L-L Multilevel Boost Converter Topology for Renewable Energy Applications: A New Series Voltage Multiplier L-L Converter of XY Family

Mahajan Sagar Bhaskar Sanjeevikumar Padmanaban
Department of Electrical & Electronics Engineering,
Faculty of Engineering and the Built Environment,
University of Johannesburg, Auckland Park, Johannesburg, South Africa
sagar25.mahajan@gmail.com; sanjeevi_12@yahoo.co.in

Viliam Fedák
Department of Electrical Engineering and Mechatronics,
Technical University, Kosice,
Slovak Republic
viliam.fedak@tuke.sk

Frede Blaabjerg
Center for Reliable Power Electronics,
(CORPE),
Department of Energy Technology,
Aalborg University, Denmark
fbl@et.aau.dk

Patrick William Wheeler
Power Electronics, Machines and Control
Group (PEMC), Department of Electrical &
Electronics Engineering,
Nottingham University, United Kingdom
pat.wheeler@nottingham.ac.uk

Vigna K. Ramachandaramurthy
Institute of Power Engineering,
Department of Electrical Power
Engineering, Universiti Tenaga Nasional,
Malaysia
Vigna@uniten.edu.my

***Abstract*—A new L-L Multilevel Boost Converter (L-LMBC) topology for high gain renewable energy applications is proposed in this work. L-LMBC topology is designed to provide an operative solution for renewable energy applications which requires a high voltage conversion ratio and stack of the capacitor; such as a photovoltaic (PV) system with a Multilevel Inverter (MLI), electrical drives, automotive, hybrid electric cars etc. The proposed topology is derived by attaching the Cockcroft Walton (CW) multiplier to an upper L-converter of the LL topology of XY family. The mode of operation of L-LMBC with mathematical equations is also discussed in details. The noticeable features of proposed L-LMBC topology are: i) Only one power control switch; ii) High inverting output voltage from single input source; iii) Without the use of transformer; iv) The number of CW multiplier levels can be added to achieve high voltage without changing the connection of main circuits. The Matrix Laboratory (MATLAB) simulation results are provided and the result validates the functionality, feasibility and design of the converter.**

Keywords—Multilevel; LL Converter; XY Family; DC-DC Converter; Renewable Energy; Cockcroft Walton multiplier.

I. INTRODUCTION

It's something of an uncomfortable fact that civilized society is almost completely reliant upon fossil fuels for nearly every aspect of its existence. At some point the fossil fuels are going to be gone or become too expensive to realistically use. This problem tends to focus people on renewable energy sources. While renewable energy systems on a large scale are an important step in keeping with national and international infrastructures intact. The trend of generating high energy through a series and parallel arrangement of plenty of small voltage generating units is coming out [1]-[2]. The best example of such power system is a solar power plant which comprises a number of modules for production of energy. These modules have to feed power to inverter to insert power into the grid, but the voltage of these modules is quite low. Hence, the voltage needs to be increased before feeding an inverter [1]-[6]. To maximize the voltage different connections of solar modules are implemented, but may not suitable as shadow on any of module will bring array voltage to zero. Therefore, the applications encompassing photovoltaic systems are linked with DC-DC converter having a sufficiently high conversion ratio and which is the most paramount constituent in this power conversion stage [7]-[8]. The boost converter tends to lose its efficient performance due to the leakage resistance of the inductor and the step up in duty cycle. Thus to have risen in voltage gain greater than four times the conventional DC-DC converter is not an appropriate solution. Disrupted input current is the stellar limitation, handed down buck-boost converter which substantiates the minimal input source utilization. When the high voltage conversion ratio is required this conventional converter is not appropriate solution [5]-[7].

To work with DC-DC converters for getting high yield voltage without utilising high duty cycle for power semiconductor controlled switches, isolated converters can be signed to achieve high conversion ratio which contains transformers and coupled inductors [8]. But presence of such magnetic components tends to raise the size of the circuit as well as it increases leakage reactance of converter and also produces Electromagnetic Interference [EMI] which reduces converter function ability and efficiency. Taking this into account few ideas of different isolated converter topologies have been addressed in the literature. Transformer leakage inductance brought on the Electromagnetic Interference (EMI) problem and switching losses. Consequently, overall efficiency of the converter is low [5]-[7]. Isolated converter topologies size, weight and losses of power transformer are the major drawbacks. In order to achieve high voltage gain, cascaded and quadratic boost approach is employed in literature [9]-[10]. Outline of Cascaded Boost Converter (CBC) and Quadratic Boost is the most complex part for industries because of use several controlled switches and reactive components. The significant obstacles are high ripple current, several controlled switches and a high energy loss to attain high voltage gain and

