High Gain DC-DC Converter for Photovoltaic System

P. Thilothama[1], D. Ashokaraju [2],

[1]PG Scholar, Department of Electrical and Electronics Engineering, Government College of Engineering, Salem-11, Tamil Nadu, India
[2]Associate Professor, Department of Electrical and Electronics Engineering, Government College of Engineering, Salem-11, Tamil Nadu, India

---***---

Abstract - The, high-gain DC–DC converters dragged much attention among the researchers. But there is a concern that high-gain converters have less efficiency and high switching stresses. The converter topology has two quasi-impedance source network and a voltage multiplier cell unit to facilitate very high-gain output voltage. The input variations due to varying irradiation of photovoltaic are alleviated by employing the perturb and observe maximum power point tracking mechanism. The simulation of the work is realized in MATLAB/ Simulink arena, and hardware circuits are validated using the dsPIC30F2010 controller.

***Key Words*:** High-gain DC–DC converter, non-linear carrier controller, voltage regulation, perturb and observe maximum power point tracking, solar photovoltaic

INTRODUCTION

This article relates to the teaching concept of high-gain DC–DC converter which is a contemporary topic in power electronics. The whole world is shifting its attention towards distributed energy resources as the conventional way of interconnected system finds difficult to accommodate the power interaction through renewable power sources. This paper suggests using photovoltaic (PV) power as the source for the proposed power electronic circuitry. PV sources are made compatible to the load only through power electronic interfaces.

The high-gain power electronic interface is a novel one in this work. innovative topology is then developed. It is evident that there prevails a glooming power crisis around the globe[1] and in recent past much emphasize has been given on utilizing sustainable sources to alleviate the power deficit problem. Among the sustainable sources the most coveted is the PV resource which has peculiar advantages like pedagogy portable, scalability, etc. compared to its other equivalents. PV as such, being intermittent in nature, demands the role of power electronic interfaces mandatorily.[2–5]Also to make most out of the existing power in PV in a given point of time, along with the power electronic converters intelligent control schemes called maximum power point tracking (MPPT) are required.[6–9] These MPPT controllers work effectively to deliver the maximum power available in the PV to the load for varying environmental (irradiation and temperature) changes[12] The category of MPPT scheme can be classified predominantly according to the complexity of the algorithm, control parameters involved, interfacing power electronic topologies, etc.[13–16] Amid the well-known MPPT control techniques, the most coveted ones are perturb and observe (P&O), and incremental conductance (INC), as these two algorithms are complementary in nature and cater the need of application in which it is employed. P&O algorithm which works on iterating the power and voltage values in power–voltage (P–V) curve to find the exact operating point (V_{mpp}, I_{mpp}) at which the PV delivers maximum power.

This algorithm is a simple cost effective one compared to its INC counterpart. On the other hand, INC needs comparatively an extended competency in executing the algorithm and in this way P&O is preferred over INC in most of the PV applications.[17] In this work, the simple P&O MPPT is adopted to regulate the PV power for its respective change in irradiation and temperature. PV panels, though available in different power ratings, have voltage levels confined in the 17–40V range. A typical 250 W panel may have a maximum voltage of 36V, and therefore the DC–DC converter which interfaces PV panel and inverter loads (AC loads) drags utmost importance. The various traits of DC–DC converters like gain, efficiency, topologies (isolated and non-isolated) have to be chosen vigilantly in PV power system.[19], -[20] The step up DC–DC converter say, boost converter is the rational choice in many applications where the load voltage will be several times the source voltage. The idea of configuring the panels in series to make up the voltage to an extent may also go as a futile idea if there is a mismatch between panels due to inhomogeneous exposure of sunlight on the PV panels in an array.

Therefore, the choice of high-gain DC–DC converters is apt for PV applications and this high-gain converter can be isolated or non-isolated one. Non-isolated converters are much more preferred over its isolated equivalent due to the disadvantages like increase in size, losses and less efficient, voltage spike issues, etc.[21] To put in nutshell, the total efficiency of a typical PV –DC–DC converter- Inverter- /Grid/ Load system is primarily decided at the DC–DC conversion stage. In this context, exploring the research aspects in high-gain DC–DC converter with new topologies is highly prudent. In this research work, an innovative DC–DC circuit with effective two-loop voltage controlling mechanism has been developed. The DC–DC converter is fed by a PV system which has inherent variations in the source side due to its intermittent nature.

