A NON-ISOLATED SINGLE PHASE ON-LINE UPS WITH 110V/220V INPUT OUTPUT VOLTAGE

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Abstract – **This work deals with the development of a single phase on-line uninterruptible power supply(UPS) with 110V/220V input output voltage rating. The converter consists of an ac-dc/dc-dc three level boost converter combined with a double half bridge inverter. In this type of configuration, size, cost and efficiency are improved due to reduced number of switches and batteries, as well as no low frequency isolation transformer is required to realize bypass operation. A high frequency operation of both converters is adopted using a passive non-dissipative snubber circuit in the boost converter and the latest available commercial technology of IGBTs switches in inverters. A simple and well known control strategy is presented. Principle of operation, simulation and experimental results for a 2.6kVA prototype is presented to demonstrate UPS performance.**

Keywords – **On-line UPS systems, Transformerless UPS, common neutral connection, unity power factor, soft commutation.**

I. INTRODUCTION

Uninterruptible power supplies (UPSs) are being widely used to supply clean and reliable power to critical loads, such as: medical systems, computers, network servers, communication systems and industrial processes. They also protect sensitive loads against power outages under any normal or abnormal utility power conditions. Among different types of UPS systems, the on-line UPS is the superior topology in performance, power conditioning and load protection.

In the conventional on-line UPS configuration, consisted of a boost rectifier/PFC, battery bank, an inverter, and a static switch(bypass), it is normally required an isolating transformer for proper operation of the bypass circuit and also to improve reability of the system during failures or overload. This isolation transformer when operating at the grid frequency, both size and cost are considerable.

Others topologies were proposed to overcome this problem placing the transformer in a high frequency DC link [1], [2], [3]. Although this UPS topology incorporating a high frequency transformer reduces weight of the system, it has increased the number of active switches, compromising the system overall efficiency and reability.

Transformerless UPS incorporating common neutral bus line using half-bridge converter and inverter in both AC/DC and DC/AC conversions, has attracted special interest for applications in computer and telecommunication systems. This type of circuit is highly cost-effective and acceptable due to its total power conversion efficiency improvement and volume and weight reduction [4], [5], [6]. However, with conventional boost chopper circuits the higher the step-up ratio the lower the boost efficiency. For that reason a new boost chopper circuit configuration has been proposed in [7]. Although this topology have offered a way to reduce battery bank size, step-up ratio and capacitors unbalance, it has some disadvantages such as: AC-DC converter switches are exposed to total DC link voltage, larger reactive power flows during rectifier operation and the bidirectional boost-chopper inductor is larger than the one used in normal mode.

The single phase three-level rectifier with a half bridge inverter, seen in Fig. 1, can be advantageous for many applications. In this converter only half of the DC link voltage is applied across the rectifier switches and the current flows through only two or three power semiconductors simultaneously. Therefore this converter presents less conduction losses, and a common neutral bus line is connected between the middle point of DC capacitors link and load, making it possible to realize the bypass operation without an isolating transformer.

This topology while operating in battery powered mode, inserting the battery set before the boost inductor, does not provide a way to charge the two DC link capacitors separately. Other possibility is connecting the battery set across the DC link, but a large number of batteries in series connected is required due to the high DC bus voltage.

Fig. 2 shows a modified single phase three level rectifier and a half bridge inverter scheme reported in [8], [9], with battery set and static switches arrangement that overcomes the drawbacks related above.

The most advantages of this configuration is the possibility to correct the DC link capacitors voltage unbalance, reduce both step-up ratio of the boost converter and the number of batteries set during battery powered operation mode and fewer active switches compared with topologies presented in [4], [5], [6], [7].

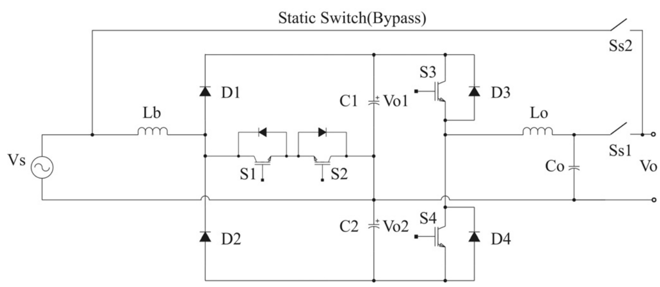

Fig. 1. Single phase three level rectifier and a half bridge inverter.

