

An Innovative Closed Loop Control of High Efficient Boost Converter for DG Applications

K. Rajesh Babu

Assistant Professor

Department of Electrical and Electronics Engineering,

Vasireddy Venkatadri Institute of Technology;

Guntur (Dt), Andhra Pradesh, India

Corresponding Author's email: kalahasthirajeshbabu@gmail.com

Abstract

Power electronics devices are widely used in different fields and for different residential applications. The expansion of their field of applications is related to the knowledge of the device behavior and their practical performances. The renewable energy sources such as PV modules, fuel cells or energy storage devices such as super capacitors or batteries deliver output voltage at the range of around 15 to 40 VDC. A boost converter is used to clamp the voltage stresses of all the switches in the interleaved converters caused by the leakage inductances present in the practical coupled inductors to a low voltage level. This paper presents a dc-dc power converter integrated closed loop system to attain high stability factor in such a way to obtain in a single conversion stage. The maximum energy extraction from photovoltaic panels, battery charging and discharging dynamic control, and high voltage step-up also is operating with soft-switching capability. This review is mainly focused on high efficiency step-up DC/DC converters with high voltage gain. The results are obtained through Matlab/Simulink software package.

Keywords: DC–DC Power Conversion, Capacitor Modules, Interleaved Methodology, PI Controller

I. INTRODUCTION

Electric utilities and end users of electric power are becoming increasingly concerned about meeting the growing energy demand. Seventy five percent of total global energy demand is supplied by the burning of fossil fuels. But increasing air pollution, global warming concerns, diminishing fossil fuels and their increasing cost have made it necessary to look towards renewable sources as a future energy solution. Since the past decade, there has been an enormous interest in many countries on renewable energy for power generation. The market liberalization and government's incentives have further accelerated the renewable energy sector growth [1]-[5].

Renewable energy source (RES) integrated at distribution level is termed as distributed generation (DG). Such systems transform energy from renewable sources into electrical energy and convert low voltage into high voltage via a step-up converter, which can convert energy into electricity using a grid inverter. In recent years, there has been an upsurge of interest in solar photovoltaic (PV) energy systems in both industry and academia. In typical PV power generation systems several photovoltaic panels are connected in series and parallel to

form an array and feed energy to a single centralized inverter or to a few parallel

'string' inverters. An alternative approach is to use an AC module, which is a combination of one PV panel and one power conditioning unit to feed power directly into the grid.

additional AC modules.

The advantages of an AC module based system over systems based on centralized inverter or parallel string inverters are as follows:

- 1) The maximum power point (MPP) of each panel can be tracked individually, thereby increasing the utilization of the whole PV system.
- 2) Detrimental effects due to shading and module mismatches are not present.
- 3) Potential arcing problems due to DC system wiring are fully avoided.
- 4) The 'plug and play' property allows easy system expansion through simple paralleling of

In general, a conventional boost converter can be adopted to provide a high step-up voltage gain with a large duty ratio. However, the conversion efficiency and the step-up voltage gain are limited due to the constraints of the losses of power switches and diodes, the equivalent series resistance of inductors and capacitors and the reverse recovery problem of diodes. However, the active switch of these converters will suffer very high voltage stress and high power dissipation due to the leakage inductance of the transformer. Although this configuration is useful in terms of system monitoring and repair, the partial shading, module mismatch, and dc connection cable losses are inevitable problems and lead to significantly reduced system energy yields [3]–[7].

The ac module, which has been proposed to improve these problems consists of a single PV panel and a micro-inverter. The micro-inverter receives the low dc voltage from the PV panel and transforms it to ac voltage then delivers it to the load or main electricity as would a small scale conventional PV inverter.

Fig.1 shows the energy of a single PV panel through the micro-inverter output to the main electricity; this is a general grid-connected ac module system. The micro-inverter is inlaid in the rear bezel of the PV panel and outputs the ac current to the load or to the main electricity; this alternative solution not only immunizes the yield loss by shadow effect but also provides flexible installation options according to the user's budget [8]–[12].

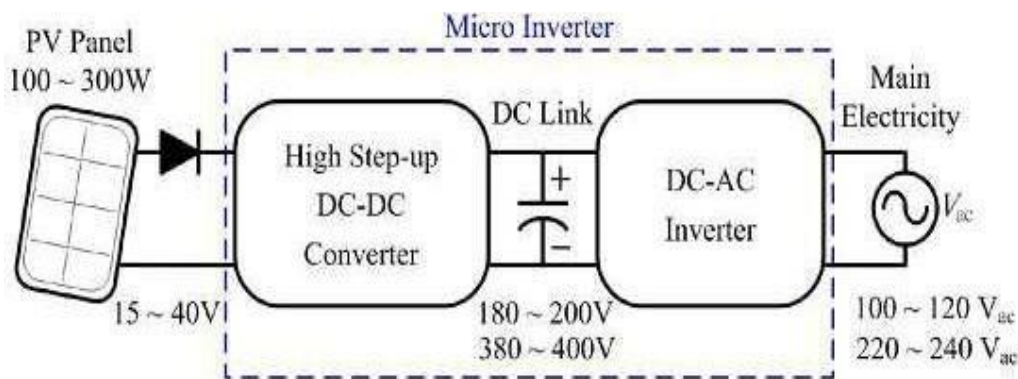


Fig.1 General Configuration of grid-connected ac module

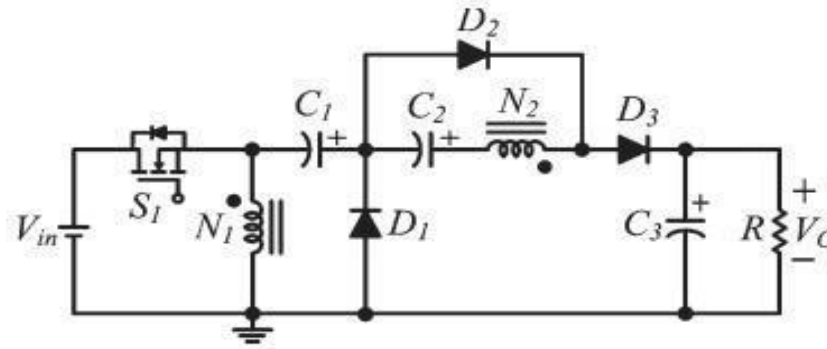


Fig. 2 Circuit Configuration of Proposed Converter

Fig. 2 shows that the maximum power point (MPP) voltage range is from 15V to 40V with various power capacities of about 100W to 300W for a single commercial PV panel. When a wide input voltage range is essential for the single stage micro-inverter, high efficiency is difficult to achieve [13]. However, the dual-stage micro-inverter, which combines a high step-up dc/dc converter and dc/ac inverter, is able to achieve efficiency as high as the conventional PV string-type inverter [14]-[18]. Fig.1 also shows that the micro-inverter integrates a high step-up dc/dc converter and dc/ac inverter. The typical Zeta converter provides either a step-up or a step-down function to the output, in a manner similar to that of the buck-boost or SEPIC converter topologies. The conventional Zeta converter is configured of two inductors, a series capacitor and a diode [19]-[25].

