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A Literature Review on Soft Switching DC-AC Converters

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***Abstract*—Soft-switching techniques had gained popularity in recent times because they offer many advantages over hard-switched PWM inverters such as high efficiency, higher power density, less losses better performance. The resonant topologies employing soft-switching are classified based on the location of resonant networks in the inverter with respect to dc link and load. This is an exhaustive study of various resonant link inverter topologies. This literature review brings out merits, limitations besides giving the basic principle of operation of various topologies.**

***Keywords*— Zero-voltage switching, zero-current switching. load resonant, resonant link, resonant transition.**

I. INTRODUCTION

The pulse width-modulated (PWM) dc ac converter or inverters has been the main choice in power electronics for decades, because of its circuit simplicity and rugged control scheme. Typical applications for PWM inverters can be found in Uninterruptible power systems (UPS), motor drives, induction heating, etc. Due to the switching losses and the limitations of semiconductor devices that are currently available, the switching frequency of PWM converters is usually around small kilo hertz when the power rating is tens of kilowatts. However, power density and circuit performance was improved with higher switching frequencies.

The main factors that contribute to the high-frequency switching losses are:

- Semiconductor device have non-zero turn-on and turn-off instsnts and thus there is a finite time during the transitions wherein the devices are conducting a significant current while a large voltage is applied across it. This results in very large energy dissipation. This power loss increases with increasing frequency.
- At high frequencies, large di/dt and dv/dt induce voltage and current oscillations in parasitic capacitors and inductors during switching transitions. These oscillations result in higher peak currents and voltage in the devices and thus the switching loss increases. Furthermore, these oscillations create noise and EMI, which can interfere with surrounding electronic equipment and other parts of the circuits.
- When the device is turned on while having a voltage across it, the energy stored in parasitic capacitance across the switch is dissipated in it. This loss increases with the frequency and is proportional to the square of the voltage across the device before turn-on.

Soft-switching techniques forces the switc voltage or current to zero before the device switching, thus avoiding voltage and current overlap during the switching transition. The advantages of soft switching are as follows:

- Low switching losses due to smaller overlap of switch voltage and current
- Low di/dt and dv/dt and thus lower voltage spike and EMI emission.
- Higher reliability due to reduced stresses in switching components
- Reduced voltage and current ratings of the devices
- Smaller reactive element.

In 1980s, lots of research efforts were done towards the use of resonant converters. The concept was to incorporate resonant tank circuit in the converters to create oscillatory (usually sinusoidal) voltage or current waveforms so that zero voltage switching (ZVS) or zero current switching (ZCS) conditions can be created for the power switches. In these converters, the principle of resonance is used in order to implement the soft-switching technique (ZVS/ZCS) for various devices . These resonant links are embedded in different locations of the inverter circuit depending upon their configurations.

II. TOPOLOGICAL CLASSIFICATION OF SOFT-SWITCHED DC–AC CONVERTERS

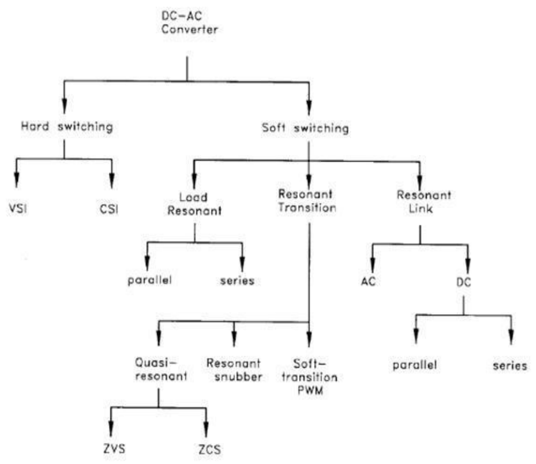

Fig. 1. A classification of the dc–ac converters.

A systematic classification of dc–ac converters is presented in Fig. 1. In general, dc–ac converter topologies can be classified mainly into hard-switching and soft-switching converters, according to their switching characteristics. In the hard-switching dc–ac converters, the power devices are connected either to a stiff current source, as in a current-source inverter (CSI), or to a stiff voltage source, as in voltage -source inverter (VSI).Sudden changes in switch current and voltage waveforms cause severe switching losses and EMI problems [1], [2]. High voltage and/or current peaks can also be observed during switching transients, because of stray inductances around power devices and parasitic capacitances.