978-1-5386-3380-9/17/$31.00 ©2017 IEEE

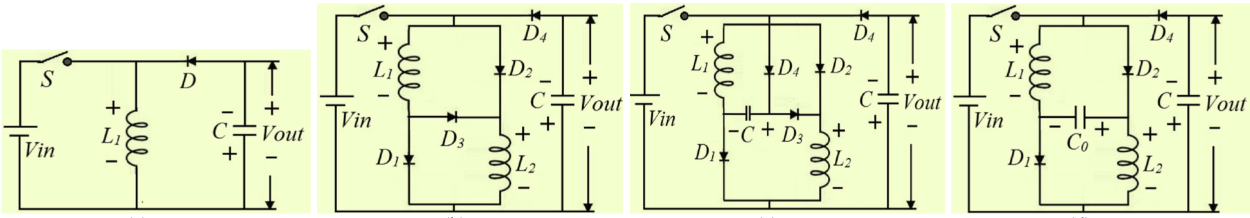

Fig. 1 Power circuit of: (a) L Converter or Buck Boost Converter (BBC); (b) SL Converter (2L Converter) or SI BBC (Switched Inductor Buck Boost Converter); (c) VLSI BBC or 2LC Converter (VLSI BBC (Buck Boost Converter)); (d) Modified VLSI or $2LC_m$ Converter (mVLSI BBC (Buck Boost Converter))

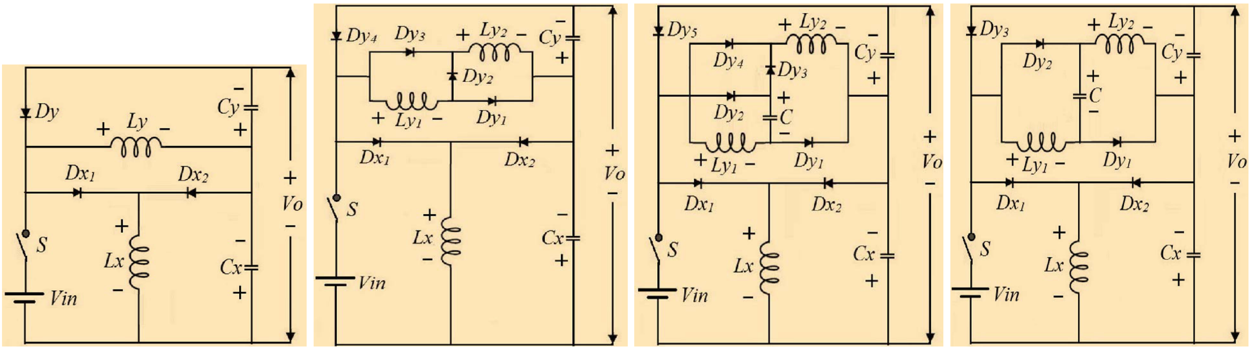

Fig. 2 Power circuit of LY topologies of XY Family: (a) L-L Converter; (b) L-2L Converter; (c) L-2LC Converter; (d) $L\text{-}2LC_m$ Converter

