Development of square wave inverter using DC/DC boost converter

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ABSTRACT

This paper proposes an alternative topology of an inverter to the existing topologies available in the market. A prototype is intended with the purpose of investigates the possibility of designing an inverter using two Boost Converters. This project initialized with a series of simulations using Matlab in order to determine the feasibility of the proposed topology. The next step is the design and development of the proposed prototype where suitable electronics components are chosen based on the simulation result. A PIC microcontroller is used to control the proposed prototype where a control scheme is created based on the programming in the microcontroller. The performance of the proposed prototype has been verified to be optimum by several practical testing using different values of capacitor, inductor and duty cycle. Lastly, data and analysis are presented in a proper mannered way. In the end, this project intends to produce stepped-up square wave output voltage waveform by proper controlling of two Boost Converters.

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1. INTRODUCTION

The inverter is known as a type of electronic device which inverts the magnitude of direct current (DC) input voltage or current from positive to negative and vice-versa at its output [1]. The inverted DC voltage or current at the output which having a same conducting period for negative and positive magnitude is recognized as symmetrical alternating current (AC). To be exactly, inverters can invert a DC source to an AC source in desired magnitude and frequency which eventually transfer power from a DC source to an AC load [2]. The inverter also known as a DC to AC converter.

There are many types of common inverters topology such as half-bridge, full-bridge, square-wave, and modified sine wave inverters [3]. Inverters are assembled from electronic switches (MOSFET, IGBT, and SCR), inductors, diodes, and capacitors. The most basic waveform that produced by an inverter is the square waveform for voltage and current [3]. In order to get a pure sinusoidal AC waveform, output filter is introduced to the inverter. The output filter has to be designed to meet the specification required for the load in the aspect of frequency, total harmonic distortion, voltage magnitude, current magnitude, and efficiency [4]. A LC low-pass filter is implemented as to progressively filter the output of inverter for a better and lower total harmonic distortion (THD) level [5]. Due to the widely used of solar panel, uninterruptible power supplies (UPS), adjustable-speed ac motor drives and running ac appliances from an automobile battery, inverter plays important roles to support every AC source application [6]. The topologies of inverter have increased since the trend has greatly moved to the renewable energy and high voltage direct current (HVDC) power transmission [6].

2. PROJECT BACKGROUND

This paper entitled Design and Development of a Square Wave Inverter using Converters. In this paper, two Boost Converters is used and connected to a common load. Boost Converters convert a DC level input voltage to another DC level output voltage stepped-up DC level output voltage. The inverter is an electronic circuit that converts a DC input voltage to an AC output voltage [3], which produces an alternating square shaped output voltage waveform. The concept of the research is combining two Boost Converters which are connected to a common load to give an inverter-like output voltage waveform. The expected result is a square wave output voltage waveform that is a stepped-up voltage level that has both positive and negative portions of the voltage by proper controlling of two Boost Converters. The alternative inverter topology that designed and developed in this study is named as Square Wave Boost Inverter (SWBI).

2.1. Problem statement

The desideratum of efficient inverters which used to convert DC energy to conventional AC form has increased [8]. This project proposes a prototype with the purpose of investigating and provides alternative topologies of an inverter to convert the DC voltage to AC voltage. In this project, Boost Converter is implemented in the inverter to convert DC voltage to AC voltage. The implementation of Boost Converter in an inverter can provide step-up operation mode where the output voltage varies according to the mode of operation and it also can be used to control the frequency of the output voltage [9-10]. In order to make it works, a proper consideration in design and developing of the inverter such as choosing the suitable components are required. Besides that, a control scheme for the proposed inverter has to be configured in order to provide either stepped-down or stepped-up square wave output voltage waveform of the inverter. A critical evaluation is then performed to scrutinize the performance of the proposed inverter.

2.2. Design consideration

In order to perform analysis on a Boost Inverter, firstly the Boost Converter is assumed to be ideal and lossless during the steady-state operation. There are two subintervals that involve the analysis which referred to the switch and diode respectively. Due to the DC output voltage of the Boost converter that depends on the inductor average voltage and current, the analysis of current and voltage of the inductor is carried out during the two subintervals, which are referred as the switching period during on and off, respectively [2]. The switching frequency is defined as the period of the switch to turn on and off in the Boost Converter where Tsw is the period of one complete conduction cycle and f_{sw} is the switching frequency of the circuit. The switching interval must consider the fundamental frequency of the inverter waveform.

