Modified Boost with Switched Inductor Different Configurational Structures for DC-DC Converter for Renewable Application

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***Abstract*—The proposed work represents the modified high voltage conversion boost converter (MBC) and its four different configurations using Switched Inductor (SI) structure-Modified Boost Converter with LL Configuration (MB-LL), Modified Boost Converter with XL Configuration (MBSI-XL), Modified Boost Converter with LY Configuration (MBSI-LY), and Modified Boost Converter with XY Configuration (MBSI-XY). All four configurations are having a single controlled device and derive from the conventional boost converter by hosting boosting circuit in the conventional boost converter. The comparative analysis of four configurations of MBC is done in the paper. The voltage conversion analysis by considering internal voltage drop and without considering voltage drop across the passive device is carried out. The comparison of four configurations of MBC is done on the basis of the voltage conversion ratio, number of components and efficiency of the converter. Four configurations of MBC are simulated in MatLab Simulink for 250W. The simulation results validate the achievability of the modified boost converter.**

Keywords—High Gain DC-DC Converter; Modified Boost Converter; Switched Inductor; Photovoltaic Application;

I. INTRODUCTION

As population increases, the demand for electricity is continuously increasing and fossil fuels are not enough to fulfill the demands. The alternative solution for the demand is solar energy. Due to clean and abundant nature of solar energy, it's a viable solution for fossil fuel in next few years. It's readily available anywhere. The solar energy can be effectively used for electric vehicles, electric drives, home appliances, etc. The photovoltaic (PV) panel is used to convert solar energy into electric energy. The voltage generated from PV panel is very low and its fluctuating from day to evening time. The environmental condition also affects the nature of output voltage of PV panel [1]-[3]. The DC voltage generated from a PV panel, cannot be directly give to electrical drives or electrical appliance because it's fluctuating nature and low voltage. The voltage generated from PV panel can be increased by two methods, one is by connecting a number of PV panel in series according voltage requirement. But disadvantage of this method is again voltage varies with environmental conditions and it's not a good option to increase voltage. The second one is using step-up DC-DC converter. There are several step-up DC-DC converter is discussed in literature survey [4]. The conventional boost, buck-boost, Cuk, SEPIC, Luo converter have a moderate voltage conversion ratio, which is not suitable for high voltage application.

In [4], high gain multilevel DC-DC converter is presented by using voltage multiplier circuit at the load side. The voltage conversion ratio of converter is increased by increasing the number of diode and capacitor. The drawback of multilevel converter is efficiency decreases with increasing number of level. In [5]-[8], XY converter family is discussed. The voltage conversion ratio of XY converter family members is moderate. The advantage of XY converter is no reverse current flow into input supply. In proposing converter, the high value of the inductor is used at the input side to avoid the reverse flow of current into input supply.

In [9]-[10] N_X and $2N_X$ converter is discussed. It is another type of multilevel DC-DC converter. N_X and $2N_X$ give inverted high voltage conversion ratio. The disadvantage is

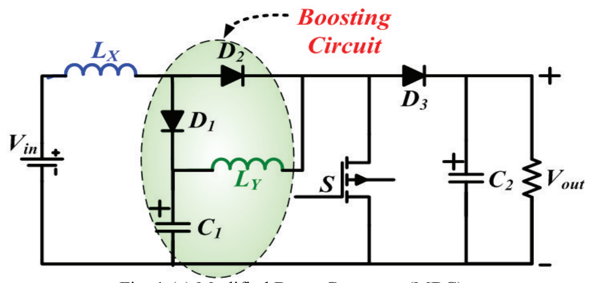


Fig. 1 (a) Modified Boost Converter (MBC).

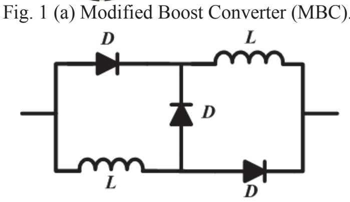


Fig. 1 (b) Switched Inductor (SI) Structure.

