ADJUSTABLE, DC-LINK- BASED, REGENERATIVE ELECTRONIC LOAD APPLIED TO AC- AND DC-OUTPUT EQUIPMENT

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Abstract – **This paper deals with a second part of the analysis of a novel, Regenerative Electronic Load, intended to high efficiency burn-in tests of AC- and DC-output power supplies. It is based on the rectifier/inverter configuration of a DC-DC transmission system, here called DC-link. The main purpose of this Electronic Load is to allow the energy to flow from the source side (converter in the rectifier mode) to the load side (converter in the inverter mode), conducted through a bulky power inductor, whose internal equivalent resistance is the responsible by the small part (around 10% of total amount) that will be effectively locally dissipated. Its implementation makes use of thyristor technology, and can be applied both to AC- and DC-output power supplies. As the DC-output has already, partially discussed in previous paper, this one, particularly, deals with application intended to AC-output equipment. Operating principle, main equations, simulation and experimental results are also presented.**

KEYWORDS:

Electronic load, Regenerative electronic load, Burn-in test, Power converters, HVDC transmission system.

I. Introduction

Burn-in tests usually accomplished in power electronics laboratories involve dissipation of quite high levels of electric energy in power resistor banks (some kilowatts). The usually resistor-made-up loads, sometimes power electronic-switched (in this case, also named electronic loads), are non-regenerative, in general. This means the whole electric energy drained from the equipment under test is locally dissipated, and for long time, since this characterizes burn-in tests. The loading adjustment of the usual resistive load is made up by steps, and not in a desired smoothing fashion. This makes more difficult the full range test of the under-test-power supply.

The need for a kind of load that satisfies the load requirements of the various types of converters usually tested in power electronics laboratories, has led to the proposed Regenerative Electronic Load. It is intended to act as an adjustable electronic load, suitable for being used with equipment such as DC-DC or AC-DC converters. The DC-output version has already discussed [1,2], and just some extra details (including some experimental results) are presented here. Concerning the AC-output Electronic Load, this one is focused on the next sections by means of working principle, simulation results and some other designing details.

Switched electronic loads intended to burn-in test of power equipment in power electronics laboratories are present in the market, though they are usually not regenerative [3], what means they allow the test to be done, with versatility, but without energy save. In the technical literature one can find some regenerative Electronic Load (E-Load), but intended for low power, single-phase applications [4]. This is verified from the fact that the power topology is made up of just two high frequency-switched, main power devices, although the output-stage may be implemented by means of a power transistor, three-phase bridge.

A revision of the high voltage direct current power transmission (HVDC) theory is used to show how the power flow control is reached in that scheme. As is known, the HVDC transmission system is a reality worldwide, making it possible to transmit great blocks of energy in high DC voltage such as the double bipolar ± 600kV (plus and minus 600kV), which is the case of the Itaipu hydroelectric plant, HVDC system. This DC transmission system is a tie line between the 50Hz, AC electric system of Ciudad del Este, Paraguay, and the 60Hz, AC electric system of Ibiúnas in southeastern Brazil. In the light of such a kind of DC transmission system involving a thyristor controlled rectifier in the source terminal and a similar topology operated in the inverter mode [5], an electronic load system can be thought of doing the same thing between any converter and the electric grid of the laboratory. The similarities and the differences between these systems are to be studied in order to establish the best way of controlling the current drained by the electronic load when connected to the output terminals of the electronic equipment under test. A brief revision of such a transmission system is presented in reference [1].

Based on this HVDC transmission system, an Electronic Load may be developed: any DC- or AC-output equipment could be powered by means of a connection of its (DC) output to an inverter-mode, rectifier bridge through a very small resistance, like the line resistance of the HVDC system. This resistance will be implemented by means of the equivalent series resistance of a smoothing filtering reactor (L) .

II. Operating Principle

There are two possible basic types of this Regenerative *E-Load*: one for DC-output and another for AC-output. Fig. 1 and Fig. 2 show the basic configuration involving the equipment under test, the electronic load and the electric grid, for both types.

