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Design and analysis of high gain Re Boost-Luo converter for high power DC application

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ABSTRACT

This paper introduces a new Re Boost-Luo converter which is a combination of Luo converter and Fly back converter. This proposed converter provides high output gain with low amount of input DC voltage with less duty cycle. In this proposed methodology, the number of inductors utilized gets reduced, thus suppressing the leakage reactance problem. The new converter presented here is also suitable for PV fed renewable applications. The proposed Re-Boost Luo converter reduces the ripples in the converter output voltage very effectively. With the fly back topology, this designed new converter tracks the isolated output voltage with reduced ripples. The PI controller performs closed loop voltage operation with variable input voltage. This controller achieves steady state operation with different input and load variation. Matlab simulation is developed for verifying the performance of the proposed system.

Selection and Peer-review under responsibility of the scientific committee of the International Conference on Future Generation Functional Materials and Research 2020.

1. Introduction

The Isolated DC-DC converters are commonly utilized for high power application because of high efficiency, simple control, steady state input current, high voltage gain and lower order voltage ripple contents. In recent days, many researchers have focussed on Luo converter due to high output voltage gain and continuous input current operation. This proposed converter is developed from Super lift elementary Luo converter topology. The PV application also requires high gain converters with optimized algorithms for tracking maximum power from input side. The boost converters are widely used in researches [1,2]. The output voltage gain is very low for a boost and buck-boost converter topologies and it also has higher order ripple contents in its output voltage and thus the buck-boost type converter suffers from output voltage polarity problem. This drawback reduces the effectiveness of the converter. Buck-boost converter voltage is a non-isolated voltage. These drawbacks are overcome in [3]. The isolated boost integrated converter is developed even though the gain is very less for this converter. To reduce the leakage reactance problem, magnetically coupled DC-DC converter is developed. This converter having high efficiency, the different shaped inductors reduce the leakage reactance problem [4].

The isolated buck boost converter with active rectifiers are discussed in [4], in this the waveform is discontinuous for the converter input waveform. This increase the output voltage ripples. The single switch operation increases the switching losses. These drawbacks are overcome in [5]. For both buck and boost operation separate switches are used. But in this converter, power loss is very high due to two switch operation. In paper [6] to boost the output voltage, cascaded type converters are used. But here capacitor is working in discontinuous mode, this reduce the efficiency of the work. The low output gain problem is solved in [7]. The SEPIC converter is used to increase the output gain with less duty cycle. This can reduce the switching stress with less output voltage and current ripples. For PV based renewable applications, this converter is suitable. The SEPIC converter with bridgeless topology is discussed in [8]. But this system only suitable for AC input power based applications. The SEPIC converter drawbacks are overcame by the Modified SEPIC converter and this converter topology is used in medium power applications [9]. Re lift converters are used in high power applications [10,11]. This type of converters reduces the voltage stress for the DC-DC converter. But it requires huge amount of inductance. LLC converters are introduced in [12], this LLC converters utilizing the transformer for increasing the output voltage gain. This converter output depends on the transformer turns ratio.

Finally Luo converter is developed to achieve high output gain with lifting constant all the existing issues are overcome. The

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proposed hybrid-lift DC-DC converter increases the output voltage gain with less ripple content. The PI controller achieves steady state voltage operation.

2. Proposed Re Boost-Luo converter

This proposed converter is a combination of elementary Super lift Luo converter and Fly back converter. The circuit has four diodes, four capacitors and one step up isolation transformer. The coil from this transformer is used as an inductor. The Re Boost-Luo converter is shown in Fig. 1.

The main advantage of proposed converter is continuous input current operation; the transformer primary winding achieves this operation. The two mode of operation is explained here and also the switch on and switch off periods are analysed.

During switch on period, magnetizing inductance of the isolation transformer gets charged, at that time, the diode D1 to D4 in off condition and also the capacitor C1, C2 and C3 in discharging condition.

The Figs. 2 and 3 indicate the current direction of the proposed converter during on and off period.

2.1. Mode 1 operation

During mode 1 the switch S of the Re-boost converter is turned ON. This causes the current to flow through the primary of the isolation transformer thus charging the magnetizing inductance of the transformer at this time the secondary winding is not in conduction. Meanwhile the capacitor C1 gets charged up by the capacitor Co which is in charged state due by the previous operations at this stage the diode D3 is at forward biased condition. Now the output capacitor Co gets disconnected from the remaining part of the circuit as the diodes D2 in off state and Co discharges through the output load resistor R_L.

2.2. Mode 2 operation

In mode 2 the switch S is turned off. This time the current flow direction through the transformers primary doesn't get changed it follows the same direction as the in Mode 1 thus causing the input current to be continues in nature compared to other converters. At this mode the diodes D1 in forward bias that is turns on leaving diode D2 in off state. The capacitor C2 gets charged through the diodes D1 while the capacitor C1 which was charged by the previous mode gets added up with primary inductors charge and flows towards the output capacitor Co through the transformers secondary winding and charges the output capacitor to a higher voltage compared to the input voltage this voltage level can be controlled by increasing or decreasing the duty cycle and frequency (Fig. 4).