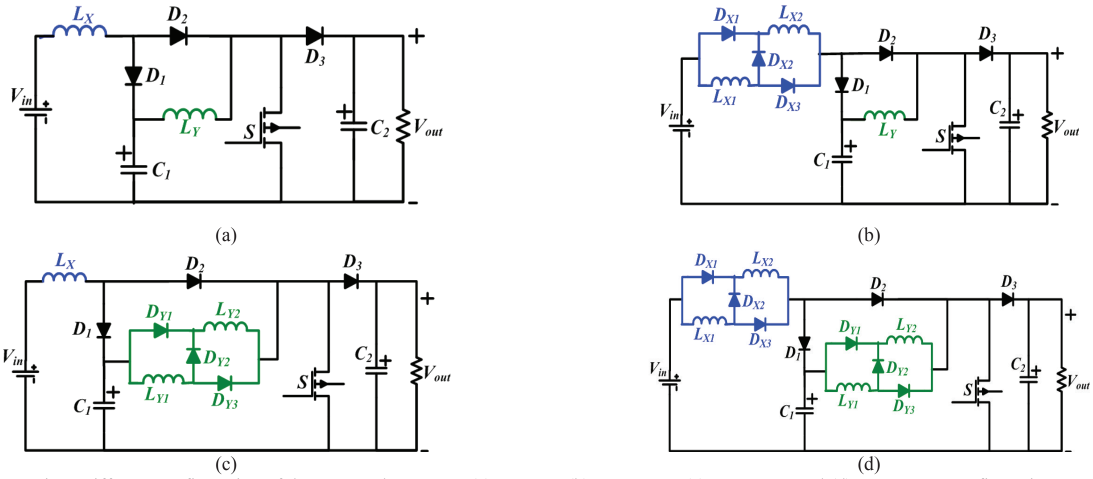


Fig.2 Different configuration of the proposed converter (a) MB-LL, (b) MBSI-XL, (c) MBSI-LY and (d) MBSI-XY Configuration.

efficiency decreases due to the increasing number of diodes at load side. Diffenent high gain converter with switched inductor structure is discussed in [11] -[13], the voltage conversion ratio of presenting a paper is increased by replacing inductor by switched inductor structure. By considering advantage and disadvantage of various converters discussed in literature survey, the modified boost converter and its four different configurations with switched inductor structure is presented in the paper.

II. Modified Boost Converter

The proposed converter is Modified Boost Converter (MBC). By addition of boosting circuit in conventional boost converter, the conversion ratio of modified boost converter is increasing. The boosting circuit consist of one inductor and one capacitor along with two uncontrolled diodes as shown in Fig.1 (a). The modified boost converter consists of two inductors, two capacitors, three diodes and single controlled power device.

The modified boost converter classified into four different configurations depending upon its inductor structure. In modified boost converter structure, if inductor L_X and L_Y are keeping as it same, then the configuration is named as Modified Boost Converter with LL configuration (MB-LL) as shown in Fig 2(a). If inductor L_X is replaced by switched inductor (SI) structure as shown in Fig. 1(b) then it's named as Modified Boost Converter with XL configuration (MBSI-XL) as shown in Fig. 2(b). Similarly inductor L_Y is replaced by SI structure, then its named as Modified Boost Converter with LY configuration (MBSI-LY) as shown in Fig.2(c). and both inductor L_X and L_Y are replaced by SI structure, then its named as Modified Boost Converter with XY configuration (MBSI-XY) as shown in Fig.2(d). The number components of four different configurations of the modified boost converter are shown in table-I.

A. Working of Proposed Modified Boost Converter

The working of four configurations of the modified boost converter is same. The working of modified boost converter depends on condition of controlled device, i.e. ON and OFF condition. The MBC converter consists only single controlled device. The working is divided into two parts, Mode-I and Mode-II as discuss in detail in following section.

