



HIGH GAIN DC-DC CONVERTER USING ACTIVE LC2D NETWORK WITH MINIMUM COMPONENT

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ABSTRACT

A multi-stage ultra-gain converter using minimum component including a single semiconductor switch is proposed. The proposed converter is formulated using an active inductor-capacitor-two diodes (LC2D) network. The basic structure of the converter called as a cubic gain converter is formulated using twelve components including a semiconductor switch. The operation of the converter is discussed for continuous and discontinuous modes of operations. The converter performance due to the parasitic elements is discussed, and the Si C-based semiconductor devices are selected to reduce the effect of parasitic elements. A 250 W, 50 kHz cubic gain converter prototype is made and the test results are recorded. The results prove that the operation of the cubic gain converter low duty ratio helps to attain 91.6% efficiency. The proposed structure of the n -stage and the detailed analysis of the cubic gain converter are the major novelties and contributions of this paper. The operation of the cubic gain converter is also confirmed using a hardware prototype in the laboratory environment.

Key words: DC-DC converter, multi-stage DC-DC Converters, high gain converters, quadratic converter.

1. INTRODUCTION

The high gain DC-DC converter is employed in the applications like uninterruptible power supply, solar photovoltaic, fuel cell, high-density discharge lamps used in automobiles, X-ray machines, etc. Though the conventional boost converter is preferred in some of the above applications, limited voltage gain, higher duty ratio to realize DC voltage-gain, etc., restrict the utilization of the boost DC-DC converter. In literature, several DC-DC converters are reported using switched capacitor, cascaded boost, voltage multipliers and switched inductor concepts. With each additional stage leads to a significant output voltage. The step-up n -stage DC-DC converters are reported. The converter improvement, but each stage requires an additional switch with more number of reactive components. The converter uses ten components with single switch and has a gain of $(2-D)/(1-D)^2$. To improve the voltage gain using a single switch, a voltage double cell-based modified quadratic boost converter is reported. When the converter is coupled with voltage double, the main objective of a multistage DC to DC converter using. The results prove that the operation of the cubic gain converter in low duty ratio helps to attain 91.6% efficiency. The step-up n -stage DC-DC converters are reported. The converter with each additional stage leads to a significant output voltage improvement, but each stage requires an additional switch with more number of reactive components. The converter uses ten components with a single switch and has again of $(2-D)/(1-D)^2$. To improve the voltage gain using a single switch,

a voltage double cell-based modified quadratic boost converter is reported. When the converter is coupled with voltage double, the total components increases. But, the voltage gain is not increased significantly. The converter with each additional stage leads to a significant output voltage improvement, but each stage requires an additional switch with more number of reactive components.

2. LITERATURE REVIEW

YIN, Y., ZENG, Y., CHEN, X., FAN, Y.: “A DIGITAL METHOD OF POWER SHARING AND CROSS-REGULATION SUPPRESSION DC CONVERTER”: *overview.J. In,13(2016).*

This paper presents a digital method to regulate the single-inductor multiple-input multiple-output (SI-MIMO) dc-dc converter, which can integrate renewable sources and loads as the hybrid renewable energy system with less components.

WANG, X., WANG, J.T., ZHANG, X., SONG, J.: “A MULTI INPUT DC CONVERTER TOPOLOGIES in: IEEE FAIBLE TENSION FAIBLE COMMUNICATION (FTFC)”, Paris, pp 1-4(2013)

Multi-port converters have fewer components count and less conversion stage than the traditional power processing solution which adopts several independent two-port converters. This paper emphasis on the use of a single power processing stage to interface multiple power inputs integrates power conversion for a hybrid power source. The classification of various multiport dc-dc converters topologies both isolated and non isolated are studied and the features are listed.

