

Analysis of Three Phase Induction Motor Supplied by SVPWM Inverter for Electric Bike Application

Amir Hamzah,^{a,*} Suwitno,^a Romy,^b and Ronaldi Hutabalian^a

^a)Electrical Engineering, Universitas Riau, Indonesia

^b)Mechanical Engineering, Universitas Riau, Indonesia

*Corresponding author: amir.hamzah@eng.unri.ac.id

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ABSTRACT

Electric drive on an electric bike, consist of electric motor, power converter and electronic controller. These are the mover of electric vehicle system. This paper discussed the three-phase inverter with Space Vector Pulse Width Modulation (SVPWM) method as a three-phase induction motor drive in electric bike application. The discussed that are modeled by using MATLAB/SIMULINK. The purpose of this paper is to get the analysis of the three-phase inverter SVPWM as a three-phase induction motor drive with specification 500 W, 50 V, 50 Hz and 8 poles. Converter using a battery with a voltage 48 V. Before the battery voltage is converted by an inverter, battery voltage was increased through a boost converter up to 70.62 V. Through simulation with MATLAB software was obtained curve of sinusoidal voltage, current, and speed of the motor by SVPWM controlled system. In this paper also tested against changes in the value of the fundamental frequency inverter. Test results show that the inverter can be set the speed of the motor at a frequency of 20 Hz to 50 Hz.

Electric drive on an electric bikes, consist of electric motor, power converter and electronic controller. These are the mover of electric vehicle systems. This paper discussed the three-phase induction motor supplied by Space Vector Pulse Width Modulation (SVPWM) inverter. They discussed that are modeled by using MATLAB/SIMULINK. The purpose of this paper is to get the analysis of the three-phase inverter SVPWM as a three-phase induction motor drive with specification 500 W, 50 V, 50 Hz and 8 poles. Converter using a battery with a voltage 48 V.

KEY WORDS: *electric bike, three-phase induction motor, SVPWM inverter.*

NOMENCLATURE

| | |
|------------|--|
| v_{qs}^s | Stationary Reference Frame Stator q Axis Voltage |
| v_{ds}^s | Stationary Reference Frame Stator d Axis Voltage |
| v_{qr}^s | Stationary Reference Frame Rotor q Axis Voltage |
| v_{dr}^s | Stationary Reference Frame Rotor d Axis Voltage |
| T_{em} | Electromagnetic Torque |
| r_{qs} | Stator q Axis Resistance |
| r_{ds} | Stator d Axis Resistance |
| r_r | Rotor Resistance |

1.0 INTRODUCTION

Various types of electric bike have been produced by various manufacturer in developed countries. Some type and application of electric bike can be distinguished by the type of bike, the type of electric motor used, the way the installation of electric motors, the type of transmission used, the type of throttle, the location of the electric motor and the type of battery used. One of the differences of the various types of electric bike are the type of electric motor that used as a driver of the bike. Most electric bikes on the market using dc brushed and brushless dc machine as a driving force. The advantages of the two machines are a source of electrical energy from the battery in the form of electrical energy direct current can be directly used by the dc machine without the need for converters as energy convert direct current power into

electrical energy of alternating current [1-5].

Induction machine can be operated as a motor and generator. Advantages of induction machine compared with other type of machines are : the construction is simple, do not require a brush, reliable, and low maintenance cost. However, induction machine also has the disadvantages, that is, difficult speed control, power factor is low at low load, efficient drops at low load and poor starting torque. In this paper has been the analysis and design of SVPWM three-phase induction motor drive inverter to be used as a driver on an electric bike.