PROPOSED SINGLE SWITCH HYBRID DC/DC CONVERTER AND ANALYSIS

The proposed DC/DC converter integrates two quasi-networks (continuous conduction quasi-impedance source (qZS) and discontinuous conduction qZS) and a single stage voltage multiplier for PV power generation system as shown in Fig.1 Three inductors (L_1, L_2, and L_3); four capacitors (C_1, C_2, C_3, and C_4); two diodes (D_1, D_2) form the Z source converter, and inductor (L_4); capacitors (C_5 and C_6); diodes (D_3, D_4, and D_5) form the voltage multiplier circuit. Moreover, it inherits the additional merits such as common input and output ground, continuous input current, buck or boost of the input voltage by varying the duty cycle D.

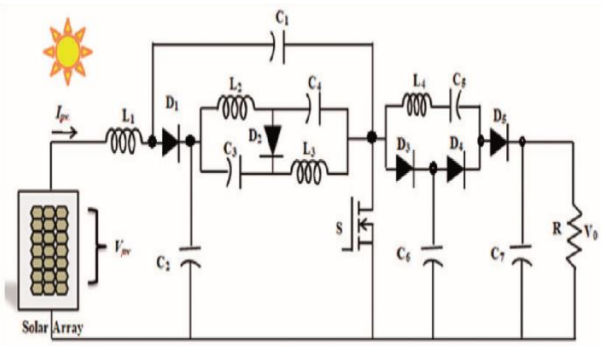
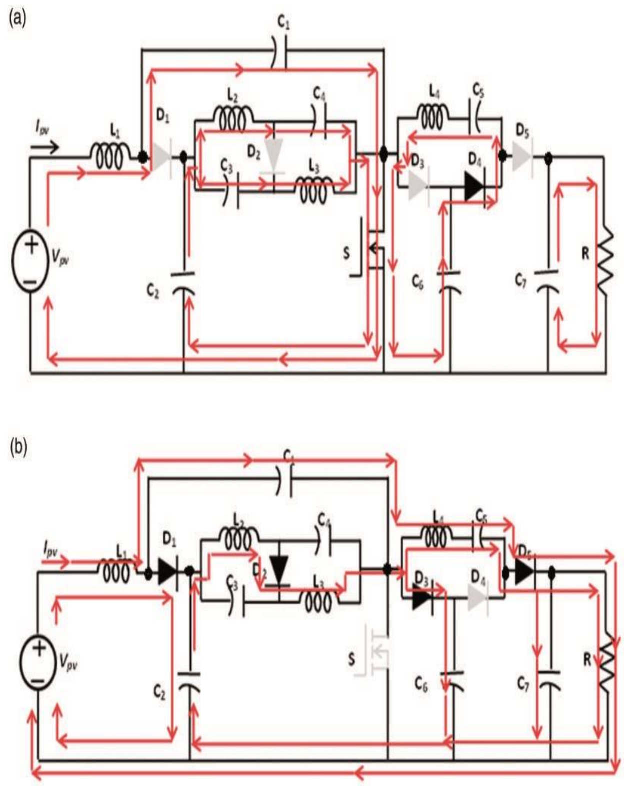


Fig 1. Proposed DC/DC converter for PV power generation system.

ANALYSIS OF THE PROPOSED CONVERTER

The proposed converter is analyzed by assuming that the components employed are ideal, the capacitors are sufficiently large enough to provide constant voltage and the converter operates in continuous conduction mode (CCM). The operating modes of the converter with current flow path are shown in Figure 2.

Mode I (DTs). Figure 2(a) demonstrates the equivalent circuit of the proposed converter in first operating mode. During this mode, the boost switch S is ON, whereas the diodes D_1–D_3 and D_5 are in OFF state. The time interval of this mode is assumed as DT_s. The panel output voltage V_{PV} and the capacitor C_1 discharges the energy to the inductor L_1. On the



other hand, the capacitors C_2– C_6 charge the inductors L_2, L_3, and L_4. Voltage drop across of the C_7 appears across the load.

