A NEW PROPOSAL OF A LINE CONDITIONER

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Abstract – **In this paper a study performed on an AC/AC line conditioner is presented. The voltage regulation is obtained by means of a switched power stage, composed of two current sources used to modulate the desired RMS value and waveform in the output stage. Mathematical analysis, experimental and simulation results are presented.**

KEYWORDS

AC/AC Voltage regulator, AC/AC Line conditioner.

I. INTRODUCTION

Today, the improvement of power quality delivered to customers is a special topic in Power Electronics applications. The AC mains voltage supplied to customers should be RMS value constant and sinusoidal waveform, without harmonic distortions. A clean and stable AC voltage source is required in the voltage sensitive equipments, such as personal computers, telecommunication systems, biomedical instrumentations, as well, electronic equipments used in a common home, TV receivers, sound systems, VCR's and others. A basic characteristic of all electronics devices is the necessity of a regulated AC input voltage. This is achieved introducing an AC voltage regulator between the power system and the equipment. The non-linearity is another characteristic of this type of devices.

There are so many topologies of AC single phase voltage regulators, each one has its characteristics with advantages and disadvantages. The most of these AC/AC regulators are electromechanics, such as transformers with taps. These equipments are robust and they have many secondary windings that are appropriately added or subtracted to the line voltage obtaining their stabilization. This operation is made with low frequency switching and it results some voltage steps and spikes in the regulated output voltage [1]. Another possibility to AC voltage regulators is the AC/DC/AC conversion. Traditionally, this conversion is made using two converters in order to obtain a fast regulation of the output voltage and power factor correction. An example is the Boost/Inverter regulator, Fig. 1, one of the most commons topologies among the switched regulators. This regulator uses a rectifier stage (AC/DC), a Boost pre-regulator, to provide unity power factor, and an Inverter circuit (DC/AC) to obtain an AC voltage with the RMS value and frequency desired in the load. The drawbacks of this scheme are the high cost, the large size, and the low efficiency; the last one because the power is processed twice. The topology supplies the load total power and this is a disadvantage too, because its semiconductors, inductors and capacitors should be designed to full load.

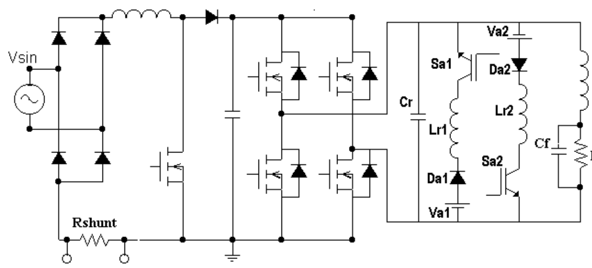


Fig. 1 – AC/DC/AC Boost-Inverter voltage regulator.

Nowadays, the series active filter topology has been used to regulate the AC voltage in single-phase loads. A basic configuration of a common series regulator (series active filter) is showed in Fig. 2. It needs a rectifier, a large capacitor (Cd) and a filter stage before the low frequency transformer, and employees an AC/DC/AC conversion. This application does not need to supply the total load power, but only the necessary to obtain a regulated output voltage; this is the great advantage of this topology.

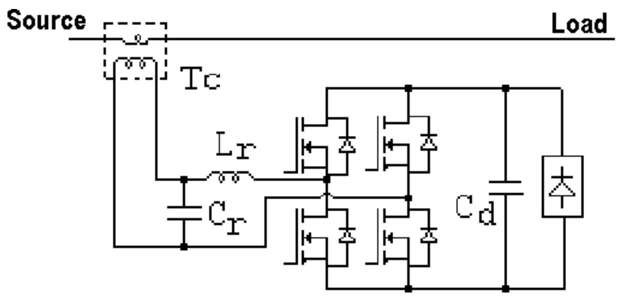


Fig. 2 - Common series active filter used as DC/AC voltage regulator.

Others AC series regulator topologies are presented in [2-8]**.** These topologies supply only a percentage of load total power and are useful in high power applications. An example is showed in Fig.3. In this case it employees a direct AC conversion, e.g., it does not need a DC stage. A disadvantage of this structure is the high number of semiconductors because the switches must be bi-directional, however it does not need a filter stage.

