MULTI-POLE ZVT CONVERTERS: A NOVEL METHODOLOGY SYNTHESIS

J. L. Russi, M. L. Martins, L. Schuch*, J. R. Pinheiro and H. L. Hey

Power Electronics and Control Research Group - GEPOC
Federal University of Santa Maria - UFSM
97105-900 - Santa Maria - RS – Brazil
jrussi@gmail.com, hey@smail.ufsm.br - www.ufsm.br/gepoc

*Lutheran University of Brazil – ULBRA
CEP: 97020-001 – Santa Maria, RS – Brazil
lschuch@ieee.org - http://www.ulbra.br

Abstract – **This paper proposes a novel synthesis methodology to generate integrated ZVT topologies, as well to systematize the topologies already known. It is presented an approach to classify the single pole ZVT converters. This approach can be expanded to multi-pole systems, such as poly-phase inverters and rectifiers, Uninterruptible Power Supplies and Variable-Speed Drives. The connections among several topologies presented so far are easily seen by means of the general diagrams shown in this paper. The analysis and understanding of advantages, disadvantages, merits and limitations of each converter is made easier since these converters are obtained from a common approach presented in this paper.**

Keywords – **Integrated ZVT Converters, Multi-Pole Systems, Soft-Switching.**

I. INTRODUCTION

The increasing demand on electric facilities such as conditioning energy equipment (UPSs), together with the stringent dynamic performance, efficiency, reliability, and size requirements imposed by the new global market, make the multi-stage systems one of the focus of the power electronics researches all over the world. Multi-stage and Multi-pole systems are comprised by a set of PWM Basic Building Blocks, as shown in Fig. 1(a).

To attend the performance and efficiency requirements of multi-pole systems such as high efficiency, good dynamic response and high power density, the soft-switching techniques can be an attractive choice [5], [8], [10], [14], [15], [18], [19], [21]. The soft-switching techniques introduce additional components to the PWM Basic Building Block aiming to shape the current and voltage waveforms during the switching intervals, alleviating the switching losses and therefore, allowing higher frequency operation enabling high efficiency, good dynamic response, low output harmonic level, high input power factor and high power density.

Among the soft-switching techniques, the ZVT (Zero-Voltage Transition) technique has gathered the interest of engineers because it allows the closest operation to the PWM counterpart [3], [4], [6]-[20]. This characteristic is quite important, once it permits that most of the knowledge acquired for the control and modulation techniques be easily applied to ZVT converters.

Multi-pole soft-switched systems can be obtained by adding individual soft-switching cells (such as the ones from [5], [8], [10], [14], [15], [18], [19], [21]) to each pole of the system. However, this procedure presents some inconvenient such as larger volume and cost and the increase in the number of switches and in the amount of isolated drives likewise. Besides, it reduces the reliability due to the increase in the amount of components.

To attend the severe market competition and industry cost constraints, the researches concerning soft-switching have been driven to integrated topologies [2]-[4], [9], [11], [12], [20], [27], [28] once that these topologies have less components and this way, the resulting structure is more compact, cheaper and can be more reliable, making them more attractive. On the other hand, it may introduce synchronous switching requirements and more complex modulation techniques.

Among the soft-switching techniques The ZVT converters present characteristics which interest the industry such as the simplicity of the topologies, the roughness and wide load soft-switching range.

Integrated soft-switching cells have been presented in [2]-[4], [9], [11], [12], [20], [27], [28] however none of these works provide an efficient methodology to evaluate or even synthesize integrated ZVT topologies. In order to fulfill this blank, this paper proposes a systematic methodology to synthesize multi-pole ZVT converters.

In addition, this paper shows that there ate connections among a set of works that originally concerned only of the proposed topology, showing that these topologies are based on the same principle. The approach presented herein shows the possibilities of implementation of simplified ZVT converters and this way, new topologies are derived. Furthermore, the analysis and understanding of advantages, disadvantages, merits and limitations of each converter is made easier since these converters are obtained from a common approach.

Moreover, since the topologies so far known are derived of only four diagrams, derived in this paper, their understanding by newcomers and experts is made much faster.

This paper is organized as follows: In Section II it is presented a classification for the ZVT cells for a single bidirectional pole. Section III presents the ZVT synthesis methodology principle. Sections IV and V individualize the synthesis methodology for classes A and B. Experimental results are provided in Section VI. Finally, Section VI presents a summary of this paper.

II. ZVT CONVERTERS

A. Single-pole bidirectional ZVT operation principle

A bidirectional single-pole can be seen in Fig. 1(a), which is the PWM Basic Building Block.