Three-phase inverter with SVPWM (Space Vector Pulse Width Modulation) technique is a converter that can be used to control the speed of an induction motor. SVPWM method is the incorporation of vector control the motor speed with a PWM (Pulse Width Modulation) which is used as a regulator of amplitude and frequency. Space Vector PWM (SVPWM) was originally developed as an approach vector for Pulse Width Modulation (PWM) for three-phase inverter. This is a more sophisticated technique to generate a sine wave that provides a higher voltage to the motor with a total harmonic distortion is lower. The main goal of any modulation technique to gain fundamental component output variable has a maximum with minimum harmonics. SVPWM is advanced PWM method of calculation intensive and perhaps the best technique for the application of Variable Frequency Drive (VFD) [7 - 13].

2.0 MATERIAL AND METHOD

Induction motors are widely used in industries, households and traction applications. Both stator and rotor windings are fed by an alternating current. Stator currents in the direct supply of electricity and the current source is obtained from the induction rotor stator winding. When the three-phase voltage source given to the three-phase windings on the stator, it will generate a rotating magnetic field. It has powerful rotary field uniform and moving at the same angle to the stator frequency. Rotor assumed a state of rest, this rotating magnetic field induces an electromagnetic force to the rotor windings. Because the rotor is connected to a short circuit, then the current will circulate in it, it will produce a reaction. According to Lenz's law, this is a reaction to counter the current source of the rotor, the emf induced in the rotor, and then rotating magnetic field itself.

2.1 The Three-Phase Induction Machine Equivalent Circuit

Three-phase induction machine model used in this analysis is the model of stationary reference frame. Voltage equation:

$$v_{qs}^s = r_s i_{qs}^s + \frac{p}{\omega_b} \psi_{qs}^s \quad (1)$$

$$v_{ds}^s = r_s i_{ds}^s + \frac{p}{\omega_b} \psi_{ds}^s \quad (2)$$

$$v_{0s} = r_s i_{0s} + \frac{p}{\omega_b} \psi_{0s} \quad (3)$$

$$v_{qr}^s = r_r i_{qr}^s + \frac{p}{\omega_b} \psi_{qr}^s - \frac{\omega_r}{\omega_b} \psi_{dr}^s \quad (4)$$

$$v_{dr}^s = r_r i_{dr}^s + \frac{p}{\omega_b} \psi_{dr}^s + \frac{\omega_r}{\omega_b} \psi_{qr}^s \quad (5)$$

$$v_{0r} = r_r i_{0r} + \frac{p}{\omega_b} \psi_{0r} \quad (6)$$

Torque equation:

$$T_{em} = \frac{3}{2} \frac{P}{2\omega_b} (\psi_{qr}^s i_{dr}^s - \psi_{dr}^s i_{qr}^s) \quad (7)$$

From equation (1) - (6) can be made equivalent circuit of an induction machine as shown in Figure 1.

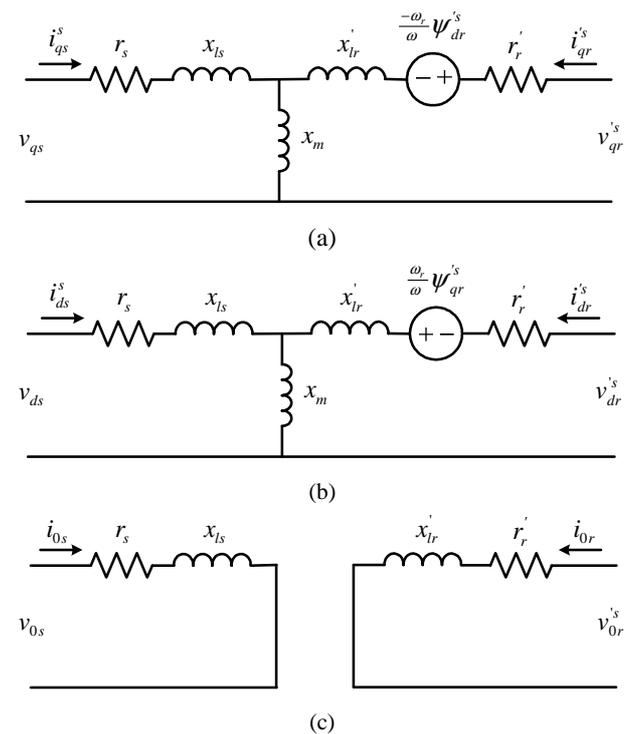


Figure 1: Equivalent circuit of three-phase induction machine. (a) q axis (b). d axis (c). zero sequence

