http://dx.doi.org/10.21172/ijiet.114.05

A Novel High Efficiency Bidirectional Soft Switching DC-DC Converter

Jeena Joseph[1], Kavitha Issac[2], Veena Mathew[3]

[1]Post Graduate student, [2]Assistant Professor, Department of EEE,. Mar Athanasius College of Engineering ,Kothamangalam , Kerala India

[3]Assistant Professor, Department of Mathematics,. Mar Athanasius College of Engineering ,Kothamangalam , Kerala India

Abstract-A novel topology for a non-isolated bidirectional DC-DC converter is presented here with soft-switching capability, it usually operates at a zero-voltage-switching (ZVS) condition. In this circuit additional auxiliary circuit added for obtaining soft switching condition instead of adding auxiliary switches. The suggested auxiliary circuit consists of one resonant inductor and two capacitors. Soft-switching technology is to reduce switching losses. By generating and keeping a recycle current in the auxiliary circuits, this topology can provide soft-switching conditions for both switches. Due to the existence of the auxiliary circuits, it can reduce the current ripple in the main inductor. Here no auxiliary switches are used and also two main switches work in ZVS conditions. Main characteristic of this topology is not only operated with soft switching method but has simple structure and high efficiency. The modified converter simulated using MATLAB/SIMULINK R2014a software. The switching pulses for the control circuit is generated using PIC16F877A microcontroller. Hardware prototype of the proposed soft switching bidirectional DC-DC converter is implemented and observed output voltage of 6.37V for an input voltage of 30V.

IndexTerms—*Bidirectional DC-DC Converter, Soft switching, non-isolated converter, ZVS, high-efficiency, resonant networks.*

INTRODUCTION

Due to the rapidly increasing economy and enormous demand for energy, the global energy crisis has been aggravated. To deal with this energy problem, researches on environmental friendly system such as the electric vehicles and distributed power system [1] have been carried out. In these applications, an energy storage system like a battery system must be needed to save and use energy. The BDC is categorized into an isolated converter [2] and a non-isolated converter [3].

The demands of bidirectional DC-DC converter (BDC) are smaller size, lighter weight and higher efficiency etc. In order to minimize the size of BDC, the switching frequency must be increased. However, the increase of switching frequency results in higher switching losses. To solve this problem, many soft switching technology that employ resonant networks widely used in DC-DC converters.

Traditionally the zero voltage transition (ZVT) method and zero current transition (ZCT) method are effective soft-switching technologies applied to the half-bridge bidirectional DC-DC converter. However due to the existence of commutation problems, at least two auxiliaryswitches are needed for a bidirectional ZVT topology. The control timing of auxiliary switches is different from the main switches. This will increase the control complexity of the bidirectional converter.

To reduce the control complexity coupled inductors and auxiliary diodes were used in [4], which give soft-switching condition for the active switches. The auxiliary switches in this topology is only used to control operation directions, thus control complexity is reduced. To reduce the number of auxiliary switches, a new non-isolated bidirectional soft-switching topology with one auxiliary switch is in [5].

Here a novel high efficiency bidirectional soft switching DC-DC converter is proposed. This topology employs only a small resonance inductor and two capacitors to provide soft-switching conditions for the bidirectional DC-DC converter. This topology has no auxiliary switches and both switches work in ZVS condition.

HIGH EFFICIENCY BIDIRECTIONAL SOFT SWITCHING DC-DC CONVERTER

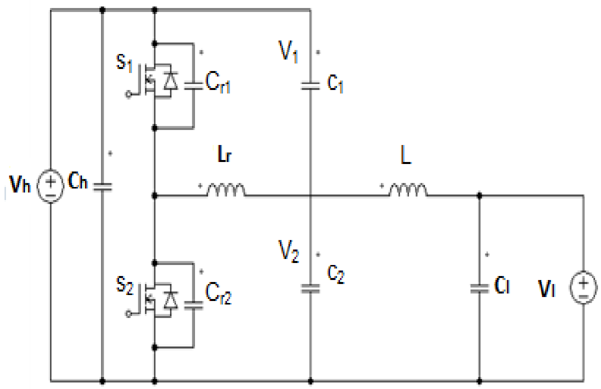

Fig. 1. Bidirectional DC-DC Converter proposed in [7]

Fig. 1 shows the conventional converter[7]. The auxiliary circuit consists of a resonant inductor (Lr), two resonant capacitors (Cr1, Cr2) and two parallel capacitors (C1 and C2). Through using these components, both switches (S1 and S2) are performed as ZVS turn-on or turn-off without switching loss.

