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Optimization of Boost Inductor Size Using Multiple DC-DC Boost Converter Configurations for Multilevel Inverter Applications

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Abstract: This study proposes using multiple non-isolated DC-DC boost converters to optimize the performance of boost inductors in multilevel inverter (MLI) systems. A bulky boost inductor can increase the overall weight of the multilevel inverter system. The configuration selection and converter design are crucial aspects in achieving these objectives. The number and arrangement of boost converters are based on the desired multilevel inverter topology, with each converter designated based on input voltage, output voltage, current rating, and switching frequency. Advanced software, PLECS software tools, is used for computation analysis. The output voltage gained is slightly different from expected, but a snubber circuit is used to minimize voltage spikes. Optimizing boost inductor size offers potential benefits, such as space-saving in applications with limited space for component placement. Additionally, smaller inductors have small core losses, leading to improved efficiency in boost converter design.

Keywords: Bulky Boost Inductor, Multiple DC-DC Boost, Optimization Boost Inductor Size, MLI

1. Introduction

Multilevel inverters, also known as MLI, are widely used in various power applications, including electric vehicle applications, photovoltaic systems applications, low-power loads applications, and grid integration systems applications [1]. The requirement for higher-power equipment has boosted the need for MLI. MLIs can operate at high voltage levels, have low switching losses, are very efficient, and emit little Electromagnetic Interference (EMI) [2][3]. There are three general topologies of MLI: neutral point clamp multilevel inverter (NPCMLI), flying capacitor multilevel inverter (FCMLI), and cascaded H-bridge multilevel inverter (CHMLI) [4]. The chosen type for this project is CHMLI. The DC-DC boost converter is important in industrial applications. It is common in electric vehicles, renewable energy systems, fuel cells, and uninterruptible power supply (UPS) systems [5][6]. These applications

need converters that are light in weight, volume, and cost, as well as having a high conversion efficiency. DC-DC converters are significant in power electronics because they can handle input-output fluctuations, electrical isolation, and output voltage regulation in the presence of changes in input and load current [7]-[8]. Multiple DC-DC boost converters are proposed in this project to overcome the limitations of conventional boost converters in generating high voltage with a high voltage gain.

To work correctly, the CHMLI requires several DC power sources. It also requires a separate DC source as well as a high-voltage supply. To enhance the input voltage and provide a larger output voltage, the proposed approach employs numerous DC-DC boost converters. However, due to their large duty cycle requirements, typical DC-DC boost converters have limits in generating high voltage [1][6]. It is feasible to achieve a higher output voltage than the input voltage by raising the duty cycle of the converter. The disadvantages of conventional DC boost converters are low power density, low efficiency due to bulky passive components, and high current stress [7][8].

These multiple boost converters distribute current flow, reducing stress on individual components. As a result, the inductor core size can be reduced, resulting in decreased converter volume and size. This technique seeks to improve performance, power density, efficiency, and power losses. Furthermore, having several boost converters provides operational redundancy, ensuring that the system can function even if one of the DC supply sources fails.

2. Materials and Methods

This section will present the necessary methods taken into account to successfully implement the project. The aim is to optimize the boost inductor size hence the PLECS software will be used for the simulation works for this project to analyze the output voltage of the boost converters.

2.1 Scopes of Project

In fulfilling the objectives of this project, the scopes in this project are stated as the following:

- The focus will be on improving the operation of the conventional DC-DC boost converter to the multiple DC-DC boost converters.
- The input of multiple DC-DC boost converters will have a ratio of 1:2:4 equal to 12V:24V:48V.
- The maximum output voltage and maximum power of the DC-DC boost converter are approximately 325V and 390W.
- The software that will be used for the simulation works is PLECS software applications.
- The main parameters that are considered in this project include the power losses, the volume of the converters and the efficiency of the DC-DC boost converter.