However, leakage inductance issues that relate to the voltage spike and the efficiency remain significant. An integrated boost-fly back converter based on a coupled inductor with high efficiency and high step-up voltage gain has been presented in [26]-[30]. The energy stored in the leakage inductor is recycled into the output during the switch off period. Thus, the efficiency can be increased and the voltage stress on the active switch can be suppressed. Many step-up converters, which use an output voltage stacking to increase the voltage gain, are presented [31]-[33]. This paper proposes the a new converter topology operated under closed loop control action by using PI controller to achieve high stability with low steady state error values and evaluated by using Matlab/Simulink platform.

II. PROPOSED CONVERTER TOPOLOGY

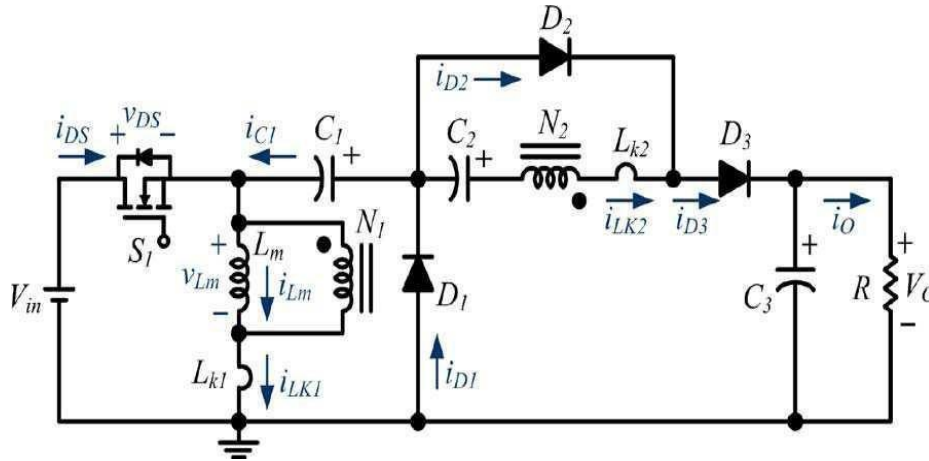


Fig. 3 Simplified circuit model of proposed converter

The simplified circuit model of the proposed converter is shown in Fig. The coupled inductor T_1 includes a magnetizing inductor L_m , primary and secondary leakage inductors L_{k1} and L_{k2} and an ideal transformer primary winding N_1 and secondary winding N_2 . To simplify the circuit analysis of the proposed converter the following assumptions are made.

- 1) All components are ideal except for the leakage inductance of coupled inductor T_1 . The ON-state resistance $R_{DS} (ON)$ and all parasitic capacitances of the main switch S_1 are neglected as are the forward voltage drops of the diodes $D_1 \sim D_3$.

- 2) The capacitors $C_1 \sim C_3$ are sufficiently large that the voltages across them are considered to be constant.

- 3) The ESR of capacitors $C_1 \sim C_3$ and the parasitic resistance of coupled-inductor T_1 are neglected.

- 4) The turn's ratio n of the coupled inductor T_1 winding is equal to N_2/N_1 .

The operating principles for continuous-conduction mode (CCM) are now presented in detail. Fig. 4 shows the typical waveform of several major components during one

switching period. The five operating modes are described as follows.

A. CCM OPERATION

Mode I[t₀,t₁]: In this transition interval, the secondary leakage inductor L_{k2} is

continuously releasing its energy to capacitor C₂. The current flow path is shown in Fig. 5(a); as shown, switch S₁ and diodes D₂ are conducting. The current i_{Lm} is descending because source voltage V_{in} is applied on

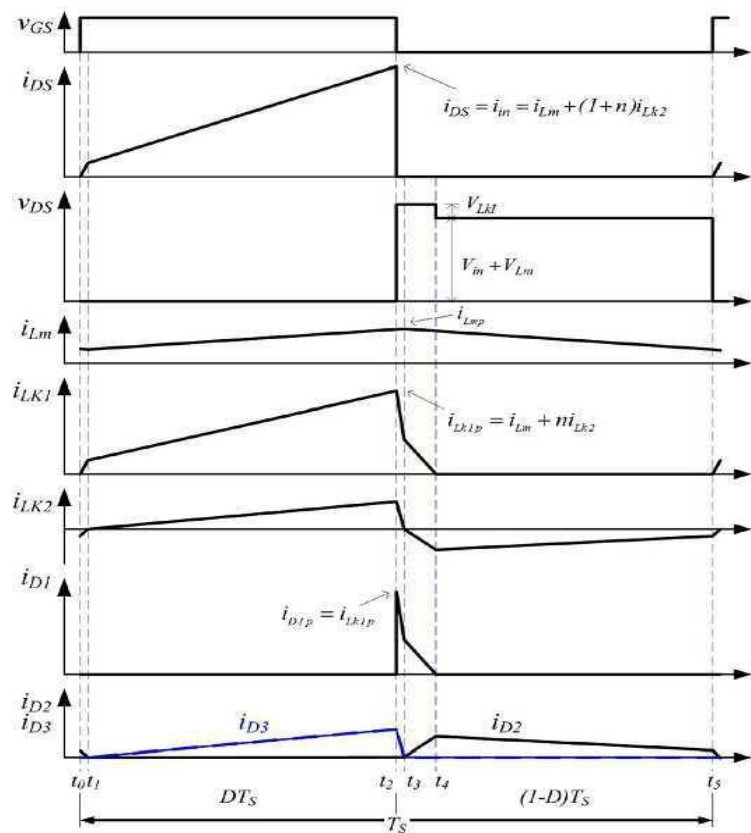


Fig.4 Typical waveforms of the proposed converter at CCM operation

Magnetizing inductor L_m and primary leakage inductor L_{k1} ; meanwhile, L_m is also releasing its energy to the secondary winding as well as charging capacitor C_2 along with the decrease in energy. The charging current i_{D2} and i_{C2} are also decreasing. The secondary leakage inductor current i_{LK2} is declining according to i_{Lm}/n . Once the increasing i_{LK1} equals the decreasing i_{Lm} at $t=t_1$ this mode ends.

