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INTEGRATION CONCEPT OF AUXILIARY COMMUTATION CIRCUITS: THE ZVT CASE STUDY

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Abstract – **This paper proposes the concept of integrated auxiliary commutation circuits (iACC) applied to systems with several power conversion stages. This concept has two main objectives, namely: to reduce the number of additional elements to accomplish the soft-switching, and to use the circulating energy from one commutation to assist another one, so that the efficiency is improved without penalizing the cost of the system. Some rules for obtaining new iACCs are presented. New iZVT circuits are applied to a double-conversion UPS to illustrate the functionality and applicability of this concept. By using these circuits, the main switches operate under soft-commutation of ZVT type, and the auxiliary switches are turned on and off under ZCS or ZVS. Experimental results of three prototypes (1.2kW@100kHz) are presented to demonstrate the good performance of the iZVT and the feasibility of the proposed concept.**

I. INTRODUCTION

In the last decades men searched for reducing the size, weight and cost of their equipments and implements, as well as increasing the performance and efficiency of the same. This phenomenon can be clearly seen in computer history and evolution [1], and it is a result of the advances related to the understanding of the semiconductor, which made the transistor invention possible, a fact that brought the miniaturization revolution and reduced the cost of electronic devices [2]. As a result, the amount of elements put together in an IC has doubled every 24 months since then [1]. The IC popularization occurred mostly due to the integration of devices and/or functions and the resulting cost reduction.

Considering that, why didn't the Power Electronics follow the same path of the digital technologies? The answers for this question face a paradigm: working with high power and high frequencies, i.e., high levels of these two physical quantities are incompatible with the technologies available nowadays.

The main factors that must be taken into consideration when it is intended to make a functional and spatial integration of power devices are related to mechanical, thermic and electromagnetic interference (EMI) issues. Among them, the main issue is the energy dissipation that becomes one of the main risk points for the operation of an integrated system, together with the costs for doing researches in this field and producing this kind of system.

This paper aims to generalize a functional integration concept in order to use it in Power Electronics, considering that just a single integrated auxiliary commutation circuit (iACC) will be used to obtain zero voltage switching of all switches of the system. In these integrated systems many semiconductors are going to perform different functions: sometimes they will operate as auxiliary switch in the commutation process, sometimes they will operate as the main switch and the circulating reactive energy are reused. By this integration concept, it is possible to reduce the components number in the system, and, as a consequence, its weight and size are also reduced, what leads to an improvement in its performance, the final result being the miniaturization and the cost reduction.

There are many techniques used for obtaining the soft switching, e.g., snubbers [3], ZVS [4], ZCS [5], ZVT [6], ZCT [7], ZCZVT [8]. The ZVT technique stands out by its simplicity, high efficiency, reduced auxiliary components, easy design and auxiliary elements out of the main power flow. Considering these features, this technique in particular, which was one of the few that received attention from industries [9], was thoroughly studied and many improvements were proposed [10]-[19]. In this sense it was chosen as the start point for this integration study.

Aiming to reduce the costs and the circulating reactive energy related to the systems with several power conversion stages, which need ACC, this work proposes an integration concept of ZVT ACC that uses the same resultant reactive energy from the a commutation for assist another one. Here are presented the design procedure, rules for obtaining the iACC, an analysis of the circulating reactive energy and experimental results which demonstrate the performance of the proposed concept.

II. INTEGRATED CONCEPT OF ACC

The integration concept is based on the idea of the conventional soft-switching technique, where the energy of the converter is diverted to the ACC to change the state (on or off) of the main semiconductor devices, enabling soft-switching under zero voltage and/or zero current. When the commutation process concludes, the resultant circulating energy is regenerated to the converter (system) to give high efficiency.

Following this view of the soft-switching process, the aim of this new ACC integration concept is to reprocess the circulating energy resultant from one commutation to assist another one. In other words, instead of using one ACC for each converter that composes the system, it is proposed to use only one integrated auxiliary commutation circuit (iACC), which re-uses the energy of the commutations. It is important to stress that this concept is valid not only for systems with two power conversion stages, but also for systems with multi-stage power conversion systems, as shown in Fig. 1, where it is simpler to integrate the ACCs and energy resulting from commutations is used more efficiently. The Fig. 1 represents a system with n converters, where the circulating energy from one or more commutations is used to assist other commutations. This integration concept can be used with any soft-switching technique or distinct combinations of them. In all situations, two objectives must be achieved: reduction in the number of additional elements to obtain the soft-switching, and reprocessing the energy from one or more commutations, trapped in the inductor, to assist others.

