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Two – Quadrant Converter with RNSIC Analysis having Capacitors on the AC side

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Abstract – A new topology for a two – quadrant converter is presented. In the AC/DC transfer mode the converter works as a rectifier with near sinusoidal input currents (RNSIC), while in the DC/AC transfer mode it works as a square-wave pulse switching inverter. Some suggestions for the converter design are given and a comparison with two–quadrant PWM converter is made.

Keywords: power quality, two-quadrant converter, square-wave pulse switching inverter.

I. INTRODUCTION

Most of the applications use three – phase converters, for two – quadrant operation in AC power supplies where the objective is to produce sinusoidal current waveforms on the AC side. For example, in motor drives with regenerative braking, the power flow through the utility interface converter reverses during the regenerative braking while the kinetic energy associated with the inertias of the motor and load is recovered and fed back to the utility system [1, 2]. Usually, the three – phase converters for two – quadrant operation use PWM switching techniques in order to reduce higher current harmonics on the AC side. Governments and international organizations have introduced new standards (in the United States, IEEE 519, and in Europe IEC 61000 – 3) which limit the harmonic content of the current drawn from the power line by rectifiers [3, 4].

Figure 1a presents the most popular topology used in adjustable speed drives (ASD), uninterruptible power supplies (UPS), and more recently in PWM rectifiers. This topology has the advantage of using a low – cost three – phase module with a bi-directional energy flow capability.

Due to the rapid changes in voltages and currents of a switching converter, a PWM rectifier is a source of EMI. The PWM rectifier, even though it has near sinusoidal input currents, has important disadvantages as compared with the inexpensive three –phase rectifiers with diodes: larger switching losses, high per – unit current rating, poor immunity to shoot – though faults, higher cost and less reliability [1, 2].

II. NEW CONVERTER CONFIGURATION

A new converter for two – quadrant is presented in this paper; it is equipped with 6 transistors (e.g. IGBT) having square-wave pulse switching (that is not PWM) operation, as shown in Fig. 2a. When the energy is transferred from the AC side to DC side, the transistors are off and the converter works as a RNSIC (Rectifier with Near Sinusoidal Input Currents), as described in [5-7]. When the energy is transferred from the DC side to the AC side, the transistors are controlled to conduct for θ angles (square-wave pulse switching) and the converter works as inverter, as show in Figs. 2b and 3.

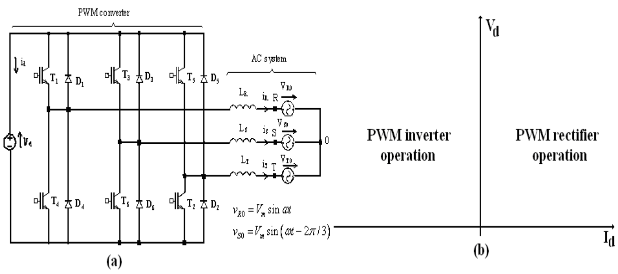

Fig. 1 Converter for two – quadrant based on PWM principle;
(a) Configuration; (b) Operation modes

Inductors L_2 have values several times smaller than L_1. For the case of operation in inverter mode, the voltage V_d is considered to be 15-25 % greater than for the case of rectifier system operation. Diodes $D_1^{'} - D_6^{'}$ are chosen according to the RNSIC component design specification, while the diodes $D_1 – D_6$ are rated for much smaller average currents.

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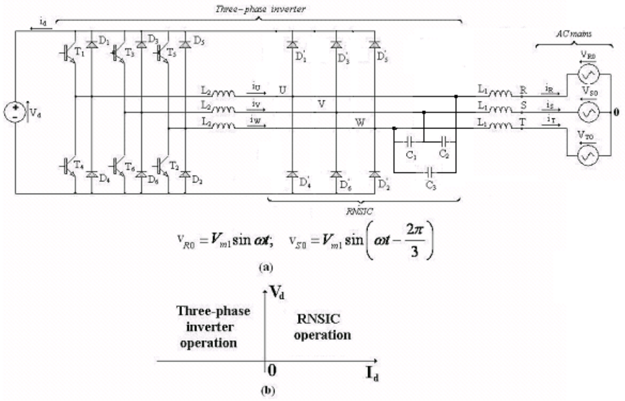


Fig. 2 Converter for two – quadrant with RNSIC; (a) Configuration; (b) Operations

Capacitors C_1 – C_3 have the same capacity, C, fulfilling the condition, [5– 7]:

$$0,05 \le L_1 C\omega^2 \le 0,10 \tag{1}$$

The switch of the converter in Fig. 2a from the inverter mode operation to the rectifier mode operation and reverse can be rapidly accomplished during a utility grid cycle $T = \frac{2\pi}{\omega}$.

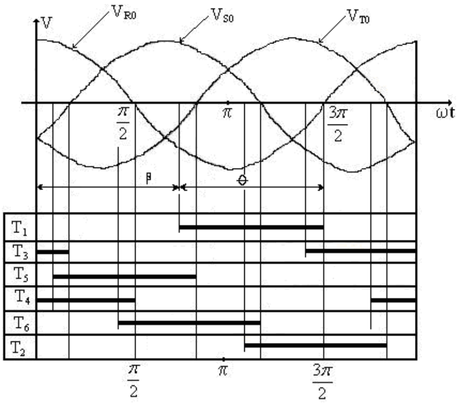


Fig. 3 Control program of the transistors.

