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High Power Density Multi-Mosfet-Based Series Resonant Inverter for Induction Heating Applications

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Article Info	ABSTRACT
	Induction heating application uses uniquely high frequency series resonant inverter for achieving high conversion efficiency. The proposed work focus on improving the practical constraints in requiring the cooling arrangements necessary for switching devices used in resonant inverter due to higher switching and conduction losses. By introducing high frequency Multi-MOSFET based series resonant inverter for the application of induction heating with the following merits such as minimum switching and conduction losses using low voltage grade of automotive MOSFET's and higher conversion efficiency with high frequency operation. By adding series combination of low voltage rated Multi MOSFET switches, temperature variation according to the on-state resistance issues can be avoided by sharing the voltage across the switches depends on the number of switches connected in the bridge circuit without comprising existing systems performance parameters such as THD, power factor and output power. Simulation results also presents to verify that the proposed system achieve higher converter efficiency.

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1. INTRODUCTION

Induction heating (IH) has mainly used in home and industrial application. Induction heating is the process of heat generated within the object itself, not via heat conduction by an external heat source and it is based on the eddy current and skin resistance of coils. In IH applications, higher switching frequency brings two benefits: reducing the components size, and high power density in the region of the exterior of the heating objects. The increased frequency results more switching loss which blocks the efforts to raise the frequency. Because of high switching frequency higher order Harmonics and acoustic noises are generated and switching edges of switches. It addresses the EMC that is subjected to the un-intentional generation, propagation and reception of electromagnetic energy in regards to electromagnetic interference. Hence, EMC filter means combination of passive elements to minimize the noise which is produced by emission and susceptibility issues [1]-[2]. Next stage, an AC-DC converter provides supply to the inverter block. The rectifier can be either a non-controlled stage, i.e. diode rectifier, or a controlled one. IH Includes power factor correction boost converter the main objective is to draw a sinusoidal current, in-phase with the utility voltage as well as increase the rectifier output [3]-[4]. Semiconductor switches IGBT and MOSFET normally used in IH. The IGBT device is selectable which gives minimum on-state losses, higher efficiency than the high-voltage MOSFET devices [5]. Nevertheless, the main drawback of the IGBT's are large switching times and limitation of increasing switching frequency (<20 KHz). Whereas the high-voltage MOSFET carries minimum switching loss and high frequency applications (>200KHZ). According to above, MOSFET device

appears to be chosen for IH as it uses for High frequency application [6]. Nonetheless, MOSFET devices has variation in temperature depends upon on-state resistance that leads the voltage stress across the devices. Proposed series combination of MOSFET devices enables both an on- state losses minimization and decreased switching times while requiring the same chip area [7]-[10]. Furthermore, the temperature variation of the on-state resistance is reduced, enabling greater efficiency even if a greater ambient temperature is reflected (90∘C). The motivation for using combination of series-connected MOSFETs switch is to minimize the voltage stress on the MOSFETs. Thus recover the breakdown voltage. Hence the switch heat management and system performance will be enriched. Series resonant converter is used to enhance the soft switching operation by creating ZVS or ZCS [11]-[13]. IH coil inductance series\parallel connected to reduce the switching loss. In proposed circuit, chooses the ZVS as capacitor connected in series with IH coil inductance to create resonant circuit [14]-[15]. Switched capacitor bank added to improve the output power of the implemented inverter as it's done by charging/discharging through the auxiliary switch [6].

2.   CIRCUIT DIAGRAM

Figure 1 shows the basic configuration of the proposed high frequency inverter circuit. The inverter circuit mainly comprises of half bridges with upper section and lower section. Upper switches are MH1, MH2, MH3 and lower switches are ML1, ML2, ML3, load (L0 and R0). Each MOSFET switch consists of anti parallel diode and capacitor to obtain the ZVS condition and protection of switches. PFC boost converter circuit comprises of inductor (Lp), switch (Qp), capacitor (Cp) and diode (Dp), resonant capacitors (Cr1), and auxiliary switched capacitor network (Cr2). Cr1is engaged in series with IH load and creates resonance with load L0. Switched capacitor Cr2 is connected in parallel with Q3 and also creates the resonance and zero voltage soft-switching condition of QS. L0 and R0 are the inductance and resistance of the IH coil and load, respectively.