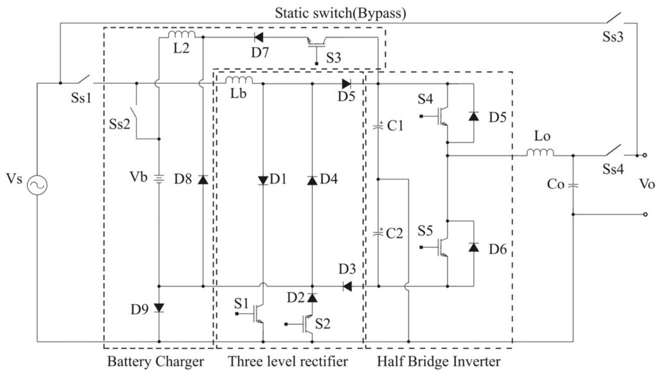

Fig. 2. Modified three level rectifier with half bridge inverter scheme.

These topologies with common neutral PWM boost rectifier in the front end of the UPS system are characterized as voltage doublers [10] requiring a minimum DC link voltage of 622V for operation of the boost rectifier when the utility voltage is 220Vac. This operating voltage requires higher cost semiconductors and passive components. Moreover, it requires a very high voltage battery bank, which leads to increased storage battery cost and lower reability.

In this paper it is proposed a circuit configuration that combines the advantages of the presented topologies with common neutral connection, three level rectifier and half bridge inverter, and, at the same time it can operate for any input/output voltage (110V/220V) requirements.

II. PROPOSED UPS CIRCUIT

A. Circuit Description

The schematic of the single phase on-line UPS with universal input output voltage is shown in Fig. 3. Due to the high voltage of the DC link required by the 220Vac utility supply, an autotransformer with three taps provides the operation of the UPS with 110Vac. Using this configuration is possible to use the topologies proposed with common neutral connection without increasing to much the system overall cost. The autotransformer is, at least, 50% cheaper and half the weight of the isolating transformer, which is normally bulky and heavy while operating in commercial AC line frequency. That solution makes this UPS topology possible to work in any conventional utility AC voltage (110V/220V).

This scheme also has the capability of supplying two different levels of load voltage. In this system the two specifications of input voltages fixes the two outputs voltages, so the ratings of output voltages are 110Vac and 220Vac. To achieve this, a double half bridge circuit [11] provides two outputs of 110Vac, each one with half of total output power of the boost converter.

Synchronizing operation of both half bridge inverters legs, it is possible to generate two sinusoidal voltages in phase with 110Vac rms. This operation provides 220Vac output voltage in the connection showed in Fig. 3. This is obtained by the sum of the two individual outputs voltages. When using only this tap as load, it could deliver total output power of two half bridge legs.

If there are loads in both 110Vac and 220Vac output, the system also has the same performance, providing a high quality sinusoidal voltage for each output, sharing output power while respecting the limit of the power capacity of each 110Vac and 220Vac output, Two separated control schemes, one for each half bridge leg, have been used, as will be explained further.

To perform bypass operation, four static switches have been used for connecting AC line directly to load during system overload or problems with the converters operation. Two additional static switches or electromagnetic contactors are used to commutate between ac line mode to battery mode.

A simple buck converter, showed also in Fig. 3, is used to perform battery charging regulation.

B. Principle of Operation

The operation of the proposed UPS can be divided in three modes: the on-line mode, the battery powered mode and the bypass mode.

1) The On-line mode operation: In accordance with the utility voltage level, an automatic detector sets the UPS for the proper input voltage. When the utility voltage is 220Vac, the voltage selector should go to position 1, applying the 220V utility voltage across the autotransformer 220V winding, and a tap divides input voltage providing to the