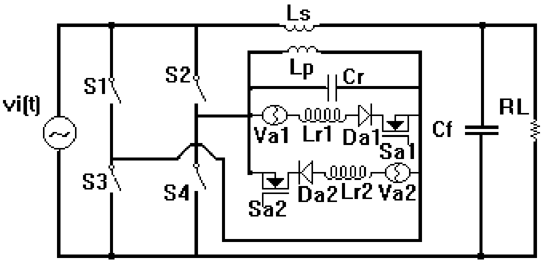
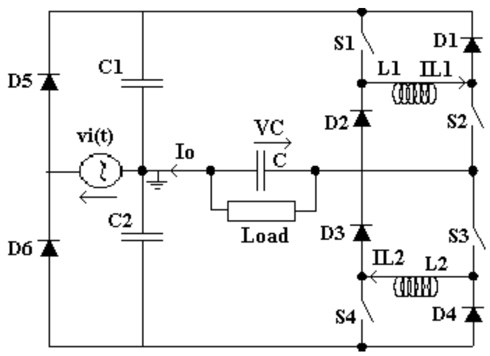
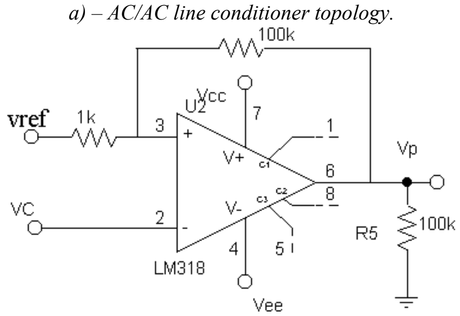


Fig. 3 - Series active filter used as direct AC/AC voltage regulator.

The proposed line conditioner, shown in Fig. 4a, is formed by two inductors, four active switches, six diodes and three capacitors. The inductors L1 and L2 work as current sources and operate alternatively, supplying the capacitor C and modulating its voltage. The output modulated waveform voltage is determined by a reference signal. An advantage of this topology is the output stage has a voltage source characteristic, so it does not need a filter stage, reducing weight and price. The proposed regulator circuit control is very simple and uses only a schmitt trigger comparator, Fig.4b, to generate the correct pulses sequence to modulate a sinusoidal waveform in the output capacitor. This topology is an improvement to the regulator presented in [7,8]. The two voltage sources used to fed the inductors L1 and L2 can be changed by a simple half bridge rectifier, where the capacitors C1 and C2 are very small, without to damage the output voltage regulation.



a) – AC/AC line conditioner topology.



b) – Line conditioner circuit control.

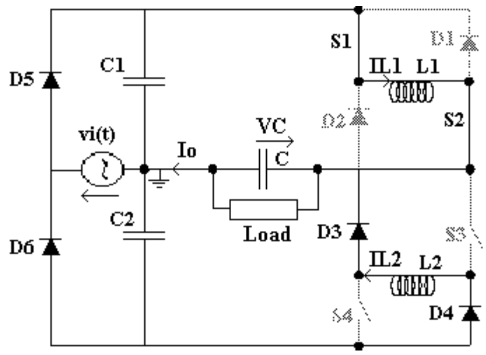
Fig. 4 - The proposed AC/AC line conditioner.

II. PRINCIPLE OF THE OPERATION

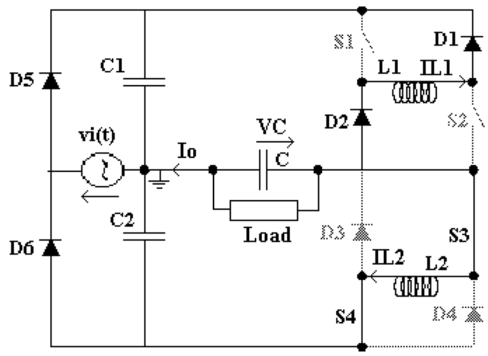
The power stage diagram of the proposed circuit is composed by two current sources that are implemented to modulate the voltage across the output capacitor C. The configuration is basically two Forward converters operating as current source due to the inductors L1 and L2. The modulated voltage across the capacitor C is applied to the load. An advantage of this topology is that it does not need a filter stage; the modulated voltage across the output capacitor is a quasi-sinusoidal waveform, with low harmonic content. This topology can be analyzed as two PWM Buck CC converters operating separately, each one having two operating stages, a linear and an energy restoration stage. The operating principle is presented as follows:

First stage (Fig. 5a) - Switches S_1 e S_2 are turned on and switches S_3 e S_4 are turned off. The voltage across the capacitor rises due to the current source IL1. During this stage, if there is energy stored in the filter inductor L2, the diodes D_3 and D_4 are directly polarized. This energy returns to the capacitor C2, through the output capacitor C, contributing to increase its voltage. Thus, one Forward converter has a transferring power stage, and the other an energy restoration stage.

