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A NEW TOPOLOGY OF THREE PHASE BUCK-BOOST INVERTER WITH BUFFER INDUCTOR

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ABSTRACT

The electric vehicle inverter requires an induction motor drive with a high output of voltage and current to reduce the number of batteries used and in turn to reduce the vehicle's weight. In this paper, a new topology of a three-phase buck-boost inverter (TPBBI) with a buffer inductor (BI) is proposed. The performance of the proposed inverter topology was tested using a power simulator program. The inverter was designed with a proper component of inductors and capacitors. For a given load resistor, it was shown that the inverter can produce a sinusoidal output voltage and current with an amplification of more than three times. A simulation was also carried out in a case of an inverter loaded to three-phase induction motor with a specific torque and moment of inertia. It was demonstrated that the inverter still can produce the sinusoidal output voltage and current and can reduce the applied torque and thus a stable condition of the inverter can be maintained. The proposed inverter is suitable to be implemented for the electric vehicle.

***Key-words**: Three Phase Buck-Boost Inverter (Tpbbi), Buffer Inductor (Bi), Topology, Spwm, Electric Vehicle.*

1. INTRODUCTION

An inverter is an electronic device to convert the DC input voltage into AC output voltage in adjustable size and frequency [1]. The inverter is applied in uninterruptible power supply (UPS), active filter, and motor control [1–9]. It is divided into three topologies by comparing the output voltage to the input voltage. They are buck, boost, and buck – boost inverters. Based on the principle works, inverter grouped in two configurations, namely single-stage inverter and multi-stage inverter [3]. It is also grouped into three major groups of voltage source inverter (VSI), current source inverter (CSI) and pulse width modulation (PWM) [1].

The electric vehicle that uses an induction motor as a driving force, a DC voltage source either from dry battery or lead acid battery is converted into the AC output voltage using the inverter. The lead acid battery has a lower cost but heavier when compared to the dry battery. The heavier vehicle's weight due to the battery requires a strong inverter. The electric vehicle's motor also needs a capability to motion the electric vehicle at any given conditions such as constant speed, acceleration, or de-acceleration. The perfect inverter for the above conditions is buck–boost inverter because its output voltage can be adjusted when necessary.

Actually in the free market is very difficult to get buck-boost inverter with specifications as needed for electric vehicle. Inverters are available most of the buck inverter , or boost inverter with the strengthening of the output voltage is very small.

There were several single phase boost and buck–boost inverters suggested previously, such as those proposed by Caceres and Barbi [4]. They are two DC to DC inverters in parallel with DC voltage source. Each conductor is modulated to produce DC bias sinusoidal output voltage in unipolar with phase difference of 180 degrees. The output voltage across the load R shows a pure sinusoidal waveform. Other researcher, Vasquez et. all [5] suggested a single phase buck - boost inverter with similar topology and working principle proposed by Caceres and Barbi. Their research resulted in the strengthening of the peak-to-peak output voltage of about 2.5 times of the input voltage.

One of the researchers who developed the three-phase boost inverter is B. Koushki et. all. [6]. Developed inverter configuration includes a single-stage inverter with 6 switches.

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Strengthening the voltage generated less than two times the input voltage. Therefore need to be designed specifically buck-boost inverter for electric vehicle.

In this paper proposed a new topology of a three phase buck-boost inverter with a buffer inductor (TPBBI-BI). It is developed from the conventional TPBBI by adding a pair of inductor at the output terminal. The proposed topology then simulated and the results were analyzed to obtain the characteristics of the output voltage and current, among other things, the form of waves, wave symmetry, the magnitude of the amplitude and frequency, and phase. The proposed topology can provide the output voltage of more than three times of the input voltage.

2. INVERTER TOPOLOGY

There are several methods to classify inverter, including by electric isolation between input and output or the input dc voltage than the output ac voltage. Depending on the input dc voltage comparison to the output ac voltage, inverters can be buck inverters or conventional voltage source inverter (VSI) as shown in figure 1 [1][6], boost inverters as shown in figure 2 [6], or buck-boost inverters. The buck inverter cannot produce AC output voltage greater than the DC input voltage.

