New Shoot-Through Control Methods for qZSI-Based DC/DC Converters

Indrek Roasto, *Member, IEEE*, Dmitri Vinnikov, *Senior Member, IEEE*, Janis Zakis, *Member, IEEE*, and Oleksandr Husev, *Student Member, IEEE*

Abstract—Shoot-through control methods for qZSI-based dc/dc converters are presented and studied. The major goal was to increase efficiency. A new modulation technique, pulse width modulation (PWM) with shifted shoot-through, is compared with the conventional PWM shoot-through control method. The new method reduces switching frequency of bottom side transistors and inherently features partial soft switching. Previous studies have shown that the biggest drawback of PWM control with shoot-through is unequal switching frequencies of transistors. One solution to that problem could be signal swapping that has been proposed by the authors of this paper. All control methods are first simulated and then experimentally verified on a test prototype.

Index Terms—DC/DC converter, quasi-Z-source inverter, shoot-through control methods, switching losses.

Fig. 1. Simplified power circuit diagram of the proposed converter.

I. INTRODUCTION

A QUASI-Z-SOURCE inverter (qZSI), as a sine wave inverter for ac loads, has been widely studied [1]–[8]. In 2009, researchers of the Department of Electrical Drives and Power Electronics, Tallinn University of Technology proposed a new application field for the qZSI as an isolated step-up dc/dc converter [9]–[13]. The baseline topology of the quasi-Z-source (qZS) based dc/dc converter (Fig. 1) consists of the quasi-Z-source network that includes two capacitors ($C1$ and $C2$), a diode ($D1$), and two inductors ($L1$ and $L2$). The high-frequency step-up isolation transformer (Tr) is supplied by the IGBT-based single-phase inverter ($T1 \ldots T4$). To reduce the turns ratio of the transformer a voltage doubler rectifier based on two capacitors ($C3$ and $C4$) and two diodes ($D2$ and $D3$) was implemented in the output.

The qZSI inherits all the advantages of the Z-source inverter, which can realize buck/boost, inversion and power conditioning in a single stage with improved reliability. In addition, the qZSI has the unique advantages of lower component ratings and constant dc current from the source [4], [14]. All these features make qZSI an attractive converter for renewable and alternative energy sources [15]–[19].

The authors are with the Department of Electrical Drives and Power Electronics, Tallinn University of Technology, 19086 Tallinn, Estonia (e-mail: indrek.roasto@ieee.org; dmitri.vinnikov@ieee.org; janis.zakis@ieee.org; oleksandr.husev@ieee.org).
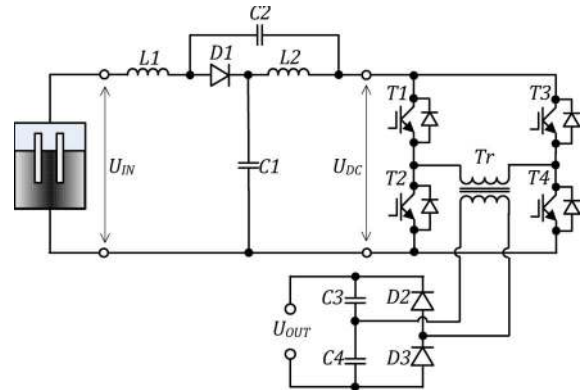
The proposed converter is designed to be a power conditioning unit for a fuel cell powered systems. It is characterized by low voltage and high current values, which normally results in high losses of the system. Thus, serious attention should be paid to loss reduction not only in conductors but also in the semiconductor switches of the inverter. Losses in IGBT switches can be significantly reduced by proper control methods. One of the benefits that the qZS topology offers is soft switching without additional components. The number of soft switching transients achievable depends mostly on the modulation method. In some cases both zero current switching (ZCS) and zero voltage switching (ZVS) are possible over full operation range [14].

Two basic shoot-through control techniques for the qZS-based dc/dc converter were recently proposed: pulse width modulation (PWM) and phase shift modulation (PSM) [20], [21]. In both cases, shoot-through is generated during zero states. The zero and shoot-through states are spread over the switching period so that the number of higher harmonics in the transformer primary could be reduced. To reduce switching losses of the transistors, the number of shoot-through states per period is limited by two. Moreover, to decrease the conduction losses of the transistors, shoot-through current is evenly distributed between both inverter legs [20].

According to [22] both methods (PWM, PSM) are fairly identical in terms of conduction losses since the number of conduction states and their duration remain unchanged. However, due to an increased number of hard-switched commutations in the case of the PSM shoot-through control method, switching losses were increased by more than 20%. Moreover, PSM injects noticeably higher overvoltages into the system compared to the PWM control [20]. Taking all that into account, PWM control seems to be the best control method for the qZS-based dc/dc
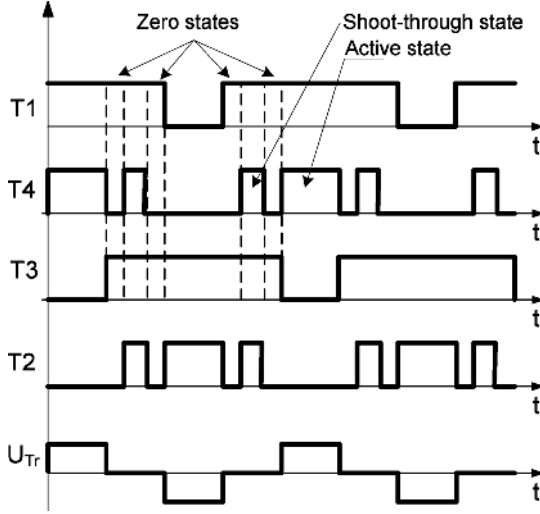
Fig. 2. Generation of PWM signals with shoot-through during zero states.