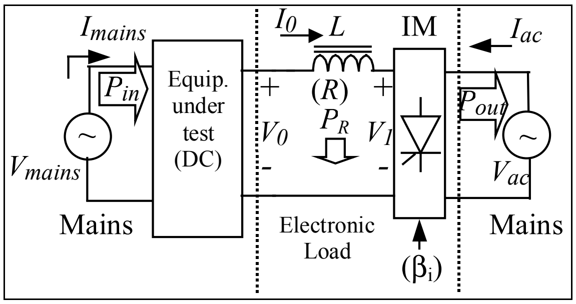

Fig. 1 Electronic load for DC-output equipment.

In this figure, the powers mean: P_{in}: processed power, P_R: dissipated power, and P_{out}: regenerated power

The basic operating principle establishes that the power to be drained from the equipment under test will be dissipated partially in the resistor *R*, of small value, with its major part yielded back to the grid. (More details are given in [1].)

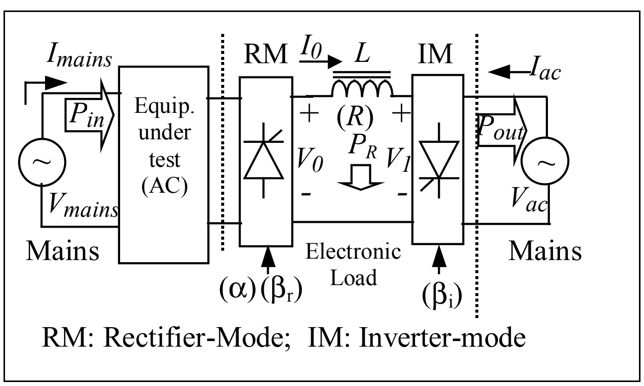

Fig. 2 Electronic load for AC-output equipment.

A simple potentiometer is capable of controlling the loading level, which can be adjusted simply by means of the advance angle (β_i), for the DC-output *E-Load*. For de the case of the AC-output *E-load* there are three possibilities of controlling the power flow: by means of the delay angle (α) and the advance angle (β_r) of the RM Rectifier Bridge, and the advance angle (β_i) of the IM Rectifier Bridge.

III. Main Power Relations for the *E-Load*

The main equations governing the *E-Load* can be derived from the simplified, single-phase circuit of Fig. 3, which is the case 1: *E-Load* for DC-output equipment [1].

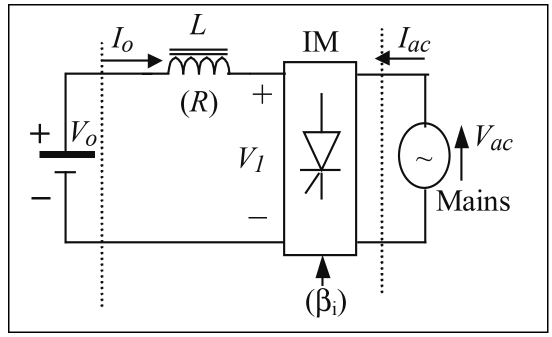

Fig. 3 Simplified *E-Load* circuit.

Reference [1] shows the derivation of these equations, related to a basic analysis, giving the resultant power curves shown in Fig. 4.

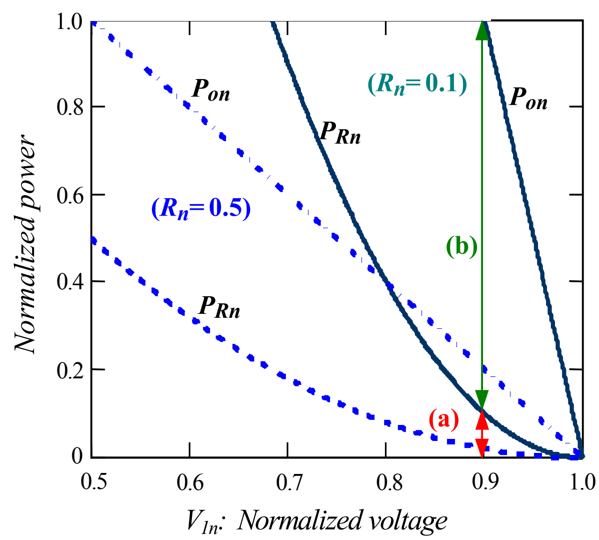

Fig. 4 Normalized power: lost (P_{Rn}), and regenerated (P_{on}).