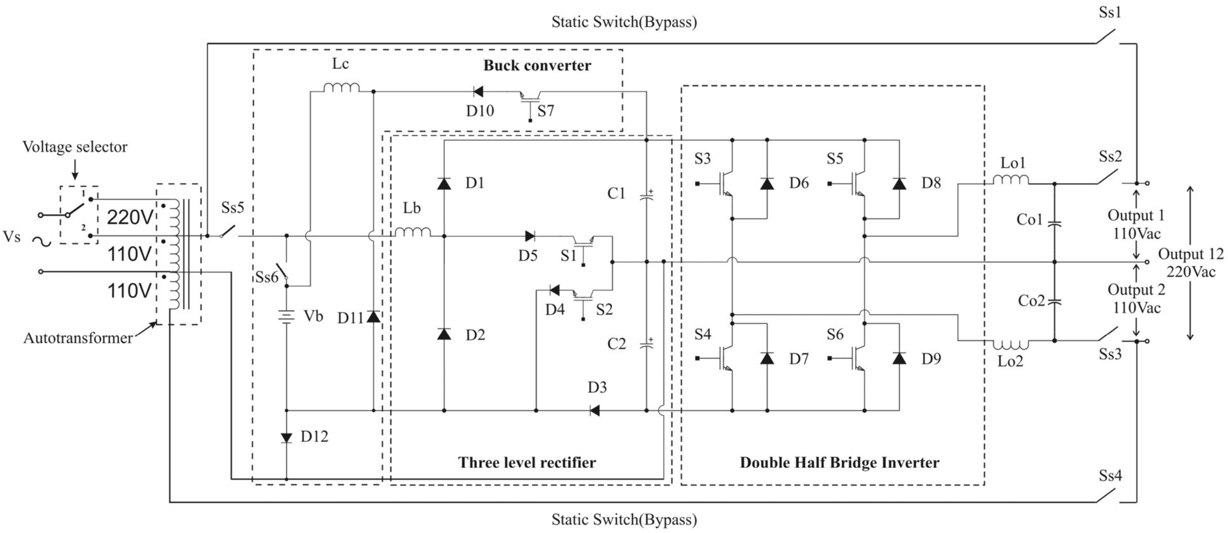

Fig. 3. Proposed single phase on-line UPS topology with 110V/220V input output voltage.

boost rectifier with 110Vac. On the other hand, if the utility voltage is 110Vac, the voltage selector should be switched to position 2, which winding is always supplying the converter with the same input voltage value. During the on-line operation mode S_{s5}, S_{s2} and S_{s3} are kept on and S_{s1}, S_{s4} and S_{s6} kept off. The control of the three level rectifier operating in the boost mode is realized in such a way to provide an ac line current with low THD and high power factor, while maintaining a constant and balanced dc voltage across the DC link capacitors. The generated current paths and switches state in accordance with Vs of the boost mode operation is shown in Table I. The double half bridge inverter operates as two independently half bridges, as well known and used in literature, synchronized to obtain 220Vac output by the sum of two 110Vac outputs in phase.

2) Battery powered mode operation: When the supervisory circuit detects ac line failure, switch Ss_5 is turned off and Ss_6 turns on, transferring the input of the boost converter from the ac utility to the battery bank for boost dc/dc operation, which now function as described in table I. In this way as the on-line operation mode, battery transfer energy to each capacitor during half cycle of the utility. V_{bat} represents which capacitor that will receive energy during battery powered operation with its respective current path.

3) Bypass mode operation: During overload in the UPS converter, a supervisory circuit detects the fault and sets static switches Ss_1 and Ss_4 to on while Ss_2 and Ss_3 are set to off in order to isolate the failure. This provides zero time transfer ratio. The autotransformer has three taps, two of them to supply the UPS input in 110Vac as mentioned above and the third one is used in the bypass mode supplying the second half bridge leg output with 110Vac.

C. Control Strategy

A simplified analog scheme with a supervisory circuit using an 8-bit high performance RISC microcontroller PIC16F870 is implemented in this work.

1) Three level boost converter control strategy: The three level boost converter operating control scheme for both on-line mode and battery powered mode is showed in Fig. 4. A simple control strategy using UC3854B controller from Texas Instruments is adopted as main controller to accomplish a low distortion sinusoidal ac line current, using instantaneous average current mode control [12]. An external

