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Resonant Snubber Based Soft-Switching Inverters for Electric Propulsion Drives

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Abstract-This paper summarizes recently developed soft-switching inverters and proposes two alternative options for electric propulsion drives. The newly developed soft-switching inverter employs an auxiliary switch and a resonant inductor per phase to produce a zero voltage across the main switch so that the main switch can turn on at the zero-voltage condition. Both the auxiliary switch and the resonant inductor are operating at a fractional duty, and thus are small in size as compared to the main inverter circuit components. Operation modes in a complete zero-voltage switching cycle for the single-phase soft-switching inverter are described in detail with graphical explanations. The circuit operation was first verified by a computer simulation and then tested with an 1-kW single-phase and an 100-kW three-phase inverters. Experimental results are presented to show the superior performance in efficiency improvement, EMI reduction, and d*v*/d*t* reduction of the proposed soft-switching inverters.

I. Introduction

Being a contender against the traditional internal combustion engine (ICE), the electric propulsion drive must demonstrate its superiority in cost-effectiveness, efficiency, power density, reliability, and robustness. The drive should be compatible with other vehicle components. In other words, the operation of the ICE in a hybrid electric vehicle should not upset the electric propulsion drive, and the electric propulsion drive should also avoid any interference such as acoustic noise and electromagnetic interference (EMI) with other vehicle components.

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It is reasonable to set some power electronics performance targets for electric propulsion drives [1], e.g.,

- efficiency: >98% peak and >80% at 10% speed,
- cost: <$10/kW,
- power density: >100kW/ft^3,
- dv/dt: <1000V/μs,
- switching frequency: >20kHz,
- reliability: no failure before the end of the vehicle life,
- EMI: zero emission and no interference, and
- robustness: redundant with limp home mode.

These performance targets are very ambitious with today's technology status. In order to achieve these targets, one may exploit advancement of one or more of the following technical areas:

- inverter circuit topology: new cost-effective and highly efficient soft-switching inverters,
- device: lower voltage drop, less switching loss and higher power density MOS gate turn-off devices, ultra fast reverse recovery diodes, and high-frequency, high-temperature rated super capacitors,
- layout and packaging: minimum loop inductance along the dc bus and the device path, innovative cooling design, and standardization of packaging, and
- circuit integration: integrated circuits for gate drives, protection circuitry and controllers, sharing resources with the under-developed power electronics building block (PEBB) [2].

The inverter topology needs to be addressed first because devices and components are built around it. According to the efficiency analysis in [3], the traditional hard switching inverter will not meet the performance targets even with the improved devices because of switching loss and dv/dt induced problems. Several soft-switching inverters have been proposed in the past, and some of them have the potential of achieving high efficiency operation over a wide speed range [3]. These new soft-switching inverters have emerged as a new family of power converters for electric propulsion drives. Early concepts of using thyristor based series resonant link current source converters were replaced by gate-turn-off device based parallel resonant link voltage source converters [4~8] in late 1980s. Moving from current source to voltage source makes sense for battery-powered systems. However, the resonant dc link inverters present some fundamental problems such as over-voltage penalty in main switching devices and a highly dissipative resonant inductor.

A new set of resonant snubber based inverters (RSIs) [9~14] were then proposed to overcome the fundamental drawback to the resonant dc link based inverters. These RSIs already demonstrate their potential in high-power electric propulsion applications. Two RSI circuit topologies are being proposed in this paper. Their operating principle will be discussed in detail. The limitations of these new RSIs will also be addressed.

II. WHY SOFT SWITCHING?

Traditional hard-switching inverters presented several problems during switching. Fig. 1(a) illustrates the device voltage, current and power during switching. During turn-on, the device current rises from zero to the load current with additional diode reverse recovery and stray capacitor charging and discharging currents on top of the load current. Typically, a current spike will occur, and the peak device power consumption is extremely high.

During turn-off, the device voltage rises. Due to the leakage inductance in the loop, a voltage overshoot caused by Ldi/dt will occur, and the device voltage will exceed the dc bus voltage. This voltage overshoot can be reduced by a good circuit layout and high frequency dc bus capacitors. The turn-off loss varies among different types of devices depending upon the turn-off delay and current fall time. The power MOSFET consumes least turn-off loss. The insulated gate bipolar transistor (IGBT) turn-off loss also varies among different manufacturing processes and its associated minority carrier lifetime killing [15]. Some ultrafast IGBTs may have low turn-off loss close to that of power MOSFETs. The bipolar junction transistors (BJTs), in general, have a long turn-off delay time and consequently, high switching losses.

Another switching problem is the voltage rise and fall rate, dv/dt. During turn-on, the voltage falls to zero when the opposite switch turns on. During turn-off, the voltage rises to the dc bus voltage with an overshoot. Typical switching dv/dt is higher than 2000V/μs. With a small gate drive resistor, this dv/dt can be higher than 5000V/μs. Consider a machine winding stray capacitance, typically between 2 and 10 nF, a value measured with off-the-shelf electric machines in our laboratory. The common mode leakage current due to dv/dt and capacitance coupling can be as high as 50A.

Paralleling a capacitor across the device will significantly reduce the turn-off loss and turn-off dv/dt, but on the other hand largely increase the turn-on loss. Fig. 1(b) explains the device turn-on with capacitors across the devices. For an initial condition that the load current is flowing in diode D3, when S1 is turned on, it needs to turn off diode D3, and the energy stored in capacitor C_{r1} will be discharged to

S1 with a near-zero resistance path. When diode D3 is turned off, capacitor C_{r3} will be charged to the dc link voltage through the main switch S1, also with a near-zero resistance path. The diode reverse recovery, capacitor charge, and capacitor discharge currents are typically much larger than the load current which causes large turn-on losses. The waveforms shown in Fig. 1(b) indicate that the peak device turn-on current can be as high as or higher than 20 times the load current for the slow reverse recovery diode case.