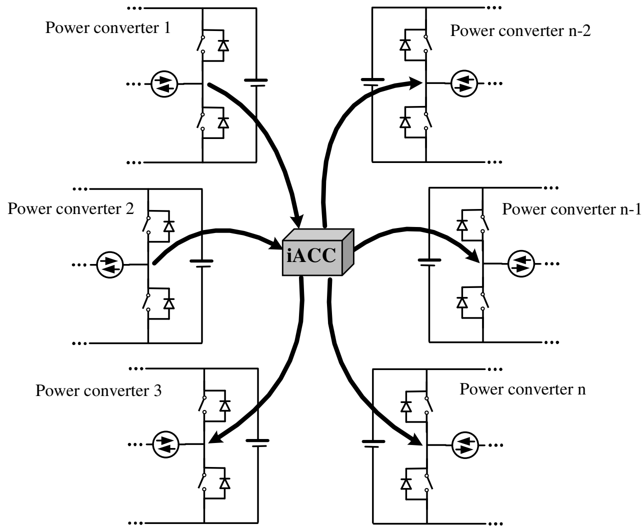


Fig. 1. The proposed integration principle.

In the systems that use the iACC the commutation process can take place in two different ways: serial – which reuses the circulating reactive energy – and parallel – which just reduces the additional components. These two switching modes are explained as follow:

Serial process:

The integrated commutation process takes place in two different steps, namely:

Step 1: The energy accumulated in the capacitor in parallel with the main switch where the commutation is intended to occur is transferred in a resonant mode to the iACC inductor. In this step the voltage in the main switch is taken to zero and the switch is turned-on in ZVT-type.

Step 2: The energy accumulated in the inductor is used to take to zero the voltage in any other main switch that is intended to be switched. The moment when the voltage in the switch reaches zero, it is put under ZVT-type conduction and the remaining energy that may be accumulated in the inductor is regenerated to the system sources.

Parallel process:

The integrated parallel commutation is similar to what happens in the ZVT ACC [6], the main difference being the fact that the ACC will use the same auxiliary switch [20]. Since this switching was already presented, it will not be detailed in this work.

III. MATHEMATICAL EQUATION

Doing the equation of the integrated commutation process requires the use of the system presented in Fig. 2, due to the fact that it is easily understandable and formed by only two PWM cells (one with the boost-type commutation [22] and the other with the buck-type commutation [22]).

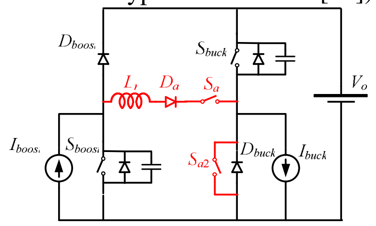


Fig. 2. iACC for a input stage of the an UPS (boost + buck)

The first step for the equation is define the following variables: ω_{r1} angular resonance frequency of the first resonant stage; Z_1 characteristic impedance of the first resonant stage; ω_{r2} angular resonance frequency of the second resonant stage; Z_2 characteristic impedance of the second resonant stage; described by the equation:

$$\omega_{r1}=\sqrt{\frac{1}{L_r.C_{s\,boost}}},\quad Z_1=\sqrt{\frac{L_r}{C_{s\,boost}}},$$

$$\omega_{r2}=\sqrt{\frac{1}{L_r.C_{s\,buck}}}\quad \text{and}\quad Z_2=\sqrt{\frac{L_r}{C_{s\,buck}}}.$$

Next follows the description of the operation stages of the integrated commutation process.