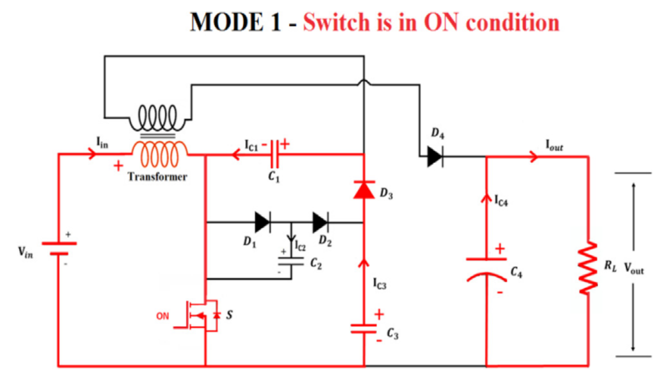

Fig. 2. Switch on mode condition flow diagram.

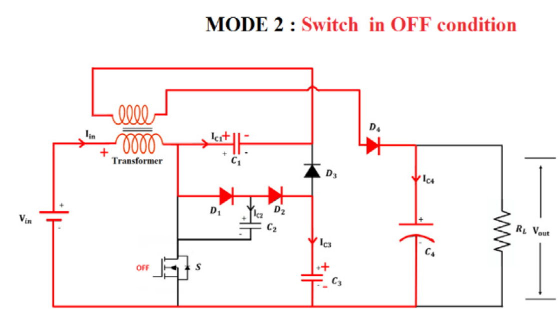

Fig. 3. Switch off mode condition flow diagram.

3. Analysis of proposed Re Boost Luo converter

The Luo converter's circuit diagram is given in Fig. 5.

The output potential difference of the above elementary converter is,

$$V_o = \left(\frac{(2-\alpha)}{(1-\alpha)}\right)V_{in} \tag{1}$$

where α is the duty cycle.

From the Eq. (1),

$$\text{Output gain } G = (V_o)/V_{in} = \left(\frac{(2-\alpha)}{(1-\alpha)}\right) \tag{2}$$

The transformer will work as an inductor when its primary and secondary windings are connected in cascade. Hence for the purpose of analysis, the proposed transformer structure is viewed as an inductor. Now the input current will be the sum of current flowing through the inductor and capacitor.

The input rate of flow of electron, I_{in} is given by

$$I_{in} = I_{L1} + I_{C1} \tag{3}$$

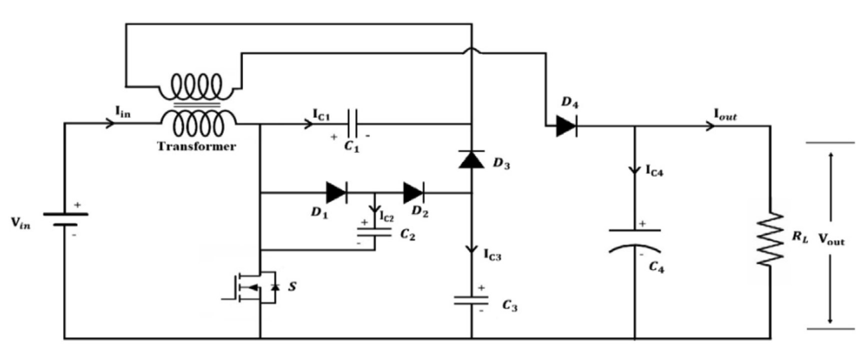

Fig. 1. New topology of DC-DC Re-Boost Luo converter.

