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Design and Simulation of a Cascade Boost DC-DC Converter as a Single-Phase Inverter Power Supply

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ABSTRACT

Currently, the need for new renewable energy is getting higher, so the development of equipment in supporting this is increasingly rapid. designing an inverter that has a high output voltage can be done in several ways, namely by developing from the basic topology of the inverter or developing an inverter input side voltage boost DC-DC converter that has a high gain ratio capability or by using a step up transformer as an AC voltage booster, but it is inefficient considering that the step up transformer has a heavy weight, and reduces space. In this research the researchers designed a cascade boost converter as a single-phase inverter power supply. The cascade boost converter is used as a DC voltage increase where the DC high voltage is entered into a single phase inverter as a DC power supply and the inverter converts from DC-AC. Without using a step up transformer as an AC voltage booster. The inverter is combined with an LC filter as a wave filter to make it close to a sinusoidal wave. The simulation results show that the whole system is able to output a voltage of 220VAC RMS with a frequency of 50Hz.

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1. INTRODUCTION

At this time the need for new renewable energy is getting higher, so the development of equipment in supporting it is getting faster. One of them is the development of inverter technology that can be connected to the network to create dependability of solar panel systems and other renewable energy systems [1], wind power turbine systems [2].

In designing an inverter that has a high output voltage can be done in several ways, namely by developing from the basic topology of the inverter or developing a DC-DC converter that increases the input side voltage of the inverter which has a high gain ratio capability. In terms of inverter development (DC-AC), a single-phase inverter applied to a solar power generation system with a new topology where the inductor pairs with a single-phase switch and the addition of capacitors with the aim of strengthening the output voltage on the inverter [3]. Furthermore, a single-phase inverter with seven levelling can produce three times the output voltage [4]. Single phase inverter without transformer as a voltage booster on the output side of the inverter as a PV application [5]. Another innovation that can be developed from the inverter side is to design a new topology, namely the boost inverter as an output voltage booster on the DC-AC converter [6]-[7]. In addition to the development of the DC-AC converter side, another side that can be developed to achieve high output voltage at the inverter output is to embed a DC-DC converter on the input side of the inverter with high gain. These DC voltage boosters use a DC-DC boost converter.. Boost converters with twice the voltage boost are used in single phase inverters with the aim of reducing the use of step up transformers on the output side of the inverter [8]-[12]. Cascade boost DC-DC converter is one of the most widely applied [13]-[15].

The goal of this study is to create a DC-DC cascade boost converter with a single phase inverter in which the cascade boost functions as a DC side voltage booster or inverter input side to reach a voltage above 300 VDC, then integrated with a single-phase inverter having a sinusoidal alternating current output voltage of 220VAC, 50 Hz without using a step up transformer. The inverter is equipped with an LC filter as a filter to achieve an output voltage waveform close to pure sinusoidal. The initial stage of steady state analysis on the boost cascade, then the next stage is the inverter which then the results that have been designed will be simulated using PSIM software.

2. METHOD

The research method is divided into three stages, namely explaining the fundamental design of ordinary DC-DC boost converters, analysis to determine the steady-state output voltage of the DC-DC cascade boost converter, next an examination of how a single-phase inverter works, switching combinations, the equation for the output voltage, then the output of the inverter is filtered using inductors and capacitors (LC filter) in order to obtain waveform results that are close to sinusoidal.

2.1. Basic Topology of DC-DC Boost Converter

In order to increase the DC voltage, a DC-DC Boost converter is used. The output voltage of this converter will be greater than the input voltage. Technically, increasing the voltage by applying a trigger to the switch in use, such as a MOSFET. By varying the duty cycle of the PWM (Pulse Width Modulation) signal. The converter is made up of five major parts. The basic structure of the DC-DC boost converter is shown in Figure 1.