Letters (a) and (b) in Fig. 4 indicate the amount of power lost and injected in the mains, respectively, for an R_n=0.1 per unit (in a base, rated resistance R_b, equal to the rated, output resistance of the under-test power supply). The abacus shows two possible designing choices, with their normalized lost (P_{Rn}) and injected or regenerated (P_{on}) power. The curves to the right are, naturally, the best choice, under the point of view of efficiency of the burn-in test. This is because the normalized inverter voltage (V_{1n}) is chosen 0,9 pu (90%), which means: the normalized power equals 1,0 pu (100%) or the rated output power of the DC-output, when the voltage across the inverter terminals is 0,9 pu. Therefore, the power dissipated in the internal equivalent resistance of the filtering inductor is 0,1 pu (or 10% of the nominal power supply under test).

This basic analysis shows the utility of such a regenerative electronic load. For output power greater than 2-3kW, the three-phase Thyristor, Rectifier Bridge topology is the most indicated, because of the equally distributed power among the phases. The section V shows some simulation results for the three-phase, DC-output *E-Load*, with high-frequency filtering and reactive compensation. (More discussion on these topics are found in [1,2].)

IV. Experimental Results for the 1ϕ, DC-output *E-Load*

To complement the already made analysis presented in the first part of this paper [1], some experimental results reached for a single-phase, DC-output *E-Load* are shown in Fig. 5.

These results confirm the theoretical and simulation studies already made and discussed on previous works [1,2].

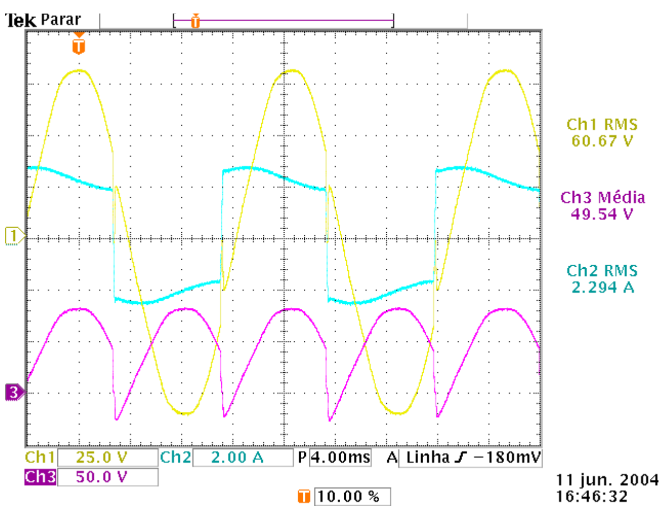

Fig. 5 Mains Current ($-I_{ac}$, Ch2) and Voltage (V_{ac}, Ch1), and Inverter Voltage (V_1, Ch3), for medium power.

V. Simulation Results for the 3ϕ, DC-output-*E-Load*

Based on the above operating principle's considerations, some simulation studies have been made for the three-phase, DC-output *E-Load*, without filtering and reactive compensation, according to the first part of this paper [1]. Now, keeping these same constraints, some simulations results for the three-phase case are presented here.

First, a DC voltage source (60V) played the role of the DC-output equipment (circuit shown in Fig 3, but for three-phase electric grid). Fig. 6 shows the *E-Load* drawing off a heavy load (2kW) by means of an advance angle β_i equal to 26 degrees, with an average load current equal to 28 A.

In Fig. 7 the same equipment is shown being controlled by means of an advance angle (β_i) of 20 degrees, with an average load current around 16 A (light load ≈ 960W).

Although not cited, these simulations have been performed by using an *E-Load* circuit that includes an additional output, step-down autotransformer [1,2] needed to match the voltage levels of the output voltage power supply and the mains voltage. The autotransformer stepped down the voltage to approximately $26V_{RMS}$, phase-to-neutral, from the $127V_{RMS}$ of the mains.