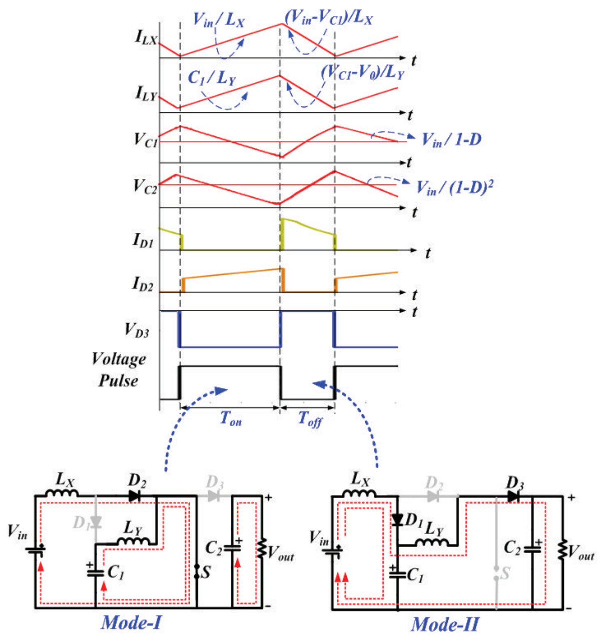


Fig.3 Operation of proposed Converter.

1) Mode-I

The Mode-I is in between 0 to DT_s as shown in Fig.3. Where D is duty ratio and T_s is switching frequency. Between this duration, the controlled device is in conducting mode. Diode D_2 is in forward bias condition due to input supply V_{in}. Diode D_1 and D_3 are not conducting due to reverse bias condition ensue due to capacitor C_1 and C_2 respectively as shown in Fig.3.

The inductors L_X and L_Y are charged from input supply V_{in} and capacitor C_1 respectively. The current flowing through the inductor is rising and slope of capacitor voltage is decreasing due to its discharging nature as shown in Fig.3. Capacitor C_2 is discharged into the load.

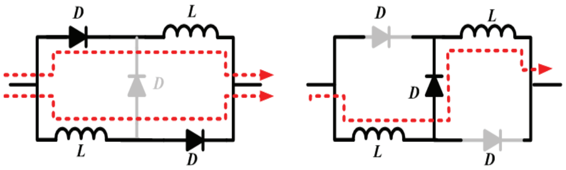


Fig. 4 SI module working modes (a) charging and (b) discharging.

2) Mode-II

The mode-II is in between DT_s to T_s. Between this duration, the controlled device is in non-conducting mode. Inductor L_X is discharges into capacitor C_1 along with input supply V_{in} through diode D_1.The inductor L_X and L_Y are demagnetized along with input supply V_{in} into capacitor C_2 through diode D_3. In mode-II, two inductor are demagnetized or current flowing through inductor L_X and L_Y is decreasing as shown in Fig.3. The two capacitor C_1, and C_2 are charged from inductor L_X, L_Y and input supply V_{in}. The current flowing through Capacitor C_1 and C_2 is increasing as shown in Fig.3.

The working of other three configurations is same as like to modify boost converter. In switched inductor structure, both inductor charges in parallel from input supply V_{in} through the diodes and discharge in series with input supply as shown in Fig 4(a) and (b). The switched inductor structure increases the gain of the converter by (1+D) times.

III. Analysis of Voltage Conversion Ratio of Proposed Modified Boost Converter

The analysis of the voltage conversion ratio of proposed modified boost converter- LL, XL, LY and XY configurations are done in this section. The analysis is done for with the considering voltage drop across the diode, inductor and one controlled switch as equal to V_d. The analysis of proposed converter is based on volt second balance law of the inductor.

1) Modified Boost Converter with LL Configuration

When controlled device S is in ON condition, the voltage appearing across the inductors is

$$\left.\begin{aligned} V_{LX} &= V_{in} - 3V_d \\ V_{LY} &= V_{C1} - 2V_d \end{aligned}\right\} \text{ON state} \tag{1}$$

The voltage appearing across inductors in OFF state condition

$$\left.\begin{aligned} V_{LX} &= V_{in} - V_{C1} - 2V_d \\ V_{LY} &= V_{in} - V_{LX} - V_0 - 4V_d \\ V_{L2} &= V_{C1} - V_0 - 2V_d \end{aligned}\right\} \text{OFF state} \tag{2}$$

According to volt second balance law for Inductor L_X

$$\left.\begin{aligned} &(V_{in} - 3V_d)D + (V_{in} - V_{C1} - 2V_d)(1-D) = 0 \\ &V_{C1} = \left(\frac{1}{1-D}\right)V_{in} - \left(\frac{2+D}{1-D}\right)V_d \end{aligned}\right\} \tag{3}$$