Stage 1 (t_0-t_1): Initially, it is considered that the currents I_{boost} and I_{buck} flow, respectively, by D_{boost} and D_{buck}, and all the switches are turned off at this moment. The auxiliary switches S_a and S_{a2} are turned-on in ZCS due to the presence of the inductor L_r. It is important to point out that S_{a2} is also turned-on in ZVS, due to the fact that the current I_{buck} flows through the diode D_{buck}. At this point, the output voltage V_o is applied at the inductor (L_r) and the current that flows through it starts increasing linearly.

$$i_{Lr}(t)=\frac{V_o.\omega_{r1}}{Z_1}.t \tag{1}$$

$$\Delta t_1=\frac{L_r.I_{boost}}{V_o} \tag{2}$$

Stage 2 (t_1-t_2): The moment when the current, flowing through the resonant inductor, reaches the current value I_{boost}, the capacitor $C_{s\,boost}$ energy resonates with the energy of the inductor L_r, causing the voltage at the capacitor to reach zero Volt, and closing this stage. The difference between the current at the inductor L_r and the I_{boost} flows through the antiparallel diode of the switch S_{boost}.

$$i_{Lr}(t)=I_{boost}+\frac{V_o}{Z_1}.\sin(\omega_{r1}.t) \tag{3}$$

$$v_{Cs\,boost}(t)=V_o.\cos(\omega_{r1}.t) \tag{4}$$

$$\Delta t_2=\frac{\pi}{2.\omega_{r1}} \tag{5}$$

Stage 3 (t_2-t_3): While the current flows through the antiparallel diode, the main switch S_{boost} should be turned-on in zero voltage transition (ZVT). The voltage at the inductor is clamped to zero Volt and its current remains constant.

$$i_{Lr}(t)=I_{boost}+\frac{V_o}{Z_1} \tag{6}$$

Stage 4 (t_3-t_4): This stage starts with the auxiliary switch Sa2 turned-off (ZVS). Then the resonance of the energy accumulated at L_r along with the energy of the capacitor $C_{S\,buck}$ (second resonant stage), causes the voltage at the capacitor to reach zero Volt, closing this stage. The difference between the current at the inductor L_r and the I_{buck} flows through the antiparallel diode of the switch S_{buck}.

$$i_{Lr}(t) = I_{buck} + \left(I_{boost} + \frac{V_o}{Z_1} - I_{buck} \right) \cos\left(\omega_{r2} t\right) \tag{7}$$

$$v_{Csbuck}(t) = \left(I_{buck} - I_{boost}\right) Z_2 \sin\left(\omega_{r2} t\right) + \left(1 - \sin\left(\omega_{r2} t\right)\right) V_o \tag{8}$$

$$\Delta t_4 = \frac{\arcsin\left(V_o \Big/ Z_2 \left(I_{boost} + \frac{V_o}{Z_1} - I_{buck} \right) \right)}{\omega_{r2}} \tag{9}$$

Stage 5 (t_4-t_5): While the current flows through the antiparallel diode, the main switch S_{buck} should be turned-on in ZVT. At this point, the voltage $-V_o$ is applied to the inductor (L_r) and the current that flows through it starts decreasing linearly.

$$i_{Lr}(t) = I_{bat} + \left(I_{in} + \frac{V_o}{Z_1} - I_{bat} \right) \cos\left(\omega_{r2} \Delta t_4\right) - \frac{V_o}{L_r} t \tag{10}$$

$$\Delta t_5 = \left(I_{bat} + \left(I_{in} + \frac{V_o}{Z_1} - I_{bat} \right) \cos\left(\omega_{r2} \Delta t_4\right) \right) \frac{L_r}{V_o} \tag{11}$$

Stage 6 (t_5-t_6): The currents I_{boost} and I_{buck} flow completely through the switches S_{boost} and S_{buck}, respectively. The auxiliary switch S_a is turned off at ZCS.

The subsequent stages, related to the turned-off switches, are independent from the iACC, being aided only by the capacitors in parallel with the switches.

IV. RULES FOR OBTAINING THE iACC

This section will describe the basic rules for obtaining the new iACC through the proposed concept. It is important to point out that these rules don't lead to a single iACC, but there are many possible alternatives. The explanation for each rule will be presented in the final version of this paper.

Rule 1: The system should be composed by two or more PWM cells.

The larger the number of subsystems (converters), the larger the possibilities to make the integration, the larger the freedom degree, including a better utilization of the circulating reactive energy.

Rule 2: The system commutations should occur in a synchronic way.

For the energy from a commutation can be used for assisting another one, there must be a synchronism between them, i.e., the switching frequencies should be equal or multiple.

Rule 3: Definitions of the operation modes.

Thanks to the integration, the several subsystems are now seen as a single format, and the analysis is made separately for each operation mode.

Rule 4: Definition of the commutation type (boost-type or buck-type).

Based on the commutation type [22] present in each operation mode it is possible to define the way the integration should be made.

