Performance Evaluations of Quasi Resonant DC Link Assisted Three Phase Soft Switching Inverter for AC Servo Motor Drive

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Abstract: **This paper presents a circuit of the quasi-resonant DC link to achieve soft-switching three phase inverter using intelligent IGBT power module. The soft-switching operation in this circuit is confirmed simulation and experimental results. Its conductive noise is measured for electrical AC motor drive as compared with that of the conventional hard switching inverter.**

Index Terms: **Soft switching, Active auxiliary quasi-resonant DC link snubber, EMI/RFI evaluations**

I. INTRODUCTION

In recent years, with the development of power conversion circuit topologies, using MOS gate controlled power semiconductor devices; MOSFETs and IGBTs, the increase in the switching frequency of the inverter becomes indispensable in order to improve its controllability, to reduce undesired acoustic sound, and to downsize the equipment. However, in conventional hard switching inverters, switching power losses of power semiconductor devices as well as EMI noise levels become larger. Moreover, in the inverter or converter which is applied to the variable speed AC motor or servo drives, the new problems are breaking out due to the high dv/dt such as the high-frequency leak current which flows into the ground line through the stray capacitance between the stator windings and the frame of the motor, the motor shaft voltage and the bearing current. On this account, the inverter AC servo drive installations with the high speed power semiconductor devices such as IGBT, MOSFET etc. tend to have these problems more and more obviously.

As a solution for these problems, the soft switching power conversion circuit techniques which turn on and off all the power semiconductor devices in the switching mode semiconductor power conversion systems under the zero voltage or zero current mode transitions using the active auxiliary quasi-resonant snubber, and its related control techniques are indispensable.

This paper deals with the three-phase soft switching inverter using the quasi-resonant DC link snubber for the AC servo motor drive. And presents the evaluations for the soft switching of the quasi-resonant snubber circuit. The conductive noise of the three phase voltage-fed inverter using this quasi-resonant snubber is measured for AC servo motor drive, and evaluated as compared with that of the conventional hard switching three-phase inverter.

II. CIRCUIT TOPOLOGY AND OPERATING PRICIPLE

The system configuration of the AC servo motor drive control system using quasi-resonant DC link snubber assisted three phase voltage soft switching inverter is described in Fig.1. The stator windings of the PM motor play as the low pass filter of the three phase voltage-fed inverter.

The soft switching operation of inverter is based on the loss-less capacitors using LC quasi-resonant phenomenon. Using this effect, the DC busline voltage across the quasi-resonant capacitor C_r which is connected in parallel to the inverter switch is brought down to the zero voltage, and then, ZVS/ZCS turn on and ZVS turn off in the main active power switches of the voltage-fed inverter bridge arm are able to be achieved. This circuit topology is composed with the switch S_{c1} of the circuit in order to clamp the DC busline at the DC voltage source V_s, the

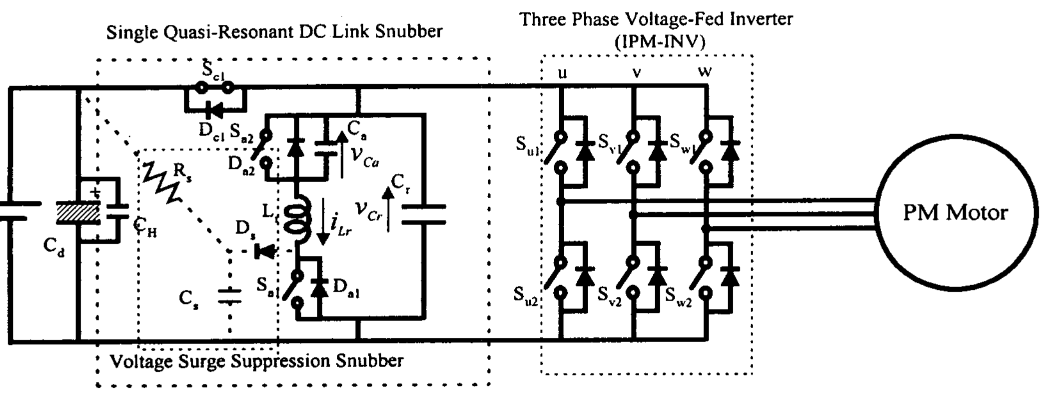


Fig.1. Auxiliary quasi-resonant dc link snubber-assisted soft switching inverter for AC servo motor drive system.

