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DESIGNING OF HIGH GAIN CONVERTER FOR ELECTRIC VEHICLE APPLICATIONS

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Abstract

Currently electric vehicles are replacing fuel powered vehicles and it ruling the automobile industry. Globally, EV cars are fast selling and make revolution in automobile industry. To enrich the performance of EV, a compact circuit topology with low loss is required. Probably standalone EV cars will be the futuristic of EV because it adopts sustainable resource for power generating system with its infrastructure. The achievement of desired output voltage is questionable as it will be influenced by environmental factors. To supply a constant DC voltage towards the load, a DC-DC converter is required. The purpose of a converter is producing high DC voltage by adjusting the load demand and change in source voltage. The traditional converters are impossible to supply maximum output voltage with low duty ratio. Perhaps, the duty ratio is increased by changing the voltage gain will results in high switching stress. To overcome these problems, and maintain a steady state voltage across the load terminal a novel DC-DC converter is required. So, this study proposes a high gain converter for higher voltage applications and it stabilise low input voltage into a lossless higher output voltage. The usage of PID controller controls the switching cycle of this circuit. To validate the performance of the converter, it is operated with change in source voltage from 24 to 48V and achieved a higher voltage gain of 500V under low switching frequency. It is experimentally proven that this proposed converter outperformed traditional converters with higher voltage gain.

Index Terms – Electric Vehicle (EV), DC-DC Converter, Boost Converter, High Gain Converter, PID Controller .

I. INTRODUCTION

Nowadays EV car usage is increasing considerably due to the controlling of air pollution and the cost of fuel. The principle of an EV is charging the battery for a while and operating the motor. The battery charging/discharging and operation of the load is based on the power electronic converters. They play a crucial role in performing plug-in charging [1] or stand-alone charging [2] and maximising the voltage fed to the motor when the source voltage is very low. Power converters remarkably gain attention among researchers who contribute to designing and analysing electric vehicle operation and construction of charging stations. The evolution of DC-DC converters starts with buck, boost, and buck-boost converters. With the development of power electronics, the fundamental circuit is reconstructed using numerous active and passive components. But still, it is growing, as it has plenty of applications such as railways, DC distribution systems, renewable resources, and battery charging [3]. The purpose of a DC-DC converter is to increase/decrease the input voltage to a desired voltage range. Especially, the boost converter maximises the low input voltage to a higher output voltage, which is a huge factor for the installation of a boost converter where a higher voltage is required. However, it has drawbacks such as low efficiency, higher voltage stress, and upswing electromagnetic interference. To exceed the usual voltage, gain with a conventional boost converter, there will be chances of the duty ratio surpassing the pre-set threshold value. It generates voltage and current stress on the converter. Furthermore, the parasitic resistance of the passive components experiences a considerable rise which impacts the voltage and efficiency of the circuit.

The converters are coupled between source and load and it is categorised into isolated and non-isolated type [4]. An isolated converter has an electrical isolation between the source and load. It effectually splits the circuit into a pair to restrict the current flowing through the circuit utilising a high-frequency transformer. The size and cost of that converter is very high. It is mostly used in high-power appliances. Flyback, forward, half and full-bridge, and LLC are some of the isolated converters. The non-isolated converter is further categorised into coupled inductor and non-coupled inductor-based approach. As with conventional boost converters, when operating coupled inductor-based circuits at a higher duty ratio result in problems such as switching stress, lack of efficiency, and leakage inductance. This study especially looks at non-coupled inductor circuits. The non-isolated converter is chosen as it doesn't require isolating the source from the load. Also, it permits the input current to flow directly towards the load as it shares a common ground.

