Three-Phase Soft-Switched Quasi Resonant DC Link Inverter for Induction Motor Drive Application

Dimitar Spirov[1] and Nikolay Komitov[2]

Abstract – **A zero-voltage transition soft-switching inverter for an induction motor drive is developed. The proposed soft-switching inverter is formed from the traditional pulse-width modulated (PWM) inverter by simply augmenting with auxiliary resonant circuits, and the soft switching is achieved through applying PWM switching control signals with suitable delays for the switches. The designed soft-switching inverter is used for powering an induction motor drive to test its effectiveness. The proposed drive system is modelled and its performance is simulated in PSpice. The simulation results show that a smaller switching loss and higher conversion efficiency are obtained by the proposed soft-switching inverter.**

Keywords – **Induction motor drive, Soft-switching inverter, Zero-voltage transition.**

I. Introduction

Inverters have many applications in power electronic devices. The performance of a pulse-width modulated inverter-fed system can be much improved by increasing the switching frequency. In hard switching inverters, a higher switching frequency leads to increased switching losses which consequently increases the size of the snubber circuits [1, 2]. This will suffer by giving large switching stresses of the power devices. In addition, electromagnetic interference increases and efficiency decreases. To overcome these problems, the application of soft switching techniques is essential [1-5].

The resonant DC-link inverter is the most commonly used one for induction motor drives, owing to its simplicity, but it possesses the disadvantage of having a high resonant link voltage, which is equal to or greater than twice the supply voltage [1].

Quasi-resonant (QR) inverters offer several advantages compared with resonant DC-link inverters with regard to resonant link design and control, device rating requirements and use of pulse width modulation (PWM) [6]. The QR inverter schemes generate zero-voltage instants in the DC link at controllable instants that can be synchronised with any PWM transition command, thus ensuring a zero-voltage switching condition of inverter devices. As a result, these inverters can be operated at high switching frequencies with high efficiency [6].

The passively clamped QR inverter is reported in [7]. This topology satisfying most of the essential requirements, such as low clamp factor, simple resonance control, guaranteed zero-link voltage condition, PWM capability, use of only one auxiliary switch and recycling of resonant energy. The only drawback of this scheme was the high reverse voltage requirement of the clamp diode. This problem can be solved by use of a separate, low-voltage DC source [5, 6]. Another possible solution could be to use a simple R-C parallel circuit to maintain low voltage [6].

One of the main QR inverter research goals is to achieve soft switching conditions with a minimum number of auxiliary circuit elements [2]. Reducing the number of auxiliary switches simplifies the control circuit and decreases the inverter cost.

The object of this work is to develop and simulated in PSpice a tree-phase induction motor drive fed by a PWM voltage source soft-switching inverter. It is necessary to investigate a performance of proposed drive system for the dynamic and steady-state modes.

II. Simulation model

The circuit diagram of the QR inverter is illustrated in Fig. 1. This topology is similar to the classic converter, plus an auxiliary circuit consists of switch S_a, antiparallel diode D_a and the coupled inductors L_{r1} and L_{r2}. The dc-link switch is S_L and the dc-link resonant capacitor is C_r.

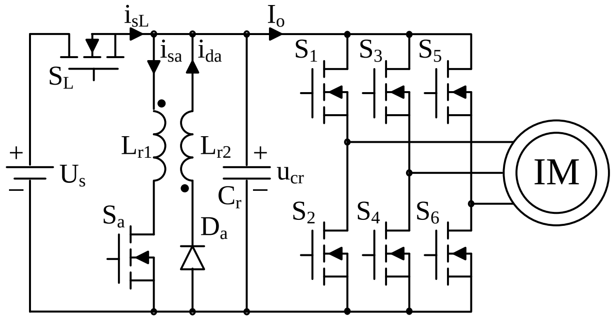

Fig. 1. QR DC-link inverter

The circuit operates by setting up a resonating dc link that periodically returns the dc bus voltage to zero. During the interval that the diodes in antiparallel with the main inverter devices are conducting, all inverter devices may be turned off, if desired, with minimal turn-off losses. At the same time, all incoming devices may be turned on with zero turn-on losses.