In the soft-switched topologies, a high-frequency resonant network is added to the conventional hard-switching topology. The resonant network can be composed of only passive elements L and C and or it also have additional auxiliary diodes or switches. As a result, the switch voltage or current swings and crosses zero points thus, creating the soft-switching conditions for the power devices .Therefore, the switching waveforms are shaped by the resonant network such that the switching losses can be minimized, the switch stresses can be reduced.

Therefore, depending upon the chosen resonant network scheme, different shapes of voltage and current waveforms in the converter can be obtained. In this paper, the classification of soft-switching converter ,is presented in Fig. 1, is based upon the location of the resonant network (load, inverter bridge, and dc bus) in the converter system, switching waveforms characteristic (ZVS or ZCS), and the type of resonance (series or parallel). These can be explained as follows.

1) *Load resonant dc–ac converter*—An *LC* resonant tank is added at the load side in parallel,series or in a combination of series and parallel *LC* scheme. Hence, the ZCS or ZVS condition can be produced for the active switches on the inverter bridge. The dc-bus waveform of the load resonant dc ac converter was unaltered.

2) *Resonant transition dc–ac converter*—A resonant network is added to the inverter bridge, there by creating the ZVS or ZCS condition. The parasitics of the switches can be part of the resonant scheme. The input dc bus is not altered here

3) *Resonant link dc–ac converter*—The resonant network is connected between the input dc source and the inverter bridge thus, the input bus voltage is oscillating in order to create the soft-switching conditions for the power devices. Therefore, the input buses of these resonant link converters systems are different from the conventional PWM system. In the following sections, the basic features of each soft switched converter type will be analysed.

III. LOAD RESONANT DC-AC CONVERTERS

The load resonant dc-ac converters are classified into 2 types; series-loaded resonant (SLR) and parallel-loaded resonant (PLR). Typical circuit of series and parallel resonant half-bridge dc-ac converters are shown in Fig..2. In load resonant dc-ac converters, an LC resonant tank is added to the load side in parallel, or series or in a combination of series and parallel LC scheme.

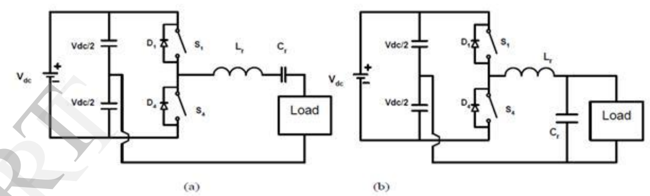

Fig. 2. Series and parallel load resonant dc-ac converters.

The resonant tank will oscillates with a resonant frequency (fr) during the entire switching period (Ts = 1/fs, fs is converter frequency). As a result, the resonant tank produces the oscillating load voltage and current waveforms, which create ZCS or ZVS conditions for the switching device. In

either case i.e., SLR or in PLR, the resonant period will decides the conduction of switching devices. The nature of the current at the output is controlled by the relationship between fs and fr. In case of SLR, it is possible to use thyristors as switches at a low switching frequency, whereas the controllable switches are used for fs which is greater than fr.

LIMITATIONS OF THE LOAD RESONANT DC-AC CONVERTER

- Load resonant converters are ideally suited for constant load power applications.
- Since both the resonant elements and the switching devices be connected in power transfer path ,the switching devices will suffer from high voltage and current stresses
- The size and volume of LC components becomes very larger
- Better voltage regulation is possible by tuning load closer to the resonant frequency
- In order to reduce the output distortions and to achieve a wide range of output voltage, the quality factor (Q) of the resonant tank must be as high.

IV. RESONANT TRANSITION DC AC CONVERTERS

In resonant transition dc ac converters, the input bus voltage (VSI) or current (CSI) was fixed. The soft-switching condition will implemented by resonating the voltage or current of the inverter switches. Ideally, the resonant network should be activated only at the switching transition intervals and should make the resonance circulating energy be as minimum as possible and completely decoupled from the main power transfer to the load. Frequently, the parasitics of the devices could be part of the resonant scheme. However, the resonance energy would be enough to create the soft- switching conditions (ZVS or ZCS), irrespective of the variations in the load. parameters.

