American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-5, Issue-7, pp-106-111
www.ajer.org
Research Paper Open Access

A Novel High Gain DC-DC Step up Converter

M. Al Mamun[1], Golam Sarowar[2], Dr. Md. Ashraful Hoque[3]
[1]*(Lecturer, Dept. of EEE, Southeast University, Bangladesh)*
[2]*(Assistant Professor, Dept. of EEE, Islamic University of Technology, Bangladesh)*
[3](*Professor, Dept. of EEE, Islamic University of Technology, Bangladesh*)

ABSTRACT: *High gain dc-dc converters are widely used to maximize the energy harvest for renewable energy systems, for example, photovoltaic systems and fuel cell. Conventional boost converters usually operates at extreme duty cycle to obtain high voltage gain. Operation at extreme duty cycle leads to reverse recovery problem at the switches, high conduction loss, electromagnetic interference etc. This paper proposes a very high gain dc-dc step up converter operating at very low duty cycle (i.e. duty cycle <0.5). The additional advantage of the proposed converter is that a single control signal is used for the switches which reduces the operation complexity. The steady-state theoretical analysis described in this paper is finally verified by simulation results.*

Keywords: *dc-dc boost converter, duty cycle, voltage gain, voltage stress, voltage ripple*

I. INTRODUCTION

In the recent years, the demand of renewable energy systems, for example, photovoltaic systems, fuel cell etc. has increased significantly due to the shortage and environmental threat of fossil fuels. As these renewable systems generate dc power at low voltage level, high gain dc-dc step up converters are getting more and more attentions and lots of researches have been conducted on it [1]. Also, the industrial applications, for example, uninterruptable power supply, high intensity discharge lamps for automobile headlamps, X-ray systems, TV-CRTs require high step-up voltage gain dc-dc power conversion [2]–[4].To obtain high gain dc-dc conversion several dc-dc converters are employed which are basically divided into two categories-non isolated and isolated converters. Non isolated converters like conventional boost converter, cascaded converter, switched inductor and switched capacitor converters operate at high duty cycle to obtain high voltage gain [5]-[6]. Operating at high duty cycle leads to some unavoidable problems like reverse recovery problem, high conduction loss and electromagnetic interference etc. Self-lift converter, dual and multi-output dc-dc converters discussed in [7]-[9] can almost overcome these problems. These converters can give different dc voltage levels but the voltage gains are not that much high than that of the conventional boost converter.

On the other hand, isolated converters such as fly-back converter, push-pull converter, forward converter, bridge converter etc. involve transformer to isolate the input side from output side. By increasing the turns ratio of the transformer, it is possible to have a high voltage gain. But this also leads to some unavoidable problems, for example, non-linearity of the transformer, voltage spike at the switches during the off state due to the increased inductance, larger size, higher cost etc. [10]-[13].

This paper presents a very high gain non isolated dc-dc step up converter which is able to overcome the above issues. It operates at a very low duty cycle (i.e. duty cycle < 0.5). The switches used in the converter circuit are controlled by a single control signal which reduces the operation complexity and increases the efficiency. The rigorous steady-state analysis is verified by the software PSIM.

Rest of the paper is organized as follows. Operation of the proposed converter with different operating modes and mathematical validation are presented in section II. Section III presents Simulation results and section IV ends the paper with a conclusion.

II. PROPOSED CONVERTER

The proposed converter in Fig. 1 involves three inductors (L_1, $L_2$and L_3), three capacitors (C_1, C_2 and C_3), four diodes (D_1, D_2, D_3 and D_4) and four high frequency controlled switches (S_1, S_2, S_3 and S_4). MOSFETs are used as the high frequency controlled switches and these are operated based on a single duty cycle generated by Pulse Width Modulation (PWM) technique. $V_i$represents the low dc input voltage from PV source or fuel cell. The resistive load is connected across the capacitor C_3.

