# A New Control Strategy for the Boost DC-AC Inverter

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***Abstract*-This paper proposes a new control strategy for the Boost DC-AC inverter that interactively controls each Boost converter by means of a new double-loop regulation scheme. Simulation and experimental results show that this strategy is robust, accurate and highly insensitive to input voltage and output load variations.**

## I. Introduction

The Boost DC-AC inverter (shown in Fig. 1), also known as Boost inverter, is a special topology that consists of two individual Boost converters. These Boosts are driven by two 180° phase-shifted DC-biased sinusoidal references whose differential output is an AC output voltage with a peak value that can be lower or greater than the DC input voltage. The advantages of this structure have been broadly explained in literature [1-4].

The control of this structure requires controlling both Boost converters. However, the Boost converter is a difficult system to be controlled. Several methods based on the small-signal linearized model have been designed to control the Boost around the operation point for which that model is calculated [5-7]. However, these methods are not valid to control the Boosts of the inverter because now the operation point is changing and so do the model parameters.

The sliding mode control has been proposed to control the variable operation point Boost converter, and hence the Boost inverter [2-3]. This control strategy achieves good steady state results. However, sliding mode control has some disadvantages related to the required complex theory, the variable switching frequency, the lack of an inductance averaged-current control and the constraints to the controller parameter selection [4].

The control strategy for the Boost inverter described in this paper proposes a new interactive regulation of both Boost converters, being each one of them controlled by means of an also new control scheme. This control scheme consists of two control loops, an inner inductance current control loop and an outer output voltage control loop [8]. Both control loops are based on the averaged continuos-time model of the Boost topology [9] and include some compensations in order to deal with the variable operating condition of both Boosts. Besides, these compensations make the controlled system be robust to both input DC voltage and AC output current variations, which represents a very valuable additional advantage. Simulation and experimental results show the good behaviour of this new control strategy and its better characteristics in comparison with the sliding mode control.

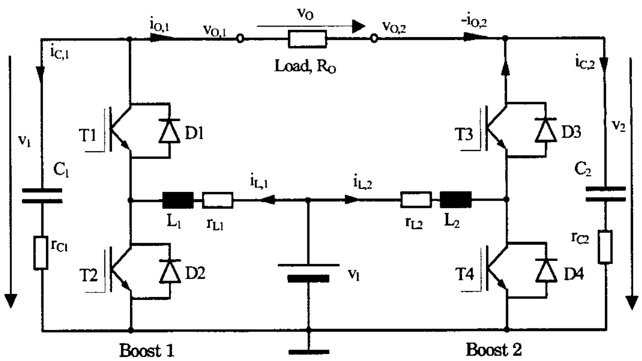


Fig. 1. Boost DC-AC inverter

## II. A new control strategy for the Boost converter

As mentioned in the introduction, each Boost converter is proposed to be controlled by means of a new control strategy based on the Boost averaged continuos-time model, which is described by the following equations:

$$v_I - v_L = (1-d)v_O \tag{1}$$

$$i_C + i_O = (1-d)i_L \tag{2}$$

where $v_o$ is the capacitor (or output) voltage, $v_I$ is the input voltage, $v_L$ is the inductor voltage, $i_o$ is the output current, $i_C$ is the capacitor current, $i_L$ is the inductor current and $d$ is the time-averaged value of the duty cycle.

Transfer functions for the inductor and capacitor are

$$\frac{I_L(s)}{V_L(s)} = \frac{1}{r_L + Ls} \tag{3}$$

$$\frac{V_O(s)}{I_C(s)} = \frac{1+r_C Cs}{Cs} \tag{4}$$

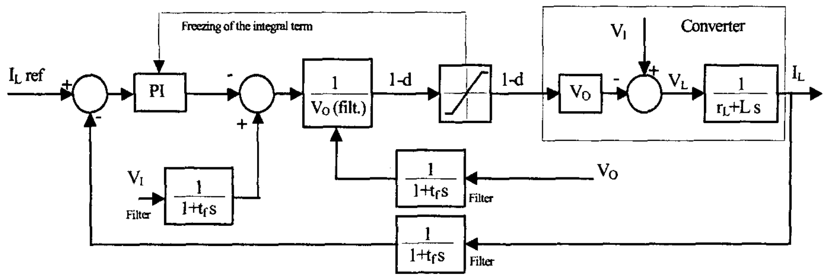


Fig. 2. Inductor current control loop

where $L$, $C$, $r_L$ and $r_C$ are the values for the inductance, capacity, and inductor and capacitor resistance.

