choke inductor (Lm)	8mH
Electrolytic capacitor (Co)	220µFμF
Load resistor (R)	10ΩΩ

The simulation result ensure the zero voltage switching of active single switch (as shown in fig.14) and zero current switching of diode(as shown in fig.15). Additionally, a voltage mode control is provided. So the output voltage is kept constant, when the load changes.

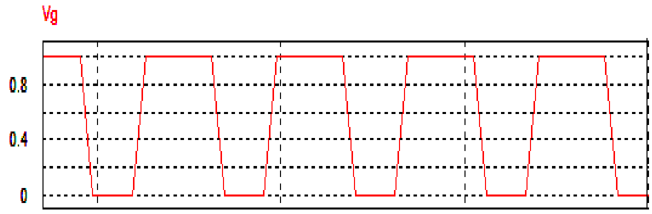

Fig.9. trigger signal for the switch(S)

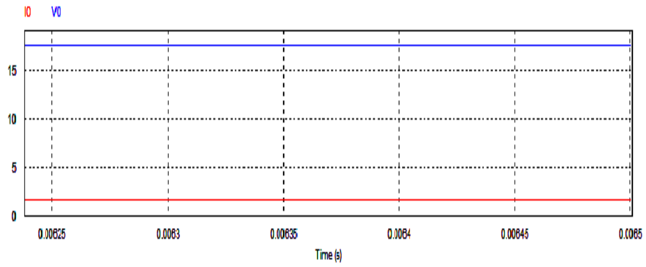

Fig.10. Output voltage and current of the proposed converter

Fig.11. voltage and current through resonant capacitor(C)

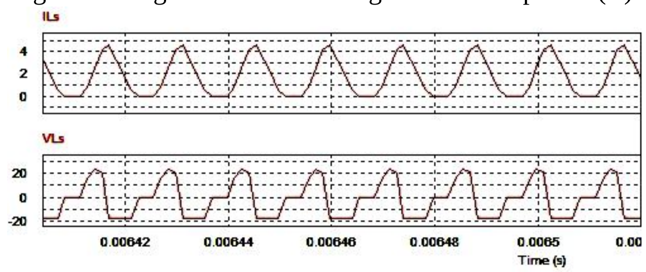

Fig.12. voltage and current through resonant inductor (L_s)

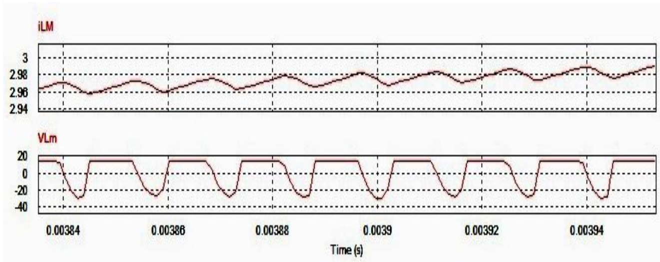

Fig.13. voltage and current through choke inductor(L_m)

A.Soft switching of switch and diode

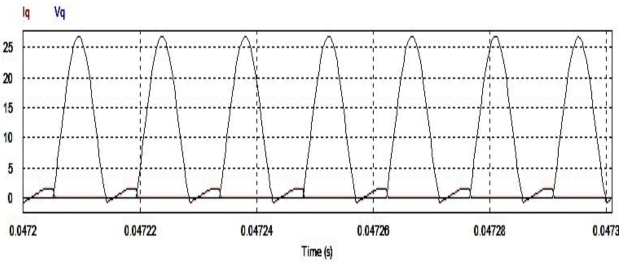

Fig.14. soft switching of switch

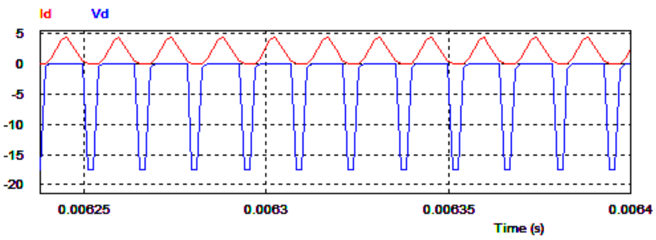

Fig.15. Soft switching of diode

B. Load regulation

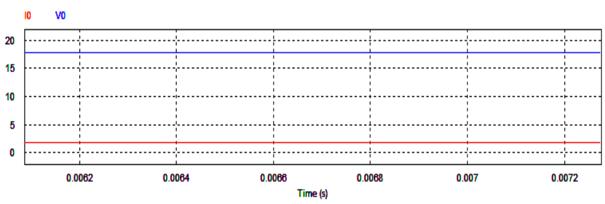

Fig.16. output voltage and current at full load, R=10Ω, V_O=18V.

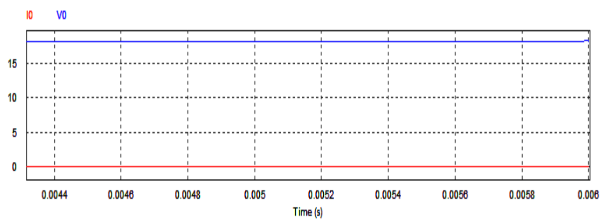

Fig.17. output voltage and current at no load, R=1000Ω, V_O=18V

VI.CONCLUSION

This paper explains a closed loop control of soft-switched single switch resonant converter. Compared with other topologies, it requires less number of switches and no need of bulky transformers. This topology is simpler and cheaper. The single switch resonant converter offer advantages of soft switching techniques thus reduce switching losses and voltage stabilization. Simulation is carried out for proposed system using PSIM, simulation results shows that zero voltage switching for switch and zero current switching for energy blocking diode is attained. And voltage regulation for the load changes also attained for the proposed topology. This soft-switched single switch resonant converter can be used for renewable and portable applications.

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