The hard-switching turn-on current in the main switch S1 can be formulated in (1) where current $I_{D3(rr)}$ is the reverse recovery current of the free-wheeling diode, D3.

$$I_{S1} = I_{Load} + I_{D3(rr)} + I_{Cr1} + I_{Cr3} \quad (1)$$

The result of such high turn-on current is an excessive turn-on loss and switching noise. The situation can be worse when using a standard power MOSFET as the main switch.

After observing so many problems with the hard-switching inverter, the use of soft-switching inverter is a logical choice to serve the following purposes:

1) Eliminate switching losses
   - Improve efficiency
   - Better utilize devices
   - Reduce heat sink size and cooling requirement
2) Reduce switching d*v*/d*t*
   - Avoid capacitance coupling currents between windings
   - Avoid induced currents through bearings
   - Eliminate switching associated EMI
3) Allow high frequency switching
   - Avoid acoustic noise
   - Reduce torque and current ripple
   - Respond faster

III. Overview of State-of-the-Art Soft-Switching Inverters

The resonant dc link (RDCL) inverter family has been around for a decade. The basic RDCL inverter is to employ a resonant inductor-capacitor circuit between the dc source and the inverter bridge to supply a resonating voltage across the inverter bridge [4]. The peak resonating voltage is twice the supply voltage under no load condition and more than three times the supply voltage under the transition from the full motoring mode to the full regeneration mode. This over-voltage can be clamped to 1.3 to 1.4 times the supply voltage [5], but the added components will result in cost and reliability penalties. Several improved versions have been proposed to overcome the fundamental drawback to the ordinary resonant dc link inverter [6~8], but they are all suffered from over-voltage and reliability problems.

To avoid the over-voltage problem, several resonant snubber based soft-switching inverter circuits have been proposed [9~14]. The basic concept of the RSI is to utilize the resonant capacitor across the device to achieve zero turn-off loss and the resonant inductor along with an auxiliary switch to achieve zero-voltage turn-on. The auxiliary switch does not turn on until the main switches require a transition from one state to another state. When the auxiliary switch turns on, a resonant pulse diverts the current from upper or lower switch to its opposite side diode, thus allowing the main switch to turn on at zero voltage. The auxiliary switch is then turned off when the current swings back to zero.

Among these soft-switching inverters, the resonant snubber based inverter described in [9,10] is considered as the ordinary resonant snubber based inverter or called "auxiliary resonant commutated pole" (ARCP) inverter. The ARCP inverter uses the traditional inverter bridge as the base circuit but adds a set of bi-directionally controlled switches for each phase to generate resonance. The required size of the auxiliary switch is only a fraction of the main switch, and the main switches do not have over-voltage or over-current problems. Individual phases can also be modulated independently, avoiding possible subharmonic problems. However, a voltage unbalance problem occurs between the split dc bus capacitors of ARCP inverter. especially at low speed operation.

A simplified resonant snubber version, also known as "resonant transition inverter" (RTI), using only one auxiliary switch has been proposed in boost rectifier application [11,12]. The RTI can also be used in motor drives. However, it presents some problems such as requirement of three resonant branches resonated simultaneously, six ultra fast recovery diodes to block reverse recovery currents introduced in the resonant circuit, and voltage clamping devices to avoid over-voltage across the resonant switch. Because the resonance relies on the auxiliary branch with at least one upper switch and one lower main switch turn-on, the RTI is difficult to operate when it runs into zero state (meaning upper three or lower three switches on simultaneously). Another problem is the high current stress in the auxiliary switch due to its high switching duty. The current stress in the auxiliary switch and simultaneous three-phase transitions may prevent this circuit from high-power applications.

IV. CIRCUIT OPERATION OF THE PROPOSED RSIs

Two versions of the resonant snubber inverters, Y-configured and Δ-configured, are being proposed as the options to the electric propulsion drives. Figs. 2(a) and 2(b) show the Y- and Δ-configured RSIs, respectively. Each phase leg has an added resonant branch consisting a switch-diode pair and a resonant inductor. The topology requires one additional auxiliary switch for each phase, but the size of the auxiliary switch can be much smaller than that of the main switches because of low duty cycle. Depending on the switching frequency and the inductor design, typical size of the auxiliary switch is less than one-tenth of the main switch.

The operation of the resonant snubber inverter is to produce a zero voltage across the device using the resonant branch including an auxiliary switch, a resonant inductor, and the stray capacitance of the device. Using Fig. 2(a) as the example, if the phase-**a** load current is flowing through D4, D3 and D5 which are anti-paralleled with S4, S3 and S5, in order to turn on switch S1 at the zero voltage, we can turn on Sb and Sc to create a current path through S3//S5, $L_b//L_c$, Sb//Sc, Sa, L_a, and S4. The supply voltage is now fully charging to this current path, and the inductor current is linearly increased. When the current in inductor L_a is higher than the load current in phase **a**, we can then turn S4, S3 and S5 off to form a resonance that charges and discharges stray capacitors C_1~C_6. After resonance, the voltage across C_1 tends to be negative which will be clamped to zero by the anti-paralleled diode D_1, and S1 can then be switched at zero voltage condition. The same procedure can also be applied to other phases and switches.