The ZVT soft-switching technique provides a parallel path to divert the current coming from or going into the pole. This way, the current through the outgoing device can be taken to zero before the ongoing device to be turned on. In order to

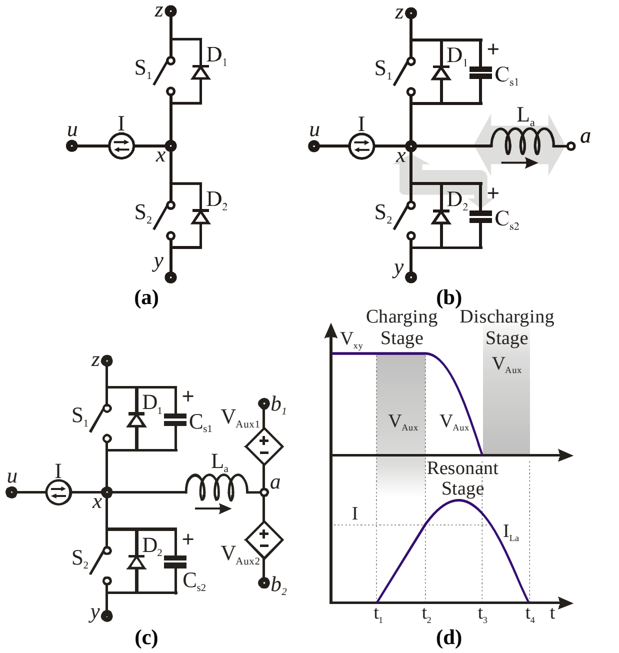


Fig. 1 - (a) Bidirectional pole; (b) Basic principle of a ZVT switching cell; (c) ZVT switching cell; and (d) Pole voltage and auxiliary inductor waveforms.

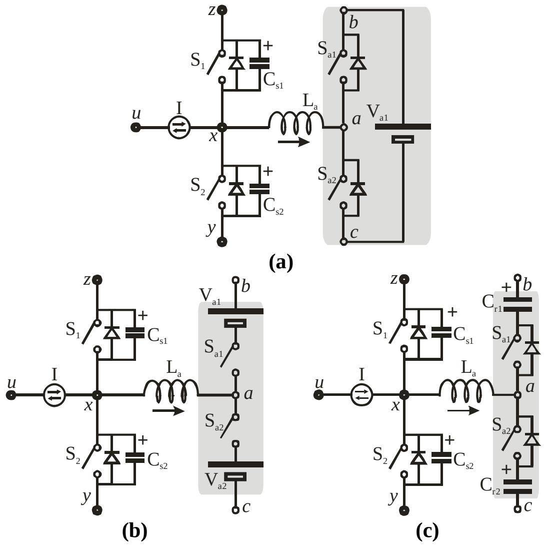


Fig. 2 - Possibilities for the implementation of the auxiliary voltage source. (a) Class A: Switched power supply; (b) Class B: DC voltage source; and (c) Class C: Resonant voltage source.

accomplish this task and also provide a limited *di/dt* rate, the auxiliary path must comprise at least an inductive element, L_a (Fig. 1(b)). As the auxiliary circuit must be active only during the transition intervals, the charge stored in the inductor must be discharged after the PWM pole commutation. To achieve the L_a discharge, the auxiliary circuit must provide a negative polarity across the terminals of L_a. This negative polarity is produced by a set of elements that characterize the Auxiliary Voltage Source (AVS), V_{aux1} and V_{aux2}, shown in Fig. 1(c).

To commutate from D_1 to S_2, the AVS must be able to provide a voltage smaller than V_{xy} during the charging interval (t_1-t_2) in order to divert the current from the pole to the auxiliary circuit, Fig. 1(d). The energy stored in L_a during the charging interval must be enough to discharge the capacitors in parallel with the switches within the resonant interval (t_2-t_3). During the discharging interval (t_3-t_4), the value generated by the AVS must be bigger than V_{xy}, Fig. 1(d), to demagnetize the auxiliary inductor. A similar commutation process occurs to commutate from D_2 to S_1.

Depending on how the AVS is implemented, the auxiliary ZVT circuit will hold distinct characteristics.

In a general way there are three different modes for the implementation of the AVS [23]. Therefore, the auxiliary ZVT switching cells can be classified according to the way that the auxiliary voltage source (shaded in Fig. 2) is implemented. For bidirectional single-pole converters, three different classes can be derived, similarly as it is presented in [23] for DC-DC converters.

➢ Class A – ZVT PWM converters with switched auxiliary voltage source (Fig. 2(a)) [5]: The auxiliary voltage source for this class of converters is implemented by a switch that changes the values of voltage applied over the resonant inductor by shifting the connection of the common terminal of this switch to terminals with different voltage levels. During the inductor charging stage, a constant voltage is applied across the inductor terminals that will increase the current through this inductor. After achieving the soft-switching conditions for the turn-on of an active switch, the auxiliary switch is turned off in order to apply a negative voltage across the resonant inductor to demagnetize it. The main problem of this class is the auxiliary switch turn-off. If the auxiliary switch is implemented by majority carriers device type (MOSFET), it will suffer from turn-off capacitive losses and if it is implemented by minority carriers device type (IGBT) there will be losses due to its tailing current.

➢ Class B – ZVT PWM converters with auxiliary DC voltage source (Fig. 2(b)) [8], [10], [14] and [19]: This class of converters has auxiliary DC power supplies which make possible that the current through the auxiliary circuit returns to zero after a main switch to be turned-on. Therefore, the auxiliary switch turns-off under zero current. The auxiliary voltage power supplies are generally implemented by the DC-rail midpoint [8], [19] (Fig. 2 (b)) or through magnetic coupling [10], [14]. For the latter case, according to the transformer/coupled inductor configuration, the current which flows through the auxiliary switch can be even smaller than the pole current, reducing the current stress and this way, the resistive losses in the auxiliary circuit. However, some of the converters of this class have problems related to the practical implementation of the magnetic coupled voltage source, such as the residual magnetizing current [15].