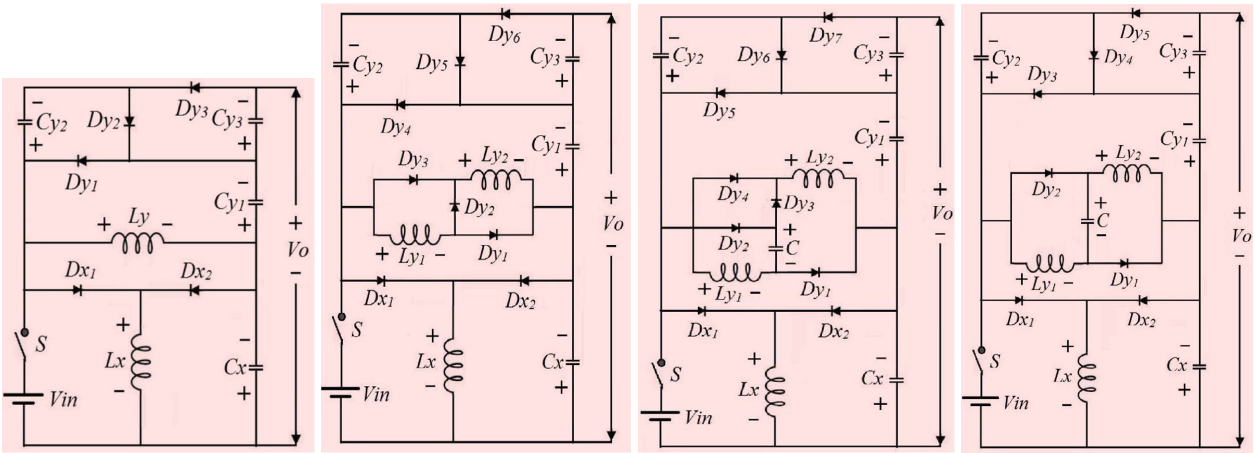

Fig.3: Power circuit of LY topologies with voltage doubler: (a) L-LVD Converter; (b) L-2LVD Converter; (c) L-2LCVD Converter; (d) $L\text{-}2LC_mVD$ Converter

efficiency. In [11]-[12], several reactive networks like SC, SI, VLSI and modified VLSI cells are addressed to achieve high voltage and to remove the drawback of conventional converter. Power circuit of the Buck-Boost converter with single inductor, SL, VLSI and modified VLSI are shown in Fig. 1 and voltage gain of converters is given in Table I. Based on these four converters, a new breed named as XY family of the converter is proposed for renewable energy application to achieve high voltage [11]. Total 16 topologies are articulated in XY family, which are appropriate to provide high voltage gain.

In [12], based on X-converter XY Family is divided into four sub-categories named as LY, 2LY, 2LCY and $2LC_mY$ converters. The power circuit of LY converters is shown in Fig. 2(a) to Fig. 2(d) and voltage gains of converters are given in table-I. Four new LY Converter named as L-LVD, L-2LVD, L-2LCVD and $L\text{-}2LC_mVD$ are also proposed to achieve high gain transfer ratio using voltage doubler [12]. The power circuit of LY converters with voltage doubler is shown in Fig. 3(a) to Fig. 3(d) and voltage gain of converters are given in Table I.

Recently, several DC-DC multilevel topologies have been addressed to remove drawback of cascaded converter and isolated converter topologies [13]-[15]. But, a high number of uncontrolled semiconductor devices and capacitor circuitry (stages of the multiplier) are required to design the existing DC-DC multilevel converter for high conversion ratio. In this paper a new L-L Multilevel Boost Converter (L-LMBC) topology is proposed for high gain renewable energy application. L-LMBC topology is designed to provide an

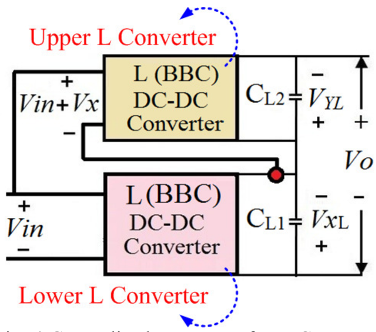

Fig. 4 Generalised structure of L-L Converter

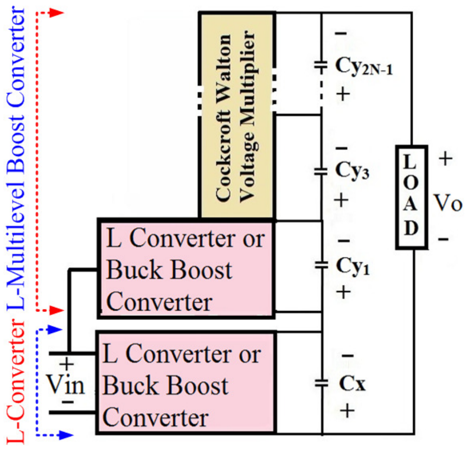

Fig. 5 Generalised structure of L-LMBC
(X=L Converter and Y=L-MBC)

Table-I: Conversion ratio of recently Buck Boost and LY converter topologies for boost application