These two proposed RSIs are most suitable for three-phase brushless dc motors because such motors operate like a single-phase machine between each commutation period. For Δ-configured circuit, the auxiliary branches can be combined to form different directional resonant currents. Using the branch between **a** and **b** as an example, to conduct the resonant current from **a** to **b**, we can simply turn on Sa. However, to conduct the resonant current from **b** to **a**, we need to turn on Sb and Sc. Although the operation is not symmetrical, the zero-voltage switching can be achieved by a proper timing control.

Both Y-configured and Δ-configured RSIs share the same structure in the single-phase version. The Y-configured single-phase RSI has two auxiliary switches in series, while the Δ-configured single-phase RSI has two auxiliary switches in parallel. Fig. 3 is the Y-configured single-phase RSI circuit. For the Δ-configured version, we can simply connect the two auxiliary switches in anti-parallel and reduce the two inductors to one. The circuit in Fig. 3 consists of four main switches, S1, S2, S3 and S4, and their corresponding anti-paralleled diodes D1, D2, D3 and D4. The resonant snubber branch consists of two resonant inductors, L_{r1} and L_{r2}, two auxiliary switches with anti-paralleled diodes, S_{r1} and S_{r2}, and resonant capacitors, C_{r1}, C_{r2}, C_{r3} and C_{r4}. The resonant capacitors can be externally added or internal stray capacitors. These capacitors allow the main devices to turn off at the lossless condition. However, the lossless turn-on requires activation of resonant switches, S_{r1} and S_{r2}. The inverter output is a resistor-inductor load, i.e., R_o and L_o.

The operation of the single-phase inverter can be better understood because less components are involved. Notice that the arrow signs in Fig. 3 indicate the nominal current directions, not the initial conditions. For an initially positive load current, turning off S1 and S4 will divert the load current to D2 and D3, and thus S2 and S3 can be turned on at the zero voltage without the need of auxiliary resonant circuit operation. However, turning on S1 and S4 will need to turn off D2 and D3, causing a large reverse recovery current spike. An auxiliary resonant stage is thus needed to avoid non-zero voltage switching.

The step-by-step zero-voltage operating modes for turning on S1 and S4 at the positive initial load current condition can be illustrated in Fig. 4(a). Fig. 4(b) shows the corresponding waveforms at different operating modes for a transition cycle. The following description along with Fig. 4 illustrates detailed operation of a zero-voltage switching single-phase inverter at the positive load current condition.

Mode 0 ($t_0 \sim t_1$): This is the initial condition that a positive load current is free-wheeling through D2 and D3 while S2 and S3 remain on.

Mode 1 ($t_1 \sim t_2$): At t_1, turn on the resonant switch S_{r2}. The resonant inductor current, I_{Lr2}, is built up linearly. The current in switches S2 and S3 gradually reduces to zero at t_2 when the resonant inductor current equals the load current.

Mode 2 ($t_2 \sim t_3$): The inductor current exceeds the load current at t_2, and devices S2 and S3 can be turned off after t_2. Capacitors C_{r2} and C_{r3} serve as lossless snubbers to allow zero voltage turn-off and to slow down the voltage rise rate (dv/dt).

Mode 3 ($t_3 \sim t_4$): The resonant capacitors conduct at time t_3 after turning off devices S2 and S3; capacitors C_{r2} and C_{r3} are charged to the full dc link voltage, V_s; and C_{r1} and C_{r4} are discharged to zero voltage at t_4.

Mode 4 ($t_4 \sim t_5$): The resonant current starts decreasing, and the load current is diverted to diodes D1 and D4. Switches S1 and S4 can now be turned on at zero voltage. At time t_5, the resonant current equals the load current, and the diode current is diverted to the switch.

Mode 5 ($t_5 \sim t_6$): The resonant current keeps decreasing, and the resonant switch current is decreased linearly. At time t_6, the resonant current drops to zero, and the current in the resonant switch S_{r2} returns to zero.

V. HARDWARE IMPLEMENTATION AND EXPERIMENTAL RESULTS

A. Single-Phase Unit

A single-phase 1-kW resonant snubber inverter was built and tested with an electric fan as the load to prove the concept. The inverter main switches are controlled by a standard sinusoidal PWM method. The magnitude of the sinusoidal wave needs to be proportional to its frequency (constant V/f) for the fan speed control. In a traditional hard-switching PWM, the PWM signal turns off one pair of diagonal switches first and turns on the opposite side switches after a short dead time to avoid shoot-through. In the proposed soft-switching inverter, the PWM signal turns on the auxiliary switch first. After a short delay (less than 1.5 μs), the main switches will then follow with the standard PWM switching sequence in a traditional hard-switching inverter. The small time delay is to charge the resonant inductor with a sufficient amount of energy to discharge the capacitor voltage to zero. Because the timing control is effective to achieve zero-voltage switching, it is not necessary to have the voltage or current sensors in the auxiliary branches. The resonant circuit implementation is essentially simple and low cost.

For comparison purposes, the inverter was implemented with both hard- and soft-switching functions in a programmable logic device. The control logic has the option of running in the hard-switching mode simply by disabling the auxiliary switch. Fig. 5(a) shows the oscillograms which compare the different experimental load current results obtained for hard- and soft-switching inverters. Apparently high frequency EMI is greatly reduced by the proposed soft-switching method.

Fig. 5(b) illustrates the main switch device turn-on and turn-off characteristics under hard- and soft-switching condition. For hard-switching, the turn-off dv/dt is initially controlled by the capacitor across the device but rises sharply with a dv/dt higher than 1500 V/μs when the opposite-side device turns on. For soft-switching, the drain-source voltage, V_{ds}, dv/dt is completely controlled by the capacitor and is approximately 220 V/μs. This indicates that the turn-off dv/dt is manageable by the added external capacitors. Instead of being determined by the device turn-off characteristics, the magnitude of dv/dt is now determined by $I_o/(2C_r)$ where I_o is the device turn-off current and C_r is the resonant capacitor across each device. The soft-switching turn-on dv/dt rate is similar to its turn-off counterpart except that the direction is different.