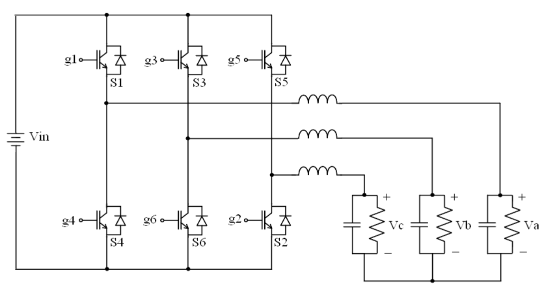

Figure 1 Conventional Buck Type Inverter

The output voltage of inverter are Va, Vb, and Vc. If the inverter feeds a star connected, waveform has six step wave. When an upper IGBT (S1, S3, or S5) is switched ON, the corresponding lower IGBT (S4, S6, or S2) is siwtched OFF. Both of the switches in the same leg cannot be turn on in the same time. Sequence of couples switch ON from step 1 to step 6 is as follows:

a. Step 1 ($0^0 – 60^0$) : S5 , S6 , S1
b. Step 2 ($60^0 – 120^0$) : S6 , S1 , S2
c. Step 3 ($120^0 – 180^0$) : S1 , S2 , S3
d. Step 4 ($180^0 – 240^0$) : S2 , S3 , S4
e. Step 5 ($240^0 – 300^0$) : S3 , S4 , S5
f. Step 6 ($300^0 – 360^0$) : S4 , S5 , S6

In order to obtain AC output voltage higher than DC input voltage, added boost converter betwen source and the DC to AC buck type converter as shown in figure 2. For big power and high voltage, this topology is costly and less efficient associated with the volume and weight.

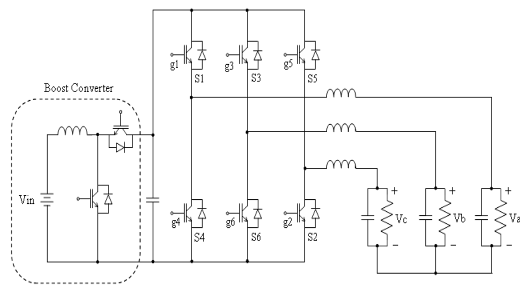

FIGURE 2 CIRCUIT TO MAKE AC VOLTAGE GREATER THAN DC INPUT VOLTAGE.

3. PROPOSED NEW TOPOLOGY

The proposed a new topology of TPBBI with BI as shown in figure 3. It is including the type of single stage with six switches. Topological differences with the conventional topology is the addition of the inductor at the output terminal. Additional inductor position is more advantageous when compared with the conventional topology, because it helps keep the electrical charge at the loop more energized. With the addition of the inductor the output voltage is expected to be larger than the conventional topology.

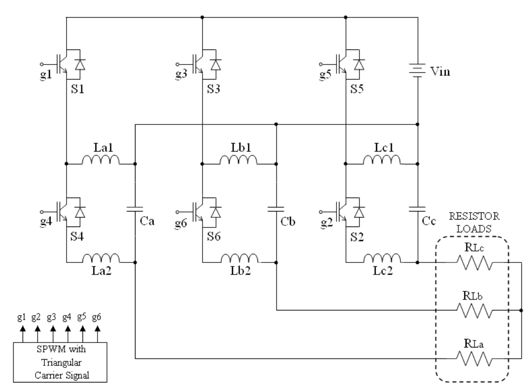

Figure 3 Proposed New Tpbbi With Bi.