Converter Topology	Voltage Conversion Ratio
L Converter or Buck Boost Converter (BBC) (Fig. 1(a))	$G_L = -D/(1-D)$
SL Converter (2L Converter) or SI BBC (Switched Inductor Buck Boost Converter) (Fig. 1(b))	$G_{2L} = -2D/1-D$
VLSI BBC or 2LC Converter (VLSI BBC (Buck Boost Converter)) (Fig. 1(c))	$G_{2LC} = -(1+D/1-D)$
Modified VLSI BBC or 2LCm Converter (mVLSI BBC (Buck Boost Converter)) (Fig. 1(d))	$G_{2LCm} = -(1+D/1-D)$
L-L Converter (Fig. 2(a))	$Gx_L = D/(1-D)$ $Gy_L = ((Gx_L+1)D)/(1-D)$ $G_{L-L} = -(Gx_L + Gy_L)$
L-2LConverter (Fig. 2(b))	$Gx_L = D/(1-D)$ $Gy_{2L} = ((Gx_L+1)2D)/(1-D)$ $G_{L-2L} = -(Gx_L + Gy_{2L})$
L-2LC Converter (Fig. 2(c))	$Gx_L = D/(1-D)$ $Gy_{2LC} = ((Gx_L+1)(1+D))/(1-D)$ $G_{L-2LC} = -(Gx_L + Gy_{2LC})$
L-2LC$_m$ Converter (Fig2.(d))	$Gx_L = D/(1-D)$ $Gy_{2LCm} = ((Gx_L+1)(1+D))/(1-D)$ $G_{L-2LC} = -(Gx_L + Gy_{2LCm})$
L-LVD Converter (Fig. 2(e))	$Gx_L = D/(1-D)$ $Gy_1 = ((Gx_L+1)D)/(1-D)$ $Gy_2 = Gy_3 = (1+Gx_L+Gy_1)$ $G_{L-LVD} = -(Gx_L + Gy_1 + Gy_3)$
L-2LVD Converter (Fig. 2(f))	$Gx_L = D/(1-D)$ $Gy_1 = ((Gx_L+1)2D)/(1-D)$ $Gy_2 = Gy_3 = (1+Gx_L+Gy_1)$ $G_{L\text{-}2LVD} = -(Gx_L + Gy_1 + Gy_3)$
L-2LCVD Converter (Fig. 2(g))	$Gx_L = D/(1-D)$ $Gy_1 = ((Gx_L+1)(1+D)/(1-D)$ $Gy_2 = Gy_3 = (1+Gx_L+Gy_1)$ $G_{L\text{-}2LCVD} = -(Gx_L + Gy_1 + Gy_3)$
L-2LCmVD Converter (Fig. 2(h))	$Gx_L = D/(1-D)$ $Gy_1 = ((Gx_L+1)(1+D)/(1-D)$ $Gy_2 = Gy_3 = (1+Gx_L+Gy_1)$ $G_{L\text{-}2LCmVD} = -(Gx_L + Gy_1 + Gy_3)$

operative solution for renewable energy applications which requires a high voltage conversion ratio and stack of the capacitor; such as a photovoltaic (PV) system to fed MLI, electrical drives, automotive, hybrid electric cars etc.

The proposed L-LMBC topology combines the feature of Cockcroft Walton (CW) multiplier and L-L topology of XY family. The mode of operation of L-LMBC with mathematical equations is also discussed in the details. The striking features of the proposed L-LMBC topology are:

- Only one power control switch
- High inverting output voltage from a single input source
- Without the use of transformer
- The number of CW multiplier levels can be added to achieve the voltage without changing the connection of main circuits.

II. Proposed Converter: L-L Multilevel Boost Converter (L-LMBC) Topology

The detail categorization of XY family is articulated in [7]. LY breed of XY family consists of L-L, L-2L, L-2LC and L-2LC$_m$ converter topologies. L-L breed of LY converter family consists of two separate X (Lower) and Y (upper) power converters where X and Y Converter is L converter. The generalized structure of L-L converter is shown Fig. 4. L-L Multilevel Boost Converter (L-LMBC) topology is derived by attaching Cockcroft Walton (CW) voltage multiplier to an

TABLE II LY AND L-LMBC TOPOLOGIES AND ITS COMPONENTS REQUIREMENT

Component details	LY DC-DC converter [7]				L-YVD (L-Y with voltage doublers) DC-DC converter [8]				Proposed L-LMBC Topology (N is level of L-MBC converter)
	L-L	L-2L	L-2LC	L-2LC$_m$	L-LVD	L-2LVD	L-2LCVD	L-2LC$_m$VD	L-LMBC
Number of switches	1	1	1	1	1	1	1	1	1
Number of Inductor	2	3	3	3	2	3	3	3	2
Number of Capacitors	2	2	3	3	4	4	5	5	2N
Number of diodes	3	6	7	5	5	8	9	7	2N+1

upper L converter of the L-L converter. Thus, L-L Multilevel Boost Converter (L-LMBC) topology is a combination of L converter and L Multilevel Boost Converter (L-MBC). The generalized structure of L-LMBC is shown Fig. 5. The DC supply is directly connected to the below L converter. Series connection of the supply voltage and output side voltage of L converter is fed as input to L Multilevel Boost Converter (L-MBC). The total output voltage generated at the output side of L-L topology is equal to the negative sum of the output side voltage of lower L converter and upper L converter as in (1). The total output voltage generated at the output side of the L-LMBC topology is equal to the negative sum of the output side voltage of L converter and L-MBC as in (2). The power circuit of L-LMBC is shown in Fig. 6(a). And the number of components and device's requirement to design LY converter, LY with voltage doublers (L-YVD) [12] converter and L-LMBC topologies are provided in Table II.