➢ Class C – ZVT PWM converters with auxiliary resonant voltage source (Fig. 2(c)) [21]: the converters of this class keep the favorable characteristic of turn-off under zero current for the auxiliary switch (as it occurs for Class B) by an LC resonant tank. On the other hand, the auxiliary network exposes the main switches to current stress and additional reactive energy, which worsens the converter efficiency. This class, besides the general operation intervals depicted in Fig. 1(d) may present an additional operation mode to reset the resonant capacitors (C_{r1} and C_{r2}) to their initial conditions [29].

The converters of Class A are attractive since they have a small number of auxiliary elements. On the other hand, these converters present problems related to the commutation of the auxiliary switches. For the converters of Class B, it is

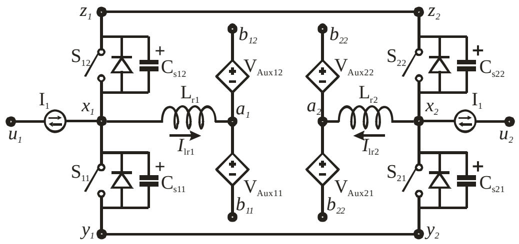


Fig. 3 - Multi-pole converter with individual ZVT auxiliary cell.

possible to reduce the reactive energy diverted to the auxiliary circuit by the proper design of the voltage level of the auxiliary voltage source, what can decrease the conduction losses in the auxiliary switch. However, the converters of this class need a transformer or the DC-rail midpoint to implement the auxiliary voltage source. The converters of Class C present an additional complexity related to the design of the resonant tank, since there are third-order stages involved in the commutation process. On the other hand, the auxiliary circuit can be more compact than for Class B. Class C converters present zero current conditions for the auxiliary switches, as Class B converters do.

B. Multi-pole bi-directional ZVT operation principle

The parallel connection of n PWM Basic Building Blocks, alike the one of Fig. 1(a) will lead to a multi-pole PWM converter.

Soft-switching conditions can be obtained for every switch of multi-pole converters simply by adding soft-switching cells, derived from the configurations shown in Fig. 2 [5], [8], [10], [14], [15], [18], [19], [21], for each of the poles which compose the system as presented in [2]-[4], [9], [11]-[14], [22]. The inconvenient of this procedure is that the number of auxiliary switches usually increases to twice the number of poles and the amount of drives needed for these switches increases likewise.

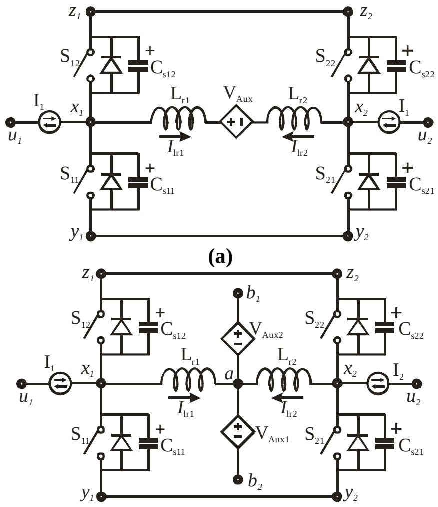
In Fig. 3 it can be seen a system with two bidirectional poles in which the ZVT cells are connected in an independent arrangement. It can be seen that there are AVSs for each pole to control the voltage applied on inductors L_{r1} and L_{r2} and this way, the energy flow through the auxiliary circuits.

To reduce the amount of auxiliary components, some auxiliary device must be shared by more than one auxiliary circuit. Generally the component shared is either a switch or an auxiliary voltage source. The procedure of sharing components will allow to reduce the number of auxiliary devices providing more attractive (more compact and less expensive) auxiliary circuits.

Aiming to reduce the number of components in the auxiliary circuit, the voltage sources can be interconnected, Fig. 4. This can be attained by (i) the series connection of the AVSs (the current is transferred from one pole to another, Fig. 4 (a)) or (ii) by connecting the AVSs in parallel (the current from the poles is diverted to/from a terminal with constant voltage level, Fig. 4 (b)).

C. Arrangements for multi-pole auxiliary switches

The two alternatives aforementioned require the simultaneous turn-off of all passive switches since for these arrangements the operation of the two (or more) auxiliary networks is dependent of each other. To allow the independent turn-off of the active switches a diode bridge must be inserted between the interconnection of the auxiliary branches of the system.



(a)

(b)

Fig. 4 - Possibilities of connection of the auxiliary voltage source for a system of bidirectional converters.

The auxiliary circuit, in parallel with the switches of a pole must have the following elements: (i) an inductor to allow the current to be diverted from/to the main circuit with a finite *di/dt* rate; (ii) an arrangement of diodes and switches to control the current flow from one pole to another or to a voltage source; and (iii) an auxiliary voltage source to control the charging and discharging of the auxiliary inductor.

To allow the sharing of auxiliary components, it is necessary the utilization of switches which may have more than a single output/input. Some basic arrangements of unidirectional voltage and current switches are shown, as follows.