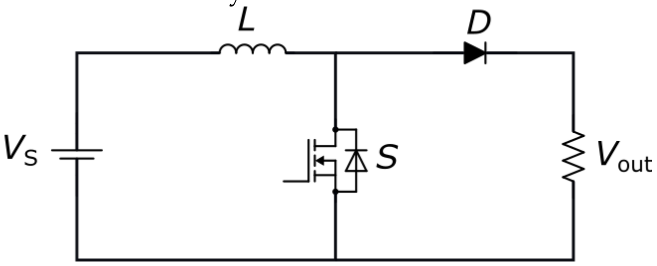


Fig.1.Traditional boost converter

To solve the drawbacks of traditional converter, this paper proposes a high-gain DC-DC converter. In general, lighter-weight EVs accelerate faster than usual as it has low mass and put less load on the battery pack, which prolongs the life of the battery. Other factors such as cost, number of components, and size are considered. The predefined factors are considered while designing EVs and low-rating battery packs are employed in many of the vehicles whereas a high gain converter is required and the function of it is maximising the input voltage to the desired value with low switching stress. Conceptually it is applicable, but in real-world scenarios, several tests need to take place to test its feasibility and make a promising technique for high-power applications. On account of this, a high gain DC-DC converter with fewer components is designed in this research and possibly makes this circuit fit to operate as per the above-mentioned facts and experimental analysis of this converter is verified by varying the input voltage. This converter can promisingly achieve high output voltage at a lower duty ratio that effectually decreases the stress on the active components. The PID controller incorporated in this study adjusts the switching cycle of the converter as per the desired output voltage.

The integration of traditional Cuk and boost converter is developed to high voltage gain [5]. At 0.5 duty ratio, the developed converter obtained a higher output voltage. The model's performance is compared with conventional buck-boost, boost, and quadratic buck-boost converter. The results showing that the conventional approaches imply a higher voltage gain at higher duty ratio, which is relatively near to 0.7, 0.8, and 0.9. For this analysis, an input voltage of 10V is fed to the circuit and it achieved an output voltage of 40V. The output voltage of this converter is square form of the conventional boost converter. So, the voltage gain witnessing that this converter is suited to low rated applications. In reference [6], the authors combining modified boost converter with Zeta converter to obtain semi-quadratic voltage gain and it is utilised for industrial applications and sustainable power generating systems. During step down operation, it achieved output voltage of 10V and in step up operation it achieved 20-76V. But this component utilised for this circuit is large in number.

Later, a PV-wind fed multiple input transformer coupled DC converter is proposed [7]. Though it has multiple inputs, the circuit topology is complex because it combines a bidirectional buck-boost converter with a transformer-coupled half-bridge boost converter. The size and cost of the circuit are high as it possesses a transformer and several switches used for stabilising the DC output voltage. The multiple switches may cause high switching stress, which results in low efficiency even voltage gain is maximum. Following this, a double boost converter with coupled inductance and double voltage is recommended as a replacement for a traditional boost converter that has been used in any of the high-power applications [8]. The leakage inductance affects the parasitic capacitance in the circuit, which is absorbed by the clamping capacitor. Next, a SEPIC-based high step-up converter designed for renewable resources is discussed in [9]. The SEPIC converter has the advantage of continuous input current. The continuous input current makes this circuit suitable for renewable resources. The coupled inductor with voltage multiplier cells incorporated in this circuit improves the output power. The design complexity in designing DC-DC converters is high voltage and current ripple, and lack of efficiency. To resolve such limitations an interleaved boost converter is proposed [10]. The efficacy of this circuit is enhanced by integrating N number of parallel converters within the circuit. Therefore, the above survey confirms that the design of a high step-up converter with fewer switches and passive components led to maximum output voltage with a low duty ratio and switching stress. The main objectives of this analysis are:

- Design a high-gain converter for low-power EV applications.
- To operate the converter with low switching stress, adapt to the load change and obtain desired voltage range.
- Build with fewer components and lessen the maintenance.
- Simple, compact, and reliable circuit.

The remaining portion of the study is organised as follows: In section 2, the works relevant to numerous DC-DC converters are discussed. Section 3 explains it under CCM and DCM. The voltage gain of the converter under varying source voltage and duty ratio is examined in section 4. The conclusion of this study is delivered in section 5.

II. PROPOSED HIGH GAIN CONVERTER

The following figure 2 shows the configuration of the proposed converter. It comprised a pair of inductors L_1 and L_2, two input capacitors C_1, C_2, and a single output capacitor C_3, and three diodes D1, D_2, and D_3. The duty ratio (D) of both switches is controlled by the PID controller. This control technique facilitates the converter to obtain the desired output voltage if any change in input or load occurs. Motivated by the inescapable usage of DC-DC converter in power electronic applications, the operation and performance of this high gain converter are studied. It operates under continuous and discontinuous conduction mode and the following section briefly explains its modes of operation.