L-L Converter

$$\left.\begin{aligned} Vo &= -\left(V_{XL} + V_{YL}\right) \\ V_{XL} &= VC_x \\ V_{YL} &= VC_y \end{aligned}\right\} \tag{1}$$

L-L Multilevel Boost Converter

$$\left.\begin{aligned} Vo &= -\left(V_L + V_{L-MBC}\right) \\ V_L &= VC_x \\ V_{L-MBC} &= VC_{y1} + VC_{y3} + \ldots + VC_{y2N-1} \\ Vo &= -\left(VC_x + VC_{y1} + VC_{y3} + \ldots + VC_{y2N-1}\right) \end{aligned}\right\} \tag{2}$$

To design an N-level L-LMBC converter, a single controlled switch, 2 inductors, 2N capacitor and 2N+1 uncontrolled switches (diodes) are required where N is the number of the output level of the L-LMBC.

A. Mode of Operation of L-LMBC

The operation of L-LMBC is divided into 2 modes when the controlled switch is ON and another when the controlled switch is OFF. Equivalent circuit of the L-LMBC in ON and OFF state is shown in Fig. 6(b) and Fig. 6(c) respectively. In order to study the L-LMBC converter, steady state operation is considered and the following assumptions are considered: i) DC supply is pure; ii) All power devices are ideal, thus device efficiency is 100 %; iii) Identical inductor with same rating; iv) Zero ripples at capacitors.

ON state equations

$$\left.\begin{aligned} &VL_x = V_{in} \\ &VL_y = VC_x + V_{in} \\ &VC_{y2} = VC_x + VC_{y1} + V_{in} \\ &VC_{y2} + VC_{y4} = VC_x + VC_{y1} + VC_{y3} + V_{in} \\ &VC_{y2} + VC_{y4} + .. + VC_{y2N-2} \\ &= VC_x + VC_{y1} + VC_{y3} + \ldots. + VC_{y2N-3} + V_{in} \end{aligned}\right\} \tag{3}$$

OFF state equations

$$\left.\begin{aligned} &VC_x = -VL_x \\ &VC_{y1} = -VL_y \\ &VC_{y3} = VC_{y2} \\ &VC_{y3} + VC_{y5} = VC_{y2} + VC_{y4} \\ &VC_{y3} + VC_{y5} + \ldots + VC_{y2N-1} \\ &= VC_{y2} + VC_{y4} + .. + VC_{y2N-2} \end{aligned}\right\} \tag{4}$$

$$VC_x = \frac{V_{in} D}{1 - D} \tag{5}$$

$$G_X = G_L = \frac{VC_X}{V_{in}} = \frac{D}{1 - D} \tag{6}$$

where, G_L is voltage gain of L Converter.

$$VC_{y1} = \frac{D(G_L + 1)V_{in}}{1 - D} \tag{7}$$

$$G_{y1} = \frac{VC_{y1}}{V_{in}} = \frac{D(G_L + 1)}{1 - D} \tag{8}$$

where, G_{y1} is the ratio of voltage across the capacitor C_{y1} and input supply voltage V_{in}.

