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A New Voltage Doubler Based DC-DC 2LCm-Y Power Converter Topologies for High-Voltage/Low-Current Renewable Energy Applications

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Abstract—In this treatise, a new voltage doubler based DC-DC 2LCm-Y power converter topologies are uttered for the high-voltage/low-current renewable energy applications. L-Y, 2L-Y, 2L-C-Y and 2LCm-Y power converter categories are recently proposed in the existing X-Y converter family. To provide an effective and viable solution to renewable energy system; four new voltage doubler based converters (2LCm-LVD, 2LCm-2LVD, 2LCm-2LCVD and 2LCm-2LCmVD converters) are proposed in 2LCm-Y converter category. The proposed converters are well suited for renewable energy applications which required high output voltage power converter such as a Photovoltaic Multilevel DC-AC converter system, renewable High Voltage Direct Current (HVDC) applications, Hybrid Electric Vehicles (HEV) etc. The perceptible characteristics of proposed 2LCm-Y power converter topologies are presented in detail. Working of 2LCm-Y proposed converters with the derivation of \( \frac{V_o}{V_{in}} \) is discussed in detail. Proposed converter topologies are simulated in the Numerical Computing Matrix Laboratory 9.0 (R2016a) software. The simulation results are discussed in detail and it constantly showed the high-quality agreement with hypothetical analysis and validates the functionality and characteristics of the proposed 2LCm-Y converter topologies of X-Y converter family.

Keywords—X-Y Converter Family; DC-DC Converter; Voltage Doubler; High-Voltage; Low-Current; Renewable Energy.

I. INTRODUCTION

Presently, looking forward for renewable energy it has become more popular day by day and it can be considered as prominent solution to fulfill energy demand of community. The renewable sources are reliable and plentiful in nature and can be harvested and consequently not defenseless against any sort of dangers. Thus, energy organization concentrates on unlimited of renewable power source assets for power era [1]-[2]. Massive energy era through a course of action of various little voltage producing units is getting mainstream like series and parallel association of solar cell or panels. Consequently, series and parallel association of solar module is not an appropriate way out for accomplish high voltage and high current because of necessity of extensive area and high cost is required. The fine case of such electric power framework is a photovoltaic power plant which contains various photovoltaic oriented boards/modules for generation of energy. Produced voltage at each photovoltaic based boards/module is inadequate for feeding the electric energy directly to inverter for handy application or to insert it into the electric network or grid. Therefore, series connection of solar panels/module is not a suitable and practicable solution to achieve high voltage due to requirement of large area and high cost is needed [3]. Thus, DC-DC converter is requisite to lift the voltage with adequate high conversion ratio before feeding it into inverter. Along these lines, DC-DC converter is the most imperative constituent in the renewable power conversion stage. Conventional DC-DC converter because of various constrains is not a good technical solution to attain high voltage conversion ratio. These constrains includes excess voltage stress across switch, high rating of components and capability of conventional boost converter starts deteriorating with increase in duty cycle [4]-[5]. Major real restriction of traditional Buck-Boost Converter (BBC) is discontinuous input current which shows the negligible use of power source. Depends on the bountiful novel idea numerous isolated transformer and coupled inductor based power converters are proposed in the literature to achieve high \( \frac{V_o}{V_{in}} \) without using high duty cycle for the power switch [5]-[7]. However, magnitude and leakage reactance of converter is increased because of occupancy of transformer and coupled inductor. The converter usefulness, functionality and performance additionally degrade because of making of Electro-Magnetic-Interference (EMI) by such magnetic parts. The primary drawbacks of isolated converter topologies are extensive in size, weight and losses of power transformer. Size and leakage reactance of converter is increases due to tenancy of transformer and coupled inductor. To defeat the disadvantages of isolated DC-DC converter numerous Cascaded Boost Converters (CBCs) are proposed in literature for renewable energy applications [8]-[9]. The control circuit of CBCs is most complex part for real time application due to several controlled switches and reactive components. The major drawbacks of cascaded converter is high ripple current, several controlled switches, high energy loss to attain a high voltage gain and low efficiency. Quadratic Boost Converter (QBC) is proposed by utilizing less number of power controlled devices to defeat the disadvantage of CBC. But in QBC, the voltage appeared in OFF state across the power control device is
Fig. 1. X-Y converter family generalized structure and hierarchy of L-Y, 2L-Y, 2LC-Y, 2LCm-Y, 2LCm-L, 2LCm-2L, 2LCm-2LC and 2LCm-2LCm power converters.