XU, B., XU, L.D., CAI, H., XIE, C., HU, J., BU, F: “STRUCTURE OF MULTI INPUT MULTI OUTPUT DC-DC CONVERTER”. *IEEE TRANS.Ind.Inf.10(2),1578-1586(2014).*

In this study, a new structure for multi-input multi- output (MIMO) dc-dc boost converter is proposed. The number of inputs and outputs of the converter are arbitrary and independent from each other. The proposed topology has the advantages of both dc- dc boost and switched-capacitor converters. This converter is proper to use in applications like photovoltaic or fuel cell systems. The main advantages of the proposed structure are possibility of using energy supplies with different voltage-current characteristics, continuous input current, high voltage gain without high duty cycle, and possibility of performing at high switching frequencies.

3. WORKING PRINCIPLE

A multi-stage ultra-gain converter using minimum component including a single semiconductor switch is proposed. The proposed converter is formulated using an active inductor-capacitor-two diodes (LC2D) network. The results prove that the operation of the cubic gain converter in low duty ratio helps to attain 91.6% efficiency. The output voltage from the first stage is then fed into the second stage of the converter, where the same process is repeated. Each stage provides a small increase in voltage, and the total output voltage is the sum of the output voltages of all the stages. The configuration of the ultra-gain multi-stage converter is derived using an active LC2D network. Fig. 1 shows the schematic of the LC2D network. In the LC2D network-based ultra-gain converter, stored energy of an inductor is recycled in a capacitor, and this capacitor with the input source supplies energy into another inductor. Then, the stored energy of those two inductors is free wheeled into the load side in a series manner. This operation is repeated in each LC2D network, and the network thus helps to attain a significant DC-voltage gain using minimum components. Each stage of the LC2D network consists an inductor, a capacitor and pair of diodes.

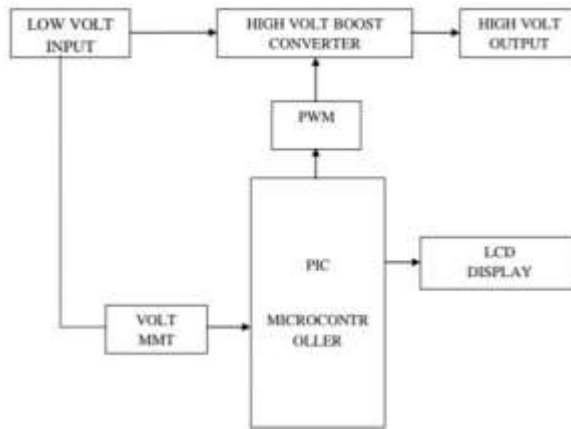


Fig No:1 Block Diagram

4. MAJOR COMPONENTS

PIC MICROCONTROLLER

HIGH VOLT BOOST CONVERTER WITH LC2D NETWORK
MOSFET

LCD DISPLAY

Microcontroller that has been used for this project is from PIC series. PIC microcontroller is the first RISC based microcontroller fabricated in CMOS (complementary metal oxide semiconductor) that uses separate bus for instruction and data allowing simultaneous access of program and data memory. The main advantage of CMOS and RISC combination is low power consumption resulting in a very small chip size with a small pin count. The main advantage of CMOS is that it has immunity to noise than other fabrication techniques.

LC2D NETWORK WITH MINIMUM COMPONENT

An active LC2D network with minimum components is to efficiently step up or step down the voltage of a DC power source to a desired level using a compact and cost-effective circuit. The active LC2D network is a type of voltage converter topology that uses a combination of inductors, capacitors, and active components such as MOSFETs or BJTs to achieve high efficiency and fast response time. As displayed in the gate pulse of S is turned low, hence the stored energy of the inductors are freewheeled along with the input voltage V_s into the load. Together, the inductor L1 pushes its stored energy to C1, and L2 charges C2.