auxiliary switches S_{a1} and S_{a2} for transfering resonant mode, the resonant capacitor C_r connected in parallel to the inverter switch S_{INV}, the resonant capacitor C_a connected in parallel to the switch S_{a2}, and the quasi-resonant inductor L_r. The U-phase arm equivalent circuit as shown in Fig.2 is used in order to explain the operation mode of the auxiliary active quasi-resonant DC link single snubber circuit. Each operation mode is represented in Fig.3.

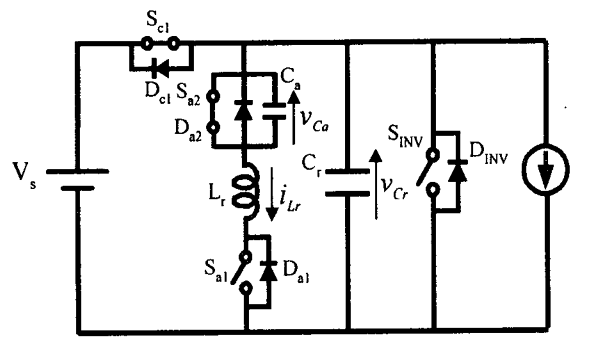


Fig.2. equivalent circuit of auxiliary quasi-resonant dc link snubber circuit.

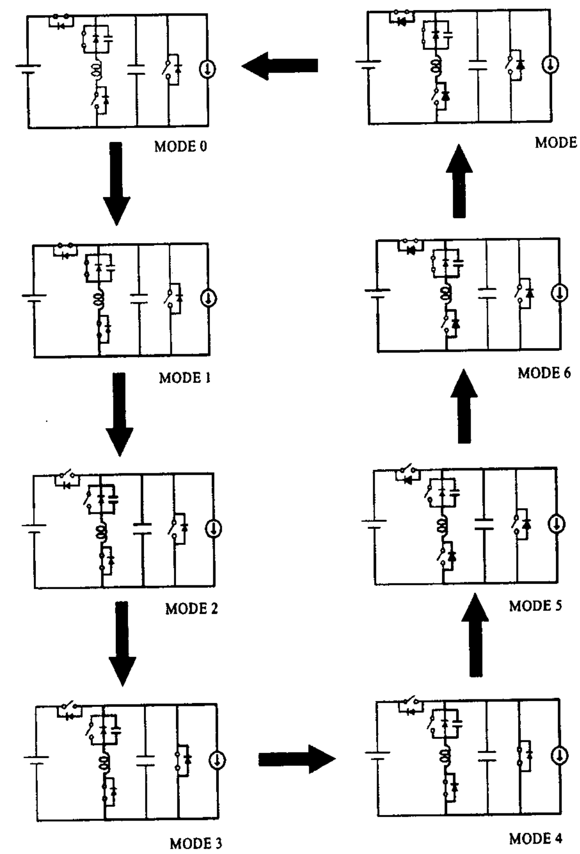


Fig.3. Soft switching mode transitions and its equivalent circuits.

Mode 0

The voltage clamp switch S_{c1} and the auxiliary switch S_{a2} are both on state and the load current is flowing.

Mode 1

When the switching signal of the inverter main switches comes, S_{a1} is turned on at the ZCS condition. And then, the quasi-resonant inductor current i_{Lr} is boosted enough to pull down the main quasi-resonant capacitor voltage to zero volt.

Mode 2

When the quasi-resonant inductor current i_{Lr} reaches to the first quasi-resonant initial current I_{boost1}, S_{c1} and S_{a2} are both turned off at ZVS condition, and the quasi-resonance with L_r, C_r and C_a starts.

Mode 3

When the main capacitor voltage v_{cr} is pulled down to the zero voltage, the diode which is connected to the main switch S_{INV} is conducted and then S_{INV} is turned on at ZVS/ZCS condition.

Mode 4

The quasi-resonant inductor current i_{Lr} begins to increase to the negative direction and it is boosted enough to boost the main capacitor voltage to the DC voltage source voltage V_s. The auxiliary switch S_{a1} is turned off at ZVS/ZCS condition during this period.

