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High Voltage CUK Based DC-AC Converter for Renewable Energy Resources Using VLSI Module

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Abstract: In this thesis, an improved structure of modified CUK converter (MCCVLSI) is presented using Voltage Lift Switched Inductor (VLSI) module. The proposed converter provides a negative high DC voltage which is then converted into AC supply using inverter domestic applications. A three new modified CUK converter structures are derived with the help of VLSI module as; MCCVLSI-XLL, and MCCVLSI-LLZ. The complete mathematical analysis is provided to calculated voltage conversion ratio. Moreover, the proposed structures are compared with each other's in terms of voltage conversion ratio and number of components. The working mode of MCCVLSI-XLL is explained in details. The qualities of the presented structures are reviewed in details. The simulation results are provided and the obtained results show a good agreement with theoretical analysis. The proposed scheme is simple and easy to implement.

Keywords: Modified Cuk Converter; Voltage Lift Technique; Negative Output; High Voltage; DC-AC; Renewable Energy

I. INTRODUCTION

In recent years, many power electronics researchers are engaged to find a new converter structure to utilize renewable energy sources efficiently. Due to free of cost, availability, plentiful in nature, pollution free and advancement in technologies, many researcher claims that photovoltaic is one of the leading energy sector . The output terminal voltage of photovoltaic cell is low and thus series-parallel arrangement of photovoltaic cells is used to achieve required high voltage and high current. But series connection of photovoltaic cells is not suitable technique to achieve high voltage due to large number of photovoltaic cell requirement. A converter is necessary, which step-up the output voltage according to requirement. As a result, DC to DC power converter plays the important block in photovoltaic system. Based on the input and output terminals, DC to DC power converters are categorized into two types; isolated and non-isolated. In isolated structure of DC-DC converter, transformer and coupled inductors are utilizing to isolate the input and output terminal. These converters provides a higher voltage at the output port by utilizing proper transformer windings turns ratio and coupling ratio of coupled inductors . However, size, cost and bulkiness of the converter is increases due to utilization of transformer and coupled inductor. Furthermore, the efficiency of converter is reduced due to Electromagnetic Interference (EMI) and leakage inductance of transformer.

Recently several non-isolated converters structures are proposed with high conversion ratio, higher efficiency and without using transformer and coupled inductor. Thus, size and bulkiness of power converter is reduced. Traditional buck and boost converters are the two types of DC to DC converter which provides positive output voltage and designed by using single inductor, switch and diode arrangement. To combine the feature of buck and boost converter, a new arrangement is designed called buck-boost converter. Buck- boost converter provides a negative output voltage with step- down and step-up capability. The discontinuous input current is the main drawback of buck-boost converter which proves the less utilization of input source. To overcome the downside of buck-boost converter, derived converters (CUK, SEPIC and Zeta) are proposed by hybridization of traditional buck, boost and buck-boost converter. CUK converter provides a negative output voltage with continuous output and input current. But the voltage conversion ratio of these converters is low; due to this reason modification in CUK converter is required to step-up the voltage with large conversion ratio. Quadratic and cascaded boost converter is employed to achieve high voltage but, large number of inductor and synchronization of several switches is main drawback of these converters.

Recently, multilevel DC to DC converters are proposed by using Cockcroft Walton (CW) voltage multiplier to overcome the drawback of cascaded and quadratic converter. In below reference paper, inverting Nx converter is proposed which provides N times negative voltage compared to traditional boost converter. In, 2Nx converter is presented which provides a double negative output voltage compared to Nx converter. In below reference paper, 4Nx converter is proposed which provides a double output voltage compared to 2Nx DC-DC converter. But large number of capacitor and diodes is the main drawback of these converters'-Y DC to DC converter family is proposed to remove the drawbacks of above discussed converter. In below reference paper, new

structure of CUK converter (MCC) is presented by combining the features of boost and CUK converter. This CUK converter structure provides an inverting voltage with high voltage conversion ratio compared to traditional DC-DC converter. In this thesis, new two converter structures are derived to enhance the voltage generated from renewable energy source with high value. The presented converter provides a higher voltage conversion ratio compared to MCC.