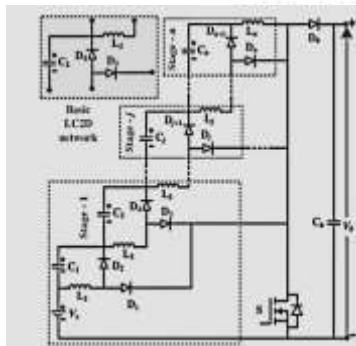


Fig.2 Proposed LC2D network-based multistage DC-DC converter

The step-up n -stage DC-DC converters are reported. The converter with each additional stage leads to a significant output voltage improvement, but each stage requires an additional switch. In literature, several DC-DC converters are reported using switched capacitor, cascaded boost, voltage multipliers and switched inductor concepts.

Table I Design specification

| Component | Specification |
|--|---|
| Power rating | 250 W |
| Input source V_{s1}, V_{s2} , Output voltage V_{01}, V_{02} | 45 V, 24 V, 800 V, 650 V |
| Inductors L_1, L_2 and L_3 | 1.6mH, 5mH, 12mH |
| Capacitors | 100 μ F |
| Switching frequency | 50 kHz |
| Diodes part numbers D_1, D_2 & D_0 D_3 & D_4 | FFSH20120A- F085 FFSH2065B- F085 |
| Switch part number | C2M0040120 D |

The voltage stress of various devices present in the cubic gain converter are recorded, and depicted. The voltage stress of the diode D_1 matches with the theoretical value of $V_s D / (1-D)$. The voltage stress of the diodes D_4 and D_3 match with the theoretical values of respectively, $V_s / (1-D)^2$ and $V_s D / (1-D)^3$. Similarly, the voltage stress of the diode D_0 and the switch that are equal to the output voltage also match with the experimental waveforms. The performance of the cubic gain converter is also verified by considering the input voltage of $V_s = 10V$ and $V_0 = 100 V$ for $D = 0.382$ and the output waveforms.

5. PERFORMANCE COMPARISON OF CUBIC GAIN CONVERTER

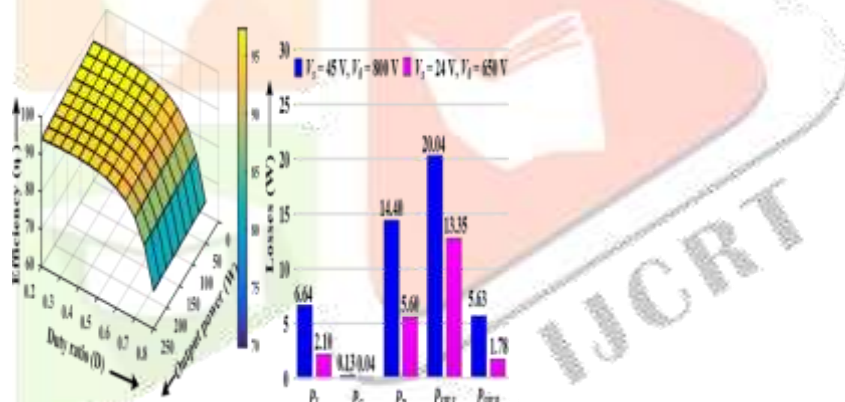
A comparison study of the cubic gain converter with the conventional converters with respect to the output voltage gain, semiconductor devices and reactive elements is given in Table II. The cubic gain converter attains a high DC-voltage gain of 125 at 80% duty ratio using minimum components of twelve including a single semiconductor switch as given in Table II. As per the proposed structure, the capacitors help to store energy in the inductors with high voltage, and this inductors alone pushes the stored energy into the load. Whereas the involvement of the capacitors in the discharge path affects the output voltage because of the parasitic element of the capacitors. The dc-dc converter can be classified as buck or boost depending on where the supplementary energy storage is located. Energy storage is put on the high voltage side in the buck type, whereas it is positioned on the low voltage side in the boost type capacitor, cascaded boost, voltage multipliers and switched inductor concepts DC-DC converters are reported using switched capacitor, cascaded boost, voltage multipliers and switched inductor concepts. The step-up n -stage DC-DC converters are reported. The converter with each additional stage leads to a significant output voltage improvement, but each stage requires an additional switch with more number of reactive components.