Fig. 2 shows one of the topologies of conventional converter. This topology is also for the half bridge buck/boost bidirectional DC-DC converter. It has different connection of auxiliary capacitors and also have same characteristics to conventional topology. This modified converter can obtain ZVS condition for both switches without auxiliary switches. This converter can reduce current ripples in the main inductor L and help C_h to reduce high side voltage ripples.

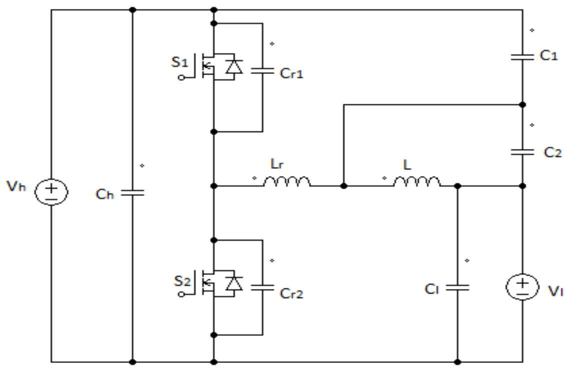

Fig. 2. Proposed High Efficiency Bidirectional DC-DC Converter

OPERATING PRINCIPLE

The converter has buck and boost operating modes botha have 6 operating modes each.

Buck Operation

The circuits of operating modes of buck converter are shown in Fig. 3. It has 6 operating modes.

a) *Mode 1*

S_1 is turned off and then C_{r1} starts to charge and C_{r2} starts to discharge. The charge and discharge process provides zero voltage switching off condition for S_1.

b) *Mode 2*

The voltage of Cr2 decreases to 0, Dr2 conducts. The voltage of S2 is clamped to 0.This will provide zero voltage switching on condition for S2 shown in Fig. 3 (b)

c) *Mode 3*

S2 is turned on. The zero voltage switching on state is obtained.

d) *Mode 4*

S2 is turned off. Cr1 starts to discharge and Cr2 starts to charge. The charge and discharge process provides zero voltage switching off condition for S2.

e) *Mode 5*

The voltage of Cr1 decreases to 0, Dr1 conducts. The voltage of S1 is clamped to 0. This will provide zero voltage switching on condition for S1.

f) *Mode 6*

In Fig. 3 (f) shows mode 6. S1 is turned on in zero voltage switching state.