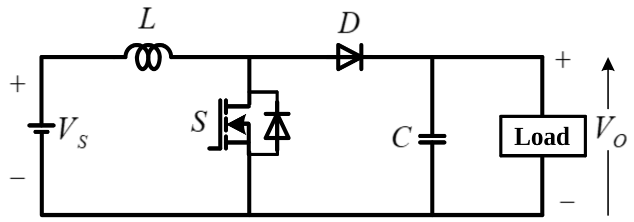

Figure 1. DC-DC Boost Converter Topology

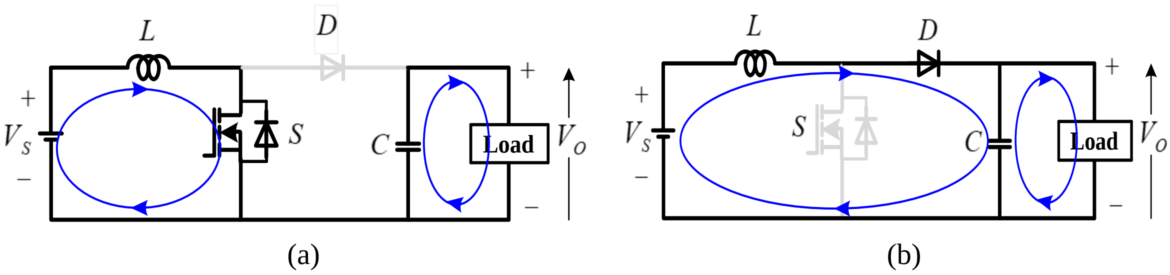

Figure 2. The DC-DC Boost Converter Works: (a) ON condition, (b) OFF condition

The basic structure of the boost converter is shown in Figure 1, while Figure 2 is the workings of the boost converter when the MOSFET (in this case as a switch) works in two conditions, namely, in the ON and OFF state. Referring to reference [16] regarding steady state analysis, when the switch condition is ON (Figure 2a) the amount of voltage on the inductor is,

$$V_L = V_S = L\frac{di_L}{dt} \text{ atau } \frac{di_L}{dt} = \frac{V_S}{L} \tag{1}$$

When the switch is closed, the current will grow linearly, and the amount of the current change in the inductor will be constant,

$$\frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{DT} = \frac{V_S}{L} \tag{2}$$

From equation (2) if simplified, When the switch is closed, the magnitude is,

$$(\Delta i_{L\,tutup}) = \frac{V_S DT}{L} \tag{3}$$

If the switch is in the open or OFF position, the inductor current cannot change immediately instead, the diode will be forward-biased to drain the current, providing that the output voltage is constant,

$$V_L = V_S - V_O = L\frac{di_L}{dt} \tag{4}$$

$$\frac{di_L}{dt} = \frac{V_S - V_O}{L} \tag{5}$$

When the switch is open, the change in inductor current is constant, hence the current changes linearly. When the switch is turned off, the amount of the change in inductor current is,

$$\frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{(1-D)T} = \frac{V_S - V_O}{L} \tag{6}$$

For Δi_L when the switch is open,

$$(\Delta i_{L\,buka}) = \frac{(V_S - V_O)(1-D)T}{L} \tag{7}$$

The change in inductor current must be zero for the converter to operate in steady state. So if it substitutes equation (3) and equation (7) will become,

$$\Delta i_{L\,tutup} + \Delta i_{L\,buka} = 0 \tag{8}$$

$$\frac{V_S DT}{L} + \frac{(V_S - V_O)(1-D)T}{L} = 0 \tag{9}$$

From equation (9), if simplified, it will become equation (10).

$$V_S(D + 1 - D) - V_O(1 - D) = 0 \tag{10}$$

From equation (10), if simplified, it will become equation (11).

$$V_O = \frac{V_S}{1-D} \tag{11}$$

Then the magnitude of the output voltage on the DC-DC Boost converter is listed in equation (11).

2.2. Cascade Boost DC-DC Converter Topology

The cascade boost DC-DC converter topology is basically a boost converter added with another boost topology. The boost topology is composed of two stages that function to increase the DC output voltage over that of a standard boost converter. Figure 3 is the topology of the cascade boost converter (CCB).