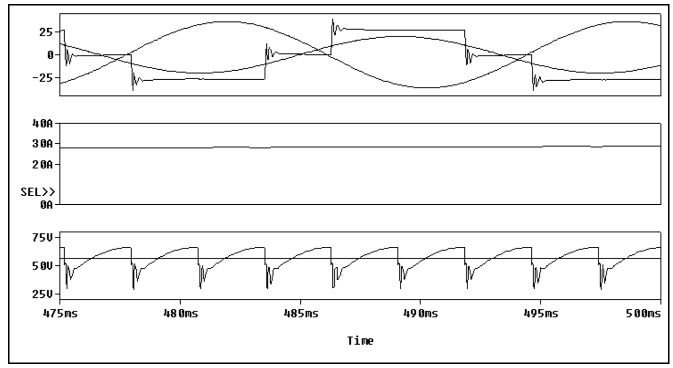

Fig 6 Waveforms of voltages and currents for a three-phase, DC-output *E-Load* with heavy load (almost 2kW).

On the top of this figure are the phase-to-neutral voltage and the quasi-square wave line current along with its fundamental component, to show the displacement angle between the voltage and the current (in this case: 26 degrees). The curve in the middle ($28A_{DC}$ in average) is the DC-output current smoothed by the high valued inductor (250mH).

On the bottom one can see the instantaneous V_1 voltage (the rectified voltage across the terminals of the IM Rectifier Bridge, Fig. 2) along with its average value: 56.7V.

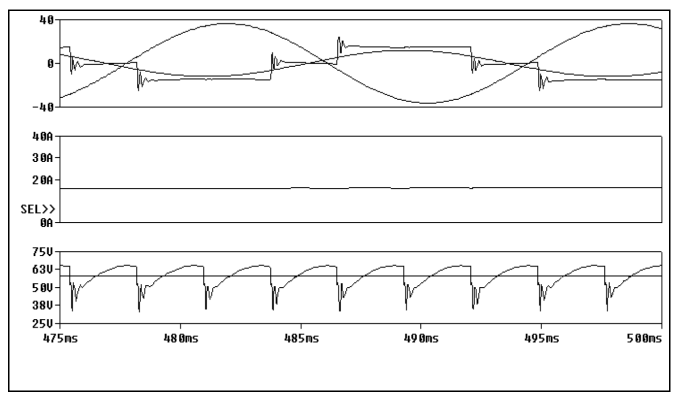

Fig 7 Waveforms of voltages and currents for a three-phase DC-output equipment with light load (0.96kW)

On the top of this Fig. 7 are the phase-to-neutral voltage and the quasi-square wave line current along with its fundamental component, to show the displacement angle between the voltage and the current (in this case: 20 degrees). The curve in the middle ($16A_{DC}$ in average) is the smoothed DC-output current.

On the bottom one can see the instantaneous V_1 voltage (the rectified voltage across the terminals of the IM Rectifier Bridge) along with its average value: 58, greater than that of Fig. 6, so that the current through the inductor (I_o), on the output of the DC equipment under test, be less than the current in that case.

These results show the *E-load* circuit capability of handling the output currents of DC-output power supplies during burn-in and static loading tests.

VI. Single-phase, AC-output *E-Load*

In Case 2, an AC-output voltage, single-phase equipment is under test. Fig. 8 shows simulation results for the circuit of Fig 2, using control angles of the rectifier (α) equal to zero degree and inverter (β_i) equal to 25 degrees. The *E-Load*, in this case, emulates a resistive load (unity power factor load), due to the null displacement angle between the fundamental line current and the voltage of the AC-output power supply.

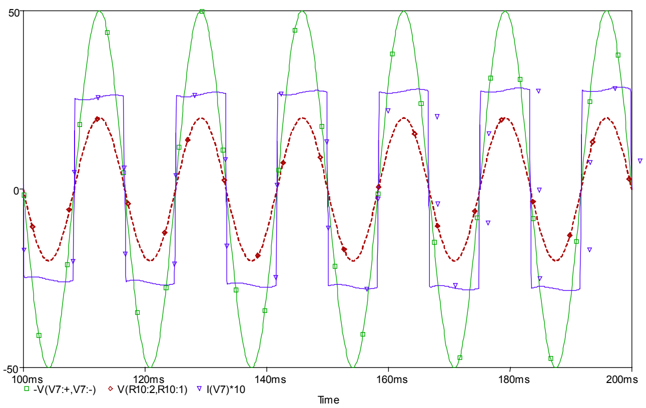

Fig 8 Voltage and current for a single-phase, AC-output *E-Load*, with α=0^o and β=0^o.