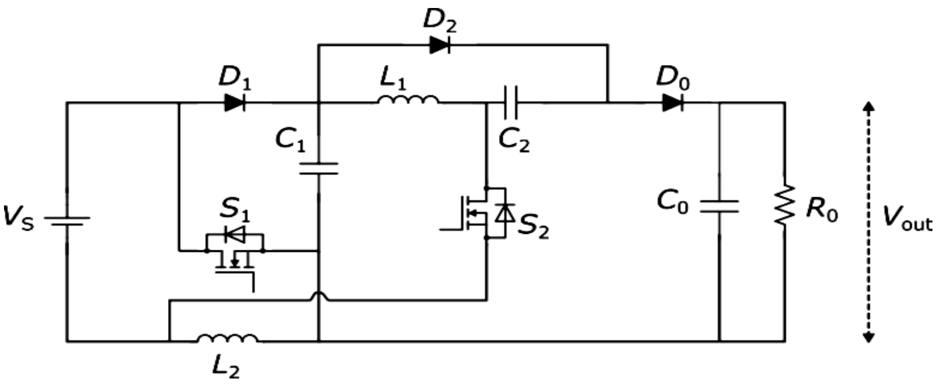
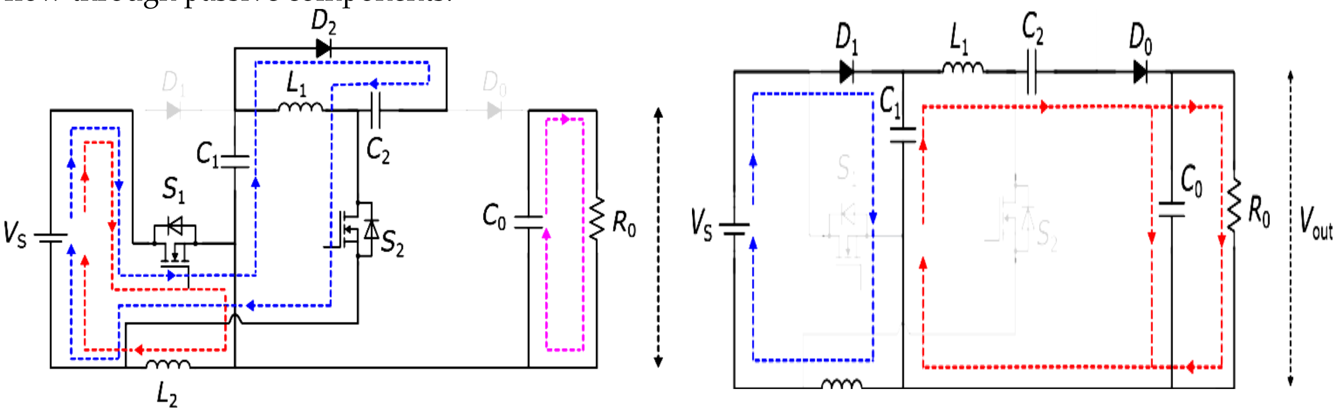


Fig.2. High gain DC-DC converter

A. Continuous Conduction Mode

As per the switching cycle, the mode of operation is categorized into two. Accordingly, both the switches are switched ON and OFF simultaneously. During CCM, both the inductors are energised. Moreover, the source voltage is entirely transmitted to the load passive components, which maximise the current passing through L_1 and L_2. Figure 4 (a) shows voltage and current flow through passive components.