- Nowadays, DC-DC Multilevel Boost Converters (MBC) is addressed in literature to overcome the drawback of above discussed converter using diode and capacitor networks [10]-[14]. In [11], inverted high voltage with conversion ratio 20 and 40 at duty cycle 75% is accomplished using Nx and 2Nx MBC. Reduce current/voltage ripple with high non-inverting voltage is attained by using Nx, 2Nx IMBC [12]-[13]. The multilevel DC-DC converter topology discussed above gives a suitable way to accomplish high voltage however, required substantial number of diode and capacitor. In [14], X-Y converter family is proposed to attain high voltage conversion ratio by utilizing least number of components. In view of the arrangement of inductor, total sixteen converter topologies are proposed in X-Y family. In [15], to achieve high conversion ratio (Vo/Vin) novel four L-Y converter topologies using voltage doubler (L-LVD, L-2LVD, L-2LCVD and L-2LC) and modified-Voltage-Lift-Switched-Inductor (mVLSI) are articulated.

A new voltage doubler based DC-DC 2LCm-Y power converter topologies (2LCm-LVD, 2LCm-2LVD, 2LCm-2LCVD and 2LCm-2LCmVD converters) are proposed in this treatise to provide an effective and viable solution to renewable energy system such as a Photovoltaic Multilevel DC-AC converter system, renewable High Voltage Direct Current (HVDC) applications, Hybrid Electric Vehicles (HEV) etc. The perceivable characteristics of proposed 2LCm-Y power converter topologies are i) Single input source ii) Single controlled semiconductor device iii) High inverting Vo/Vin at average duty cycle iv) High-voltage and low-current at the output side of converter v) Minimum internal resistance vi) Transformer-less and coupled inductor-less power converter topologies. The concept of proposed converter is verified through Numerical Computing Matrix Laboratory 9.0 (R2016a) software.

II. REVIEW OF EXISTING 2LCm-Y DC-DC CONVERTERS: A MEMBERS OF X-Y CONVERTER FAMILY

Fig. 1 depicts the X-Y power converter family generalized structure and hierarchy of L-Y, 2L-Y, 2LC-Y, 2LCm-Y, 2LCm-L, 2LCm-2L, 2LCm-2LC and 2LCm-2LCm converters. In X-Y family two separate DC-DC converters named as X-converter and Y-converter are associated in particular way as depicted in Fig. 1. The contribution for X-converter is directly fed from the input source voltage (Vin) and for Y-converter contribution voltage is addition of input source voltage (Vin) and output of X-converter. The total output voltage of X-Y converter is easily measured by equation (1) in which VX and VY are the output of converter X and Y. Gx and Gy are the voltage conversion ratio of converter X and Y.

\[ V_o = - (V_x + V_y) \]
\[ V_x = G_x \times V_{in} \]
\[ V_y = G_y \times V_{in} \]

(1)

The various combination of Single Inductor (L), Switch-Inductor (SI or 2L), Voltage-Lift-Switched-Inductor (VLSI or 2LC) and modified-Voltage-Lift-Switched-Inductor (mVLSI or 2LCm) network are employed to designed X-Y converter category of X-Y converter family. Depending on X converter entire X-Y converter family (sixteen topologies) are categorized into four sub categories: L-Y, 2L-Y, 2LC-Y and 2LCm-Y converter. The entire categorization is shown in Fig. 1. 2LCm-L, 2LCm-2L, 2LCm-2LC and 2LCm-2LCm power converter topologies are existing four member of 2LCm-Y power converter category of X-Y converter family. The power circuits of existing 2LCm-Y converter are shown in Fig. 2(a)-(d). X-converter is 2LCm (modified Voltage-Lift-Switched-Inductor BBC or mVLSI-BBC) in 2LCm-Y power converter category of X-Y converter family. The supply for 2LCm-Y power converter is directly fed from the input source voltage (Vin) and for Y converter supply voltage is addition of input source voltage (Vin) and output voltage of 2LCm converter (X converter, \( V_{X2LCm} \)). As a result, the output voltage of 2LCm-Y power converter is inverting summation of output voltage of 2LCm converter (X converter) and Y converter as shown in equation (2).

