AC – AC Converters for UPS

Rusalin Lucian R. Păun
Facultatea de Grup Şcolar Industrial „Ştefan Anghel” Reşiţa
Bulevardul Alexandru Ioan Cuza nr. 39, 320110, Reşiţa, CS, Romania, email: lucipaun@yahoo.fr

Abstract **–** This paper propose a new control technique for single – phase AC – AC converters used for a on-line UPS with a good dynamic response, a reduced-parts components, a good output characteristic, a good power-factor correction(PFC). This converter no needs an isolation transformer. 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, on-line UPS, power factor correction, PWM rectifier.

I. INTRODUCTION

Uninterruptible power supply (UPS) system are utilised for a many critical loads including computers, telecommunication systems and medical equipment to prevent the normal function interruption because disturbance in grid power such as outage, voltage sag, voltage glitch or voltage surge. On-line UPS systems are preferred where a highly reliable uninterruptible power supply is required. A various topology of on-line UPS systems up to 5 kV are reported in the literature [1],[2],[3],[4],[5]. The on-line UPS systems can use the bidirectional DC/DC converter.

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 double- conversion UPS plays important role in the design of a high performance for on-line UPS. The circuit topology is highly dependent on the overall efficiency, safety, regulation, costs.

The topology of double-conversion UPS is shown in Fig. 1.

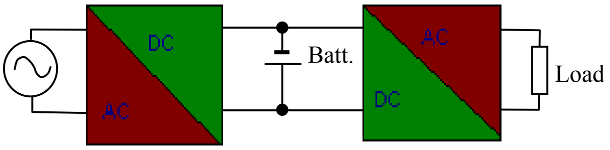

Fig.1 On-line UPS converter topology

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.2

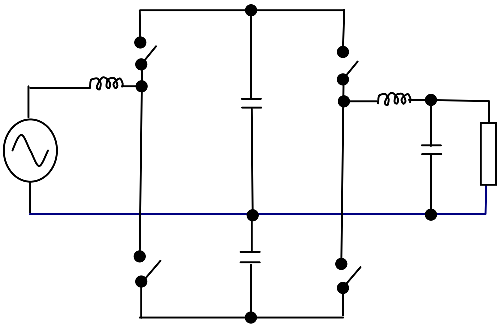

Fig.2 Single-phase common-neutral AC-AC converter topology

Figure 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 four parts: a common – neutral half-bridge PWM rectifier, a step-down DC/DC converter with battery bank, a static switch and an half – bridge inverter.

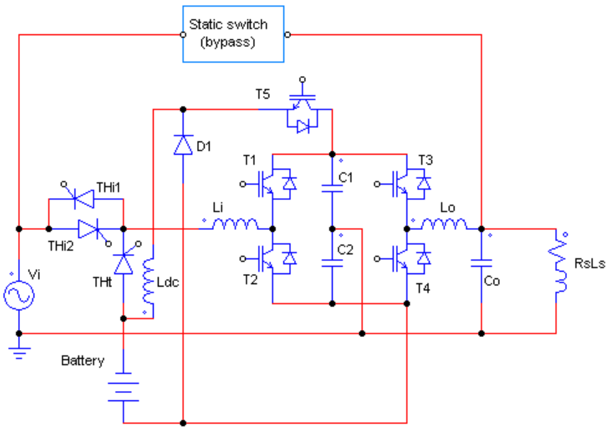

Fig.3 Single-phase on-line UPS based on a half – bridge PWM converter and inverter

One of the most important features of UPS system is their reliability and availability. The component that influences these characteristics is the battery. This UPS topology use a bidirectional DC/DC converter to connect the battery in UPS system.

The proposed UPS system has three operating modes: normal, stored-energy and bypass. In the normal mode of operation, the input AC voltage is within the permissible tolerance domain and the power is passed from the AC/DC rectifier to the DC/AC inverter and the load is continuously supplied with the AC power. The THt switch is turned off. The buck converter maintains the battery bank at full-charged. In the stored-energy mode, the input AC voltage is out of the permissible tolerance range, the switches THi1 and THi2 are turned off, the switch THt is turned on and the power is transferred to the AC line from the battery bank, and through the DC/AC inverter, to the load.