Volt second balance law for Inductor L_Y

$$\left.\begin{aligned} &(V_{C1} - 2V_d)D + (V_{C1} - V_0 - 2V_d)(1-D) = 0 \\ &V_0 = \left(\frac{1}{1-D}\right)V_{C1} - \left(\frac{1}{1-D}\right)2V_d \end{aligned}\right\} \tag{4}$$

By (3)

$$V_0 = \left(\frac{1}{(1-D)^2}\right)V_{in} - \left(\frac{4-D}{(1-D)^2}\right)V_d \tag{5}$$

Without considering internal voltage drop, the voltage conversion ratio is

$$V_0 = \frac{1}{(1-D)^2}V_{in} \tag{6}$$

2) Modified Boost Converter with XL Configuration

When controlled device S is in ON condition, the voltage appearing across the inductors is

$$\left.\begin{aligned} V_{LX1} &= V_{LX2} = V_{in} - 4V_d \\ V_{LY} &= V_{C1} - 2V_d \end{aligned}\right\} \text{ON state} \tag{7}$$

The voltage equation in OFF state condition

$$\left.\begin{aligned} &V_{in} - V_{LX1} - V_{LX2} - V_{C1} - 4V_d = 0 \\ &V_{LX} = \frac{V_{in} - V_{C1} - 4V_d}{2} \\ &V_{LY} = V_{C1} - V_0 - 2V_d \end{aligned}\right\} \text{OFF state} \tag{8}$$

For Inductor L_X

$$\left.\begin{aligned} &(V_{in} - 4V_d)D + \left(\frac{V_{in} - V_{C1} - 4V_d}{2}\right)(1-D) = 0 \\ &V_{C1} = \left(\frac{1+D}{1-D}\right)V_{in} - \left(\frac{1+D}{1-D}\right)4V_d \end{aligned}\right\} \tag{9}$$

For Inductor L_Y

$$\left.\begin{aligned} &(V_{C1} - 2V_d)D - (V_{C1} - V_0 - 2V_d)(1-D) = 0 \\ &V_0 = \frac{V_{C1}}{(1-D)} - \frac{2V_d}{1-D} \end{aligned}\right\} \tag{10}$$

By (9)

$$V_0 = \left(\frac{1+D}{(1-D)^2}\right)V_{in} - \left(\frac{3+D}{(1-D)^2}\right)2V_d \tag{11}$$

If the internal voltage drop is neglected, then the voltage conversion ratio is

$$V_0 = \left(\frac{1+D}{(1-D)^2}\right)V_{in} \tag{12}$$

3) Modified Boost Converter with LY Configuration

When controlled device S is in ON condition, the voltage appearing across the inductors is

$$\left.\begin{aligned} V_{LX} &= V_{in} - 3V_d \\ V_{LY1} &= V_{LY2} = V_{C1} - 3V_d \end{aligned}\right\} \text{ON state} \tag{13}$$

The voltage equation in OFF state condition

$$\left.\begin{aligned} V_{LX} &= V_{in} - V_{C1} - 2V_d \\ V_{LY} &= \frac{V_{C1} - V_0 - 4V_d}{2} \end{aligned}\right\} \text{OFF state} \tag{14}$$

For Inductor L_X

$$\left.\begin{aligned} &(V_{in} - 3V_d)D + (V_{in} - V_{C1} - 2V_d)(1-D) = 0 \\ &V_{C1} = \left(\frac{1}{1-D}\right)V_{in} - \left(\frac{2+D}{1-D}\right)V_d \end{aligned}\right\} \tag{15}$$

For Inductor L_Y

$$\left.\begin{aligned} &(V_{C1} - 3V_d)D - \frac{(V_{C1} - V_0 - 4V_d)}{2}(1-D) = 0 \\ &V_0 = \left(\frac{1+D}{1-D}\right)V_{C1} - \left(\frac{2+D}{1-D}\right)2V_d \end{aligned}\right\} \tag{16}$$

From (15)

$$V_0 = \left(\frac{1+D}{(1-D)^2}\right)V_{in} - \left(\frac{6+D-D^2}{(1-D)^2}\right)V_d \tag{17}$$