The proposed inductor current control loop of the new double-loop control strategy, which is shown in Fig. 2, is based on (1) and (3). In variable operating conditions, these equations show a non-linear system that depends on the output voltage ($v_O$), and in which the input voltage ($v_I$) appears as an external perturbation. The output voltage can actually be considered a variable gain and therefore it can be compensated by means of a gain that is the inverse value of this output voltage. This can be done due to the much higher current loop bandwidth in comparison with the output voltage bandwidth. The influence of the input voltage $v_I$ is cancelled by adding again to the control loop this perturbation with its opposite value. With both compensations, the plant to be controlled consists only of the inductor transfer function given by (3). Then the proportional-integral (PI) controller can be designed by traditional methods. The required filtering of the electrical variables to eliminate switching harmonics has no influence on the loop dynamics because the switching frequency is much higher than the loop bandwidth. Finally, the calculated value of 1-$d$, which actually gives the value of the duty cycle, is limited in order to avoid too high voltages and noise influences, and a freezing action of the controller integral term is activated in case of saturation.

The output voltage loop, which is presented in Fig. 3, is derived from (2) and (4) and based on the same philosophy as the current loop. However, the plant to be controlled, i.e. the converter, shows now a variable gain defined by 1-$d$, which cannot be completely compensated because its dynamic behaviour is much faster than the loop. Although the use of a strongly filtered inverse gain has been proved with good results, the compensation by means of the gain defined by $v_O/v_I$ has shown to achieve more accurate and fast results. That compensation can be done because, due to the relatively small size of the inductance in power Boost converters, inductor energy variations are negligible in comparison with those produced in the input supply, output capacitor and output load. With this compensation strategy, quick duty cycle variations will not be completely neutralized, but variations up to the voltage loop bandwidth will be successfully compensated. Therefore, this strategy permits the system to track accurately different voltage references up to the loop bandwidth. Finally, the external output current perturbation that exhibits the converter model can be neutralized by adding again this perturbation to the control loop. As the inductor current is considered instantaneously controlled, the final plant to be controlled consists only of the capacitor transfer function described by (4), and therefore, the PI controller can now be designed by simple traditional techniques. As with the current loop, filtering of variables and freezing of the controller integral term are also used with no consequences for the control loop behaviour.

## III. CONTROL OF THE BOOST DC-AC INVERTER

The output voltage control of the Boost DC-AC inverter is achieved by implementing the previously described control strategy on both Boosts, and driving them with proper voltage references. Traditionally, both Boosts are driven by the following independent DC-biased sinusoidal references:

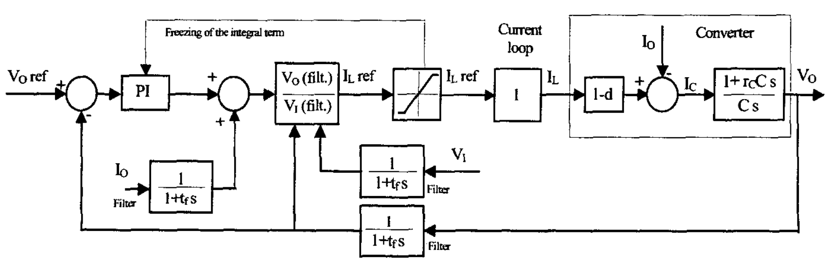


Fig. 3. Output voltage control loop

$$v_{1,ref} = V_{DC} + \frac{1}{\sqrt{2}} V \sin(\omega t)$$
$$v_{2,ref} = V_{DC} - \frac{1}{\sqrt{2}} V \sin(\omega t) \quad (5)$$

where $V$ is the AC output voltage rms-value and $V_{DC}$ the references DC-bias.

The main disadvantage of this first method is that the inverter output voltage is not directly controlled, and can be affected by transient errors and DC offsets.