(a) (b)

Fig.3.Modes of operation (a). Mode 1 and (b) Mode 2

Mode 1: In this phase, both the switches are closed, and the diode D2 is forward reverse biased. The source current IS energising C_1, L_1, C_2, and L_2. Also, the energy stored in C_0 gets de-energised by energising the load terminal. During mode 1, the flow of current through the circuit is represented in Figure 3 (a). By applying Kirchhoff's voltage law (KVL), the voltage across the passive components namely C_1, C_2, L_1, and L_2 are written by,

$$V_{L1} = V_{C2} = V_S + V_{C1} \tag{1}$$

$$V_{L2} = V_S \tag{2}$$

Mode 2: Both the switches are kept open and diode D_2 is reverse biased. The energy flow in this mode is represented in Figure 3(b). The de-energising of passive components energises the output capacitor and the load. In the next stage, the Co drains its energy towards R_O. In such a way, a constant voltage is maintained at RO. By applying KVL, the voltage across passive components is written as,

$$V_{C1} - V_{L1} + V_{C2} - V_{Out} = 0 \qquad (3)$$

$$V_{L1} = V_{C1} + V_{C2} - V_{Out} \qquad (4)$$

Substituting eqn (1) in eqn (3),

$$V_{L1} = V_{C1} + V_S + V_{C1} - V_{Out} \qquad (5)$$

$$V_{L1} = 2V_{C1} + V_S - V_{Out} \qquad (6)$$

$$V_{L2} = V_S - V_{C1} \qquad (7)$$

Applying voltage-inductor balance across L2,

$$V_S D + (V_S - V_{C1})(1 - D) = 0 \qquad (8)$$

$$V_{C1} = \frac{V_S}{1 - D} \qquad (9)$$

Applying voltage-inductor balance across L2,

$$(V_S + V_{C1})D + (2V_{C1} + V_S - V_{Out})(1 - D) = 0 \qquad (10)$$

Eqn has been written as,

$$V_{C1}(2 - D) - V_{Out}(1 - D) + V_S = 0 \qquad (11)$$

Substituting eqn (9) in (11),

$$\frac{V_S(2 - D)}{1 - D} - V_{Out}(1 - D) + V_S = 0 \qquad (12)$$

$$\therefore \frac{V_{Out}}{V_S} = \frac{(3 - 2D)}{(1 - D)^2} \qquad (13)$$

Whereas V_S-source voltage, V_{C1}, V_{C2}-voltage observed at capacitors C_1 and C_2, V_{L1}, V_{L2}-voltage observed at Inductors L_1 and L_2, V_{out}-load voltage.

B. Dis-continuous Conduction Mode (DCM)

Any discontinuity of any of the inductors makes the circuit operate under DCM. The waveform shown in Figure 4 (b) describes the voltage and current across both the inductors. The operation of the converter under DCM is written as,