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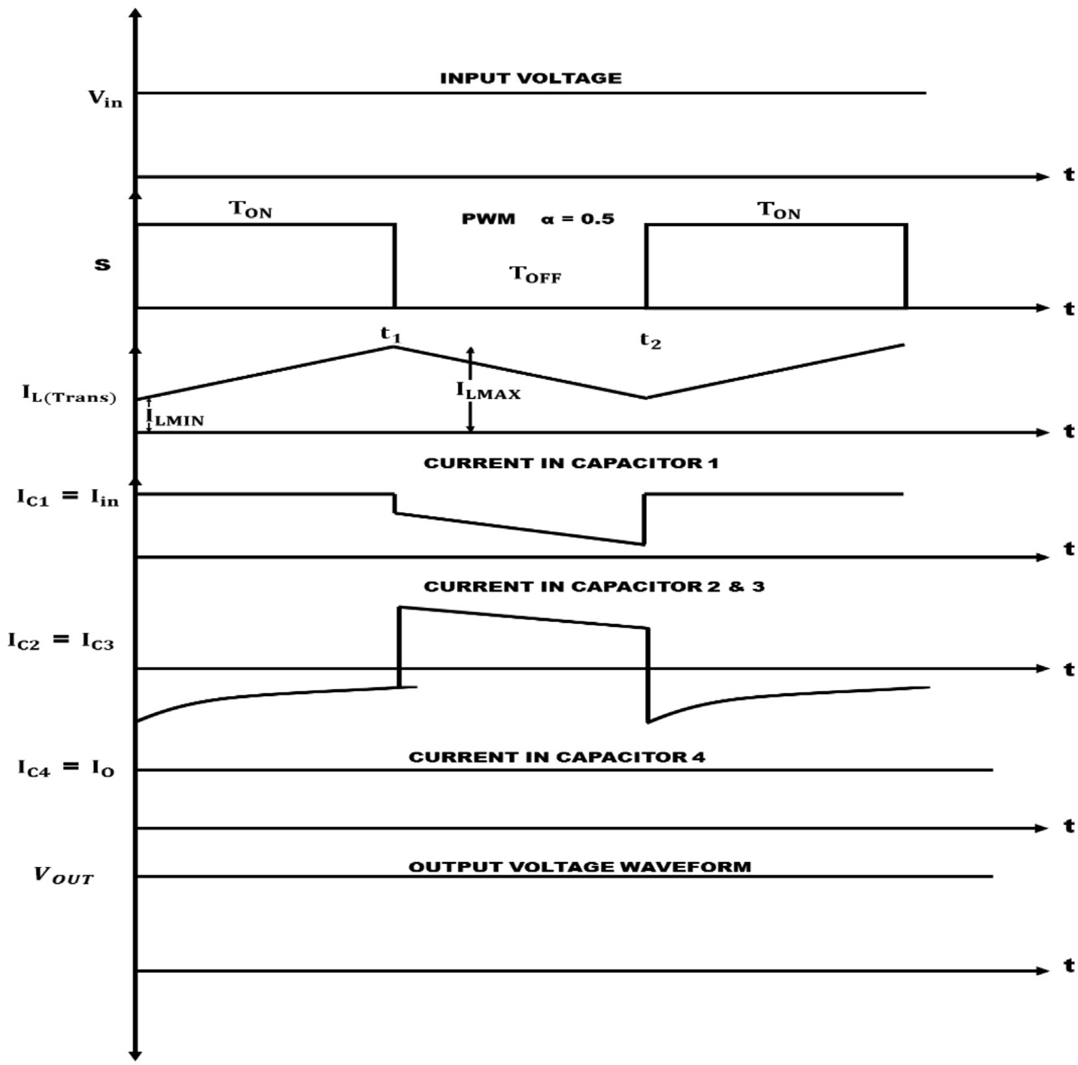

Fig. 4. Switching waveform of proposed Re Boost Luo converter.

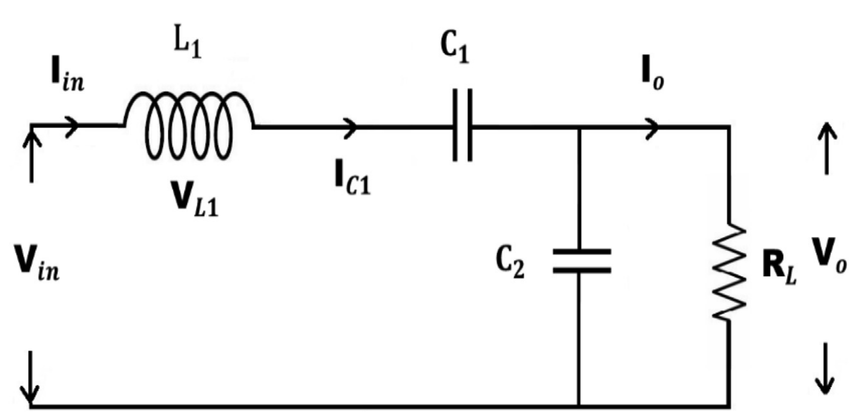

Fig. 5. Elementary circuit of Luo converter.

The ripple currents present in the inductor is given α

$$\Delta T_{L1} = \frac{V_{in}.\alpha.T}{L1} \quad (4)$$

where T → Total time of the switching pulse

The ripple in the output voltage is expressed as,

$$\Delta V_0 = \frac{I_0(1-\alpha).T}{C_2} \quad (5)$$

$$\mathrm{T} = \frac{1}{f} \quad (6)$$

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$$I_0 = \frac{V_0}{R} \tag{7}$$

Sub (6) & (7) in Eq. (5),

$$\Delta V_0 = \frac{Vo(1-\alpha)}{fC2R} \tag{8}$$

From Eq. (1)

$$V_{in} = V_0\left(\frac{1-\alpha}{2-\alpha}\right) \tag{9}$$

Input current,

$$I_{in} = \frac{V_{in}}{R} = \frac{V_0}{R}\left(\frac{1-\alpha}{2-\alpha}\right) \tag{10}$$

Therefore,

$$\frac{V_{in}}{I_{in}} = \left(\frac{(1-\ \alpha)}{(2-\ \alpha)}\right)^2 \cdot \frac{V_0}{V_0/R}$$

$$\frac{V_{in}}{I_{in}} = \left(\frac{(1-\alpha)}{(2-\alpha)}\right)^2 \mathrm{R} \tag{11}$$

From the above equations, we can derive the model for the proposed Re Boost-Luo Converter.

Re Boost-Luo Converter is done with conventional fly back converters and elementary super life Luo Converter. An elementary Luo Converter with three diodes and three capacitor forms the proposed converter. In order to achieve high output gain, transformer is used as an Inductor.

In proposed converter, the capacitor C_1 is changed with input voltage. The ripple current of the primary winding of the transformer is,

$$\Delta I_{L1} = \frac{\mathrm{Vin}.\alpha.\mathrm{T}}{L1_{(N1)}} \tag{12}$$

where $L_{1\ (N1)\rightarrow}$ Inductance of the multi taped transformer primary winding.