The equivalent circuit of modes of operation are described below with considering the inverter section. Figure 2 shows the switching pulses of the different switches.
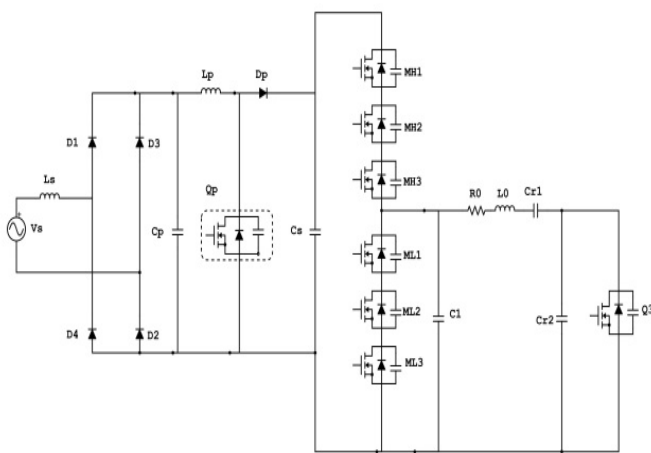

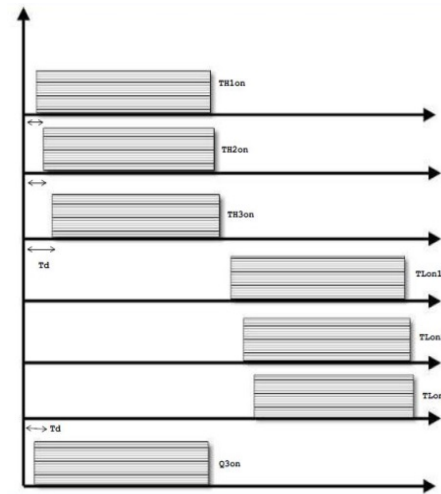Figure 1. Proposed Series resonant converter   Figure 2. PWM signals for MOSFET

There are three operating modes. Each mode is characterized by an equivalent circuit. The real challenge is how to feed the PWM signal to Multi MOSFET switches that will be done by sinusoidal PWM techniques. Series stacked switches are triggered with duty cycle. Time delay and phase delay will be given to avoid the large current available at switching time. For the reason, provides delay in switching sequence diagram.

a.   Mode I

Figure 3 explains the operation of mode1. The switch Q3 conducts for a time Q3 on with delay time Td. For the period of Q3on + Td, the upper switch MH1, MH2& MH3 conducts for the time interval THON1, THON2 & THON3 with delay. Henceforth first mode of operation, the current flows from the source Vdc to the switch MH1-MH2 - MH3, the IH load and the source through the switch Q3.
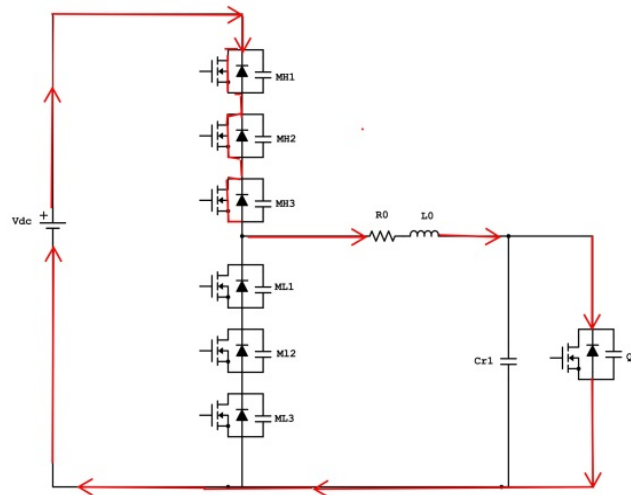
Figure 3. Mode I- Proposed converter

b.   Mode II
        Figure 4 shows the second mode of operation, the switch MH1- MH2- MH3 still conducts for a delay time Td. It allows the Cr1 to charge with positive polarization in the upper plate and negative polarization in the lower plate. Assume that the resonant capacitor Cr1 in the IH load discharges through the auxiliary switch diode D3 and series conducting MOSFET's upper bridge diode. It can be anticipated that the ZVS condition can be accomplished for switches MH1, MH2 & MH3 and Q3. The lower side snubber capacitor C1 arrangement only plays the function for protection of the circuit.
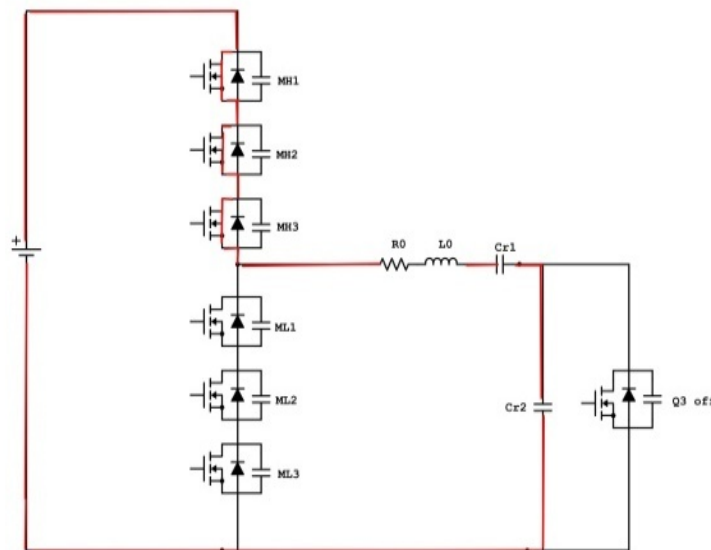