Mode 5

When the quasi-resonant inductor current i_{Lr} reaches to the second quasi-resonant initial current I_{boost2}, S_{INV} is turned off at ZVS condition, and the quasi-resonance with L_r, C_r and C_a starts.

Mode 6

When the main quasi-resonant capacitor voltage v_{cr} reaches to the DC voltage source voltage V_s, the diode D_{c1} which is connected to the voltage clamp switch in back-to-back conducts. $S_{c1}$and S_{a2} are both turned on at the ZVS/ZCS condition while the diode D_{c1} is conducts.

Mode 7

The quasi-resonant inductor current flows through D_{c1} and regenerated to the DC voltage source V_s.

The switching patterns of each power semiconductor device and the voltage and current waveforms of the quasi-resonant snubber circuit are illustrated in Fig.4.

Ⅲ. EXPERIMENTAL EVALUATIONS

The configuration of the experimental system and the specification of the experimental system are shown in Fig.5 and table 1, respectively. In this system, the operation of the auxiliary active quasi-resonant DC link snubber three phase voltage-fed inverter is confirmed, and the conductive noise of the system is measured.

In this experiment, since IPM (PM50RSA060) is used for the inverter main switches, the on time and off time both have about 2 μsec delay. As a result, the switching timing of the main circuit is delayed if the switching pattern indicated in Fig.4 is applied. Therefore, the first quasi-resonant start signal is used as a trigger signal and the switching timing of the main switches are decided by 74LS123. In terms of the motor control, the current loop and the speed loop are not configured yet, and the vector control is carried out setting the d-axis voltage reference at zero and the q-axis voltage reference as a constant value.

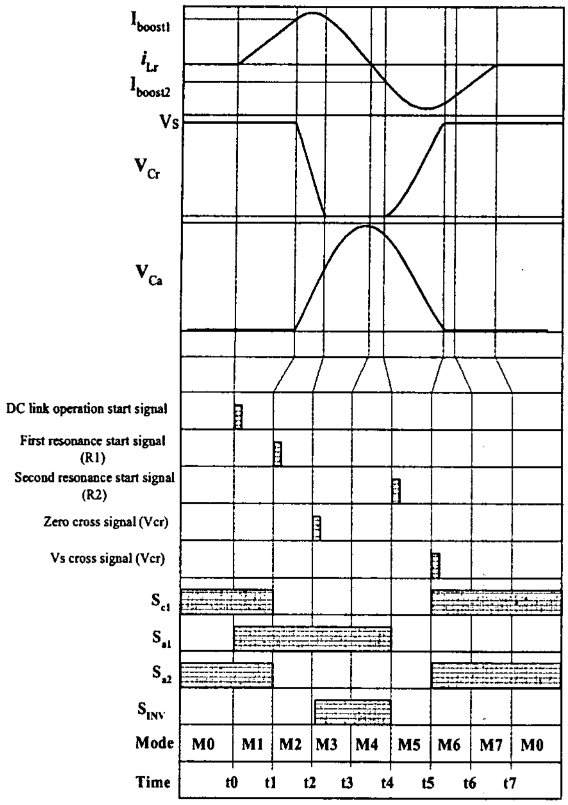


Fig.4. Switching patterns and the operation waveforms of the quasi-resonant dc link snubber.

TABLE 1 EXPERIMENTAL SPECIFICATIONS

DC power source voltage		V_s	280[V]
Auxiliary resonant snubber circuit	Main resonant capacitor	C_r	10[nF]
	Auxiliary resonant capacitor	C_a	10[nF]
	Resonant inductor	L_r	101[μH]
	Power switching devices (IGBT: CM75DY-12H)	S_c, S_{a1}, S_{a2}	Maximum rate I_c=75[A], V_{CES}=600[V]
Voltage serge suppression snubber	Voltage clamp capacitor	C_s	0.22[mF]
	Snubber diode	D_s	USR30P12
	Snubber registance	R_s	20[Ω]
PM motor (BM0230 by Shinko Electric Co., Ltd, Japan)	Leakage inductance	L_{load}	10[mH]
	Stator registance	R_{load}	7.5[Ω]
	Number of magnetic pole	P	8
	Rated current	I_{max}	1.4[Arms]
Main circuit	Power switching devices (IPM: PM50RSA060)	S_{u1}~S_{w2}	Maximum rate I_c=50[A], V_{CES}=600[V]
Sampling frequency		T_s	10[kHz]