$$G_{y2} = \frac{VC_{y2}}{V_{in}} = (1 + G_L + G_{y1}) \tag{9}$$

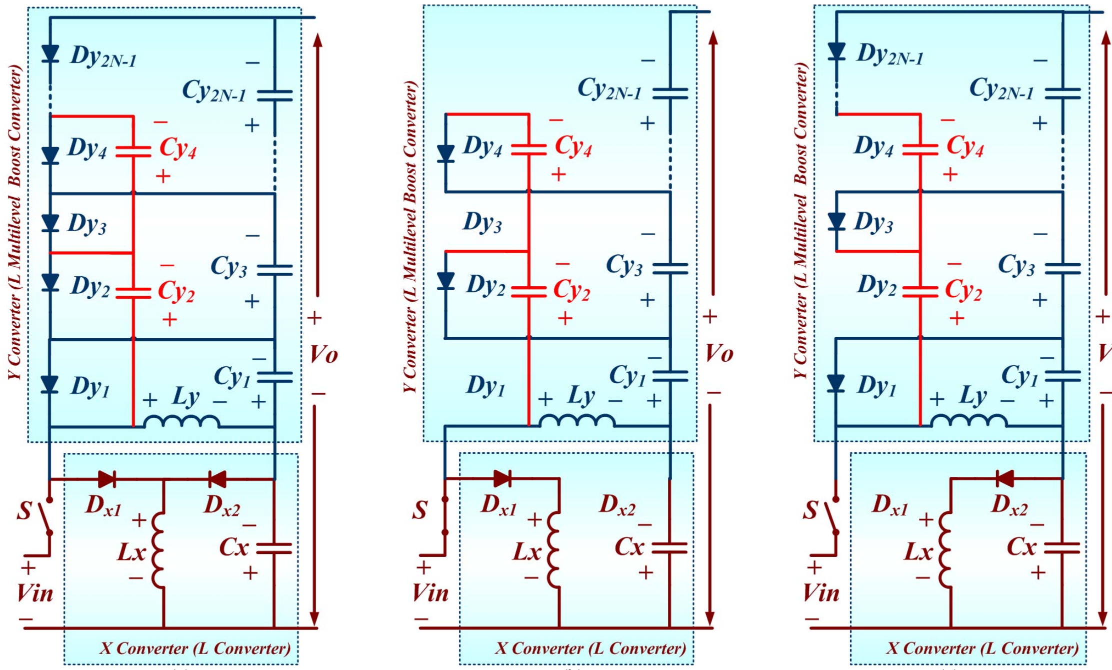

Fig.6 Topologies: (a) Proposed L-LMBC Topology; (b) ON State of L-LMBC Topology; (b) OFF State of L-LMBC Topology

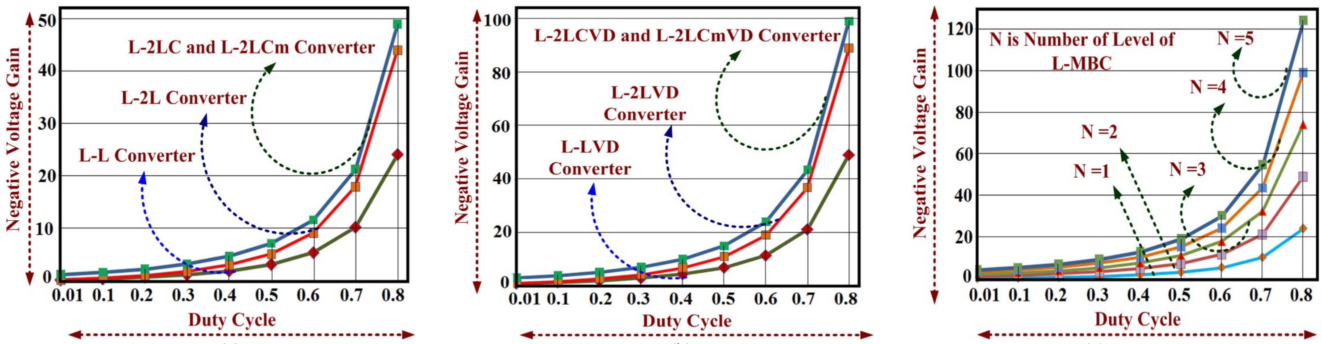

Fig. 7 Graph of the voltage gain (negative voltage gain is considered) versus Duty Cycle: (a) LY Converters topologies; (b) L-Y with Voltage Doubler (L-YVD) converters topologies; (c) L-LMBC for different level. (N= Number of levels of L-MBC)

where, G_{y2} is the ratio of voltage across the capacitor C_{y2} and the input supply voltage V_{in}.

$$\left.\begin{array}{l} G_{y2}=G_{y3}=....=G_{y2N-1}=(1+G_L+G_{y1}) \\ G_y=G_{L\text{-}MBC}=G_{y1}+G_{y3}+G_{y5}+...+G_{y2N-1} \end{array}\right\} \quad (10)$$

$$G_{L\text{-}L\ MBC}=G_L+G_{L\text{-}MBC}=\frac{V_O}{V_{in}}=-(G_x+G_y) \quad (11)$$

where, $G_{L\text{-}LMBC}$ is the voltage gain of L-LMBC. This is calculated by considering ideal components (voltage drop across all components is zero). The graph of voltage gain versus duty cycle of LY converter, L-Y with voltage doubler (L-YVD) and L-LMBC is shown in Fig. 7(a) to Fig. 7(c) (the negative voltage is considered and thus overall gain is positive). It is observed that L-LMBC provides high voltage gain compared to LY converter and L-Y with voltage doubler.

