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Auxiliary Switch Based HF-ZCS Resonant DC-DC Converter

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ABSTRACT—This paper explores the design of Novel Auxiliary switch dc-dc boost power converter operating in the High Frequency (HF, 10–30 KHz) range. The main switch and auxiliary switch operate at zero-current-switching (ZCS) turn on and turn off, and all passive semiconductor devices in this converter operate at zero-voltage-switching (ZVS) turn on and turn off. Besides operating at constant frequency and reducing commutation losses, this new converter have no additional current stress and conduction loss in the main switch in comparison to the hard switching converter counterpart. The methods are presented for assessment and comparison of results in HF operation under soft switching and soft gating conditions. These methods are applied to the development of a 16W resonant boost converter operating at a switching frequency of 30KHz. Design of power stage, resonant gate drive, hardware design procedure ,simulation result and hardware results are treated in detail. For demonstration, a prototype Novel Auxiliary switch system is designed and implemented with discrete components to deliver 16W peak power with 88.9% of efficiency.

KEYWORDS: Multiresonant Converter, ON-OFF Control, Resonant Converter, Resonant Gating, Zero-Current Switching, Zero Voltage Switching.

I. INTRODUCTION

THE COST, SIZE, and performance of dc-dc power converters are heavily dependent on the required size of passive components such as inductors and capacitors. The sizes of passive components often dominate over the switching devices and control circuits, constraining power density. Likewise, the achievable converter transient performance (essentially, the rate at which the converter can adapt its operating condition) is limited by the energy stored in the passive components. Because required component values and energy storage decrease as frequency increases, there is a motivation to do the Operation of switching power converters at high frequency as possible commensurate with practical constraints such as efficiency.

The Zero Current Switching (ZCS) resonant technique is praised for its high power capability, fast transient response and ease of control. The Resonant dc-dc converters have also been widely used in industry. For minimization of size and weight, increasing switching frequency in the resonant converter is required. However, increasing switching frequency will result in the more switching losses and electromagnetic interference (EMI). Recently ,for improving this problem, a number of soft-switching technique were proposed aimed at combining desirable features of both the Very High Frequency and resonant techniques. The zero-voltage-switching (ZVS) approaches are desirable for majority of carrier semiconductor devices such as MOSFET's, since the turn-on loss caused by the output capacitance is large. The zero-current-switching approaches are suitable for the minority of carrier semiconductor devices such as insulated gate bipolar transistors (IGBT's), since the turn-off loss is large due to the current tail characteristics. In recent year, IGBT's are preferred for high-power applications, since IGBT's have a higher voltage rating, higher power density, and lower cost compared to MOSFET's. However, IGBT's are relatively slow in switching speed, so the switching losses and the high frequency of operation are two well-known problems.In order to overcome previous problems, a number of ZCS Resonant techniques have been proposed. In the Approaches proposed in and , ZCS of the active switches is achieved by using a resonant inductor in series with the main switch and a resonant capacitor in series which leads to a substantial increase in conduction loss. This phenomenon is eliminated in the approaches proposed in by the resonating current for ZCS flows only through the auxiliary circuit, thus, the current stress of the main switch is eliminated[5]. But it presents two power diodes in the power transfer path, which increases conduction losses of the diodes.This paper proposes a new ZCS Resonant auxiliary circuit that improves the drawbacks of the previously proposed ZCS Resonant converters. The proposed auxiliary circuit provides ZCS condition for both the main switches and auxiliary Switch, and the all passive semiconductor devices in the ZCS Resonant converters operate at zero-voltage-switching turn on and turn off. Since the circulating current for the soft switching flows only through the auxiliary circuit, the conduction loss and current stress of the main switch are minimized. A new family of DC-DC converters based on the proposed ZCS Resonant switch cell is proposed. Besides operating at constant frequency and with reduced commutation losses, these new converters have no additional current stress and conduction losses in the main switch in comparison to the hard switching converter counterpart.

In the above literature, the voltage control scheme for three phase induction motor drive is not implemented using SVM. In this paper, the simulink model for the voltage control scheme of SVM fed induction motor is developed and the results are presented.