Besides the reduction of d*v*/d*t* and EMI problems, the experimental results also showed major improvement of the inverter efficiency. The inverter efficiency was evaluated with the inverter input measured by a dc volt meter and a dc ampere meter and the output measured by a 30-kHz bandwidth digital power meter. Fig. 6 shows the efficiency comparison of the inverter operating at hard- and soft-switching modes over the tested speed range (from 30 Hz to 70 Hz). The rated frequency for this electric fan motor is 60 Hz. The efficiency improvement at the half-speed is about 16%, and at the rated speed is about 6%. The efficiency advantage of the soft-switching at speeds higher than the rated speed is gradually diminished because the inverter operation is in the transition from PWM to square-wave mode. Energy savings at low speeds are apparently more significant than savings at high speeds because the switching losses are relatively higher at low speeds. This result confirms the findings in [3]. In fact, the low speed efficiency of the soft-switching inverter can be further improved with variable timing control to vary the charging time of the resonant inductor, which can make a major efficiency improvement over a wide load range for a high-power system.

The efficiency of hard- and soft-switching inverters can be predicted with mathematical models [3] and [16]. Dash lines in Fig. 6 show the predicted efficiency results which indicate that the models developed in [3] and [16] reasonably predict the inverter efficiency over a wide speed range.

B. Three-Phase Unit

Using the circuit shown in Fig. 2, two three-phase 100-kW inverters have been constructed and tested with inductive loads. The inverters are rated 320-V, 330-A, suitable for electric propulsion drive applications. Major inverter circuit components are listed below.

Main Devices	Two single IGBT modules: 1MBI600LP-600 and 1MBI600LN-600 (600V, 600A) in series for each phase-leg
Auxiliary Devices	IRGPC50FD2 (600 V, 39 A)
Inductor:	2.2 μH (6×#16 twisted wire with magnetic shield)
Capacitor:	0.27 μF (Polypropylene)

Fig. 7 shows the photograph of the 100-kW inverter packaged in a notebook size. A 14-layer printed circuit board (serving as a high-frequency capacitor) holds the dc bus capacitors and is mounted on top of the main devices to reduce the parasitic inductance. The gate drives are mounted directly on top of the main devices, and the control circuitry (not shown) will be stacked on top of the dc bus capacitors. The size of the auxiliary device is only a fraction of the main device. As compared to the traditional passive snubber (diode-capacitor-big resistor), the resonant snubber (switch- capacitor-small inductor) dramatically reduces the physical size.

Before being configured into the soft-switching mode, the unit was tested in the hard-switching mode with dc bus capacitors (3000-µF electrolytic plus 54-µF polypropylene) as snubbers, and the resonant capacitors were disconnected . The resulting device turn-off voltage and load current waveforms are shown in Fig. 8(a). At 250-V dc input voltage and 120-A load current, I_{Load}, the device (S4) collector-emitter voltage, $V_{ce\text{-}S4}$, presents a high switching dv/dt of approximately 3000 V/µs and a 10% voltage overshoot. After reconfiguring into the soft-switching mode, the unit was tested at 300-V dc bus voltage. The electrolytic capacitors were reduced to 1760 µF. Experimental load current, I_{Load}, resonant current, I_{La}, and two device voltages, $V_{ce\text{-}S4}$ and $V_{ce\text{-}S6}$, waveforms are shown in Fig. 8(b). For a turn-off current of 60 A, the device turn-off dv/dt is about 300 V/µs and the voltage overshoot is negligible. This result proves that the resonant snubber based soft-switching inverter alleviates several problems experienced in the traditional hard-switching inverters.

Fig. 9 compares hard- and soft-switching input current, I_{dc}, and trapezoidal output currents, i_a, i_c, at 160-A load for a complete cycle at 100-Hz fundamental frequency. The hard switching presents severe EMI noises with more than 400-A peak-to-peak current ripple on the dc link. However, the soft-switching shows only 25-A peak-to-peak ripple current. With 22°C ambient temperature, the case temperature of dc bus capacitors was 70°C at half-load condition when running under hard-switching condition. However, for the same load condition, the temperature was dropped to 37°C when running under soft-switching condition, greatly saving the life of the bulk capacitors.

Using the models developed in [3] and [16], the efficiency at different torque of a 60-kW inverter driving a 65-hp induction motor was evaluated over a wide speed range. This drive was designed for an electric prolusion drive to be used in a hybrid electric vehicle with a rated speed of 3000 rpm and full torque of 160 Nm. The evaluated efficiency profiles from 15% to 200% rated speed for a standard sinusoidal PWM hard- and a Y-configured soft-switching inverters are shown in Figs. 10(a) and 10(b).

The estimated efficiency profiles for the electric propulsion drive over the entire speed range agree with the experimental results in a single-phase motor drive. Again, the efficiency improvement at low speeds is much more significant than that at high speeds. This is very crucial to an electric propulsion drive because most urban driving cycles are running at low speeds. The energy savings with the proposed

RSIs over the traditional hard-switching inverters for an electric propulsion system can be very dramatic especially for urban driving.