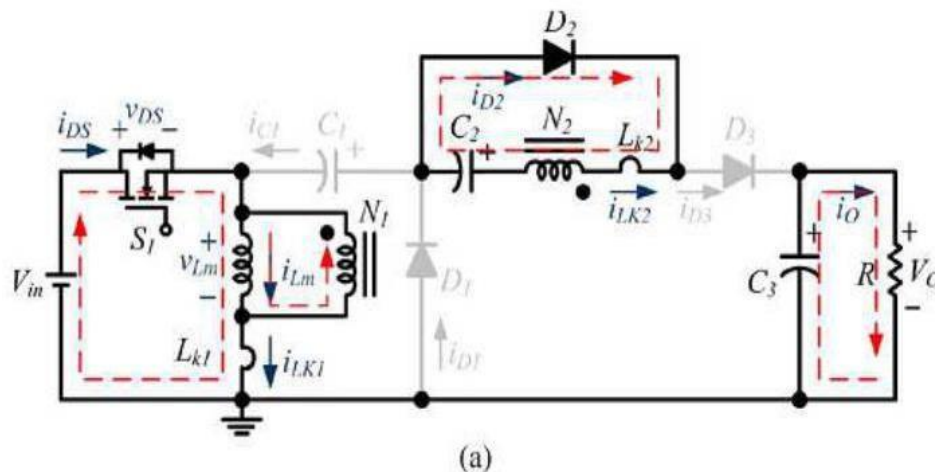
$$i_{in}^I(t) = i_{DS}^I(t) = i_{LK1}^I(t) \quad (1)$$

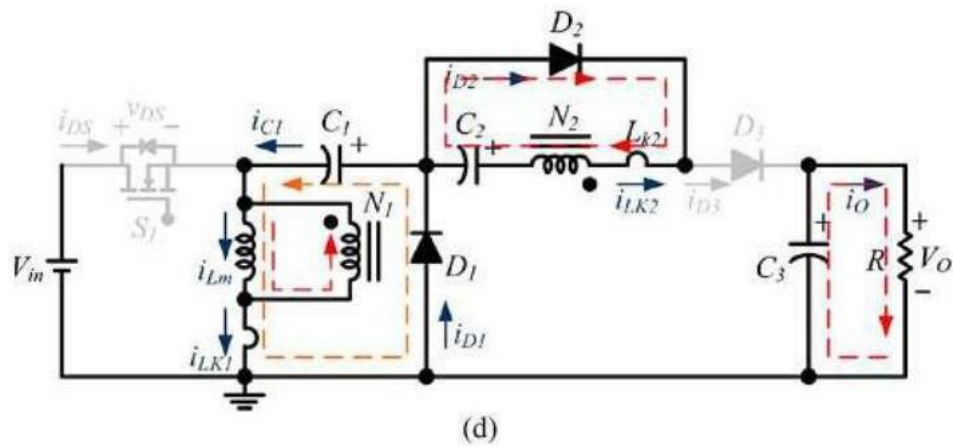
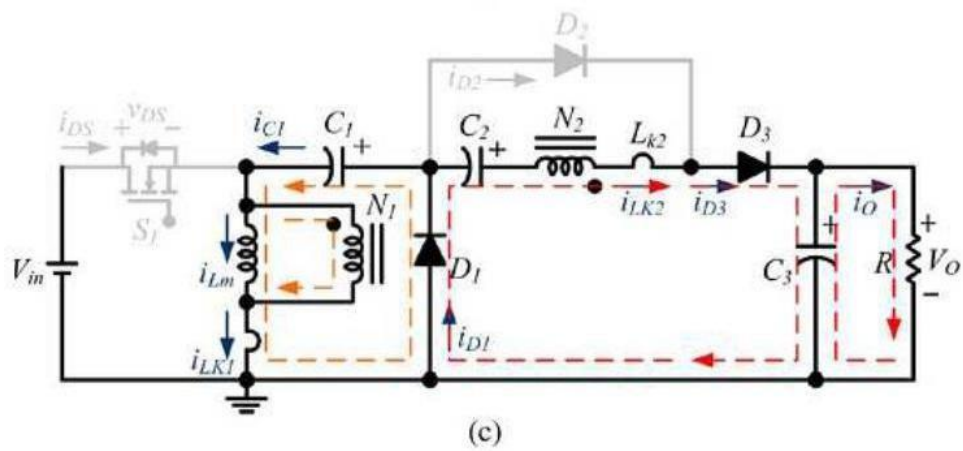
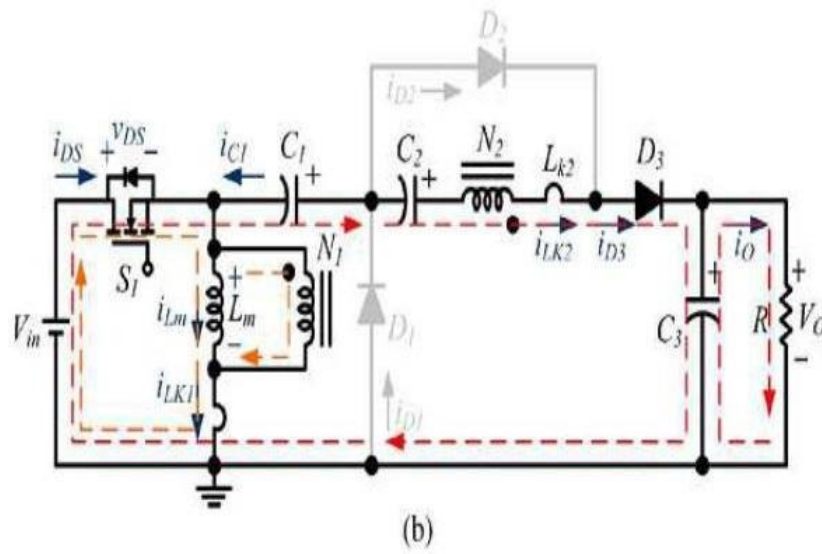
$$\frac{di_{Lm}^I(t)}{dt} = \frac{v_{Lm}}{L_m} \quad (2)$$

$$\frac{di_{LK1}^I(t)}{dt} = \frac{V_{in} - v_{Lm}}{L_{k1}} \quad (3)$$

$$i_{LK2}^I(t) = \frac{i_{Lm}^I(t) - i_{LK1}^I(t)}{n} \quad (4)$$

Mode II $[t_1, t_2]$: During this interval, source energy V_{in} is series connected with C_1 , C_2 , secondary winding N_2 , and L_{k2} to charge output capacitor C_3 and load R ; meanwhile magnetizing inductor L_m is also receiving energy from V_{in} . The current flow path is shown in Fig.5 (b); as illustrated, switch S_1 remains on, and only diode D_3 is conducting. The i_{Lm} , i_{LK1} , and i_{D3} are increasing because the V_{in} is crossing L_{k1} , L_m and primary winding N_1 ; L_m and L_{k1} are storing energy from V_{in} ; meanwhile, V_{in} is also in series with N_2 of coupled inductor T_1 , and capacitors C_1 and C_2 are discharging their energy to capacitor C_3 and load R , which leads to increases in i_{Lm} , i_{LK1} , i_{DS} , and i_{D3} .