$$V_S D_1 + (V_S - V_{C1})D_2 = 0 \qquad (14)$$

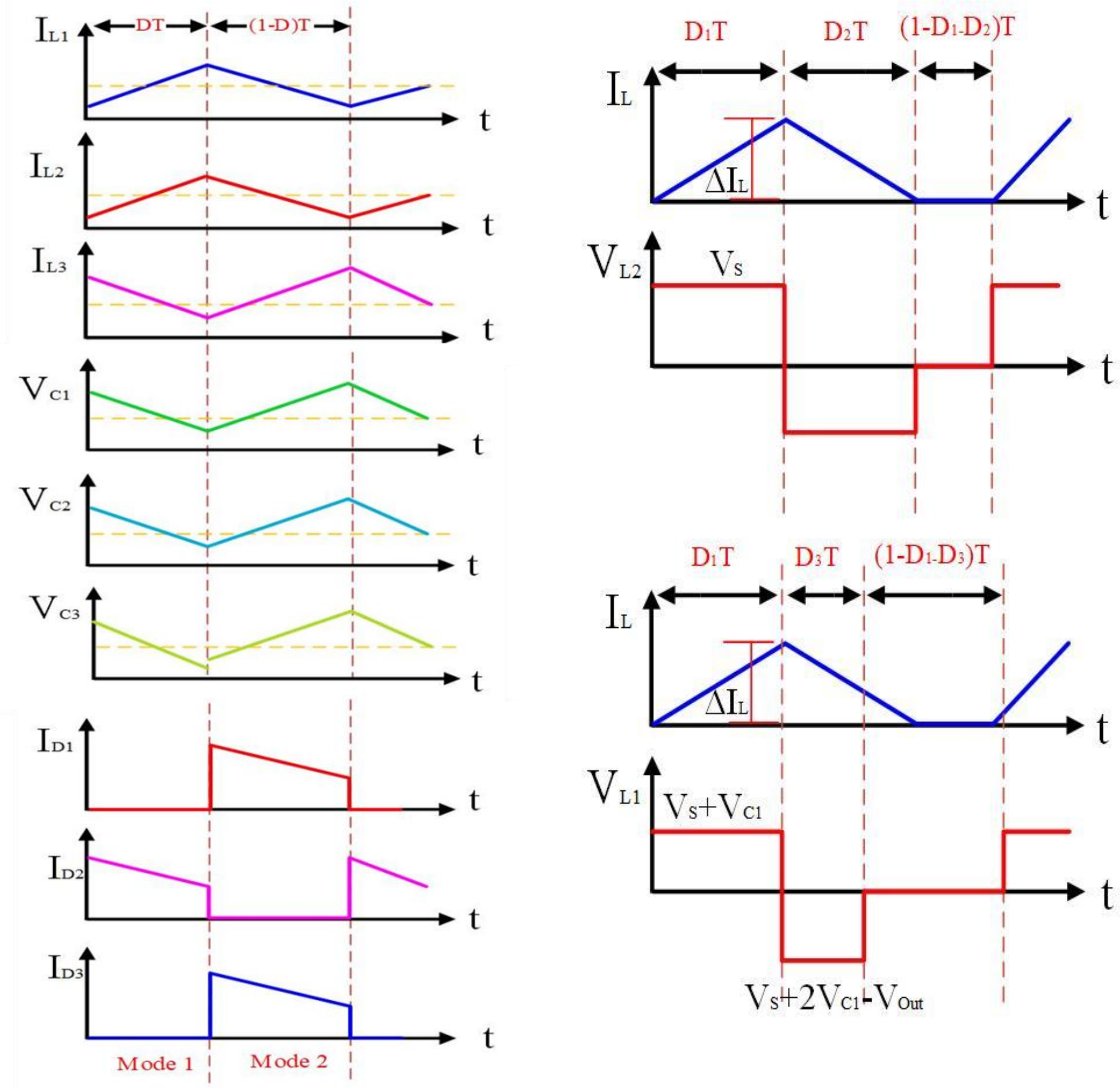
$$V_{C1} = \frac{V_S D_1 + V_S D_2}{D_2} \qquad (15)$$

$$(V_S + V_{C1})D_1 + 2(V_S + V_{C1} - V_{Out}) = 0 \qquad (16)$$

Substituting eqn (15) in (16),

$$\left(V_S + \frac{V_S D_1 + V_S D_2}{D_2}\right)D_1 + 2\left(V_S + \frac{V_S D_1 + V_S D_2}{D_2} - V_{Out}\right) = 0 \qquad (17)$$

$$\therefore \quad \frac{V_{Out}}{V_S} = \left(\frac{2D_1^2 + 4(D_1 D_2 + D_1 D_3 + D_2 D_3)}{D_2 D_3}\right) \qquad (18)$$



(a) (b)

Fig.4.Mode of Conduction waveform (a)CCM and (b) DCM

C. Designing of Passive components

Typically, the proper selection of passive components is mandatory in contribution to switching devices to enhance the operation of a converter. This section discusses determining the value of inductor and capacitor. The size of such elements is determined by factors namely load voltage, switching frequency, and duty cycle. The higher switching frequency will enhance the performance and decrease the size of the passive components. However, it results in higher switching stress. So proper care upon designing components is required.