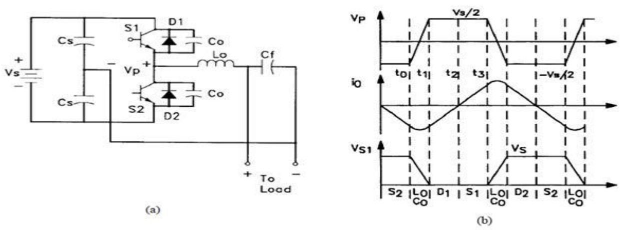

Fig. 3 Resonant transition inverter and waveforms

Also, the resonant network should operates according to the controller commanding signals, which are usually provided by PWM-type controller The inverters which based on the principle of resonant transition technique may be classified

into following 3 categories. (a) Soft-transition PWM inverter (b) Resonant snubber inverter (c) Quasi-Resonant inverter

V. RESONANT LINK DC AC CONVERTERS

The resonant link dc-ac converters shifts the resonant network from the inverter bridge to the dc bus.

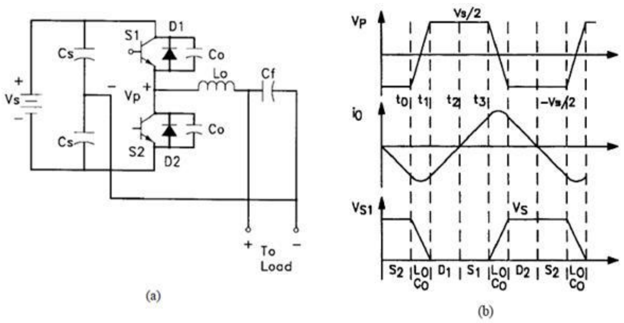

Fig. 4 : Resonant link inverter and waveforms

Depending on the resonant network configuration and the switching scheme, the resonant link dc - ac converters can be divided into 2 types.

1) Resonant ac-link dc ac converter (RACLC) : The link waveform could be either an alternating voltage or alternating current, in order to create ZVS or ZCS conditions for the inverter bridge. Hence, bidirectional switches can be used.

2) Resonant dc-link dc ac converter (RDCLC): The link is a dc- biased oscillating waveform, so that unidirectional switches can be implemented in the inverter bridge and with ZVS or ZCS conditions.

ADVANTAGES OF RDCL

- minimum no: of power devices,
- elimination of snubbers and switching losses
- high switching frequency,
- low acoustic noise,
- excellent transient response and dynamics,
- multiquadrant operation,
- unity PF and low harmonics on ac line side,
- low sensitivity to parasitic impedance and device
- suitable for high power levels with GTO devices,

The resonant dc link concept can also be extended to a multiquadrant three-phase-ac-to-three-phase-ac power converter with low harmonic currents on both the output and the input sides.

VI. SIMULATION

Here a comparison of hard switching inverter with soft switching inverter using MATLAB/SIMULINK is performed. The Table 1 shows the input parameters used to perform the simulations for HSI.

Table .1: Simulation values of hard switching inverter

PARAMETER	VALUE
Input Voltage	115 V
Supply frequency	50Hz
Resistance	10 ohm

Simulations have been performed using the above design to find the impedance network parameters in MATLAB/SIMULINK .The SIMULINK model for Voltage source inverter and soft switching Inverter are modeled from its basic diagrams of Figure 5 and Figure 6. From the basic simulations we can throughly find out the differences in both type of switching.

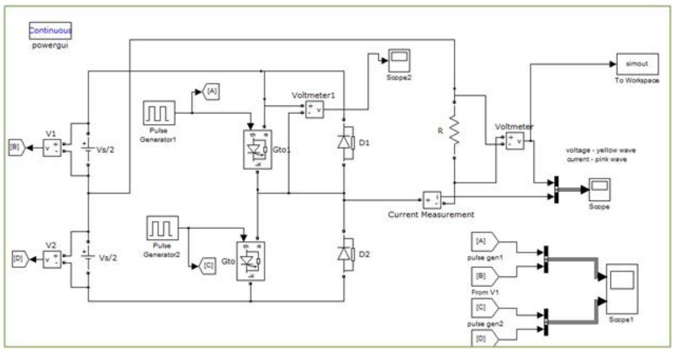

Fig 5 : Simulink model of voltage source inverter

In case of hard switching inverter we take an example of voltage source inverter.In soft switching inverter we take the example of Series Loaded Resonant Converter.