\[ V_o = V_{2LCm-Y} = -(V_{X2LCm} + V_Y) \]
\[ V_o = V_{2LCm-Y} = -(G_x V_{X2LCm} + G_y V_{in}) \text{ or } \]
\[ V_o = V_{2LCm-Y} = -(G_x + G_y) V_{in} \]

(2)

III. VOLTAGE DOUBLER BASED 2LCm-Y DC-DC CONVERTER TOPOLOGIES (PROPOSED TOPOLOGIES)

Four voltage doubler based 2LCm-Y power converter topologies in 2LCm-Y category of X-Y family are proposed to accomplish higher (Vo/Vin) voltage conversion ratio compared to conventional 2LCm-Y converter configurations. Y-converter of conventional 2LCm-Y converter category is modified by employing voltage doubler stage to design proposed converter topologies. Four proposed voltage doubler based power converter topologies are i) 2LCm-LVD power converter (where Y-converter is LVD converter which combines the features of L converter (conventional Buck Boost) and voltage doubler (VD) and X converter is 2LCm converter) ii) 2LCm-2LVD (where Y-converter is 2LVD converter which combines the features of 2L converter (Switched Inductor Buck Boost) and voltage doubler (VD) and X converter is 2LCm converter)
iii) 2LCm-2LCVD (where Y-converter is 2LCVD converter which combines the features of 2LC converter (Voltage Lift Switched Inductor Buck Boost) and voltage doubler (VD) and X converter is 2LCm converter) iv) 2LCm-2LCmVD (where Y-converter is 2LCmVD converter which combines the features of 2LCm converter (modified Voltage Lift Switched Inductor Buck Boost) and voltage doubler (VD) and X converter is 2LCm converter). The main power circuit of proposed four voltage doubler based converters is depicted in Fig. 3(a)-(d). The detailed information of requirement of number component to design 2LCm-Y converter is tabulated in table-I. The detail information of requirement of number component to design 2LCm converter is tabulated in table-I. The number of component needed to design 2LCmVD converter which is Y-converter of 2LCm-2LCmVD power converter is four capacitors and four inductors (charging path is \(S-DX1-DX3-LX1-Vn\)) whereas inductor \(LX2\) is charged by input voltage \(V_n\) (charging path is \(S-LX1-DY4-LX2-Vn\)). The slope of current flowing through \(LX1\) and \(LX2\) inductor is positive at the same time. Hence inductor \(LX1\) and \(LX2\) are magnetized. Thus, \(LX1\) inductor is magnetized by capacitor \(C_T\) voltage and input supply \(V_n\) by way of uncontrolled devices \(DX1\) and controlled device \(S\) (charging path is \(V_n-S-DX1-DX3-LX1-Vn\)). By way of uncontrolled devices \(DX1\), \(DX3\), \(DX2\) and controlled device \(S\); capacitor \(C_T\) is get charged by input voltage \(V_n\) (charging path is \(V_n-S-DX1-DX3-C_T-DX2-Vn\)). The slope of current flowing through \(LX1\) and \(LX2\) inductor is positive at the same time. Hence inductor \(LX1\) and \(LX2\) are magnetized. Thus, \(LX1\) inductor is magnetized by capacitor \(C_T\) voltage and input supply \(V_n\) by way of uncontrolled devices \(DX1\) and controlled device \(S\) (charging path is \(V_n-S-DX1-DX3-LX1-Vn\)). By way of uncontrolled devices \(DX1\), \(DX2\) and controlled device \(S\); capacitor \(C_T\) is get charged by capacitor \(C_T\) voltage and input voltage \(V_n\) (charging path is \(V_n-S-DX1-DX3-C_T-Vn\)). By way of uncontrolled devices \(DX1\) and controlled device \(S\), capacitor \(C_T\) is get charged by input voltage \(V_n\), capacitor \(C_T\) and \(C_T\) voltage (charging path is \(V_n-S-C_T-DX1-C_T-Vn\)). Thus, inverting addition of capacitor \(C_T\) and \(C_T\) (\(C_T=C_T+C_T\)) voltages is output voltage of 2LCm-2LCmVD power converter.