A possible solution for this problem is to set a reference for the first Boost and use the second Boost to control directly the inverter output voltage, being therefore the references for each Boost

$$v_{1,ref} = V_{DC} + \frac{1}{\sqrt{2}} V \sin(\omega t)$$
$$v_{2,ref} = v_1 - v_{o,ref} = v_1 - \sqrt{2} V \sin(\omega t) \quad (6)$$

In short, the first Boost gives the primary reference and the second one compensates variations on the inverter AC output voltage. In this way, transient perturbations can be better rejected.

A third method is proposed that improves the system response in case of perturbations. Boost dynamic properties depend on the actual value of its duty cycle, which obviously is changing with the varying output voltage. Fastest dynamics appear at the lowest levels of the duty cycles. Therefore, the Boost that has to compensate the output voltage variations can be selected depending on the sign of the sinusoidal output voltage. Then, the new references for each Boost are now:

$$if\ \sin(\omega t) < 0 \Rightarrow \begin{cases} v_{1,ref} = V_{DC} + \frac{1}{\sqrt{2}} V \sin(\omega t) \\ v_{2,ref} = v_1 - v_{o,ref} = v_1 - \sqrt{2} V \sin(\omega t) \end{cases}$$
$$if\ \sin(\omega t) > 0 \Rightarrow \begin{cases} v_{1,ref} = v_2 + v_{o,ref} = v_2 + \sqrt{2} V \sin(\omega t) \\ v_{2,ref} = V_{DC} - \frac{1}{\sqrt{2}} V \sin(\omega t) \end{cases} \quad (7)$$

The three methods have been analyzed and the third method has been confirmed to be quicker and achieve best results being thus implemented in the inverter prototype. However, an important restriction of this third method is its difficult of physical implementation. Due to the necessary reference changes at the zero crossing of the sinusoidal waveform, little perturbations can appear at these points in the output voltage that can create small harmonics. Therefore, small tracking errors are required in order to avoid output voltage perturbations.

## IV. SIMULATION RESULTS AND COMPARISON WITH THE SLIDING MODE CONTROL

The characteristics of the control strategy proposed in this paper have been satisfactorily tested both by theoretical simulations and practical experimentation. Each Boost is controlled by means of the double-loop control scheme introduced before, and the so-called "third" method previously proposed is used to generate the voltage references for both Boosts.

The inverter parameters have the following values:
$L = 150\mu H;\ C = 30\mu F;\ r_L = 10m\Omega;\ R_O = 25\Omega;$
$V_I = 50V;\ V = 120V;\ V_{DC} = 150V;$
$f_s = 20kHz;\ f = 50Hz;$
where $R_o$ is the output load, $f_s$ the switching frequency, and $f$ the AC output frequency.

The main characteristics of the double-loop control scheme for each Boost are a current loop bandwidth close to 4 kHz and a voltage loop bandwidth of about 400 Hz, which permits an accurate tracking of the 50 Hz voltage references.

Nominal operating simulation results are presented in Fig. 4. First graph shows the inverter output voltage and its voltage reference. This graph proves that the control strategy achieves an accurate output voltage tracking. Second graph presents the output voltages of both Boost converters and the DC input supply voltage, and the last graph shows both inductor currents. As it can be seen, the double-loop control scheme for each Boost obtains accurate output voltages with the Boosts working in a variable operating condition while keeping inductor currents under control.