If the internal voltage drop is neglected, then the voltage conversion ratio is

$$V_0 = \left(\frac{1+D}{(1-D)^2}\right)V_{in} \tag{18}$$

4) Modified Boost Converter with XY Configuration

When controlled device S is in ON condition, the voltage appearing across the inductors is

$$\left.\begin{aligned} V_{LX1} &= V_{LX2} = V_{in} - 4V_d \\ V_{LY1} &= V_{LY2} = V_{C1} - 3V_d \end{aligned}\right\} \text{ON state} \tag{19}$$

The voltage equation in OFF state condition

$$\left.\begin{aligned} V_{LX} &= \frac{V_{in} - V_{C1} - 4V_d}{2} \\ V_{LY} &= \frac{V_{C1} - V_0 - 4V_d}{2} \end{aligned}\right\} \text{OFF state} \tag{20}$$

For Inductor L_X

$$\left.\begin{aligned} &(V_{in} - 4V_d)D + \left(\frac{V_{in} - V_{C1} - 4V_d}{2}\right)(1-D) = 0 \\ &V_{C1} = \left(\frac{1+D}{1-D}\right)V_{in} - \left(\frac{1+D}{1-D}\right)4V_d \end{aligned}\right\} \tag{21}$$

For Inductor L_Y

$$\left.\begin{aligned} &(V_{C1} - 3V_d)D - \frac{(V_{C1} - V_0 - 4V_d)}{2}(1-D) = 0 \\ &V_0 = \left(\frac{1+D}{1-D}\right)V_{C1} - \left(\frac{2+D}{1-D}\right)2V_d \end{aligned}\right\} \tag{22}$$

From (21)

$$V_0 = \left(\frac{1+D}{1-D}\right)^2 V_{in} - 2\left(\frac{D^2+3D+4}{(1-D)^2}\right)V_d \tag{23}$$

If the internal voltage drop is neglected, then the voltage conversion ratio is

$$V_0 = \left(\frac{1+D}{1-D}\right)^2 V_{in} \tag{24}$$

IV. Results and Discussion

The proposed MB-LL, MBSI-XL, MBSI-LY and MBSI-XY configuration converters are designed for 250W resistive load. The high switching frequency (50kHz) is adopted to reduce the ripple content in output voltage and current and to reducing the component's size. The proposed converters are simulated in Matlab, Simulink 2014. The input supply for proposed converter is regulated 10V DC as shown in Fig.5. The time constant of regulated voltage supply is 0.05.

1) Modified Boost Converter with LL Configuration

The resistive load of 49Ω is designated for MB-LL configuration. The voltage across capacitor C_1 is 33.33V at 70% duty cycle as shown in Fig.6 (a). The output voltage of MB-LL configuration is 110.1V in Matlab, Simulink simulation as shown in Fig.6 (b). The output current of MB-

TABLE I. Number of Components and Voltage Conversion Ratio of Proposed Converter

Modified Boost Converter with Switched Inductor (SI) Configuration						
Modified Boost Converter		Component			Voltage Conversion Ratio	
		Inductor	Capacitor	Diode	V_{C1}/V_{in}	V_0/V_{in}
(SI) Structure	LL	2	2	3	1/(1-D)	$1/(1-D)^2$
	XL	3	2	6	(1+D)/(1-D)	$(1+D)/(1-D)^2$
	LY	3	2	6	1/(1-D)	$(1+D)/(1-D)^2$
	XY	4	2	9	(1+D)/(1-D)	$(1+D)^2/(1-D)^2$

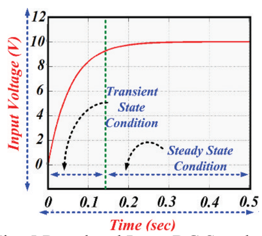
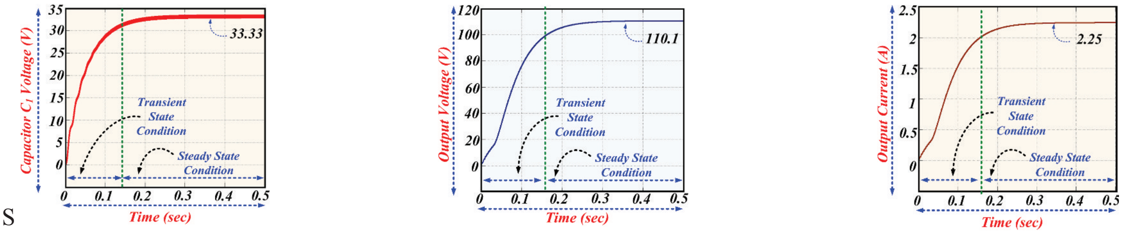


Fig. 5 Regulated Input DC Supply.