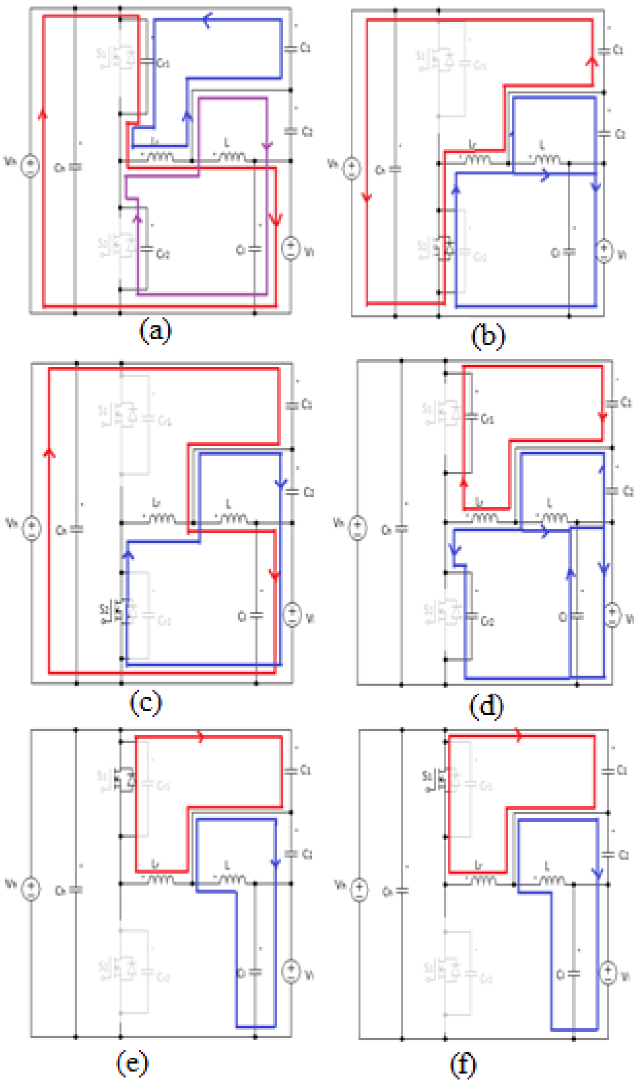

Fig. 3. Buck operation (a)Mode 1, (b)Mode 2, (c) Mode 3, (d)Mode 4, (e)Mode 5, (f)Mode 6

Boost Operation

Fig. 4 gives the circuit of operating modes for boost converter. It also has 6 operating modes in one switching period. Based on Fig. 3 and Fig. 4 the boost operation is similar to buck operation. The only difference is the direction of current through main inductor i_L. The operating mode analysis can reference the buck operation.

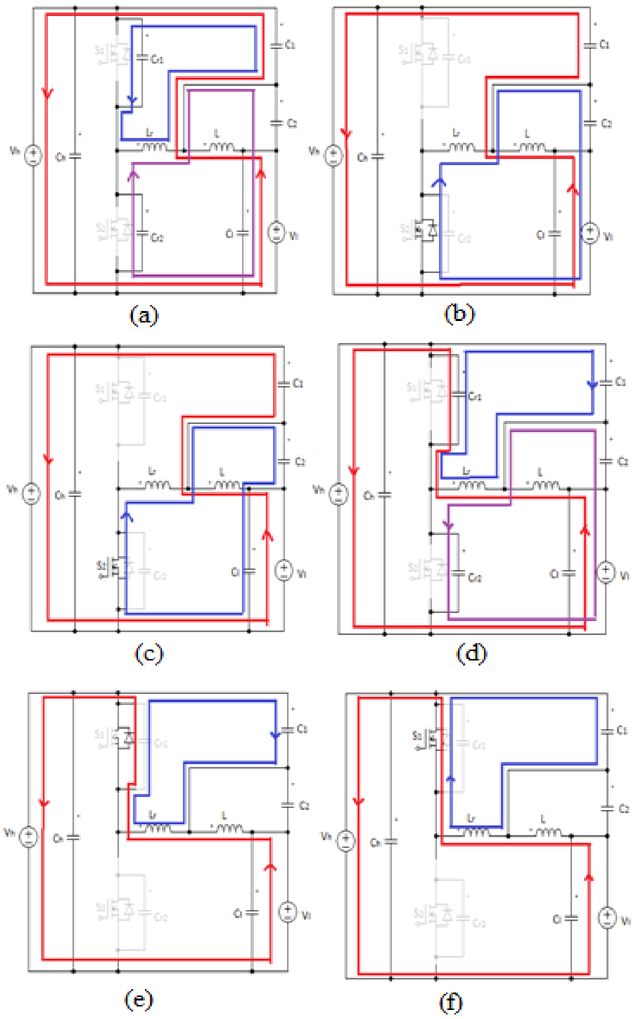

Fig. 4. Boost operation (a)Mode 1, (b)Mode 2, (c) Mode 3, (d)Mode 4, (e)Mode 5, (f)Mode 6