Fig. 3. Generation of PWM signals with shifted shoot-through during zero states.

	Top side		Bottom side	
	T1	T3	T2	T4
Active state	1	0	0	1
Zero state	1	1	0	0
Shoot-through	1	1	1	1
Zero state	1	1	0	0
Active state	0	1	1	0
Zero state	1	1	0	0
Shoot-through	1	1	1	1
Zero state	1	1	0	0

converter. The only problem with the PWM shoot-through control is that it imposes unequal operating frequencies of the transistors, which results in unequal switching losses.

Today's major trend in power electronics is to increase efficiency. It is only achievable by optimizing operation parameters and components of a converter. One should avoid over- or under- loaded components. That is the reason why in the current research focus is on equalizing switching losses in the qZS inverter. This paper discusses the PWM shoot-through control method in detail. The authors have also proposed several new improved PWM control methods such as shifted shoot-through control and swapped PWM control, which allow us to achieve better performance of the converter.

II. PWM SHOOT-THROUGH CONTROL METHODS OF qZS BASED DC/DC CONVERTER

A. PWM Control Principle

The PWM control principle of a qZS-based dc/dc converter is shown in Fig. 2. Shoot-through states should be placed so that they would not disturb the shape of the primary voltage of the isolation transformer. This enables us to keep the number of higher harmonics to a minimum. One way to accomplish that is to generate shoot-through inside zero states, as shown in Fig. 2. It must be pointed out that zero states are always generated by the same pair of switches: either the top ($T1$ and $T3$) or the bottom ($T2$ and $T4$) transistors. Currently the top side transistors were used.

The minimum number of shoot-through states per period of the isolation transformer is two. One shoot-through state per period would cause discontinuous mode input current and the qZSI starts to behave abnormally. In general, the maximum number of shoot-through states is not limited. However, one should bear in mind that every additional shoot-through state automatically increases the switching frequency of the transistors and switching losses. Thus, the number of shoot-through states should be kept to a minimum. During shoot-through the current through the inverter switches reaches its maximum. The voltage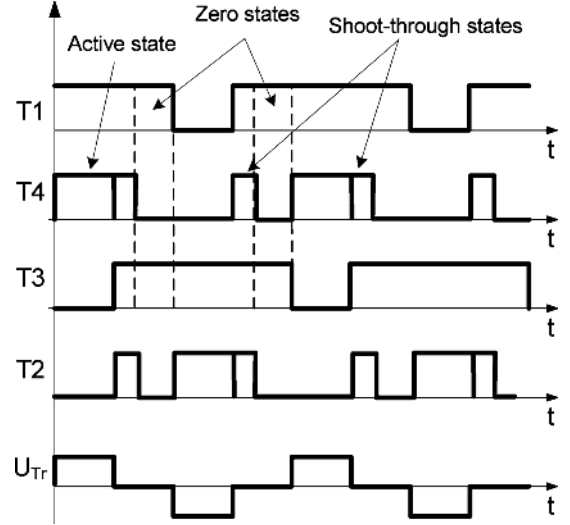 in the dc-link (U_{DC}) drops to zero. The voltage of the isolation transformer (U_{Tr}) remains unchanged, as indicated in Fig. 2.

B. PWM Control With Shifted Shoot-Through

This modulation technique was proposed by the authors as an alternative to the conventional PWM control that was explained previously. To equalize transistor switching losses, the shoot-through states are shifted towards active states, as shown in Fig. 3. As a result, there is one switching transient less for bottom side transistors, as indicated in Table II. The states are shown for one period of the isolation transformer. As it can be seen, bottom side transistors have now two times higher operating frequency compared to the top side transistors. However, shoot-through states remain inside zero states, which is the condition required to keep the transformer voltage unchanged.

C. Further Improvements of the PWM Control Principle

By shifting shoot-through states towards active states the switching losses of transistors could be balanced to some degree. However, the switching frequency of top and bottom side transistors is still different, thus also switching losses. Since, the main target was to completely equalize transistor switching losses, we developed a further improvement method. The idea is to periodically swap transistors so that each transistor would work half the time as a top side and half the time as a bottom

TABLE II
SWITCHING STATES SEQUENCE PER ONE PERIOD OF PWM
WITH SHIFTED SHOOT-THROUGH

	Top side		Bottom side	
	T1	T3	T2	T4
Active state	1	0	0	1
Shoot-through	1	1	1	1
Zero state	1	1	0	0
Active state	0	1	1	0
Shoot-through	1	1	1	1
Zero state	1	1	0	0