Figure 2. Equivalent circuit of the proposed converter with various current flow paths: (a) Mode I and (b) Mode II.

By applying Kirchhoff's Voltage Law (KVL), the potential drop across inductors L_1–L_3 can be stated as

$$V_{L1} = V_{PV} + V_{C1},\ V_{L2} = V_{C2} + V_{C4},\ V_{L3} = V_{C2} + V_{C3},\quad V_{L4} = V_{C6} - V_{C5}$$

On account of the symmetric nature of L_2 and L_3, C_3 and C_4, voltage across these components are given by

$$V_{L4} = V_{L3},\ V_{C3} = V_{C4}$$

Mode II ((1–D)Ts). Figure 2(b) demonstrates the equivalent circuit of the proposed converter in second operating mode. During this mode, the boost switch S is OFF, whereas the diodes D_1–D_3 and D_5 are in ON state. The time interval of this mode is assumed as $(1–D)T_s$. The panel output voltage V_{PV} charges the inductor L_1 and the energy stored in the inductors L_2, L_3, and L_4 discharges via the capacitors C_1–C_6 to the load

R. By applying the circuit, the potential drop across various components can be stated as

$$V_{L1} = V_{PV} - V_{C2},\ V_{L3} = -V_{C1} - V_{L2},\ V_{C1} = V_{C2} + V_{C4},$$

$$V_{O} = V_{C1} + V_{C2} + V_{C5}$$

Voltage multiplier is used to boost the static gain of the converter by (Xþ1), where X is the number of multiplier cells connected.[23] Here, a single cell voltage multiplier (C=1) is connected in series with the DC/DC converter to boost the output voltage. Thus, the output voltage is given by

$$V_0 = \frac{X+1}{(1-D)^2}\ V_{PV}$$

INDUCTOR DESIGN

The expression for the inductor can be derived by assuming the current ripple (DI) to an allowable limit. During CCM operation, the following expressions can be deduced

$$L = \frac{V_{L}\,dt}{di_L} = \frac{V_{L}\,D}{\Delta I_L f_S}$$

CAPACITOR DESIGN

The expression for the capacitor can be derived by assuming the voltage ripple (DV_c) to an allowable limit. During CCM operation, the following expressions can be derived

$$C = \frac{i_c dt_c}{dV_c} = \frac{i_c D}{\Delta V_c f_s}$$

Control strategy

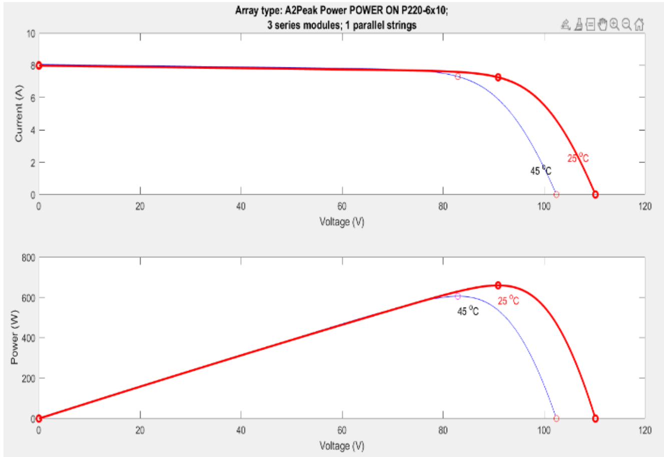
It consists of essentially control loop, one at the source side. P&O algorithm known for its simple execution and reliable operation is employed in this work to enhance the power delivery capability of the PV structure when it is exposed to varying environmental conditions. The load side regulation is achieved through a dynamic carrier voltage regulation which alleviates the load intermittencies.

P&O algorithm

Since its inception, P&O algorithm remains to be very compatible for many applications. In this algorithm, small change in the control signal of the power converter is occasionally introduced in the array voltage or current with respect to the output power of the previous cycle. If the rate of change of output power with respect to panel voltage increases positively ($dP_{PV}/dV_{PV} > 0$), then the path for attaining the operating point moves in one direction and vice versa. If the perturbation rate is selected vigilantly, the oscillations in the power output are so meek.

