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Improved performances AC – AC Single-Phase Converters

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Abstract - This paper propose a new control technique for single – phase AC – AC Converters with a good dynamic response, a good output characteristic, a good power-factor correction(PFC) and a small number of components. A power factor correction rectifier and an inverter with the proposed control scheme has been designed and simulated using Caspoc2007, validating the concept.

Keywords: AC-AC single – phase converter, power factor correction, PWM rectifier.

I. INTRODUCTION

The attention devoted to the quality of the currents absorbed from the AC single – phase grid by electronic and electric equipment is increasing due several reasons. A low power factor reduce the used active power while a significant harmonic distortion of the causes EMI problems and interferences between different system connected a same AC power line. Has been developed many interface systems which improve the power factor of standard electric and electronic loads.

The AC–AC converters are splitted in AC–DC–AC converter (indirect) and AC– C converters (quasi – direct). The AC–AC converters are used in drives that require regenerating power capabilities like cranes, turbines, elevators, electrical AC motors and so on.

Directly AC–AC converters have been investigated for miniaturization, high efficiency, harmonic reduction of mains current, reduced parts, low prices.

This paper proposed a presentation of a single – phase PWM rectifier – inverter AC–AC converter and details the method controls.

The PWM AC–AC converters system is mainly used in industrial drives systems where controls of voltage level and frequency value at the induction machines are needed.

II. PROPOSED CIRCUIT DESCRIPTION

The selection of development of a circuit topology for a single-phase converter plays important role in the design of a high performance for these converters. The circuit topology is highly dependent on the overall efficiency, safety, regulation, costs.

One of the most utilized configurations is half-bridge PFC converter topology. This configuration has advantages of common-neutral point and a minimal number of power switches requirement, and has disadvantages of higher voltage stress and need fast response balance control of the totem-pole capacitor bank. The topology of single-phase common-neutral ac-ac converter is shown in Fig.1

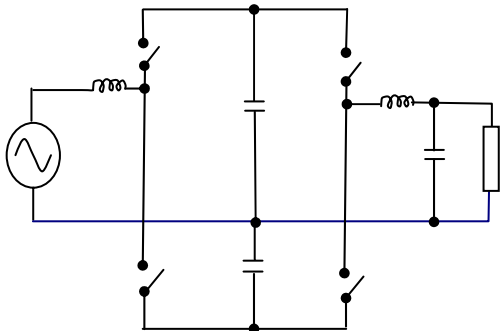

Fig.1 Single-phase common-neutral AC-AC converter topology

The converter needs 4 power switches, an input inductance and an output LC filter.

Figure 2 [3] shows the circuit configuration of this converter which can improve the power factor and can realize a good sine wave form at output.. The circuits have two parts: a common – neutral half-bridge PWM rectifier and an half – bridge inverter.

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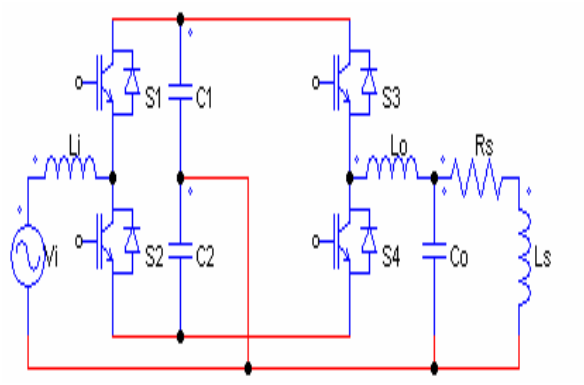

Fig.2 Single-phase AC-AC converter based on a half – bridge PWM converter and inverter

This converter is realized with IGBT. IGBT have a easy command and are able to stand a forward high voltage and direct current; other hand, the IGBT have o good power dissipation in commutation.

III. PWM RECTIFIER

The front– end part of proposed converter is a common–neutral half- bridge converter. The function is described below:

During the positive half cycle of the input AC voltage, when switch S_2 is on, the expression for the voltage across the input inductor L_i is [1]:

$$V_{Li} = L_i \frac{di_i}{dt} = V_i + V_{C2} \quad (1)$$

The voltage applied across the input inductor is positive and the inductor current increases. During this time, the current path is $\boldsymbol{V_i^+ - L_i - S_2 - C_2 - V_i^-}$. When switch S_2 is turned off, the inductor current needs to flow in the same direction. The path, during this time, is $\boldsymbol{V_i^+ - L_i}$ – ***reverse diode of*** $\boldsymbol{S_1 - C_1 - V_i^-}$. The capacitor C_1 is charged with the energy stored in inductor L_i. The voltage across the input inductor L_i is [1]:

$$V_{Li} = L_i \frac{di_i}{dt} = V_i - V_{C1} \quad (2)$$

Since V_{C1} is larger than V_i, the voltage applied across the input inductor is negative and the inductor current decreases. So, during the positive half – cycle of the input voltage, the input power factor and the DC voltage of the capacitor C_1 are controlled by the duty ratio of switch S_2.