The potential difference in the capacitor C_2 is

$$V_{C2} = \left(\frac{(2-\alpha)}{(1-\alpha)}\right)V_{in} \tag{13}$$

The ripple currents in the secondary winding of Luo transformer is,

$$\Delta I_{L2} = \frac{V_{C2}.\alpha.T}{L2_{(N2)}} \tag{14}$$

Voltage in the capacitor C3 is,

$$V_{C3} = \left(\frac{(2-\alpha)}{(1-\alpha)}\right)V_{in} \tag{15}$$

Voltage in the capacitor C_4 is expressed as,

$$V_{C4} = V_0 \tag{16}$$

The potential difference at the output of the proposed Re-Boost Luo Converter is,

$$V_0 = \frac{N_2}{N_1}\left(\frac{(2-\alpha)}{(1-\alpha)}\right)V_{in} \tag{17}$$

where

$N_2 \rightarrow$ No of turns in the secondary winding.
$N_1 \rightarrow$ No of turns in the primary winding.

The potential difference at the output of converter depends on number of turns and duty cycle of the converter.

4. Design new converter

The proposed Re Boost Luo converter has designed for 20–70 V DC input voltage and expected reference output voltage is 200 V.

Therefore

V_{in} = 20 V
V_{out} = 200 V

Re Boost-Luo converter output voltage is given by,

$$\mathrm{V_o} = \left(\frac{N_2}{N_1}\right)\left(\frac{(2-\alpha)}{(1-\alpha)}\right)\cdot \mathrm{V_{in}}$$

(i) Turns Ratio:

From the above equation,
Number of turns ratio in the isolation transformer required is

$$\frac{N_2}{N_1} = \frac{V_0}{V_{in}}\cdot\left(\frac{(1-\alpha)}{(2-\alpha)}\right) \tag{18}$$

Initial duty cycle α = 0.5

$$\frac{200}{20}\cdot\left(\frac{(1-0.5)}{(2-0.5)}\right)$$

$$= 10 \times \left(\frac{0.5}{1.5}\right)$$

$$= 10 \times 0.33$$

$$= 3.33(\ 3)$$

Therefore turns ratio used here is 1:3 where ($\frac{N_2}{N_1} = 3$).

(ii) Output Gain:

Output gain is calculated from,

$$\frac{V_0}{V_{in}} = \frac{N_2}{N_1}\cdot\left(\frac{(2-\alpha)}{(1-\alpha)}\right) \tag{19}$$

$$= 3.33\cdot\left(\frac{(2-0.5)}{(1-0.5)}\right)$$

$$= 3.33(1.5/0.5)$$

$$= 3.33 \times 3$$

$$G = 9.99$$

Output gain = 10 = G

(iii) Load Resistance:

In the proposed system, the output power requirement is 200 W,

$$I_{out} = \frac{P_{out}}{V_{out}} \tag{20}$$

$$= \frac{200}{200}$$

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$I_{out} = 1$ Amps

Load Resistance

$$R_L = \frac{V_{out}}{I_{out}} \tag{21}$$

$$= \frac{200}{1}$$

$$R_L = 200\Omega$$

(iv) Capacitor Voltages:

The voltage across each capacitor is found from the formula given below,

V_{c1} = Input voltage V_{in}

V_{c1} = 20 V

Voltage across capacitor C_2 and C_3 are,

$$V_{C2} = V_{C3} \cdot \left(\frac{(2-\alpha)}{(1-\alpha)}\right) \cdot (V_{in})$$

$$= \left(\frac{(2-0.5)}{(1-0.5)}\right)(20)$$

$$= 3 \times 20$$

$$V_{C2} = V_{C3} = 60V$$

Voltage across capacitor C_4 is

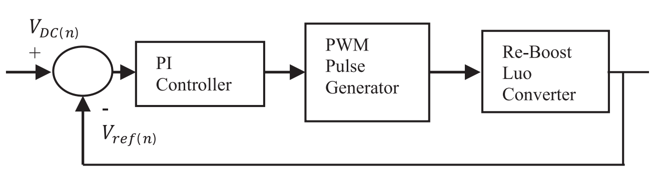

Fig. 6. Closed loop PI controller of the proposed converter.

$$V_{C4} = V_0 = 200 \text{ V}$$

5. Control algorithm

The potential difference at the Re-Boost Luo converter output is kept constant by the PI controller. The PI controllers react to a blunder sign in a shut control circle and endeavours to modify the constrained amount to accomplish the ideal framework reaction. The advantage of the PI controller is that it is very well balanced observationally by modifying one value and watching the adjustment in framework reaction. It is accepted that the controller is implemented in every now and again with the goal that the framework is appropriately managed. This blunder is controlled by the controller to deliver a direction signal to the plant. The attributes of the PI controller in the voltage ordering of Re-Boost Luo converter is characterized by the overshoot in the follow up mode and furthermore the less burden unsettling influence dismissals. It is utilized in control frameworks because it is viewed as a steady in a consistent state when loud information is utilized. The reference and the actual potential difference of the DC-DC converter are fed to the comparator. The output of the comparator is applied to PI controller such that the PI controller gains are added with a reference signal. This reference and carrier signals are compared to get PWM pulses. This PWM pulse is applied to Re-Boost Luo converter. The potential difference V_{DC} at the output of converter and reference potential V_{ref} are compared to produce the error and this error is applied to the PI controller. The error voltage can be calculated as,

$$\Delta V_{err(n)} = V_{ref(n)} + V_{DC(n)} \tag{22}$$

The PI controller output is given as,

$$I_{ref} = K_{P1}\left(\Delta V_{err(n)} - \Delta V_{err(n-1)} + K_{I1}.\Delta V_{err(n)}\right. \tag{23}$$

The optimized K_p & K_i values define the duty cycle for maintaining constant output voltage.