II. THE NOVEL BASED AUXILIARY CIRCUIT FOR RESONANT BOOST TOPOLOGY

Fig.1 shows a schematic of the new Novel auxiliary switch resonant dc–dc boost converter topology.[1] This paper presents a converter operating with soft commutation at the main switches and the auxiliary switch devices.[9] The design is optimized for low device current stress and High Frequency (HF) operation at a fixed frequency and duty ratio. This enables the use of resonant gating and zero-current switching for high efficiency.[10] The converter can be viewed as a special version of resonant boost converter because it has one auxiliary switch in addition with main switch. To improve the accuracy of the model as regards circuit dynamics and loss, several additional aspects of the power circuit components are considered in the converter design proceeds by first creating a model for a simulation program such as SPICE. Fig.2.shows the Ideal wave forms for the proposed circuit.[2] Then some modifications are done based on results in the power circuit component value after that Hardware circuit model was designed.[11]

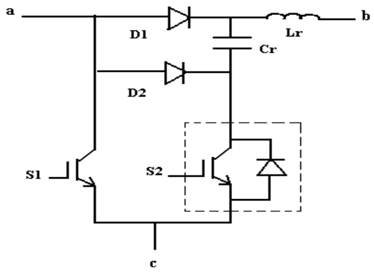

Fig 1. New Proposed Novel Auxiliary Switch Model

At High Frequencies, traditional hard-switched gating typically incurs too much loss for acceptable efficiency.[3] Instead, with a power stage and control scheme designed to operate at a fixed frequency and duty ratio, resonant gating is advantageous. By recovering a portion of the gate energy in each cycle, much lower power is required to drive the gate[12]. Fig.3 shows the simulated gate pulse waveforms[4]. In addition to achieving low-power operation, a practical gate drive must reach steady state rapidly at start up and shutdown to maintain good converter transient response and high efficiency under ON–OFF condition.[13]

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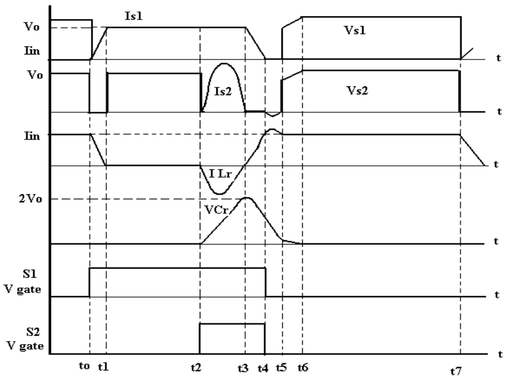

Fig.2. Ideal Circuit Waveforms

Fig.4.Shows the hardware output pulse for the proposed model. To that end, two different low-loss gate drivers were designed; one for main switch and another for auxiliary switch.[14] In the case of the 30-KHz converter, the gate terminal of the switch cannot be driven below the source due to a protection diode integrated with the switch. For this reason, a scheme similar to that presented in [12] was developed. Added components provide a gate Signal to the auxiliary IGBT, the duty cycle of triggering wave form decides the power circuit efficiency, and for resonance this is also one of the parameter. So, based on design the circuit was implemented[15].

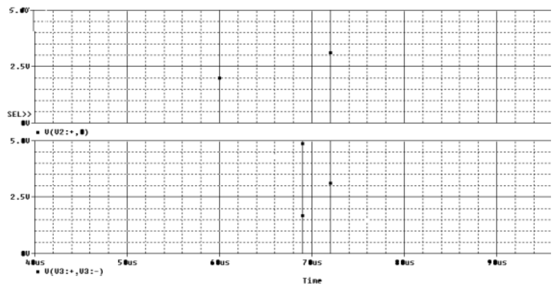

Fig 3.Simulation gate pulses

III. **DESIGN PROCEDURES AND SIMULATION RESULT**

The switches of the minority carrier type devices such as IGBT's are used as main switch and auxiliary switch, since their commutations are ZCS[5]. A special care should be taken to design the resonant inductor (Lr) and resonant capacitor (Cr). When the resonance between resonant Inductor and capacitor happens, at resonance the voltage across the capacitor must reach a value twice the input applied voltage and the Inductor current should be Zero.[16] Fig.7 and Fig.8 shows simulated resonant Capacitor voltage and Inductor current waveforms. This is the feature of the ZCS. [6]