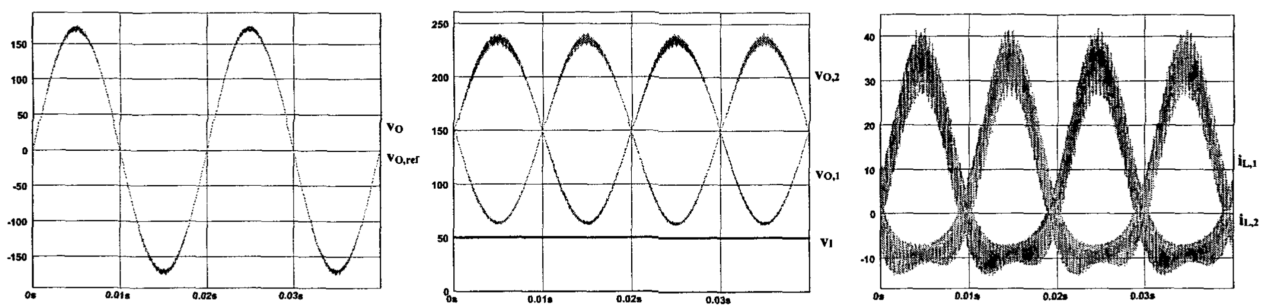


Fig. 4. Nominal operating simulation results

The robustness of the control strategy to both input DC voltage variations and output load changes is demonstrated in Fig. 5 and Fig. 6. The first simulation (Fig. 5) shows the system behaviour when a sinusoidal-wave of 15 V is added to the 40 V DC voltage. In the second one (Fig. 6), the nominal output load is connected at the first sinusoidal maximum, and removed at the second. Both figures reveal that, due both to the compensations implemented in the double-loop control scheme and to the method used to generate the two Boosts voltage references, the control strategy achieves a fast and stable control of the inverter output voltage even in these difficult operating situations.

In order to compare the sliding mode control to the control strategy proposed in this paper, a sliding mode control scheme has been designed for the two Boosts of the inverter. Fig. 7 shows the scheme for Boost 1. Sliding mode control uses a sliding surface which is a linear combination of the inductor current and capacitor voltage errors, with coefficients $k_1$ and $k_2$, respectively. The sliding surface generates the switching pulses to the semiconductor devices by means of an hysteresis comparator. The switching frequency that results from this scheme is not constant. Although it can be upper bound, the output voltage will show low-order harmonics. This problem does not appear in the new control strategy as it works with a constant switching frequency.

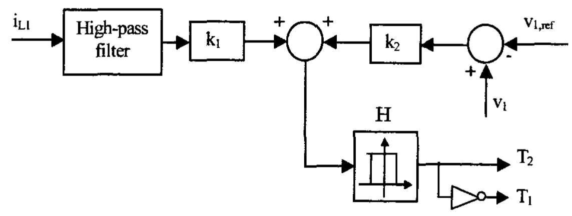


Fig. 7. Sliding mode control scheme

Due to the difficulty calculating the inductor current reference, the current error is taken as the high-frequency component of the inductor current, and thus measured by means of high-filtering the current. The main disadvantage of this current error calculation is the lack of control of the inductor current average value, which can lead the current to reach high and dangerous values in some situations such as strong load changes.

The calculation of the control parameters $k_1$ and $k_2$ is restricted by the sliding mode existence and the system response fastness [2,4]. The parameters of the designed sliding mode controller for each Boost are $k_1$=0.0427 and $k_2$=0.022.

Steady state simulations with the designed sliding mode controller are quite good specially considering the Boosts variable operating condition. However, its dynamic behaviour in transient situations is worse than the proposed control strategy. This is shown in Fig. 8, which presents the simulated sliding mode control behaviour for the same output load variations as those done in Fig. 6. As it can be seen, the proposed control strategy has better performance in transient situations with a more fast, accurate and controlled response.

As it was mentioned before, an important disadvantage of the sliding mode control is the lack of control of the inductor