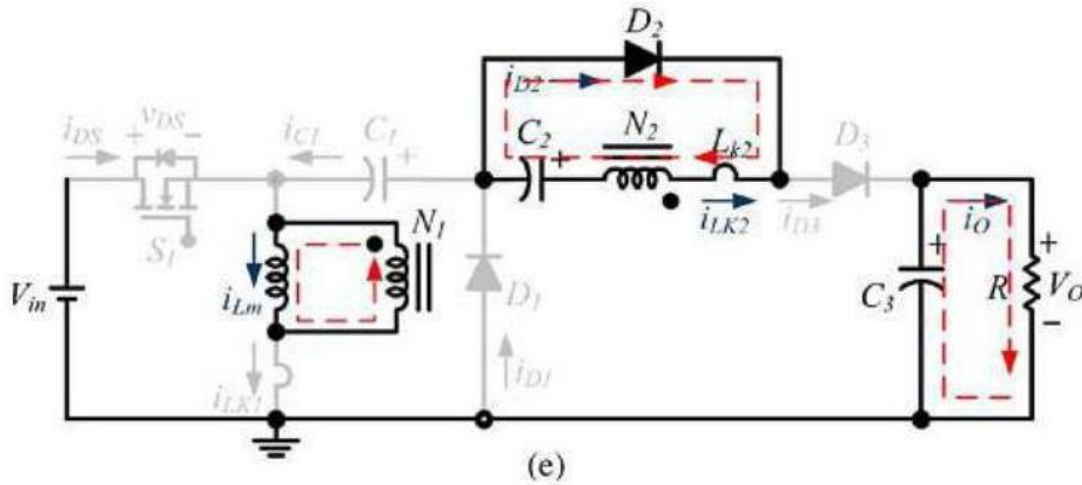


Fig.5 Current flow path in five operating modes during one switching period in CCM operation (a) Mode I (b) Mode II (c) Mode III (d) Mode IV (e) Mode V

This mode ends when switch S1 is turned off at $t=t_2$

$$i_{Lm}^{II}(t) = i_{Lk1}^{II}(t) - ni_{Lk2}^{II}(t) \quad (5)$$

$$\frac{di_{Lm}^{II}(t)}{dt} = \frac{V_{in}}{L_m} \quad (6)$$

$$i_{in}^{II}(t) = i_{DS}^{II}(t) = i_{Lm}^{II}(t) + (1+n)i_{Lk2}^{II}(t) \quad (7)$$

$$\frac{di_{Lk2}^{II}(t)}{dt} = \frac{di_{D3}^{II}(t)}{dt} = \frac{(1+n)V_{in} + V_{C1} + V_{C2}}{L_{k2}} \quad (8)$$

Mode III [t_2, t_3]: During this transition interval, secondary leakage inductor L_{k2} keeps charging C_3 when switch S_1 is off. The current flow path is shown in Fig. 5(c), and only diodes D_1 and D_3 are conducting. The energy stored in leakage

inductor L_{k1} flows through diode D_2 . Meanwhile, the L_{k2} keeps the same current direction as in the prior mode and is in series with C_2 to charge output capacitor C_3 and load R . The voltage across S_1 is the summation of V_{in} , V_{Lm} , and V_{Lk1} . Currents i_{Lk1} and i_{Lk2} are rapidly declining but i_{Lm} is increasing because L_m is receiving energy from L_{k2} . Once current i_{Lk2} drops to zero this mode ends at $t=t_3$.

$$i_{in}^{III}(t) = 0 \quad (9)$$

$$i_{Lm}^{III}(t) = i_{Lk1}^{III}(t) - ni_{Lk2}^{III}(t) \quad (10)$$

$$\frac{di_{Lk1}^{III}(t)}{dt} = \frac{-V_{C1} - v_{Lm}}{L_{k1}} \quad (11)$$

$$\frac{di_{Lk2}^{III}(t)}{dt} = \frac{di_{D3}^{III}(t)}{dt} = \frac{nv_{Lm} + V_{C2} - V_O}{L_{k2}} \quad (12)$$

Mode IV [t₃,t₄]: During this transition interval, the energy stored in magnetizing inductor L_m releases simultaneously to C_1 and C_2 . The current flow path is shown in Fig. 5(d). Only diodes D_1 and D_2 are conducting.

Currents i_{Lk1} and i_{D1} are persistently decreased because leakage energy still flows through diode D_1 and continues charging capacitor C_1 . The L_m is delivering its energy through T_1 and D_2 to charge capacitor C_2 . The energy stored in capacitors C_3 is constantly discharged to the load R . The voltage across S_1 is the same as previous mode.

Currents i_{Lk1} and i_{Lm} are decreasing, but i_{D2} is increasing. This mode ends when current i_{Lk1} is zero at $t=t_4$

$$i_{Lm}^{IV}(t) = i_{Lk1}^{IV}(t) - ni_{Lk2}^{IV}(t) \quad (13)$$

$$\frac{di_{Lk1}^{IV}(t)}{dt} = \frac{-V_{C1} - v_{Lm}}{L_{k1}} \quad (14)$$

$$\frac{di_{Lk2}^{IV}(t)}{dt} = \frac{V_{C2} + nv_{Lm}}{L_{k2}} \quad (15)$$

Mode V [t₄,t₅]: During this interval, magnetizing inductor L_m is constantly

transferring energy to C_2 . The current flow path is shown in Fig. 5(e), and only diode D_2 is conducting.