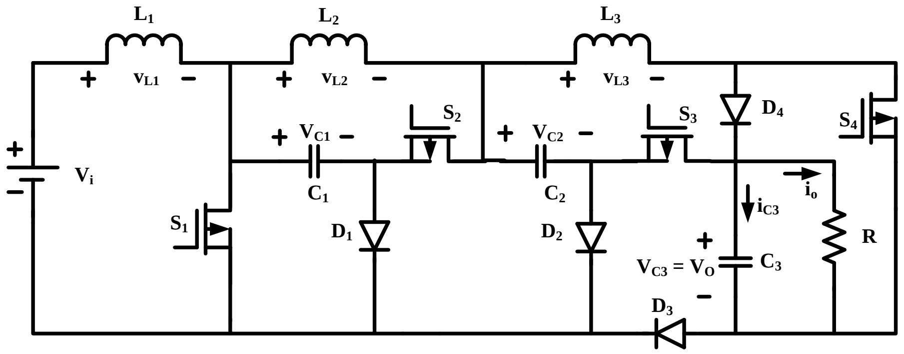


Fig. 1: Proposed high gain dc-dc step up converter

1. *Steady State Analysis of the Proposed Converter*

The operation in steady state is discussed as follows.

Let,
V_i= Low input voltage
V_{L1} = Voltage across inductor L_1
V_{L2} = Voltage across inductor L_2
V_{L3} = Voltage across inductor L_3
V_{C1} = Voltage across capacitor C_1
V_{C2}= Voltage across capacitor C_2
V_{C3} = Voltage across capacitor C_3
$V_O = V_{C3}$ = Output voltage across R
T_s= Switching time period of controlled switches
T_{on} = Switch ON time period of controlled switches
D = duty cycle of controlled switches (ratio of T_{on} to T_s)

1.1. *When S_1, S_2, S_3 and S_4 are Turned OFF*

When all four switches are turned OFF, all four diodes D_1, D_2, D_3 and D_4 are forward biased and this is depicted in Fig. 2. V_i, L_1, L_2 and L_3 energize C_1, C_2, C_3 and supply power to the load. KVL applied in the loops in Fig. 2 gives the voltages across L_1, L_2 and L_3 as follows,

$V_{L1} = V_i - V_{C1}$……………………………(1)
$V_{L2} = V_{C1} - V_{C2}$……………………………(2)
$V_{L3} = V_{C2} - V_{C3}$..(3)

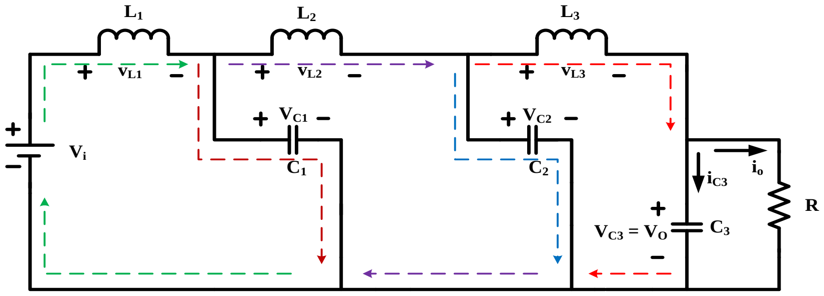


Fig. 2. Equivalent circuit when all the switches are OFF

1.2. *When S_1, S_2, S_3 and S_4 are Turned ON*

When all four switches are turned ON, all four diodes D_1, D_2, D_3, D_4 are reversed biased and this is depicted in Fig. 3. Now, the inductors L_1, L_2 and L_3 are energized by the source voltage V_i and the capacitors C_1, C_2 and C_3. The load is supplied by the capacitor C_3 and V_i. KVL applied in the loops in Fig. 3 gives the voltages across L_1, L_2 and L_3 as follows,
$V_{L1} = V_i$…………………(4)
$V_{L2} = V_{C1}$………………..(5)
$V_{L3} = V_{C2} + V_{C3}$………..(6)

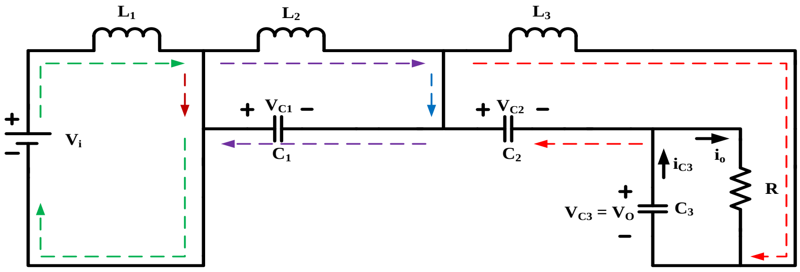


Fig. 3. Equivalent circuit when all the switches are ON

Now, by using equations (1) and (4), volt-second balance across L_1 is given by

$$V_iDT_s + (V_i - V_{C1})\,(1 - D)\,T_s = 0$$

Or, $V_{C1} = \frac{V_i}{1-D}$

Similarly, by using equations (2) and (5), volt-second balance across L_2 is given by