Fig 3 Waveform for V-I & P-V characteristic

PROPOSED CONVERTER WITH P&O MPPT



ALGORITHM

When solar panel feeds the proposed converter, the high-gain converter amplifies the output voltage waveform corresponds to the irradiations. Typically for 0.95 SUNS irradiations, 17.8V is amplified to 210V which is shown in Figure 4) demonstrates the corresponding current and power waveforms, respectively.

Table 1. Parameters.

Description	*Value*
L1, L2, L3	470 mH
L_4	60 mH
C1, C3, C4, C5	330 mF
C_2	450 mF
C_6	100 mF
C_7	150 mF
f_s	15 kHz

Simulation voltage and current waveforms of each element in the circuit for a duty cycle D=0.45 is shown in Figure 5. demonstrates that output voltage. Also, it can be inferred from the figure that ripple in the inductors are very low as it is connected between the capacitors. The voltage across the diode D_4 is shown in Figure 5(c). Similarly, the voltage across the diodes D_1, D_2, D_3 are shown in Figure 6. From the figures, it can be concluded that diodes D_1, D_2, D_3 are in complement state of operation with D_4. The current flowing through the capacitor C_7 is shown in Figure 5(d). Hardware results of the simulated waveform is shown in Figure 6. The extracted hardware results are in line with the simulated one.

RESULTS AND DISCUSSION

The performance of the proposed high-gain DC/DC converter with P&O MPPT algorithm and NLCC technique is simulated using the Matlab/Simulink and experimentally realized with the dsPIC30F4011 controller.

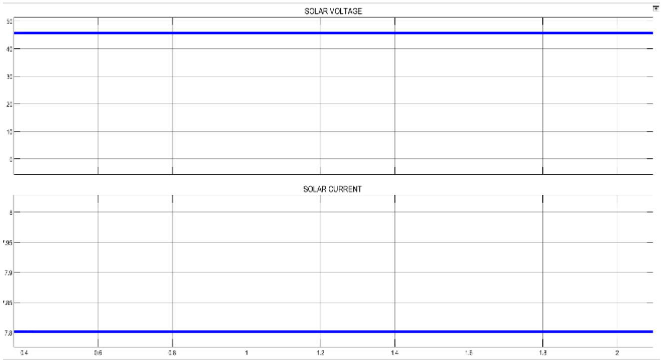


Fig 4. Input current and Voltage

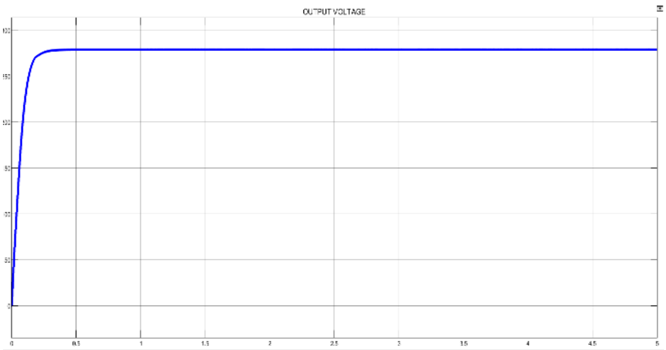


Fig 5. Output voltage

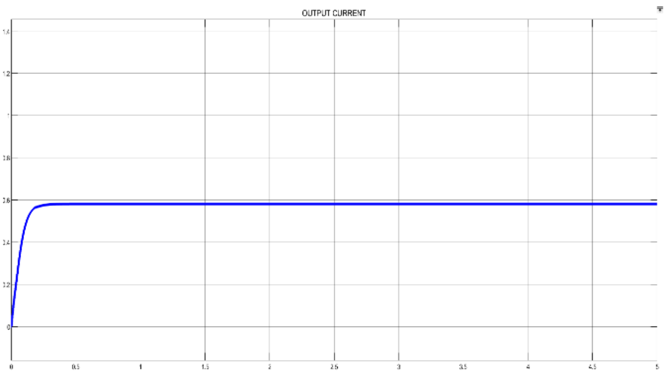


Fig 6. Output Power

The values for inductance and capacitance are determined by having the criteria of 5% output ripple as per the IEEE standards. The converter is tested with the various uncertain conditions like varying irradiation and varying load scenario. The following subsection gives the detail about it.