Figure 4. Mode II- Proposed converter

c.   Mode III
        Figure 5 shows the third mode of operation the lower switch ML1, ML2, ML3 is switched on for the time interval of TLon1, TLon2 & TLon3. The charged capacitor Cr1 release the stored energy through the switch ML1, ML2, ML3.Later the capacitor releases completely, the reverse biased current flows through auxiliary switch diode D3 and ML1, ML2, ML3 switch diodes. Since the turn on of the switch Q3 can be done at zero voltage, and the losses in the switching at the condition of turn on can be decreased. It completes one cycle of operation.
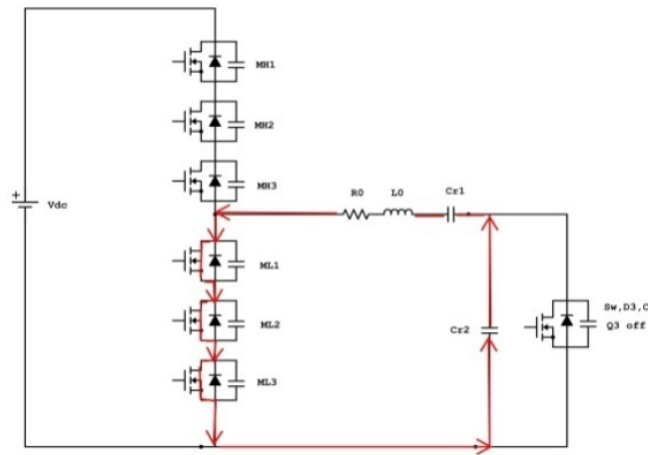
Figure 5. Mode III- Proposed converter

The switched capacitor Cr2 acts as a boost capacitor that increases the output voltage and output power. It will be understand from the simulation results.

3. SIMULATION RESULTS

The results of simulation are posted below and found the MOSFET switch voltage stress get shared based on the number of switch connected in the half bride series resonant inverter as well as THD value reduced. The simulation of six switches, four switches and two switch half bridge inverter was carried out using MATLAB/ Simulink. The six switch half bridge series inverter outputs are shown in Figure 6 and 7. It shows that voltage stress on single switch is 73V. The FFT analysis indicated as THD value of 4.77%.
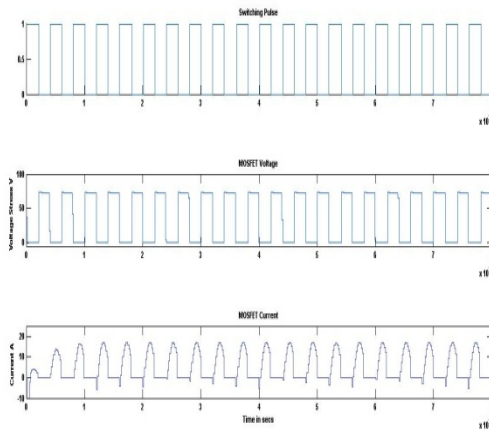

Figure 6. PWM, voltage and current of six switch inverter
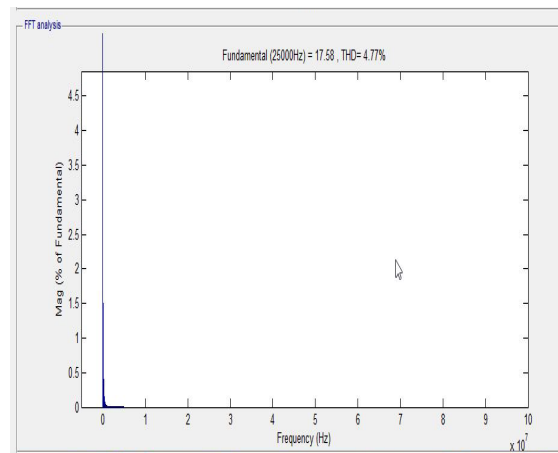