$$f_{sw} = \frac{1}{T_{sw}} \tag{1}$$

The duty cycle of the switch, d during on time will determine the inductor average voltage and current of the converter and it can be determined by the following equation:

$$d = \frac{V_o}{V_s} \tag{2}$$

Continuous Conduction Mode (CCM) for Boost Converters is desirable for most of the DC-DC conversion applications [7]. The minimum value of inductance is calculated such that the inductor current, I_L, flows continuously above zero. In order words, the boundary of CCM is determined by the value of I_{max} and I_{min}. Thus, the minimum inductance, L_{min}, is formulated by

$$L_{\min} = \frac{V_{in} \times \left(V_{out} - V_{in}\right)}{\Delta I_L \times f_{sw} \times V_{out}} \tag{3}$$

The output capacitance that determine the output voltage ripple which desired by the designers is given by

$$C = \frac{I_{out(\max)} \times \mathrm{D}}{f_{sw} \times \Delta V_{out}} \tag{4}$$

For the output section, the inverter are connected to the low pass LC filter where it requires some calculation and the main equation is given by

$$f_c = \frac{1}{2\pi RC} \tag{5}$$

2.3. Design perspectives

The design aspect is based on the compromised of every electronics component that required in the SMPS. The designer has to choose every component by referring to the specification needed. There are no rules for a designer to choose specific electronic components but the designer has to a trade-off between size, performance and cost of the DC-DC converters [7].

The ripple current in the inductor is commonly chosen to be 30% of the load current which same as the ripple voltage. The switching frequency is always chosen to be at a higher value which preferably greater than 25 kHz. The inductor is usually selected which having 125% higher than the value of minimum inductance value to prevent the CCM goes to DCM while for the capacitance value has to choose higher value than the minimum value in order to smooth the ripple voltage. Both components have to be selected with appropriate current and voltage rating [7].

In order to generate the Inverter output voltage from the combination of two Boost converter, the proper switching scheme needs to be decided as mention earlier as the desired fundamental frequency for the inverter is 50 Hz.

3. CONTROL SCHEME

There are varies of a control scheme for inverter such as pulse width modulation (PWM) and sinusoidal pulse width modulation (SPWM) in order to generate output waveform of the inverter which is more sinusoidal like. The control scheme not only can reduce the filter requirements but it also can control the output voltage amplitude. The only disadvantages are the complex of a control circuit for the switches and increasing switching losses but this drawback can be reduced by using the programmable controller such as peripheral integrated circuit (PIC) and a field-programmable gate array (FPGA) [12].

In order to maintain the desired output voltage over a large range of input, the control method of PWM can generate a modified square wave which based on the amplitude modulation in the PWM [11]. The modified square wave inverters can eliminate harmonics content which depends on the level of the modified square wave. For a 3-level modified square wave inverter, it can reduce THD to 23.8% from a square wave which is 45% in THD [3]. Figure 1 shows an example of 3-level modified sine-wave inverters output voltage waveform.

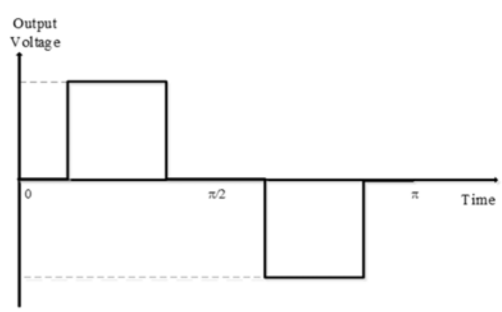

Figure 1. Modified square wave inverters waveform

3.1. Proposed inverter design

In SWBI, two Boost Converters will be used and connected to a common load which illustrated in Figure 2. This connection will be produced a square waveform when conduct alternately which resembles an inverter. Figure 3 shows that the proposed circuit design to form an inverter from the boost converter circuit. The addition of two MOSFETs at the end of boost converter where S3 and S4 to ensure the alternation process can be made between positive and negative cycle. The specification of switching is shown in Table 1 above. The switching pattern is selected to be in high switching state for boost converter as the nature of boost converter needs a high switching frequency to level up the low voltage into a higher level of voltage.