3.1 Principles of Operation

The working principle of TPBBI-BI identical to conventional inverter, which is based on the state of the switch S1 through S6. The state of switched (ON or OFF) are controlled by the

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SPWM. It is based on generating a sequance of voltage pulses at a certain frequency and sinusoidal modulated pulse-widths. Each inverter phase has a comparator which is fed with the reference voltage for that phase and symmetrical triangular carrier wave which is common to all three phase as shown figure 4 [2].

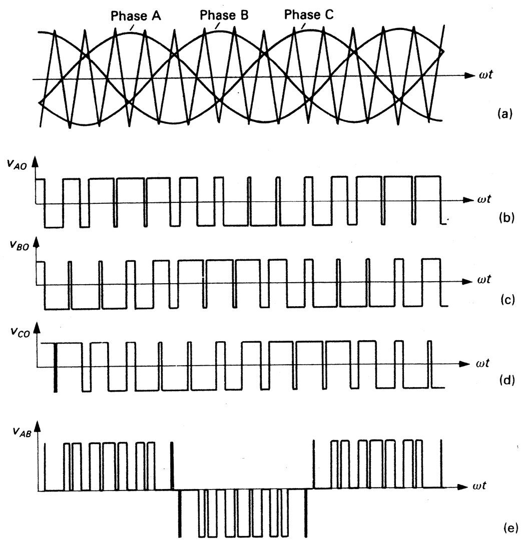

Figure 4 Voltage waveform for a three phase sinusoidal PWM inverter : a. Comparator voltage; b. c. d. pole voltage; e. ac line voltage [2].

3.2 Modeling of TPBBI with BI

In the three-phase bridge voltage source inverter with a balanced wye-connected load, the sum of the instantaneous line-to-neutral voltages is zero [2], so that

$$V_{AN} + V_{BN} + V_{CN} = 0 \quad (1)$$

The line voltage

$$\begin{aligned} V_{AB} &= V_{AO} - V_{BO} \\ V_{BC} &= V_{BO} - V_{CO} \\ V_{CA} &= V_{CO} - V_{AO} \end{aligned} \quad (2)$$

The phase voltages can be obtained from the line voltagea as,

$$\begin{bmatrix} V_{ab} \\ V_{bc} \\ V_{ca} \end{bmatrix} = \begin{bmatrix} V_{an} & - & V_{bn} \\ V_{bn} & - & V_{cn} \\ V_{cn} & - & V_{an} \end{bmatrix} \quad (3)$$

The phase voltage vector $[V_{an} \quad V_{bn} \quad V_{cn}]^T$ as

$$\begin{bmatrix} V_{ab} \\ V_{bc} \\ V_{ca} \end{bmatrix} = \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} \quad (4)$$

The phase voltages add to zero, the phase load voltages can be written as

$$\begin{bmatrix} V_{ab} \\ V_{bc} \\ 0 \end{bmatrix} = \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} \quad (5)$$

which implies

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 2 & 1 & 1 \\ -1 & 1 & 1 \\ -1 & -2 & 1 \end{bmatrix} \begin{bmatrix} V_{ab} \\ V_{bc} \\ 0 \end{bmatrix} \quad (6)$$

4. RESULT AND DISCUSSION

A simulator PSIM ver 9.0 was used to find out the characteristics of the TPBBI with BI. Simulations done for two kinds of loads, first a resistor load and the second induction motor load. The inverter is consisted of 10 batteries (type lead acid – 46B24L GS Battery Indonesia as specified in Table 1) with Vin = 120 V, La1 = Lb1 = Lc1 = 5,75 µH, La2 = Lb2 = Lc2 = 15,7 µH, Ca = Cb = Cc = 500 µF, and load resistance R = 1 Ω to R = 3 Ω. The reference voltage or signal frequency used in the simulation are 50 Hz and 60 Hz, while the carrier frequency is between 2000 Hz to 4800 Hz. The battery is assumed as an ideal voltage source, it is not reduced by a function of time.

