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Analysis and Comparison of Bridgeless LUO Converter and Bridgeless buck-Boost Converter

Jayeshri T.Badole
Dept of Electrical Engg.
PCE, Nagpur
email: jayeshri.b@gmail.com

Dr.(Mrs.) S.P. Muley
Professor
Dept of Electrical Engg.
PCE, Nagpur

Mr. Rahul Adle
Assistant Professor
Dept of Electrical Engg
PCE, Nagpur

Abstract— This paper presents an analysis of bridgeless converters using two methodologies. The conventional converter have higher switching losses due to presence of diode bridge rectifier in front end, hence use of improved quality converters such as bridgeless converters is preferred. The bridgeless configurations being used are of two types i.e., by using bridgeless Luo (BL-Luo) converter and by using bridgeless (BL) buck-boost converter. The bridgeless converters used eliminates diode bridge rectifier, thus reducing conduction losses which are incurred by these topologies. The analysis is done by comparing both converters in aspect of their performance. The performance of the proposed bridgeless converters is simulated in MATLAB/Simulink.

Keywords- Bridgeles(BL) buck-boost converter, bridgeless Luo (BL-Luo).

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I. Introduction

Bridgeless converters have the inherent quality of having improved power factor at ac mains. Bridgeless converters are becoming increasingly popular in past decade due to their high efficiency. The diode bridge rectifier in front-end is eliminated in these configurations, which reduce conduction losses associated with it. The elimination of diode bridge improves overall efficiency of the system, hence bridgeless converters termed as improved power quality converters.

The conventional converters fed BLDC motor drive use a pulse width modulated voltage source inverter for speed control with constant dc voltage. This scheme has higher switching losses in voltage source inverter (VSI). The speed of BLDC motor is directly proportional to dc link voltage, therefore speed control is achieved by varying dc link voltage of VSI. Hence this allows switching at fundamental frequency of VSI i.e. electronic commutation. This helps in reducing switching losses. This type of conventional converters have electromagnetic interference (EMI) problems such as eddy current loss, hysteresis loss, skin effect, high overshoot transients and voltage drop which affect the performance and overall efficiency of the system. Therefore improved power quality converters (IPQC's) must be used for improving power quality at ac mains. This helps in reducing EMI problems [1][2].

The bridgeless buck and boost converters have been reported in literature [3][4]. The bridgeless SEPIC and Cuk converter are also popular due to having wide range of voltage conversion ratio [5][6]. The comparative analysis of various converter topologies for PFC (power factor correction) in switched reluctance motor drives is reported in [7].

The Luo converter is been used due to inherent characteristics of voltage lifting [8]-[12]. There are many versions of Luo converter voltage lifting technique such as relift, superlift and ultralift are reported in [10]-[12]. The use of Luo converter as a power factor corrected converter is explored in [13]. The bridgeless Luo converter is combination of two dc to dc converters with semiconductor switches connected in there circuit. They result in reducing the current stresses in active and passive switches. The Luo converters are new dc to dc converters having low ripple voltage and ripple current. They have high quality output wave, high transfer voltage gain and high power density. The buck-boost converter configuration is best in bridgeless converter topologies for wide range of dc link voltage control applications (i.e. bucking and boosting mode). The bridgeless buck and boost converters are presented in [14]. These can work in both voltage buck as well as voltage boost mode [14][15]. The proposed BL buck–boost converter is also reported but use three switches which is not a cost-effective solution [15].

This paper presents an analysis and comparison for bridgeless converters i.e. BL Luo and BL buck-boost converter for its performance.

The Fig. 1 and Fig. 2 shows circuit for BL Luo and BL buck-boost converter.