TABLE I. Boost Operation Switching States

On-Line operation current path		
Vs cycle	Energy storage in inductor Lb	Energy transfer to DC link
(+)	Vs ➔ Lb ➔ D5 ➔ S1 ➔ Vs	Vs ➔ Lb ➔ D1 ➔ C1 ➔ Vs
(-)	Vs ➔ S2 ➔ D4 ➔ D2 ➔ Lb ➔ Vs	Vs ➔ C2 ➔ D3 ➔ D2 ➔ Lb ➔ Vs
Battery powered operation current path		
V_{bat}	Energy storage in inductor Lb	Energy transfer to DC link
(C1)	Vb ➔ Lb ➔ D5 ➔ S1 ➔ S2 ➔ D4 ➔ Vb	Vb ➔ Lb ➔ D1 ➔ C1 ➔ S2 ➔ D4 ➔ Vb
(C2)	Vb ➔ Lb ➔ D5 ➔ S1 ➔ S2 ➔ D4 ➔Vb	Vb ➔ Lb ➔ D5 ➔ S1 ➔ C2 ➔ D3 ➔ Vb

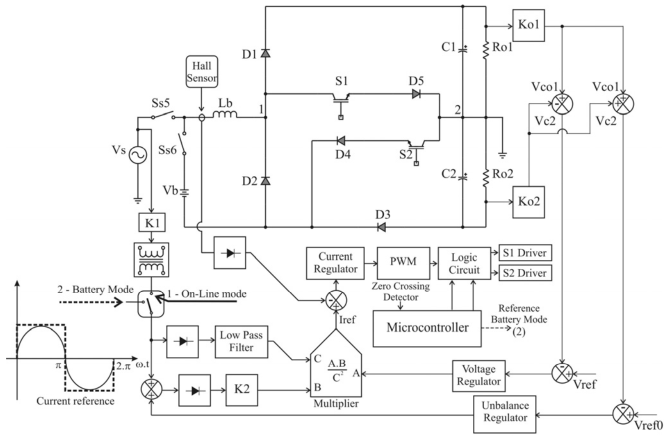

Fig. 4. Three level boost converter control block.

regulator is used to obtain voltage balance compensation signal to be add with input current reference.

During on-line mode of operation the current reference signal is obtained from AC line when controller switch mode relay is in position 1.Then in battery operation mode is switched to position 2 to provide a symmetric dc reference. To accomplish capacitors voltage balance in battery powered mode it is necessary this waveform in current reference. A logic circuit after PWM signal is synchronized by microcontroller and used to provide gating signals for S1 and S2 switches in both operations modes.

2) Double half-bridge control strategy: Due to the fact that each half bridge inverter have a separated output, two similar PID controllers were used to provide output voltage regulation. Fig. 5 shows a reduced scheme of the inverters control block. Sinusoidal pulse width modulation technique for the closed-loop regulation with a LC filter at the output provides a high quality sinusoidal voltage to load. Bipolar modulation strategy is adopted, applying a two level voltage waveform in the input of LC filter.

In the circuit shown in Fig. 5, the reference sinewave generated by the microcontroller is synchronized with the utility and compared with the output voltage, so the output voltage is always equal to the reference sinewave of each inverter. The microcontroller with an external D/A converter generates a sinewave reference synchronized with the utility voltage. The main feature of this control strategy is that the sinusoidal reference voltage for each half bridge controller is delayed 180º from each other in order to provide a sum of two output voltage when supplying the load in 220Vac.

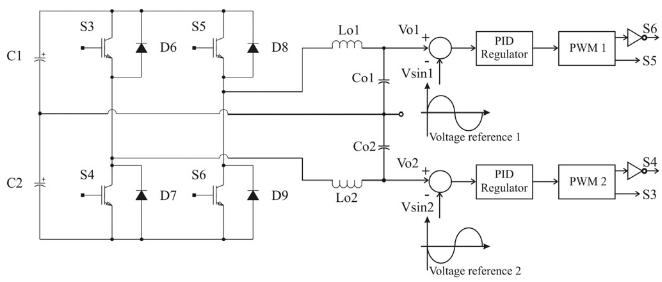

Fig. 5. Simplified double half bridge control block.

III. PASSIVE NON-DISSIPATIVE SNUBBER CIRCUIT APPLIED IN THE FRONT END CONVERTER

A passive non-dissipative snubber circuit presented in [13] was employed to achieve soft commutation, during turn-on and turn-off in both active switches in three level converter, increasing system overall efficiency in any operation mode and allowing the increase of switching frequency operation of the three level converter.