TABLE III
OPERATING PARAMETERS OF THE CONVERTER

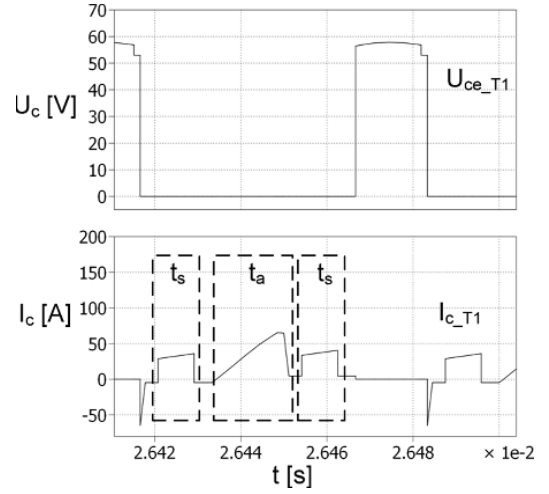| Parameter	Value
Input voltage, U_{IN}	30 V
Desired DC-link voltage, U_{DC}	60 V
Load resistance, R_{load}	300 Ohm
Operating frequency of qZS-network, f_{qZS}	30 kHz
Operating frequency of transformer, f_{Tr}	15 kHz
Shoot-through state, t_S	8.3 μs
Active state, t_A	33.3 μs
Zero state, t_Z	8.3 μs
Inductance of inductors $L1$ and $L2$	50 μH
Capacitance of capacitors $C1$ and $C2$	240 μF
Transformer turns ratio	1:5

Fig. 4. Diagonal swapping of transistors. (a) PWM. (b) PWM with shifted shoot-through.

Fig. 5. Current and voltage of top side transistor T1 in the case of PWM control with shoot-through.

side switch. It is achieved by swapping control signals of the transistors.

Swapping may occur at any time instant but should not affect the transformer voltage. Moreover, swapping should be instantaneous to all transistors. There are two possibilities to swap top and bottom transistors: vertical swapping and diagonal swapping.

In the case of vertical swapping, T1 is swapped with T2 and T3 with T4. The benefit of this method is that it is easy to implement it on most microcontrollers. The complementary transistor pair (T1/T2 or T3/T4) requires only one PWM generator with two complementary outputs. Many microcontrollers dedicated to power electronic applications also feature pins swapping of complementary outputs. However, as a drawback, vertical swapping causes a phase shift (180°) in the transformer voltage. This kind of a disturbance can push the transformer into saturation and must be avoided. Thus, vertical swapping can be considered as unsuitable in the current case.

In the case of diagonal swapping, T1 is swapped with T4 and T2 with T3. Since diagonally placed transistors work in phase, swapping causes no phase shift and the transformer voltage remains unaffected, as shown in Fig. 4. Both control methods, PWM and PWM with shifted shoot-through, can be swapped.

Diagonal swapping can fully equalize switching frequencies and losses of transistors. The drawback of this method is that it is relatively difficult to be implemented on a microcontroller. Usually diagonally placed transistors in the full-bridge are controlled by separate PWM channels, which cannot be swapped on most of microcontrollers. Therefore, some additional hardware is needed to carry out swapping.

III. SIMULATION RESULTS

The proposed new PWM control method together with two swapping techniques was simulated within PSIM simulation software. To predict the behavior of the real converter accurately, also some losses were taken into account: input inductors have internal resistance, diodes, and transistors have forward voltage drop. Operation parameters of the investigated converter (Table III) were selected for the case of maximal voltage boost when the maximal current in the input side of the converter appears. The converter was loaded by the 300 Ω resistor and the system power was around 1 kW.

In the case of the conventional PWM control with shoot-through, full soft switching (i.e., ZVS and ZCS) is possible for top side transistors. Moreover, soft switching is achieved for both: shoot-through and active states, as shown in Fig. 5. Bottom side transistors are hard switched, as shown in Fig. 6.
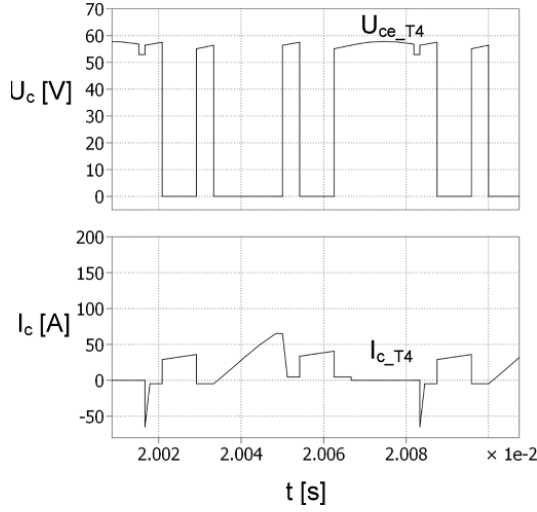
Fig. 6. Current and voltage of bottom side transistor T4 in the case of PWM control with shoot-through.
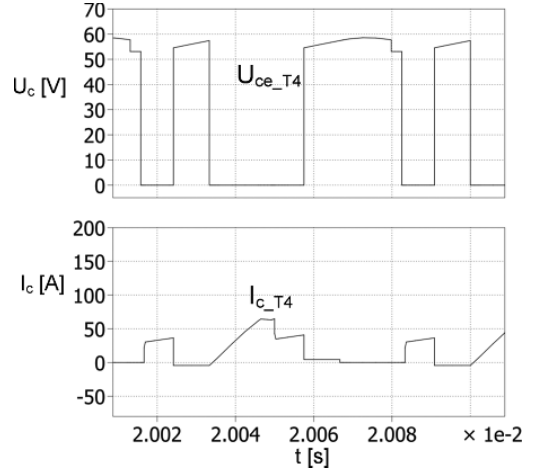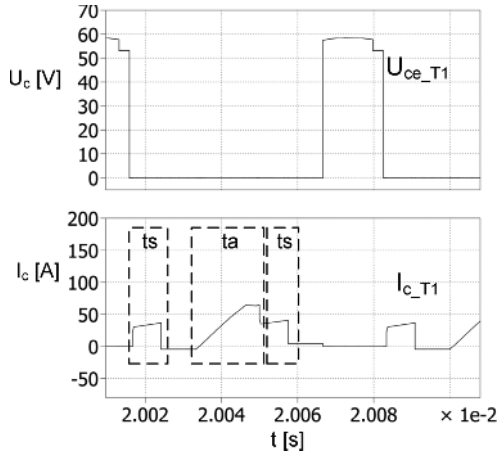