Main input supply is isolated from the power circuit of 2LCm converter when semiconductor control device \(S\) is in OFF-state (open circuit). The slope of current flowing through inductor \(LX1\), \(LX2\) is negative. Hence \(LX1\), \(LX2\) inductors demagnetized in series with capacitor \(C_T\) by way of uncontrolled device \(D_{X1}\) to transfer the stored energy to capacitor \(C_T\) (charging path is \(LX1-C_T-LX2-DX1\)). The slope of current flowing through inductor \(LX1\), \(LX2\) is negative. Hence, at the same time \(LX1\), \(LX2\) inductor demagnetized in series with capacitor \(C_T\) by way of uncontrolled device \(D_{X1}\) to transfer the stored energy to charge the capacitor \(C_T\) (charging path is \(LX1-C_T-LX2-DX1\)). \(C_T\) capacitor transferred its energy to charge \(C_T\) capacitor by way of uncontrolled device \(D_{X1}\). Thus, inverting addition of capacitor \(C_T\) and \(C_T\) (\(C_T=C_T+C_T\)) voltages is output voltage of 2LCm-2LCmVD power converter. Inductor current slope is analyzed for the 2LCm-2LCmVD power converter and the nature of inductor current is shown in Fig. 4. It is observed that that all the inductors available in proposed 2LCm-2LCmVD converter are magnetized when the semiconductor controlled device is in ON-state and demagnetized when semiconductor controlled device is in OFF-state.

IV. DERIVATION OF VOLTAGE CONVERSION RATIO FOR PROPOSED 2LCm-Y CONVERTER
Proposed voltage doubler based 2LCm-Y converter voltage conversion ratio is derived by considering following assumption i) Constant ripple free pure DC input supply (Vin) ii) Voltage Vd is the ON-state voltage drop of all semiconductor devices, hence if Vd = 0 all the semiconductor devices are ideal (100% efficient) iii) for simplicity assume drop at inductor due to internal resistance of inductor is Vd iv) assume very small ripple at capacitors. Consider K is the duty cycle.

A. Voltage Doubler Based 2LCm-LVD Converter

Fig. 3(a) depicts the power circuit of voltage doubler based 2LCm-LVD Converter.

\[ G_{\text{X2LCm-LVD}} = G_{\text{XY}} = \frac{V_o}{V_{\text{in}}} = \frac{V_{\text{Y1LVD}}}{V_{\text{in}}} = \frac{G_X}{G_Y} = \frac{G_{\text{X2LCm-LVD}}}{G_{\text{Y2LCm-LVD}}} \]  \hspace{1cm} (8)

B. Voltage Doubler Based 2LCm-2LVD Converter

Fig. 3(b) depicts the power circuit of voltage doubler based 2LCm-2LVD Converter.

\[ G_{\text{X2LCm-2LVD}} = G_{\text{XY}} = \frac{V_o}{V_{\text{in}}} = \frac{V_{\text{Y1-2LVD}}}{V_{\text{in}}} = \frac{G_X}{G_Y} = \frac{G_{\text{X2LCm-2LVD}}}{G_{\text{Y2LCm-2LVD}}} \]  \hspace{1cm} (14)

### TABLE I. NUMBER OF COMPONENTS DETAILS

<table>
<thead>
<tr>
<th>No. of Component</th>
<th>2LCm-L</th>
<th>2LCm-2L</th>
<th>2LCm-2LC</th>
<th>2LCm-2LCm</th>
<th>2LCm-LVD</th>
<th>2LCm-2LVD</th>
<th>2LCm-2LCVD</th>
<th>2LCm-2LCmVD</th>
</tr>
</thead>
<tbody>
<tr>
<td>switches</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>inductors</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>capacitors</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>diodes</td>
<td>5</td>
<td>8</td>
<td>9</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>10</td>
<td>11</td>
</tr>
</tbody>
</table>