2.2 Implementation of the Project

The implementation of the project can be referred to as presented in Figure 1. Because MLI requires numerous sources to function, the recommended solution is to create multiple DC-DC boost converter combinations to supply the MLI. The typical DC-DC boost converter has a large boost inductor size and low power density, the boost inductor size will be optimized to reduce the size of the inductor component. The PLECS software will be used to simulate the optimization of the boost inductor in the boost converter. Following the optimization of the boost inductor, the simulation of many DC-DC boost converters with the MLI will be performed to analyze the output voltage and output power obtained.
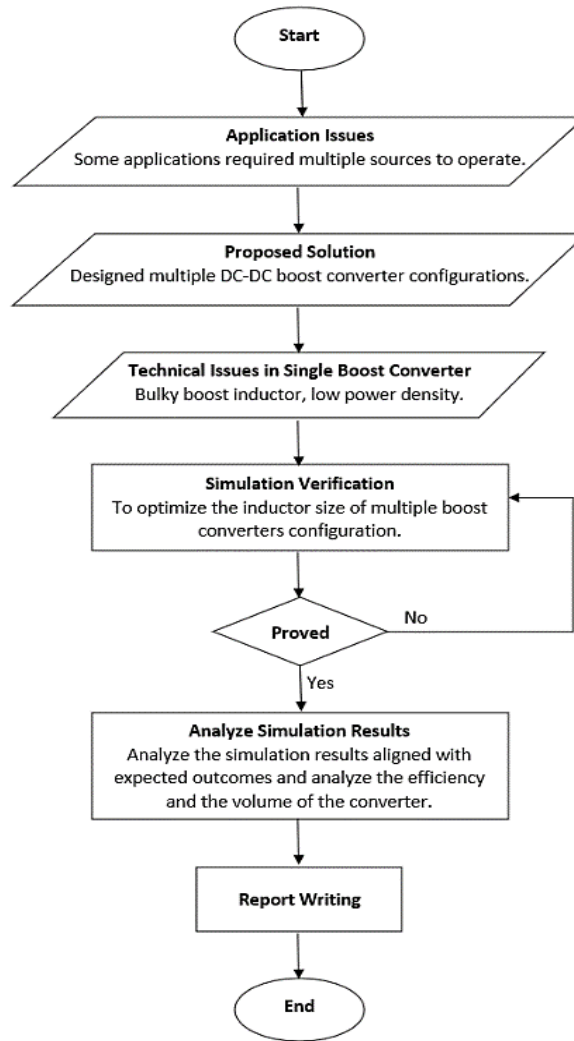
Figure 1: The flow chart of the project

The block diagram of the project can be referred to in Figure 2. Based on the block diagram, the DC power supply will be supplied for each multiple DC-DC boost converter separately. DC-DC boost converter will be connected to the MLI. In the real-life case, the system will be connected to the load.
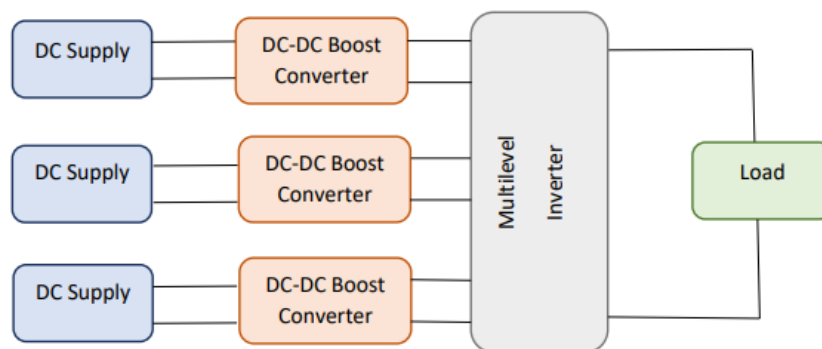