This UPS system 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 S2 is on, the expression for the voltage across the input inductor Li is [1]:

$$V_{Li} = L_i \frac{di_i}{dt} = V_i + V_{C2} \tag{1}$$

The voltage applied across the input inductor is positive and the inductor current increases. During this time, the current path is 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 V_i+ - L_i – reverse diode of 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]:

$$V_{Li} = L_i \frac{di_i}{dt} = V_i - V_{C1} \tag{2}$$

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:

$$V_{Li} = L_i \frac{di_i}{dt} = V_i - V_{C1} \tag{3}$$

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 S1 is on is 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, V_i+ - C_2 – reverse diode of 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]:

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

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 4 is shown the diagram of the implemented control of the rectifier (draws in PSIM).

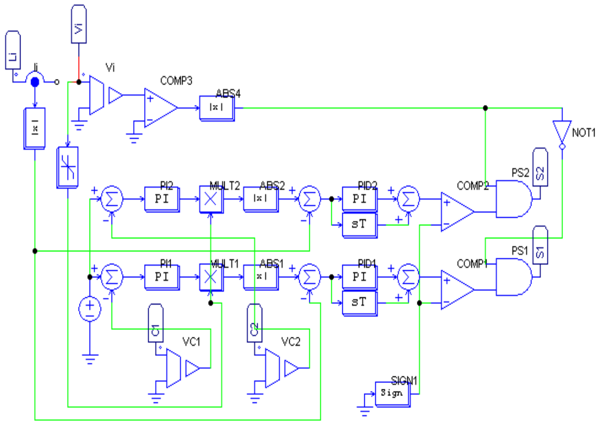

Fig.4 Control strategy of the AC – DC PWM common – neutral half-bridge rectifier.

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.

The step-down DC/DC converter charges the battery bank in the following manner [1]: when the switch S_5 is turned on, the DC voltage across the L_{dc} is positive, the current trough L_{dc} increase and charges the battery bank from the capacitor voltage V_{C1}; when switch S_5 is turned off, the inductor voltage V_{Ldc} is negative, the inductor current decreases and the battery bank is discharged through L_{dc} and D_1. The battery voltage is directly proportional with the duty ratio of S_5.

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 (Lo and Co)(RsLs 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 5 is shown the diagram of the implemented control of the inverter (draws in PSIM).

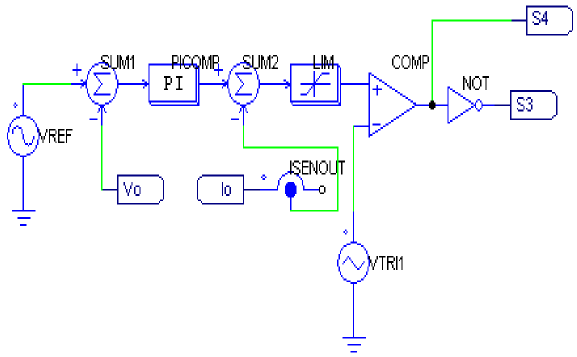

Fig.5 Control strategy for the DC – AC inverter

The control strategy employs two control loops: 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.

When the input AC voltage is beyond of the permissible tolerance range, the UPS system works in the stored-energy mode of operation. The input is transferred from the AC line to the battery bank. In this mode, the AC/DC converter works like a DC/DC converter using S_2, the reverse diode of S_1, inductor L_i and capacitors C_1 and C_2. When switch S_2 is turned on, the low battery input voltage is applied across L_I and increase the current through this inductor. When S_2 is turned off, the energy stored in L_i charges the two capacitors C_1 and C_2. The low battery voltage V_{bat} is boosted to the high DC voltage V_{dc} by turning switch on and off:

$$V_{dc} = \frac{V_{bat}}{1-D} \tag{5}$$

where D is the duty-cycle of S_2 in the stored-energy mode of operation.