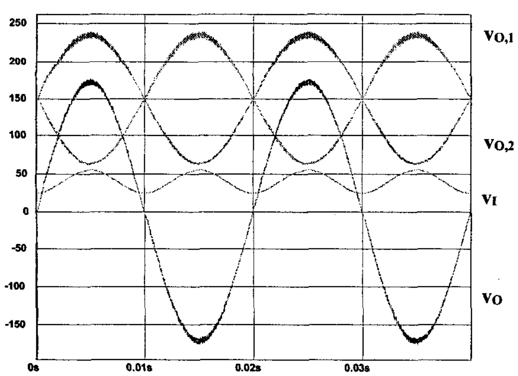


Fig. 5. Results for DC voltage variations

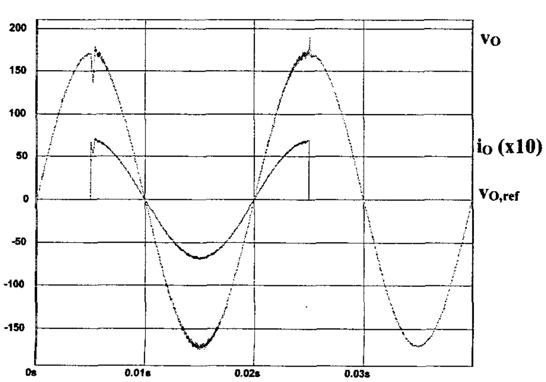


Fig. 6. Results for output load variations

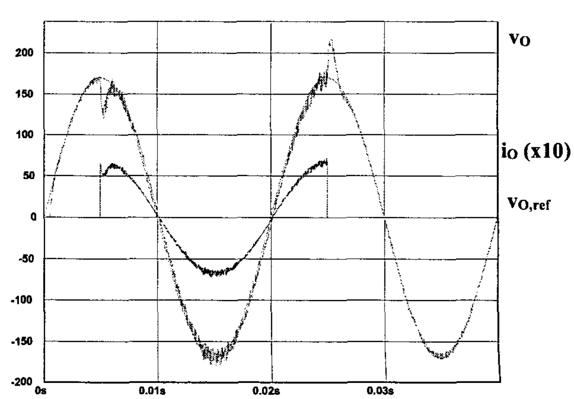


Fig. 8. Sliding mode control results for load variations

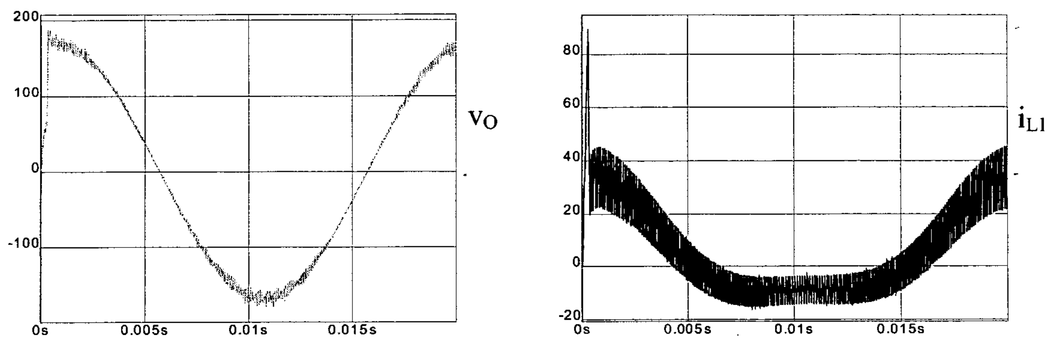


Fig. 9. Inductor current and output voltage in an inverter starting with a sliding mode control scheme

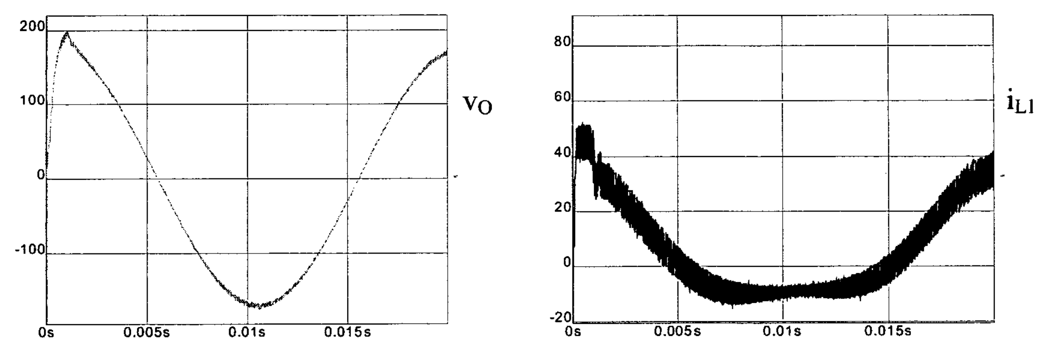


Fig. 10. Inductor current and output voltage in an inverter starting with the proposed control strategy

current average value. This problem does not exist in the new control strategy proposed in this paper, due to the existence of an inner current control loop that controls the actual value of the inductor current and can limit the maximum value of the inductor current.