II. MODIFIED CUK CONVERTER STRUCTURES WITH VLSI MODULE (MCCVLSI)

The modified CUK converter is shown in Fig. 1. To achieve high voltage conversion ratio, a VLSI module is adopted in MCC. The proposed work is extension of [19]. The VLSI module is placed on position of inductor L_X called as Modified CUK Converter with XLL configurations (MCCVLSIXLL). Similarly, and in (MCCVLSI-LLZ), VLSI module is replaced on position of inductor L_Z as shown in Fig. 2 (a)-(c). The VLSI module consists of one capacitor, two diodes and two inductors.

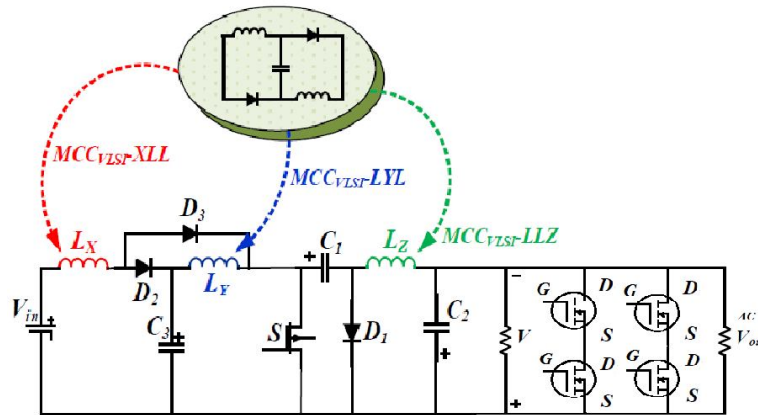
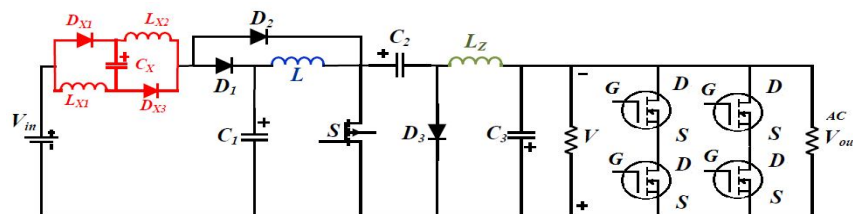


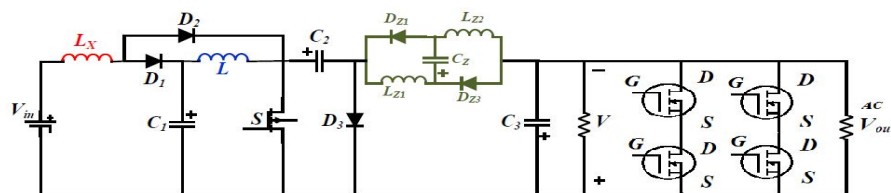
Fig. 1 Modified Cuk Converter with VLSI module (MCCVLSI)

TABLE I. PROPOSED CONVERTER

| Modified CUK Converter with VLSI Module | | | | | | |
|---|-----|-----------|---|---|--------------------------|--------------|
| Modified Converter | CUK | Component | | | Voltage Conversion Ratio | |
| | | L | C | D | V_{c1}/V_{in} | V_o/V_{in} |
| VLSI Module | XLL | 4 | 4 | 5 | $2/(1-D)$ | $2D/(1-D)^2$ |
| | LLZ | 4 | 4 | 5 | $1/(1-D)$ | $D/(1-D)^2$ |



(a)



(b)

Fig. 2 Different configurations of MCC converter with VLSI module (a) MCCVLSI-XLL and (b)MCCVLSI-LLZ

A. Operation of MCCVLSI Structure

The operating mode of three proposed converter structures is similar to each other. To understand the working of the proposed converter structures, the operation of MCCVLSI-XLL is explained in detail. In conducting state of switch S , two inductor $LX1$ and $LX2$ are charged from input supply V_{in} . The inductor LY and capacitor CX are charged from capacitor $C1$ and input supply V_{in} respectively. Inductor LZ is charged from voltage algebraic addition of capacitor $C2$ and $C3$. The equivalent circuit with characteristic waveforms for the ON state is shown in Fig. 3(a). In non-conducting state of switch S , capacitor $C1$ is charge from combination of input supply V_{in} , two inductor $LX1$, $LX2$ and capacitor CX . Capacitor $C2$ and $C3$ are charged from inductor LY and LZ respectively. The equivalent circuit with characteristic waveforms for the OFF state is shown in Fig. 3(b).