Six operating intervals can be identified. Before the first operating interval, it is assumed that S_L is on and S_a is off. This regime corresponds to the pseudo steady state conditions with link voltage equal to U_s. The output current I_o flows through S_L.

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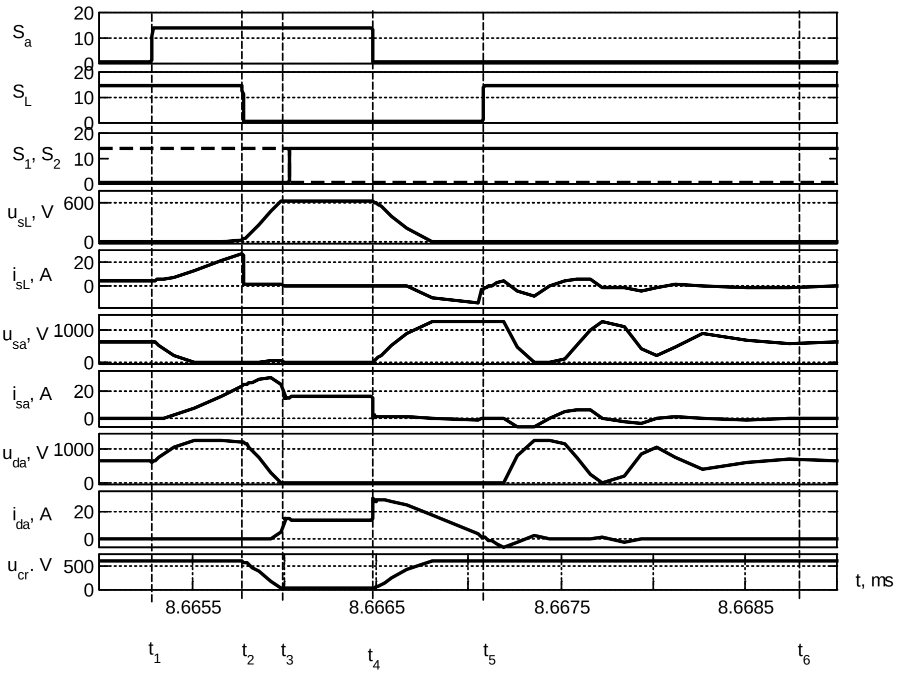

Fig. 2. Resonant link waveforms

Whenever a change in the state of the inverter main switches is desired, S_a is turned on (t_1). Due to existence of L_{r1}, the turn on of S_a is under zero-current switching condition and i_{sa} increases linearly ($t_1 \div t_2$) until it reaches I_{min} which is defined as the minimum required current of L_{r1} that guarantees the charging of C_r in interval ($t_4 \div t_5$). The design procedure of I_{min} is illustrated in [2].

When i_{sa} reaches I_{min}, switch S_L must be turned off (t_2). S_L is turned off under zero-current switching condition due to the existence of C_r. In this interval, a resonance starts between C_r and L_{r1} which decreases the dc-link voltage ($t_2 \div t_3$).

When u_{cr} reaches zero the diode D_a turns on (t_3). Thus, a fraction of the flux linkage of L_{r1}, moves to L_{r2}. In order to operate at zero-voltage switching condition, the state of the inverter switches must be changed in this interval ($t_3 \div t_4$). After the inverter switches change state, switch S_a then turned off in a zero-voltage switching manner (t_4). Thus, i_{da} current increases and begins to charge C_r ($t_4 \div t_5$).

When C_r reaches U_s, antiparallel diode of the switch S_L turns on under zero-voltage switching condition (t_5). Thus, switch S_L can be turned on under zero-voltage-zero-current switching condition. i_{da} current decreases to I_o. When the antiparallel diode of the switch S_L current reaches zero and turns off under zero-voltage-zero-current switching condition, the S_L current begins to increase until it reaches I_o and i_{da} current reaches zero (t_6).

After this interval, the link returns to the pseudo steady state and the cycle repeats for the next switching command.