$$V_{C1}\,DT_s + (V_{C1} - V_{C2})\,(1 - D)\,T_s = 0$$

Or, $V_{C2} = \frac{V_{C1}}{1-D} = \frac{V_i}{(1-D)^2}$

Similarly, by using equations (3) and (6), volt-second balance across L_3 is given by

$$(V_{C2} + V_{C3})DT_s + (V_{C2} - V_{C3})\,(1 - D)\,T_s = 0$$

Or, $V_{C3} = \frac{V_{C2}}{1-2D} = \frac{V_i}{(1-D)^2\,(1-2D)}$

So, $V_O = \frac{V_i}{(1-D)^2\,(1-2D)}$ …………………..(7)

So, voltage gain, $G = \frac{1}{(1-D)^2\,(1-2D)}$

Therefore, from the above equation it is observed that the output voltage is $\frac{1}{(1-D)^2\,(1-2D)}$ times the input voltage which is significantly high. It is possible to have a very high voltage gain if the duty cycle $D < 0.5$. The duty cycle should not be equal to 0.5 as it will cause an infinite voltage gain at the output. If the duty cycle is more than 0.5, then the voltage gain will be negative. The voltage gain$G$with respect to duty cycle D is plotted in Fig. 4

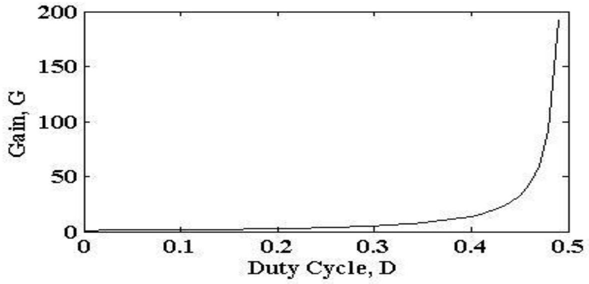


Fig. 4. Voltage gain versus Duty Cycle

III. SIMULATION RESULTS

The proposed converter circuit is designed and implemented by using PSIM 9.0. The circuit parameters taken for the simulation are tabulated in Table I. Mathematical calculation of the output voltage V_O is performed by equation (7) and it is found to be 115.03 V. The simulation gives the value of output voltage very near to 115.03 V with a negligible ripple contentwhich is within prescribed tolerable limit [14] as shown in Fig. 5. The ripple content is controlled by controlling the value of C_3.

Table I Parameter Table

Parameters	Value
Input voltage (V_i)	12 V
Switching Frequency (F_s)	10 kHz
Inductor (L_1)	1 mH
Inductor (L_2)	3 mH
Inductor (L_3)	3mH
Capacitor (C_1)	1000 µF
Capacitor (C_2)	1000 µF
Capacitor (C_3)	1000 µF
Load across C_3	100 Ω
Duty Cycle (D)	0.369

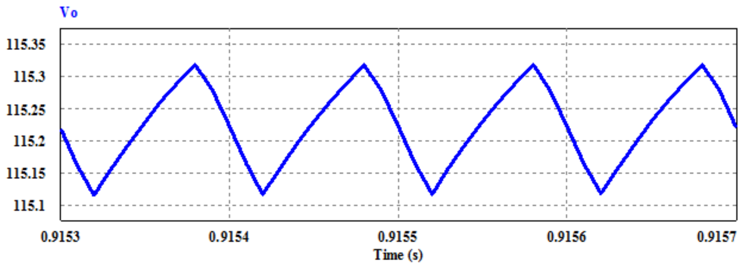
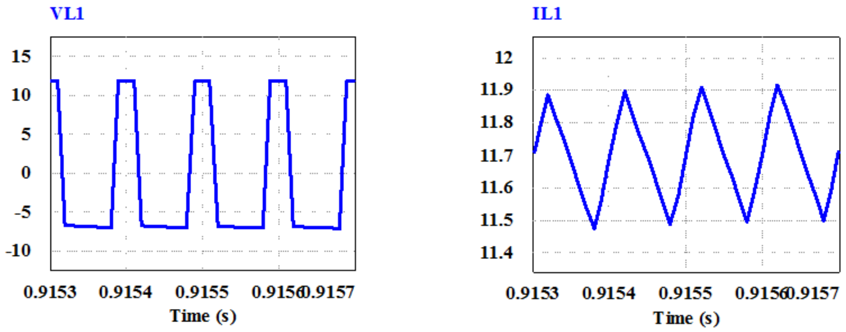