According to the phasor diagram in Fig. 4b, current i_R is given by :

$$i_R = \frac{v_{U0} - v_{R0}}{j\omega L_1} \tag{2}$$

while its active value, i_{Ra} , is given by :

$$i_{Ra} = \frac{V_{m2}}{\omega L_1}\left[\sin(\omega t + \alpha) - \frac{V_{m1}}{V_{m2}}\sin\omega t\right] \tag{3}$$

The active power transferred to the AC source is given by:

$$P = \frac{3}{2\pi}\int_0^{2\pi} i_{Ra} V_{m1}\cos\omega t \, d\omega t = \frac{3V_{m1}V_{m2}}{2\omega L_1}\sin\alpha \tag{4}$$

In order to obtain a unity power factor at the AC source, from (3) it implies that:

$$\cos\alpha = \frac{V_{m1}}{V_{m2}} \tag{5}$$

It results that the value of the power transmitted to the AC source could be varied by modifying the amplitude V_{m2} (thus the angle θ) and the angle α (thus the angle β), as show in Fig.3.

Possible applications of the converters for two – quadrant operation with RNSIC are their usage in static frequency converters with DC voltage link, designed for supplying variable voltage and frequency to the three – phase induction motor drives, as shown in Fig. 5.

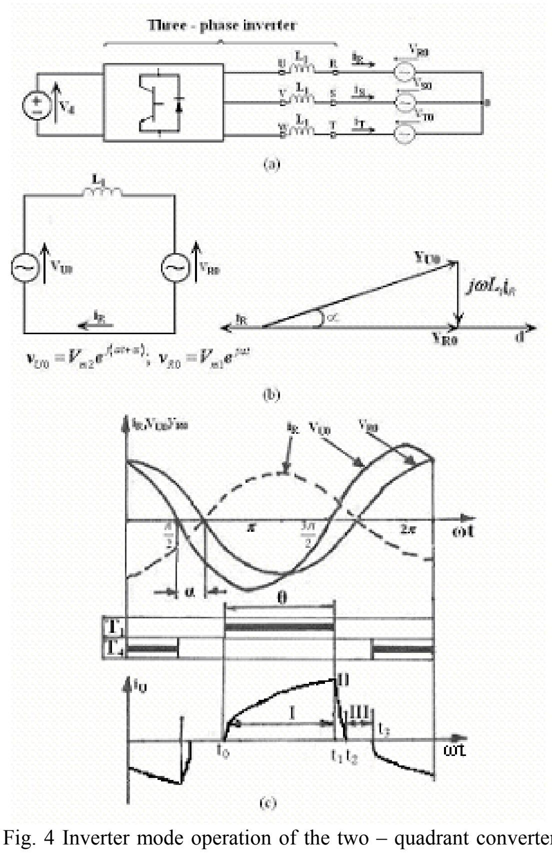


Fig. 4 Inverter mode operation of the two – quadrant converter with a RNSIC ; (a) Simplified representation; (b) Phasor diagram at unity power factor; (c) Waveforms of the currents and voltage.

For the time intervals when the induction motor drive is in the motoring regime, the input converter becomes a RNSIC converter. For this case the transistors T_1 – T_6 are off. The output switch – mode converter operates as a PWM inverter. The energy is transmitted from the power supply to the motor and the voltage on the filtering capacitor C_0 is less than $V_{d0} = \sqrt{3}\,V_m\left(1-2L_1C\omega^2\right)$.

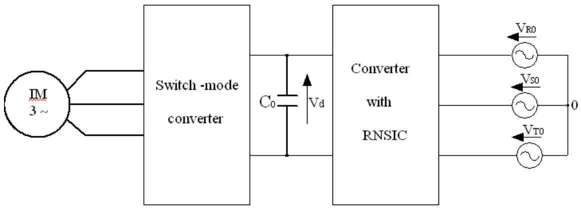


Fig. 5 Static frequency converter for two – quadrant with RNSIC

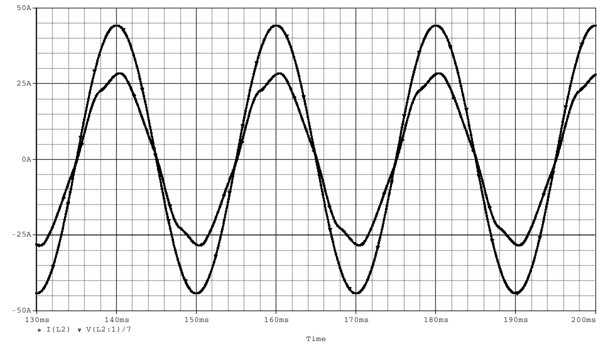
During the time interval while the induction machine (IM) is operating in breaking mode, the energy received from the motor is transmitted to the power supply. The switch – mode converter operates as a rectifier and the voltage across C_0 is greater than $\left(15-25\%\right)V_{d0}$. Further on, the energy is transmitted into AC mains by means of a three – phase inverter made up of transistors T_1 – T_6, three inductors L_2, diodes D_1 – D_6 and RNSIC. One must observe also the fact the total duration of operation as a generator for the asynchronous machine is much smaller as compared with the total motor functioning duration.