Rule 5: Definition of the integration type – serial or parallel.

If all the commutations are of the same type (only boost-type or only buck-type), the integration is called parallel, with all the switches presenting the same voltage level, and then it is necessary to add an auxiliary pole in order to produce a potential difference. On the other hand, if there is at least one switching of a different type from the others, the integration is called serial. In this integration type it is not necessary to add a pole, since there is already a natural potential difference between the cells.

Rule 6: Make the interconnection between the cells or auxiliary pole using an auxiliary branch.

Fig. 3 shows one of the auxiliary branch with the lowest number of components. The current, at the auxiliary branch, always flows from the boost-type cell to the buck-type cell.

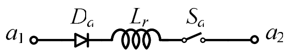


Fig. 3. Auxiliary branch for interconnecting the cells.

Rule 7: Add auxiliary switches in the current unidirectional cells.

Auxiliary switches should be added to the current unidirectional cells in order to make the path for the resonant current from one cell to another.

Rule 8: Verify if the auxiliary branches cannot share components.

Intending to minimize the number of components, cells that only inject or only divert current from a specific cell can share some of their components.

Rule 9: Definition of which commutation will supply energy in order to assist the other ones.

Choosing the cell that will assist another one is based on the system current levels that are intended to be interconnected (admitting that the voltages at the cells are equal). Therefore, in order to minimize the energy involved in the integrated commutation process, the cell with the lowest current should be taken for working as auxiliary. In the case of systems with several cells this decision is made according to the summations of the cell currents that present the same switching type (boost or buck), as described in the following equation (12).

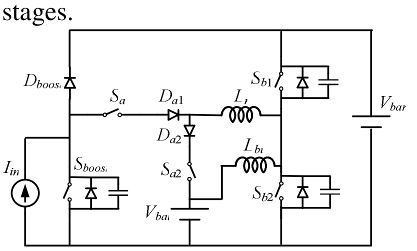
$$\sum_{1}^{n} i_{boost}(n) > \sum_{1}^{m} i_{buck}(m) \tag{12}$$

Rule 10: Verify if the iACC obtained in operation mode cannot share components.

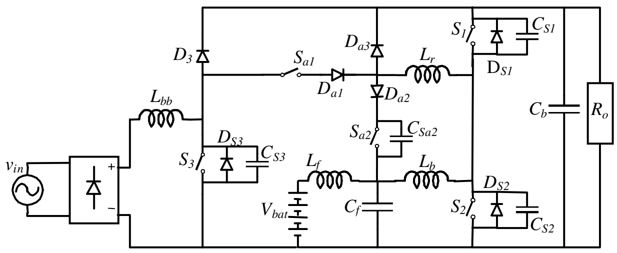
This final rule intends to conclude the integration process, and the designer's experience is very important – crucial indeed – in what refers to minimize the iACC costs. By applying these rules, the integrated ZVT ACC (iZVT) [23] is obtained at the main switches and the ZCS and/or ZVS-type at the auxiliary switches.

It is important to say that these rules apply only to DC-bus integrated systems and with ZVT commutation. However, it is still possible to use isolated iACCs that allow the integration of systems with different voltage levels and considering different switching techniques.

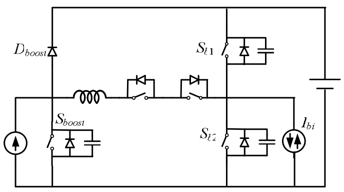
Some topologies obtained from the proposed rules are presented in Fig. 4. UPS was the system chosen for applying such rules because it is a typical system with several power conversion stages.



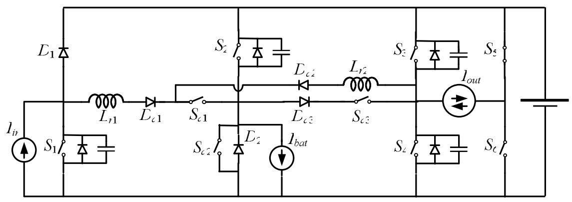
(a) Input stage UPS [24]: formed by a boost converter and a bidirectional one.