During the negative half-cycle of the AC input voltage, when switch S_1 is on, the voltage across the input inductor is negative and the inductor current decreases.

This is shown in equation:

$$V_{Li} = L_i \frac{di_i}{dt} = -V_i - V_{C1} \quad (3)$$

During this time, energy is stored in the input inductance L_i and transferred in the capacitor C_2 when switch S_1 is turned off. The current path during S_1 is on is $\mathbf{V_i^+ - C_1 – S_1 – L_i – V_i^-}$.

When switch S_1 is turned off, the inductor current needs to continue flowing in same direction. The current path will be, in this case, $\boldsymbol{Vi^+ - C_2}$ – ***reverse diode of*** $\boldsymbol{S_2 - L_i - V_i^-}$. Therefore, the capacitor C_2 is charged with the stored energy in input inductor L_i. The voltage across the input inductor L_i is [1]:

$$V_{Li} = L_i \frac{di_i}{dt} = -V_i + V_{C2} \quad (4)$$

Since V_{C2} is larger than V_i, the voltage applied across the input inductor is positive and the inductor current increases. So, during the negative half – cycle of the input voltage, the input power factor and the DC voltage of the capacitor C_2 are controlled by the duty ratio of switch S_2.

In Figure 3[1] is shown the diagram of the implemented control of the rectifier (draws in PSIM).

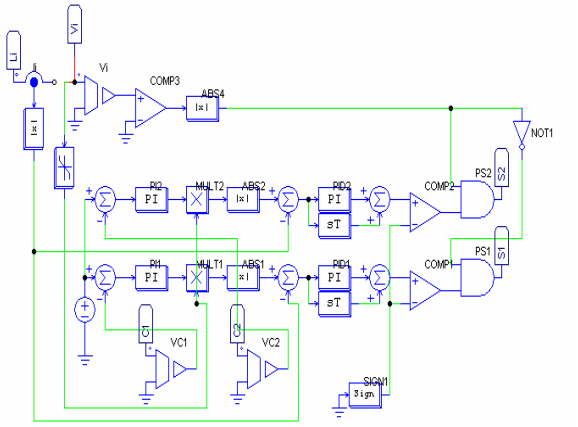

Fig.3 Control strategy of the AC – DC PWM common – neutral half-bridge rectifier.

The control strategy of the AC – DC rectifier uses multiple control loops: one outer voltage loop and one inner current loop. The outer control loop uses the voltage of the output DC – link capacitor as a feed-back signal, which is compared with a reference signal. A PI integrator compensates the error. The output of the PI integrator is used as a reference signal for the inner current regulator loop, which uses the input inductor current as a feed-back signal; at the same time, regulate the input current to be sinusoidal . The inner current loop is fast and gives a good dynamic response and, as a resulting, a good input power factor. The outer voltage loop is slower and keeps the output DC-link voltage stable at 340 V: 170 V for each capacitor C_1 and C_2; at the same time, controls the power flow of the voltage converter. The switching frequency of the PWM Carrier is 20 kHz and the waveform is saw tooth.

IV. PWM INVERTER

The DC–AC inverter is a half– bridge type, consisting in a two DC capacitors, C_1 and C_2, connected in series, two switches S_3 and S_4 and an output LC filter (L_o and C_o)(R_s and L_s are the load). The input voltage is equally divided between the two capacitors. When turning switches S_3 and S_4 on and off, the voltage applied across the load is+$V_{dc}/2$ or - $V_{dc}/2$. When switch S_3 is on, switch S_4 is off, the voltage applied across the load is +$V_{dc}/2$. Also, when switch S_3 is off, switch S_4 is on, the voltage applied across the load is -$V_{dc}/2$. To avoid shoot-through faults, there is always a dead time between the time when a switch is turned off and the other is turned on (the both switches must not be on simultaneously).

The inverter operates in high frequency SPWM strategy in order to provide a good quality sinusoidal output voltage.

In Figure 4[1] is shown the diagram of the implemented control of the inverter (draws in PSIM).