Table 1 Physical Data Type Of Battrey 46b24l

Battrey Type	Size
Dimension (mm) t x l x p	227 x 129 x 238
Capacity [Ah]	36
Discharge max [A]	150
Weight [Kg]	12.5

The first simulation done for the inverter with a balanced wye-connected resistive load as shown in figure 5. The addition of filters to obtain the voltage and current forms a smooth and there is no cutting of curve. The frequency of carrier signal and reference voltage of SPWM are 2000 Hz and 60 Hz. The results of simulation with 3 Ω load resistive shown in Figure. 6. Maximum output voltage

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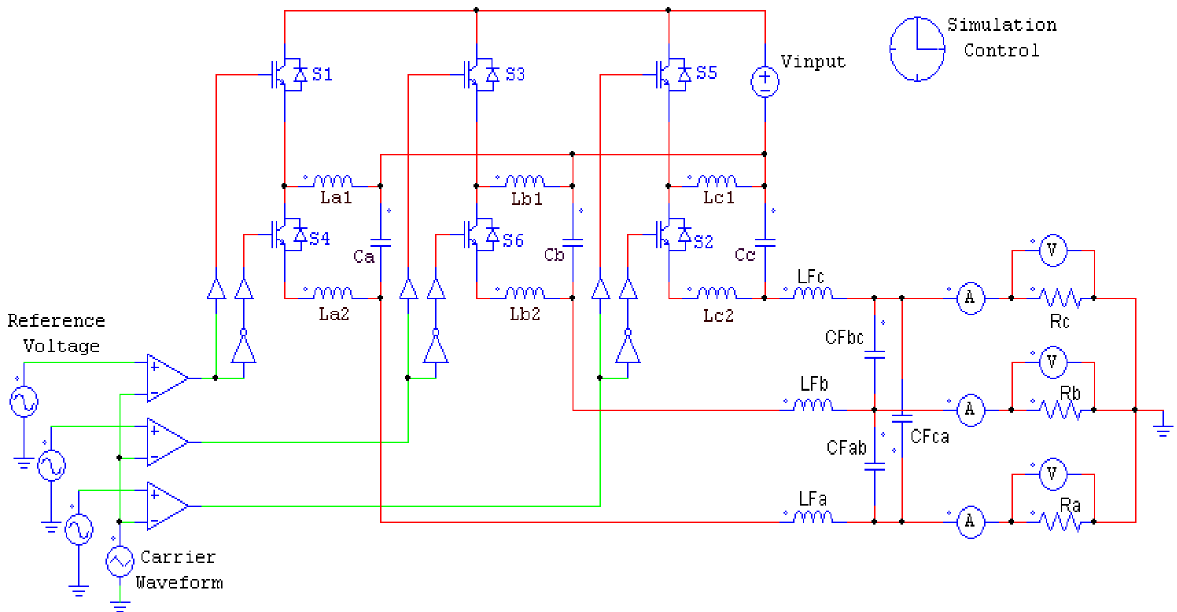
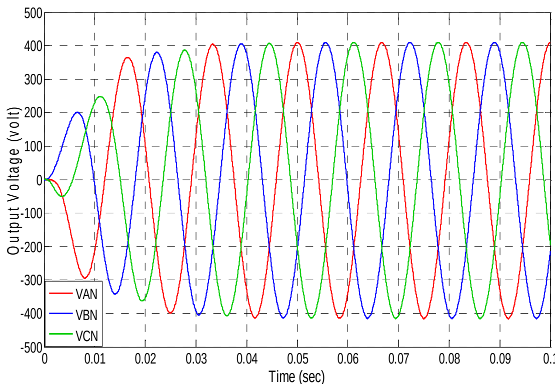
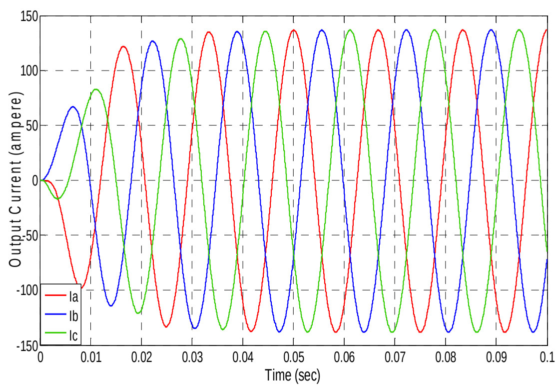