D. Designing of Inductor

The purpose of this study is to design compact-sized inductors without any distortions in the load side. Because the inductors play a vital role in energising other passive components and load. Also, it is more economical. The following equation shows the value of inductors and they are:

$$L_1 \frac{dI_{L1}}{dt} = V_S + V_{C1} \tag{19}$$

Applying eqn (9) in (19),

$$L_1 \frac{dI_{L1}}{dt} = V_S + \frac{V_S}{1-D} \tag{20}$$

$$L_1 \frac{dI_{L1}}{dt} = \frac{V_S - V_S D + V_S}{1-D} \tag{21}$$

$$L_1 \frac{\Delta I_{L1}}{DT} = \frac{2V_S - V_S D}{1-D} \tag{22}$$

$$\frac{V_{Out}}{R_O} L_1 \geq \frac{V_S(2-D)DT}{2} \tag{23}$$

$$V_{Out} L_1 \geq \frac{R_O V_S (2-D)DT}{2} \tag{24}$$

$$L_1 \geq \frac{R_O (1-D)^2 (2-D) D}{2(3-2D) f_s} \tag{25}$$

For L_2,

$$L_2 \geq \frac{R_O (1-D)^4 D^2}{2 f_s (3-2D)(1+D-2D^2)} \tag{26}$$

E. Designing of Capacitor

It is based on the maximum permissible ripple voltage along with voltage across the capacitor itself. Also, it can withstand high voltage applied across the capacitor. The value of C_1 is derived by,