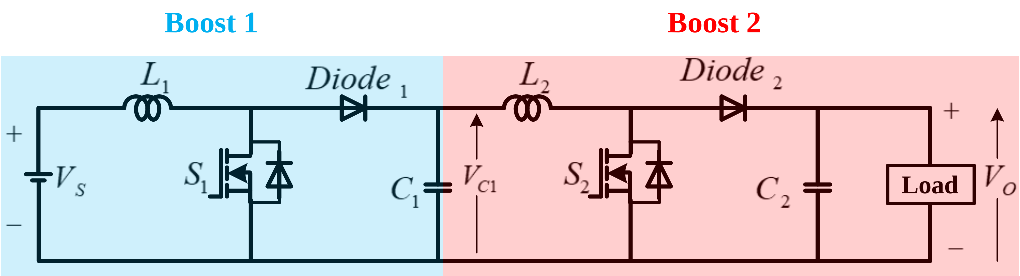

Figure 3. Cascade Boost DC-DC Converter

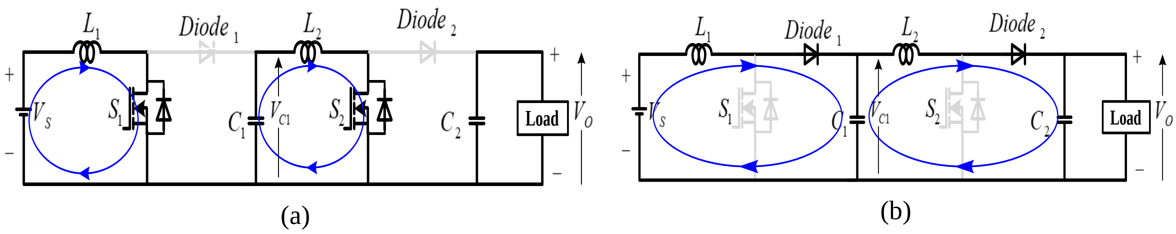

Figure 4. Cascade Boost DC-DC Converter Working Operation: (a) ON condition, (b) OFF condition

Figure 3 is the CCB converter proposed in this study as a DC side voltage booster for a single phase inverter power supply. Basically, the CCB converter is two converters combined into one to increase the voltage gain on the output side of the converter. In the condition of S1 (boost 1) and S2 ON (boost 2), the amount of voltage on L1 and L2.

L1 voltage at Boost 1,

$$V_{L1} = V_S = L1\frac{di_{L1}}{dt} \text{ atau } \frac{di_{L1}}{dt} = \frac{V_S}{L1} \quad (12)$$

L2 voltage on Boost 2,

$$V_{C1} = V_{L2} = L2\frac{di_{L2}}{dt} \; atau \; \frac{di_{L2}}{dt} = \frac{V_S}{L2} \quad (13)$$

When the switch is closed, the current will grow linearly, and the magnitude of the change in current in inductors L1 and L2 will be equal,

$$\frac{\Delta i_{L1}}{\Delta t} = \frac{\Delta i_{L1}}{DT} = \frac{V_S}{L1} \quad (14)$$

$$\frac{\Delta i_{L2}}{\Delta t} = \frac{\Delta i_{L2}}{DT} = \frac{V_S}{L2} \quad (15)$$

From equations (14) and (15) if simplified, the magnitude of , when the switch is closed is,

$$(\Delta i_{L1_{tutup}}) = \frac{V_S DT}{L1} \quad (16)$$

$$(\Delta i_L 2_{tutup}) = \frac{V_{C1}DT}{L2} \quad (17)$$

If the switch is in the open condition or OFF condition on S1 and S2, If the inductor current cannot be changed directly, the diode will be forward-biased to drain the current, providing that the output voltage remains constant,

L1 voltage at Boost 1,

$$V_{L1} = V_S - V_{C1} = L1\frac{di_{L1}}{dt} \quad (18)$$

L2 voltage on Boost 2,

$$V_{L2} = V_{C1} - V_{C2} = L2\frac{di_{L2}}{dt} \quad (19)$$

Then,

$$\frac{di_{L1}}{dt} = \frac{V_S - V_{C1}}{L1} \quad (20)$$

$$\frac{di_{L2}}{dt} = \frac{V_{C1} - V_{C2}}{L2} \quad (21)$$

When the switch is open, the change in inductor current is constant, hence the current changes linearly. When the switch on S1 and S2 is turned off, the amount of the change in inductor current is,

$$\frac{\Delta i_{L1}}{\Delta t} = \frac{\Delta i_{L1}}{(1-D)T} = \frac{V_S - V_{C1}}{L1} \quad (22)$$

$$\frac{\Delta i_{L2}}{\Delta t} = \frac{\Delta i_{L2}}{(1-D)T} = \frac{V_{C1} - V_{C2}}{L2} \quad (23)$$