2.2 SVPWM Three Phase Inverter

Three-phase inverter with SVPWM (Space Vector Pulse Width Modulation) technique is a converter that can be used to control the speed of an induction motor. SVPWM method is the incorporation of vector control the motor speed with a PWM (Pulse Width Modulation) which is used as a regulator of amplitude and frequency. Space Vector PWM (SVPWM) was originally developed as an approach vector for Pulse Width Modulation (PWM) for three-phase inverter. This is a more sophisticated technique to generate a sine wave that provides a higher voltage to the motor with a total harmonic distortion is lower. The main goal of any modulation technique to gain fundamental component output variable has a maximum with minimum harmonics. SVPWM is advanced PWM method of calculation intensive and perhaps the best technique for the application of Variable Frequency Drive (VFD) [7 - 13].

This design is planned in advance load inverters and inverter sources. Inverter load here is a three phase induction motor 50 V_{LL} and the source is a battery 48 V. In accordance with the

motor data, it would require an inverter with an output voltage of 50 Vrms or peak output voltage 70.71 V. Then, because the DC source (battery) only amounted to 48 volts, it would require a step-up converter (Boost Converter) prior to source DC is converted into AC voltage. The data that is required then made a block diagram of the study. This data collection method is to determine the parameters to be processed. The parameters are specified, that are:

- MOSFET NTB30N20, Max Rating: $V_{DS} = 200 \text{ V}$, $I_D = 30 \text{ A}$
- Battery voltage: $V_S = 48 \text{ V}$
- Fundamental frequency: $f = 50 \text{ Hz}$
- Frequency PWM inverter: $f_z = 3 \text{ kHz}$
- The PWM frequency converters riser = 25 kHz
- Modulation Index: $a = 0.8$
- Three -Phase Induction Motor Load: $P_{\text{rated}} = 500 \text{ Watt}$, $V_{LL} = 50 \text{ Volt}$, $P = 8 \text{ poles}$, $f = 50 \text{ Hz}$, $R_s = 1,791 \Omega$, $R_r = 1.2 \Omega$, $X_{ls} = 0.85 \Omega$, $X_{lr} = 0.85 \Omega$, $R_m = 100 \Omega$, $X_{m} = 11.62 \Omega$.

Modeling the whole system for three-phase inverter SVPWM method is shown in Fig 2 which this model consists of blocks and subsystems.

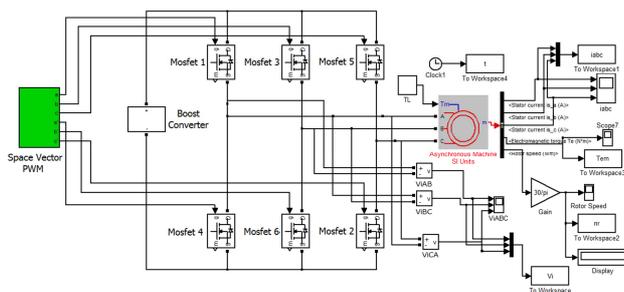


Figure 2: Inverter SVPWM

In Fig. 2, subsystem boost converter is the inverter input voltage is equal to 70.62 volts. In the SIMULINK model of the whole system, the output voltage of the boost converter is converted by an inverter into AC voltage. DC conversion processed, this is done by switching ac MOSFET arranged by Space Vector PWM subsystem. Meanwhile, for the manufacture subsystem SVPWM is shown in Fig. 3. In this SVPWM, the gate voltage (V_{GS}) is 10 Volt.