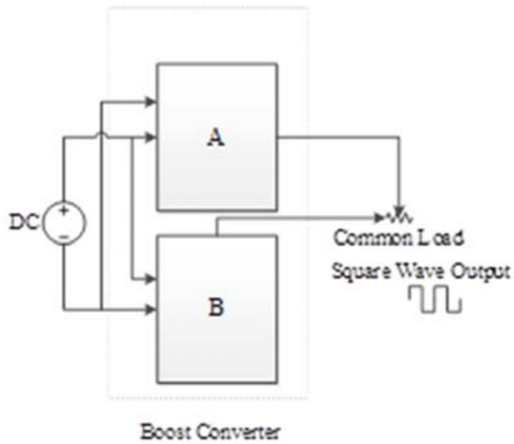

Figure 2. Block diagram of the proposed inverter

Table 1. Calculation of parameter of components

Parameter	Value
Duty cycle	0.75
Resistor	100 Ω
Capacitor	1.5 uF
Inductor	95 uH
Frequency	Boost converter = 100kHz (MOSFET 1 & 2) Inverter = 50Hz (MOSFET 3 & 4)
Input	12 V_{dc}
Output	Square wave 48 V_{ac}

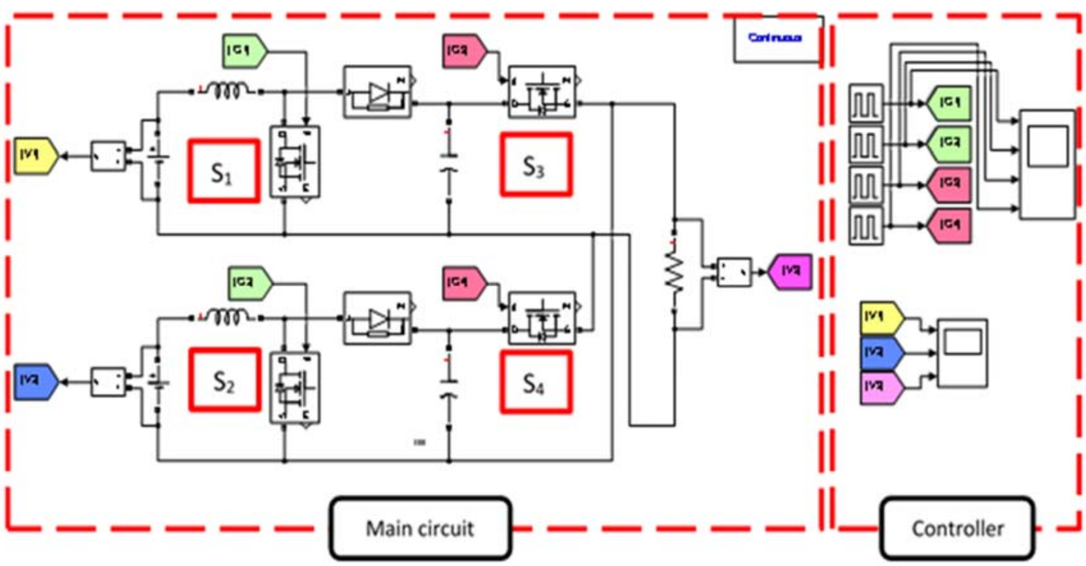

Figure 3. Block diagram of the proposed inverter

4. RESULTS

Simulation is the best tool during study phase as the circuit functionality can be tested before proceeding to the real hardware. For this paper, MATLAB Simulink tool a used to simulate the modified controller for this Boost Inverter circuit and all the parameter of the component such as R_{dson} at the MOSFET are set well at the simulation page according to the datasheet of the components.

4.1. Simulation result using MATLAB Simulink

On the controller section, the main circuit needed two types controlling scheme where the boost converter circuit need a high switching state of 100 kHz as to drive the MOSFET from a low voltage level into a higher voltage magnitude. The second switching scheme needs a low switching of 50 Hz to ensure that the generated voltage can alternate between a positive and negative side. The advantage of this topology as it is just used the switching interval of 50 Hz compared to the conventional H-bridge inverter that used high switching state. High switching state will lead to a high switching loss [13]. Table 2 demonstrates the switching state needed for each MOSFET for the main circuit.

Table 2. Switching state for MOSFET

Power swithces	Switching frequency	Condition
MOSFET 1 (S_1)	100 kHz	High Switching State
MOSFET 2 (S_2)	100 kHz	
MOSFET 3 (S_3)	50 Hz	Low Switching State
MOSFET 4 (S_4)	50 Hz	

Figure 4 above demonstrate the pulses generated for MOSFET S1 until MOSFET S4. The pulses are generated based on the fundamental frequency of 50 Hz and the one complete cycle alternation of the inverter is 0.02 seconds. The high switching state of 100 kHz driving the MOSFET S1 from 0 until 0.01 second and it is set to off state between 0.01 until 0.02 as to let the second circuit of boost converter operate at that time. In addition, the switching scheme of MOSFET S3 S4 is purposely designed exactly to be turned on and turned off exactly at 0.01 and 0.02 seconds as to ensure the alternating process is successfully achieved. The same sequencing is developed for the hardware section but using the microcontroller programming

The behavior of boost inverter output voltage shown in Figure 5 above where it shows that the input voltage is 12 VDC and the output voltage alternate between +44 VDC and -44 VDC. This result has some distortion where the result should get approximately alternation between +48 VDC and -48 VDC. This behavior is due to some voltage drop in the component, especially at the capacitor. It can be observed that the switching is successfully alternate between 0.01 and 0.02 seconds.