1. Single-Pole Single-Throw (Fig. 5 (a)), SPST: used to connect a single pole to a single output;

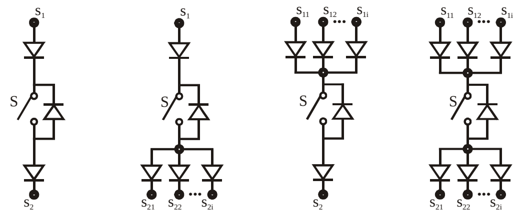
2. Single-Pole Multi-Throw (Fig. 5 (b)), SPMT: connects a single input to several poles;

3. Multi-Pole Single-Throw (Fig. 5 (c)), MPST: connects several poles to a single output;

4. Multi-Pole Multi-Throw (Fig. 5 (d)), MPMT: connects several poles to several poles.

III. GENERALIZED ZVT SYNTHESIS METHODOLOGY

The synthesis methodology is based on the diagrams of Fig. 6. As the auxiliary switches for multi-pole ZVT converters, Fig. 5, are indeed an arrangement of an active switch and at least one diode, it is more illustrative to show them as in the diagrams in Fig. 6. Each diagram is formed by inductors, AVSs and the passive and active switch blocks. When the terminals x_{m1} and x_{m2} are connected to the DC-rail, each



(a) (b) (c) (d)

Fig. 5 - Switch Arrangements. (a) Single-Pole Single Throw; (b) Single-Pole Multi Throw; (c) Multi-Pole Single-Throw; and (d) Multi-Pole Multi-Throw.

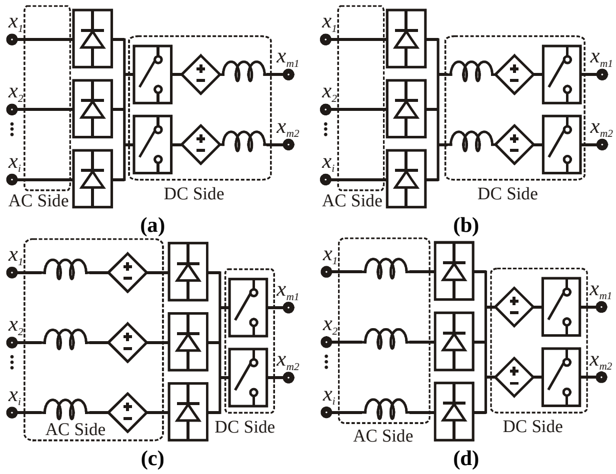


Fig. 6 - Possibilities of connection of the elements.

configuration presents a single-pole multi-throw switch (Fig. 5(b)) and a multi-pole single-throw switch (Fig. 5(c)). If these terminals (x_{m1} and x_{m2}) are shorted, then the configuration presents a multi-pole multi-throw switch.

A. Series Connected Auxiliary Voltage Source (SC-AVS)

The auxiliary circuit in Fig. 4(a) is named as Series Connected Auxiliary Voltage Source (SC-AVS). When the auxiliary circuit is activated, the current of each pole is commutated from the diode to the switch, connecting the pole to the complementary DC-rail of the commutated diode. There are several possibilities for the location of the auxiliary components for SC-AVS cells, which are illustrated in Fig. 6, where the terminals x_1, x_2, … x_i are connected to the poles of the converter. The terminals x_{m1} and x_{m2} must be shorted in order to allow the current flow from the pole (s) connected to the positive DC-rail to the pole (s) connected to the negative DC-rail, i.e. there must be at least a top and at least a bottom diode conducting.

B. Parallel Connected Auxiliary Voltage Source (PC-AVS)

The auxiliary circuit shown in Fig. 4(b) is named as Parallel Connected Auxiliary Voltage Source (PC-AVS). For this case, in Fig. 6, the terminals x_1, x_2, … x_i are connected to the poles of the converter and the terminal x_{m1} must be connected to the positive DC-rail and x_{m2} to the negative DC-rail or vice-versa. When one auxiliary switch is activated, it will be drawn current from the poles connected to the positive DC-rail or it will be injected current into the poles connected to the negative DC-rail.

The region on the left of the diodes (Fig. 6) is called AC side and the area on the right, DC side, since it is unidirectional.

IV. CLASS A ZVT SYNTHESIS METHODOLOGY

The Class A ZVT converters can be generated by the generalized diagrams shown in Fig. 6(a), 6(b) and 6(d). Since the AVS is actually implemented by the switching action of the auxiliary switch, the auxiliary switch and the auxiliary voltage source cannot appear split in the diagrams.

Case A: Consider the system comprised by a pole operating as a buck and two poles operating as boost, Fig. 7(a). In order to generate an auxiliary circuit able to commutate from the diodes to the active switches under zero-voltage conditions, the diagram shown in Fig. 6(d) is applied to the PWM converter. For Class A, the AVS is implemented by the switching action of the auxiliary switch and, this way, the AVS does not appear explicit in the topologies.

To implement the switch it is chosen the MPST switch of Fig. 5(c) since two inputs and one output are needed. The MPST (in gray) will allow the energy transfer from the boost converters to the buck converter and this way, the discharge of the capacitors in parallel with the switches.

At least an inductor must be inserted in each auxiliary path to provide the finite di/dt rate to the main diodes. The inductor (s) can be inserted in several locations. For this case, they will be inserted in the AC side.