Fig. 6 shows the turn-on turn-off snubber circuit topology applied to the three level boost converter. The passive components used in each boost diode(D_1 and D_3) are shown within the dashed line. Recovery mechanism in diode D_2 does not need to be minimized because during the negative cycle of the utility it is conducting(On-line Mode) and during the battery powered mode it is always blocked. A detailed description, operation and project procedure is presented in [13].

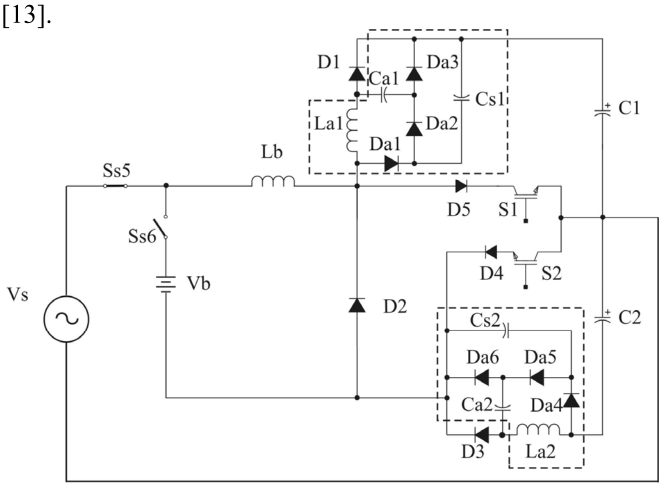

Fig. 6. Passive non-dissipative snubber circuit scheme applied in the three level boost converter.

IV. SIMULATION AND EXPERIMENTAL RESULTS

The proposed non-isolated single phase on-line UPS with 110V/220V input/output voltage design specifications are showed in table II, III, IV and V. The switching frequency of both converters was assumed f_s=50kHz.

TABLE II. Developed UPS Specifications

Input voltage	1Ø 110V / 220V ±15%
Output voltage	110V(Vo1, Vo2) / 220V(Vo12)
Commercial Frequency	50 / 60Hz
Output Power Capacity	1.3kVA per Half Bridge Inverter
Input Power Factor	0.99
Output Power Factor	0.7* – 1.0
DC Link Voltage	440V
Number of Batteries (In series)*	9 (12V/7Ah)UP1270-Unipower

TABLE III. Parameters of UPS AC/DC Converter

Three Level Boost Converter Parameters	
Boost Inductor	L_b = 330µH
DC Link Capacitors	C1 = C2 = 3000µF
Diodes D_1, D_2, D_3, D_4 and D_5	HFA25TB60
Switches S_1 and S_2	APT40GT60BR

Table IV. Parameters of UPS DC/AC Converter

Double Half Bridge Parameters	
Filter Inductors	$L_{o1} = L_{o2}$ = 280µH
Filter Capacitors	$C_{o1} = C_{o2}$ = 60µH
Switches S_3, S_4, S_5 and S_6 with Co-pack Diodes D_6, D_7, D_8 and D_9	IRGP35B60PD

Table V. Parameters of Non-Dissipative Snubber Circuit

Resonant Inductors	$L_{a1} = L_{a2}$ = 0.9µH
Polypropylene Film Capacitors	$C_{a1} = C_{a2}$ = 47nF $C_{S1} = C_{S2}$ = 680nF
Diodes D_{a1}, D_{a2}, D_{a3}, D_{a4}, D_{a5} and D_{a6}	MUR860

In the simulated circuit, have been used the same parameters of the laboratory prototype. then, comparison can be made between simulation and experimental results.

The simulation results of the input voltage, the input current and DC link capacitor voltages are shown in Figures 7(a) and 7(b). In this simulation, only the AC/DC converter was analyzed during on-line operation mode with 100% of resistive load connected in both output capacitors. In the Fig. 8, both outputs voltages and currents from each inverter can be viewed while it is supplying a non-linear load with crest factor of 3 and power factor of 0.7, resulting in each output an apparent power equal a 1.3kVA. The results in Fig. 8 were made simulating only the double half bridge inverter at full load connected in 110V outputs. Fig. 9 shows the output voltage and current while the ups is supplying a non linear load with an apparent power equal a 2.6kVA at 220V.