Table II Performance comparison

| Topology | [7] | [14] | [10] | [12] | [15] | [11] | Cubic |
|-------------------|------------------|---------------------|-----------------------|-----------------------------|-------------------------|-------------------------|---------------------|
| Switch | 4 | 2 | 1 | 2 | 2 | 2 | 1 |
| Diode | 12 | 4 | 4 | 3 | 5 | 5 | 5 |
| Capacitor | 12 | 3 | 4 | 4 | 5 | 6 | 3 |
| Inductor | 4 | 2 | 3 | 3 | 2 | 3 | 3 |
| Max gain D=0.8 | 60 | 50 | 45 | 49 | 95 | 70 | 125 |
| Voltage Gain | $\frac{12}{1-D}$ | $\frac{2}{[1-D]^2}$ | $\frac{1+D}{[1-D]^2}$ | $\frac{-D^2+2D+1}{[1-D]^2}$ | $\frac{[3+D]}{[1-D]^2}$ | $\frac{[2+D]}{[1-D]^2}$ | $\frac{1}{[1-D]^2}$ |

□ □
□ □
□ □

Though the voltage gain is slightly more in the converter reported in where the duty ratio is less than 74%, the converter utilizes fourteen components including two semiconductor switches. As per the proposed structure, the capacitors help to store energy. Its design is similar to the step-up boost converter, and like the boost converter it is a switched-mode power supply that uses two switches (a transistor and a diode), an inductor and a capacitor. The simplest way to reduce a DC voltage is to use a voltage divider circuit, but voltage dividers waste energy, since they operate by bleeding off excess power.



(a) Efficiency profile of cubic converter (b) Lossbreakdown analysis

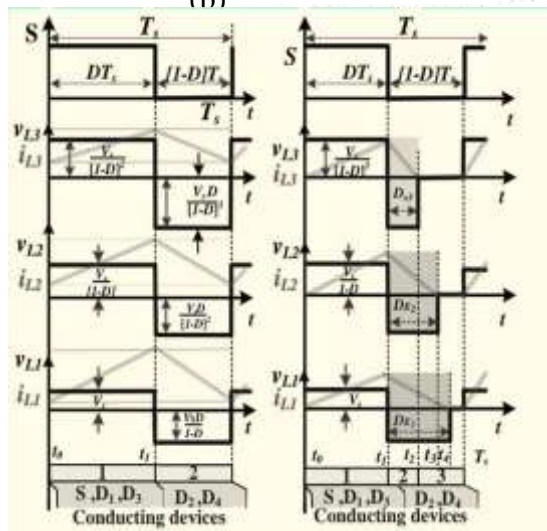


Fig 3. Operating waveforms of cubic gain converter.

(a) CCM (b) DCM Cubic gain converter.

(a) mode 1 of CCM, (b) mode 2 of

CCM and (c) DCM associated with the switch S , PSW, S is the switching loss of single semiconductor switch as given in Table II. As per the proposed structure, the capacitors help to store energy in the inductors with high voltage, and this inductor alone pushes the stored energy into the load. Whereas the involvement of the capacitors in the discharge path affects the output voltage because of the parasitic element of the capacitors. The converter reported in DC-voltage gain comparison of cubic converter.