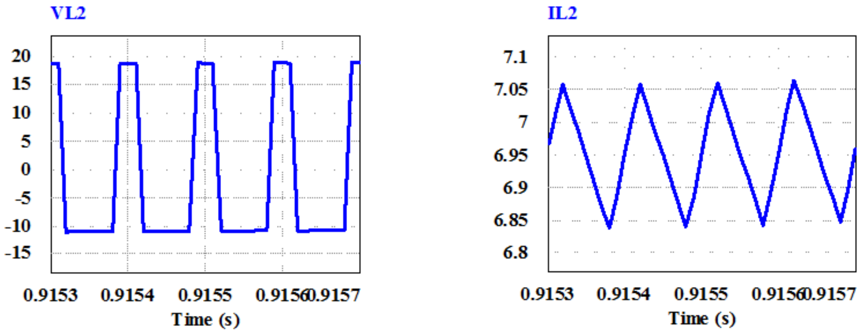
Fig. 5. Output voltage

Volt-second balances of L_1, L_2 and L_3 are shown in Fig. 6, Fig. 7 and Fig. 8 respectively along with currents through them. The currents are within limit and the ripple contents can be minimized by choosing appropriate values of inductances of L_1, L_2 and L_3.



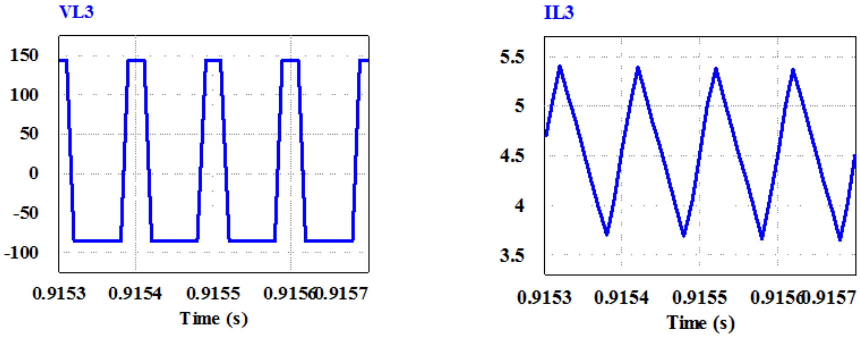
(a) (b)

Fig. 6. (a) Voltage across L_1 (in Volts) (b) Current through L_1 (in Amps)



(a) (b)

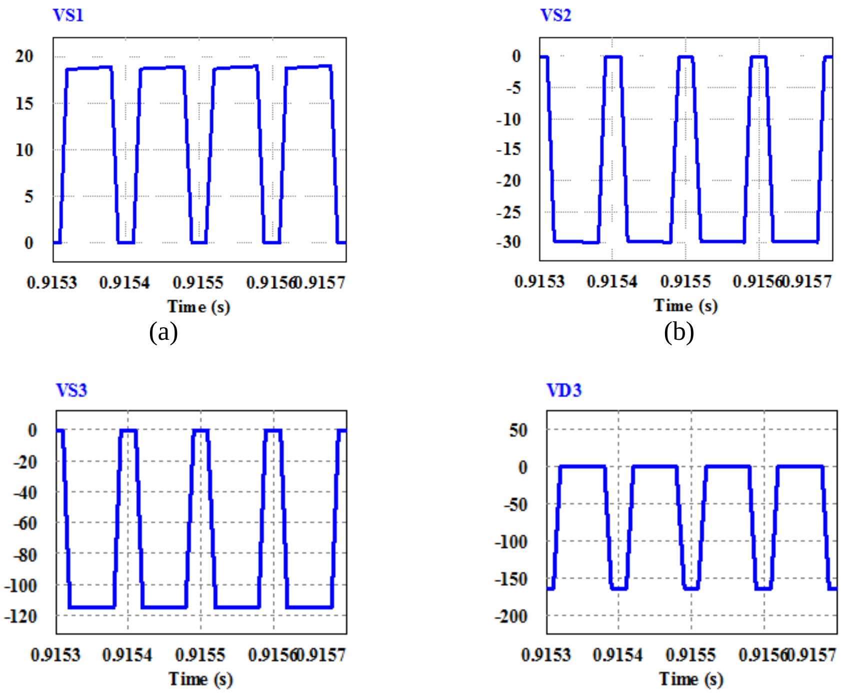
Fig. 7. (a) Voltage across L_2 (in Volts) (b) Current through L_2 (in Amps)