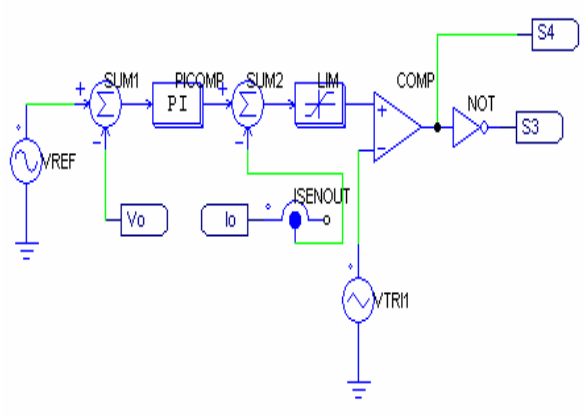

Fig.4 Control strategy for the DC – AC inverter

The control strategy employs two control loops [2]: one outer voltage loop and one inner current loop. The outer control loop uses the output voltage as a feedback signal which is compared with a reference signal. The error is compensated by a PI compensator to achieve a stable output voltage under steady-state operation. This error is also used a reference signal for the inner current regulator loop, which uses the output current as a feedback signal. The minor current loop is much faster than the outer voltage loop and improves the dynamic response of the inverter. Finally, the output voltage has a good quality even with a highly nonlinear load. The switching frequency is 20 kHz.

V. INDUCTIVE AND CAPACITIVE COMPONENTS

The selection of the AC link inductance, DC capacitors and output filter values affects the performance of the converter.

The power output of the converter is 1000 W. the efficiency of the converter is 85% and the input power is:

$$P_{in} = \frac{P_{out}}{\eta} = \frac{1000}{0.85} = 1176.5W \quad (5)$$

The minimum RMS input voltage is 100 V. The maximum input current I_{inmax} is drawn at minimum input voltage:

$$I_{in\max} = \frac{P_{in}}{V_{i\min}} = \frac{1176}{100} = 11.76A \quad (6)$$

The voltage across each DC-link capacitors is 169 V and the total voltage of the DC-link bus is 338 V.

The inductance values that would cause the input ripple current to be a fraction of the overall input current is given in the next equation[1]:

$$L_i = \frac{T \bullet V_{i\min}^2}{2I[\%] \bullet P_{out}}(1 - \frac{\sqrt{2} \bullet V_{i\min}}{V_{dc}}) = \frac{50 \bullet 100^2}{2 \bullet 0.35 \bullet 1176}(1 - \frac{\sqrt{2} \bullet 100}{338}) \cong 352\mu H \quad (7)$$

where L_i is the inductance (μH), V_{imin} is the minimum RMS input voltage, I[%] is the percent switching current ripple relative to the input current, P_{out} is the maximum output power (W) and V_{dc} is the output DC voltage (V).

A value of 350 μH has been chosen.

The selection of the DC-link capacitors C_1 and C_2 is determined by the voltage ripple specification and the AC current for each capacitor [1]. For simplicity, if we assume that the inverter output current consist of a fundamental component and a third harmonic only, and assuming that the third harmonic is 70% of the value of fundamental, which is typical for a single-phase rectifier, we have:

- the nominal inverter output current is[1]:

$$I_o = \frac{P_{out}}{U_o} = \frac{1000}{110} = 9.09A \quad (8)$$

The fundamental frequency current is[1]:

$$I_1 = \frac{I_o}{1.22} = \frac{9.09}{1.22} = 7.45\ A \quad (9)$$

The largest AC components of the DC–link capacitor current is [1] half the fundamental frequency current, whose RMS value is:

$$i_{crms} = \frac{I_1}{2} = \frac{7.45}{2} = 3.725\ A \quad (10)$$

Specifying voltage ripples ΔV_c of less than 1% or 1.69 V, we calculate the value for capacitors C_1 and C_2 according to [1]:

$$\Delta V_c = \frac{i_{crms}}{\omega C} = \frac{i_{crms}}{2\pi f \bullet C} \quad (11)$$

and

$$C = \frac{i_{crms}}{\omega \Delta V_c} = \frac{3.725}{2\pi \bullet 50 \bullet 1.69} = 7.019\,mF \quad (12)$$

Has been selected two capacitors with 7500μF/250 V value each.

The pulse width modulation output V_o from the IGBT leg is filtered by a low-pass LC filter. The cut-off frequency of the filter is set around 1.5 kHz [1], in order to eliminate the high-frequency harmonic contest of V_i. The output inductor L_0 has been selected to be 100 μH and the output capacitor C_o to be 20 μF.