III. EXPERIMENTAL AND SIMULATION RESULTS

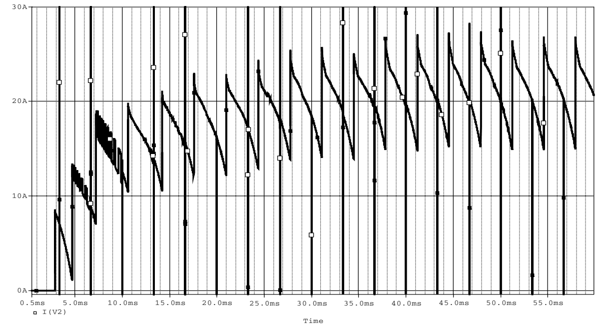
Laboratory experiments and simulations results have proved the effectiveness of the proposed converter in Fig. 2a. The laboratory prototype consists of a three – phase voltage source (with $V_m = 311$V and f = 50 Hz) and a RNSIC converter. The RNSIC is composed of six diodes, three inductors L_1 with inductance 25 mH and three DC capacitors C_1 – C_3 with capacitance 20 μF. For the three inductors L_2 we have adopted the value 25 mH.

Figures 6 and 7 show the simulations results. In Figs. 6a and 6b the waveforms of the phase current i_R and the DC current i_d are shown, for the case of the induction machine operating in motoring regime.

For power circulation in the opposite direction, Figs. 7a and 7b show the waveforms of the phase current i_R, the transistor current i_{T1} and the DC current i_d, when the induction machine is operating in breaking mode. The value of the power transmitted to the AC source can be varied by modifying the angles θ and β, as suggested in Fig. 3.

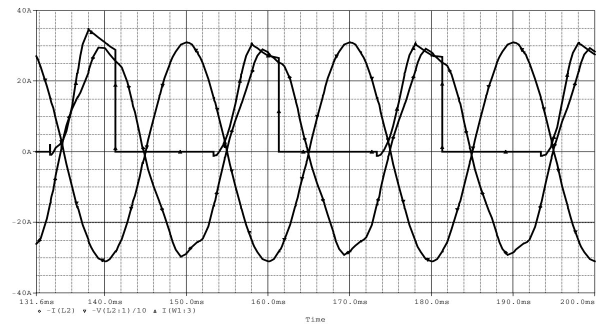


(a)

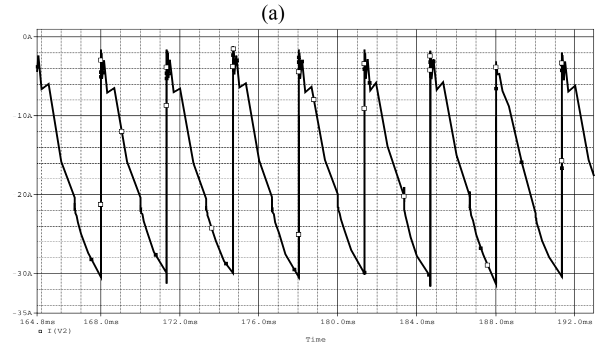


(b)

Fig. 6 Rectifier operation mode of the proposed converter with RNSIC for V_d = 600V; (a) Waveforms of the phase current i_R and the phase voltage v_{R0}; (b) Waveforms of the DC current i_d



(a)



(b)

Fig. 7 Inverter mode operation of proposed converter with a RNSIC for V_d = 800 V; (a) Waveforms of the phase current i_R, the transistor current i_{T1} and the phase voltage v_{R0}; (b) Waveforms of the DC current i_d.

IV. CONCLUSIONS

Comparing the two – quadrant PWM converter with the converter proposed in this paper one can make the following considerations:

- The proposed topology reduces the commutation losses and EMI problems. Transistors T_1 – T_6 begin to conduct only once in a utility grid cycle, at zero currents i_U, i_V and i_W (that is according to ZCS – Zero Current Switching principle).
- One of the advantages of the continuous functioning of the controllable switches (in square-wave pulse and not PWM switching), is that each inverter switch changes its state only twice per cycle, which is important at high power levels where the solid – state switches generally have slower turn – on and turn – off speeds.
- The proposed converter has increased safety due to the fact that controllable switches have much smaller total conducting durations, being blocked while the converter operates as RNSIC.
- In the case of DC to AC conversion, for the same values of the voltage V_d and AC inductances, the proposed converter provides larger output voltages V_{U0}, V_{V0} and V_{W0} and thus allows a more efficient energy transfer (obviously, at the PWM inverter, the fundamentals of the output voltages are smaller and so the transferred energy is smaller).

The simulation and experimental results proved that the fifth current harmonic is the most significant one generated in the AC mains and that its value is within the limits imposed by the IEEE Standard 519/1992.

V. REFERENCES

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