Now, the same circuit is shown in Fig 9, using control angles α equal to 30 degrees and β_r equal to 0 degree, both angles related to the RM Rectifier Bridge (on the left). The main difference between figures 8 and 9, is the fact that in this last case the *E-Load* makes the role of a lagging impedance, as one can check by the displacement angle of the fundamental currents, in relation to the voltage, comparing both figures.

In order to emulate a leading (capacitive) impedance load the RM Rectifier Bridge on the left of the circuit in Fig. 2, must be implemented by means of transistor switches instead of thyristors. This is because the thyristor Rectifier Bridge is only capable of delaying the fundamental line current concerning the corresponding voltage, by means of its delay controlling angle (α). By using transistor technology the Rectifier Bridge is now capable of drawing off advanced fundamental line current, by means of an adequate modulation (the current extinction angle control) [6]. Fig. 10 shows the corresponding simulation results for this leading impedance.

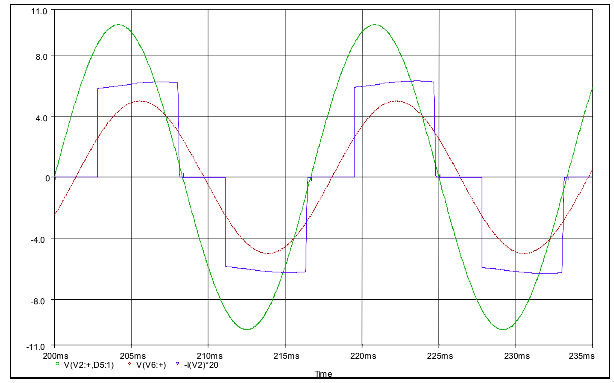

Fig 9 Voltages and currents for a single-phase, AC-output *E-Load*, with α=30° and β=0^o.

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Comments on questions concerning the need of high-frequency filtering, reactance compensation and use of step-down transformer, as an interface between the Inverter-Mode Rectifier Bridge and the mains, are already made in the first part of the paper [1].

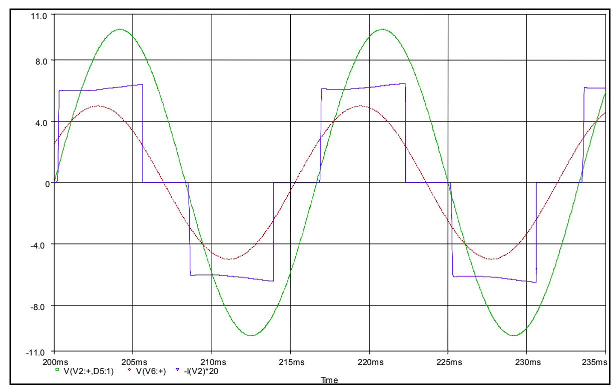

Fig 10 Voltages and currents for a single-phase, AC-output *E-Load*, with α=0° and β=30^o.

VII. Conclusion

A second part analysis of a novel Regenerative Electronic Load (*E-Load*) has been presented. This *E-Load* is based on the HVDC transmission system and presents regenerative characteristics, that provides an original solution for burn-in tests and general, smoothing controlled loading tests of both AC- and DC-output power supplies.

This technology has been developed to overcome difficulties concerning the use of discrete, resistive loads in laboratory tests of electronic equipment. In addition, to avoid the usual high power dissipation in conventional resistive banks the *E-Load* circuits allow the output power of the equipment under test to be directed back to the mains.

The Rectifier Bridge on the left side of the AC-output *E-load* must use transistor switches if it is intended to emulate leading (capacitive) impedance load.

Simulation results, for both types of these single-phase, and three-phase electronic loads have been presented. Some experimental results concerning the single-phase, DC-output *E-Load* has been particularly shown to verify the theoretical simulations.

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