In order to show this important issue, an inverter starting at the maximum point of the voltage waveform with nominal load was simulated both with the sliding mode controller and the proposed control strategy. Results are presented in Fig. 9 and Fig. 10. As it is clearly shown, the inductor current reaches very high values in the sliding mode control scheme, while this current appears completely controlled when the new control strategy is proposed.

## V EXPERIMENTAL RESULTS

In order to validate the satisfactory simulation results of the proposed control strategy, a Boost DC-AC inverter prototype has been implemented, with the same values for the components and control parameters as those indicated in the simulations. Main experimental results are shown in Fig. 11, in which the system operates under constant load with two different input voltage levels, 25 V (first graph) and 55 V (second graph). As it can be observed, different input voltage levels do not affect either the voltages of the two Boosts, or consequently, the output voltage of the inverter.

Experimental results with output current variations are shown in Fig. 12. In this test, a resistive load is suddenly connected to the inverter when the output voltage is at its maximum level. As was obtained by simulations (see Fig. 6), the experimental results show the robustness of the control strategy to output current variations even when they appeared in the highest points of the output voltage waveform.

The figures confirm the good properties shown in the simulation results. Output voltages of the two Boosts track the references with precision and good quality, and, as expected from simulations, this accurate behaviour is independent of the input voltage level and output current variations.

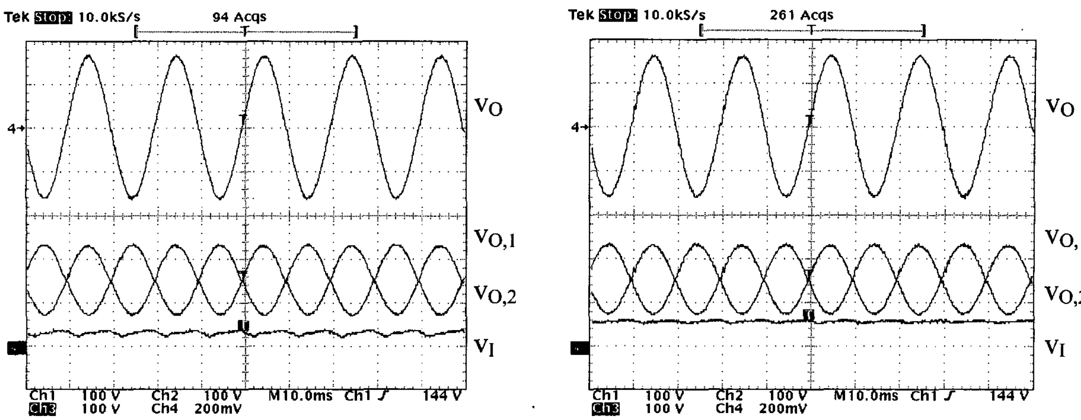


Fig. 11. Experimental results with different input voltage levels (100 V/div)

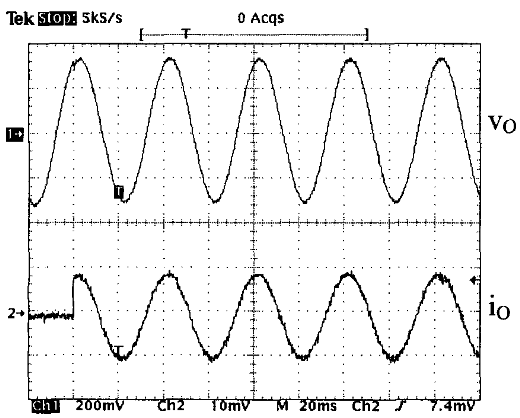


Fig. 12. Experimental results with output current variations (100 V/div and 4 A/div)

## VI Conclusions

The new control strategy proposed in this paper achieves an accurate, robust, fast, and highly immune to input voltage and output load variations control of the Boost DC-AC inverter. These properties have been confirmed by simulation and experimental results. In addition, the advantages of this control strategy in comparison with the sliding mode control have been described. The parameters of the control scheme and its physical implementation are quite simple. The controlled converter can be advantageously used in UPS, photovoltaic systems, etc.

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