Second stage (Fig. 5b) – This stage is the complement of the first stage. Switches S_3 and S_4 are turned on and switches S_1 and S_2 are turned off. The current IL2 forces the voltage on the capacitor to decrease. The diodes behavior is the same as described in the first stage. If there is energy in the inductor L1, diodes D1 and D2 are directly polarized and L1 returns its energy to capacitor C1. It can be noticed that each current source must supply a current higher than the load current in order to decrease the capacitor voltage.



a) - Transferring power through S1 and S2



b) - Transferring power through S3 and S4

Fig. 5 – Operating stages.

Capacitors C1 and C2 are completely charged in system frequency, through the half bridge rectifier formed by D5 and D6.

III. MATHEMATICAL ANALYSIS

This topology can be analyzed as two PWM Buck CC converters operating separately. The Buck EIE (voltage-current-voltage) converter is showed in Fig 6.

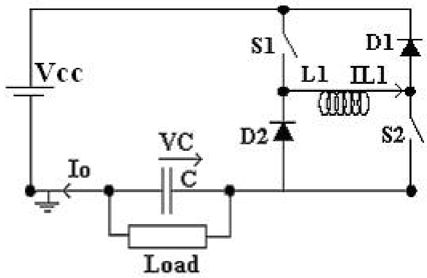


Fig. 6 – Buck EIE converter.

The inductor voltage is VL=Vcc-Vo in the first stage and, in the second stage, it is VL=-Vcc. The converter static gain can be obtained as follow:

$$\int_0^{ton}(Vcc-Vo).dt+\int_{ton}^{T}(-Vo).dt=0 \tag{1}$$

So,

$$\frac{Vo}{Vcc}=\frac{2D-1}{D} \tag{2}$$

Considering the converter without losses:

$$Vcc.Iin=Vo.Io \tag{3}$$

The load current can be obtained using eq. (2) and (3):

$$Io=\frac{Iin.D}{2D-1} \tag{4}$$

The Io and IL relationship is:

$$Io=D.IL \tag{5}$$

The inductor current can be obtained using eq. (4) and (5):

$$IL=\frac{Iin}{2D-1} \tag{6}$$

The converter operates in discontinuous conduction mode for D<0.5, and the efficiency is low due to the circulating reactive energy.

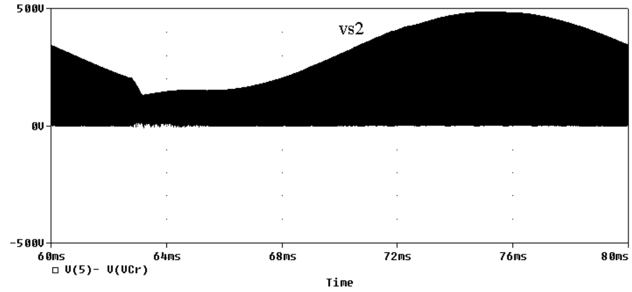
IV. SIMULATION RESULTS

The proposed topology, Fig. 4a, was analyzed by simulation using Microsim Pspice 8.0. A prototype has been build and measurements were taken in order to demonstrate the circuit operation to the voltage regulator.

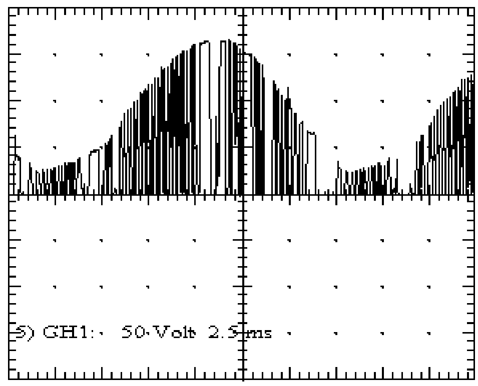
To the experimental results the following parameters were used:

vi = 70Vrms to 100Vrms; f = 60Hz; vo = 50Vrms; L1= L2= 1mH; P_0=280W, C1=C2=100uF.