$$I_{C1} \Delta T = C_1 \Delta V_{C1} \tag{27}$$

$$I_{C1} DT = C_1 \Delta V_{C1} \tag{28}$$

$$\frac{V_o}{R(1-D)} = C_1 \Delta V_{C1} \tag{29}$$

$$C_1 = \frac{V_o}{R(1-D) f_s \Delta V_{C1}} \tag{30}$$

$$V_{C1} = \frac{V_S(3-2D)}{(1-D)^2 R(1-D) f_s \Delta V_{C1}} \tag{31}$$

$$C_1 = \frac{V_S(3-2D)}{(1-D)^3 R f_s \Delta V_{C1}} \tag{32}$$

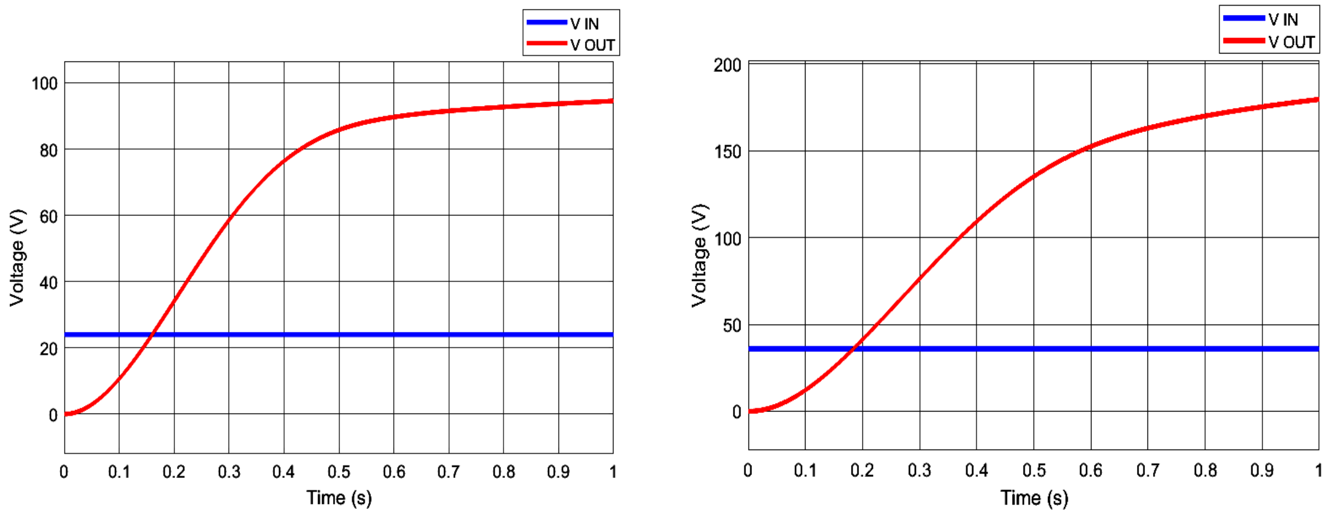
For C_2 and C_3,

$$C_2 = \frac{V_S(3-2D)}{(1-D)^2 R f_s \Delta V_{C2}} \tag{26}$$

$$C_3 = \frac{V_S(3-2D)}{(1-D)^2 R f_s \Delta V_{C3}} \tag{27}$$

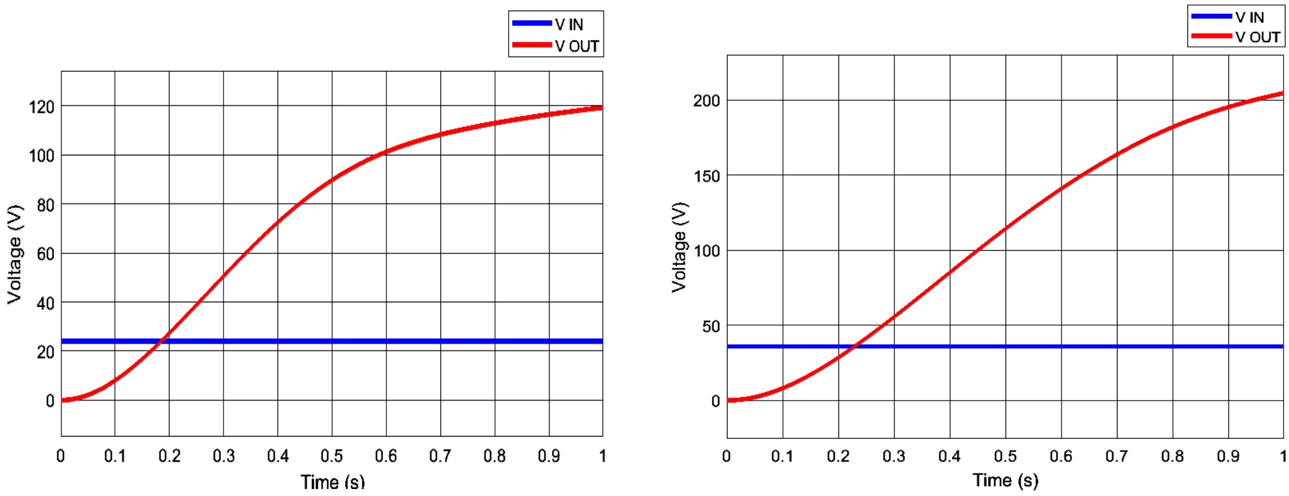
III. SIMULATION RESULT AND DISCUSSION

To evaluate the performance of the converter, it is tested under changes in voltage and duty ratio. Normally, a high duty ratio results in switching stress and lack of efficiency. Also, it shortens the life of components. This study previously addressed these issues and designed a high gain converter, which can generate high output voltage under a low duty ratio. Furthermore, it is examined by operating the converter with a duty ratio of 0.5 and a load resistance of 500Ω; but, the input voltage, V_S is set to 24V and 36V. Under this condition, the converter reached a significant voltage gain of 94.4V and 179.5V, respectively. Figure 5 shows the Vout of the converter under the change in VS. Moreover, the voltage across the input capacitors is 30V and 40V with V_S=24V. If the V_S have changed to 36V, the voltage across C_1 and C_2 is determined to be 50V and 80V. The change in input voltage is effectively managed by the PID controller that has a closed loop structure to compare output voltage with input reference voltage and adjust the duty ratio to obtain desired voltage gain. Notably, the duty ratio of both switches is kept identical.



(a) (b)

Fig.5.Output voltage of converter with duty ratio of 0.5 (a) V_S=24V (b) V_S= 36V



(a) (b)

Fig.6. Output voltage of converter with duty ratio of 0.5 (a) V_S=24V (b) V_S= 36V

Next, the duty ratio is adjusted to 0.6 with an input voltage of 24V and 36V. Under this duty ratio, the voltage Vout is regulated, but the value of R_O is set to 500Ω. When V_S is set to 24V, the voltage across C_1 and C_2 is determined to be 36.8V and 48.3V. Furthermore, the voltage across R_O is observed to be 117.6V. Lately, the value of VS is set to 36V, and the voltage across C_1, C_2, and R_O are 61.36V, 97.09V, and 214.6V. The voltage gains of the converter under a duty ratio of 0.6 is shown in Figure 6. Furthermore, the converter performance is evaluated by comparing the number of components, switching stress, and voltage gain of the converter with several other techniques in Table I.