DESIGN OF COMPONENTS

This converter is designed [7] for an input voltage of 48V and 100V for Buck and Boost mode with load resistance 11Ω and 43Ω respectively. The switching frequency is 100 kHz.

$$V_l = DV_h \qquad (1)$$

Where V_l = Low side voltage

V_h = High side voltage

From eqn(1) duty ratio D is choosen as 0.5

$$L \geq \frac{DT(V_2 - V_1)}{\Delta I_L} \quad (2)$$

http://dx.doi.org/10.21172/ijiet.114.05

$$L_r \geq \frac{D(1-D)TV_h}{\Delta I_{Lr}} \quad (3)$$

$$C = \frac{I_O D}{4 f_s \Delta V_C} \quad (4)$$

The values of inductors and capacitor are obtained from the above equations.

SIMULATION PARAMETERS

The simulation parameters used for high efficiency soft switching bidirectional DC-DC converter are shown in TABLE I.

TABLEI:SIMULATION PARAMETERS

Components	Ratings
V_h	100V DC
V_l	48V DC
f	100 KHz
L	85.1µH
L_r	12.8 µH
C_1=C_2	3 µF
C_{r1}=C_{r2}	3.3 nF
C_h	1020 µF
C_l	1002 µF
Duty Ratio	50%

SIMULATION MODEL AND RESULT

The simulation of buck converter is performed with 100V DC sources and 11Ω resistive load. The simulation results obtained are shown below.

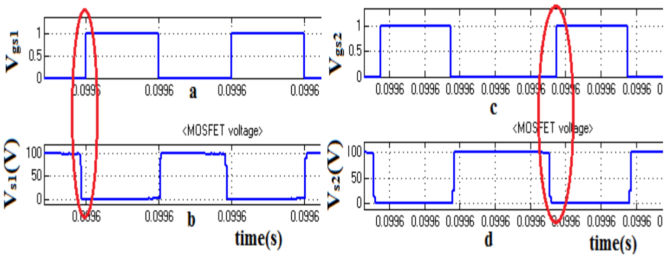

Fig. 5. Simulink Result (a) Gate Pulse for Switch 1 (b)Voltage Across Switch 1 (c) Gate Pulse for Switch 2 (d)Voltage Across Switch 2

Fig. 5 shows switching waveforms in buck operation. Fig. 5 (a) and (b) indicate the soft-switching state of S_1 and Fig. 5(c) and (d) is the soft switching state of S_2. From figures it can be seen that Vgs_1 rises after Vs_1 decreasing to zero. The zero voltage switching on condition for S_1 is obtained. Like this ZVS is also obtained for switch S_2.

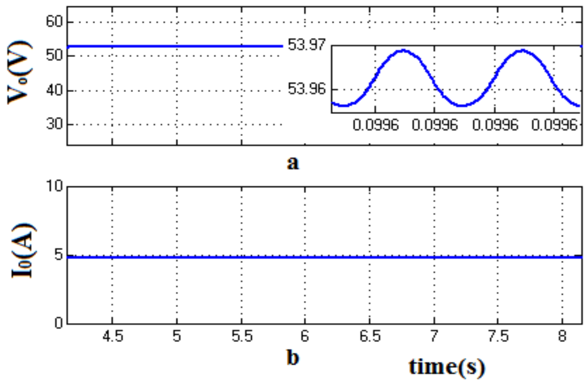

Fig. 6. Simulink Result (a)Input Voltage (b)Output Voltage

Fig. 6 shows output voltage of buck converter. The maximum output voltage is only 52.81V for an input voltage of 100V.