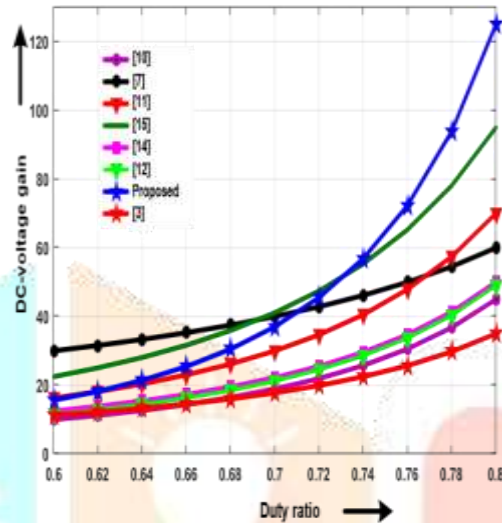
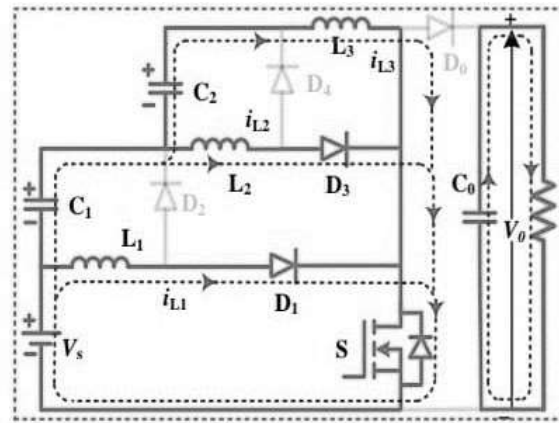


Fig. 5 Boundary between DCM and CCM

A.CCM operation

The cubic gain converter has two modes in the CCM. The circuit representation and analytical waveforms of the converter is shown respectively. Mode 1: As displayed in Fig. 3(a), the gate pulse of S is turned high at an instant t_0 . Hence, the diode D_0 becomes reverse-biased, and the inductors start charging. The inductor, L_1 charges with the voltage of V_s , and L_2 charges with a voltage of $V_s + VC_1$. Further, the inductor L_3 charges with the voltage of $V_s + VC_1 + VC_2$ as shown in Fig : (a) Continuous Conduction mode. Mode 2: As displayed in the gate pulse of S is turned low, hence the stored energy of the inductors are freewheeled along with the input voltage V_s into the load. Together, the inductor L_1 pushes its stored energy to C_1 , and L_2 charges C_2 . The analytical waveforms of the inductors are depicted. The expression of voltage across the passive elements of the cubic converter are given. The voltage gain of the cubic gain converter is derived from mode 1 and 2. As per the principle of volt-sec, the average voltage across L_3 is zero for a period T_s . The DC-voltage-gain SCCM1 of the cubic gain converter is expressed in (3). The maximum ideal DC-voltage gain achieved from (3) for the duty ratio, D of 0.8 is 125. Based on the structure of the LC2D network-based converter with stage n , the DC-voltage gain is derived in (4). The converter delivers the more output voltage at the resistive load of 800Ω , and lower output voltage at the resistive load of 200Ω . The output voltage computed using (10) is verified experimentally for the various values of the duty ratio for case I) $V_s = 10 \text{ V}$ and case ii) $V_s = 5 \text{ V}$. Fig. 9(b) confirms that the experimental values closely match with the values calculated using (10). Fig. 9(c) shows the efficiency profiles for case a) $V_s = 10 \text{ V}$ and $V_o = 100 \text{ V}$ and case b) $V_s = 5 \text{ V}$ and $V_o = 50 \text{ V}$ with respect to the output. The cubic gain converter has two modes in the CCM. The circuit representation and analytical waveforms of the converter is shown respectively power. The efficiency is found to be high compared.

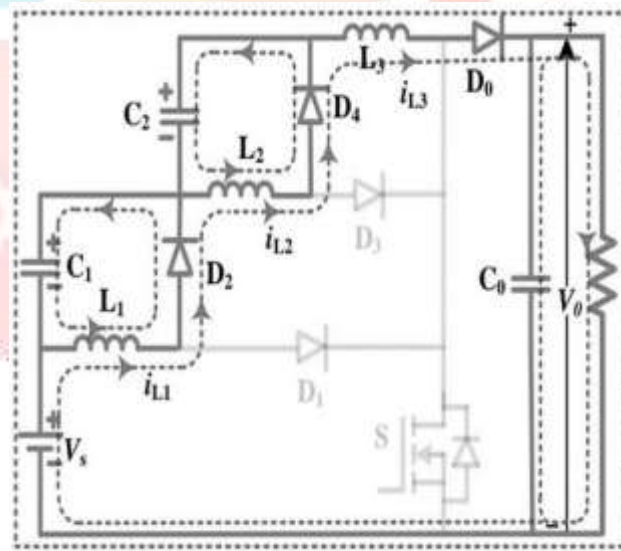


(a)