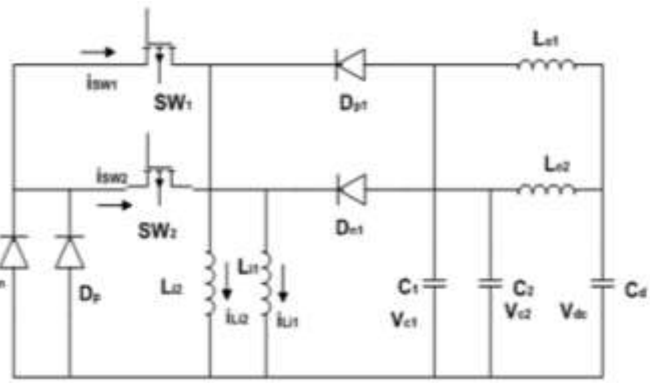

Fig.1. Bridgeless Luo converter

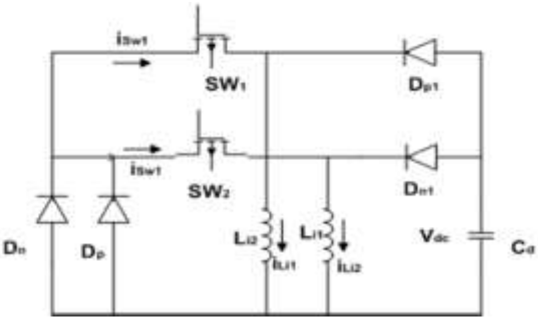

Fig.2. Bridgeless buck-boost converter

II. Principle of Operation for Bridgeless Converters

The operation of proposed BL converters is divided in two parts which includes the operation during positive and negative half cycles of supply voltage and during the complete cycle.

A. *Operation for positive and negative half cycles of supply voltage*

The bridgeless converter is so designed that two different switches operate for positive half and negative half cycles of supply voltages. In Fig. 2 for BL Luo converter; switch S_{w1}, inductor L_{i1} and L_{o1}, and diodes D_{p1} and D_p are operated to transfer energy to dc link capacitor C_d for positive half cycle and switch S_{w2}, inductor L_{i2} and L_{o2}, and diodes D_{n1} and D_n are operated to transfer energy to dc link capacitor C_d for negative half cycle. In Fig. 3 for BL buck-boost converter; switch switch S_{w1}, inductor L_{i1}, and diodes D_{p1} and D_p operate during positive half cycle and switch S_{w2}, inductor L_{i2}, and diodes D_{n1} and D_n operate during negative half cycle to transfer energy to dc link capacitor C_d .

B. *Operation during complete switching cycle*

1. ***For BL Luo converter*** – The operation of the BL-Luo converter during a complete switching cycle for a positive half cycle of supply voltage is as follows-

<u>*Mode I:*</u> When switch S_{w1} is turned on the input inductor (L_{i1}) store energy, which depends upon the current (i_{Li}) flowing through it and the inductor value (L_{i1}). The energy stored in the intermediate capacitor (C_1) is then transferred to the dc-link capacitor (C_d) and the output side inductor (L_{o1}). Hence, the voltage in the intermediate capacitor (V_{C1}) decreases, and the current in the output inductor (i_{Lo1}) and in the dc link voltage (V_{dc}) are increased.

<u>*Mode II:*</u> When switch S_{w1} is turned off, the input inductor (L_{i1}) transfers energy stored in it to the intermediate capacitor (C_1) via diode D_{p1}. Hence, the current i_{Li1} decreases till it reaches zero, and the voltage across the intermediate capacitor (V_{c1}) increase. The dc-link capacitor (C_d) provide the energy to the load; therefore the dc link voltage V_{dc} reduces in this mode.

<u>*Mode III:*</u> *There is* no energy left in the input inductor (L_{i1}), hence current i_{Li1} becomes zero and it then enters the discontinuous conduction mode of operation. In this mode the intermediate capacitor (C_1) and output inductor (L_{o1}) are discharged; hence, current i_{Lo1} and voltage V_{c1} are reduced. The dc-link voltage V_{dc} increases in this mode. And the operation is repeated when switch S_{w1} is turned on again.

In a similar way, for a negative half cycle of supply voltage, the inductor's L_{i2} and L_{o2}, diode D_{n1}, and intermediate capacitor C_2 conduct in this mode to achieve further operation for all modes.

2. ***For BL buck-boost converter*** - The operation of the BL buck-boost converter during a complete switching cycle for a positive half cycle of supply voltage is as below-

<u>*Mode I:*</u> In this mode, switch S_{w1} is turned on to charge the inductor L_{i1}; therefore an inductor current i_{Li1} increases in this mode. Diode D_p completes the input side in the circuit, where in this mode the dc link capacitor C_d is discharged.