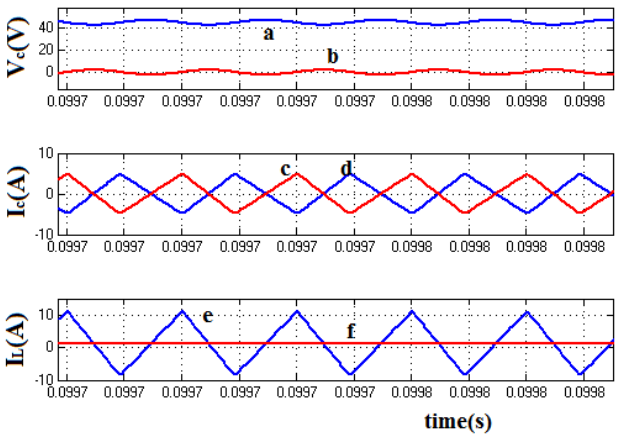

Fig. 7. Simulink Result (a)Voltage Across C1 (b)Voltage Across C2 (c)Current Through C1 (d)Current Through C2 (e)Current Through Lr (f)Current Through L

In Fig. 7(a), (b), (c) and (d) are auxiliary capacitor waveforms and (e) represent current through main inductor in buck converter and has very low ripples.

PERFORMANCE ANALYSIS

The following figure shows the performance analysis of the modified converter. Fig. 8 shows graph between voltage stress Vs duty ratio. Fig. 9 represents efficiency Vs R load. Comparatively high efficiency obtained at nearly 10Ω and 45Ω for both converters. Efficiency Vs RL load is shown in Fig. 10.

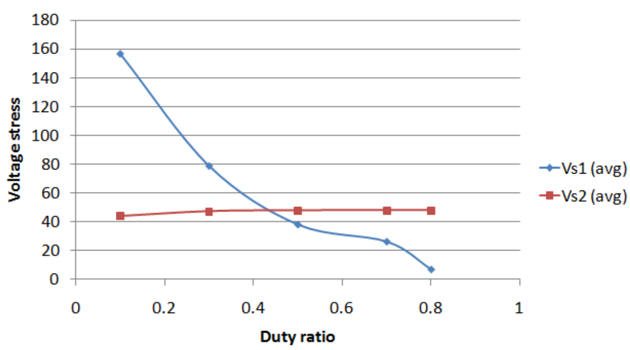

Fig. 8. Analysis (a)Voltage stress Vs Duty ratio

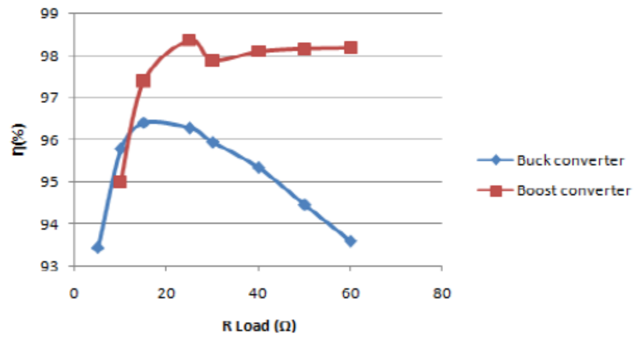

Fig. 9. Analysis (b)Efficiency Vs R load

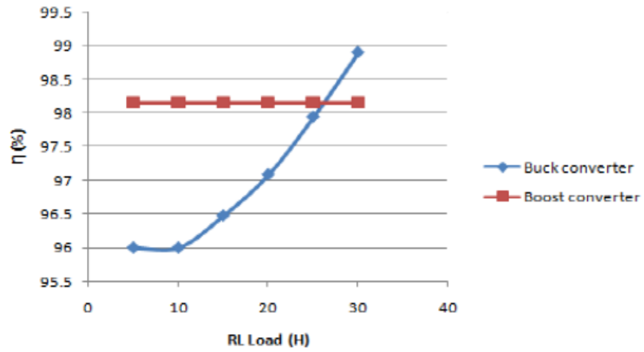

Fig. 10. Analysis (c)Efficiency Vs RL load

EXPERIMENTAL SETUP AND RESULTS

A 5W , 10KHz prototype of the high efficiency bidirectional DC-DC converter with an input voltage of 30V is implemented. TABLE II shows the specification.

The experimental setup is shown in Fig. 11 and the result obtained is given in Fig. 12. An output voltage of 6.37V is obtained from buck converter.