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:

$$P_{in} = \frac{P_{out}}{\eta} = \frac{1000}{0.85} = 1176.5W \tag{6}$$

The minimum RMS input voltage is 180 V. The maximum input current I_{inmax} is drawn at minimum input voltage:

$$I_{in\max} = \frac{P_{in}}{V_{i\min}} = \frac{1176}{180} = 6.53A \tag{7}$$

The voltage across each DC-link capacitors is 310 V and the total voltage of the DC-link bus is 620 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]:

$$L_i = \frac{T \bullet V_{i\min}^2}{2I[\%] \bullet P_{out}}\left(1 - \frac{\sqrt{2} \bullet V_{i\min}}{V_{dc}}\right) = \frac{50 \bullet 180^2}{2 \bullet 0.35 \bullet 1176}\left(1 - \frac{\sqrt{2} \bullet 180}{620}\right) \cong 1162 \mu H \tag{8}$$

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, Pout is the maximum output power (W) and V_{dc} is the output DC voltage (V).

A value of 1200 μH has been chosen.

The selection of the DC-link capacitors C1 and C2 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]:

$$I_o = \frac{P_{out}}{U_o} = \frac{1000}{220} = 4.54\ A \tag{9}$$

The fundamental frequency current is[1]:

$$I_1 = \frac{I_o}{1.22} = \frac{4.54}{1.22} = 3.72\ A \tag{10}$$

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

$$i_{crms} = \frac{I_1}{2} = \frac{3.72}{2} = 1.86\,A \tag{11}$$

Specifying voltage ripples ΔVc of less than 1% or 1.69 V, we calculate the value for capacitors C1 and C2 according to [1]:

$$\Delta V_c = \frac{i_{crms}}{\omega C} = \frac{i_{crms}}{2\pi f \bullet C} \tag{12}$$

and

$$C = \frac{i_{crms}}{\omega \Delta C} = \frac{1.86}{2\pi \bullet 50 \bullet 1.69} = 1910\ \mu F \tag{13}$$

Has been selected two capacitors with 2200μF/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_o 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.6. The test time is 0.2 s. The amplitude of the sinusoid is around 285 V.

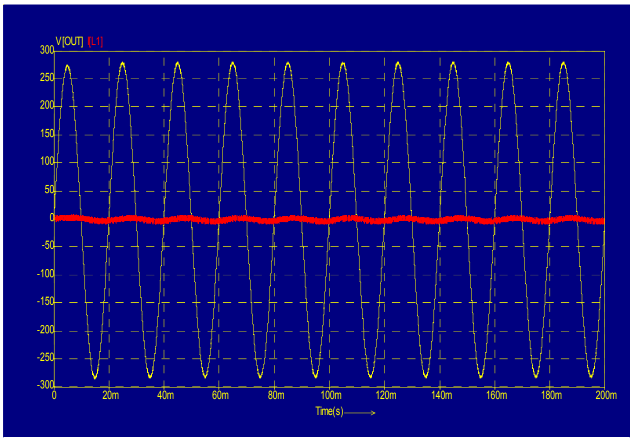

Fig.6. Waveforms for output voltage and current of the DC-AC inverter.

The differential voltage outputs waveform of the PWM rectifier is shown in the Fig.7. The values is stabilized around 165 V c.c. for each output. The test time is 0.4 s.

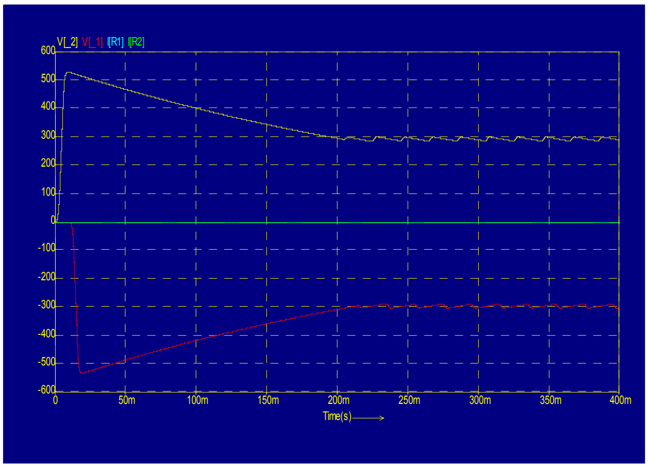

Fig.7. Waveforms for differential output voltage of the PWM rectifier.