<u>*Mode II:*</u> In this mode of operation the moment when the switch S_{w1} is turned off then the energy which is stored in inductor L_{i1} is transferred to dc link capacitor C_d till the inductor is completely discharged. The current in inductor L_{i1} reduces and further reaches to zero.

<u>*Mode III:*</u> The inductor L_{i1} enters discontinuous conduction mode and hence there is no energy left in the inductor. Therefore current i_{Li1} becomes zero. The dc link capacitor C_d supply energy to the load; hence, voltage V_{dc} across dc link capacitor C_d starts to decrease. The operation is repeated further when switch S_{w1} is turned on again after a complete switching cycle.

For the negative half cycle, switch S_{w2}, inductor L_{i2}, and diodes D_n and D_{n1} operate for voltage control in similar manner for all modes.

III. Design of BL-Luo Converter

The average voltage at input side is given as-

$$V_{in} = \frac{2\sqrt{2}V_s}{\pi} = \frac{2\sqrt{2}\times 220}{\pi} = 198.069$$

The voltage conversion or duty ratio for Luo converter is given as-

$$d = \frac{V_{dc}}{V_{dc} + V_{in}}$$

Where d is voltage conversion ratio or duty ratio

The BL Luo converter for dc link voltage control from 50 V ($V_{dc\ min}$) to 200 V ($V_{dc\ max}$). The minimum and the maximum duty ratio (d_{min} & d_{max}) corresponding to the values for ($V_{dc\ min}$) *and* ($V_{dc\ max}$) are calculated as- 0.2016 and 0.5025 using the above voltage conversion ratio.

A. *Designing of Input Inductors (L_{i1} and L_{i2})*

The value of inductance L_{ic1}, which is to be operated in critical conduction mode in the Luo converter, is given as-

$$L_{ic} = \frac{d_{min}(1-d_{min})V_{in}}{2I_o f_s}$$
$$= \frac{0.2016\times(1-0.2016)\times 198}{2\times\left(\frac{100}{50}\right)\times 20000}$$
$$= 398\mu H$$

Where f_s is switching frequency which is 20 KHz. The value of inductor selected is taken as 40 μH.

B. Designing of Intermediate Capacitors (C_1 and C_2)

The value of the intermediate capacitors (C_1 and C_2) is calculated for the duty ratio (d_{max}) is given as follows -

$$C_{1,2} = \frac{d_{max}V_C}{2f_s\, R_L\left(\frac{\Delta V_c}{2}\right)}$$
$$= \frac{0.5025 \times 398}{2 \times 20000 \times 100 \times 119.4}$$
$$= 0.419\mu F$$

Where R_L is load resistance, i.e., $V_{dc}{}^2/P_{max} = 200^2/400 = 100\Omega$ and V_c is the voltage appearing across C_1 and C_2 i.e., $V_{in} + V_c$ and ΔV_c is ripple which is taken as 60% of V_c.

Hence the values for intermediate capacitors so taken for C_1 and C_2 are selected as 0.44 μF.

C. Designing of output inductors (L_{o1} and L_{o2})

The value of the output inductors L_{o1} and L_{o2} for the ripple current in the output inductors (which is taken as 10% of I_o) is calculated as-

$$L_{o1,2} = \frac{d_{max}I_0}{16f_s{}^2\, C_{in}\left(\frac{\Delta I_o}{2}\right)}$$
$$= \frac{0.5025 \times 2}{16 \times 20000^2 \times 0.44 \times 10^{-6} \times 0.2}$$
$$= 1.78mH$$

D. Designing of DC Link Capacitor (C_d)

It is derived as follows-

$$C_d = \frac{I_0}{2\,\omega_L\,\Delta V_{dc\ min}}$$
$$= \frac{2}{2 \times 314 \times (0.03 \times 50)}$$
$$= 2123.14\mu F$$

Where ΔV_{dc} is ripple voltage in the dc link capacitor (taken as 3%) and ω_L is the line frequency in radians per second.

Hence, the value of dc-link capacitor of 2200 μF is selected.