Fig. 7. Current and voltage of the top side transistor T1 in the case of PWM control with shifted shoot-through.

PWM control with shifted shoot-through features the following soft switching transients: for active states ZVS and ZCS, for shoot-through states ZCS, as shown in Fig. 7. Unlike in the previous control method, soft switching can also be achieved for bottom side transistors. The active state is incorporated with the second shoot-through state. The transition from one state into the other is immediate, i.e., without dynamic losses (Fig. 8).

IV. EXPERIMENTAL VERIFICATION

To verify theoretical assumptions a laboratory prototype (Fig. 9) was assembled in accordance with the schematics in Fig. 1. Operating parameters were selected in accordance with the design specifications presented in Table III.

A. Practical Guidelines for Building the Control System

Microcontrollers generate PWM using timers and compare values. As a rule, conventional microcontrollers have only one or two compare values per timer, which is enough in most

Fig. 8. Current and voltage of the bottom side transistor T4 in the case of PWM control with shifted shoot-through.
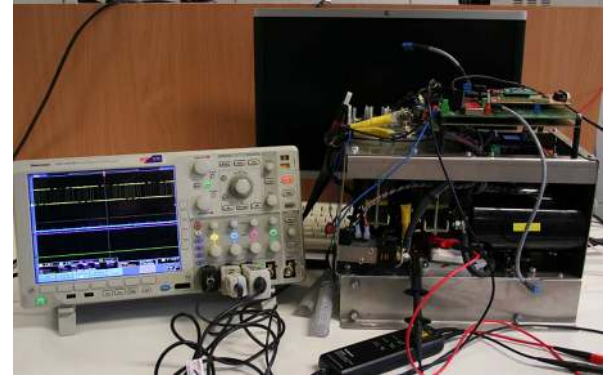

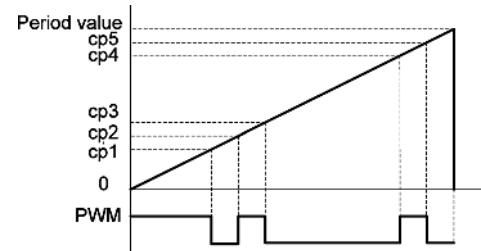Fig. 9. 2 kW test setup of the qZS-based dc/dc converter.

Fig. 10. Generation principle of PWM with shoot-through in microcontrollers.

cases. Currently, the situation is more complicated due to shoot-through states.

To generate PWM with shoot-through states up to five compare values (cp1–cp5) are needed, as shown in Fig. 10. In other words, this means that PWM with shoot-through is impossible to be implemented on most of microcontrollers. Three methods can be considered as a solution to the problem:

1) using a FPGA;
2) using a microcontroller combined with a FPGA;
3) using a microcontroller combined with an external logic circuitry.

A FPGA, as a highly configurable hardware that contains thousands of programmable logic blocks, could perfectly take
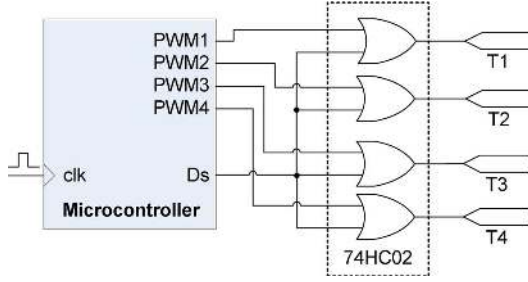
Fig. 11.   PWM generation with shoot-through using a microcontroller combined with an external logic circuitry.
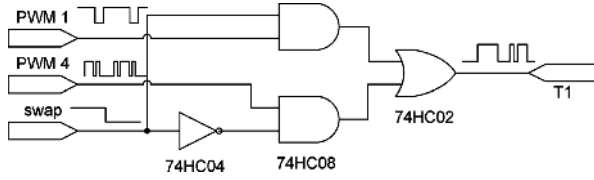

Fig. 12.   Signal swapping circuit diagram.

the role of a modulator. At the same time, relatively poor performance in handling sequential algorithms and floating point calculations makes it an impractical solution as a regulator.