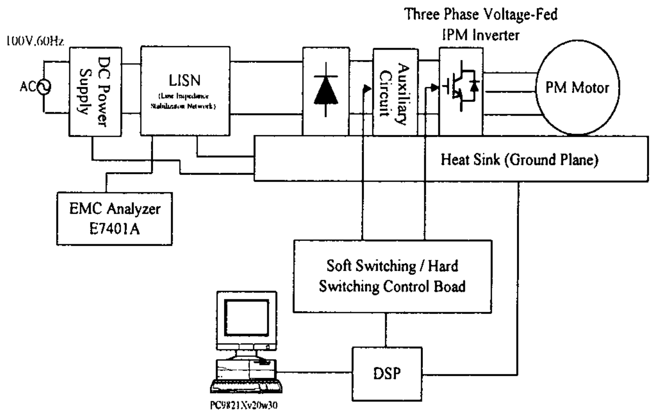


Fig.6. Conductive noise measurement configuration.

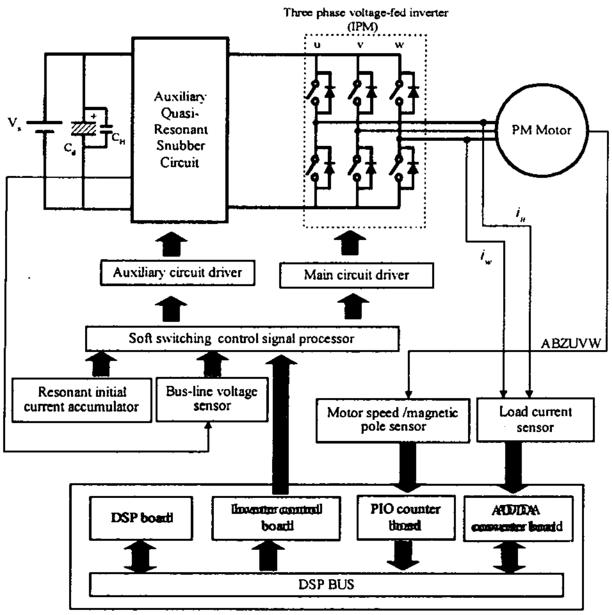


Fig.5. Experimental setup system.

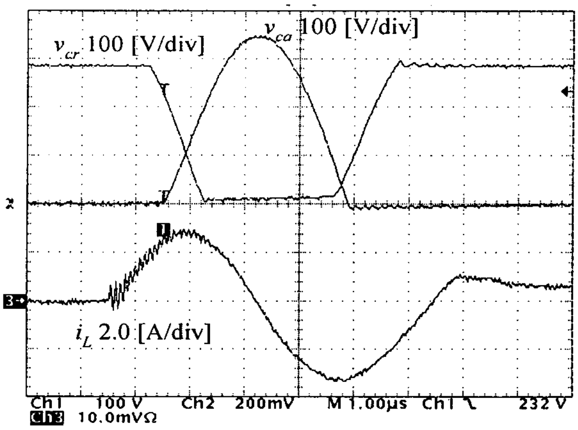
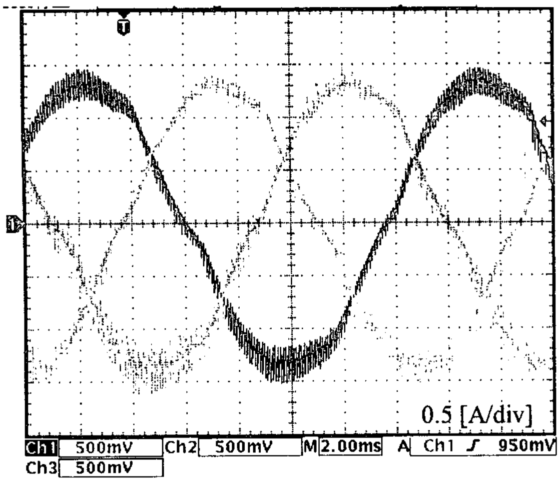