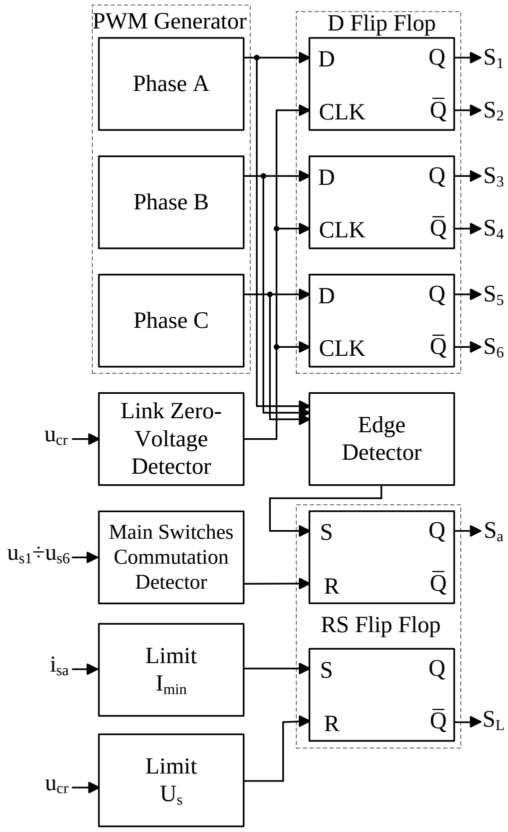

Fig. 3. Control circuit diagram for soft-switched PWM modulation

III. RECEIVED RESULTS

Simulation is done on a three phase induction motor fed by a PWM inverter developed in PSpice. The basic circuit of the proposed scheme consists of a three phase induction motor type AO-90S-4 having ratings as 1,1kW, 380V, 50 Hz which is connected to drive the constant nominal load. The PSpice model of three phase induction motor inverter drive has been developed in [7]. The technical data of the electric motor are given in Appendix.

The design of the proposed inverter involves the selection of parameters C_r, L_{r1}, L_{r2} to satisfy the desired link waveform specifications such as du/dt, di/dt and peak currents [6]. The design expressions are derived from the differential equations of each mode of the resonant cycle [1-7]. A set of parameters has been chosen as L_{r1}=10μH, L_{r2}=10μH, C_r=10nF. The magnetic coupling between L_{r1} and L_{r2} is designed as 0.9.

A three-phase sine-triangle PWM command generator was implemented to control the six inverter switches. The frequency of the carrier wave is maintained at 2 kHz.

Inverter control is implemented based on the link operation requirements, whenever a switching signal is generate, the auxiliary circuit must first be turned on to initiate a resonant transient. The inverter switches, when the link voltage reaches zero. A block diagram for a control scheme is shown in fig. 3. The edge detector locates the desired state change before the switching command is passed to the inverter switches. The detected edges are used as an input of a RS-flip flop to turn on of the auxiliary circuit. The auxiliary switch turns off, when the state of the inverter switches was changed. When i_{sa} reaches I_{min}, the pulse is used as an input of a RS-flip flop to turn off of the link circuit. The link switch turns on, when the C_r reaches U_s.

Fig. 4 shows the link voltage u_{DC}, inverter line-line voltage and phase current. It is seen that there is some distortion in the motor current. The reason for the distortion has to be attributed to the minimum link pulse requirement in the resonant inverter.

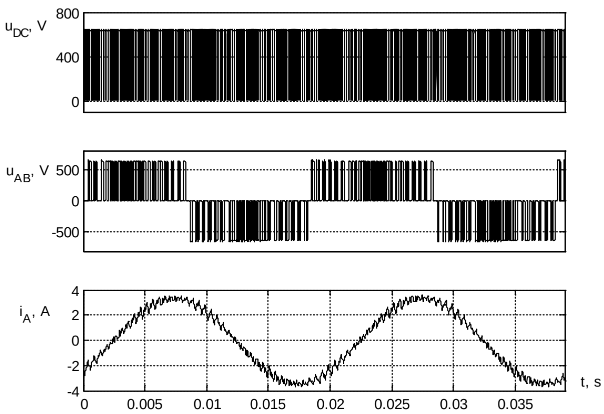

Fig. 4. Dependences u_{DC}, u_{AB}, i_A=f(t)

From the basic waveforms shown, it is seen that some limitations still exist. The control circuit must drive the auxiliary switch and the dc-link switch at the proper time. It can be observed from Fig. 2, that the state of the inverter switches can be changed 1μs after turning S_L off. When the control circuit decides to change the state of inverter switches, this action should be performed with a delay 0.6μs in order to have enough time to reduce the dc-link voltage to zero. Thus, switch S_a is turned on first and i_{sa} current increases until it reaches I_{min}. This current must be large enough (I_{min}=26.8A) to guarantee charging C_r. A larger I_{min} causes greater current stresses on S_L and S_a [2].