(a) (b)

Fig. 8. (a) Voltage across L_3 (in Volts) (b) Current through L_3 (in Amps)

The voltage stress across the power switches and diodes is a crucial parameter. The theory and the simulation shows that the voltage stresses across the switch S_1 and diode D_1 are same as the voltage across C_1shown in Fig. 9 (a) which is relatively low compared to other switches and diodes. So, the diode and the switch to be used as S_1 and D_1 respectively can be of low voltage rating which reduces the cost and size of the converter. Voltage stresses across the switch S_2 and diode D_2 shown in Fig. 9 (b) are equal to the voltage across C_2 which is higher than the S_1 and D_1. Therefore, the voltage ratings of S_2 and D_2 should be higher than S_1 and D_1. Similarly, the voltage stresses across the switches S_3, S_4 and diode D_4 shown in Fig. 9 (c) are equal to the voltage across C_3. As V_{C3} is the maximum voltage of the converter, voltage ratings of S_3, S_4 and D_4 should be high. Voltage stress across D_3 shown in Fig. 9 (d) is equal to the sum of the voltages across C_2 and C_3. Therefore, the diode to be used as D_3 should be of highest voltage rating. As MOSFETs and IGBTs are popularly used as power electronic switches, the switches used in the proposed converter can be either MOSFETs with the voltage and current ratings of 500 V and 50 A respectively or IGBTs with the voltage and current ratings of 1200 V and 400 A respectively [15]. Since the voltage and current of the proposed converter is less than the ratings of MOSFETs, MOSFETs should be used as switches in the proposed converter.



(a) (b)

(c)(d)

Fig. 9. (a) Voltage stress across S_1 (b) Voltage stress across S_2 (c) Voltage stress across S_3 (d) Voltage stress across D_3

Table II Comparison between Conventional Step Up Converter and Proposed Converter

Parameters / **Converters**	**Conventional Step Up Converter**	**Proposed Converter**
Voltage gain	$\frac{1}{1-D}$	$\frac{1}{(1-D)^2\,(1-2D)}$
Range of duty cycle, *D*	$0 < D < 1$	$0 < D < 0.5$
Output voltage ripple	0.2939% of average output voltage	0.176% of average output voltage
Input Inductor current ripple	16.73% of average inductor current	3.763% of average inductor current
Highest voltage stress across the switch(es)	$\frac{V_i}{1-D}$	$\frac{V_i}{(1-D)^2\,(1-2D)}$ across S_4 and S_3
Highest voltage stress across the diode(s)	$\frac{V_i}{1-D}$	$\frac{V_i}{(1-D)^2} + \frac{V_i}{(1-D)^2\,(1-2D)}$ across D_3
Conduction loss at the switches (proportional to *D*)	Higher due to extreme duty cycle	Lower due to lower duty cycle

The comparison shown in Table II between the conventional step up converter and proposed converter for identical input voltage of 12 V, input inductor of 1 mH and capacitor across the load of 1000 µFmakes the proposed one superior to the conventional one. It is observed that the proposed converter has a higher voltage gain at lower duty cycle than the conventional one. The amount of peak to peakoutput voltage ripple and peak to peak input inductor current ripple in the proposed one is lower. This makes it possible to use the capacitors and inductors of lower value which makes the size of the proposed converter smaller. But the voltage stresses across the switches and the diodes are higher in the proposed converter. As the magnitudes of the voltage stresses are within the prescribed tolerable limit [15], this can be acceptable to obtain high voltage gain. Again, as the conduction loss of a switch is proportional to the duty cycle [15], the proposed converter offers lower conduction loss than that of the conventional one.