The i_{Lm} is decreasing due to the magnetizing inductor energy flowing continuously through the coupled inductor T_1 to secondary winding N_2 and D_2 to charge capacitor C_2 . The energy stored in capacitors C_3 is constantly discharged to the load R . The voltage across S_1 is the summation of V_{in} and V_{Lm} .

$$\begin{aligned} \frac{di_{Lm}^V(t)}{dt} &= \frac{v_{Lm}}{L_m} \\ i_{Lk1}^V(t) &= 0 \\ \frac{di_{Lk2}^V(t)}{dt} &= \frac{nv_{Lm} + V_{C2}}{L_{k2}} \end{aligned} \quad (18)$$

III. STEADY-STATE ANALYSIS

A. CCM Operation

To simplify the steady-state analysis, only modes II and IV are considered for CCM operation and the leakage inductances at primary and secondary sides are ignored. The following equations can be written from Fig. 5(b):

$$v_{Lm} = V_{in} \quad (19)$$

$$v_{N2} = nV_{in} \quad (20)$$

During mode IV, the following equations can be written:

$$v_{Lm} = -V_{C1} \quad (21)$$

$$-v_{N2} = V_{C2}$$

Applying a volt-second balance on the magnetizing inductor L_m yields

$$\int_0^{DT_s} (V_{in})dt + \int_{DT_s}^{T_s} (-V_{C1})dt = 0 \quad (23)$$

$$\int_0^{DT_s} (nV_{in})dt + \int_{DT_s}^{T_s} (-V_{C2})dt = 0 \quad (24)$$

from which the voltage across capacitor C_1 and C_2 are obtained as follows:

$$V_{C1} = \frac{D}{1-D} V_{in} \quad (25)$$

$$V_{C2} = \frac{nD}{1-D} V_{in} \quad (26)$$

During mode II, the output voltage $V_O = V_{in} + V_{C1} + V_{N2} + V_{C2}$ as shown

$$V_O = V_{in} + \frac{D}{1-D} V_{in} + nV_{in} + \frac{nD}{1-D} V_{in} = \frac{1+n}{1-D} V_{in}$$

The dc voltage gain MCCM can be found as follows:

$$M_{CCM} = \frac{V_O}{V_{in}} = \frac{I_{in}}{I_O} = \frac{1+n}{1-D} \quad (28)$$

voltage gain MCCM as a function of duty ratio D by various turns ratios, and the straightness of the curve accounts for the correction between turns ratio n and duty ratio under the voltage gain MCCM=8. The plot of voltage gain MCCM as a function of duty ratio D of the proposed converter is compared with three different converters [14], [20] and [21]; all are under CCM operation and $n=3$.

IV. MATLAB MODELLING AND SIMULATION RESULTS

Here the simulation is carried out by two cases, in that

1. Proposed DC/DC Converter Operating Under Open Loop Condition.
2. Proposed DC/DC Converter Operating Under Closed Loop Condition.

Case 1: Proposed DC/DC Converter Operating Under Open Loop Condition

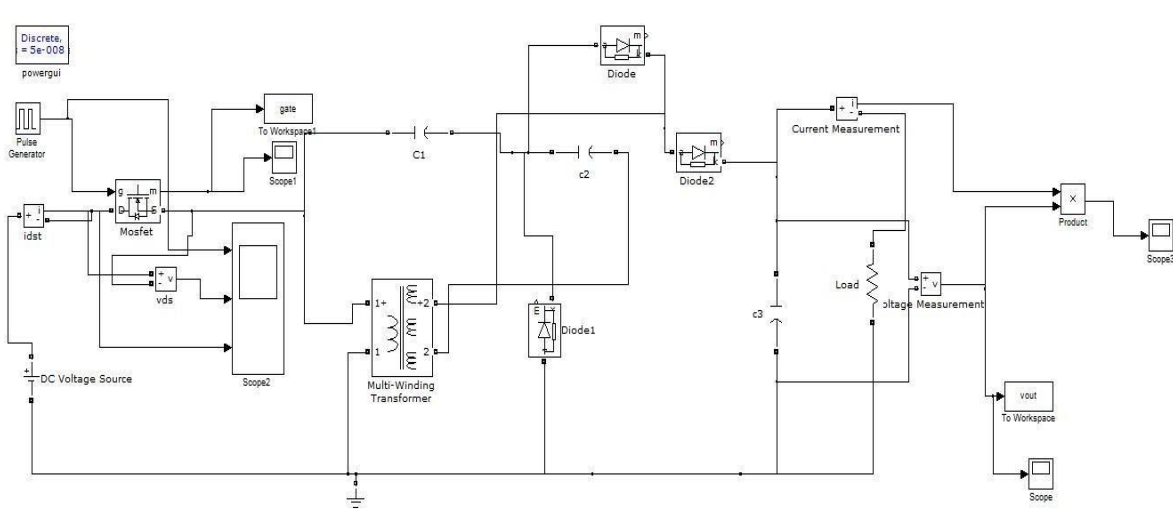


Fig.6 Matlab/Simulink Model of Proposed DC/DC Converter Operating Under Open Loop Condition

Fig.6 shows the Matlab/Simulink Model of Proposed DC/DC Converter Operating under Open Loop Condition using Matlab/Simulink Tool.

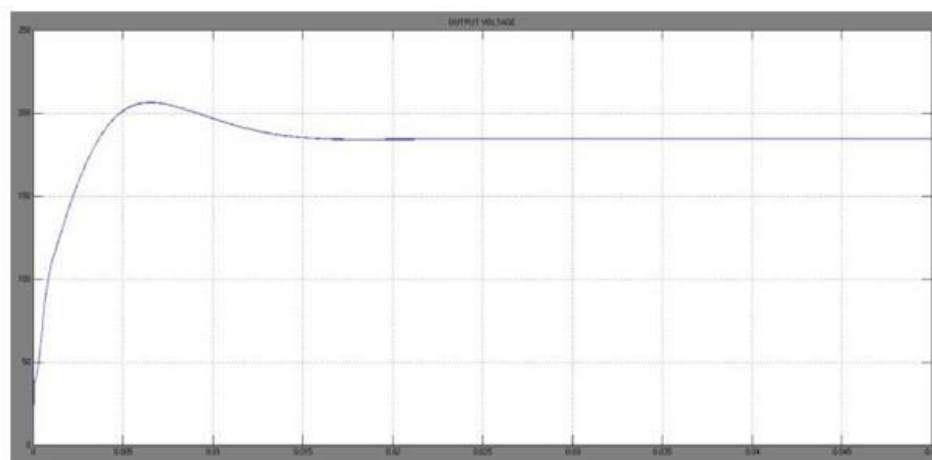


Fig.7 Output Voltage

Fig.7 shows the Output Voltage of Proposed DC/DC Converter Operating under Open Loop Condition, due to non-presence of feedback system attains low stable operation, attains 0.02 sec for fast response.