Figure 2: Block diagram of the project

A. Principles and Equations

For the conventional DC-DC boost converter principle, the input power and output power have to be equal in the ideal case. The relation between input voltage, V_{in} and output voltage, V_{out} can be referred to in Eq. 1 as shown follows:

$$\frac{V_{out}}{V_{in}} = \frac{1}{1-D} \qquad\qquad Eq. 1$$

The D is represents the duty cycle. V_{in} is the source of voltage and V_{out} is the voltage that needs to be set based on the requirement of the input voltage of the inverter. To design the inductor, the formula is as follows:

$$\Delta I_L = \frac{V_L T_L}{L} \qquad\qquad Eq. 2$$

The ΔI_L is represents the ripple current, V_L is the inductor voltage and T_L is the time charging of the inductor. The time charging of the inductor can be calculated by following the formula:

$$T_L = \frac{D}{f_{sw}} \qquad\qquad Eq. 3$$

To ensure that the inductor of boost inductor operates in continuous current mode (CCM) can be determined by calculating the average inductor. The formula for the average inductor can be calculated as follows:

$$L_{min} = \frac{D(1-D)^2 R}{2 f_{sw}} \qquad\qquad Eq. 4$$

3. Results and Discussion

This section will present the results and discussion that were obtained through the simulation works. Before conducting a simulation some parameters of boost converters will be determined and calculated first. The parameters of the boost converters can be referred in Table 1.

Table 1: Boost converters parameters values

Parameters	Values
Input Voltage	$V_{in(1)} = 12V$ $V_{in(2)} = 24V$ $V_{in(3)} = 48V$
Output Voltage	$V_{out(1)} = 25V$ $V_{out(2)} = 75V$ $V_{out(3)} = 225V$
Input Power	$P_{in(1)} = 30W$ $P_{in(2)} = 90W$ $P_{in(3)} = 270W$
Output Power	$P_{out(1)} = 30W$ $P_{out(2)} = 90W$ $P_{out(3)} = 270W$
Frequency switching	$f_{sw} = 100kHz$

Some parameters of the boost converters need to be calculated such as input and output current, duty cycle, resistor and the average inductor values to ensure the boost operates in CCM mode. The calculated parameters and its values are shown in the Table 2.

Table 2: Boost converters calculated parameters values.

Parameters	Values
Input Current	$I_{in(1)} = 2.5A$ $I_{in(2)} = 3.75A$ $I_{in(3)} = 5.625A$
Output Current	$I_{out(1)} = 1.2A$ $I_{out(2)} = 1.2A$ $I_{out(3)} = 1.2A$
Duty Cycle	$D_1 = 0.52$ $D_2 = 0.68$ $D_3 = 0.787$
Resistor	$R_1 = 20.833\Omega$ $R_2 = 62.5\Omega$ $R_3 = 187.5\Omega$
Average Inductor	$L_{min(1)} = 12.48\mu H$ $L_{min(2)} = 21.76\mu H$ $L_{min(3)} = 33.47\mu H$