E. Designing of Input Filter (L_f and C_f)

The maximum value of capacitance is given by-

$$C_{max} = \frac{I_{peak}}{\omega_L V_{peak}}\tan(\theta)$$
$$= \frac{\frac{400\sqrt{2}}{220}}{314 \times 220\sqrt{2}}\tan(1^\circ)$$
$$= 459.4nF$$

Where V_{peak} and I_{peak} represents the peak values of voltage and current and θ represents the displacement angle between them which is taken 1°.

The value of inductance given by-

$$L_f = L_{req} + L_s = \frac{1}{4\pi^2 f_c{}^2 C_f}$$
$$= L_{req} + 0.04\left(\frac{1}{\omega_L}\right)\left(\frac{V_s{}^2}{P_o}\right)$$
$$L_f = \frac{1}{4\pi^2 \times 2000^2 \times 330 \times 10^{-9}} - 0.04\left(\frac{1}{314}\right)\left(\frac{220^2}{400}\right)$$
$$= 3.77\ mH$$

Hence value for LC fiter is choosen as $3.77\ mH$ and $330\ nF$.

IV. Design of BL Buck-Boost Converter

The designing for BL buck-boost converter is similar as for BL Luo converter as mentioned in part III.

The calculated parameters for BL buck-boost are-

1. The value for input inductors (L_{i1} and L_{i2}) are selected as 35 μH.
2. The value for dc link capacitor (C_d) is 2200 μF.
3. The value for input filter (L_f and C_f) are $1.57\ mH$ and $330\ nF$.

V. Simulated Performance of Proposed Converters

Fig.3 shows the Simulink model for BL Luo converter and Fig.4 shows the simulation results for it .

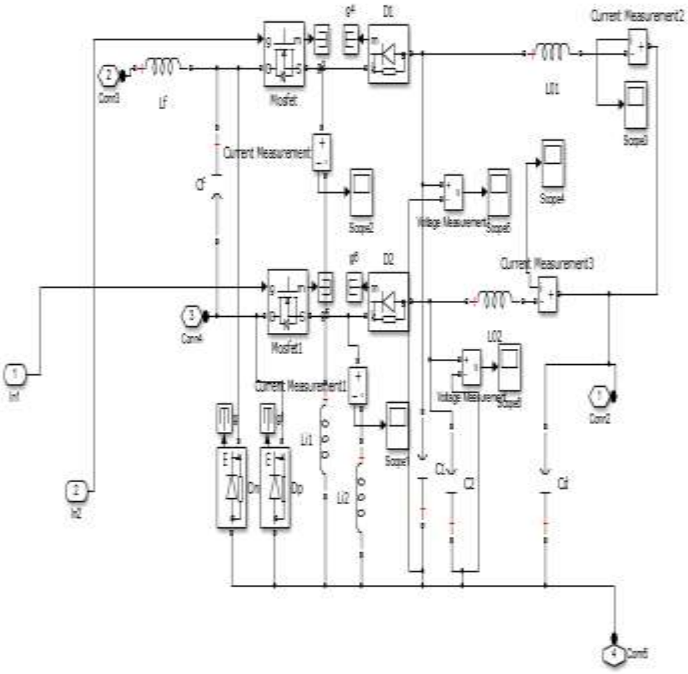

Fig 3. Simulink model for BL Luo converter

Fig.4 shows the Simulink model for BL buck-boost converter and Fig.6 shows the simulation results for it.

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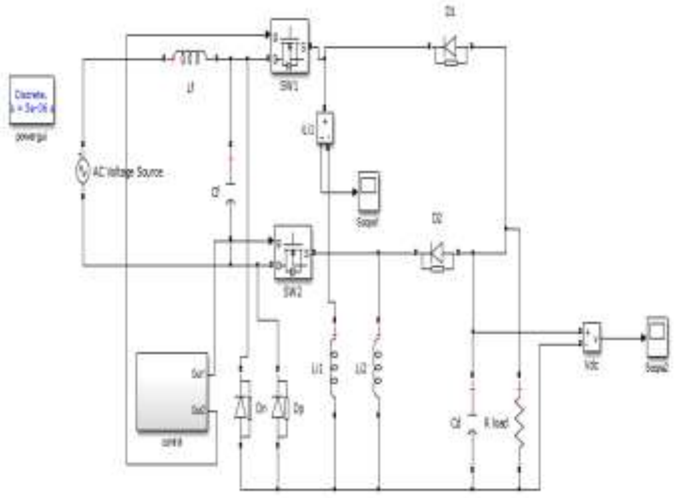