The fall time for the link voltage is about 990ns. The zero link voltage condition maintained for about 1.3μs. The rise time for the link voltage is more than 1.7μs.

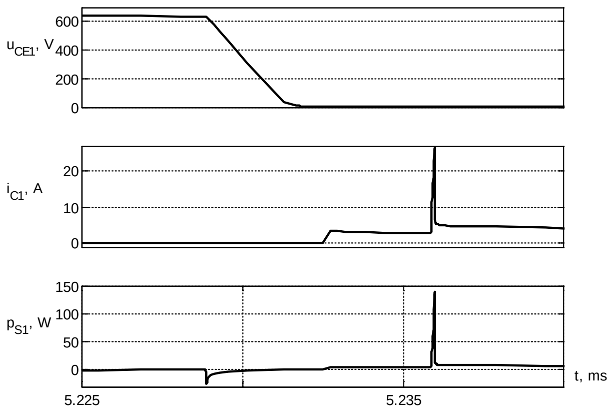

Fig. 5. Dependences u_{CE1}, i_{C1}, p_{S1} =f(t) with “soft switching” control scheme

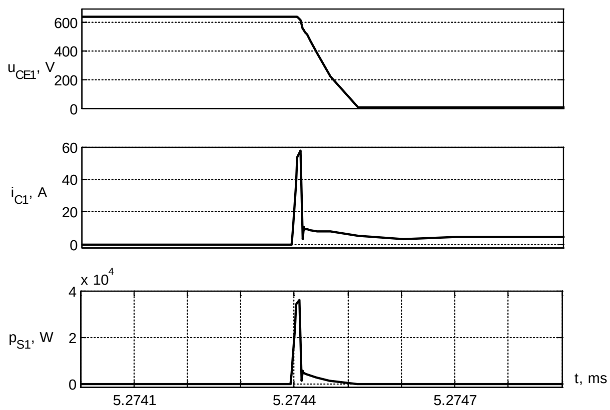

Fig. 6. Dependences u_{CE1}, i_{C1}, p_{S1} =f(t) without “soft switching” control scheme

Management of inverter drives attached proposed control algorithm for "soft switching" voltage of the keys. Fig. 5 shows the shapes of the current, voltage and power losses in the switches of the test circuit. For comparison are shown in scheme losses without “soft switching” control scheme (Fig. 6).

From fig. 5 and fig. 6 is seen that the current through transistor S_1 begins to flow in the reset voltage on it. This led to a significant reduction in switching losses - in the case of pulses presented in the figure of 8730 W when dealing with "hard switching" to 8.127 W when using "soft switching", i.e. 8722 W reduce the emitted power. Amplitude value of current through the transistor S_1 at work "hard switching" is 59.37 A, when using "soft switching" is 3.15 A, i.e. with 56.22 A reducing the amplitude value.

IV. Conclusion

A tree-phase induction motor drive fed by a PWM voltage source soft-switching QR inverter is presented. The proposed circuit uses two additional switches to create zero-voltage instants in the DC link.

The proposed drive system is modeled and its performance is simulated in PSpice. Simulation results show that the proposed scheme for the "soft switching" is obtained a significant reduction of the power losses in the power switches and the reduction of the amplitude values of the current through the transistors as compared with the scheme of "hard switching".

Appendix

Induction motor type AO-90S-4

P_N=1,1kW; U_N=380V; I_N=2,8A; f=50Hz; p_p=2; n_N=1410min^{-1}; M_N=7,45Nm; cosφ=0,8; J_m=0,001kgm^2.

Parameters for $s=s_N$

R_s=7.45Ω; R_r=5.00255Ω; $L_{\sigma s}$=0.01839H; $L_{\sigma r}$=0.01839H; L_m=0.33475H.

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