After determining the parameters values, the simulation work will be conducted to analyze the simulation circuits. The multiple boost converters configurations will be connected with MLI. The simulation is done by using PLECS software to analyze the simulation results. Each converter will be connected with 3 level CHBI to analyze the output voltage will be same as expected output voltage. The circuit connection of connection of boost converter with 3 level CHBI can be referred from Figure 3 to Figure 5. Meanwhile the output voltage obtained for each converter can be referred from Figure 6 until Figure 8.
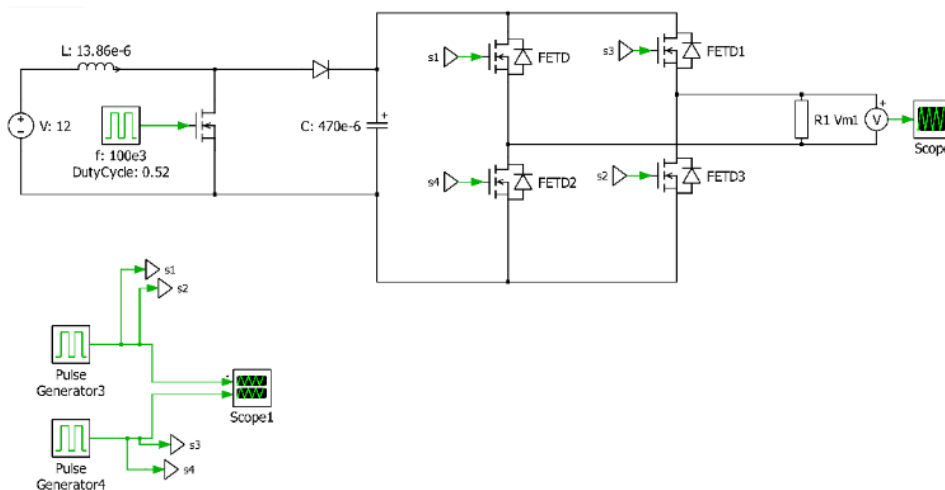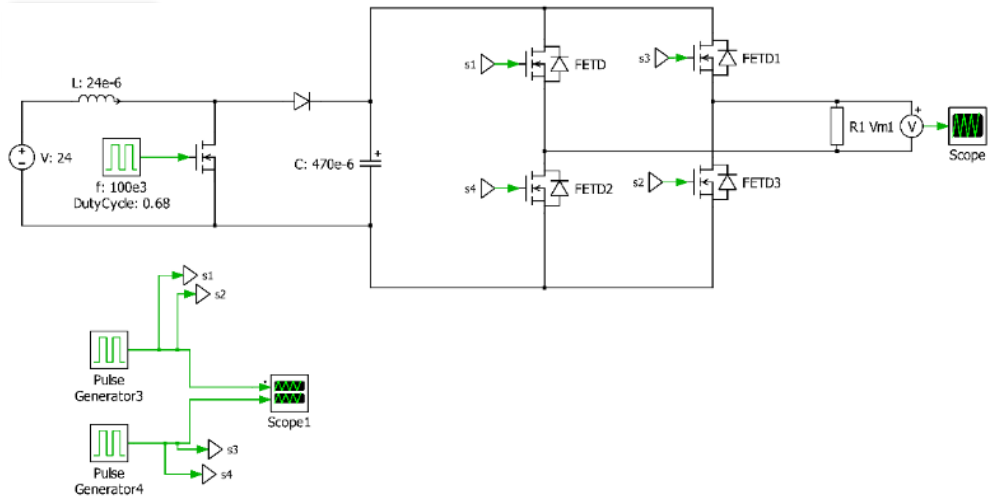

Figure 3: Boost converter 1 with 3 level CHBI
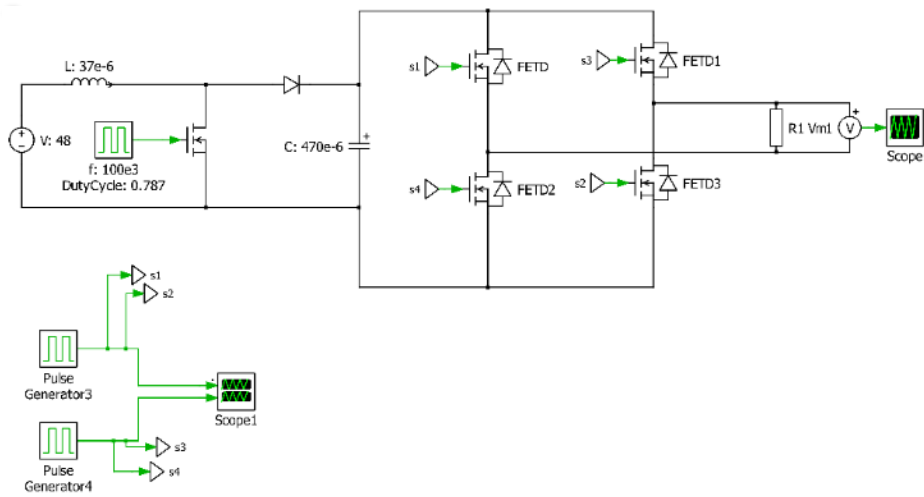
Figure 4: Boost converter 2 with 3 level CHBI