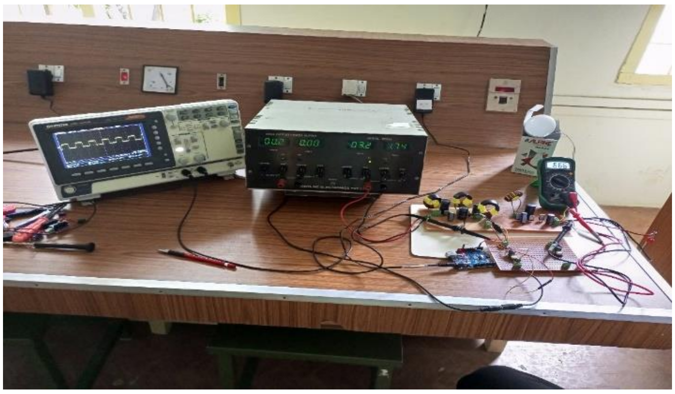
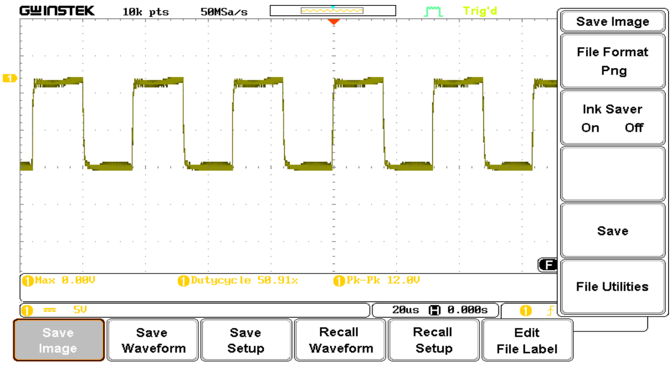


Fig 7. Hardware setup for High gain DC-DC converter

Fig 8. Pulse with modulation waveform



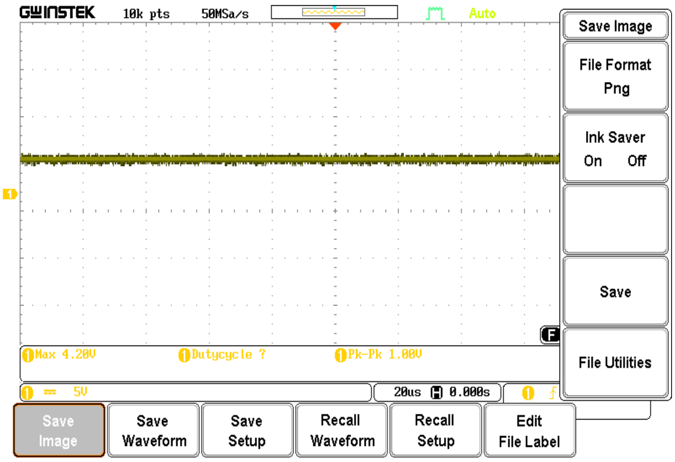


Fig 9. Output voltage waveform

The hard ware results have been tested with the D = 45% and the voltage we have given as 3v the obtained voltage is 8V.