III. SIMULATION RESULT AND DISCUSSION

The proposed L-LMBC topology is simulated for 4-level (4-level of L-MBC) in MATLAB using DC supply 10 V, rated power 100 W. The power control switch is controlled by switching frequency 50 kHz and duty ratio 0.60 (T_{on} = 60 % of T). Output voltage and input voltage of L-LMBC shown in Fig. 8(a). First, it is observed that negative 240 V is achieved from 10 V DC supply from L-LMBC. Thus, the voltage gain of L-LMBC is -24 at 60 % duty cycle. Fig. 8(b) depicts the output current waveform of L-LMBC. For rated power 100 W it is observed that the output current of L-LMBC is negative 0.42 A. Fig. 8(c) depicts the voltage across the capacitors of L-LMBC. First; it is observed that L converter of L-LMBC generates 15 V voltage ($-V_{Cx}$ = -15 V). Second; it is observed that the voltage across capacitor C_{y1} (1 Level of L-MBC) of L-LMBC is equal to 37.5 V ($-V_{Cy1}$ = -37.5 V). Third; it is observed that the voltage across capacitors $C_{y3}+C_{y5}+C_{y7}$ (2nd + 3rd + 4th level) of L-LMBC is equal to 187.5 V (negative voltage across the capacitors $C_{y3}+C_{y5}+C_{y7}$ is - 187.5 V). The output voltage of L-

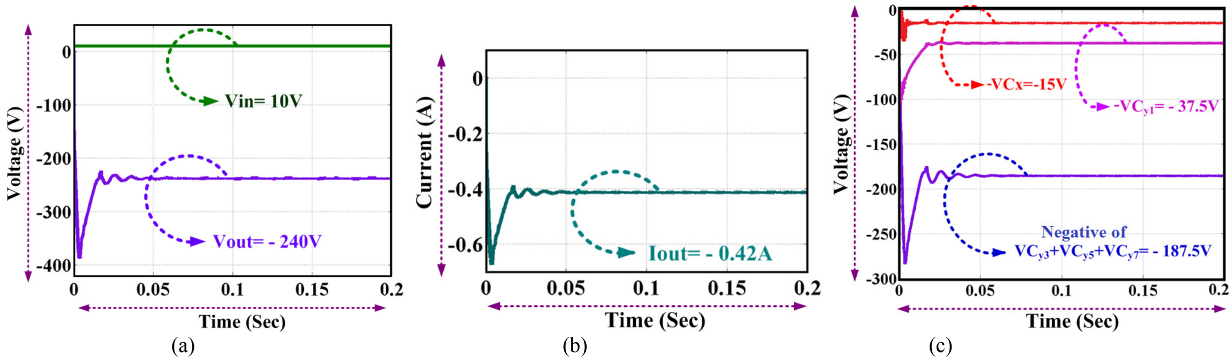

Fig. 8 Simulation result of proposed L-LMBC with considering ideal diode and switch $V_d = 0$: (a) Output Voltage versus Duty Cycle; (b) Output Current versus Duty cycle; (c) voltage across capacitor of L-LMBC

LMBC is an addition of output voltage of L converter and the output voltage of L-MBC (here 4-level L-MBC is considered). Thus, total negative 240 V is achieved at the output of L-LMBC when 60 % duty cycle is used. (L converter and L-LMBC output voltage is -37.5 V and -187.5 V respectively).

IV. Conclusion

A new L-LMBC converter topology is present which provides an operative solution for renewable energy applications requiring a high voltage conversion ratio and stack of the capacitor; such as a photovoltaic system to fed MLI, electrical drives, automotive, hybrid electric cars, etc. The proposed converter combines the function of the L-L converter and Cockcroft Walton (CW) multiplier. L-LMBC converter topology is a combination of L converter (Buck Boost) and L-MBC. Moreover, proposed L-LMBC converter is compared with existing LY and L-YVD converter topologies. The proposed L-LMBC converter topology gives a higher negative voltage gain compared to existing LY converter and L-YVD converter topology of XY family. The noticeable features of proposed L-LMBC topologies are: i) Only one power control switch; ii) High inverting output voltage from single input source; iii) Without the use of transformer; iv) The number of CW multiplier levels can be added to achieve the voltage without modifying of main circuits. The MATLAB simulation results are presented and results show a good conformity with a theoretical approach and verified the functionality the L-LMC converter topologies.

Acknowledgment

The research was supported by the project of the SlovakGrant Agency VEGA No 1/0464/15 titled “Research of New Principles and Methods for Design of Electrotechnical Systems”.

References

[1] Yam P. Siwakoti, P.C. Loh, F. Blaabjerg, S.J. Andreasen and G.E. Town, “Y-source impedance network based boost DC/DC converter for distributed generation,” IEEE Trans. on Ind. Electron., vol. 62, no. 2, pp. 1059-1069, 2015.