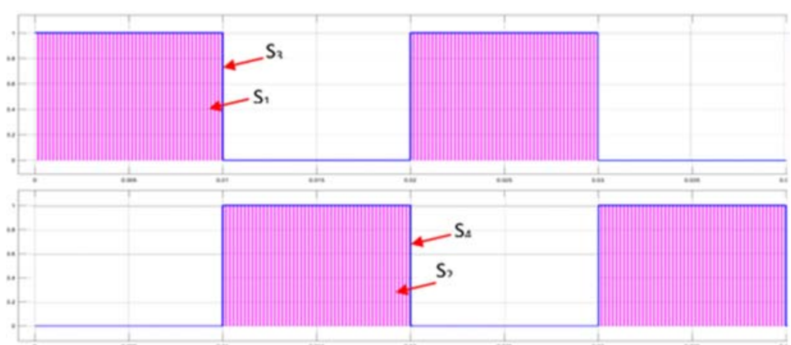

Figure 4. Controller scheme for boost inverter circuit

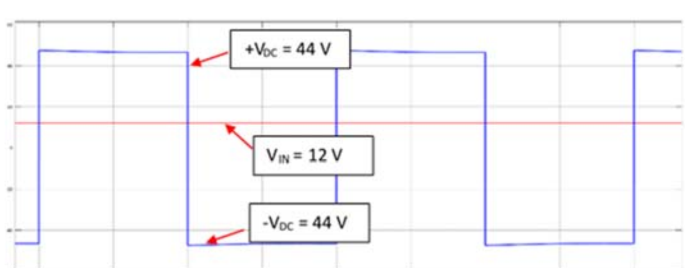

Figure 5. Simulation results of square wave boost inverter

4.2. Controller section

In this project, IRF540 was chosen as the MOSFETs to construct the inverter. Based on IRF540, the gate-to-source voltage, Vgs is 20V, there for gate drivers are needed to drive four unit of MOSFETs as shown in Figure 6. The circuit consists of 4 units of MOSFETs together with 4 units of gate drivers. The gate driver configuration comes with HCPL 3810 optocoupler to isolate the main circuit and the controller circuit for safety purposes. The capacitors used are the electrolytic types as it is more suitable for power application purposes.

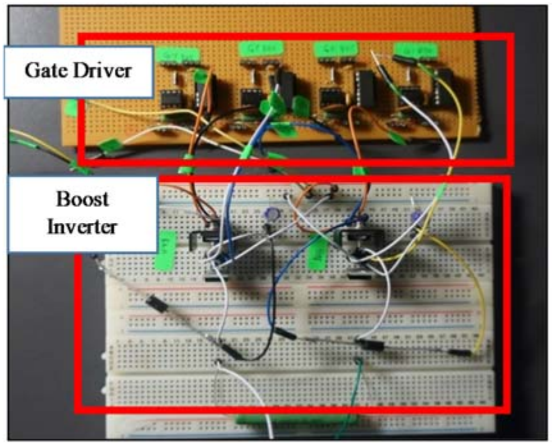

Figure 6. Developed boost inverter

Figure 7 shows the pulses generated by the gate driver that controlled by the PIC microcontroller injected into switching devices for controlling parallel boost converter circuit. For the single stage, the frequency used was 100 kHz and the cycle was same with high switching for parallel boost converter circuit control. In parallel mode, the high switching count to achieve 0.01s for half cycle was calculated to make sure the high switching will simultaneously on and off with it low switching. The same term was applied to another half cycle. Figure 7 are the generated pulses for the four units of MOSFETs and it is the combination of high switching and low switching state.