6. Simulation result

The performance of the proposed mathematical model of DC-DC converter is verified using the simulation with the parameters and the specifications as listed below.

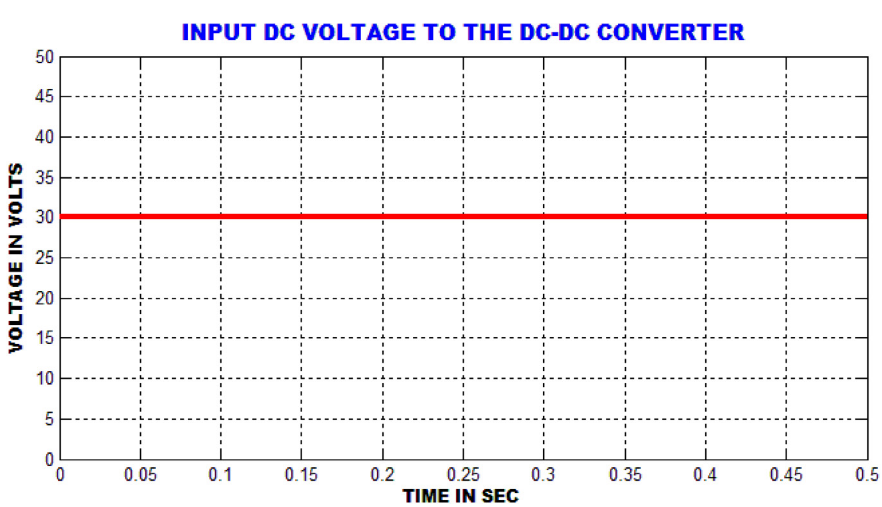

Fig. 7. Input DC voltage of the proposed converter.

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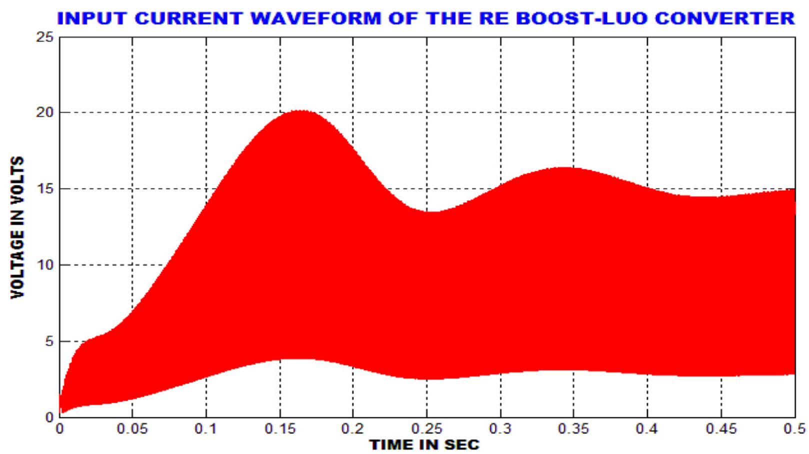

Fig. 8. Simulation result of input current waveform of the DC-DC converter.

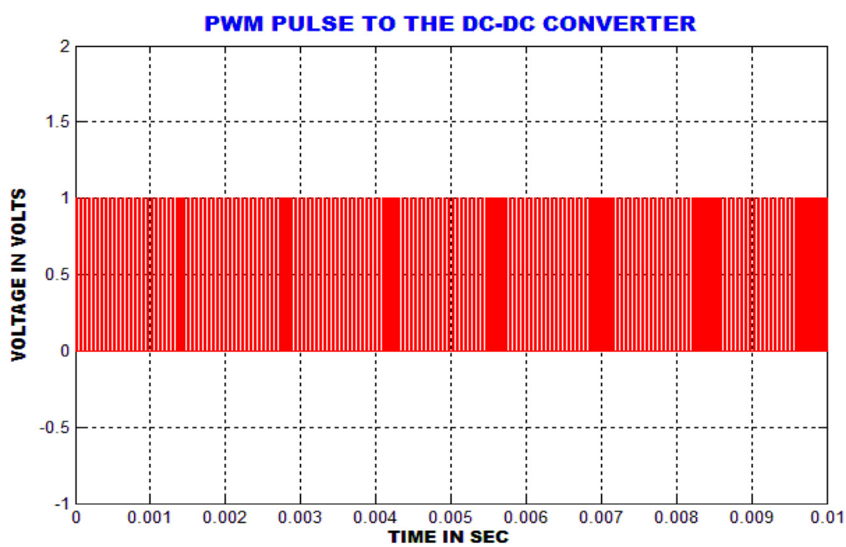

Fig. 9. Simulation results of PWM Pulse to the converter.