[2] Yam, P. Siwakoti, F. Blaabjerg, and P.C. Loh, “High step-up trans-inverse (Tx-1) DC–DC converter for distributed generation system,” IEEE Trans. on Ind. Electron., vol. 63, no. 7, pp. 4278–4291, Jul. 2016.

[3] M. Forouzesh, Yam, P. Siwakoti, S. Gorji, F. Blaabjerg, and B. Lehman, “A survey on voltage boosting techniques for step-up DC-DC converters,” IEEE Energy Conversion Congress and Exposition (ECCE 2016), Milwaukee, WI. 2016.

[4] P. Sanjeevikumar, G. Grandi, F. Blaabjerg, P. Wheeler, P. Siano, and M. Hammami, “A comprehensive analysis and hardware implementation of control strategies for high output voltage DC-DC boost power converter,” Intl. Journal of Computational Intelligence System (IJCIS), Atlantis Press and Taylor and Francis publications, vol. 10, no. 1, pp. 140–152, 2017.

[5] S.B. Mahajan, P. Sanjeevikumar, F. Blaabjerg, O. Ojo, S. Seshagiri, and R. Kulkarni, “Inverting Nx and 2Nx non isolated multilevel boost converter for renewable energy application,” 4th IET International Conference On Clean Energy and Technology, Kuala Lumpur, Malaysia.

[6] F. Tofoli, P. Castro, W. Paula, and S.O.J. Demercil, “Survey on non-isolated high-voltage step-up dc–dc topologies based on the boost converter,” IET Power Electron., pp. 1–14, July 2015.

[7] S.B. Mahajan, P. Sanjeevikumar, O. Ojo, M. Rivera, and R. Kulkarani, “Non-isolated and inverting Nx multilevel boost converter for photovoltaic DC link applications,” IEEE International Conference on Automatica, XXII Congress of the Chilean Association of Automatic Control, IEEE ICA/ACCA’16, University of Talca, (Chile), Oct. 2016.

[8] T. Changchien, S. Liang, J. Chen, and L. S. Yang, “Step-up DC–DC converter by coupled inductor and voltage-lift technique,” IET Power Electron., vol. 3, no. 3, pp. 369–378, May 2010.

[9] Shih-Ming C., T. Liang, L. Yang, and J. Chen, “A cascaded high step-up DC-DC converter with single switch for microsource applications,” IEEE Trans. Power Electr., vol. 26 (4), 1146-1153. 2011.

[10] P. Saadat, and K. Abba, “A single-switch high Step-Up DC-DC Converter Based on Quadratic Boost,” IEEE Trans. on In. Elec., vol. 63 (12), pp. 7733-7742, 2016.

[11] S.B. Mahajan, P. Sanjeevikumar, P. Wheeler, F. Blaabjerg, M. Rivera, A.H. Ertas, and R. Kulkarni, “XY converter family: A new breed of Buck boost converter for high step-up renewable energy applications,” IEEE International Conference on Automatica, XXII Congress of the Chilean Association of Automatic Control, IEEE ICA/ACCA’16, University of Talca, (Chile), Oct. 2016.

[12] S.B. Mahajan, P. Sanjeevikumar, F. Blaabjerg, R. Kulkarni, S. Seshagiri, and A. Hajizadeh, “Novel LY converter topologies for high gain transfer ratio - a new breed of XY family,” 4th IET International Conference On Clean Energy and Technology, Kuala Lumpur, Malaysia.

[13] S.B. Mahajan, R. Kulkarni, P. Sanjeevikumar, P. Siano, and F. Blaabjerg: “Hybrid non-isolated and non inverting Nx interleaved DC-DC multilevel boost converter for renewable energy applications,” The 16th IEEE International Conference on Environment and Electrical Engineering, (IEEE-EEEIC'16), Florence (Italy).

[14] J. Caro, J. Mayo, R. Cabrera, A. Rodriguez, S. Nacu, R., and Castillo-Ibarra “A Family of DC-DC multiplier converters”, Online publication: 10 Feb. 2011.

[15] S.B. Mahajan, R. Kulkarni, P. Sanjeevikumar, F. Blaabjerg, V. Fedák, and M. Cernat: “Non isolated and non-inverting Cockcroft Walton multiplier based hybrid 2Nx interleaved boost converter for renewable energy applications,” IEEE Conf. on 17th The Power Electronics and Motion Control, (IEEE-PEMC'16), Varna Bulgaria. Sep. 2016.