CCM operation

B. DCM Operation

The cubic gain converter contains three modes in the DCM operation. The first two modes of the cubic gain converter are same like the mode 1 and mode 2 (CCM) operations. But, the current of the inductors start rising from zero. In mode 1, the current of the inductors reach the finite values respectively, i_{Lp1} , i_{Lp2} and i_{Lp3} . In mode 2, the switch is turned off. Hence, the current of L_1 , L_2 and L_3 start falling down towards zero as displayed. After an interval of $T_s D_x^3$, i_{L3} reaches to zero state, and the current of remaining two inductors continue to fall down further. The status of the current of the inductors at the mode 2 is presented in Fig 3(b). In mode 3, i_{L3} reaches the zero state at the instant t_2 , and i_{L3} continues its zero state till the next cycle starts. (c) shows the circuit of LC2D network-based converter during mode 3 operation of the cubic gain converter is written as given.



(b)

DCM Operation

(a) Output voltage with parasitic elements (b) $P_o V_s \% \eta$ (c) $D V_s V_o$ from the above 0.75 duty ratio. The converter delivers the more output voltage at the resistive load of 800Ω , and lower output voltage at the resistive load of 200Ω . The output voltage computed using (10) is verified experimentally for the various values of the duty ratio for case i) $V_s = 10V$ and case ii) $V_s = 5 V$. confirms that the experimental values closely match with the values calculated using (10). Fig. 9(c) shows the efficiency profiles for case a) $V_s = 10 V$ and $V_o = 100 V$ and case b) $V_s = 5 V$ and $V_o = 50 V$ with respect to the output power. The efficiency of case (a) is found to be high compared to case (b). The first two modes of the cubic gain converter are same like the mode 1 and mode 2 (CCM) operations. the passive elements of the cubic converter are given. The voltage gain of the cubic gain converter is derived from mode 1 and 2.

The DC-voltage gain obtained during CCM operation of the cubic gain converter and other recent reported converters is displayed. The voltage gain of the cubic gain converter is derived from mode 1 and 2. The DC-voltage gain obtained during CCM operation of the cubic gain converter and other recent reported converters is displayed. The cubic converter with minimum components attains an ultra-DC-voltage gain compared to the existing converters.

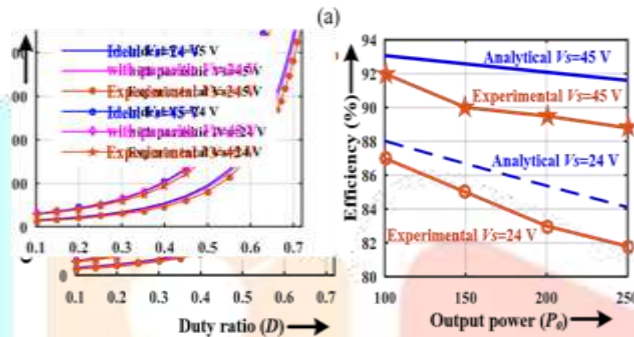
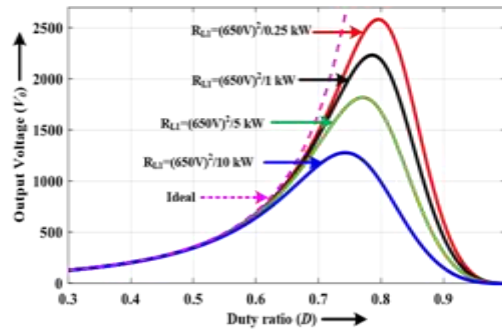


Fig. 6 (a) Output voltage with parasitic elements
(b) P_0 Vs $\% \eta$ (c) D Vs V_0 from the above 0.75 duty ratio.