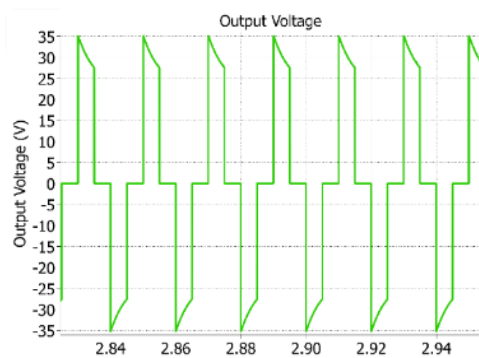**Figure 5: Boost converter 3 with 3 level CHBI**

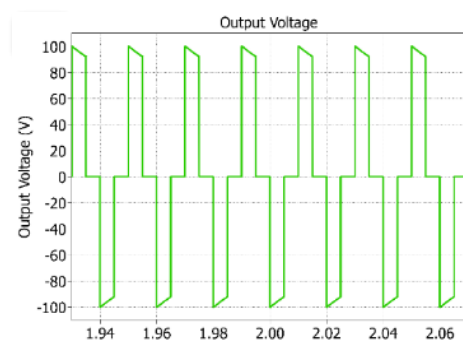**Figure 6: Output voltage graph for boost converter 1**

Figure 7: Output voltage graph for boost converter 2

Figure 8: Output voltage graph for boost converter 3

The output voltage obtained from the simulation can be summarized and referred to Table 3. Based on the table below, can be seen that there are slightly increment in the output voltage obtained compare with the desired output voltage.

Table 3: Summary of the output voltage results

Boost Converter	Input Voltage (V)	Desired Output Voltage (V)	Obtained Output Voltage (V)
Boost Converter 1	12	25	30.1627
Boost Converter 2	24	75	95.1772
Boost Converter 3	48	225	285.404

There are few possible issues occurs in increment of the output voltage obtained from the simulation might be due to the control and modulation scheme used in the 3 level CHBI, switching losses in the power semiconductor devices or due to the transient response and stability. Voltage spikes or overshoots can be caused by switching losses. As a result, adding snubber circuits to boost converters helps solve the problems associated with obtaining the desired output voltage.

The simulation of each boost converter with additional snubber circuit in the boost converter connected with the 3 level CHBI can be referred to Figure 9. The output voltage obtained from the simulation for each boost converter can be referred from Figure 10 to Figure 12. The designation of the snubber circuit is by adding passive components which are resistor and capacitor also known as RC snubber. The connection of the RC snubber circuit in the boost converter will be connected in parallel to the switching of the boost converter. The value for the RC snubber circuit will be varied at the resistor value, while the capacitor value will be fixed with value 47µF.
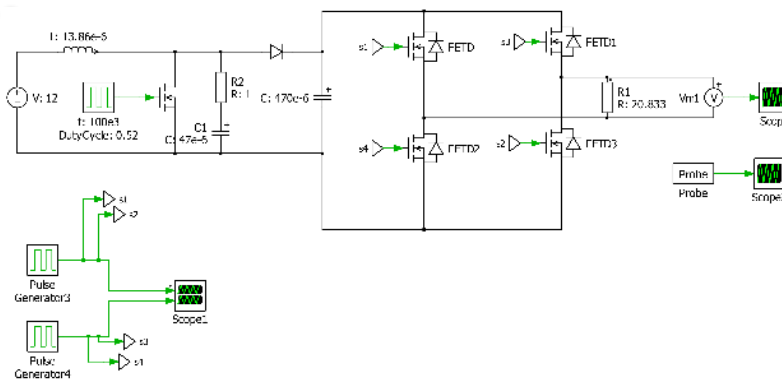