Figs. 7*a* and 7*b* show simulation and experimental waveforms to the switch S1. Switch S1 voltage is the capacitor C1 voltage plus the capacitor sinusoidal voltage (output voltage). It can be observed that switch S1 should be designed to twice input voltage peak. The diodes have the same voltage as switch S1.



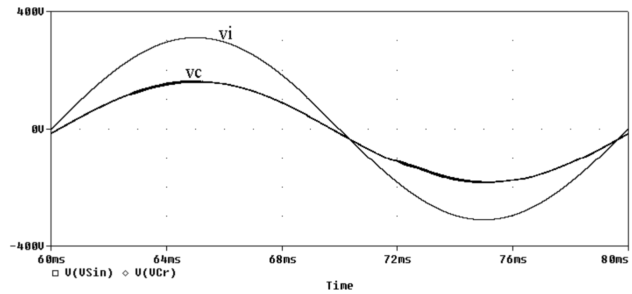
a) – Switch S1 voltage (simulation).



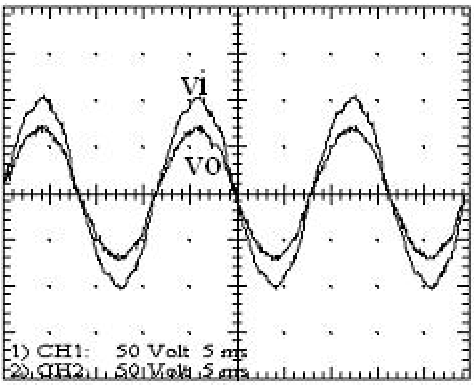
b) – Switch S1 voltage (experimental).

Fig. 7 – S1 switch voltage.

The regulated output voltage (vc), with the input voltage (vi), can be observed in Figs. 8. The two current sources present in the topology are used to modulate de output voltage (vc), and the system voltage (vi) is used only to supply the necessary energy to this operation. The output voltage has the same waveform as the reference signal. So, this topology is, really, a signal amplifier.



a) –Output voltage (simulation).



a) –Output voltage (experimental).

Fig. 8 – Input and output voltage.

In Fig. 9 it was included spikes, with 300V peak value, in the input voltage. It can be noticed that these spikes are not present in output voltage, this result proof that the regulator works correctly. However these spikes are presented in the switches voltage what is a disadvantage.

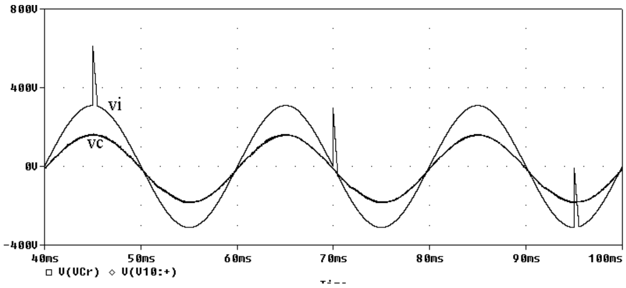
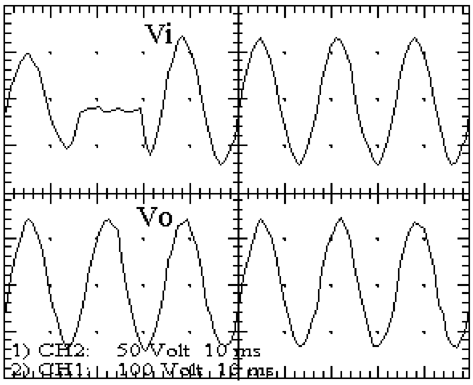


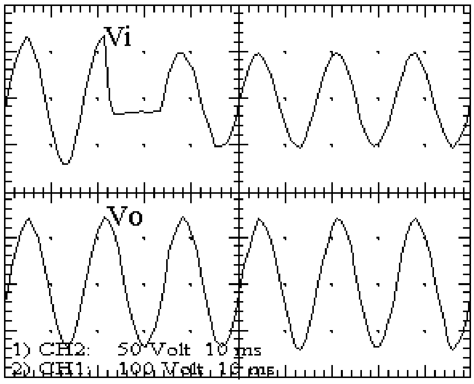
Fig.9 – Output voltage without spikes.