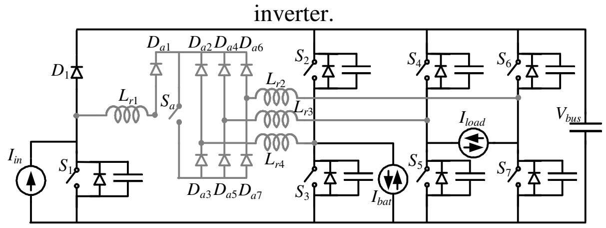
(b) Variation at the iACC [25]: formed by a boost converter and a bidirectional one.



(c). Input stage UPS (not published): formed by a boost converter and a buck one.



(d) UPS [26]: formed by a boost converter, a buck one and an inverter.



(e) UPS [20]: formed by a boost converter, a buck one and an inverter.

Fig. 4. iACC topologies obtained from the proposed rules.

V. ANALYSIS OF THE ENERGY INVOLVED IN THE COMMUTATION PROCESS

The analysis of the energy involved in the integrated commutation process will be made by means of the mathematical equation presented in section IV, with the proof of the circulating reactive energy reduction. In order to perform this comparative study, independent ACC [6] will be used. The energy accumulated in the resonant inductors will be calculated through equation (13), while the quadratic value of resonant current will be calculated through equation (14). It is important to point out that through the total energy (W_{total}) it is obtained the quantity order of the reactive energy commutation process and of the inductors' size, while the RMS current ($I_{quad\ total}$) gives a quantity order of the auxiliary circuit's ohmic losses.

This analysis does not intend to model the system, since the complexity and the wide range of possibilities would make the analysis restricted and applied only to some component technologies. The aim of this analysis is just to make some inferences about the quantity order of the reactive energy and of the losses referred to the conventional and integrated commutation processes.

$$W_{total} = \frac{1}{2}\left(L_{R1}I_1^2 + L_{R2}I_2^2 + \ldots + L_{Rn}I_n^2\right) \qquad (13)$$

$$\mathrm{I}_{quad_{\ total}} = \left(\frac{1}{T_s}\int_0^{T_s} i_{Lr_1}(t)^2\,dt\right)^2 + \ldots + \left(\frac{1}{T_s}\int_0^{T_s} i_{Lr_n}(t)^2\,dt\right)^2 \qquad (14)$$

For this analysis it will be used the topology presented in Fig. 2, taking MOSFET IRFP460A as the main switch and MUR1560 as the auxiliary diode. Based on these components, the design parameters di/dt$_{(max)}$ and t_f were obtained. It is important to point out that MOSFET IRFP460A shows an output capacitance (C_{oss}) which is typical of 870pF, therefore, it is not necessary to use the external capacitor in parallel with the switch as snubber if I_{in} < 28,8A and V_o = 400V.

The parameters used in the analysis were the following:

V_o = 400 V; f_s = 100 kHz; di/dt = 100 A/us; t_f = 58 ns; $C_{s\ buck}$ = $C_{s\ boost}$ = 870 nF; L_r = 4 uH, I_{buck} = 2A and I_{in} = 0-20A

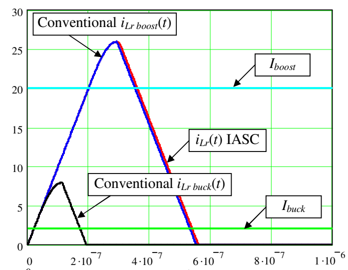


Fig. 5. Resonant current for the system with iACC and conventional ACC (I_{boost} = 20A e I_{buck} = 2A).

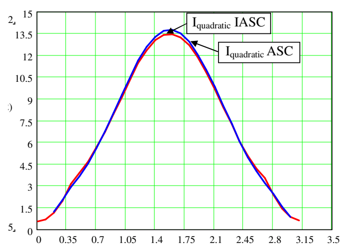


Fig. 6. Total quadratic current (I_{boost} =0-20A and I_{buck} = 2A).

Fig. 5 shows the resonant currents for the system using the conventional ACC and iACC, with maximum current values (I_{boost} = 20A e I_{buck} = 2A). The total quadratic current for both input stages can be seen in Fig. 6. This graphic show that the quadratic values present the same quantity order, i.e., the ohmic losses are similar.

The circulating reactive energy, considering both systems, is presented in Fig. 7 (I_{boost} = 0-20A and I_{buck}= 2A.), where it can be seen the circulating reactive energy reduction when the proposed iACC is used. In order to verify the circulating reactive energy behavior, graphics (see Fig. 8) of the total energy (W_{total}) in function of the I_{boost} variation and the I_{buck}

variation were designed. This figure demonstrates the circulating reactive energy reduction in the proposed system.