The second option has higher prospects from that point of view. A FPGA could be used as a modulator while the microcontroller could handle all the needed calculations and measurements in the converter.

The third option should be considered when the price and the development time are dominant parameters. The main idea here is to generate the shoot-through vector separately from PWM and mix signals by the help of an external logic, as indicated in Fig. 11. Currently we need only one OR logic block like 74HC02 to link together PWM and shoot-through states in the microcontroller output. Clearly, this is the cheapest and simplest solution of the three options.

Swapping requires more external logic components (74HC04, 74HC08, 74HC02), as shown in Fig. 12. The microcontroller generates an auxiliary signal *swap*, which determines the swapping frequency and timing. Signals *PWM1* and *PWM4* are the corresponding microcontroller outputs with the added shoot-through vector. The external logic makes the swapping according to the signal *swap*. The output $T1$ is connected with the corresponding IGBT driver. The same principle is used for all four channels. The result is shown in Fig. 13. The switching frequency of each transistor is periodically changing but over a longer period it becomes clear that all transistors are switched with a similar control pattern. Moreover, this also means that transistors are evenly loaded and should have equal switching losses.

Swapping can occur at any time instant but should not affect the transformer voltage. As mentioned before, this is only possible with diagonal swapping, i.e., diagonally placed transistors of a full-bridge will be swapped. Two control signals and the transformer primary voltage are shown in Fig. 14. As expected, no disturbances can be recognized in the transformer voltage despite swapping and the converter is working normally.
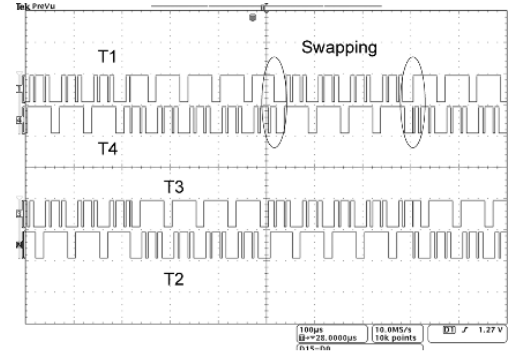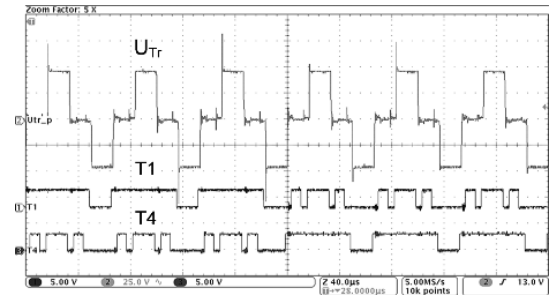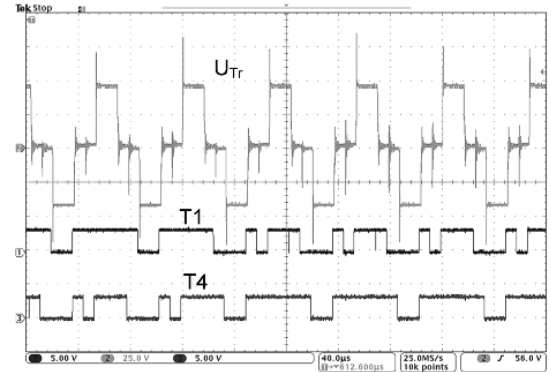

(a)
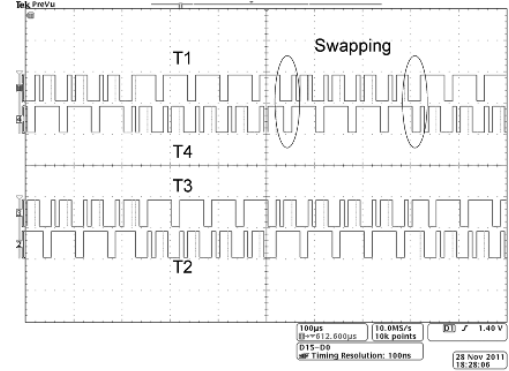
(b)

Fig. 13.   Diagonal swapping of control signals. (a) PWM control with shoot-through. (b) PWM control with shifted shoot-through.

(a)

(b)