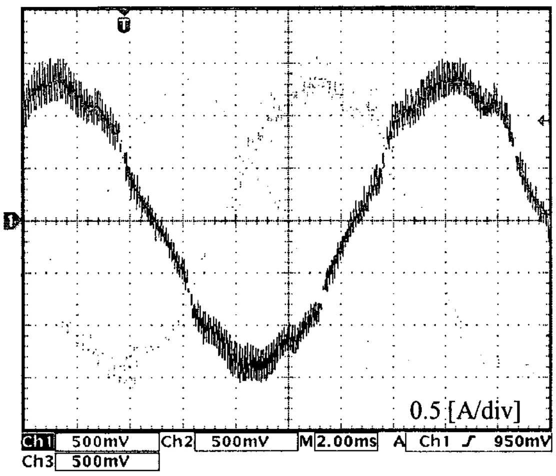
Fig.7. Operation waveforms of quasi-resonant dc link snubber circuit.

For the conductive noise measurement, the soft switching and the hard switching are compared under the condition of the same peak load current value.

Additionally, for the conductive noise measurement, the line impedance stabilization network (LISN) and the EMC analyzer are used as illustrated in Figure 6.



(a) Hard Switching



(b) Soft Switching

Fig.8. Three-phase load current.

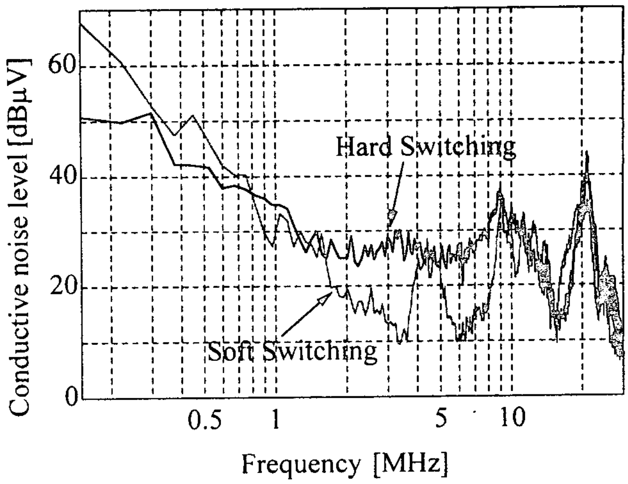


Fig.9. Conductive noise measurements (Normal Mode).

In the experimental system, the operation of the auxiliary active resonant DC link snubber three phase voltage-fed inverter is confirmed, and the conductive noise of the system is measured. Figure.7 indicates the operation waveorms of the active auxiliary resonant snubber circuit. According to this figure, the voltage of the main quasi-resonant capacitor which is connected in parallel to the inverter main switches is pulled down to the zero voltage and pulled up to the DC bus-line voltage V_s, and all the main switches in the inverter achieved the zero voltage soft switching (ZVS) during this DC bus-line notch mode period. Figure.8 indicates the U-phase load current wave.

The conductive noise measurement result is shown in Fig.9. In order to compare the soft switching with hard switching, the noise measurement is carried out under the peak load current at 0.8A. The frequency band of the measurement ranges from 150kHz to 30MHz. This soft switching inverter reduced the conductive noise level compared with the hard switching inverter under the frequency band between 1.6MHz and 4MHz, and 5MHz and 9MHz. In this case, 20dB of the noise level can be reduced at most. On the other hand, under the band width of 8MHz, this soft switching inverter increased the noise level compared to the hard switching inverter. Therefore, the additional improvement is required for this inverter.

Ⅳ. CONCLUSIONS

A circuit topology of the auxiliary active quasi-resonant DC link snubber was introduced as a snubber of the soft switching three phase inverter for small scale PM motor drive systems, and its operation modes and the experimental results were described from a practical point of view. The operation of the auxiliary active resonant snubber assisted three phase voltage-fed soft switching inverter was confirmed and the conductive noise measurement was carried out in the PM motor drive. As a result, the possibility of the electro-magnetic noise reduction by the soft switching has been verified.

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