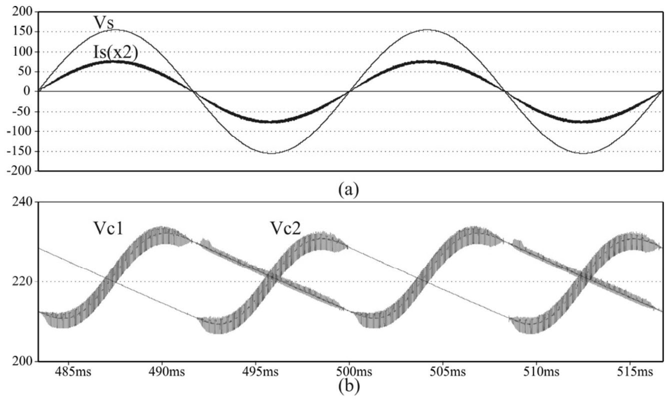

Fig. 7. Simulation results a) Input voltage and current(x2) and b) DC link capacitors voltage.

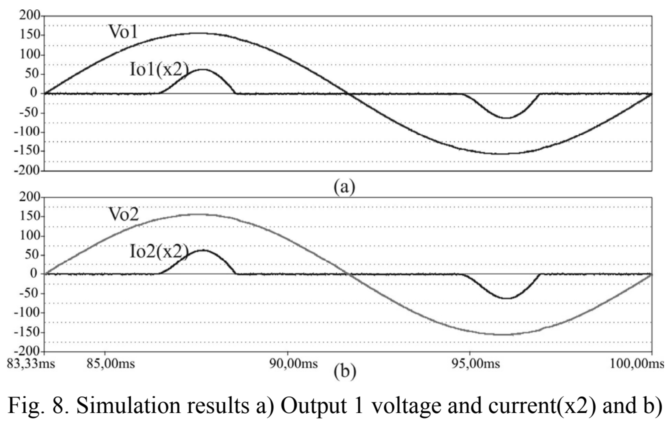

Fig. 8. Simulation results a) Output 1 voltage and current(x2) and b) Output 2 voltage and current(x2).

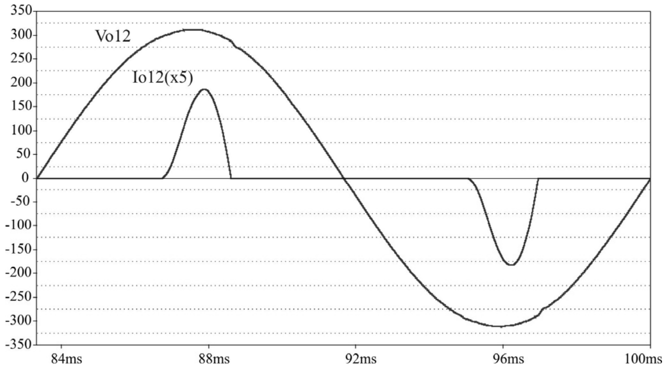

Fig. 9. Simulation results. UPS output voltage and current(x5).

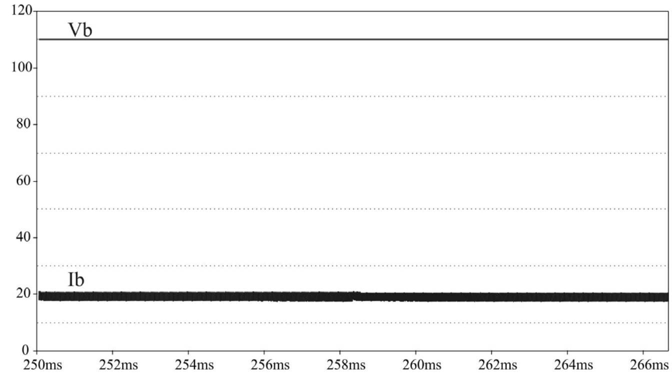

Fig. 10. Simulation results. Batteries voltage and current.

Fig. 10 shows the batteries voltage and current drawn during battery powered mode, while the battery bank is in the nominal voltage and the inverter is supplying a non-linear load in both voltage ratings.