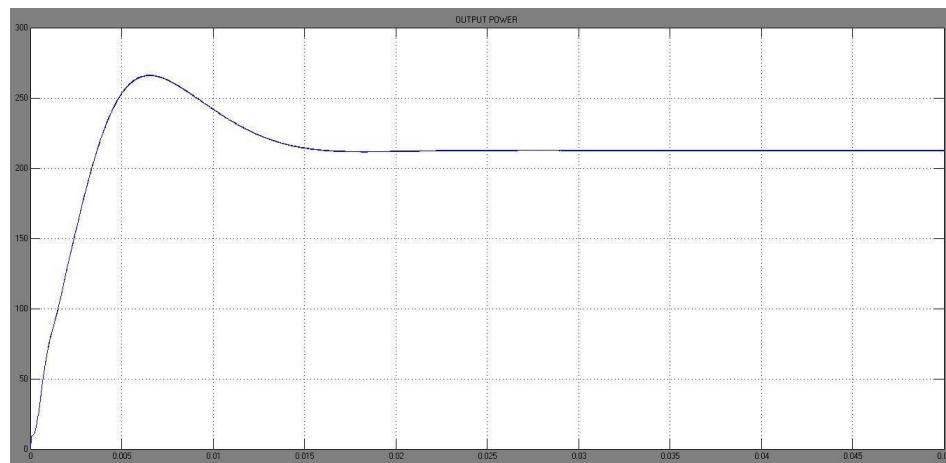


Fig.8 Output Power

Fig.8 shows the Output Power of Proposed DC/DC Converter Operating under Open Loop Condition.

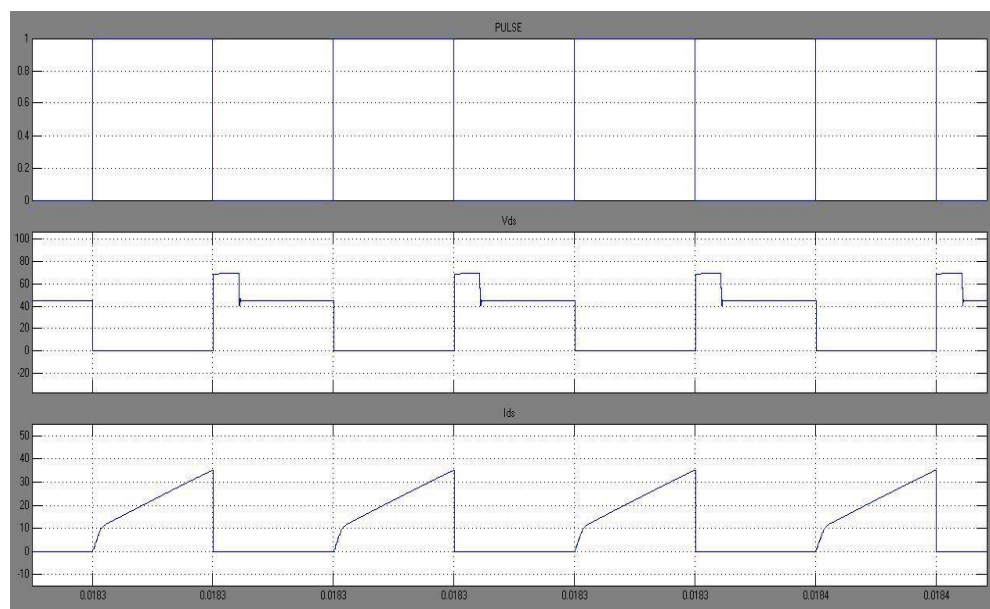


Fig.9 Switching States, Vds, Ids

Fig.9 shows the Switching States, Vds, Ids of Proposed DC/DC Converter Operating under Open Loop Condition.

Case 2: Proposed DC/DC Converter Operating Under Closed Loop Condition

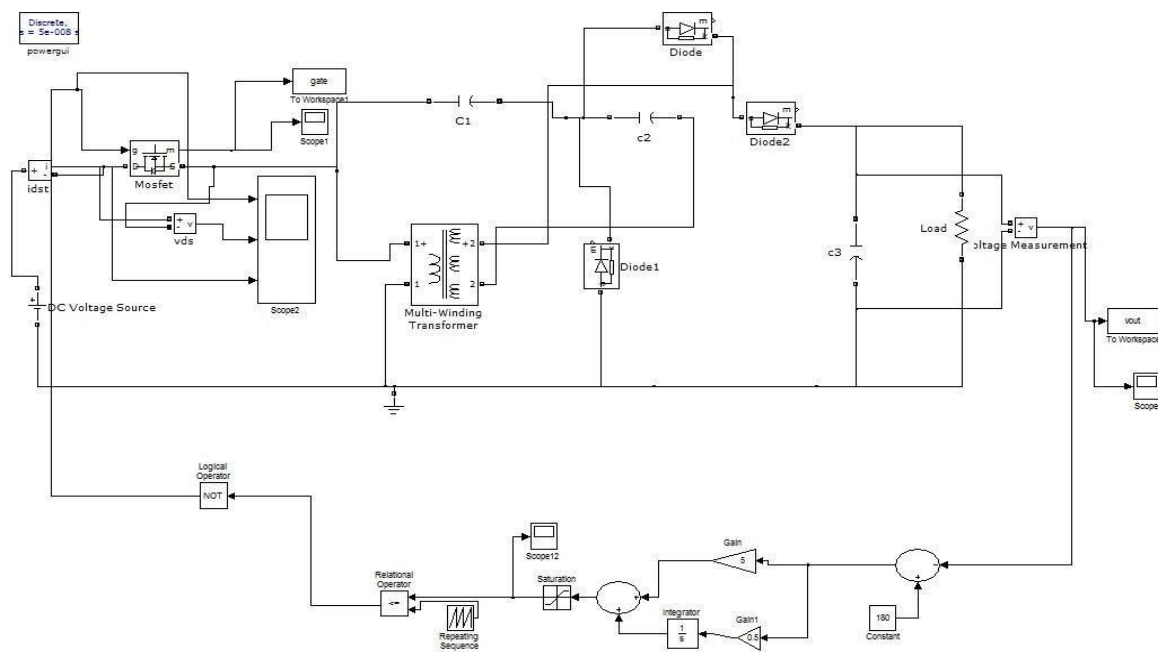


Fig.10 Matlab/Simulink Model of Proposed DC/DC Converter Operating Under Closed Loop Condition

Fig.10 shows the Matlab/Simulink Model of Proposed DC/DC Converter Operating under Closed Loop Condition using Matlab/Simulink Tool.