For Δi_{L1}, Δi_{L2} when the switch is open,

$$(\Delta i_{L1\,buka}) = \frac{(V_S - V_{C1})(1-D)T}{L1} \quad (24)$$

$$(\Delta i_{L2\,buka}) = \frac{(V_{C1} - V_{C2})(1-D)T}{L2} \quad (25)$$

The change in inductor current must be zero for the converter to operate in steady state. So if it substitute equation (16) (17) and equation (24) (25) will become,

$$\Delta i_{L1\,tutup} + \Delta i_{L1\,buka} = 0 \quad (26)$$

$$\Delta i_{L2\,tutup} + \Delta i_{L2\,buka} = 0 \quad (27)$$

$$\frac{V_S DT}{L1} + \frac{(V_S - V_{C1})(1-D)T}{L1} = 0 \quad (28)$$

$$V_{C1} = \frac{V_S}{1-D} \quad (29)$$

Equation (29) is the voltage across capacitor C1 for boost 1. The simplification of equation (27) is,

$$\frac{V_{C1}DT}{L2}+\frac{(V_{C1}-V_{C2})(1-D)T}{L2}=0 \tag{30}$$

$$V_{C1}=V_{C2}\,(1-D) \tag{31}$$

If you substitute equation (29) with equation (31), it becomes,

$$V_{C2}\,(1-D)\;=\frac{V_S}{1-D} \tag{32}$$

$$V_{C2}=\frac{V_S}{(1-D)(1-D)} \tag{33}$$

Where the magnitude of the voltage in capacitor C2 is parallel to the load, the magnitude of the output voltage of the CCB converter is,

$$V_O=\frac{V_S}{(1-D)(1-D)} \tag{34}$$

To find the amount of inductors L1 and L2 installed in the CCB converter, Based on reference [17], the inductor current of each stage can be determined from the quantity of input and output power,

$$P_{in}=P_{Out} \tag{35}$$

$$V_sI_s=\frac{{V_o}^2}{R} \tag{36}$$

$$V_sI_s=\frac{\left(\frac{V_S}{1-D}\right)^2}{R} \tag{37}$$

$$V_sI_s=\frac{{V_S}^2}{(1-D)^2R} \tag{38}$$

The magnitude of $V_sI_s=V_sI_L$, then,

$$V_sI_L=\frac{{V_S}^2}{(1-D)^2R} \tag{39}$$

$$I_L=\frac{V_S}{(1-D)^2R} \tag{40}$$

The magnitudes of the highest and minimum inductor currents in both inductors are,

$$I_{Lmax}=I_L+\frac{\Delta iL}{2}=\frac{V_S}{(1-D)^2R}+\frac{V_SDT}{2L} \tag{41}$$

$$I_{Lmin} = I_L - \frac{\Delta iL}{2} = \frac{V_S}{(1-D)^2 R} - \frac{V_S DT}{2L} \quad (42)$$

Where R is the amount of resistance in the load, is the input voltage, is the duty cycle in one period. Positive conditions are required for the inductor current to be continuous. As a result, the difference between continuous and discontinuous inductor current is dictated by,

$$I_{min} = 0 = \frac{V_S}{(1-D)^2 R} - \frac{V_S DT}{2L} \quad (43)$$

$$\frac{V_S}{(1-D)^2 R} = \frac{V_S DT}{2L} = \frac{V_S D}{2Lf} \quad (44)$$

Where L is the inductor, f is the switching frequency, D is the duty cycle. Therefore, the minimum combination of inductance and switching frequency for continuous current in a cascade boost converter is,

$$(Lf)_{min} = \frac{D(1-D)^2 R}{2}$$
$$L_{min} = \frac{D(1-D)^2 R}{2f} \quad (45)$$

For the minimum capacitor size C1 and C2 are,

$$C_{min} = \frac{V_O DT}{R \Delta V_O} = \frac{V_O D}{R \Delta V_O f} \quad (46)$$

2.2. Inverter Topology

Inverter topology is basically a converter that functions as a DC-AC converter. The type of inverter used in this research is a full bridge inverter. In this type of inverter work system, the output voltage can be +Vdc, -Vdc or zero, depending on the switch. Figure 5 is a full bridge inverter topology.

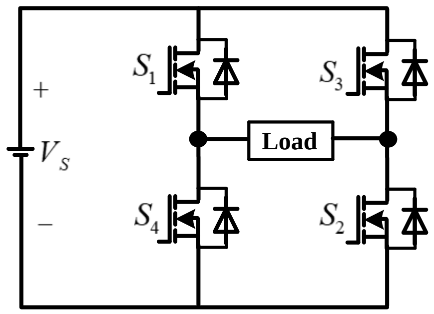

Figure 5. Single Phase Inverter

Figure 5 depicts the basic circuit of a full bridge single phase inverter with four MOSFET switches S1, S2, S3, and S4. In Figure 6 is the working operation of the inverter.