Fig 4. Simulink model for BL buck-boost converter

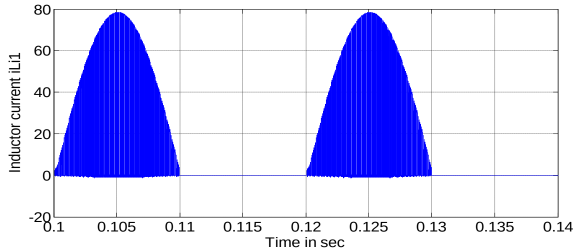
Simulation is carried out in MATLAB/Simulink with following parameters-

For BL Luo converter-

L_f = 3.77* 10^{-3} H , C_f = 330* 10^{-9} F, L_{i1}= L_{i2}= 40* 10^{-6} H, L_{o1} = L_{o2} = 1.78* 10^{-3}H ,C_1 = C_2 = 0.44* 10^{-6}F, C_d = 2200* 10^{-6}F.

For BL buck-boost converter-

L_f = 1.57* 10^{-3} H, C_f = 330* 10^{-9} F, L_{i1} = L_{i2} = 35* 10^{-6} H, C_d = 2200* 10^{-6}F.



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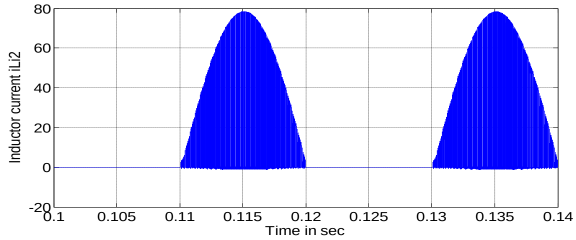

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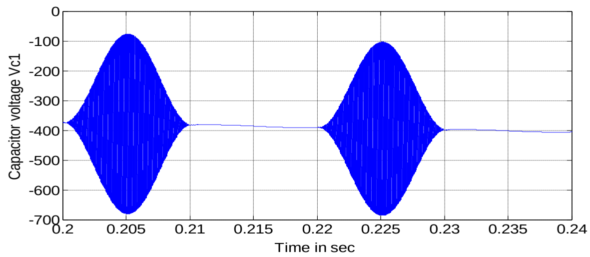
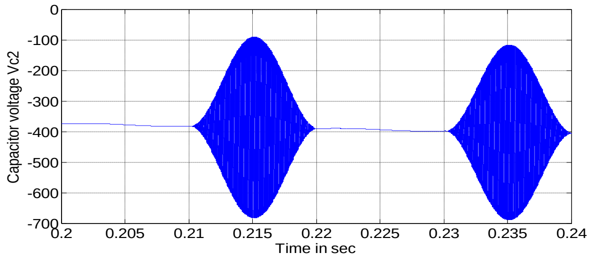
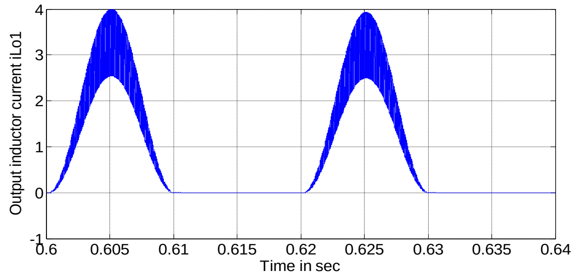


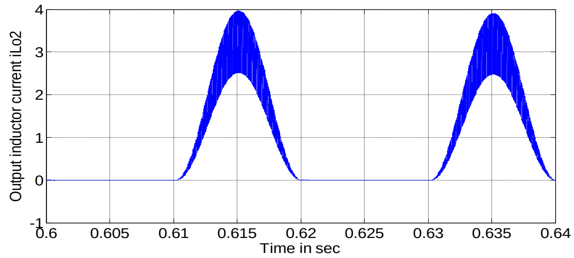
(c)