Figure 7. FFT analysis of six switch inverter

The four switch half bridge series inverter outputs are shown in Figure 8 and 9. It shows that voltage stress on single switch is 110V. The FFT analysis indicated as THD value of 4.94%.
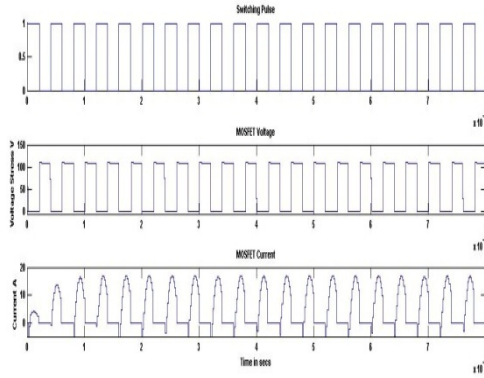
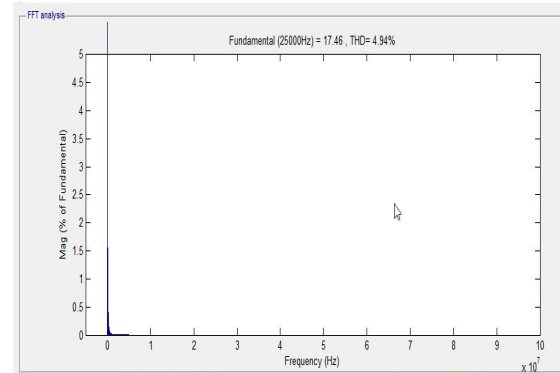Figure 8. PWM, voltage and current of four switch inverter

Figure 9. FFT analysis of four switch inverter

The two switch half bridge series inverter outputs are shown in Figure 10 and 11. It shows that voltage stress on single switch is 220V. The FFT analysis indicated as THD value of 5.15%.
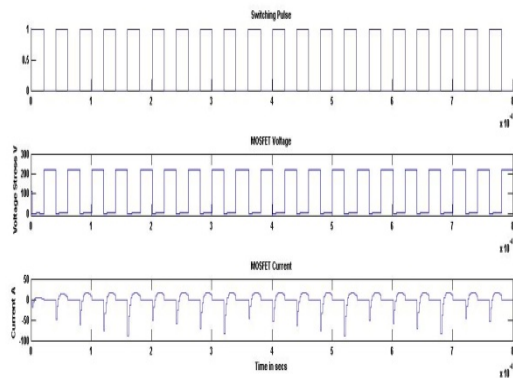

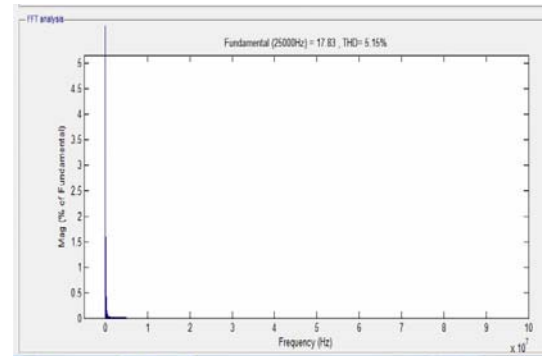Figure 10. PWM, voltage and current of two switch inverter

Figure 11. FFT analysis of four switch inverter

d.   Simulation Specification

Table 1. Specification parameter for new topoplogy

DC input voltage, Vdc	220 V
Switching frequency, fs	25 KHZ
Load resistance, R0	7 ohm
Load inductance, L0	146 Micro Henry
Snubber capacitor,C1	0.02 Micro Farad
Resonant capacitor, Cr1	0.33 Micro Farad
Switched capacitor, Cr2	0.3 Micro Farad

e.   Performance Parameter
The performance parameters are such as voltage stress, conduction loss, switching loss, THD where compared with two switch four switch and six switch series resonant inverter. From this comparison result we conclude that six switch series resonant inverter provides better result compared to other technique.

Table 2. Comparison of series resonant inverter with different topology

Parameters	Two Switch Half Bridge Inverter	Four Switch Half Bridge Inverter	Six Switch Half Bridge Inverter
Voltage stress on each switch	220 V	110 V	73 V
Switching frequency	25 KHZ	25 KHZ	25 KHZ
No of switches	2	4	6
Output current	17.2 A	16.85 A	16.6 A
Output Voltage	462 V	454 V	445 V
Output Power	1.1 KW	1.09 KW	1.03 KW
Percentage of THD	5.15%	4.94 %	4.77 %
Conduction loss	15.76 W	15.12 W	14.61 W
Switching loss	3.074 W	1.505 W	0.98 W

4.   CONCLUSION

In this paper, a new approach based on the series operation of low-voltage MOSFET has been successfully proposed. On the top of that, the decreased switching time of MOSFET devices reduces switching and conduction losses, further increasing the efficiency of conversion and achieved good performances considering the ZVS operation mode of this resonant converter in a profitable way. Finally, a comparative evaluation discussion, we understood that existing system Two Switch-MOSFET break down voltage can be recovered as it to be led to reduce the cooling arrangements and increase the power conversion efficiency.

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