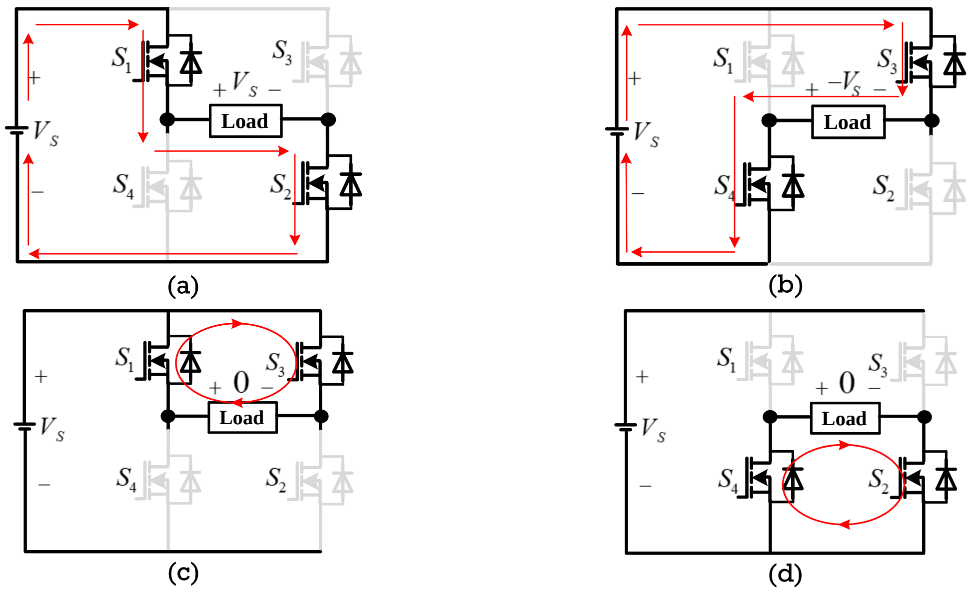

Figure 6. Single Phase Inverter Working Operation, (a) S1 and S2 closed, (b) S3 and S4 closed, (c) S1 and S3 closed, S2 and S4 closed

Figure 6 is the work operation of a full bridge inverter, Switches S1 and S4, as well as switches S2 and S3, should not be closed at the same time. If closed at the same time will result in a short circuit at the source. The switch is not ON and OFF simultaneously because it will cause a short circuit. Below is a table of inverter output voltage in the combination of switching.

Table 1. Combination of Switching

Closed Switch	Output Voltage (Vo)
S1 and S2	+Vs
S3 and S4	-Vs
S1 and S3	0
S4 and S2	0

Table 1 shows the amplitude of the output voltage resulting from the combination of switching as shown in Figure 5. The magnitude of the complete bridge inverter's rms output voltage is then,

$$V_O = \left(\frac{2}{T_0}\int_0^{\frac{T_0}{2}} V_s{}^2 dt\right)^{1/2} = V_s \qquad (47)$$

Where is the DC source voltage, is the output voltage, is the period.

3. RESULTS AND DISCUSSION

In the discussion, the design results will be validated using PSIM software to see the magnitude of the output voltage of the entire system that has been designed. The system will be connected to a resistive load to see the inverter output waveform whose inverter input side comes from the output voltage of the CCB converter and the CCB converter source comes from a 24VDC battery. Below is the topology of the CCB Converter and Inverter (CCB-I Converter) along with the proposed specifications.