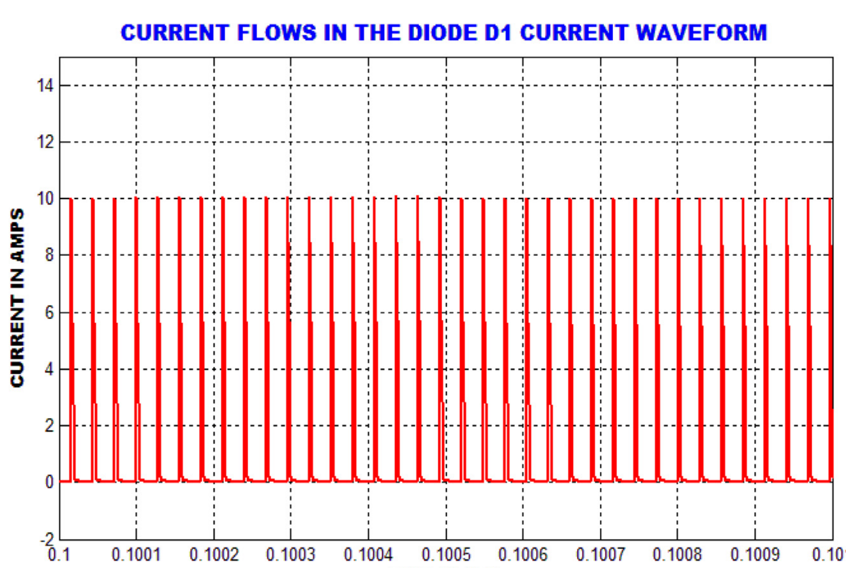

Fig. 10. Current through Diode D1 of proposed converter.

Components	Symbols	Rating
Source Voltage	v_{in}	20 V to 70 V DC
Source Current	i_i	11 A
Capacitors	C_1,C_2,C_3 &C_4	10uf/250v & 22uf/350v
Isolation transformer	$N_1 : N_2$	1:3
Output load current		1 Amps
Switching frequency	f	100 KHZ
Output Power	P_0	200 W

The proposed system is implemented using Matlab simulation The Fig. 6. Shows the simulation result of input voltage to the Re Boost-Luo converter.

The Fig. 7 shows the input current waveform of the proposed DC-DC Re Boost-Luo converter. The primary winding of the magnetizing transformer inductance maintains the input current as continuous.

The PWM pulses applied to the Re Boost Luo converter is shown in Fig. 8. The PWM pulse is produced by the PI controller. The actual potential from the DC-DC converter is compared with the reference value and this error is transferred to the PI controller. The reference signal and carrier signals are compared to produce the PWM pulses.

The Figs. 9–12 shows the current waveform of proposed converter Diode D1 to D4.

The Figs. 13–15 shows the simulation result of voltage waveform of the capacitor. It is found that the potential across the capacitor C2 is same as the input voltage.

The simulation result of the DC-DC converter voltage is given in Fig. 16. The PI controller maintains a constant output with given input voltages.

The Fig. 17 depicts the simulation result of load current waveform of the converter (Fig. 18).

The proposed Luo converter overcomes the drawbacks of existing topology. The existing Lift based Luo converter has utilized more number of inductor to achieve high output voltage with the minimum input voltage. But the proposed converter has attained high output gain with less components, thereby the voltage stress is reduced and the efficiency is increased.

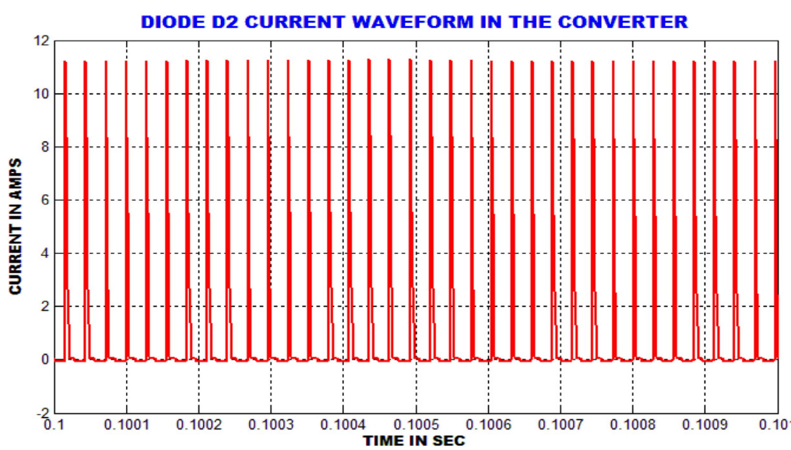

Fig. 11. Current through Diode D2 of proposed converter.