The converter reported in has only eleven components. But, it has limited voltage gain and two semiconductor switches. The expression of voltage across the passive elements of the cubic converter are given. The voltage gain of the cubic gain converter is derived from mode 1 and 2. Each stage provides a small increase in voltage, and the total output voltage is the sum of the output voltages of all the stages. The current of the inductors starts rising from zero of the output voltages of all the stages. The DC-voltage gain obtained during CCM operation of the cubic gain converter and other recent reported converters is displayed. The cubic converter with minimum components attains an ultra-DC-voltage gain compared to the existing converters. The converter reported in the converter reported in also has slightly better gain when the duty ratio less than 71%, but the parasitic elements present in the active switched capacitor network leads a significant drop in the voltage gain practically. Moreover, the converter contains thirty-two components including four switches.

6. EXPERIMENT RESULTS AND DISCUSSION

A 250 W 50 kHz prototype is made to confirm the operation of the cubic gain converter experimentally. To observe the experimental waveforms of the cubic gain converter, 45 V input voltage and 0.632 duty ratio are considered to attain 800 V output voltage. Si C-based power MOSFET and power diodes are chosen to fabricate the cubic gain converter. The part number of each component and the designed capacitors and inductors are given, conveys that the inductor L_1 charges from the source voltage, V_s for duty ratio of D , and discharges to the capacitor C_1 with the voltage of V_{C1} . The voltage across the inductor V_{L3} with the voltage V_0 of the cubic gain converter are recorded, and the recorded waveforms are displayed in illustrates that L_2 charges with the voltage of $V_s + V_{C1}$ for duty ratio D , and L_2 discharges the stored energy to C_2 with the voltage of V_{C2} for $(1-D) T$. In literature, several DC-DC converters are reported using switched capacitor, cascaded boost, voltage multipliers and switched inductor concepts.



Fig 7 Snap Shot of KIT

The step-up n -stage DC-DC converters are reported. The converter with each additional stage leads to a significant output voltage improvement, but each stage requires an additional switch with more number of reactive components. The converter uses ten components with a single switch and has a gain of $(2-D)/(1-D)^2$. To improve the voltage gain using a single switch, a voltage double cell-based modified quadratic boost converter is reported. When the converter is coupled with voltage double, the total components increases. But, the voltage gain is not increased significantly. By using multiple stages of the active LC2D network, the converter can achieve higher voltage conversion ratios while maintaining a small footprint and low component count. The use of active components also allows for greater control over the voltage and current output of the converter, making it well-suited for a wide range of applications such as power supplies for electronics, motor drives, and renewable energy systems. Overall, the objective of a multistage DC to DC converter.

7. CONCLUSION

In this paper, the structure of an active LC2D network based ultra-gain multi-stage DC-DC converter is presented. Operation of the LC2D network-based converter with a single stage called as a cubic gain converter is analyzed and boundary condition between DCM and CCM is derived. The cubic converter is designed for $V_o = 100$ V and $V_s = 10$ V with 250 W, 50 kHz. In the proposed cubic converter, the Si based semiconductor switches are selected to achieve better performance. With the help of the Si devices, the cubic gain converter achieves the analytical efficiency of 91.6% at 250 W output power. The performance comparison of the cubic converter demonstrations that the proposed cubic converter achieves 100 V output voltage at lower value of the duty ratio compared to other converters. The operation of the cubic gain converter is also confirmed using a hardware prototype in the laboratory environment. The ultra-DC-voltage gain produced by the proposed converter using less components attracts the potential application of the converter in uninterruptible power supply, stand-alone solar photovoltaic, fuel cell, high-density discharge lamps used in automobiles, X-ray machines etc.

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