Table I. Comparison of Proposed system with other approaches

Reference	**Number of components**				**Voltage Gain**	**Switch voltage stress**
	Diode	**Inductor**	**Capacitor**	**Switch**		
[11]	3	2	2	2	$\frac{2D}{(1-D)^2}$	$S_1 = \frac{(1-D)V_O}{2D}$ $S_2 = \frac{(1+D)V_O}{2D}$
[12]	6	2	4	2	$\frac{3-3D+D^2}{(1-D)^2}$	$S_{1,2} = \frac{2V_O}{(3-D+D^2)}$
[13]	7	4	1	2	$\frac{1+3D}{1-3D}$	$S_{1,2} = \frac{V_O}{1+D}$
[14]	7	4	3	2	$\frac{3+D}{1-D}$	$S_1 = \frac{2V_O}{(3+D)}$ $S_1 = \frac{V_O(1+D)}{(3+D)}$
[15]	3	2	3	2	$\frac{D^2-3D+3}{(1-D)^2}$	$S_1 = \frac{V_O(1-D)^3}{D^2-3D+3}$ $S_2 = \frac{V_O(1-D)^2}{D^2-3D+3}$
Proposed work	3	2	3	2	$\frac{(3-2D)}{(1-D)^2}$	$S_1 = \frac{V_O(1-D)^3}{(3-2D)}$ $S_2 = \frac{V_O - 2V_O D(1-D)^2}{(3-2D)}$

The graph shown in Figure 7 compares the voltage gain of the proposed converter with other approaches. Relatively, the proposed model obtained better output voltage. In common, the non-isolated step-up converters are not used whereas the duty ratio crosses 0.8. If it increases, the voltage gain decreases along with the rise of conduction loss. The number of components used for the proposed study is lower than the reference [11-13]. Considerably the voltage gain of this proposed circuit is increased when the duty ratio outdoes 0.1, which is shown in this graph. The converter proposed in [14] contains more components which increases the size of the circuit. Relatively this converter obtained lower efficiency than the proposed study. Remarkably, the voltage gains of [15] increases more than previously mentioned techniques.

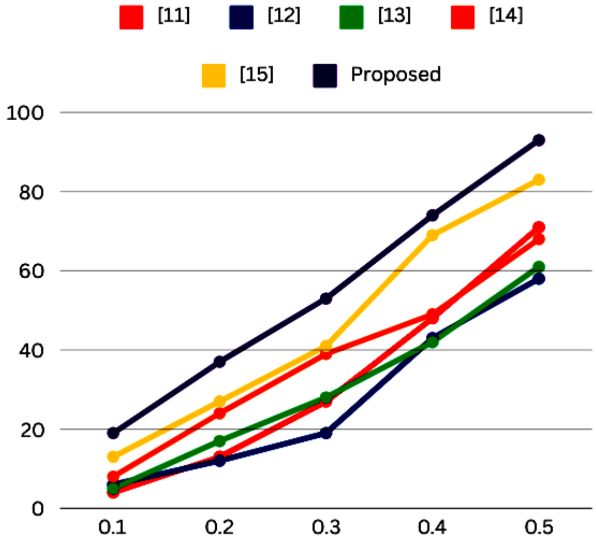


Fig.7.Voltage gain comparison of proposed verses other techniques

IV. CONCLUSION

The evolution of converters and the necessity of high-gain converters in power electronics applications are studied in this analysis. Also, the design and development of the proposed converter with determining of passive components is done. The experimental results show that this technique improved the voltage gain of the converter under the change in load and duty ratio. The low switching stress and high voltage gain under a low duty ratio are the advantages of this technique. This proposed converter is tested under various input voltage of 24V and 36V and a duty ratio of 0.5 has obtained load voltage of 94.4V and 179.5V, respectively. Similarly, the duty ratio is changed to 0.6 and obtained load voltage of 117.6V and 214.6V, respectively. It is reported that this high gain converter is crucial for electric vehicle applications as it delivers high output voltage towards the voltage when subjecting any change in load.

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