The operation of the ZVT converters of Class A is typically composed by the inductor charging stage, a resonant stage and finally the inductor discharging stage, which starts with the turn-off of the auxiliary switch. As the inductor discharging stage occurs when the auxiliary switch turns off, there must be an alternative path to discharge this inductor. This path is usually implemented by a diode connected between the inductor and the auxiliary switch. In this case, the extra diode, D_a, is inserted to demagnetize L_a.

Case B: The system comprised by a boost and two buck converters, Fig. 7(b). By applying a procedure similar to the one described above, the topology in Fig. 7(b) is obtained. As it can be seen, this topology is useful to commutate the complementary diodes of Fig. 7(a). The diagram of Fig. 6(d) is used, although in this case, the diodes conduct in the opposite direction of Fig. 7(a) making the switch SPMT (Fig. 5(b)) the best option. Diode D_a, is inserted to demagnetize L_a.

Case C: Bidirectional poles: Intending to make the same auxiliary circuit able to commutate every upper and every

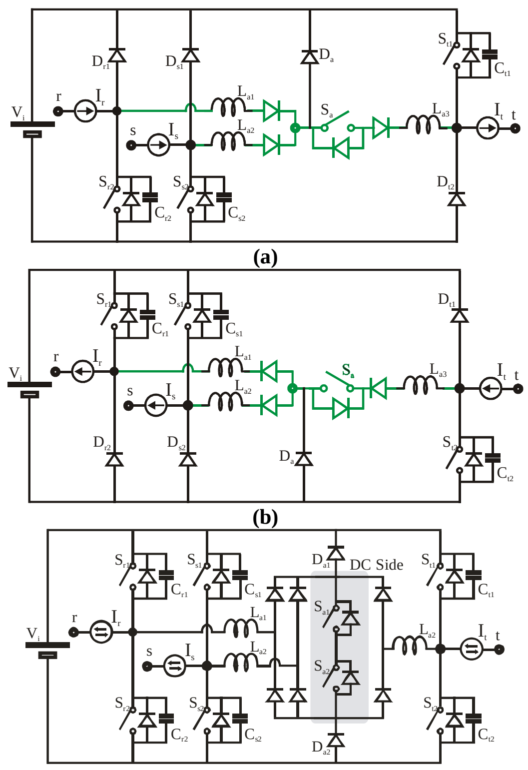


Fig. 7 - Synthesis example using the diagram from Fig. 6(d). (a) Case A; (b) Case B; (c) Both cases.

lower diode of the topology of Fig. 7(c) the auxiliary circuit must permit bidirectional current flow. This way, a diode bridge is inserted, what will generate a unidirectional region which is named DC Side. The area outside the diode bridge is the AC Side and is symmetrical for bidirectional poles. Rearranging the switches within the DC Side, the soft-switching cell of Fig. 7(c) is obtained. This cell presents a SPMT switch and a MPST switch which are indeed a MPMT witch. One of the auxiliary switches (S_{a1} or S_{a2}) can be suppressed since it is redundant.

In Fig. 8 are presented the SC-AVS cells based on the diagram blocks shown in Fig. 6 for three phase PWM converters. As commented, the terminals x_{m1} and x_{m2} are shorted (terminal x_m) for the SC-AVS and the configuration presents a multi-pole multi-throw switch (Fig. 5 (d)). If the DC-rail midpoint is unavailable, the auxiliary cells can be simplified, leading to just one auxiliary inductor (Fig. 8 (a)) and just one auxiliary switch (Fig. 8(b) and (c)). On the other hand, if the DC-rail midpoint is available, the terminal x_m can be connected to it, reducing by half the voltage applied to the auxiliary switches.

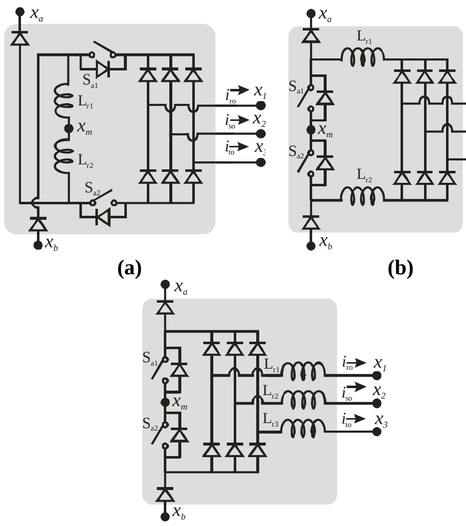

(a) (b) (c)

Fig. 8 - Class A: SC-AVS cells. (a) [22]; (b) [4]; (c) [2], [3], [4] (center tapped), [20], [22] and [24].

It can be seen that the soft-switching cells of Fig. 8(a), Fig. 8(b) and Fig. 8(c) correspond to the diagrams of Fig. 6(a), Fig. 6(b) and Fig. 6(d), respectively. From the diagram of Fig. 6(c) it cannot be obtained any converter from Class A, since the voltage source and the switches are actually the same component, i.e., they cannot appear split as in Fig. 6(c).

The PC-AVS converters are generated connecting terminals x_{m1} and x_{m2} to opposite DC-rails (Fig. 9(a) and Fig. 9(b). The converters shown in Fig. 9(a) and Fig. 9(b) correspond to those of Fig. 6(c) and Fig. 6(b), respectively. The diagram in Fig. 6(a) could not generate any PC-AVS due to inductor demagnetization issues.