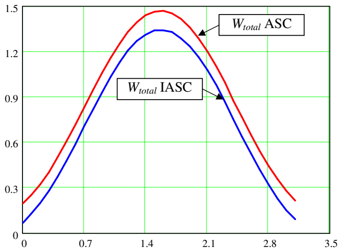


Fig. 7. Total energy (x1000).

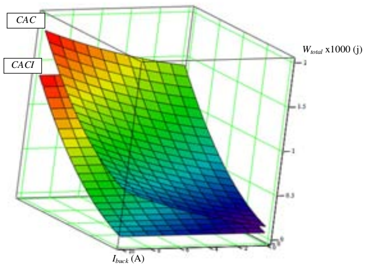


Fig. 8. Total energy

A practical application that proves the theoretical results of this section was presented in [22] where it was possible to obtain a reduction of 32,8% in the circulating reactive energy and a reduction of 3,6% in the total quadratic current. In this sense, there was an increase in the system efficiency of 1,1%, along with the reduction of the number of components, what also means cost reduction.

VI. DESIGN PROCEDURE

The design concerning the resonant elements (inductors and capacitors) is performed in this way:

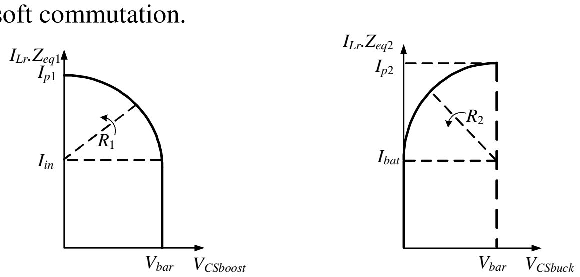
The design of the resonant inductors is made by (15) considering the maximum di/dt allowed in the semiconductors.

$$L_r = \frac{V_o}{di/dt_{(max)}} \qquad (15)$$

$$C_{snubber} = \frac{I_{pico} t_f}{\sqrt{12}\ \ V_o} \qquad (16)$$

where: V_o – is the voltage at the resonant inductor; $di/dt_{(max)}$ – is the maximum current cross-over in the semiconductors; I_{pico} – the peak current in the commutation; and t_f – is the fall time of the switch used.

The snubber capacitors should be designed for assuring the soft commutation.



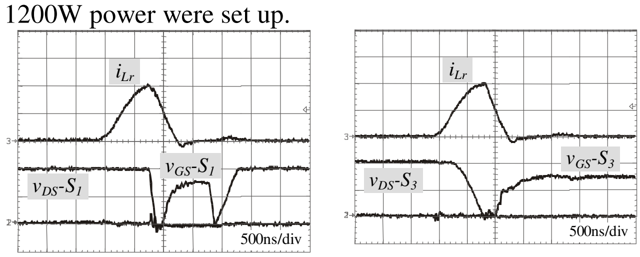
(a) (b)

Fig. 9. State plan of the integrated commutation process: (a) first step, (b) second step.

In order to assure the soft commutation, the energy accumulated in the resonant inductor of the iACC, on step 1, should be enough for taking the voltage at the other switch to zero, on step 2. In this sense, through the state plans (Fig. 9), by equating the radii R_1 and R_2, it is obtained the value of the capacitor that will supply energy for the other. The other capacitors should be designed as snubbers, through equation (16) [21], which reduces the reactive energy involved in the commutation process.

VII. EXPERIMENTAL RESULTS

The aim of the experimental results is to demonstrate the operation of the iACCs and their respective design procedure. For doing so, two prototypes with 580W and 1200W power were set up.



(a) 10A/div., vDS 200V/div. e vGS 100V/div. (b) 2/div., vDS 200V/div. e vGS 100V/div.

Fig. 10. Commutation process of the main switches: (a) current through L_r, voltage at the switch S_1 and its command; (b) current through L_r, voltage at the switch S_3 and its command.