The input voltage and the input current are shown in Figs. 11(a) and 11(e) respectively, where high power factor with low THD were obtained. The experimental results in Figs. 11(a), (b), (c) and (d) were made during on-line mode operation with linear load at both outputs. The waveforms shown in Fig.11(e), (f), (g) and (h) were obtained when the inverters are supplying non-linear loads with crest factor of 3 and power factor of 0.65. DC link capacitors voltages are shown in Figs. 11(b) and 11(c). The UPS control maintains balanced voltages in upper and lower DC link capacitors even if the inverters type of load are modified. The output voltages and currents are shown in Figs. 11(c), (d), (g) and (h) where can be seen that a high quality sinusoidal voltage waveform is supplied by the inverter independent of the characteristic of load connected. Figs. 11(c) and 11(g) show the condition for full load at each output of the inverters resulting in a 110V rms supply, and in Figs. 11(d) and 11(h) show the condition for full load in both outputs resulting in a 220V rms connection as shown in the Fig. 3. Efficiency, power factor and outputs regulation voltages versus output power are showed in Figs. 11(i) and 11(j) respectively, where the indicated voltages are the

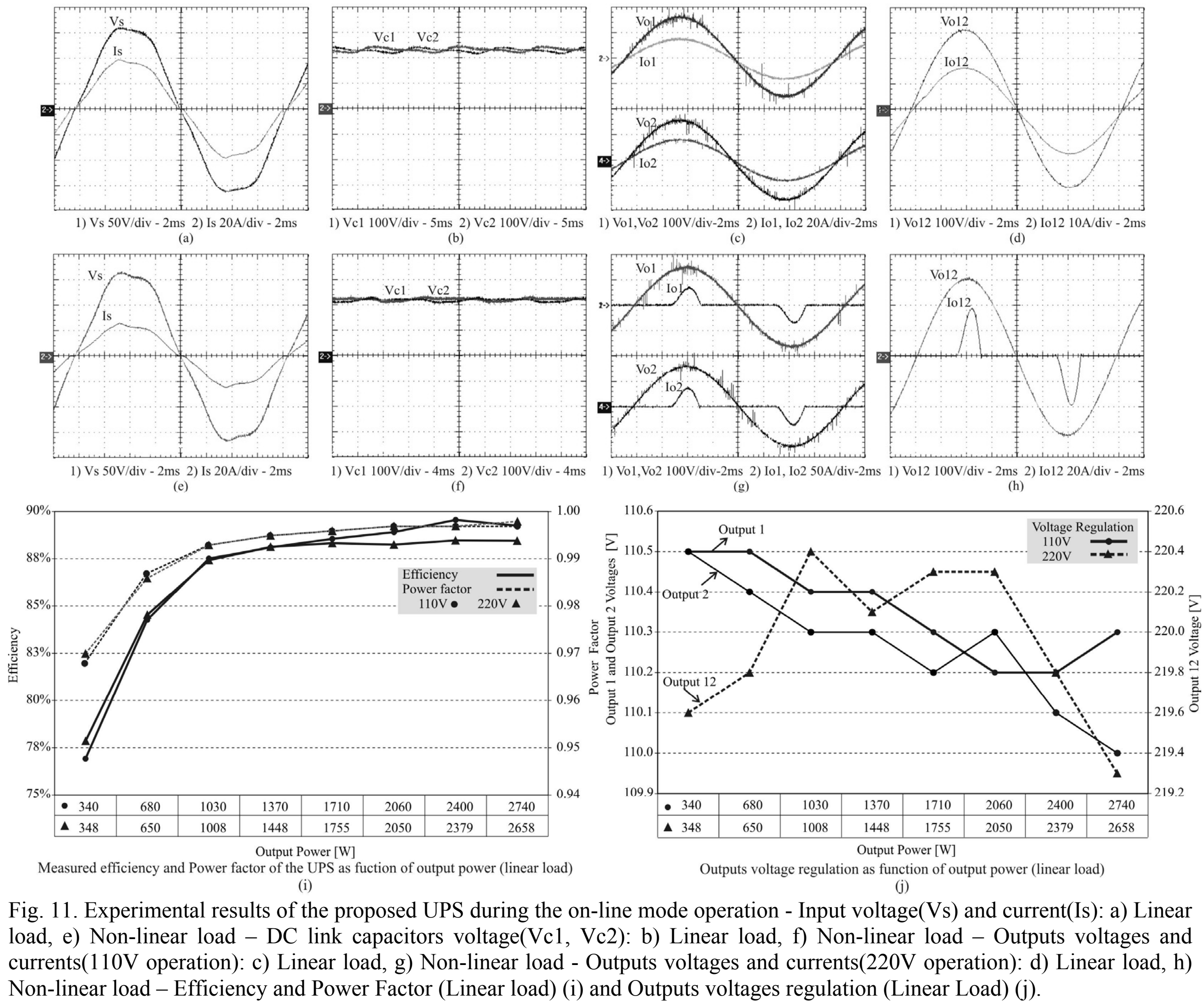

Fig. 11. Experimental results of the proposed UPS during the on-line mode operation - Input voltage(Vs) and current(Is): a) Linear load, e) Non-linear load – DC link capacitors voltage(Vc1, Vc2): b) Linear load, f) Non-linear load – Outputs voltages and currents(110V operation): c) Linear load, g) Non-linear load - Outputs voltages and currents(220V operation): d) Linear load, h) Non-linear load – Efficiency and Power Factor (Linear load) (i) and Outputs voltages regulation (Linear Load) (j).

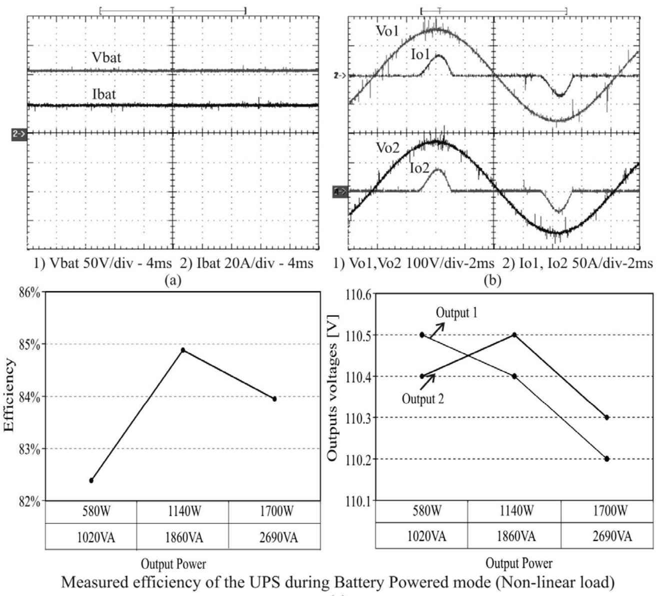

Fig. 12. Experimental results during the battered power mode – Battery input voltage and current (a) – Outputs voltages and currents (b) – Efficiency of the proposed UPS (c)