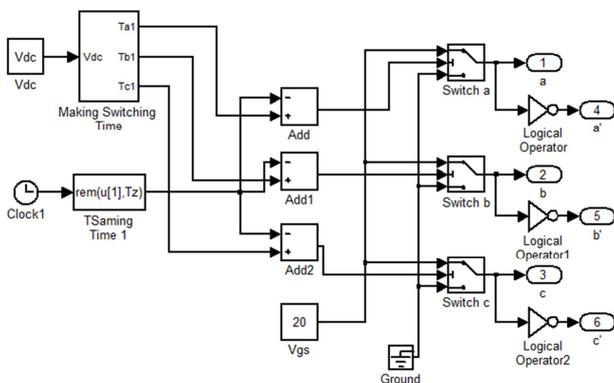


Figure 3: Subsystem Space Vector PWM

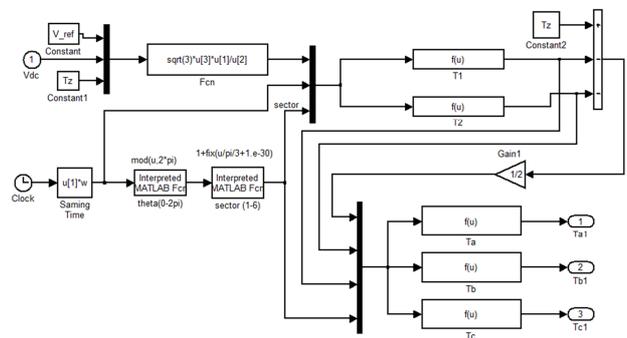


Figure 4: Subsystem switching time

In SVPWM subsystem contained switching time subsystem (Fig. 4), where this subsystem is the time when the switch will “on” and “off”, then also regulated by regulating the sectors that plays a role. Where six active sectors are will set the time of the switching MOSFET.

3.0 RESULTS AND DISCUSSION

The result of the data analysis is an implementation method of SVPWM. There are three steps in the implementation SVPWM determined.

1. The value of V_d , V_q , V_{ref} and α
To determine the value of V_d , V_q , V_{ref} and α can be calculated using:

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} \quad (8)$$

$$V_{ref} = a \times \frac{2}{3} V_{dc} \quad (11)$$

$$\alpha = \tan^{-1} \left(\frac{V_d}{V_q} \right) \quad (12)$$

2. Switching time T_1 , T_2 , and T_0
To determine the duration of T_1 , T_2 , and T_0 used equation:

$$\begin{aligned} \therefore T_1 &= \frac{\sqrt{3} \cdot T_z \cdot |V_{ref}|}{V_{dc}} \left(\sin \left(\frac{\pi}{3} - \alpha + \frac{n-1}{3} \pi \right) \right) \\ &= \frac{\sqrt{3} \cdot T_z \cdot |V_{ref}|}{V_{dc}} \left(\sin \frac{n}{3} \pi - \alpha \right) \\ &= \frac{\sqrt{3} \cdot T_z \cdot |V_{ref}|}{V_{dc}} \left(\sin \frac{n}{3} \pi \cos \alpha - \cos \frac{n}{3} \pi \sin \alpha \right) \end{aligned}$$

$$\begin{aligned} \therefore T_2 &= \frac{\sqrt{3} \cdot T_z \cdot |\bar{V}_{ref}|}{V_{dc}} \left(\sin \left(\alpha - \frac{n-1}{3} \pi \right) \right) \\ &= \frac{\sqrt{3} \cdot T_z \cdot |\bar{V}_{ref}|}{V_{dc}} \left(-\cos \alpha \cdot \sin \frac{n-1}{3} \pi + \cos \frac{n-1}{3} \pi \right) \end{aligned} \quad (13)$$

$$\therefore T_0 = T_z - T_1 - T_2, \quad \left(\begin{array}{l} \text{where, } n = 1 - 6 \text{ (sector } 1 - 6) \\ 0 \leq \alpha \leq 60^\circ \end{array} \right)$$

3. Switching time each switch in each sector.

Analysis Result of Three Phase Inverter Simulation

a. The inverter output voltage phase to phase (V_{iAB} , V_{iBC} , V_{iCA})
Inverter converted DC voltage to AC voltage. In Fig. 6, it can be seen the simulation results is sinusoidal voltage waveform box and phase to phase voltage peaks measured in the simulation is 70.62 Volt. The frequency of AC voltages is 50 Hz.