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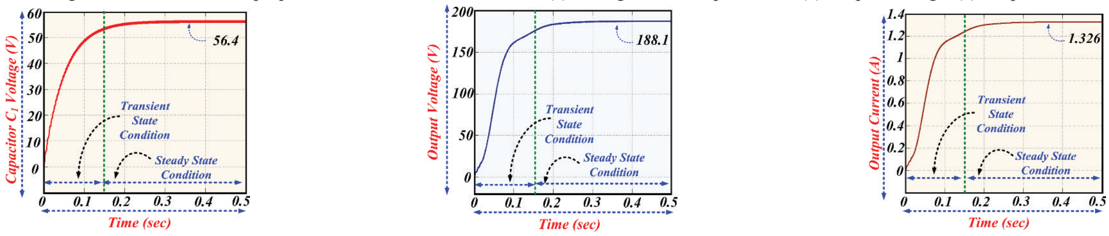
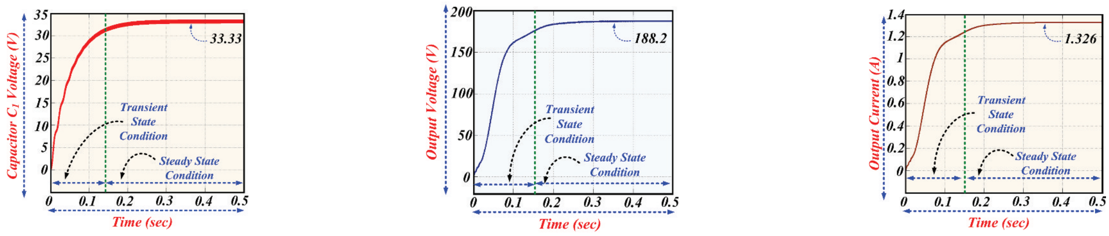
(a) (b) (c)

Fig.6 Simulation result of proposed MB-LL structure Converter (a) Voltage across Capacitor C_1, (b) Output Voltage, (c) Output Current.



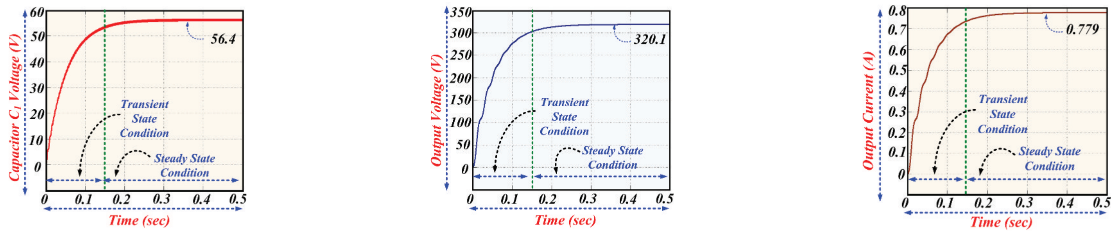
(a) (b) (c)

Fig.7 Simulation result of proposed MBSI-XL structure Converter (a) Voltage across Capacitor C_1, (b) Output Voltage, (c) Output Current.



(a) (b) (c)

Fig.8 Simulation result of proposed MBSI-LY structure Converter (a) Voltage across Capacitor C_1, (b) Output Voltage, (c) Output Current.



(a) (b) (c)

Fig.9 Simulation result of proposed MBSI-XY structure converter (a) Voltage across capacitor C_1, (b) Output voltage, (c) Output current.

LL configuration is 2.25A as shown in Fig.6 (c).

2) Modified Boost Converter with XL Configuration

The resistive load of 142Ω is designated for MBSI-XL configuration. The voltage across capacitor C_1 is 56.61V at 70% duty cycle as shown in Fig.7 (a). The output voltage of MBSI-XL configuration is 188.51V in Matlab, Simulink simulation as shown in Fig.7 (b). The output current of MBSI-XL configuration converter is 1.327 A as shown in Fig.7 (c).