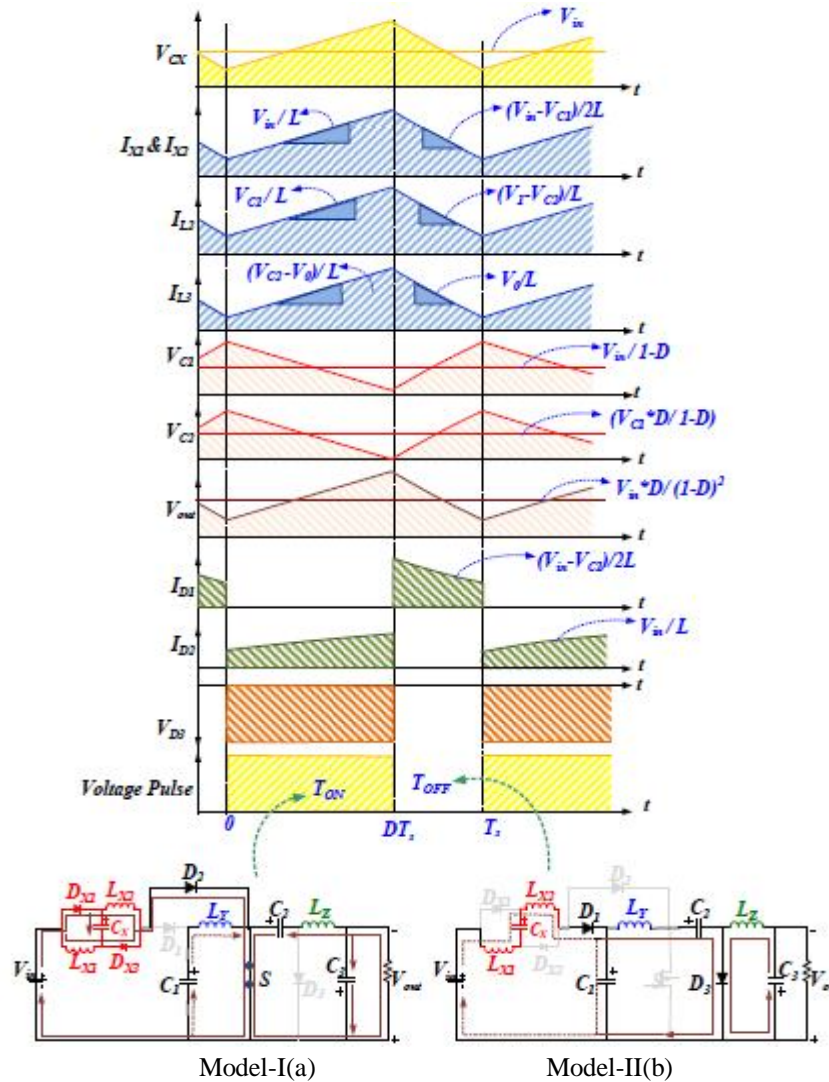


Fig. 3 MCCVLSI-XLL working mode (a) charging and (b) discharging

III. MATHEMATICAL ANALYSIS OF MCCVLSI STRUCTURES

The mathematical analysis of three proposed converter structures is done according to the voltage second balance method. The internal voltage drop across the circuit components is neglected or consider as zero. To analyze the circuits, two inductor of VLSI module should be equal in rating ($LX1=LX2=LX$).