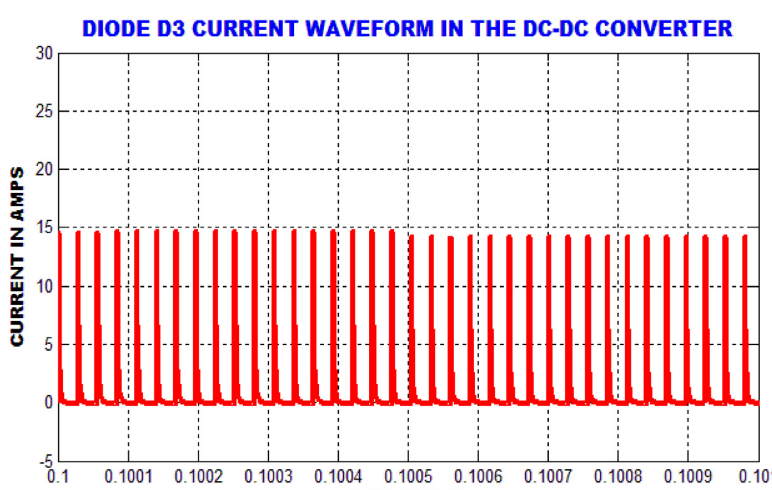

Fig. 12. Current through Diode D3 of proposed converter.

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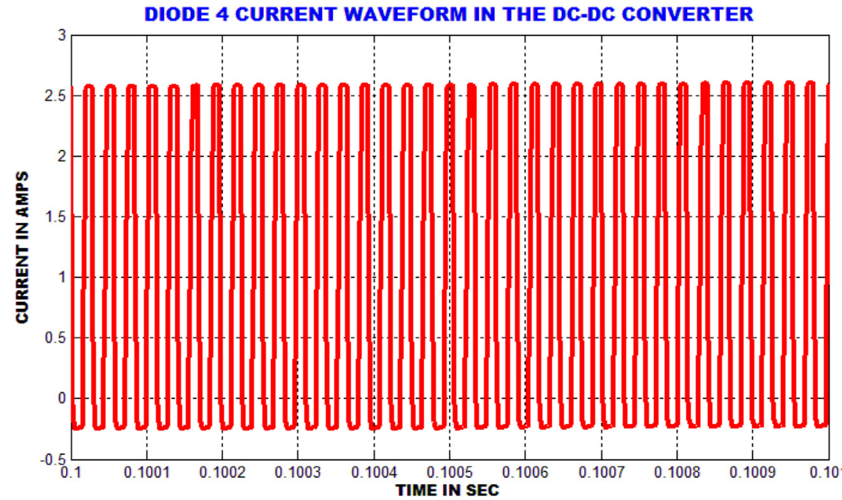

Fig. 13. Current through Diode D4 of proposed converter.

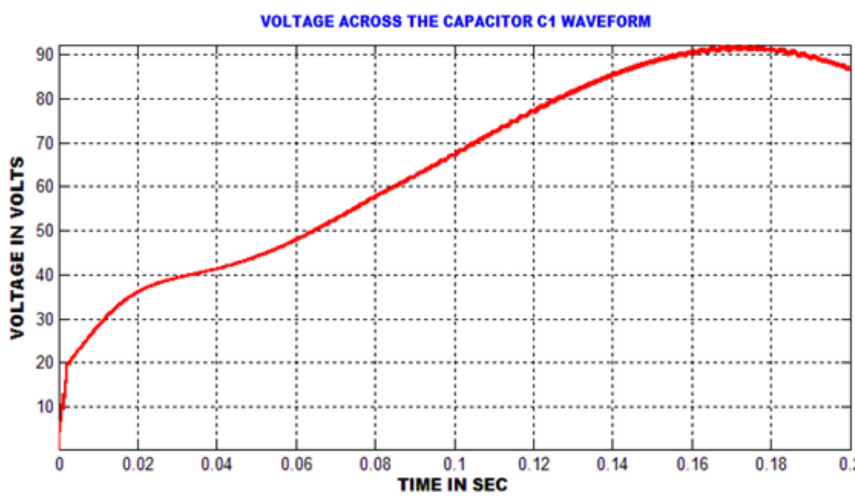

Fig. 14. Voltage across capacitor C1.

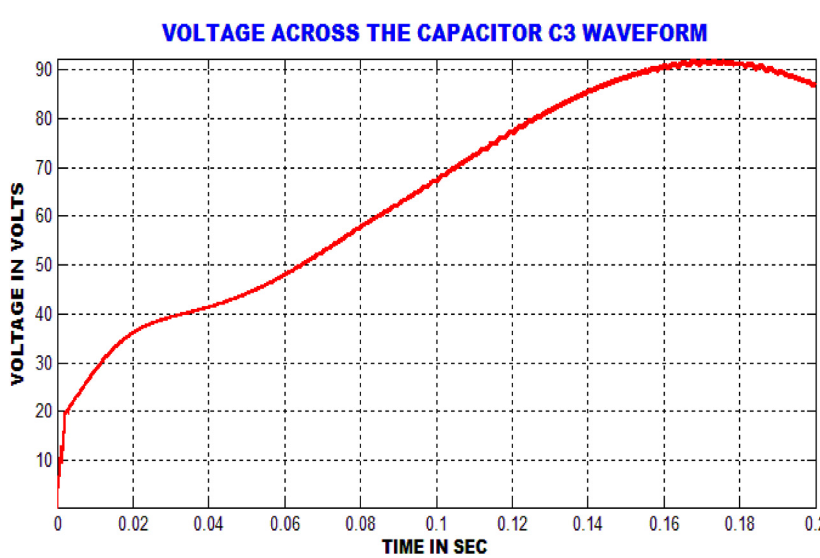

Fig. 15. Voltage across capacitor C3.