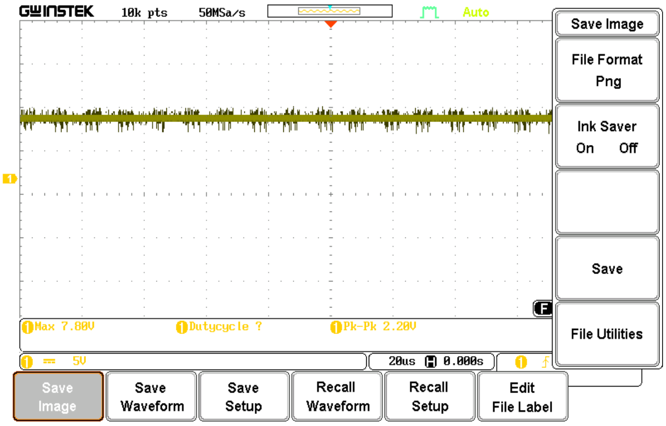


Fig 10. Input Voltage waveform

CONCLUSION

The High gain DC-DC converter has been designed with a rated output power and voltage of 160W and 260 volts. The voltage and current ripple of the converter has come in the desirable range. The objective of switch stress reduction has been attained which is made to be independent of the output voltage. It has an efficiency of 85-87%. The DC-DC converter has been successfully simulated in MATLAB Simulink environment. The output of the converter has attained successful output results. The hardware of the converter output has been designed and assembled with a coupled inductor of unity turns ratio. In the Hard ware the load has been given as battery charging. The c programming embedded in the ARDUINO gives an output pulse width modulation with a duty cycle of 25 percent. The output achieved is satisfactory with an output voltage level of 260 volts.The High gain DC-DC converter has mainly designed for the renewable application such as Devices which use rechargeable batteries include automobile starters, portable consumer devices, light vehicles (such as motorized wheelchairs, golf carts, electric bicycles, and electric forklifts), road vehicles (cars, vans, trucks, motorbikes), trains, small airplanes, tools, uninterruptible power supplies, and battery storage power stations.

References

1. Tripathi L, Mishra AK, Dubey AK, et al. Renewable energy: an over view on itscontribution in current energy scenario of India. Renewable Sustainable Energy Rev 2016; 60: 226–233.
2. Pan H, Qi L, Zhang X, et al. A portable renewable solar energy-powered cooling systembased on wireless power transfer for a vehicle cabin. Appl Energy 2017; 195: 334–343.
3. Mapurunga Caracas JV, de CarvalhoFarias G, Moreira Teixeira LF, et al. Implementation of a high-efficiency, high-lifetime, and low-cost converter for an autonomous photovoltaic water pumping system. IEEE Trans Ind Appl 2014; 50: 631–641.
4. Bennett T, Zilouchian A and Messenger R. Photo voltaic model and converter topologyconsiderations for MPPT purposes. Sol Energy 2012; 86: 2029–2040.
5. Zhang Y, et al. Comparison of conventional DC–DC converter and a family of diodeassisted DC–DC converter in renewable energy applications. J Power Electron 2014; 14: 203–216.
6. Sridhar R, Jeevananthan S, Dash SS, et al. A new maximum power tracking in PVsystem during partially shaded conditions based on shuffled frog leap algorithm. J Exp Theor Artif Intell 2017; 29: 481–493.
7. Kheldoun A, Bradai R, Boukenoui R, et al. A new golden section method-based maximum power point tracking algorithm for photovoltaic systems. Energy Convers Manag 2016; 111: 125–136.
8. Elgendy MA, Zahawi B and Atkinson DJ. Assessment of the incremental conductancemaximum power point tracking algorithm. IEEE Trans Sustain Energy 2013; 4: 108–117.
9. Ahmed J and Salam Z. An enhanced adaptive P&O MPPT for fast and efficient trackingunder varying environmental conditions. IEEE Trans Sustain Energy 2018; 9: 1487–1496.
10. Soon TK and Mekhilef S. A fast-converging MPPT technique for photovoltaic systemunder fast-varying solar irradiation and load resistance. IEEE Trans Ind Inf 2015; 11: 176–186.
11. Eltawil MA and Zhao Z. MPPT Techniques for photovoltaic applications renewableand sustainable energy. Reviews 2013; 25: 793–813.
12. Reisi AR, Moradi MH and Jamasb S. Classification and comparison of maximumpower point tracking techniques for photovoltaic system: a review. Renewable Sustainable Energy Rev 2013; 19: 433–443.
13. Kamarzaman NA and Tan CW. A comprehensive review of maximum power pointtracking algorithms for photovoltaic systems. Renewable Sustainable Energy Rev 2014; 37: 585–598.