TABLE II: COMPONENTS USED FOR PROTOTYPE

Components	Ratings
V_h	30V
V_l	5V
f	10 KHz
L	164 µH
L_r	24 µH
C_1=C_2	100 µF
MOSFET	IRF540
Controller	PIC16F877A
Driver IC	TLP250

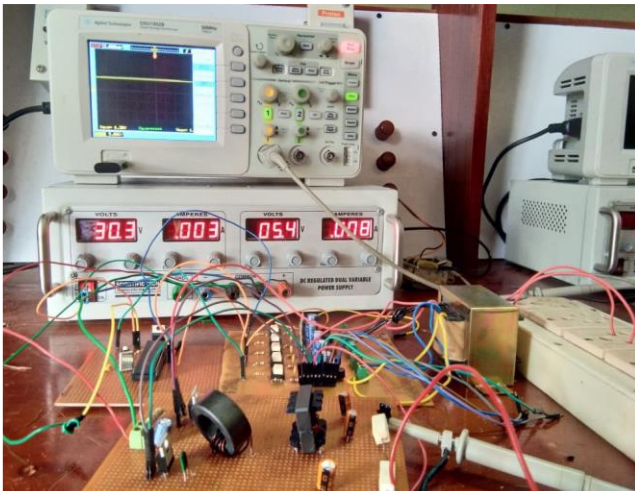

Fig.11. Experimental setup

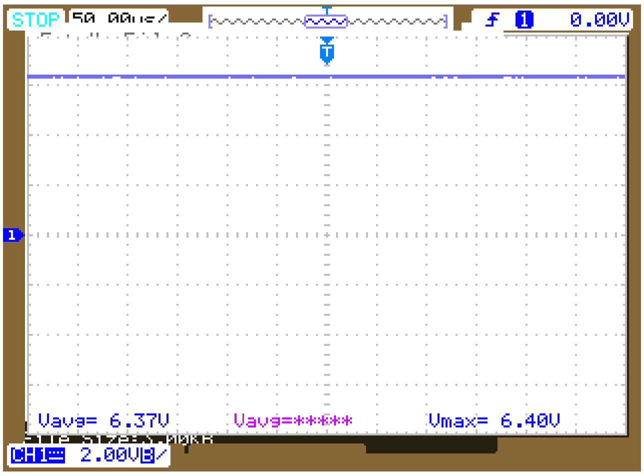

Fig. 12: Output voltage waveform

The power supply consist of astep down transformer, full bridge diode rectifier, filter capacitor and a regulator IC (7812). IRF540 MOSFET is used as switches. TLP250 driver isused to drive the MOSFET. To generate the switching signal PIC16F8771A was programmed in the laboratory and necessary waveforms are obtained. The switches are working in 10kHz frequency and have a duty ratio of 0.2. The rating of main inductor is164µH and resonance inductor is 24µH. The main capacitors are 100µF each.

CONCLUSION

This paper proposes a novel high efficiency bidirectional soft switching DC-DC converter. This converter is based on a bidirectional half-bridge type buck-boost topology. It has a resonant inductor, two resonant capacitors and two parallel capacitors additionally compared to conventional half bridge topology. The modified converter has no additional switch for soft switching of the main switch and can achieve zero voltage switching for all switches by using resonant circuit. Proposed converter can achieve higher efficiency of 96% for buck operation and 98% for boost operation. The current ripple of the main inductor is reduced due to the existence of losses and losses in the capacitors. It has no additional voltage stress and is equal to V_h that is nearly 100V. The experimental prototype of the modified converter is implemented with an input voltage of 30V and 6.37V is obtained as output.

ACKNOWLEDGMENT

I would like to express my heartfelt gratitude to **Prof. Kavitha Issac,** EEE Department, MA college of engineering, for providing me guidance and motivation to accomplish my work. She has been very patient and has given me immense freedom during the course of work. I would also like to thank **Prof. Veena Mathew** for the support and motivation throughout the completion of this work.