A. MCCVLSI-LLL

The voltage conversion ratio of configuration is given in below reference paper.

$$V_0 = \frac{D}{(1-D)^2} V_{IN}$$

B. MCCVLSI-XLL Configuration

The ON state equations of three inductors are

$$V_{LX1} = V_{LX2} = V_{CX} = V_{in}$$

$$V_{LY} = V_{C1}$$

$$V_{LZ} = V_{C2} - V_0$$

The OFF state equations of three inductors are

$$V_{LX} = \frac{V_{in} - V_{C1} + V_{CX}}{2}$$

$$V_{LY} = V_{C1} - V_{C2}$$

$$V_{LZ} = -V_0$$

According to volt second balance method for inductor *LX*, *LY* and *LZ* are

$$V_{C1} = \left(\frac{2}{1-D} \right) V_{in}$$

$$V_{C2} = \frac{V_{C1}}{1-D}$$

$$V_0 = DV_{C2}$$

Using the above equation,

$$V_0 = \frac{2D}{(1-D)^2} V_{in}$$

C. MCCVLSI-LYL Configuration

The ON state equations of three inductors are

$$V_{LX} = V_{in}$$

$$V_{LY1} = V_{LY2} = V_{CY} = V_{C1} \quad V_{LZ} = V_{C2} -$$

$$V_0$$

The OFF state equations of three inductors are

$$V_{LX} = V_{in} - V_{C1}$$

$$V_{LY} = \frac{V_{C1} - V_{C2} + V_{CY}}{2} \quad V_{LZ} = -V_0$$

According to volt second balance method for inductor *LX*, *LY* and *LZ* are

$$V_{C1} = \left(\frac{V_{in}}{1-D} \right)$$

$$V_{C2} = \left(\frac{2}{1-D} \right) V_{C1} V_0 =$$

$$DV_{C2}$$

Using above three equations,

$$V_0 = \frac{2D}{(1-D)^2} V_{in}$$

D. MCCVLSI-LLZ Configuration

The ON state equations of three inductors are

$$V_{LX} = V_{in}$$

$$V_{LY} = V_{C1}$$

$$V_{LZ1} = V_{LZ2} = V_{CZ} = V_{C2} - V_0$$

The OFF state equations of three inductors are

$$V_{LX} = V_{in} - V_{C1} \quad V_{LY} =$$

$$V_{C1} - V_{C2} \quad V_{LZ} = \frac{V_{CZ} + V_0}{2}$$

According to voltage second balance method for inductor *LX*, *LY* and *LZ* are

$$V_{C1} = \left(\frac{1}{1-D}\right) V_{in}$$

$$V_{C2} = \left(\frac{1}{1-D}\right) V_{C1}$$

$$V_0 = \left(\frac{1+D}{2}\right) V_{C2}$$

Using the above three equations we get,

$$V_0 = \left(\frac{1+D}{2(1-D)^2}\right) V_{in}$$

IV. SIMULATION RESULT AND DISCUSSION

The proposed converter structures are simulated in Matlab R2014a with resistive load and at the power of 250W. All three configurations are simulated with 70 % duty ratio at 50 kHz switching frequency. The proposed converters drive on regulated 10V DC supply with time constant of 0.04 as shown in Fig. 4.

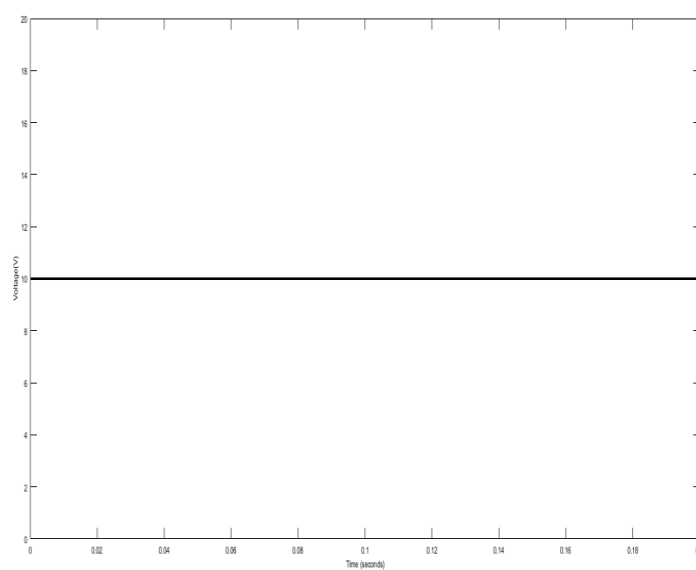
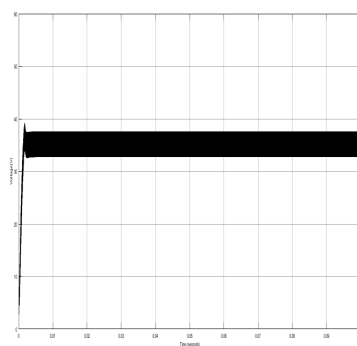
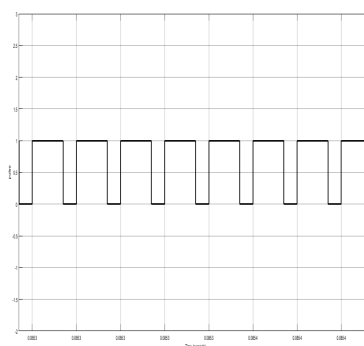