VI. SIMULATION RESULT

The CASPOC2007 simulation software package was used to design and simulate the circuits. The PWM rectifier and the PWM inverter was designed and simulated separately. The output waveform for the output inverter voltage is shown in Fig.5. The test time is 0.2 s. The amplitude of the sinusoid is around 169 V.

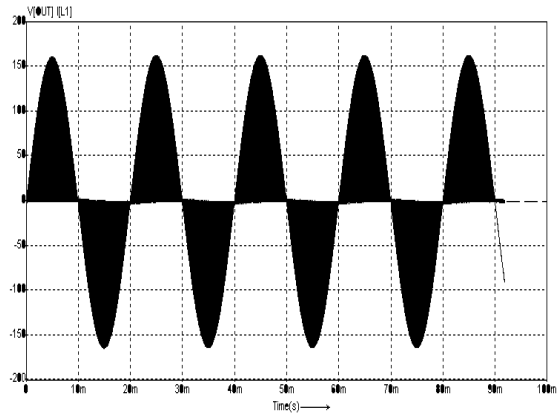

Fig.5. Waveforms for output voltage and current of the DC-AC inverter.

The differential voltage outputs waveform of the PWM rectifier is shown in the Fig.6. The values is stabilized around 165 V c.c. for each output. The test time is 0.4 s.

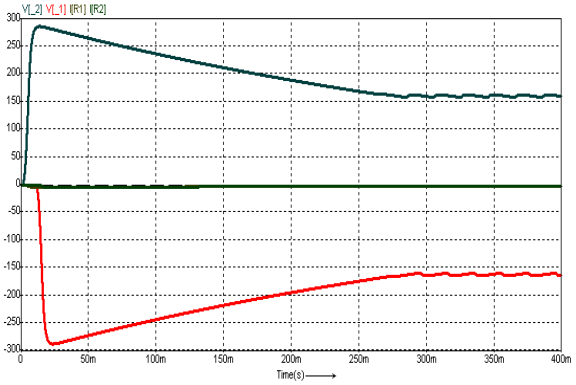

Fig.6. Waveforms for differential output voltage of the PWM rectifier.

The input AC voltage and current is shown in Fig. 7. The input current is sine wave and in phase with the input voltage resulting a good power factor.
In Fig. 8 is shown the DFT for the input voltage and current; the significant component is the 50 Hz.

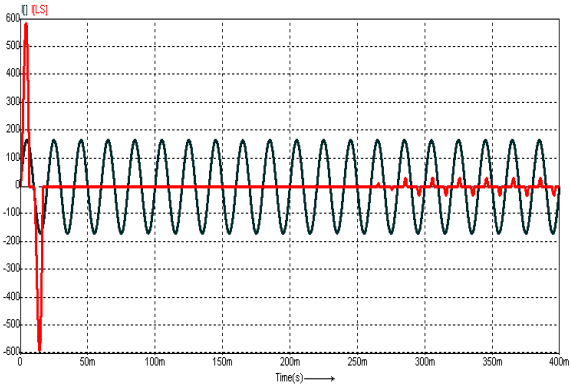

Fig.7. Waveforms for input voltage and current of the PWM rectifier.

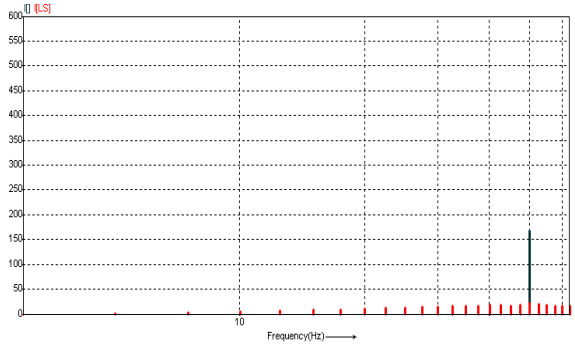

Fig.8. DFT for input voltage and current of the PWM rectifier.

VII. CONCLUSION

The implemented control circuits have good performance characteristics, and power factor compensation. The circuits can be utilized in AC-DC PWM rectifier, DC-AC inverter or AC-DC-AC converter.

VIII. APPENDIX

Table I Specification of proposed PWM Rectifier

PWM Rectifier Parameters	
Power Rating	1000 W
Input Voltage	110 Vac / 50 Hz
Output Voltage	2 * 169 V
PWM Frequency	20 kHz

Table II Specification of proposed PWM Inverter

Inverter Parameters	
Power Rating	1000 W
Input Voltage	2 * 169 Vac
Output Voltage	110 Vac / 50 Hz
PWM Frequency	20 kHz

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