The input AC voltage and current is shown in Fig. 8. The input current is sine wave and in phase with the input voltage resulting a good power factor.

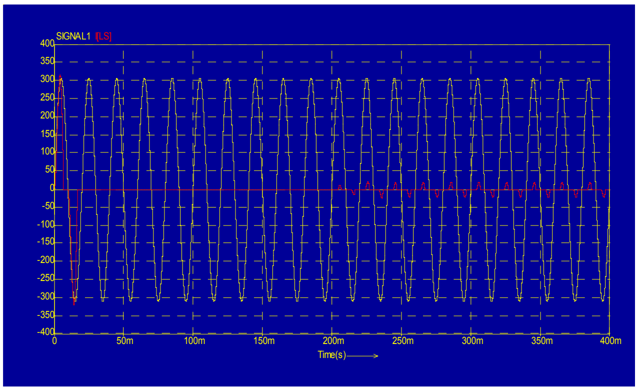

Fig.8. Waveforms for input voltage and current of the PWM rectifier.

In Fig. 9 is shown the DFT for the input voltage and current; the significant component is the 50 Hz.

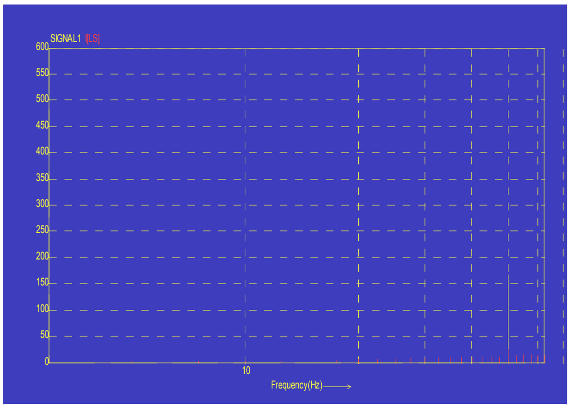

Fig.9. DFT for input voltage and current of the PWM rectifier.

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, on-line UPS systems or AC-DC-AC converter.

VIII. Appendix

Table I Specification of proposed PWM Rectifier

PWM Rectifier Parameters	
Power Rating	1000 W
Input Voltage	220 Vac / 50 Hz
Output Voltage	2 * 310 V
PWM Frequency	20 kHz

Table II Specification of proposed PWM Inverter

Inverter Parameters	
Power Rating	330 W
Input Voltage	2 * 310 Vac
Output Voltage	220 Vac / 50 Hz
PWM Frequency	20 kHz

IX. REFERENCES

[1] Ali Emadi, Abdolhosein Nasiri, Stoyan B. Bekiarov „Uninterruptible Power Supplies and Active Filters”, CRC Press, 2005

[2] V. Popescu, „Electronică de putere” Editura de Vest, 2005

[3] Gui-Jia Su, IEEE Senior Member, Donald J. Adams, „Comparative Study of Power Factor Correction Converters for Single-Phase Half-Bridge Inverters” – Paper PESC 2001

[4] L. Rossetto, G. Spiazzi, P. Tenti „Control Techniques for Power Factor Correction” – Paper

[4] M. Nakamura, Y. Fujitani, S. Kawauchi, „Several recent circuits in the Small Power UPS System” , National Convention Record, IEE IAS Japan (JIASC) vol.2, No. S-1-2-2, 1995

[5] K. Kuroki, „The Main Circuit Configuration of UPS”, JIASC, vol.2, No.S. 1-3, 1995