Fig. 4 Regulated input supply

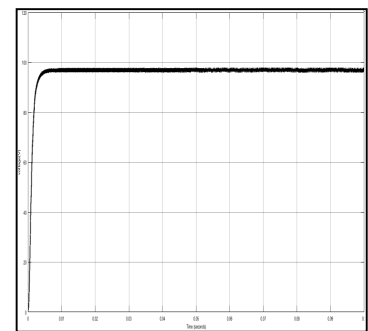
In MCCVLSI-XLL structures, capacitor $C1$ is charge up to 35.5V as shown in Fig. 5(a). The pulse output as shown in Fig. 5(b). The dc output voltage is 97.5V as shown in Fig. 5(c).The dc output current is 0.48A as shown in Fig. 5(e).The ac output voltage is 97.4V as shown in Fig. 5(d).The ac output current is 0.48A as shown in Fig. 5(e).



(a) Capacitor output voltage



(b) Pulse Output



(c) Dc Output Voltage

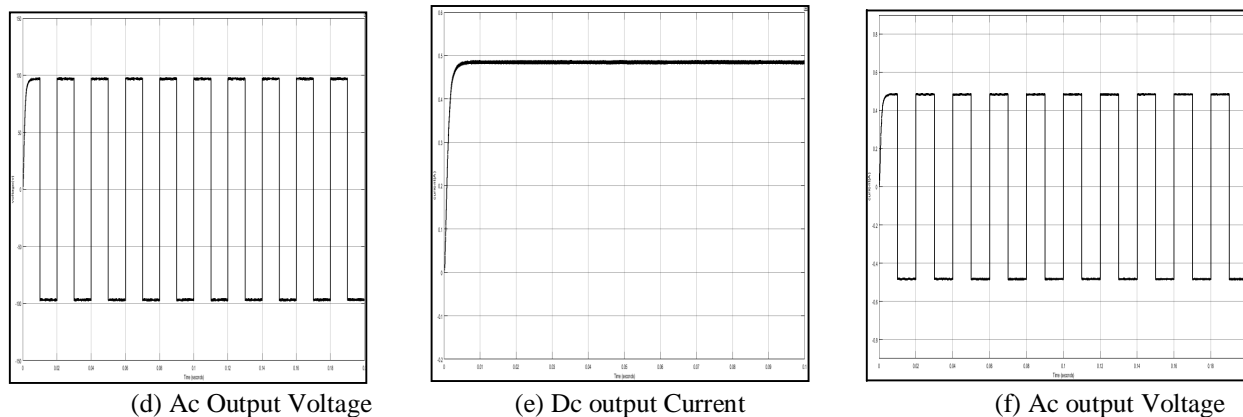


Fig. 5 Simulation result of MCC-XLL structure converter outputs

In MCCVLSI-LLZ structures, capacitor $C1$ is charge up to 29.7V as shown in Fig. 6(a). The pulse output as shown in Fig. 6(b). The dc output voltage is 76.3V as shown in Fig. 6(c).The dc output current is 0.38A as shown in Fig. 6(e).The ac output voltage is 76.3V as shown in Fig. 6(d).The ac output current is 0.38A as shown in Fig. 6(f).