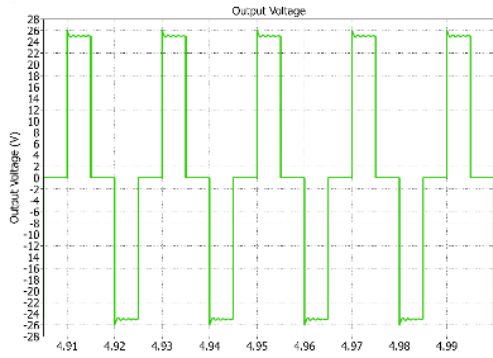**Figure 9: RC snubber circuit boost converter 1 with 3 level CHBI**

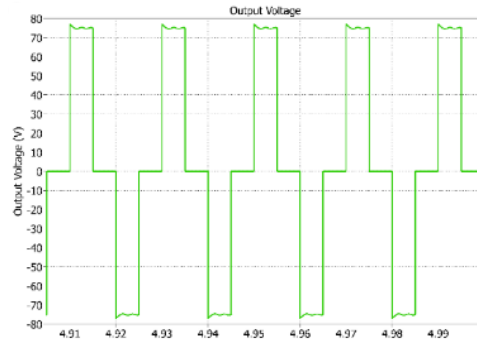**Figure 10: Output voltage graph for boost converter 1**

Figure 11: Output voltage graph for boost converter 2

Figure 12: Output voltage graph for boost converter 3

The output voltage obtained from the simulation after adding RC snubber circuit in boost converter can be summarized and referred to Table 4. Based on the table below, can be seen that the obtained output voltage from the simulation is approximately with the desired output voltage.

Table 4: Summary of the output voltage results

Boost Converter	Snubber Resistor (Ω)	Desired Output Voltage (V)	Obtained Output Voltage (V)
Boost Converter 1	1	25	24.9876
Boost Converter 2	1.5	75	75.089
Boost Converter 3	2	225	225.221

Since the obtained output voltage of boost converters are approximately to the desired output voltage, the simulation will be continued by combining the circuit if the multiple DC-DC boost converters with the asymmetric cascaded H-bridge multilevel inverter (ACHBMLI). Since the input voltage supply to each boost converter have a different value, hence ACHBMLI is used a suitable topology to use. Figure 13 below shows the connection circuits of multiple DC-DC boost converters connected with a 27 level ACHBMLI.
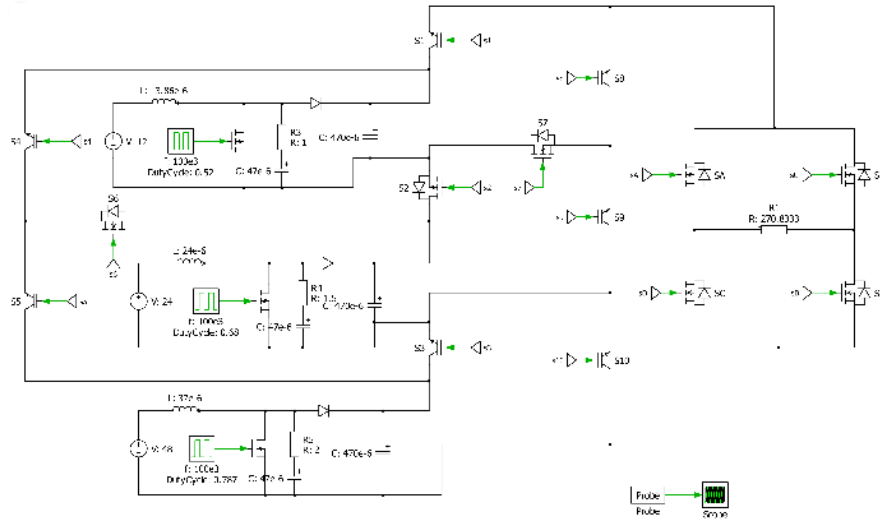
Figure 13: Circuit connection of multiple DC-DC boost converter with ACHBMLI