Table 2: Simulation values of soft switching inverter

PARAMETER	VALUE
Input voltage	115V
Supply frequency	50Hz
Resistance	10ohm
Inductor value	.02mH
Capacitor value	.03mF
Carrier frequency	5KHz
Load current	5A

In case of soft switching inverter we are adding L and C into the basic VSI circuit so that these helps in achieving resonance in the circuit and there by we can achieve zero voltage as well as zero current condition

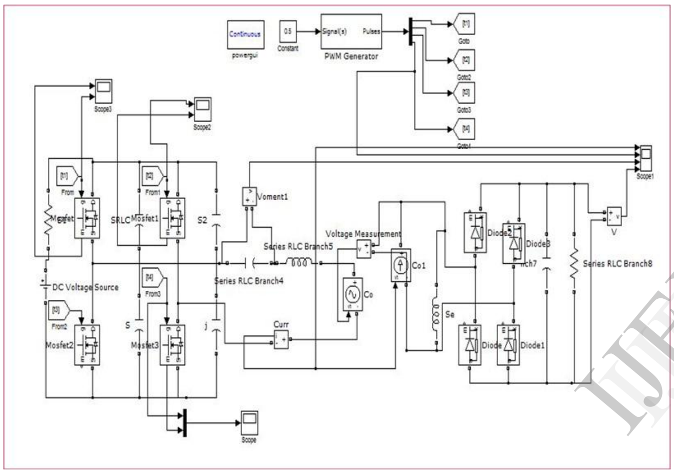

Figure 6 : Simulink model of soft switching Inverter

VII. RESULT ANALYSIS

In hard-switching inverters, higher switching frequency leads to increased switching losses, which consequently increase the size of snubber circuits and heat sinks. In addition, electromagnetic interference increases, and efficiency is decreased . To overcome these problems, applying soft switching techniques is essential . Figure shows the different waveforms that obtained for hard switching and soft switching inverters.

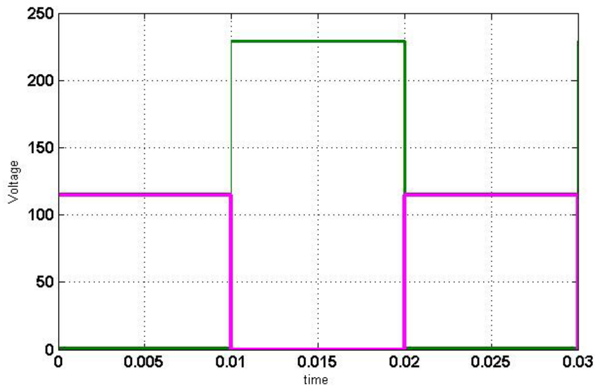

Fig 7: voltage across switch in hard switching

In case of hard switching inverter the supply voltage is 115 V. And in the figure blue line shows voltage and green line shows current. We can observe that the voltage across the switch is nearly equal to 230 V

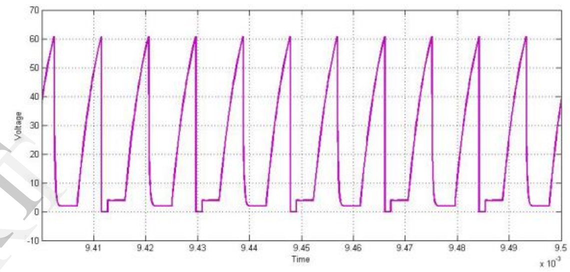

Fig 8; voltage across switch in soft switching

IMPROVING OF TURN-ON PEAK OF INVERTER SWITCH

Figure 7and 8 are voltage waves of main switches under hard switching and soft switching separately. Comparison between them can conclude that with resonant link the turn-on du/dt peak of main switch is improved greatly. The max turn-on du/dt peak of main switch decreases from 230V under hard switching to 60V under soft switching, the decreasing amplitude is beyond 30 percentage. So it can reduce EMI greatly