VI. Conclusions

The proposed resonant snubber based inverters have demonstrated the following features:

(1) efficiency improvement: under full torque condition, the efficiency at full speed and 15% speed are 97.5% and 87% as compared to 93.5% and 71% in a hard-switching inverter,

(2) d*v*/d*t* reduction: the experimental results indicated a significant reduction from 3000V/μs in hard switching improved to 300V/μs in soft-switching,

(3) EMI reduction: uncharacterized EMI noises are eliminated through soft-switching as indicated in Figs. 5 and 9,

(4) high power density: a power density of >100kW/ft^3 has been obtained as indicated in Fig. 7,

(5) ease of implementation because there is no need to have voltage or current sensor in the resonant branch,

(6) ruggedness because the stresses of the main device and bulk capacitors are reduced, and disabling the auxiliary switch does not cause the main circuit to fail, and

(7) potentially low cost because the added components are only a fraction of the size compared to the main devices, and the reduction of the heat sink and EMI filters would gain some cost saving.

Most of these features have exceeded the previously-mentioned power electronics performance targets for an electric propulsion drive. It is important to search high power density devices for further efficiency improvement and cost reduction. There is no doubt that the MCT is the device of choice for the auxiliary switch. It is also expected that the under-developed MCT based PEBB [2] can be the device of choice for the main switch provided that its latching problem during over-current is resolved, and its normally on condition is changed to normally off condition with the N-type device.

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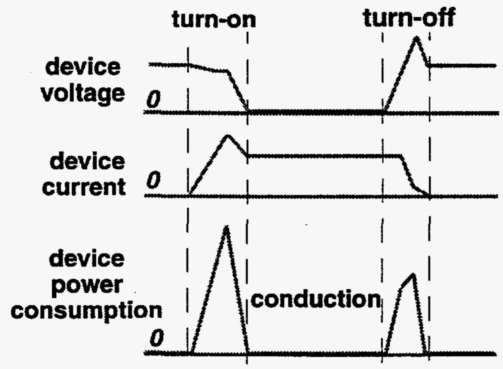
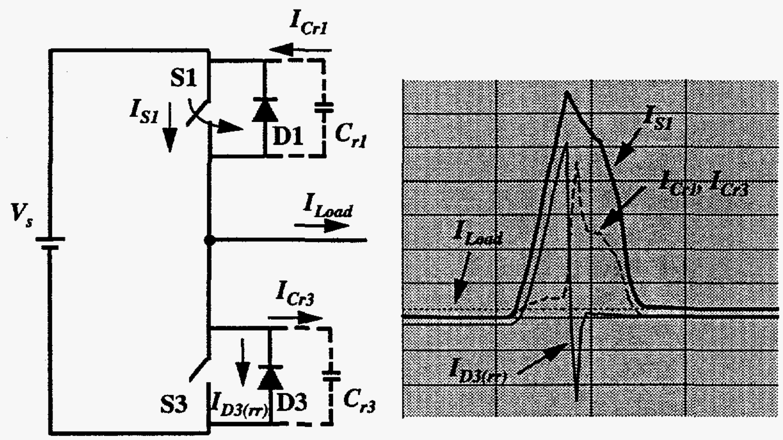
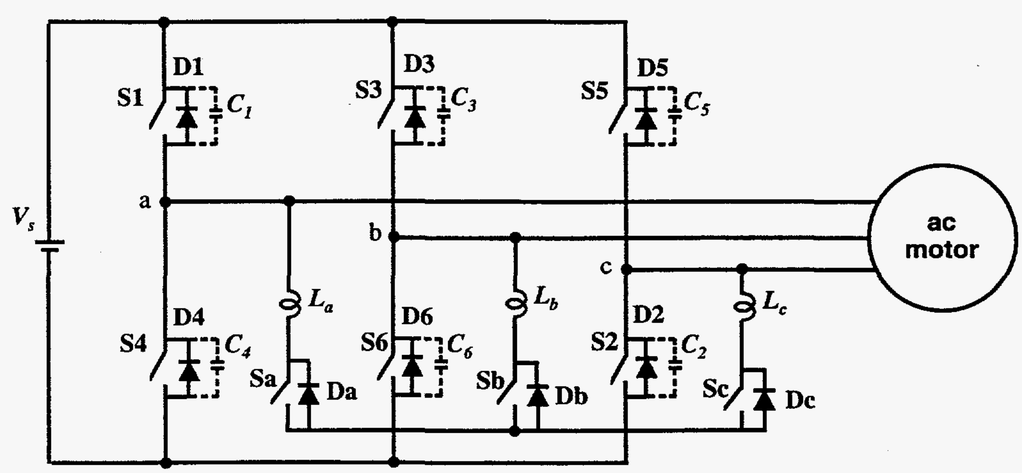


(a) Device voltage, current and power during switching.

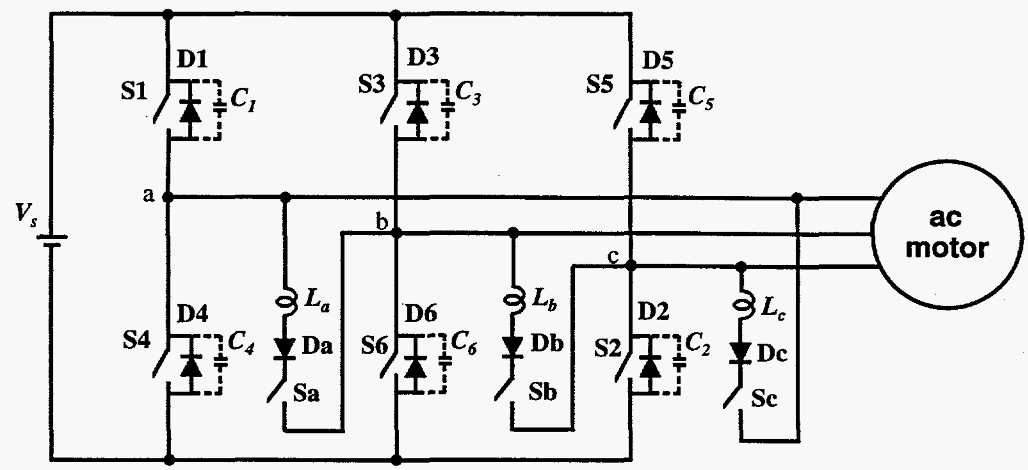


(b) Turn-on currents and waveforms with capacitor across the device

Fig. 1: Device switching waveforms under hard-switching condition.