Figure 5 Tpbbi-Bi With A Balanced Wye-Connected Resistive Load



(a)



(b)

Figure 6 Output Voltage And Current Of Tpbbi With A Balanced Wye-Connected Resistive Load R=3Ω

and current respectively are shown in table 2. When compared to the dc input voltage, the inverter has a voltage gain more than twice.

Table 2 The Voltage And Current Output Of Simulation Results With R = 3 Ω

	Peak-to-peak	rms
Voltage (volt)	410.1	275.7
Current (ampere)	136.7	91.9

Load inverter in the second simulation is a three-phase induction motors and permanent torque, shown in figure 7. Induction motor parameter values shown in Table 3. The inverter

Table 3 Parameter Of Induction Motor

Parameter	Motor I [11]
Rs (Stator)	6.03 Ω
Ls (Stator)	29.9 mH
Rr (Rotor)	6.085 Ω
Lr (Rotor)	29.9 mH
Lm (magnetizing)	489.3 mH
No. of Pole	4
Moment of Inertia	0.011787 kgm^2
Supply Freq.	50 Hz
Power Rating	746 W
Voltage	415 V

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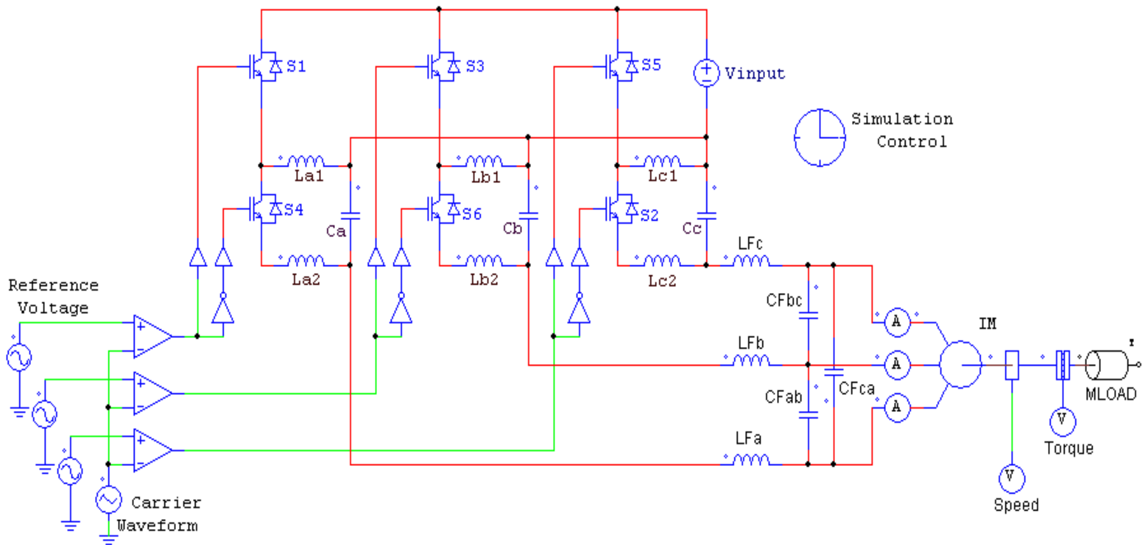

Figure 7 Tpbbi-Bi With An Induction Motor Load

parameter values used in the simulation of the first and second are the same. The initial step of this second simulation is put rotational speed sensors