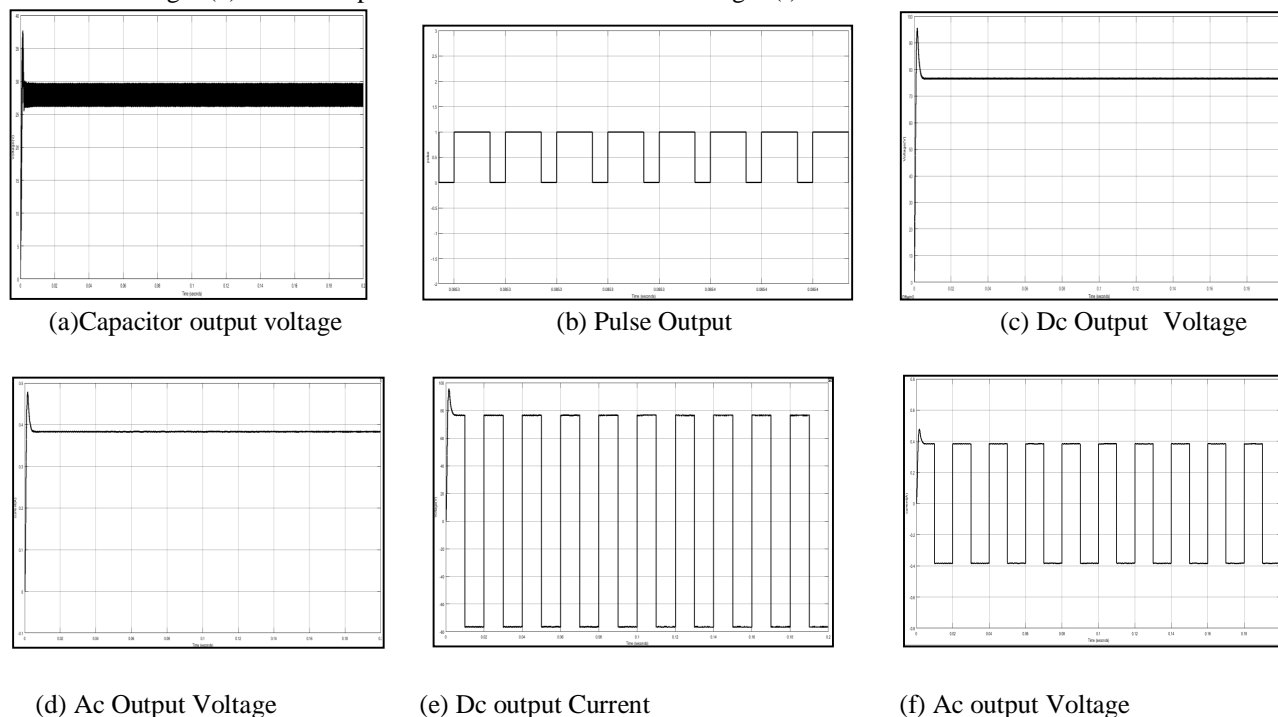


Fig. 6 Simulation result of MCC-LLZ structure converter outputs

V. CONCLUSION

Three new structures of modified CUK converter are proposed by using voltage lift switched inductor module to attain high conversion ratio. The proposed converter structures are highly suitable for renewable energy application. The derivation of voltage conversion ratio of all the proposed structures is presented in detail. The proposed converters provide a high negative voltage with continuous input current by using single switch. MCCVLSI-XLL converter structures provide 97.5V at the output terminal when 10V is supplied to converter at 70% duty cycle. MCCVLSI-LLZ converter provides a 76.3V when 10V is supplied to converter at 70% duty cycle. Moreover, all the proposed converter structures are compared to each other in terms of number of components and voltage conversion ratio. MCCVLSI-XLL and MCCVLSI-LYL converter structure provides a higher voltage conversion ratio compared to MCCVLSI-LLZ. The simulation results are given and the obtained results always showed the good agreement with theoretical analysis.

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