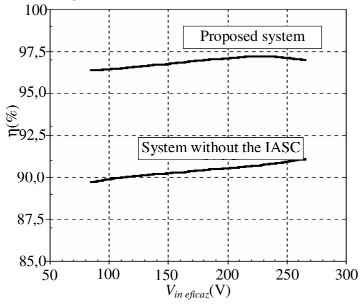
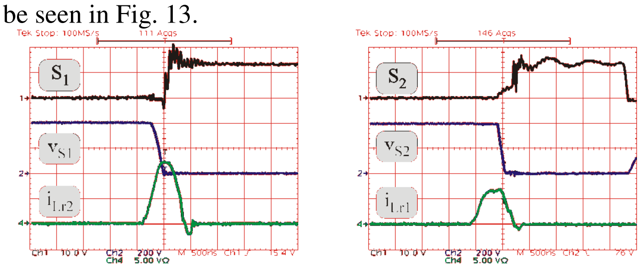


Fig. 11. System efficiency for input voltage variation (mode II).

The first topology implemented is presented in Fig. 4(b) with 580W power, working with universal input and in continues conduction mode. Fig. 10 presents the soft-switching (iZVT) of the main switches S_1 and S_3, respectively, during mode II, while the efficiency in function of the input voltage variation can be seen in Fig. 11.

Finally, the double conversion UPS topology was implemented, as shown in Fig. 4(e), with 1.2kW. The iZVT of the main switches in normal mode can be seen in Fig. 12, while the normal-mode efficiency of this same topology can be seen in Fig. 13.



(a) (b)

Fig. 12. Experimental results for the normal mode: (a) iZVT switching of S_1; (b) iZVT switching of S_2 (Ch_1 - 200V/div, . Ch_2 - 10V/div, Ch_4 – 5A/div). C

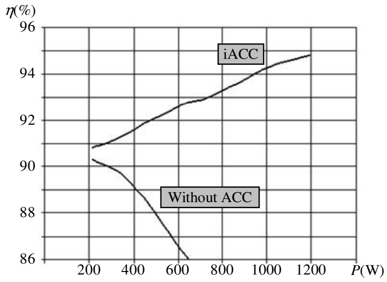


Fig. 13. Normal mode efficiency.

VIII. CONCLUSIONS

This paper presents the integration concept of ZVT ACCs, applied to systems with several power conversion stages. Using this concept, it is possible to decrease the number of additional components and the circulating energy involved in the commutation process. Consequently, it is possible to reduce the cost and to increase the efficiency and the power density of multi-converter systems. With these features, the iACCs can become more attractive to the industry.

The paper proposes ten rules for obtaining new iACCs for any application, and a practical example is included to demonstrate their application. In addition, several other topologies obtained from these rules are also shown.

A design methodology and a mathematical analysis of the system under study were made to investigate the circulating energy in the proposed iACC. This analysis can be extended to other multi-converter systems.

The input stage of a double-conversion UPS was used to demonstrate the feasibility of the concept. The simple ZVT circuit proposed in [4] was used for the comparison, because it presents the smallest number of additional components among the ZVT circuits, its design is simple, and it is well known by researchers and industry.

In all proposed iZVTs, the main switches operate under soft-commutation of ZVT type, and the auxiliary switches are turned on and off under ZCS or ZVS. When compared with ZVT circuits [4], the number of elements is reduced by half, and its efficiency is increased by more than 1%.

REFERENCES

[1] A. S. Tanenbaum, Structured Computer Organization. Prentice-Hall,. 4° ed. 2000.

[2] W. Rodrigues, D.C. S. Junior, Microeletrônica e a Universidade. Boletim informativo. Nº 1543. Ano 32. 2006. http://www.ufmg.br/boletim.

[3] M. Nakamura, M. Shimada, T. Myoui, H. Sadakata, S. Moisseev, M. Nakaoka, Performance Evaluations on Soft-Switching Boost Power Converter with a Single Auxiliary Passive Resonant Snubber. *IEEE PESC*, pp. 1057 –1062, 2001.

[4] F. C. Lee, K. H. Liu, Zero-Voltage Switching Technique in DC/DC Converters. *IEEE Transaction on Power Electronics*. Vol. 5. No. 3. p. 293-304. 1990.

[5] E. X. Yang, G. Hau, Y Jiang, F.C. Lee, “Novel Zero-Current-Transition PWM Converters”, *IEEE Transactions on Power Electronics*, Vol. 9, n. 6, pp. 601-606, 1994.

[6] G. Hua, C.-S. Leu, F.C. Lee. Novel Zero-Voltage-Transition PWM Converters. *IEEE PESC*. p. 55-60. 1992.