(a) Y-configured RSI



(b) Δ-configured RSI

Fig. 2. The Y- and Δ-configured RSIs with connection to an ac motor.

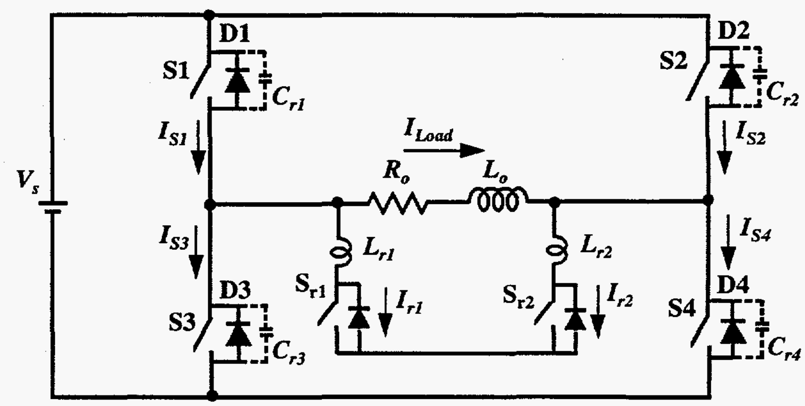
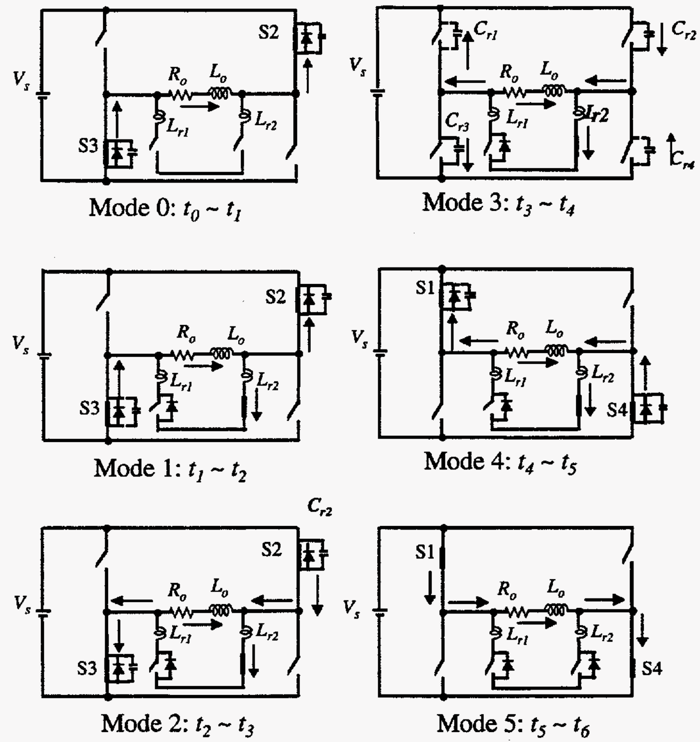
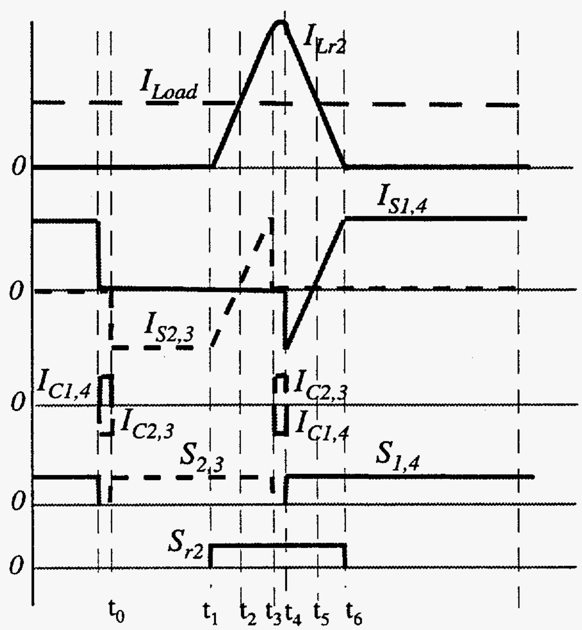


Fig. 3: A single-phase version of the proposed soft-switching inverter.



(a) Operation modes of a single-phase RSI



(b) Voltage and current waveforms

Fig. 4. Operation modes and waveforms of a single-phase RSI.