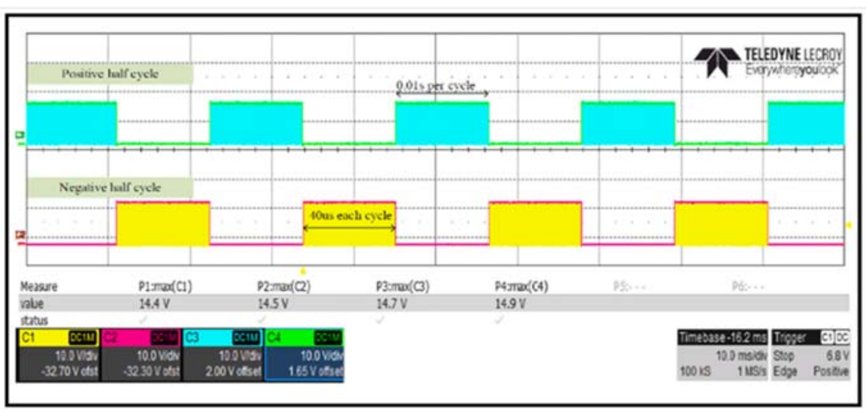

Figure 7. Generated control scheme

As shown above the generated inverter output voltage from the proposed cascaded two units of a boost converter. It is well known a single boost converter can boost up a DC voltage to a higher level. As shown in Figure 8, Channel 1 displayed the input voltage approximately 13.6 Vdc thus forming into 52.8 Vac square wave output voltage as displayed on Channel 2. Compared to simulation results in Figure 5 above, the shape of the result is almost the same but the value of output voltage is slightly higher compared to the simulation as the digital scope read the maximum/amplitude of the output voltage. In Figure 8, it is noticeable that there is a voltage spike at the beginning of the square wave. With a proper reading and ignore the voltage spike, the value of output voltage is alternate between +48 VDC and -48 VDC.

The proposed inverter will undergo harmonic performance as to progressively observe the impact of the combination of DC/DC Boost converter towards the harmonic performance of the inverter. Figure 9 demonstrates the harmonic spectrum using FFT by using Tektronix TPS2014 Digital Oscilloscope.

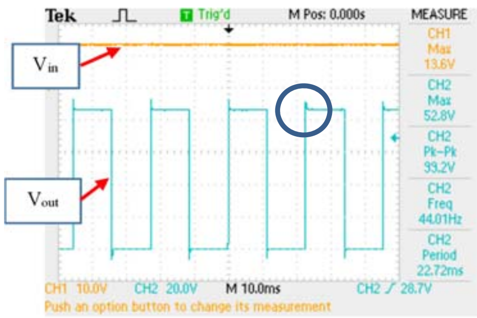

Figure 8. Input and output voltage for Boost Inverter

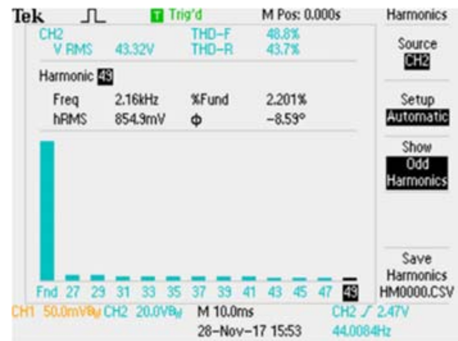

Figure 9. Harmonic results

The value of harmonic in the developed boost inverter around 48.8% which is slightly higher compared to the normal square wave inverter mention earlier where it should be in the range of 45%. The value of harmonic is still acceptable as the difference of range is just 3%.

This circuit is next tested with LC filter to filtering the square wave output voltage. The value of L and C are decided based on the value of cut-off frequency of 50 Hz and the value of C are set to be constant and low value as in 4.5 uF and value of inductor 10.7 mH. The value of inductor quite high compared to the LC filter used in the unipolar inverter as the square wave inverter is hard to be filtered out into sinusoidal due to the edge of the square wave itself. The filtered output voltage as shown in Figure 10.

Figure 10. Filtered output voltage

It can be observed that the filtering process of the output voltage is nearly unsuccessful as the nature shape is still in square wave shaped. This is due to the struggle of bending the pure square wave into a sinusoidal wave shape. Compared to the unipolar inverter, the filtering process is a way easier as there are many small pulses in the one whole cycle and it will easily bending the curve when entering the LC filter. The value of peak voltage also drops compare to the square wave after the filtering process. The suitable capacitors for filtering process are the Cap Film types as the value of ESR in the capacitors very low and these criteria will help on reducing the voltage stress.

5. CONCLUSION

The main target is to assembling an alternative topology in inverter by using two Boost Converters where the proposed inverter can produce a square wave output voltage waveform that resembled the output of an inverter. The proposed inverter was being utilized when it is using PIC Microcontroller based gate driver which produce constant gate signal voltage to MOSFETs. The results have proved that the inverter can provide others mode of operation besides the normal operation that an inverter did. Overall, the project achieves its goals. This inverter can be further improved as the topology does not need the transformer in order to level up the small input voltage. The conventional inverter that used H-bridge circuit configurations needs the transformer to level up the voltage. This configuration simultaneously improves the size of the inverter as well as the weight of the inverter itself. The design and development of a square wave inverter using Boost Converters to perform as an inverter was successful.

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