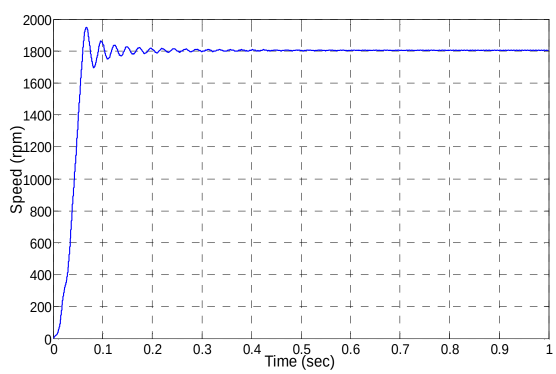

Figure 8 Speed Response Of Induction Motor At Frequency Of Reference Voltage = 60 Hz.

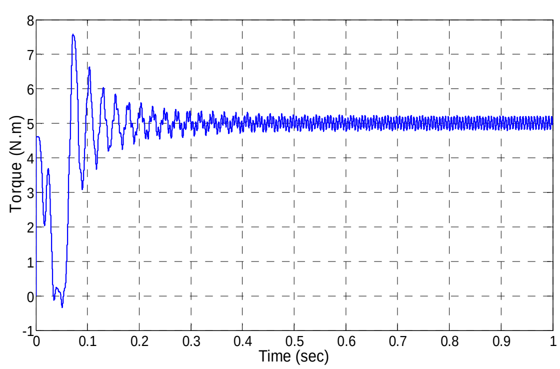

Figure 9 Torque Response Of Induction Motor At Frequency Of Reference Voltage = 60 Hz

and torque sensor between the induction motor and the mechanical load torque, shown in figure 7. Constant torque was charged to the motor is 5 N.m with a moment of inertia 0.001 kg.m^2.

The frequency of the reference voltage used in the simulation is 40 Hz to 80 Hz, with the best outcomes at 60 Hz. The speed of induction motor at frequency of reference voltage = 60 Hz shown in figure 8. Theoretically the motor speed with four poles is 1800 rpm. The speed of induction motor results of simulation is 1803 rpm, so it still qualifies as a tolerance of 2%. Based on the curve, the response included in the underdamp with the maximum overshoot 9.78% at 0.067 sec.

Torque responses of induction motor was charged with constant torque 5 N.m and moment of inertia 0.001 kg.m^2 at frequency of reference voltage = 60 Hz shown in figure 9. TPBBI-BI is

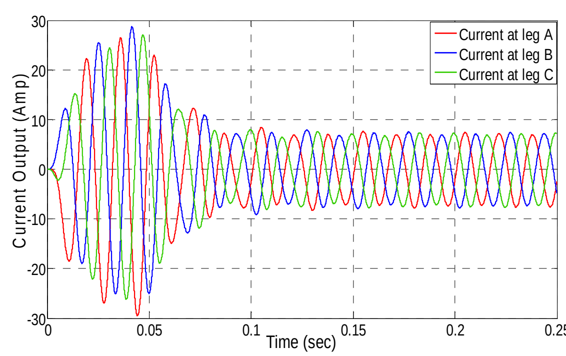

Figure 10 Current Output Of Tpbbi-Ia At Frequency Of Reference Voltage = 60 Hz

able to meet the needs of an induction motor with load, although in the early seconds of severe oscillations occur.

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Figure 10 presents the current output of TPBBI-BI when given motor load. If the curve in figure 10 compared with the curves in figure 8 and figure 9, shows that the output current after a 0.2 sec was in steady state. Based on these three curves can be stated that the TPBBI-BI can be able to produce voltage and current required by induction motors, so the response is generated according to the specifications.

5. CONCLUSION

It has been proposed the TPBBI-BI to increase the output voltage and current. The proposed TPBBI-BI with a balanced wye-connected resistive load can produce the output voltage (in rms) more than twice times of the input voltage. Inverter capable of supplying the needs of three-phase induction motor with a load of constant torque and moment of inertia. Therefore this proposed TPBBI-BI is very suitable when applied to a motor drive such as an induction motor as a driving force in an electric vehicle.

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