Fig. 14.   Swapping has no impact on transformer primary voltage. (a) PWM control with shoot-through. (b) PWM control with shifted shoot-through.
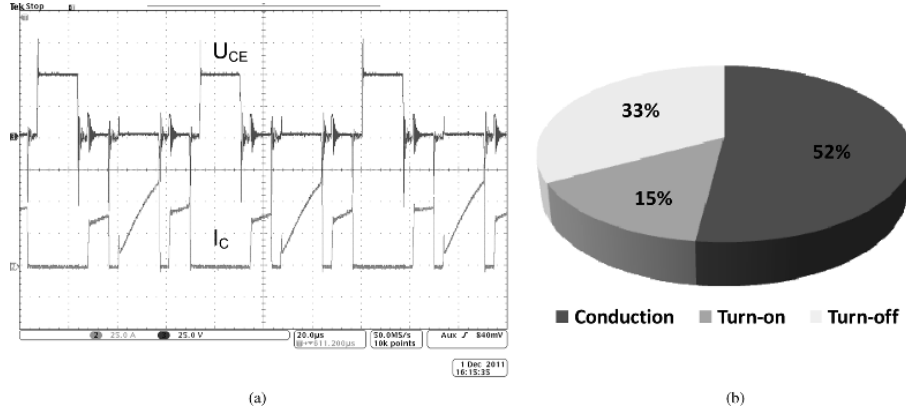
Fig. 15. PWM control with shoot-through (a) collector-emitter voltage and current and (b) power loss breakdown of the transistor T1.
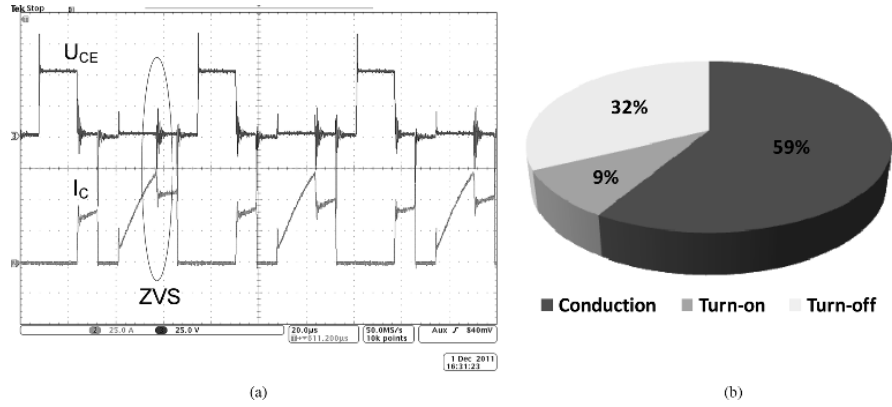

Fig. 16. PWM control with shifted shoot-through (a) collector-emitter voltage and current and (b) power loss breakdown of the transistor T1.
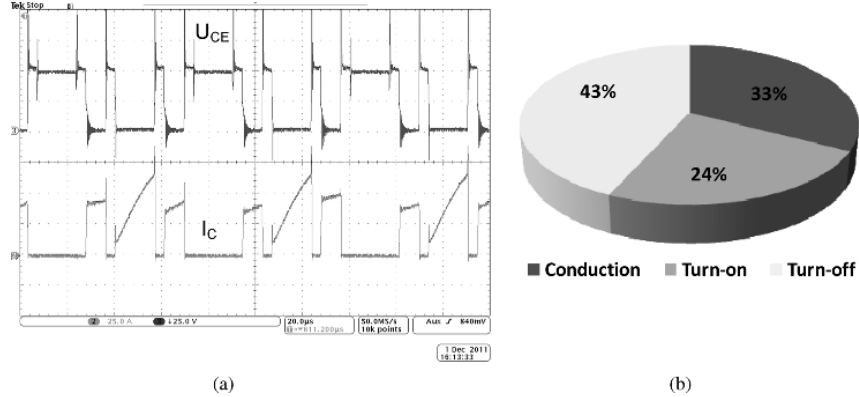

Fig. 17. PWM control with shoot-through (a) collector-emitter voltage and current and (b) power loss breakdown of the transistor T4.

B. Effects of Soft Switching

As predicted by simulations, full soft switching (ZVS and ZCS) is achieved for top side transistors in the case of the conventional PWM shoot-through control. Both shoot-through states and the active state occur with zero collector emitter voltage (U_{CE}). A drawback of the proposed PWM control method with shifted shoot-through is the loss of full soft switching properties. Namely, ZVS for the first shoot-through vector is lost, as shown in Fig. 15(b). However, the switching frequency of top side transistors is not changed.
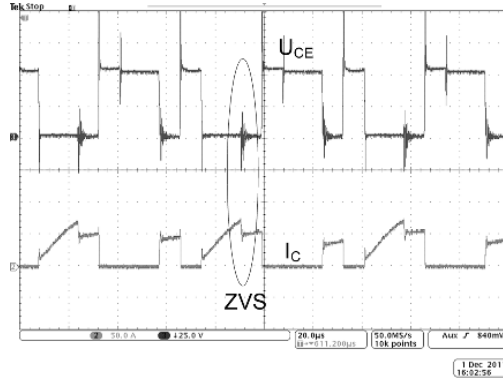
The collector current and collector-emitter voltage of the bottom transistor $T4$ are shown in Fig. 17. In the case of the conventional PWM with shoot-through, no soft switching

occurs, as shown in Fig. 17(a). In the case of the proposed PWM control with shifted shoot-through, two switching states (turn-off and turn-on) are eliminated. The second shoot-through state is shifted towards the active state so that ZVS is achieved, as shown in Fig. 17(b). The shoot-through state occurs with zero voltage. Moreover, also the switching frequency was reduced compared to the conventional PWM control method in Fig. 17(a).
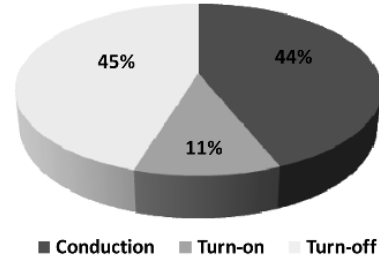
Table IV summarizes comparisons made between the conduction (P_{COND}) and switching (P_{ON}, P_{OFF}) losses for top and bottom transistor groups for one operating period of the PWM shoot-through control method.