14. Esram T and Chapman PL. Comparison of photovoltaic array maximum power pointtracking techniques. IEEE Trans Energy Convers 2007; 22: 439–449.
15. Karamia N, Moubayedb N and Outbib R. General review and classification of differentMPPT Techniques. Renewable Sustainable Energy Rev 2017; 68: 1–18.
16. Seyedmahmoudian M, Horan B, Kok Soon T, et al. State of the art artificialintelligence-based MPPT techniques for mitigating partial shading effects on PV systems – a review. Renewable Sustainable Energy Rev 2016; 64: 435–455.
17. Sivakumar S, JagabarSathik M, Manoj PS, et al. An assessment on performance ofDC–DC converters for renewable energy applications. Renewable Sustainable Energy Rev 2016; 58: 1475–1485.
18. Oliveira da Silva SA, Sampaio LP, Marcos de Oliveira F, et al. Feed-forward DC-buscontrol loop applied to a single-phase grid-connected PV system operating with PSO-based MPPT technique and active power-line conditioning. IET Renewable Power Gener 2017; 11: 183–193.
19. Swaminathan N and Lakshminarasamma N. The steady-state DC gain loss model,efficiency model, and the design guidelines for high-power, high-gain, low-input voltage DC–DC converter. IEEE Trans Ind Appl 2018; 54: 1542–1554.
20. Forouzesh M, Shen Y, Yari K, et al. High-efficiency high step-up DC–DC converterwith dual coupled inductors for grid-connected photovoltaic systems. IEEE Trans Power Electron 2018; 33: 5967–5982.
21. Prudente M, Pfitscher LL, Emmendoerfer G, et al. Voltage multiplier cells applied tonon-isolated DC–DC converters. IEEE Trans Power Electron 2008; 23: 871–887.
22. Fuad Y, de Koning WL and van der Woude JW. Pulse-width modulated d.c.–d.c.converters. Int J Electr Eng Educ 2001; 38: 54–79.
23. Tsorng-Juu L, Shih-Ming C, Lung-Sheng Y, et al. Ultra-large gain step-up switchedcapacitor DC-DC converter with coupled inductor for alternative sources of energy. IEEE Trans Circ Syst 2012; 59: 864–874.
24. Zhu M, Yu K and Luo FL. Switched-inductor Z-source inverter. IEEE Trans Power Electron 2010; 25: 2150–2158.
25. Gu B, Dominic J, Lai JS, et al. High boost ratio hybrid transformer DC-DC converterfor photovoltaic module applications. IEEE Trans Power Electron 2013; 28: 2048–2058.
26. Babaei E, Mashinchi Maheri H, Sabahi M, et al. Extendable nonisolated high gainDC–DC converter based on active–passive inductor cells. IEEE Trans Ind Electron 2018; 65: 9478–9487.
27. Lopez-Santos O and Mauricio Rico M. Educational applications of interactive tools to analyze, design, and simulate d.c.-d.c. power converters. Int J Electr Eng Educ 2014; 50: 384–394.
28. HanyunShen BZ. Hybrid Z-source boost DC–DC converters. IEEE Trans Ind Electron 2017; 64: 310–319.
29. Justin Nayagam BJ, Sathi RR and Olimuthu DIVYA. NLCC controller for SEPICbased micro-wind energy conversion system. Int J Electron 2016; 104: 555–568.
30. Tseng KC and Huang CC. High step-up high-efficiency interleaved converter with voltage multiplier module for renewable energy system. IEEE Trans Ind Electron 2014; 61: 1311–1319.
31. Shojaeian H, Heydari M and Hasanzadeh S. Improved interleaved high step-up converter with high efficiency for renewable energy applications. In: Proceedings of the 8th power electronics, drive systems & technologies conference (PEDSTC), Mashhad, 2017, pp.288–293.
32. Liu H and Li F. A novel high step-up converter with a quasi-active switched-inductorstructure for renewable energy systems. IEEE Trans Power Electron 2016; 31: 5030–5039.
33. Liu H, Li F and Ai J. A novel high step-up dual switches converter with coupledinductor and voltage multiplier cell for a renewable energy system. IEEE Trans Power Electron 2016; 31: 4974–4983.
34. Ardi H, Ajami V and Sabahi M. A novel high step-up dc-dc converter with continuousinput current integrating coupled inductor for renewable energy applications. IEEE Trans Power Electron 2017; 65: 1306–1315.
35. Moradpur R, Ardi H and Tavakoli A. Design and implementation of a new SEPICbased high step-up DC/DC converter for renewable energy applications. IEEE Trans Ind Electron 2017;65: 1290–1297.