As mentioned in the scopes of the project section, the expected maximum output voltage is approximately 325V. While based on the calculation made, the output current will be approximately 1.2A. Figure 14 shows the output voltage graph obtained from the simulation and Figure 15 is the output current graph. Table 5 presents the results obtained from the simulation and compare it with the expected outcomes.
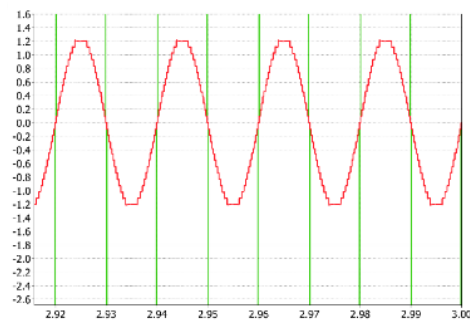

Figure 14: Output voltage graph

Figure 15: Output current graph

Table 5: Output voltage and current simulation results

Desired Output Current (A)	Obtained Output Current (A)	Desired Maximum Output Voltage (V)	Obtained Maximum Output Voltage (V)
1.2	1.20921	325	327.495

By referring to the Table 5, can be seen the maximum output voltage obtained from the simulation is 327.495V and the output current obtained is 1.20921A. Comparing the obtained output values with the desired values which is 325V for output voltage and 1.2A for the output current, can be concluded that the obtained values from the simulation closer approximation to the desired values. The benefit of the inverter is it allowed for a closer approximation to the desired sinusoidal waveform by generating a larger number of voltage steps.

B. Discussions of the Project

As the simulation employed in ideal case since input power equal to the output power, the assumption that can be made that the converter is operating at high efficiency. In an ideal case, this

would mean that the power losses in the converter are minimized. Therefore, while the losses may be minimized, they cannot be completely eliminated. As stated before, the assumptions made based on this simulation is that the converter reached a high-efficiency operating state due to during the conversion process, as the converter is effectively transferring most of the input power to the desired output. Efficiency is typically defined as the ratio of output power to input power. With input power equal to output power, the efficiency would be close to its maximum value.

The volume estimation for the simulation depends on various factors such as the design of the converter, component selection, and operating conditions. However, if the input power is equal to the output power, it suggests that the converter is optimized to efficiently transfer power without significant losses. As a result, it may be inferred that the volume of the converter can potentially be reduced compared to less efficient designs. Reducing losses typically allows for a more compact design since smaller heat sinks and cooling mechanisms may be required. However, in real-life cases, the power losses need to be calculated to define the efficiency of the system. Meanwhile, volume estimation can be calculated by referring to the datasheet for each selected component. In the data sheet electrical specifications such as voltage ratings, current ratings, power ratings, operating frequency range, input/output impedance, and operating temperature range. These specifications help in determining the component's compatibility and suitability for a specific application.

4. Conclusion

This research focused on optimizing boost inductors in multilevel inverter applications by utilizing multiple DC-DC boost converter designs. The goal was to increase the boost inductor's efficiency and performance, which is critical in multilevel inverter systems. The simulation results indicated the efficiency of the proposed optimization strategies in improving the performance of the boost inductor. The overall efficiency and dependability of these systems can be improved by using the optimized boost inductor, resulting in reduced power losses and improved voltage regulation.

Optimizing the boost inductor using multiple DC-DC boost converter configurations for multilevel inverter applications shows promising results in enhancing the inverter's performance and efficiency. The proposed configuration combines the benefits of multiple boost converters, allowing for higher voltage levels and improved power conversion characteristics. The study provides valuable insights into operating modes, the impact of inductor parameters, and validation through simulations and experimental results. Future research in this field can focus on advanced control strategies and optimization algorithms to achieve even better performance.

Acknowledgement

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