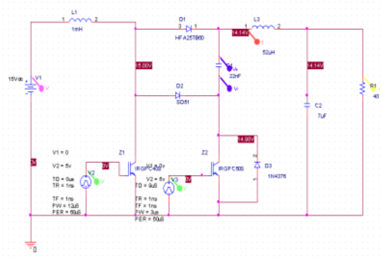

Fig 4. Simulation circuit for the proposed design

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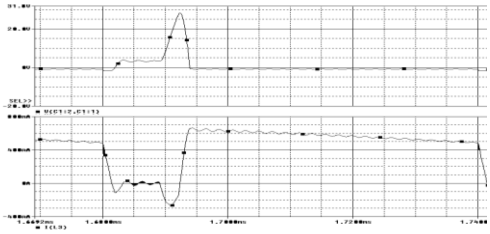

Fig 5. Simulated resonant Capacitor voltage and Inductor current waveforms

This ideal simulated waveform is compared with the below mentioned simulated wave form[17].

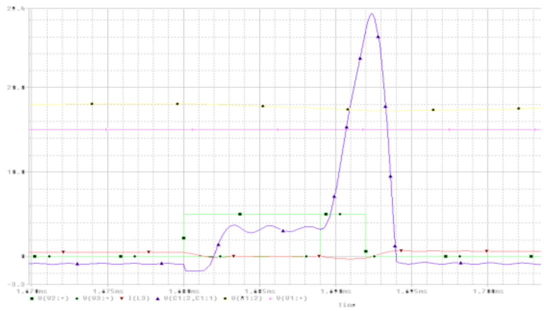

Fig 6. Simulated waveforms for the proposed circuit

Blue - Resonating capacitor voltage wave form
Red - Resonating Inductor current wave form
Green –Switching pulse
Yellow – Output voltage

IV. EXPERIMENTAL RESULTS AND RESULTS COMPARISION

A 16W, 30-KHz prototype of the proposed Novel auxiliary switch ZCS dc-dc converter has been built and tested to verify the principle of operation. Fig. 10and Fig.11 Shows the experimental circuit with the part numbers of the components used. IRG4PC40W IGBT's are used for the main switches and IRG4PC50UD used for the auxiliary switch.[18] The circulating energy and reverse recovery loss can be reduced, since there is no diode reverses recovery in the Schottky diode during the transition from the off mode to the powering. The current through switches are zero before turning off and, thus, is turned off with complete ZCS, and no tail current is exhibited. The communication phenomenon in the main switch S1, auxiliary switch S2, auxiliary diode D1, and main diode D2, are measured.[19] The experimental results demonstrate that zero-current switching is achieved at constant frequency for both active switches (S1 and S2). It should be noticed that the auxiliary diode D1 and the main diode D2 were also softly commutated under zero-voltage-switching. Therefore, the switching energy losses for this new ZCS Resonant boost converter are practically zero.[20]

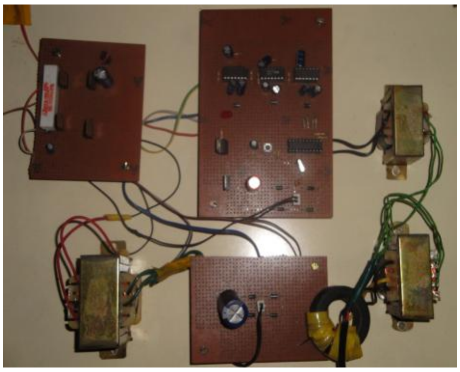

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Fig 7. Hardware circuit board

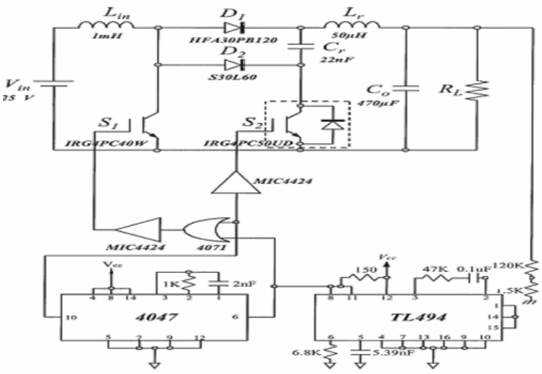

Fig 8. Schmatic circuit for the proposed design

TABLE I.
HARDWARE DESIGN COMPONENTS

S. no	Components
1	Inductor (50 µH)
2	Capacitor (22 nF)
3	IGBT(IRG4PC40W)
4	IGBT (IRG4PC50UD)
5	Diode (S30L50)
6	Diode (HFA30PB120)
7	GatedriverIC(MIC442)
8	Pulse generator (TL494)
9	PostpulsedelayIC(4047)
10	OR gate IC (4071)