REFERENCES

[1] Z. Peng, H. Li, G.-J. Su, and J. S. Lawler, "A new ZVS bidirectional DC-DC converter for fuel cell and battery application, IEEE Trans Power Electron."pp. 5465, Jan. 2004.

[2] M. Jain, M. Daniele, and P. K. Jain, "A bidirectional DC-DC converter topology for low power application, IEEE Trans. Power Electron., pp. 595-606, Jul.2000.

[3] P. Das, B. Laan, S. A. Mousavi, G. Moschopoulos, "A nonisolated bidirectional ZVS-PWM active clamped DC-DC converter, IEEE Trans. Ind. Appl., pp.553-558, Feb. 2009.

[4] L. Jiang, C. C. Mi, S. Li, M. Zhang, X. Zhang, and C. Yin, "A Novel Soft-Switching Bidirectional DCDC Converter With Coupled Inductors," IEEE Transactions on Industry Applications vol. 49, pp. 2730-2740, June 2013.

[5] M. Aamir, and H. J. Kim, \Analysis of ZVS non-isolated bidirectional DC-DC converter," in Proc. IEEE International Midwest Symposium on Circuits and Systems, 2011, pp. 1-4.

[6] S. M. Venkit, and P. C. Athira, \Solar powered ZCS bidirectional buck-boost converter used in battery energy storage systems," in Proc. International Conference on Circuit, Power and Computing Technologies 2016, pp. 1-5.

[7] Yong Zhang, Xu-Feng Cheng, and Si Cheng, "Analysis and research of a soft-switching bidirectional DC-DC converter," IEEE transaction on industrialelectronics, vol. 65, pp.1196-1204, July 2017.

[8] J. G. Kim, S. W. Park, Y. H. Kim, Y. C. Jung, and C. Y. Won, "High-efficiencybidirectional soft switching DC-DC converter," in Proc. International PowerElectronics Conference, 2010, pp.2905-2911.

[9] M. R. Mohammadi, and H. Farzanehfard, "A New Family of Zero-Voltage-Transition Nonisolated Bidirectional Converters With Simple Auxiliary Circuit,"IEEE Transactions on Industrial Electronics vol. 63, pp. 1519-1527,March 2016.

[10] In-Hwan. Oh, "A soft-switching synchronous buck converter for Zero VoltageSwitching (ZVS) in light and full load conditions," in Proc. Twenty-ThirdAnnual IEEE Applied Power Electronics Conference and Exposition,2008, pp. 1460-1464.

(**Allauthorsshouldincludebiographieswithphotoattheendofregularpapers**.)

Author's formal photo

FirstA.Authorandtheotherauthorsmayincludebiographiesattheendofregularpapers.Thefirstparagraphmaycontainaplaceand/ordateofbirth(listplace,thendate).Next,theauthor'seducationalbackgroundislisted.Thedegreesshouldbelistedwithtypeofdegreeinwhatfield,whichinstitution,city,stateorcountry,andyeardegreewasearned.Theauthor'smajorfieldofstudyshouldbelower-cased.

Thesecondparagraphusesthepronounoftheperson(heorshe)andnottheauthor'slastname.Itlistsmilitaryandworkexperience,includingsummerandfellowshipjobs.Jobtitlesarecapitalized.Thecurrentjobmusthavealocation;previouspositionsmaybelistedwithoutone.Informationconcerningpreviouspublicationsmaybeincluded.Trynottolistmorethanthreebooksorpublishedarticles.Theformatforlistingpublishersofabookwithinthebiographyis:titleofbook(city,state:publishername,year)similartoareference.Currentandpreviousresearchinterestsendstheparagraph.

Thethirdparagraphbeginswiththeauthor'stitleandlastname(e.g.,Dr.Smith,Prof.Jones,Mr.Kajor,Ms.Hunter).Listanymembershipsinprofessionalsocieties.Finally,listanyawardsandworkforcommitteesandpublications.Ifaphotographisprovided,thebiographywillbeindentedaroundit.Thephotographisplacedatthetopleftofthebiography.Personalhobbieswillbedeletedfromthebiography.