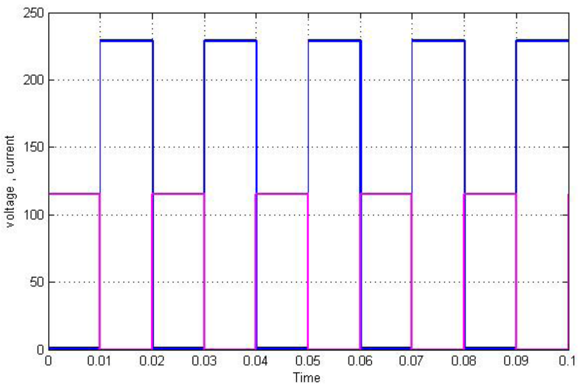

Fig 10: voltage and current across switch at the time of switching

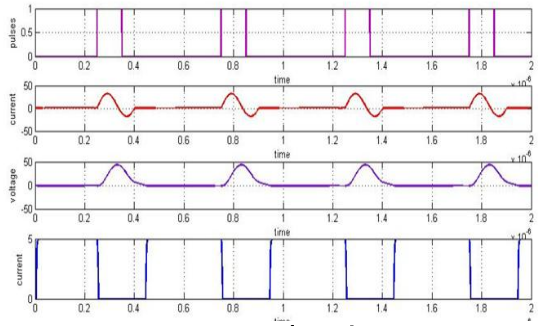

Fig 11 : soft switching

Figure below shows the input current and voltage wave forms of hard switching inverter .we can observe that at the time of switching the voltage and current will be in its peak level. Here power loss will be more. In case of soft switching inverter the switches will be turn on or turn off in zero voltage or zero current.

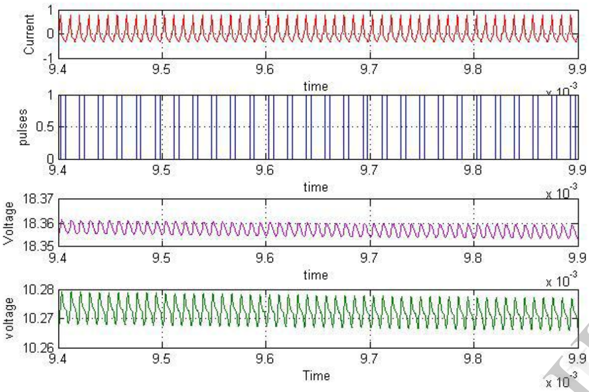

Fig 12: current through Lr, voltage across Cr in softswitching

When we increase the frequency of hard switching inverter to 10 KHz the wave forms are as shown below

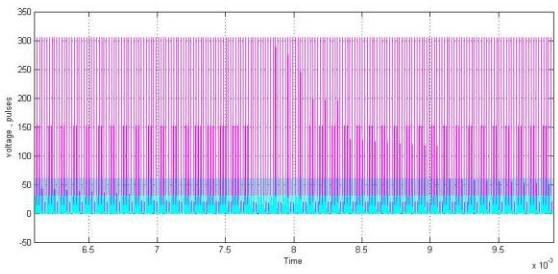

Fig 13 voltage and current across the switch (10KHz)

VIII. COMPARISON

Table 3:comparison of hard switching and soft switching

	HARD SWITCHING	SOFT SWITCHING
Switching loses	Severe	Almost zero
Overall efficiency	norm	Possibly higher
Heat sinking requirement	norm	Possibly lower
Hardware count	norm	Less
Overall power density	norm	Possibly higher
EMI problem	severe	Low
dv/dt problem	severe	Low
Modulation scheme	versatile	Limited
Maturity	Mature	developing
Cost	Norm	higher

CONCLUSION

In this paper, a systematic overview and generic classification of different soft-switched converters for dc–ac power conversion have been presented. The basic principles of each topology were shown, and some applications were also be addressed. The benefit of reducing the switching losses and increasing the power density can be achieved. However, in some of the topologies, drawbacks such as switch stresses and control complexities may occur, which can make them difficult for immediate commercial utilization. Nevertheless, in these cases, many modified topologies have been proposed, in order to overcome these drawbacks and improve the system performances.

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