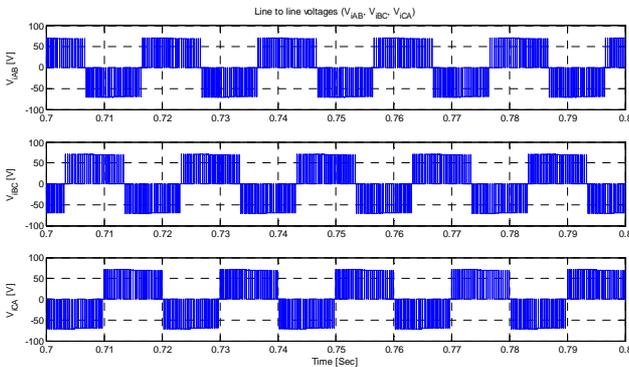


Figure 5: Inverter Output Voltage Phase to Phase

b. Load current inverter (i_A , i_B , i_C)

By disregard the motor starting current, motor peak current rating when frequency 50 Hz is 3.16 A (Fig 7.). This current is steady state current for inverter.

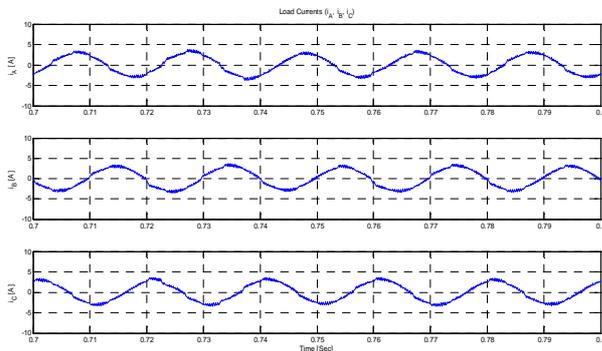


Figure 6: Load current

c. Motor speed (w_r)

Figure 7 (a) is the result of a simulation of the no load speed of three phase induction motor at frequency 50 Hz. Which can be

seen at the time $t = 0.5$ rated speed (nr) is 750 rpm. Figure 7 (b) is the result of a simulation of the loaded speed of three phase induction motor at frequency 50 Hz. Which can be seen at the time $t = 0.7$ rated speed (nr) is 700 rpm.