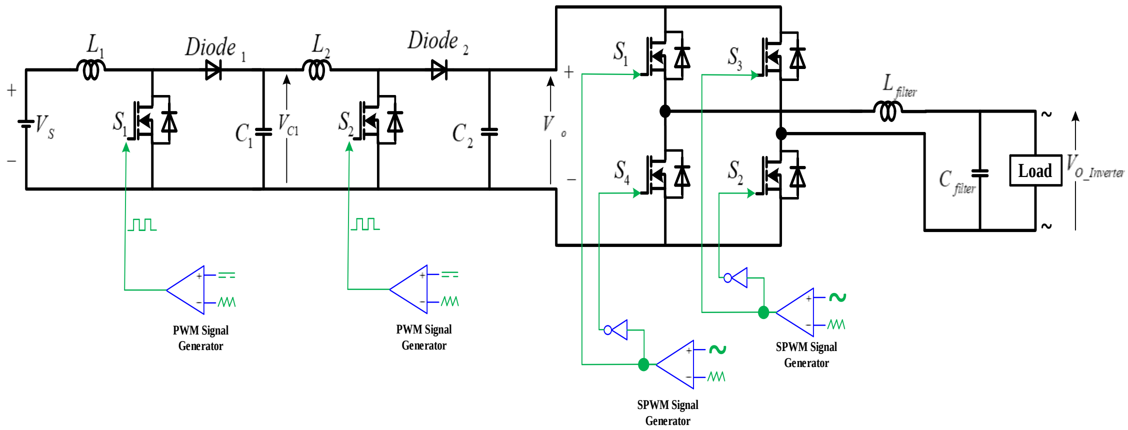

Figure 7. CCB-I Converter

Table 2. CCB Converter and Inverter Specifications

Components	Values
CCB Input Voltage (Vs)	24V
CCB Output Voltage (Vo)	336V
Duty cycle 1 (S1)	0,715
Duty cycle 2 (S2)	0,75
Capacitor 1 (C1)	4000uF
Capacitor 2 (C2)	4500uF
Inductor 1 (L1)	348uH
Inductor 2 (L2)	234uH
Filter L	100uH
Filter C	200uF
Load R	100Ω
Load L	0,002H
Inverter Output Voltage (Vo_inv)	220V

Figure 7 is the overall topology of the CCB-I converter which is a combination of the CCB converter with a single phase inverter. Table 2 is a specification of the converter and the value of the components. In the converter simulation results, the output voltage profile graph of the CCB converter and the CCB-I converter voltage will be displayed.

3.1. CCB Converter Output Voltage

In this experiment, With a 24V input voltage, the CCB converter's input and output voltage profiles will be exhibited, the duty cycle on boost 1 is 0.715 or 75.1% and the duty cycle on boost 2 is 0.75 or 75% to produce an output voltage above 336V. Figure 7 displays the simulation results of the converter.

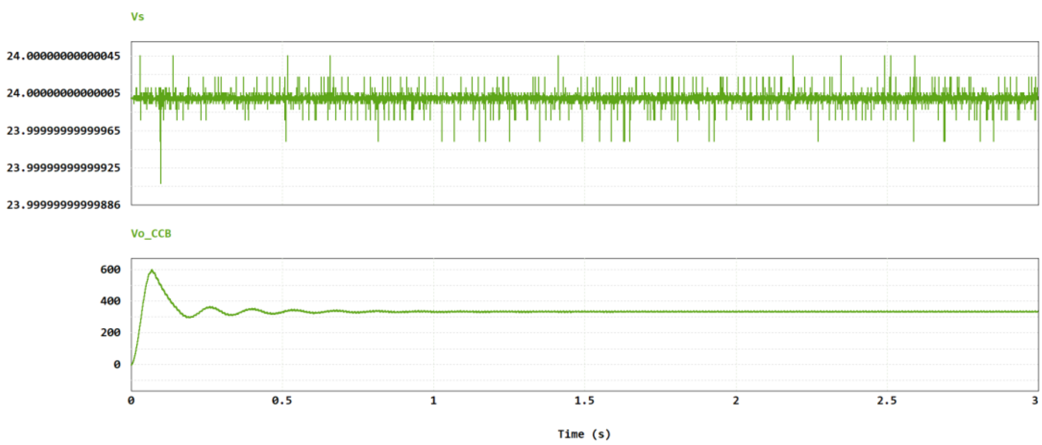

Figure 8. Input and Output Voltage

Figure 8 is the result of the input voltage and output voltage profile plot on the CCB converter. Where Vs is the input voltage of 24V and Vo_CCB is the output voltage of 334.3V.

3.2. Output Voltage of CCB-I Converter

In this experiment, the input voltage and output voltage profiles of the CCB-I converter will be displayed. Below is a picture of the inverter output voltage profile.