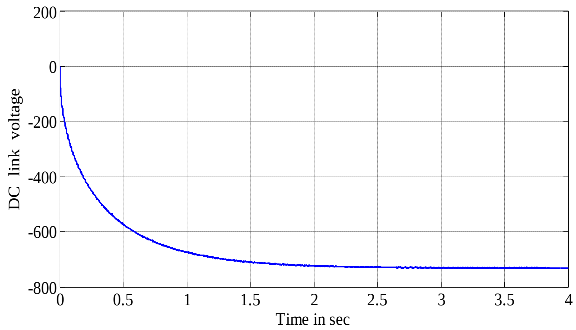
(d)



(e)

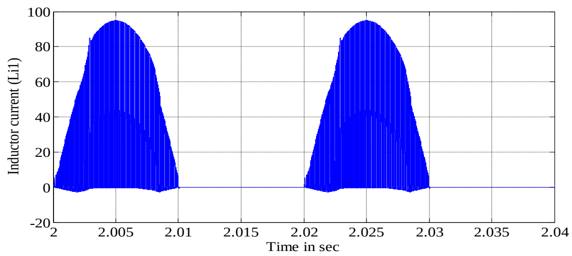


(f)



(g)

Fig 5. Simulation results Luo converter: (a),(b)- Input inductor current; (c),(d)- Capacitor voltage; (e),(f)- Output inductor current; (g)- Dc link capacitor voltage.



(a)

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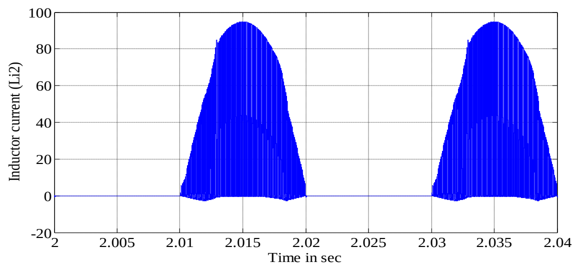

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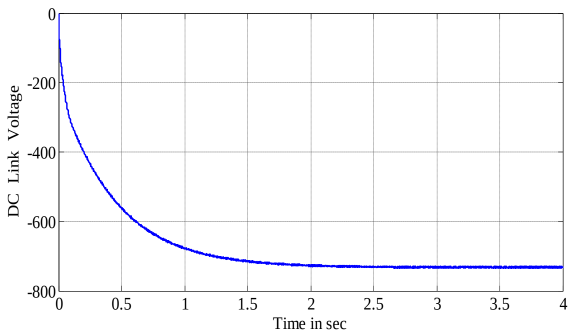

(c)

Fig 6. Simulation results for BL buck-boost converter: (a),(b)- Inductor current ; (c)- DC link capacitor voltage.

Fig 5. shows the simulation results for BL Luo converter. In this Fig 5(a), 5(b) shows the simulation result for input inductor current i.e. $(i_{Li1}\ and\ i_{Li2})$, thus showing the results for positive and negative half cycles. Fig 5(c), 5(d) shows the simulation results for intermediate capacitor voltage i.e. $(V_{C1}\ and\ V_{C2})$, it stabalizes in negative region. The results are shown for both positive as well as negative half cycle. Fig 5(e), 5(f) shows the simulation results for output inductor current i.e. $(i_{Lo1}\ and\ i_{Lo2})$ for both positive and negative half cycles thus showing the ripple current. Fig 5(g) shows the simulation result for dc link voltage.

Fig 6. shows the simulation results for BL buck-boost converter. In this fig 6(a), 6(b) shows the simulation results for input inductor current i.e. $(i_{Li1}\ and\ i_{Li2})$, showing results for positive and negative half cycles. Fig 6(c) shows the simulation result for dc-link voltage.

When the comparative analysis is done for both converters regarding dc link voltage, it is observed that BL Luo converter gives more smooth output dc link voltage in comparison with BL buck-boost converter. Thus BL Luo converter is found to be best than BL buck-boost converter in any aspect through analysis.

VI. CONCLUSION

The comparative analysis for two types of bridgeless configurations i.e BL Luo and BL buck-boost have been discussed along with its simulation in MATLAB. On the basis of comparison Luo converter is the most suitable converter. It provides high efficiency output, better speed response and reduced torque ripples when it is compared with the BL buck-boost converter.

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