Table V summarizes comparisons made between the conduction (P_{COND}) and switching (P_{ON}, P_{OFF}) losses for top and

Fig. 18. PWM control with shifted shoot-through (a) collector-emitter voltage and current and (b) power loss breakdown of the transistor T4.

TABLE IV
COMPARISON OF TRANSISTOR LOSSES IN THE PWM CONTROL

Losses State	P_{ON} (W)	P_{OFF} (W)	P_{COND} (W)	P_{SUM} (W)
Top transistors	6.2	17.1	28.6	51.9
Bot. transistors	23.4	40.6	28.9	92.9

TABLE V
COMPARISON OF TRANSISTOR LOSSES IN THE PWM CONTROL WITH SHIFTED
SHOOT-THROUGH

Losses State	P_{ON} (W)	P_{OFF} (W)	P_{COND} (W)	P_{SUM} (W)
Top transistors	2.4	8.1	34.3	44.8
Bot. transistors	5.7	24.5	34.4	64.6

bottom transistor groups for one operating period of the PWM control with shifted shoot-through.

It is noticeable from Tables IV and V that conduction losses do not change much. But due to an increased number of soft switching instants in the case of the PWM control with shifted shoot-through the switching losses were significantly decreased. It finally means that the proposed PWM control with shifted shoot-through enables the operating efficiency of a 1 kW single-phase qZSI to be increased by 4%.

V. CONCLUSIONS

A new modulation method, PWM with shifted shoot-through for qZS-based dc/dc converters, was proposed and analyzed by the authors of this paper. Unlike the conventional PWM with shoot-through the new modulation method allows achieving soft switching also for bottom side transistors. Full soft switching in the top side transistors is replaced by partial soft switching. However, the switching losses in top and bottom side transistors are more balanced when comparing with conventional PWM method.

REFERENCES

[1] M.-K. Nguyen, Y.-G. Jung, and Y.-C. Lim, "Single-Phase AC-AC converter based on quasi-Z-source topology," *IEEE Trans. Power Electron.*, vol. 25, no. 8, pp. 2200–2210, Aug. 2010.

[2] M. Nguyen, Y. Lim, and G. Cho, "Switched-Inductor quasi-Z-source inverter," *IEEE Trans. Power Electron.*, vol. 26, no. 11, pp. 3183–3191, Nov. 2011.

[3] C. J. Gajanayake, F. L. Luo, H. B. Gooi, P. L. So, and L. K. Siow, "Extended-Boost Z-source inverters," *IEEE Trans. Power Electron.*, vol. 25, no. 10, pp. 2642–2652, Oct. 2010.

[4] Y. Li, J. Anderson, F. Z. Peng, and D. Liu, "Quasi-Z-source inverter for photovoltaic generation systems," in *Proc. IEEE Appl. Power Electron. Conf.*, 2009, pp. 918–924.

[5] B. Yu, X. Ding, Y. Lu, H. Li, and X. Li, "Voltage sags on quasi-Z-source adjustable-speed drives system," in *Proc. Int. Conf. Mechatronics Automat. (ICMA)*, Aug. 7–10, 2011, pp. 1899–1904.

[6] J. Anderson and F. Z. Peng, "Four quasi-Z-source inverters," in *Proc. IEEE PESC*, Rhodes, Greece, Jun. 2008, pp. 2743–2749.

[7] Q. Lei, F. Z. Peng, and S. Yang, "Discontinuous operation modes of current-fed quasi-Z-source inverter," in *Proc. 26th Annu. IEEE Appl. Power Electron. Conf. Expo. (APEC)*, Mar. 6–11, 2011, pp. 437–441.

[8] S. Yang, F. Z. Peng, Q. Lei, R. Inoshita, and Z. Qian, "Current-fed quasi-Z-source inverter with voltage buck-boost and regeneration capability," in *Proc. IEEE Energy Convers. Congr. Expo.*, Sep. 20–24, 2009, pp. 3675–3682.

[9] D. Vinnikov and I. Roasto, "Quasi-Z-source-based isolated DC/DC converters for distributed power generation," *IEEE Trans. Ind. Electron.*, vol. 58, no. 1, pp. 192–201, Jan. 2011.

[10] D. Vinnikov, I. Roasto, R. Strzelecki, and M. Adamowicz, "Step-up DC/DC converters with cascaded quasi-Z-source network," *IEEE Trans. Ind. Electron.*, vol. 59, no. 10, pp. 3727–3736, Oct. 2012.

[11] D. Vinnikov, I. Roasto, J. Zakis, and R. Strzelecki, "New step-up DC/DC converter for fuel cell powered distributed generation systems: Some design guidelines," *Elect. Rev. (Przeglad Elektrotechniczny)*, vol. 86, no. 8, pp. 245–251, 2010.

[12] D. Vinnikov, I. Roasto, T. Jalakas, and S. Ott, "Extended boost quasi-Z-source inverters: Possibilities and challenges," *Electron. Elect. Eng.*, vol. 112, no. 6, pp. 51–56, 2011.

[13] R. Strzelecki and M. Adamowicz, "Boost-buck inverters with cascaded qZ-type impedance networks," *Elect. Rev.*, vol. 86, no. 2, pp. 370–375, 2010.