The regulator's dynamic stability was performed for load and input voltage variation. Fig. 10 shows the response to an input voltage step variation. It can be noticed that the output voltage is not affected.

The dynamic stability was performed for load step variation. Fig. 11 shows the dynamic response to a 280W – 0W and vice versa load step variation. In both cases it can be noticed that the regulator time response, in order to accept the new load condition, is worthless and the output voltage do not preset any effect of this operation.

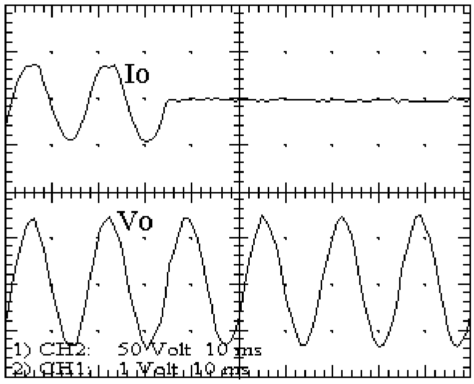


a) – Input voltage step variation – 70Vrms – 100Vrms.

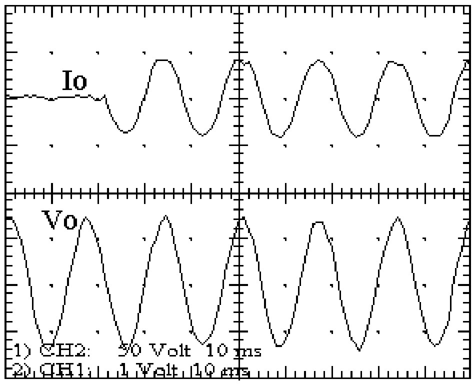


b) – Input voltage step variation – 100Vrms – 70Vrms.

Fig. 10 – Dynamic response to input voltage step variation.



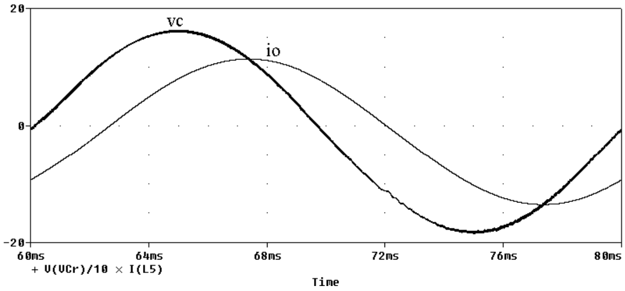
a) – Load step variation – 280W – 0W.



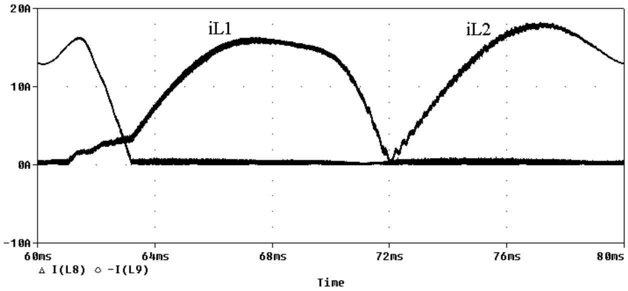
b) – Load step variation – – 0W – 280W.

Fig. 11 – Dynamic response to load step variation.

Figs. 12*a* shows the output voltage (vc) and current (io), to an inductive load. Fig. 12*b* shows waveforms to the currents through L1 and L2 inductors. It can be noticed that one current source prevail in the positive semi-cycle and the other in the negative, and that each current source supplies a current higher than the load current in order to decrease the output capacitor voltage.



a) – Output voltage and current to an inductive load.



b) – InductorsL1 and L2 currents.

Fig. 12 – Inductive load waveforms.

V. CONCLUSION

A new line conditioner topology was presented and its circuit control is very simple. The capacitors C1 and C2 can be very small, C1=C2=100uF to an output power of 280W, without to damage the output voltage regulation. The proposed topology does not need an output filter stage like others regulators, the output voltage is a quasi-sinusoidal waveform, with low harmonic content. Each current source must supply a current higher than the load current in order to decrease the output capacitor voltage. The topology was performed by simulation and experimental results were presented.

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