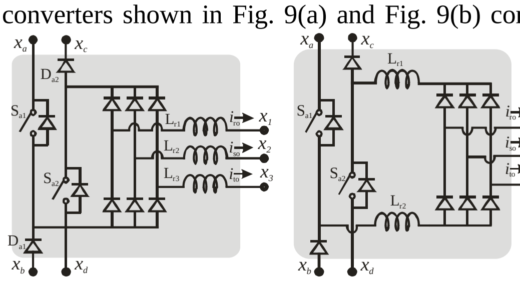

(a) (b)

Fig. 9 - Class A PC-AVS cells. (a) Unpublished; (b) Unpublished.

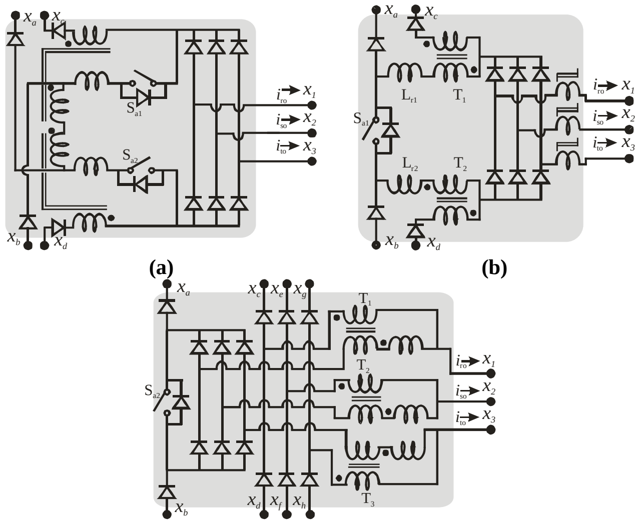

(a) (b) (c)

Fig. 10 - Class B: SC-AVS cells. (a) [9]; (b) Unpublished; (c) Unpublished;

V. CLASS B ZVT SYNTHESIS METHODOLOGY

The Class B ZVT converters are generated from the diagrams of Fig. 6, in the same way as the ones from Class A.

The auxiliary inductor can be implemented by the leakage inductance of the magnetically coupled AVS.

In Fig. 10 and Fig. 11 are shown the Class B converters which are derived from the ZVT Inverter with Inductor Feedback [15]. Several new topologies can be derived from the True PWM Pole ZVS Pole Inverter [15], from the Transformer Assisted ZVS Pole Inverter [15] and so on.

The PC-AVS three-phase cells shown in Fig. 10 are obtained from the diagrams of Fig. 6. The configurations obtained have two transformers and two active switches.

It can be seen that the soft-switching cells of Fig. 10(a), Fig. 10(b) and Fig. 10(c) correspond to the configurations of Fig. 6(a), Fig. 6(b) and Fig. 6(c), respectively.

The PC-AVS converters are generated connecting termi-

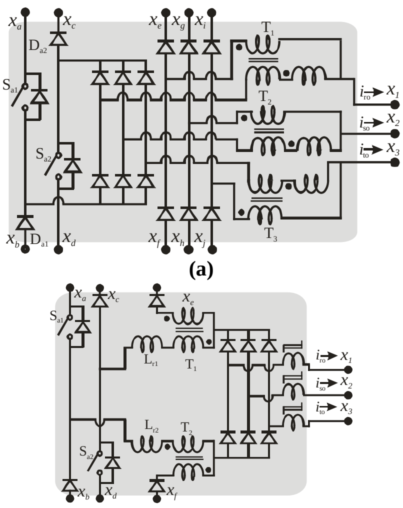

(a) (b)

Fig. 11 - Class B: PC-AVS cells. (a) Unpublished; (b) [11].

nals x_{m1} and x_{m2} to opposite DC-rails (Fig. 11(a) and Fig. 11 (b). The converters shown in Fig. 11(a) and Fig. 11(b) correspond to those of Fig. 6(c) and Fig. 6(b), respectively. The diagram in Fig. 6(a) could not generate any PC-AVS due to inductor demagnetizing issues.

VI. EXPERIMENTAL RESULTS

The procedure proposed to synthesize integrated ZVT converters can be used to generate several multi-pole systems such as poly-phase rectifiers/inverters, variable-speed drives and so on. To illustrate the feasibility of the synthesis procedure presented herein, this section presents some experimental results concerning an Uninterruptible Power Supply (UPS) system.

Fig. 12 illustrates a double conversion UPS system composed by three bidirectional poles, which are the battery charger/discharger (bidirectional converter) and the two output inverter legs (full-bridge) and by a unidirectional pole, which is the boost pre-regulator. This means that the auxiliary soft-switching cell must be able to inject current to and to drain current from the bidirectional poles and able to drain current from the unidirectional pole.