Thus, overall voltage conversion ratio of 2LCm-LVD converter is \( G_{2LCm-LVD} \) or \( G_{\text{XY}} \) and provided in equation (8).

\[ G_{2LCm-2LVD} = G_{\text{XY}} = \frac{V_o}{V_{\text{in}}} = \frac{-G_{\text{X2LCm-2LVD}}}{G_{\text{Y2LCm-2LVD}}} = \frac{-G_X + G_Y}{G_{\text{XY}}} \]  \hspace{1cm} (14)
C. Voltage Doubler Based 2LCm-2LCVD Converter

Fig. 3(c) depicts the power circuit of voltage doubler based 2LCm-2LCVD converter. The voltage conversion ratio of the converter is given by:

\[ G_{2LCm-2LCVD} = G_X \]

\[ V_{CX} = \left( 1 + K \right) \left( \frac{7V_d}{V_{in}} + \frac{KV_d}{V_{in}} \right) \quad \text{(15)} \]

\[ V_{in} = \left( 1 - K \right) \left( 1 - K \right) \left( 1 - K \right) \left( 1 - K \right) \]

\[ G_Y = \frac{V_{CY1}}{V_{in}} = \left( 1 + K \right) \left( G_{2LCm-2LCmVD} \right) + 1 \quad \text{(16)} \]

\[ G_{2LCm-2LCVD} = \frac{V_{CY2}}{V_{in}} = \left( 1 + K \right) \left( G_{2LCm-2LCmVD} \right) + 1 \quad \text{(17)} \]

\[ P_{2LCm} = 1 + G_{2LCm-2LCVD} + G_{2LCm-2LCmVD} \]

\[ G_{2LCm-2LCVD} = G_Y = G_{1} + G_{2} \quad \text{(18)} \]

\[ G_{2LCm-2LCVD} = G_{2LCm-2LCmVD} = -G_X + G_Y \quad \text{(19)} \]

D. Voltage Doubler Based 2LCm-2LCmVD Converter

Fig. 3(d) depicts the power circuit of voltage doubler based 2LCm-2LCmVD converter. The voltage conversion ratio of the converter is given by:

\[ G_{2LCm-2LCmVD} = G_X \]

\[ V_{CX} = \left( 1 + K \right) \left( \frac{7V_d}{V_{in}} + \frac{KV_d}{V_{in}} \right) \quad \text{(20)} \]

\[ V_{in} = \left( 1 - K \right) \left( 1 - K \right) \left( 1 - K \right) \left( 1 - K \right) \]

\[ G_Y = \frac{V_{CY1}}{V_{in}} = \left( 1 + K \right) \left( G_{2LCm-2LCmVD} \right) + 1 \quad \text{(21)} \]

\[ G_{2LCm-2LCmVD} = \frac{V_{CY2}}{V_{in}} = \left( 1 + K \right) \left( G_{2LCm-2LCmVD} \right) + 1 \quad \text{(22)} \]

\[ P_{2LCm} = 1 + G_{2LCm-2LCmVD} + G_{2LCm-2LCmVD} \]

\[ G_{2LCm-2LCmVD} = G_Y = G_{1} + G_{2} \quad \text{(23)} \]

\[ G_{2LCm-2LCmVD} = G_{2LCm-2LCmVD} = -G_X + G_Y \quad \text{(24)} \]

Thus, overall gain of 2LCm-2LCmVD converter is given by:

\[ G_{2LCm-2LCmVD} = G_{2LCm-2LCmVD} + G_{2LCm-2LCmVD} = G_Y \]

\[ G_{2LCm-2LCmVD} = G_X = \frac{V_{2LCm}}{V_{in}} \quad \text{(25)} \]

The relation between voltage conversion ratio versus duty for proposed voltage doubler 2LCm-Y converters with considering maximum \( V_{d} = 1 \) is shown graphically in Fig. 5. It is investigated that all the slope of voltage conversion plot is very high after 75% duty cycle. Hence quasi linear region to operate 2LCm-Y converter is 0 to 75% duty cycle. The effect of internal resistance of proposed 2LCm-Y power converter topologies of X-Y family is minimal as compared to 2LC-Y member of X-Y family.