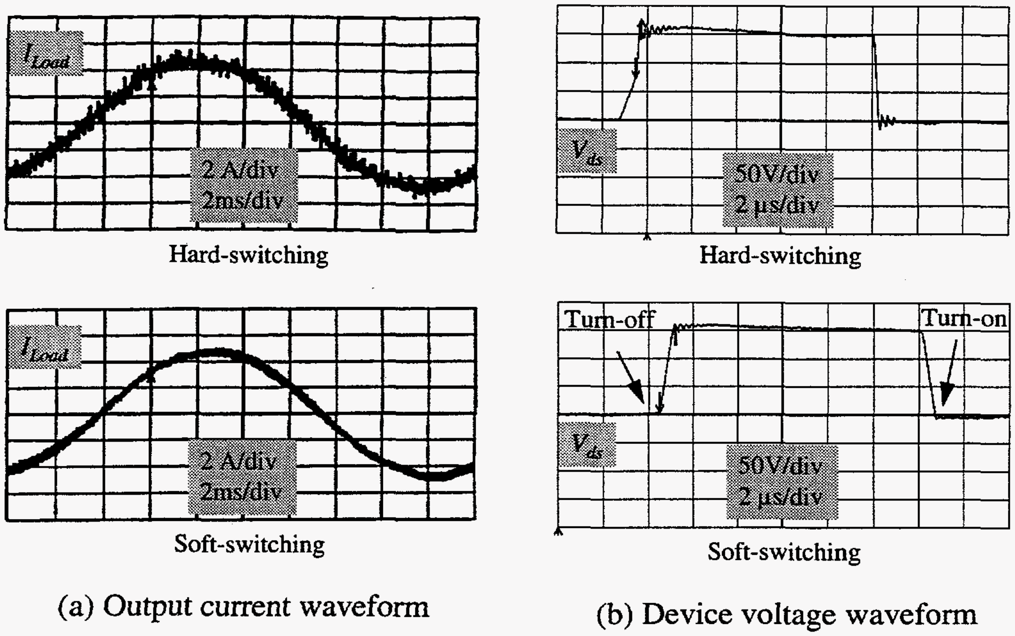


Fig. 5. Experimental output load current and device voltage comparisons between hard- and soft-switching inverters.

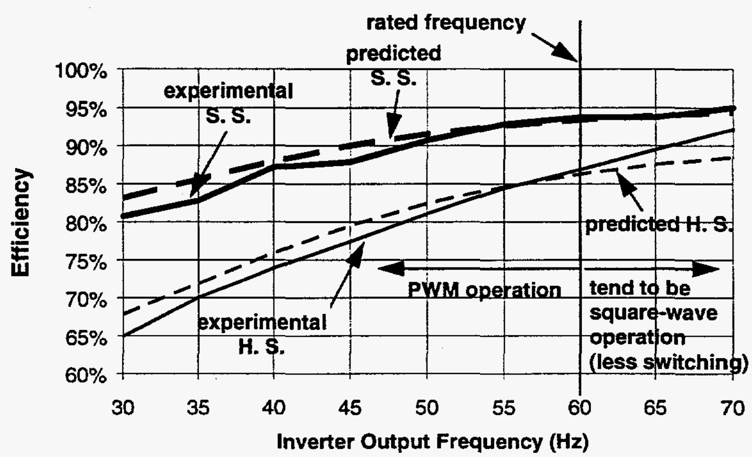


Fig. 6. Efficiency comparison between hard- and soft-switching inverters.

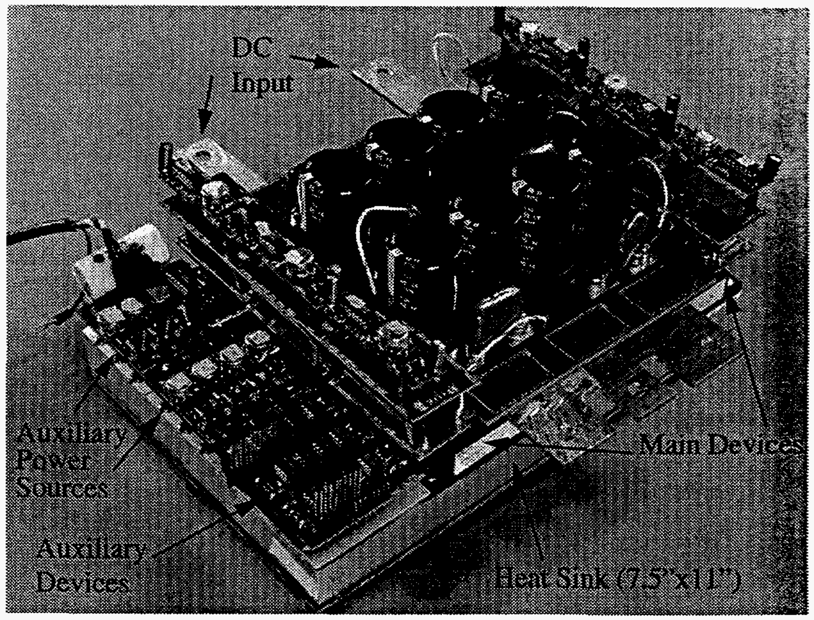
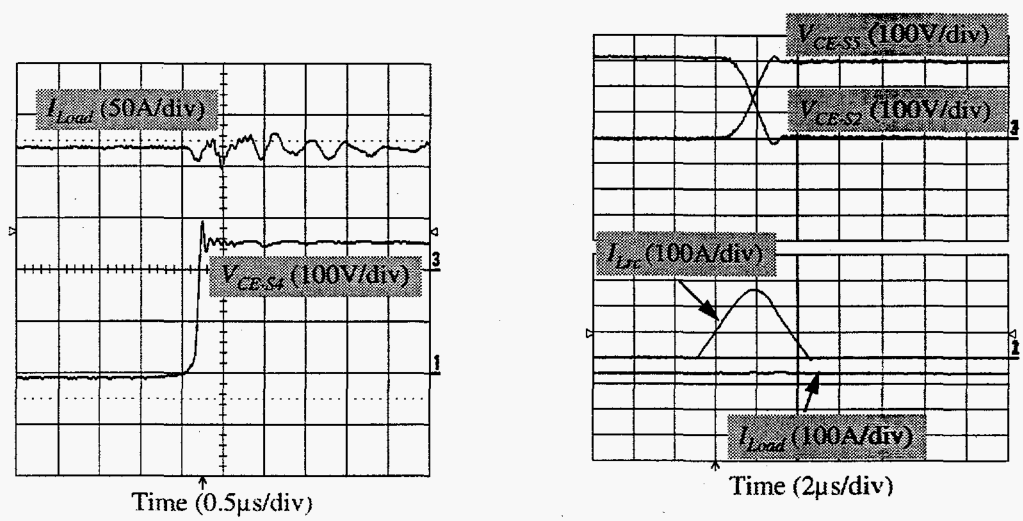
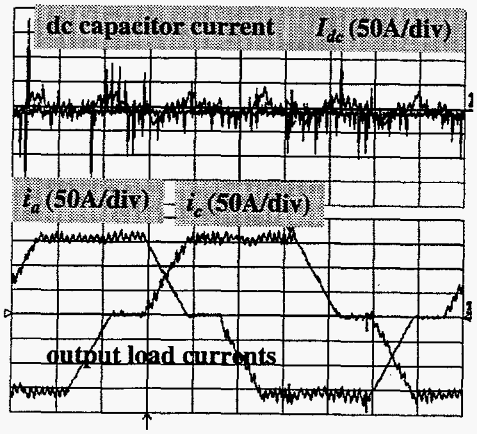