[7] E. X. Yang, G. Hau, Y Jiang, F.C. Lee. Novel Zero-Current-Transition PWM Converters. *IEEE Transactions on Power Electronics*, Vol. 9, n. 6, p. 601-606, 1994.

[8] C.M.O. Stein, H.L. Hey, A True ZCZVT Commutation Cell for PWM Converter**.** *IEEE Transactions on Power Electronics*. v. 15. n. 1. p. 185-193. 2000.

[9] J. P. Noon, UC3855A/B High Performance Power Factor Preregulator. Unitrode Corporation. P. U-153. 1999.

[10] N.P. Filho, V.J. Farias, L.C. Freitas. A Novel Family of DC-DC PWM Converters Using the Self-Resonance Principle. *IEEE Power Electronics Specialists Conference***.** p. 1385-1391. 1994.

[11] K. M. Smith, K. M. Smedley, A Comparison of Voltage-Mode Soft-Switching methods for PWM Converters. *IEEE Transactions on Power Electronics*. Vol. 12. n. 2. p. 376-386. 1997.

[12] R. Streit, D. Tollik, A High Efficiency Telecom Rectifier Using A Novel Soft-Switched Boost-Based Input Current Shaper. ***INTELEC***. p. 720-726. 1991.

[13] T. W. Kim, H. S. Kim, H. W. Ahn, An Improved ZVT PWM Boost Converter”, *IEEE PESC*, 2000.

[14] J. P. Gegner, C. Q. Lee, Zero-Voltage-Transition Converters Using an Inductor Feedback Technique. *IEEE APEC***.** p. 862 -868. vol.2. 1994.

[15] R. L. Lin, Y. Zhao, F. C. Lee, Improved Soft-Switching ZVT Converters with Active Snubber. *IEEE APEC*. 1998.

[16] G. Moschopoulos, P. Jain, G. Joos, Y.F. Liu,A Zero-Voltage Switched PWM Boost Converter With An Energy Feedforward Auxiliary Circuit. ***IEEE PESC***. 1996.

[17] C.J.Tseng, C.L. Chen, Novel ZVT-PWM Converters With Active Snubbers. *IEEE Transactions on Power Electronics*. Vol. 13. n. 5. p. 861-869. 1998.

[18] N. Jain, P. Jain, G. Joós, Analysis of a Zero Voltage Transition Boost Converter using a Soft Switching Auxiliary Circuit with Reduced Conduction Losses. *IEEE PESC*. 2001.

[19] M.L.S. Martins, H.L. Hey, J.R. Pinheiro, H. Pinheiro, H.A. Gründling. A ZVT PWM Boost Converter Using an Auxiliary Resonant Source. *IEEE APEC*. p. 1101-1107. 2002.

[20] L. Schuch, C. Rech, J.L. Russi, H.L. Hey, J.R. Pinheiro. Integrated Auxiliary Commutation Circuits: a Generalized Approach. ***IEEE PESC***, Recife, 2005.

[21] P. T. Krein, Elements of power electronics. Oxford UniversityPress. New York and Oxford. 1998.

[22] L. Schuch, C. Rech, J.R. Pinheiro. Input Stages of Double-Conversion UPS's Using Integration Concept of ZVT Auxiliary Commutation Circuit. *IEEE APEC*, Austin. 2005.

[23] L. Schuch, C. Rech, J.L. Russi, H.L. Hey, J.R. Pinheiro, Integrated Auxiliary Commutation Circuits: A Generalized Approach. ***IEEE PESC***, Recife, 2005.

[24] Schuch, L. ; Rech, C. ; Hey, H. L. ; Pinheiro, J. R. Integrated ZVT Auxiliary Commutation Circuit For Input Stage of Double-Conversion UPS's. *IEEE Transactions on Power Electronics*, v. 19, n. 6, 2004.

[25] L. Schuch, C. Rech, H.L. Hey, J.R. Pinheiro. Analysis and Design of a New High-Efficiencybi Birectional ZVT PWM Converter for DC Bus and Battery Bank Interface. *IEEE Transactions on Industry Applications,* v. 42, p. 1321. 2006.

[26] L. Schuch, C. Rech, J.R. Pinheiro. New Integration Concept of Auxiliary Commutation Circuits: ZVT Case Study. *IEEE PESC*, Aachen, 2004. p. 4121-4127.