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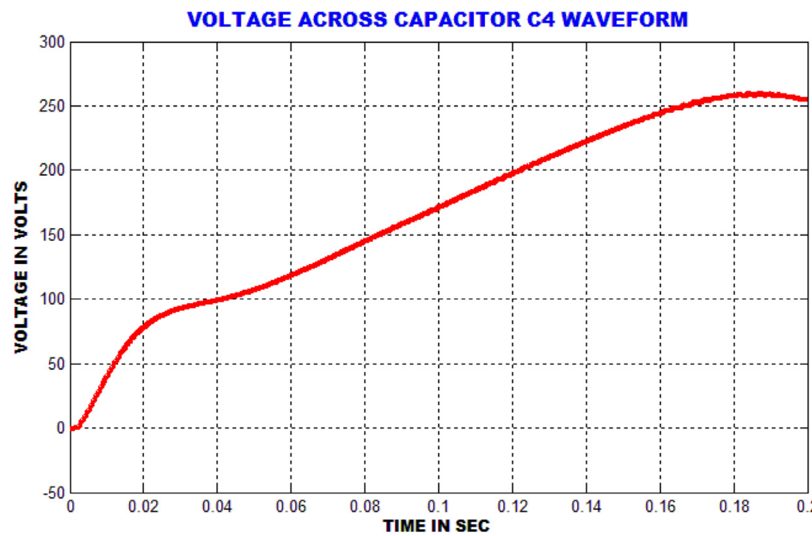

Fig. 16. Voltage across capacitor C4.

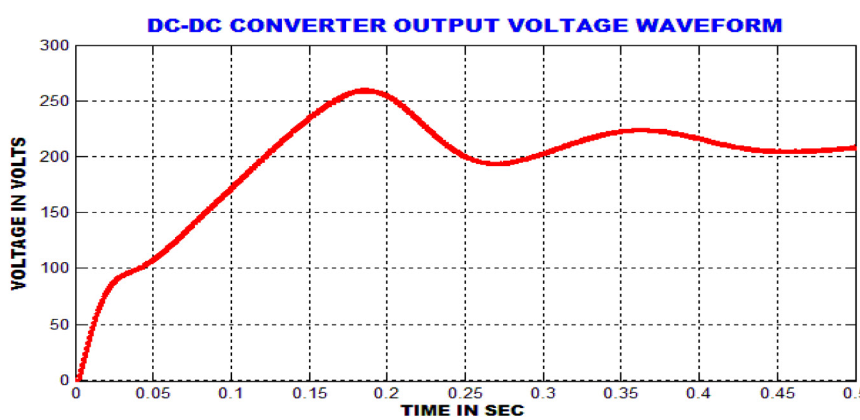

Fig. 17. DC-DC converter voltage waveform.

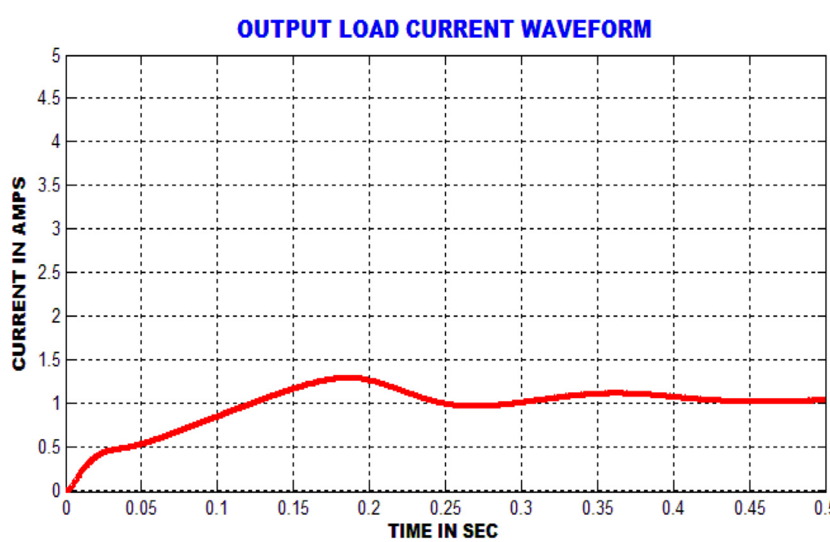

Fig. 18. Current waveform of DC-DC converter.

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7. Conclusions

The replacement of the existing super lift Luo converter with the proposed transformer-inductor structure has helped in increasing the voltage transfer gain. Here a perfect analysis of the proposed system is performed in both continuous and discontinuous modes. The PI controller is used to achieve the closed loop control and it also helps to achieve voltage stability in the converter output. The increase in the voltage transfer ratio has been attained with a number of additional modifications. With the use of the magnetically coupled inductor and diode, capacitor based voltage multiplier, the applications are tremendously increasing which is very useful in PV based high power applications.

CRediT authorship contribution statement

Ganesh Babu Loganathan: Conceptualization, Methodology, Software, Data curation, Writing - original draft, Visualization, Investigation, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Further reading

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