A soft-switching cell similar to that of Fig. 8(c) was chosen to be applied to the UPS of Fig. 12. The differences be-

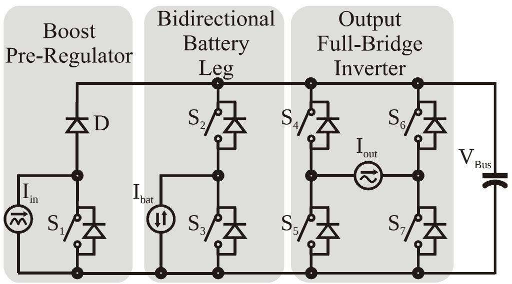


Fig. 12 - Uninterruptible Power Supply.

tween the auxiliary cell of Fig. 6(d) and the resulting topology of Fig. 13 are as follow: for a four-pole system an extra inductor (L_{r4}) is needed together with diodes D_5 and D_6 to drain/inject current into the pole of the extra leg. Since there is no connection to the capacitive DC-rail midpoint, the cell can be simplified suppressing one of the series auxiliary switches (S_{a1} or S_{a2}). Moreover, the boost pre-regulator converter does not need any current to be injected into its pole. Thus, the diode D_2 can be also suppressed. Auxiliary diodes D_1 and D_{10} may also be suppressed depending on the switching strategy. As a result the command signals of the switches become more complex since it is needed to determine with accuracy the instants when the resonant current becomes null.

This UPS system presents four distinct operation modes,

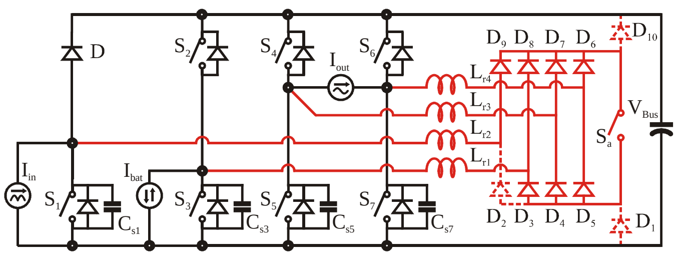


Fig. 13 - Soft-Switching UPS.

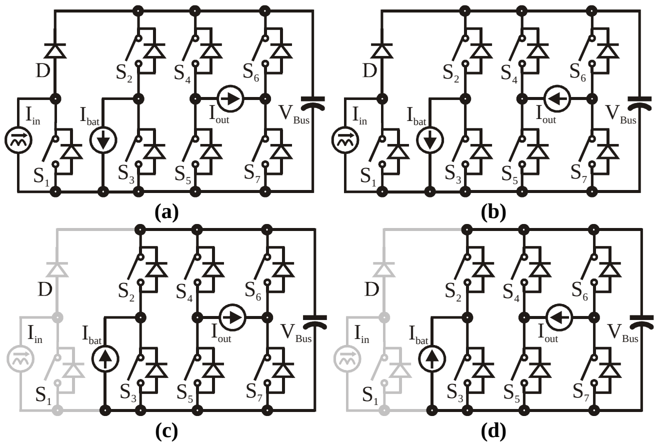


Fig. 14 - UPS Operating Modes. (a) Normal Mode (1); (b) Normal Mode (2); (c) Backup Mode (3) and (d) Backup Mode (4).

as follows:

➢ Normal Modes (1) and (2), Fig. 14(a) and (b): the boost pre-regulator supplies energy for the battery charger, which operates as a buck converter and for the output full-bridge inverter.

➢ Backup Modes (3) and (4), Fig. 14(c) and (d): the bidirectional battery converter operates as a boost converter supplying energy to the output inverter. During these modes the boost pre-regulator is inactive.

The UPS was implemented with the parameters given in Table 1 [28]. Since modes (1) and (2) as well as modes (3) and (4) are indeed very similar, except for the current direction in the full-bridge converter, the experimental results are only presented for modes (1) and (3).

Normal mode (1): During this mode the current must be drained from the most left and most right poles and injected

Table 1. Experimental Parameters and Specifications.

Parameter	Value
Nominal Power (P_o)	1000 W
Output Voltage (V_o)	220 V_{rms}
Input Voltage (V_{in})	220 V_{rms} ±10%
Battery Bank Voltage (V_{bat})	96V
DC bus (V_{bus})	400V
Current Charger of the Battery Bank (I_{bat})	1.4A
Commutation Frequency (f_s)	100 kHz
C_{s1}	3.3 nF
C_{s3}, C_{s5}, C_{s7}	0.47 nF
L_{r1}, L_{r2}, L_{r3}, L_{r4},	5 µH

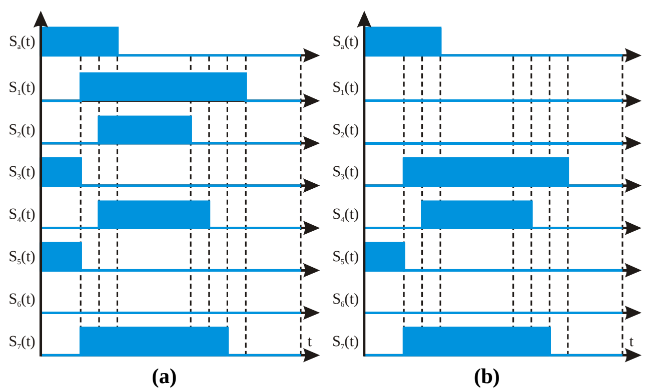


Fig. 15 - Commands Logic. (a) Normal Mode (1); and (b) Backup Mode (3).