Fig. 7. Photograph showing a 100-kW Δ-configured RSI.

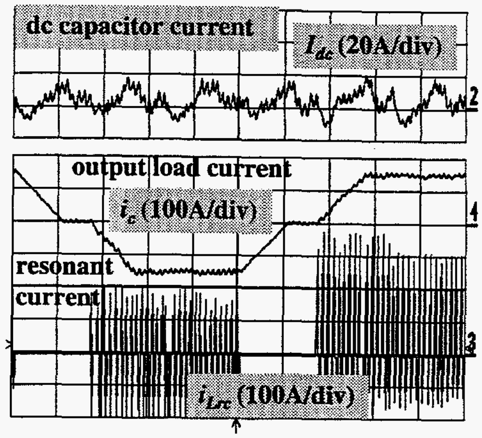


(a) Hard switching (b) Soft switching

Fig. 8. Device voltage and load current waveforms comparison between hard- and soft-switching inverters.

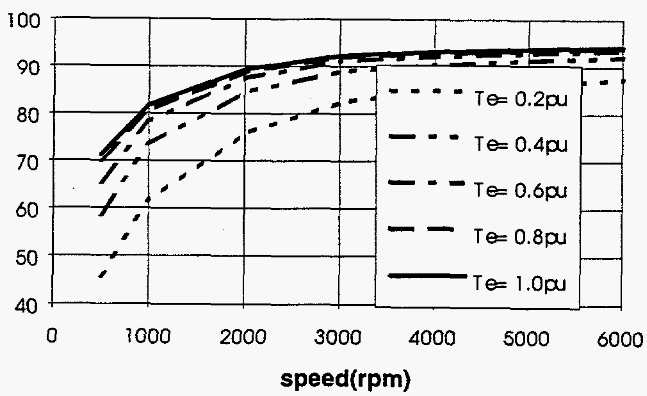


(a) Hard Switching

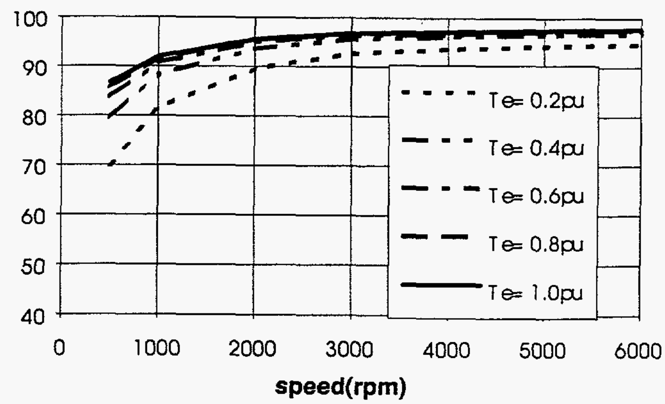


(b) Soft Switching

Fig 9. Input and output currents and voltage waveforms comparison between hard- and soft-switching inverters.



(a) Hard switching



(b) Soft switching

Fig. 10. Estimated efficiency comparison for a 60-kW inverter operating at different torque and speed conditions.

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February 9, 1996

Professor Chang-Huan Liu
IECON '96 Technical Program Chairperson
Department of Electrical Engineering
National Taiwan Institute of Technology
43 Keelung Road, Section 4
Taipei, Taiwan, Republic of China

Dear Professor Liu:

Please find the enclosed 5 copies of the paper manuscript entitled "Resonant Snubber Based Soft-Switching Inverters for Electric Propulsion Drives." This paper is being submitted to a special session on Electric Vehicle Technology organized by Professor C. C. Chan.

I will have some other duties in IECON '96. One is the panel discussion on Opportunities, State of the Art & Current Issues in Power Electronics Development, and the other one is a session chair being asked by Professor Bose. I look forward to seeing you in August. If you have any questions, please send me an email at laijs@ornl.gov or laijs@aol.com.

Sincerely,

Jih-Sheng (Jason) Lai
Lead Scientist, Power Electronics

Enclosure

JSL:adl