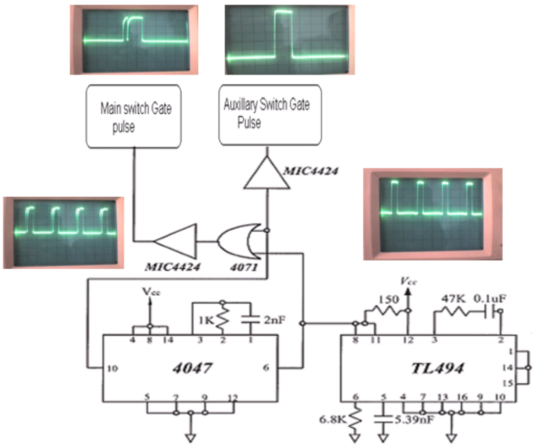

Fig 9. Hadware output for the proposed design

The above circuit shows the hardware pulse for both main switch and auxillary switch circuit.

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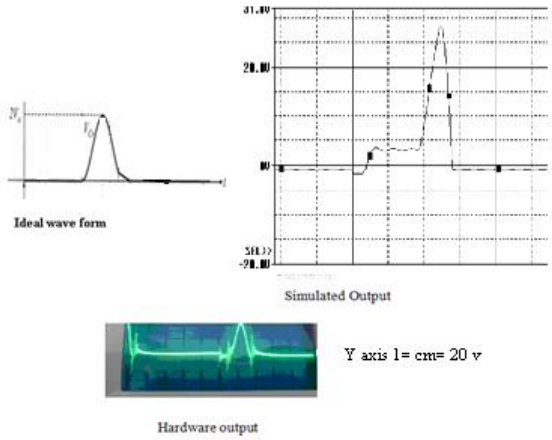

Fig 10. Comparision output of ideal and practical waveform

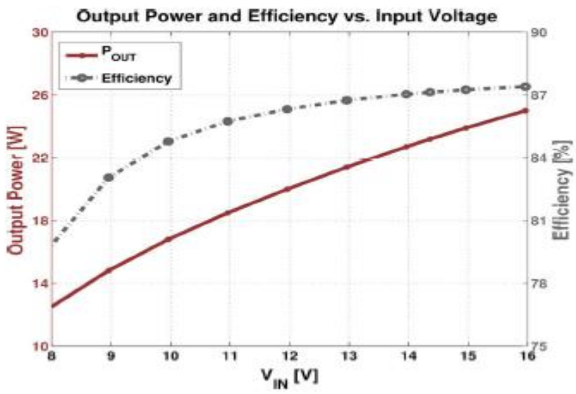

Fig 11. Graph between Output power and Efficency Vs Input voltage

V. CONCLUSION

This paper has presented a new resonant topology suitable for boost power conversion. The new topology addresses several short comings of previous designs, while maintaining all desirable properties necessary for HF power conversion, zero-Current switching and absorption of device capacitance. The paper describes experimental implementations of resonant boost converters. Operating frequency of 30-KHz, 16-W converter using a commercially available IGBT's, which achieves efficiency above 88% for nominal input and output voltages. The converter utilizes a high-bandwidth control strategy that permits excellent light-load efficiency, something that is typically difficult to implement with resonant converters. In addition to greatly reducing the physical sizes of the passive components, the High operating frequency gives the converters an inherently fast transient response. As this paper has demonstrated, it is possible to achieve miniaturization and high performance of dc–dc power converters without sacrificing efficiency. The design implementations described in this paper are expected to contribute to the development of HF dc–dc converters, paving the way for power electronics that can satisfy the needs for improved size, cost, and performance that are demanded by modern applications.

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