output types of connection (110V load or 220V load). Both graphics were made using linear loads in the outputs of the inverters. Based on experimental results in the on-line mode, the UPS system achieved a high efficiency even if operating with a high switching frequency of both converters. The results in battery powered mode are shown in Fig. 12.

In the Fig. 12(a) are shown the voltage and current drawn by the batteries set during battered powered mode operation. Two non-linear loads connected at each output of the inverter with the same characteristics as on-line mode operation were used (Outputs in 110V). As shown in this figure, average current mode control realized a continuous dc current drawn by the battery with a low ripple, enhancing the reliability and life of the battery bank. Output voltages and currents are shown in Fig. 12(b). As in the on-line operation mode, inverters operated with the same performance. The efficiency curve and output voltages regulation in this operation mode can be viewed in Fig. 12(c) for non-linear load connected at the outputs of the inverters supplied with 110V rms.

V. CONCLUSION

This paper has proposed a non-isolated single phase 110V/220V input output voltage UPS with a configuration that overcomes the problem associated with voltage doubler topologies when supplied by 220Vac as commercial voltage.

The other main advantage of the proposed topology is the possibility of supplying two different voltage ratings at the UPS output, without reducing system overall efficiency and reability. No isolating transformer is required to realize bypass operation, even if the voltage rating of the load is different as the main.

A passive non-dissipative snubber circuit was used to improve three level rectifier efficiency, while operation in both on-line and battery modes, reducing di/dt of reverse recovery mechanism in boost diodes and high current peak through the switches.

This UPS is very attractive for medium power rating (above 2kVA), and when produced in industry scale provides a highly cost-benefit, that could be used for a wide range of applications and equipments specified for 110V/220V voltage. Simulation and experimental results were presented to verify the performance of the proposed UPS system.

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