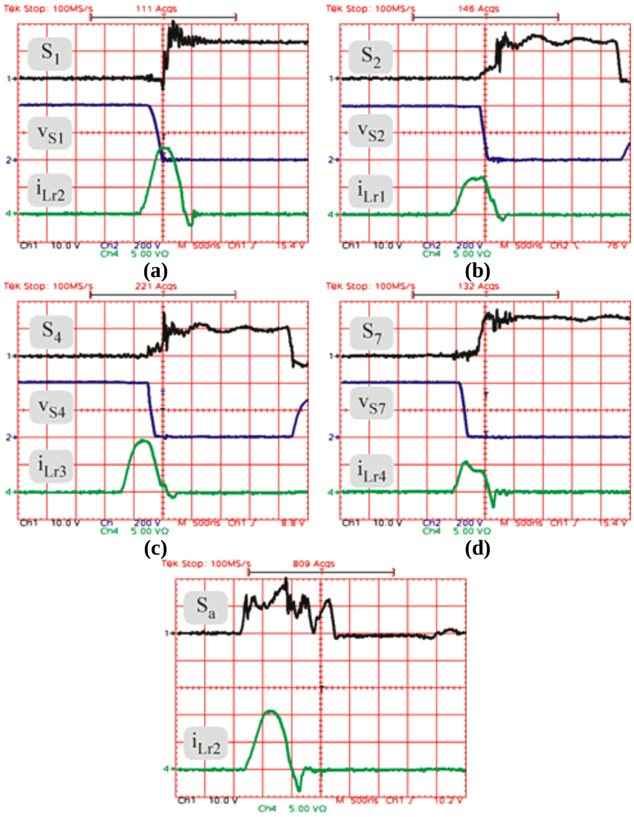


Fig. 16 - Experimental Results for Normal Mode (1). Scales: S_i– 10 V/div; v_{Si}– 200 V/div; i_{Lri}– 5 A/div; t– 500ns/div.

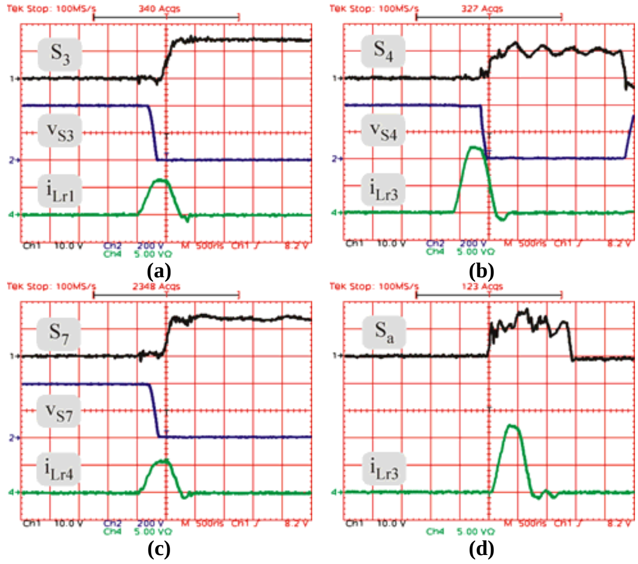


Fig. 17 - Experimental Results for Backup Mode (3). Scales: S_i– 10 V/div; v_{Si}– 200 V/div; i_{Lri}– 5 A/div; t– 500ns/div.

into the center poles, Fig. 14(a). The command logic can be seen in Fig. 15(a). Fig. 16 shows the experimental results for this mode. As shown in the waveforms, the switches S_1, S_2, S_4 and S_7 turn-on in a soft way, under ZVS (Fig. 16(a), (b), (c) and (d)). The turn-off of every active switch occurs naturally under soft-switching as it occurs for ordinary ZVT converters. Fig. 16 (e) shows that the auxiliary switch commutates under ZCS conditions.

Backup Mode (3): During this mode the current must be drained from the center left and most right poles and injected into the center right pole, Fig. 14(c). The command logic can be seen in Fig. 15(b). The experimental results for this mode can be seen in Fig. 17. As observed in the waveforms, the switches S_3, S_4 and S_7 present soft turn-on (under ZVS), Fig. 17(a), (b) and (c) respectively. The auxiliary switch S_a commutates under ZCS conditions as shown in Fig. 17 (d).

It must be noticed that the turn-on of the switches must be synchronized once that the auxiliary cell acts over all the legs of the system. This way, the reactive energy diverted from one commutation can be used to assist another one.

VII. SUMMARY

This paper presented a classification methodology for single-pole ZVT inverters based on the way the auxiliary voltage source is implemented. According to this criterion three distinct classes were defined:

➢ Class A – ZVT PWM converters with switched auxiliary voltage source;

➢ Class B – ZVT PWM converters with auxiliary DC voltage source;

➢ Class C – ZVT PWM converters with auxiliary resonant voltage source.

This concept was expanded for multi-pole ZVT converters generating four diagrams which show the possibilities for the arranges of integrated multi-pole soft-switching cells.

The general principle to generate simplified ZVT converters is illustrated by means of block diagrams and switch configurations which allow the synthesis of simplified multi-pole ZVT converters.

The diagrams presented were able to generate several integrated soft-switching cells, whether or not they are presented in the literature, showing that the converters that were published individually are actually connected among themselves and share the same principle.

Experimental results of a double-conversion UPS system were presented to validate the synthesis procedure proposed in this paper.

The synthesis methodology for Classes A and B ZVT integrated converters allowed to derive integrated ZVT converters, some of them unpublished yet. This methodology is being expanded for the other soft-switching techniques and will be presented soon.

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