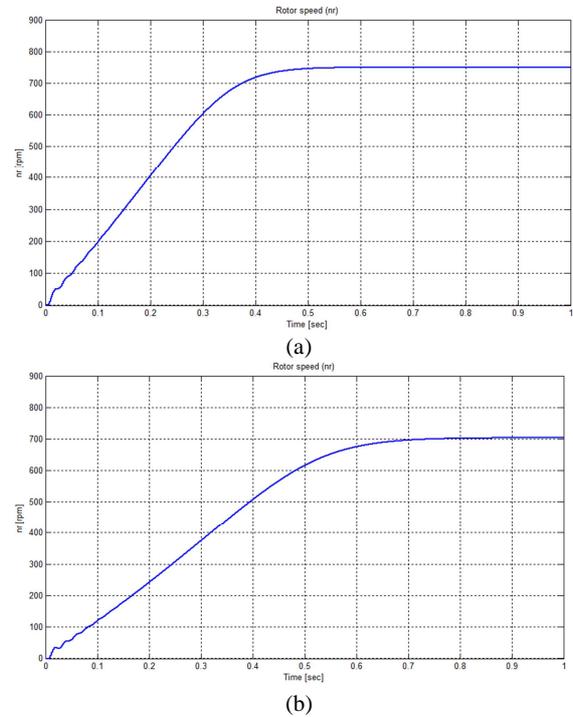


Figure 7: Motor speed, (a) no load (b) loaded

d. Effects of Changes to the Frequency Motor Speed at No-load.
SVPWM Inverter can be applied as a rotation speed control of three phase induction motor, namely by adjusting the voltage and frequency values. In this three-phase inverter system, to make the bike speed variation it takes control of the rotation by regulating the electrical frequency given on the motor. In Table 1 are shown the simulation results of testing the effect of setting the value of the frequency of the current and speed

Table 1: Simulation results Frequency Changes To Speed Without Load

| No | Frequency | N_r (rpm) |
|----|-----------|-------------|
| 1 | 20 | 223.8 |
| 2 | 25 | 299.8 |
| 3 | 30 | 374.8 |
| 4 | 35 | 450.2 |
| 5 | 40 | 525.6 |
| 6 | 45 | 599.8 |
| 7 | 50 | 674.2 |

e. Characteristic of induction motor torque under loaded.

Electric bike when under loaded is meant here is when the electric bike ride. In this simulation, the electric bike loading is simulated by giving a variation input mechanical torque on the motor. Torque is a style that is used to drive something with a

certain distance and direction. In Figure 8 (a) will be shown the electromagnetic torque when the motor without any load (torque load = 0) and (b) the electromagnetic torque when the motor loaded.

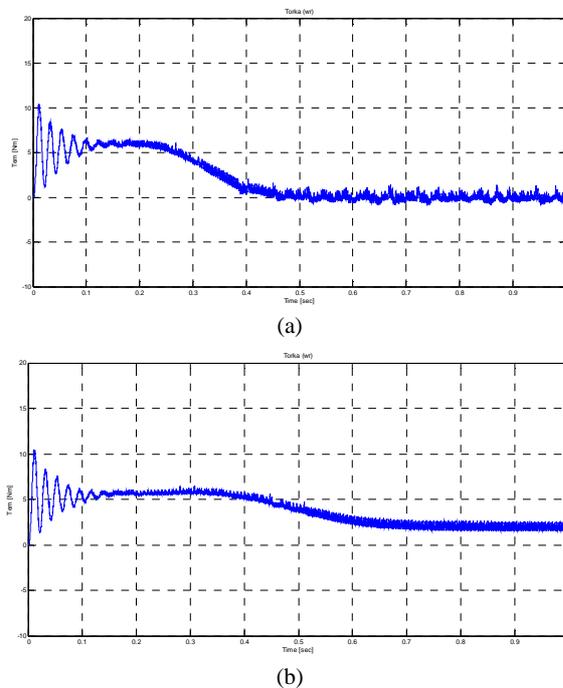


Figure 8: Motor torque, (a) no load (b) loaded.

4.0 CONCLUSION

This paper presents simulation of three phase SVPWM inverter fed induction motor drive for electric bike application. Technical specifications of three phase induction motor are $P_{rated} = 500$ Watt, $V_{LL} = 50$ Volt, $P = 8$ poles, and $f = 50$ Hz. This specification aims to create a system without transformer. In the simulation results, the three-phase inverter can run three phase induction motor $50 V_{LL}$. Where the inverter using the battery with input voltage $48 V$, which are then subsequently raised first by a boost converter that is equal to $70.62 V$. SVPWM Inverter can be applied as a rotation speed control of three phase induction motor. In this three-phase inverter system, to make the bike speed variation it takes control of the rotation by regulating the electrical frequency given on the motor. Speed of induction motor at no load, frequency 50 Hz, is 750 rpm and that current is 3.16 A. Speed of induction motor at loaded, frequency 50 Hz, is 700 rpm and that current is 5.0 A.

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