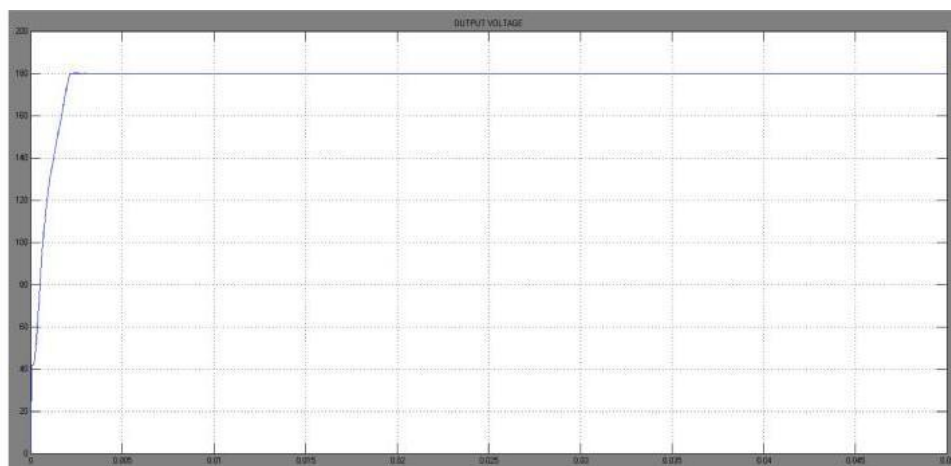


Fig.11 Output Voltage

Fig.11 shows the Output Voltage of Proposed DC/DC Converter Operating under Closed Loop Condition, due to presence of feedback system attains high stable operation, attains 0.01 sec for fast response.

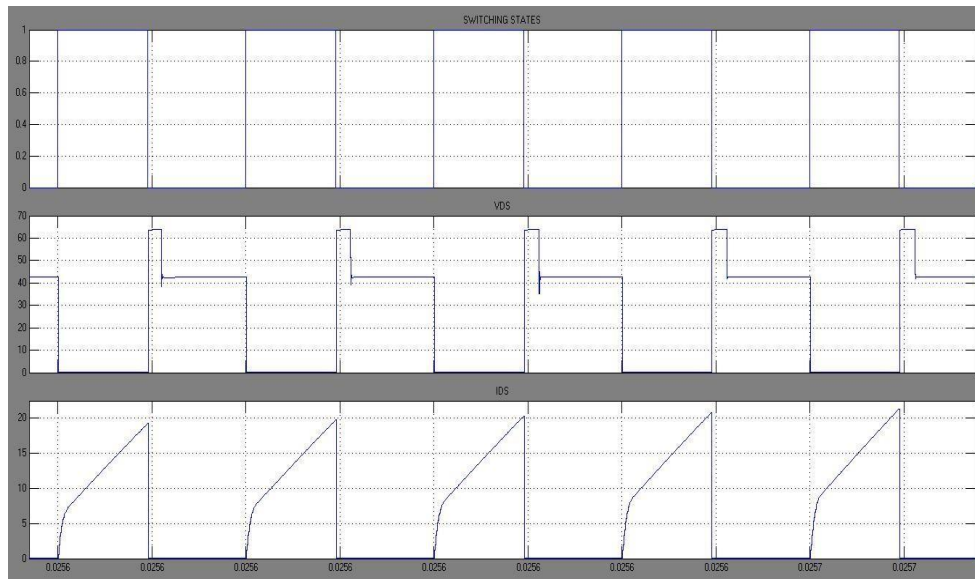


Fig.12 Switching States, Vds, Ids

Fig.12 shows the Switching States, Vds, Ids of Proposed DC/DC Converter Operating under Closed Loop Condition.

V. CONCLUSION

Power electronics applications requiring high-voltage high-power converters have been steadily growing in fields such as interfacing RES system, power quality, power systems control. The high step up dc-dc converters are usually used as the front-end converters to step from low voltage to high voltage which are required to have a large conversion ratio, high efficiency, and

small volume. The proposed converter employs the turns ratio of the coupled inductor to achieve high step-up voltage gain; based on the floating switch structure of the Zeta converter, this design successfully isolates the energy from the PV panel when the converter is non-operational, which helps to prevent injury to humans or damage to facilities. The energy of the leakage inductor of the coupled inductor is recycled, and the voltage stress across the active switch S1 has been restrained; these merits mean low ON-state resistance $R_{DS(ON)}$ can be selected, which effectively

improves the efficiency of the proposed converter.

REFERENCES

- [1] Shih-Ming Chen, Tsorng-Juu Liang, —A Boost Converter With Capacitor Multiplier and Coupled Inductor for Ac Module Applications, *IEEE Transaction on Industrial Electronics*, vol. 60, No. 4, pp. 1503-1511, April 2013.
- [2] T. Shimizu, K. Wada, and N. Nakamura, —Flyback- type single-phase utility interactive inverter with power pulsation decoupling on the dc input for an ac photovoltaic module system, *IEEE Transactions. Power Electron.*, vol. 21, no. 5, pp. 1264–1272, Jan. 2006 .
- [3] C. Rodriguez and G. A. J. Amaratunga, —Long-life time power inverter for photovoltaic ac modules, *IEEE Trans. Ind. Electron.*, vol. 55, no. 7, pp. 2593–2601, Jul. 2008.
- [4] W. Li and X. He, —Review of non-isolated high step-up dc/dc converters in photovoltaic grid-connected applications, *IEEE Trans. Ind. Electron.*, vol. 58, no. 4, pp. 1239–1250, Apr. 2011 .
- [5] S. B. Kjaer, J. K. Pedersen, and F. Blaabjerg, —A review of single-phase grid-connected inverters for photovoltaic modules, *IEEE Trans. Ind. Appl.*, vol. 41, no. 5, pp. 1292–1306, Sep./Oct . 2005.
- [6] B. Jablonska, A. L. Kooijman-van Dijk, H. F. Kaan, M. van Leeuwen, G. T. M. de Boer, and H. H. C. de Moor, —PV-private project at ECN, five years of experience with small-scale ac module PV systems, *in Proc. 20th Eur. Photovoltaic Sol. Energy Conf., Barcelona, Spain, Jun. 2005*, pp. 2728–2731.
- [7] J. J. Bzura, —The ac module: An overview and update on self-contained modular PV systems, *in Proc. IEEE Power Eng. Soc. Gen. Meeting*, Jul. 2010, pp. 1–3.
- [8] J. Falin, —Designing dc/dc converters based on ZETA topology, *Analogue Appl. J.*, pp. 16–21, 2 Q, 2010.