3) Modified Boost Converter with LY Configuration

The resistive load of 142Ω is designated for MBSI-LY configuration. The voltage across capacitor C_1 is 33.33V at 70% duty cycle as shown in Fig.8 (a). The output voltage of MBSI-LY configuration is 188.51V in Matlab, Simulink simulation as shown in Fig.8 (b). The output current of MBSI-LY configuration converter is 1.327 A as shown in Fig.8 (c).

4) Modified Boost Converter with XY Configuration

The resistive load of 410Ω is designated for MBSI-XY configuration. The voltage across capacitor C_1 is 56.61V at 70% duty cycle as shown in Fig.9 (a). The output voltage of MBSI-XY configuration is 320.46V in Matlab, Simulink simulation as shown in Fig.9 (b). The output current of MBSI-XL configuration converter is 0.78 A as shown in Fig.9 (c).

Fig. 10(a)-(d) shows the voltage conversion ratio vs duty ratio for four configurations of proposed converter. The maximum voltage conversion ratio of MB-LL configuration is 100 without considering internal voltage drop and 96.9 with considering internal voltage drop of 0.01 at 90% duty ratio as shown in Fig. 10(a). For MBSI-XY configuration, the maximum conversion ratio is 361 without considering internal voltage drop and 346 with considering internal voltage drop of 0.01 at 90% duty ratio as shown in Fig. 10(d). The MB-LL configuration have a lower voltage conversion ratio, but the higher efficiency as compared to other three configurations of MBC. The MBSI-XY Configuration having a higher voltage conversion ratio, but lower efficiency as compared to other three configurations of MBC. The MBSI-XL and MBSI-LY configuration have same voltage conversion ratio, but MBSI-LY configuration is more efficient than MBSI-XL configuration. The voltage drop in output voltage due to internal resistance is 3.22%, 4.28%, 3.31% and 4.33% of output voltage in MB-LL, MBSI-XL, MBSI-YL and MBSI-XY configuration respectively.

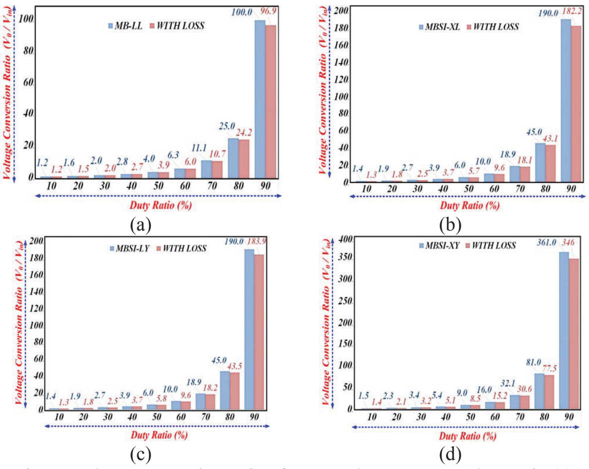


Fig.10 Voltage conversion ratio of proposed converter Vs duty ratio (a) MB-LL, (b) MBSI-XL, (c) MBSI-LY and (d) MBSI-XY Configuration.

V. Conclusion

In this paper modified boost converter and its four different configurations using Switched Inductor (SI) structure -modified boost converter with LL configuration (MB-LL), modified boost converter with XL configuration (MBSI-XL), modified boost converter with LY configuration (MBSI-LY), and modified boost converter with XY configuration (MBSI-XY) is presented. The detailed analysis of four different configurations of the modified boost converter is done. Among four configurations, MBSI-XY configuration having a higher voltage conversion ratio. MBSI-XL and MBSI-LY configuration have a similar voltage conversion ratio. The efficiency of MBSI-XY converter is low as compared to MB-LL, MBSI-XL and MBSI-LY configuration. The number of components is less in MB-LL configuration and more in MBSI-XY configuration. The MB-LL configuration is more efficient as compared to other three configurations. MBSI-LY have higher efficiency than MBSI-XL, even though have the same number of component count. The SI structure, position affects the efficiency of the converter.The comparative analysis of four different configurations of MBC is done with respective of voltage conversion ratio, number of components and efficiency of the converter. The simulation of four configurations is done in Matlab, Simulink for 250W. The Matlab results speak the achievability of the modified boost converter and its different configurations.

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