[14] J. Zakis, D. Vinnikov, and I. Roasto, "Soft-switching capability analysis of a qZSI-based DC/DC converter," in *Proc. 12th Biennial Baltic Electron. Conf. (BEC)*, Oct. 4–6, 2010, pp. 301–304.

[15] H. bu-Rub, A. Iqbal, S. K. Moin Ahmed, F. Z. Peng, Y. Li, and G. Baoming, "Quasi-Z-Source inverter-based photovoltaic generation system with maximum power tracking control using ANFIS," *IEEE Trans. Sustainable Energy*, 2012, to be published.

[16] B. Ge, H. Abu-Rub, F. Peng, Q. Lei, A. de Almeida, F. Ferreira, D. Sun, and Y. Liu, "An energy stored quasi-Z-source inverter for application to photovoltaic power system," *IEEE Trans. Ind. Electron.*, 2012, to be published.

[17] B. Ge, H. Abu-Rub, F. Peng, Q. Lei, A. de Almeida, F. Ferreira, D. Sun, and Y. Liu, "An energy stored quasi-Z-source inverter for application to photovoltaic power system," *IEEE Trans. Ind. Electron.*, 2012, to be published.

[18] D. Sun, B. Ge, H. Abu Rub, F. Z. Peng, and A. T. de Almeida, "Power flow control for quasi-Z source inverter with battery based PV power generation system," in *Proc. Energy Convers. Congr. Expo. (ECCE)*, Sep. 17–22, 2011, pp. 1051–1056.

[19] J. G. Cintron *et al.*, "Quasi-Z-source inverter withenergy storage for photovoltaic power generation systems," in *Proc. 26th Annu. IEEE Appl. Power Electron. Conf. Expo.*, Mar. 2011, pp. 401–406.

[20] I. Roasto, D. Vinnikov, T. Jalakas, J. Zakis, and S. Ott, "Experimental study of shoot-through control methods for qZSI-based DC/DC converters," in *Proc. Int. Symp. Power Electron. Elect. Drives Automat. Motion (SPEEDAM)*, Jun. 14–16, 2010, pp. 29–34.

[21] I. Roasto and D. Vinnikov, "Analysis and evaluation of PWM and PSM shoot-through control methods for voltage-fed qZSI based DC/DC converters," in *Proc. 14th Int. Power Electron. Motion Control Conf. (EPE-PEMC)*, Sep. 6–8, 2010, pp. T3-100–T3-105.

[22] D. Vinnikov, I. Roasto, J. Zakis, S. Ott, and T. Jalakas, "Analysis of switching conditions of IGBTs in modified sine wave qZSIs operated with different shoot-through control methods," *Electron. Elect. Eng.*, vol. 5(111), no. 5, pp. 45–50, 2011.

Indrek Roasto (M'10) received the B.Sc. and M.Sc. degrees in electrical engineering from Tallinn University of Technology, Tallinn, Estonia, in 2003 and 2005, respectively, and the Ph.D. degree from Tallinn University of Technology, Tallinn, Estonia, in 2009, with a dissertation devoted to the research and development of smart control and protection systems for high-voltage high-power galvanically isolated dc/dc converters.

He is currently a Senior Researcher with the Department of Electrical Drives and Power Electronics, Tallinn University of Technology. He has over 40 publications and is the holder of five utility models and one patent in the field of power electronics. His research interests are in digital control of switching power converters, including modeling, design, and implementation.

Dmitri Vinnikov (M'07–SM'11) received the Dipl. Eng., M.Sc., and Dr.Sc.Techn. degrees in electrical engineering from Tallinn University of Technology, Tallinn, Estonia, in 1999, 2001, and 2005, respectively.

He is currently a Head of the Power Electronics Research Group at the Department of Electrical Drives and Power Electronics, Tallinn University of Technology. He has authored more than 100 published papers on power converter design and development and is the holder of several patents and utility models in this application field. His research interests include switch-mode power converters, modeling and simulation of power systems, applied design of power converters and control systems, and application and development of energy storage systems.

Janis Zakis (M'10) received B.Sc., M.Sc. and Dr.Sc.Ing. degrees in electrical engineering from Riga Technical University, Riga, Latvia, in 2002, 2004 and 2008, respectively.

His current position is Senior Researcher in the Department of Electrical Drives and Power Electronics, Tallinn University of Technology, Tallinn, Estonia. He has published over 30 scientific papers in international journals and conferences and is the holder of one Utility Model in power converter design. His current research interests include modeling and simulation of switch-mode power converters, applied design of power converters for energy storage, and renewable energy systems.

Oleksandr Husev (S'11) received the B.Sc. and M.Sc. degrees in industrial electronics from Chernihiv State Technological University, Chernihiv, Ukraine, in 2007 and 2008 respectively, where he is currently working toward the Ph.D. degree. His Ph.D. dissertation is devoted to research active power filters and development of control system based on artificial intellect.

He is assistant of the Department of Industrial Electronics, Chernihiv State Technological University, and currently cooperates with the Department of Electrical Drives and Power Electronics, Tallinn University of Technology, Tallinn, Estonia. He has over 20 publications and is the holder of several patents. His research interests are in control systems for power electronic converters based on a wide range of algorithms, including modeling, design, and simulation.