- [Online]. Available: <http://focus.ti.com/lit/an/slyt372/slyt372.pdf>
- [9] B. R. Lin and F. Y. Hsieh, —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.
- [10] T. B. Marchesan, M. A. Dalla-Costa, J. M. Alonso, and R. N. do Prado, —Integrated Zeta-flyback electronic ballast to supply high-intensity discharge lamps,||IEEE Trans. Ind. Electron., vol. 54, no. 5, pp. 2918–2921, Oct. 2007.
- [11] D. Murthy-Bellur and M. K. Kazimierczuk, —Two- transistor Zeta-flyback dc-dc converter with reduced transistor voltage stress,||Electron. Lett., vol. 46, no. 10, pp. 719–720, May 2010.
- [12] T. F. Wu, S. A. Liang, and Y. M. Chen, —Design optimization for asymmetrical ZVS PWM Zeta converter,||IEEE Trans. Aerosp. Electron. Syst., vol. 39, no. 2, pp. 521–532, Apr. 2003.
- [13] M. J. Bonato, F. T. Wakabayashi, and C. A. Canesin, —A novel voltage step-down/up ZCS-PWM Zeta converter,|| inConf. Rec. IEEE IAS Annu. Meeting, 2000, pp. 2448–2454.
- [14] B. Axelrod, Y. Berkovich, S. Tapuchi, and A. Ioinovici, —Steep conversion ratio $\hat{C}_{uk}$ Zeta, and sepic converters based on a switched coupled-inductor cell,|| inProc. IEEE Power Electron. Spec. Conf., 2008, pp. 3009–3014.
- [15] B. Axelrod, Y. Berkovich, and A. Ioinovici, —Switched-capacitor/switched-inductor structures for getting transformerless hybrid dc-dc PWM converters,||IEEE Trans. Circuits Syst. I, Reg. Projects, vol. 55, no. 2, pp. 687–696, Mar. 2008.
- [16] F. L. Luo, —Switched-capacitorized dc/dc converters,|| in Proc. IEEE ICIEA, 2009, pp. 1074–1079.
- [17] G. Zhu and A. Ioinovici, —Switched-capacitor power supplies: dc voltage ratio, efficiency, ripple, regulation,||

- in Proc. IEEE ISCAS, 1996, pp. 553–556.
- [18] B. Axelrod, Y. Berkovich, and A. Ioinovici, —Transformerless dc-dc converters with a very high dc line-to-load voltage ratio, in Proc. IEEE ISCAS, 2003, vol. 3, pp. 435–438.
- [19] L. S. Yang, T. J. Liang, and J. F. Chen, —Transformerless dc-dc converters with high step-up voltage gain, IEEE Trans. Ind. Electron., vol. 56, no. 8, pp. 3144–3152, Aug. 2009.
- [20] T. J. Liang and K. C. Tseng, —Analysis of integrated boost-flyback step-up converter, Proc. Inst. Elect. Eng.—Elect. Power Appl., vol. 152, no. 2, pp. 217–225, Mar. 2005.
- [21] Q. Zhao and F. C. Lee, —High-efficiency, high step-up dc-dc converters, IEEE Trans. Power Electron., vol. 18, no. 1, pp. 65–73, Jan. 2003.
- [22] F. L. Luo and H. Ye, —Positive output multiple -lift push-pull switched capacitor Luo converters, IEEE Trans. Ind. Electron., vol. 51, no. 3, pp. 594–602, Jun. 2004.
- [23] F. L. Luo, —Six self-lift dc-dc converters, voltage lift technique, IEEE Trans. Ind. Electron., vol. 48, no. 6, pp. 1268–1272, Dec. 2001.
- [24] D. Zhou, A. Pietkiewicz, and S. Ćuk, —A three -switch high-voltage converter, IEEE Trans. Power Electron., vol. 14, no. 1, pp. 177–183, Jan. 1999.
- [25] M. Zhu and F. L. Luo, —Voltage-lift-type Ćuk converters: Topology and analysis, IET Power Electron., vol. 2, no. 2, pp. 178–191, Mar. 2009.
- [26] J. W. Baek, M. H. Ryoo, T. J. Kim, D. W. Yoo, and J. S. Kim, —High boost converter using voltage multiplier, in Proc. IEEE IECON, 2005, pp. 567–572.
- [27] K. B. Park, H. W. Seong, H. S. Kim, G. W. Moon, and M. J. Youn, —Integrated boost-sepic converter for high step-up applications, in Proc.

- IEEE Power Electron. Spec. Conf., 2008, pp. 944–950 .
- [28] S. K. Changchien, T. J. Liang, J. F. Chen, and L. S. Yang, —Novel high step-up dc-dc converter for fuel cell energy conversion system,|| IEEE Trans. Ind. Electron., vol. 57, no. 6, pp. 2007–2017, Jun. 2010.
- [29] R. J. Wai and R. Y. Duan, —High step-up converter with coupled inductor,|| IEEE Trans. Power Electron., vol. 20, no. 5, pp. 1025– 1035, Sep. 2005.
- [30] R. J. Wai, C. Y. Lin, R. Y. Duan, and Y. R. Chang, —High-efficiency dc-dc converter with high voltage gain and reduced switch stress,||IEEE Trans. Ind. Electron., vol. 54, no. 1, pp. 354–364, Feb. 2007.
- [31] B. Axelrod, Y. Berkovich, and A. Ioinovici, —Hybrid switched capacitor—Cuk/Zeta/Sepic converters in step-up mode,|| in Proc. IEEE ISCAS, 2005, vol. 2, pp. 1310–1313.
- [32] L. S. Yang, T. J. Liang, H. C. Lee, and J. F. Chen, —Novel high step-up dc-dc converter with coupled-inductor and voltage-doubler circuits,|| IEEE Trans. Ind. Electron., vol. 58, no. 9, pp. 4196–4206, Sep. 2011.
- [33] H.-L. Do, —Zero-voltage-switching synchronous buck converter with a coupled inductor,||IEEE Trans. Ind. Electron., vol. 58, no. 8, pp. 3440–3447, Aug. 2011