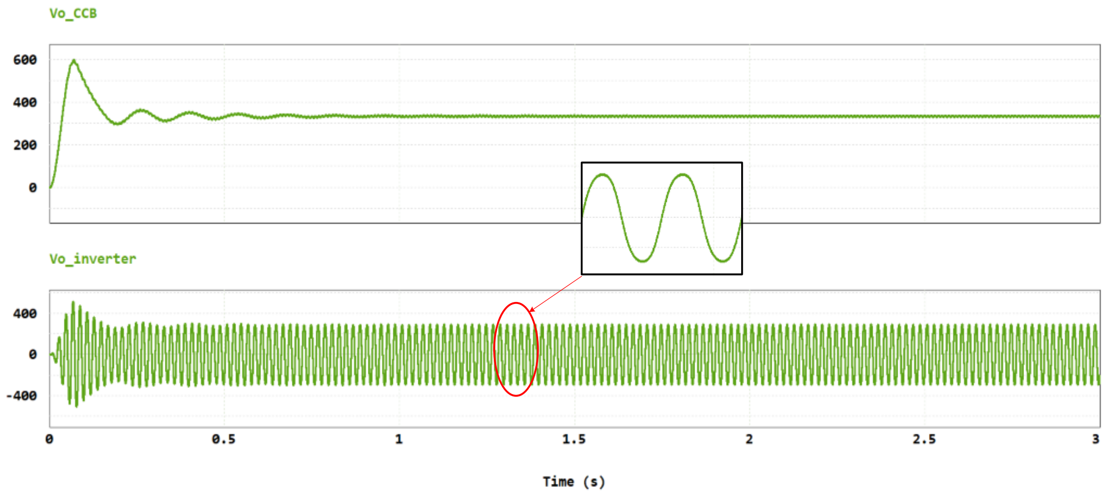

Figure 9. Input and Output Voltage

In Figure 9 where Vo_CCB is the output voltage of the CCB converter as well as the input voltage for the single-phase inverter which has a value of 334.3V, while for Vo_inverter is the inverter output wave which has a near sinusoidal with an RMS output voltage of 220VAC with a frequency of 50Hz..

3.3 Output Current of CCB-I Converter

In this session, we will look at the current waveform of a 1-phase inverter that is loaded resistively-inductively. Figure 9 is the output waveform of the converter.

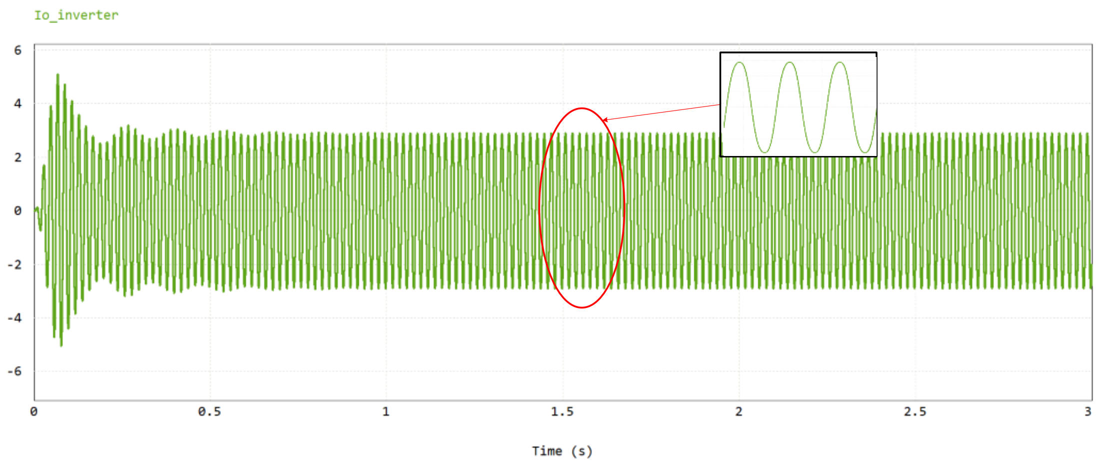

Figure 10. Output Current

In Figure 10 is the output current wave from the inverter which has a waveform close to sinusoidal. The magnitude of the RMS current in the figure is 2.21A

4. CONCLUSION

In this research, the researchers designed a CCB converter as a single-phase inverter power supply integrated into one unit with the name CCB-I converter. The CCB converter functions as a DC high voltage booster as the input voltage for the inverter. Thus the inverter can output 220VAC RMS voltage without having to use a step up transformer. In the simulation of the entire system, it shows that the CCB converter can output a voltage of 334.VDC at a duty cycle of 71.5% and 75%, then for the CCB-I converter can output the output voltage according to the target of RMS 220V, 50Hz with the help of a combination of LC filters as a filter to improve the voltage and current waves to be close to sinusoidal.

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