V. NUMERICAL COMPUTING MATRIX LABORATORY 9.0 (R2016A) SIMULATION RESULTS AND DISCUSSION

The simulation of proposed 2LCm-Y converter is worked out in Numerical Computing Matrix Laboratory 9.0 (R2016a) software with the parameters: 10V input voltage, 240W power and 60% duty cycle. The Pulse Modulation technique with 50kHz switching frequency is employed to control the switch. Fig. 6 depicts the \( V_o \) (output voltage) and \( I_o \) (output current) waveform of voltage doubler based 2LCm-LVD converter. It is investigated that the achieve voltage and current is -239.6V and -0.997A respectively. Thus, -24 voltage conversion ratio \( (V_o/V_i) \) is noticed at 60% duty cycle. Fig. 7(a) depicts the \( V_o \) (output voltage) and \( I_o \) (output current) waveform of voltage doubler based 2LCm-LVDV converter. It is investigated that the achieve voltage and current is -389.4V and -0.63A respectively. Thus, -39 voltage conversion ratio \( (V_o/V_i) \) is noticed at 60% duty cycle. Fig. 7(b) depicts the \( V_o \) (output voltage) and \( I_o \) (output current) waveform of voltage doubler based 2LCm-L2CV converter. It is investigated that the achieve voltage and current is -489.3V and -0.48A respectively. Thus, -49 voltage conversion ratio \( (V_o/V_i) \) is noticed at 60% duty cycle. Fig. 7(c) depicts the \( V_o \) (output voltage) and \( I_o \) (output current) waveform of voltage doubler based 2LCm-L2CVV converter. It is investigated that the achieve voltage and current is -489.3V and -0.48A respectively. Thus, -49 voltage conversion ratio \( (V_o/V_i) \) is noticed at 60% duty cycle. From the discussion done up till now, it is clear that 2LCm-Y converter topologies have high inverting output voltage. Second, it is investigated that the voltage conversion ratio of 2LCm-2LVD converter is greater than voltage conversion ratio of 2LCm-LVD converter \( (G_{2LCm-2LVD} < G_{2LCm-LVD}) \). Third, it is investigated that the voltage conversion ratio of converter 2LCm-2LVD and 2LCm-2LCmVD converters is greater than the voltage conversion ratio of 2LCm-L2CV converter \( (G_{2LCm-2L2CV} < G_{2LCm-2L2CV}) \). Fourth it is investigated that the proposed voltage doubler based 2LCm-Y converter topologies have greater voltage conversion ratio compared to existing 2LCm-Y (without doubler) category of X-Y converter family. Fifth, among the four voltage doubler based 2LCm-Y power converter topologies, 2LCm-2LCmVD provides a maximum conversion ratio with minimal internal resistance effect.

VI. CONCLUSION

Four new voltage doubler based 2LCm-Y (2LCm-LVD, 2LCm-2LVD, 2LCm-2LCVD and 2LCm-2LCmVD) power converter topologies are proposed which provides a acceptable and effective solution for renewable energy applications which required high-voltage/low-current power converter such as a Photovoltaic Multilevel DC-AC converter system (PV-MLI system), renewable High Voltage Direct Current (HVDC) applications, Hybrid Electric Vehicles (HEV) etc. The perceptible characteristics of proposed 2LCm-Y converters are i) Single input source ii) Single controlled semiconductor device iii) High inverting \( V_o/V_i \) at moderate duty cycle v)
High-voltage and low-current at the output side of converter v)
Minimum internal resistance vi) Transformer-less and coupled inductor-less converter topologies. Numerical software simulation results of proposed converters constantly shows high-quality agreement with hypothetical analysis.

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