IV. CONCLUSION

This paper presents a very high gain dc-dc step up converter which has several advantages over conventional step up converters. The proposed converter gives a very high voltage gain at a low duty cycle (i.e. duty cycle < 0.5) which is not possible by the conventional boost converters. Low duty cycle reduces the reverse recovery problem, conduction loss and electromagnetic interference at the switches.It offers low peak to peak output voltage ripple and low peak to peak input inductor current ripple which makes it possible to use smaller capacitors and indcutors. The operation of all the switches is based on a single duty cycle that reduces the controlling complexity of the converter.It can give the same voltage gain without using transformer as that of the isolated converters that reduces the size and cost of the proposed converter.Considering all these advantages, the proposed converter is suitable for high step-up voltage conversion applications and the simulation results verify the correctness.

REFERENCES

[1] W. Li, Y. Zhao, J. Wu, and X. He, "Interleaved high step-up converter with winding-cross-coupled inductors and voltage multiplier cells," *IEEETrans. Ind. Electron.*, vol. 27, no. 1, pp. 133–143, Jan. 2012.

[2] C. S. Chin, P. Neelakantan, and H. P. Yoong, "Maximum power point tracking for PV array under partially shaded conditions," in *Proc. IEEECICSyN*, 2011, pp. 72–77.

[3] J. C. Rosas-Caro, J. M. Ramirez, F. Z. Peng, and A. Valderrabano, "A dc–dc multilevel boost converter," *IET-Elect. Power Appl.*, vol. 59, no. 1, pp. 129–137, Jan. 2009.

[4] W. Li, J. Liu, J. Wu, and X. He, "Design and analysis of isolated ZVTboost converters for high-efficiency and high-step-up applications," *IEEETrans. Power Electron.*, vol. 22, no. 6, pp. 2363–2374, Nov. 2007.

[5] B. Axelrod, Y. Berkovich, and A. Ioinovici, "Transformer less DC-DC converters with a very high DC line-to-load voltage ratio," in Proc. IEEE Int. Symp. Circuits Syst. (ISCAS), 2003, pp. III-435-III-438.

[6] R. J. Wai and R. Y. Duan, "High-efficiency DC/DC converter with high voltage gain," IEE Proc. Electric Power Applications, vol. 152, no. 4, pp. 793-802, Jul. 2005.

[7] F. L. Luo; X. Chen, "Self-lift DC-DC Converters," Power Electronic Drives and Energy Systems for Industrial Growth, vol. 1, pp. 441-446, Dec. 1998.

[8] Ray-Lee Lin; Chi-Rung Pan; Kuang-Hua Liu, "Family of single-inductor multi-output DC-DC converters," 2009 International Conference onPower Electronics and Drive Systems (PEDS), pp.1216-1221, 2-5 Nov. 2009.

[9] Charanasomboon, T.; Devaney, M.J.; Hoft, R.G., "Single switch dual output DC-DC converter performance," IEEE Transactions on Power Electronics, vol.5, no.2, pp.241-245, Apr 1990.

[10] D. Cao, S. Jiang, and F. Z. Peng, "Low cost transformer isolated boost half-bridge micro-inverter for single-phase grid-connected photovoltaic system," in *Proc. IEEE Appl. Power Electron. Conf.*, 2012, pp. 71–78.

[11] B. R. Lin and F. Y. Hsie, "Soft-switching zeta–flyback converter with a buck-boost type of active clamp," *IEEE Trans. Ind. Electron.*, vol. 54, no. 5, pp. 2813–2822, Oct. 2007.

[12] C. M. Wang, "A novel ZCS–PWM flyback converter with a simple ZCS PWM commutation cell," *IEEE Trans. Ind. Electron.*, vol. 55, no. 2, pp. 749–757, Feb. 2008.

[13] M. Nymand and M. A. E. Alldersen, "High efficiency isolated boost dc/dc converter for high power low voltage fuel-cell applications," *IEEE Trans.Ind. Electron.*, vol. 57, no. 2, pp. 505–514, Feb. 2010.

[14] Ned Mohan, "Power Electronics: A First Course," John Wiley & Sons, Inc., Wiley, 2012

[15] Muhammad H. Rashid, "Power Electronics Handbook: Devices, Circuits, And Applications," 3rd Edition, Elsevier, 2011