J. Eng. High. Tech., 3(1)1-10,2017

ISSN 2356-8860
Journal of Engineering and Higher Technology (JEHT)
www.textroad.com

Design of Three Phase Inverter Using Hysteresis Space Vector Pulse Width Modulation for Speed Control Three Phase Induction Motor

Hendi Purnata, Mochammad Rameli, Rusdhianto Effendie AK.

Electrical Engineering Department, Sepuluh Nopember Institut of Technology, Surabaya 60111

ABSTRACT

Induction motor speed control is relatively difficult, because the generated torque and flux are related or not free. In addition to adjusting the speed, it requires inverter control. The inverter output is not a pure sinusoidal signal but it is the result of the switching. Therefore, it is necessary to be able to fix the method of switching the inverter output signal that can adjust induction motor speed with load changes. This study applies the indirect method of vector control for setting the speed. The combination of SVPWM (Space Vector Pulse Width Modulation) methods and hysteresis known as HSVPWM (Hysteresis Space Vector Pulse Width Modulation) methods. In this study, current signal is also reconstructed. The results show the ripple current at the inverter output using methods HSVPWM can be reduced 65%. The setting speed three phase induction motor vector control using indirect methods are successfully applied. A change of pace on HSVPWM method successfully achieves the set point of 600 rpm with a rise time of 0.5267 seconds, 0.723 seconds steady state and has over shoot of 0.8%. The result of testing motor between load and effective ripple is not load obtain effective at 13.35 N.m, when loaded 40 N.m get effective ripple at 13.12 N.m and when laden 80 N.m get effective ripple of 13.71 N.m.

KEYWORD—*Vector Control, Space Vector Pulse Width Modulation, Hysteresis Band, Induction motor.*

I. INTRODUCTION

Induction motors are one of the electric machines are most widely used in industry. Induction motor speed regulation in general can use the terminal voltage changes and frequency settings [1]. Induction motor a speed setting more difficult when using a DC motor, it is because the resulted of flux and torque has been related or not free. The factors that led to the induction motor control becomes more complex [2].

Conventional control such as proportional integral and proportional integral derivative used together with vector control method for motor speed better results [3]. Induction motor a speed setting using Space vector width modulation inverter controller with PI-Fuzzy Hybrid can maintain a constant motor speed even though given the burden of changing [4]. Space vector width modulation controller with iterative learning control and controller proportional integral can reduce the speed ripple than the controller hysteresis pulse width modulation but transient response at hysteresis pulse width modulation faster than with Space vector width modulation and controler hybrid iterative learning control [5]. Switching hysteresis control method in frequency is not fixed and will fluctuate based on changes in flows [6].

There is research on the changing load using the indirect vector control method Space vector width modulation. [7]. This study uses an indirect vector control method Hysteresis pulse width modulation. The controller in this study can cope with changing loads. In this study the response speed and torque changes can not be overcome because the response has not been able to follow the reference perfectly. [8].

Problem that need to resolve is the speed control of three-phase induction motor with the load changing and improving efficiency three-phase induction motors by combining the method of space vector pulse width modulation with hysteresis pulse width modulation and calculation effeciency indoction motor.

II. EASE OF USE

A. Mathematical Model Three-Phase Induction Motors [9]

AC dynamic performance of the engine is rather complex because the coil rotor three-phase stator windings move in three phases. Model of an induction motor can be described by differential equations and mutual inductance change with time, but the other models tend to be highly complex.

$$
\begin{aligned}
V_{qs} &= R_s.i_{qs} + \omega.\lambda_{ds} + p.\lambda_{qs} \\
V_{ds} &= R_s.i_{ds} - \omega.\lambda_{ds} + p.\lambda_{ds} \\
V_{qr} &= R_r.i_{qr} + (\omega - \omega_r).\lambda_{dr} + p.\lambda_{qr} \\
V_{dr} &= R_r.i_{dr} - (\omega - \omega_r).\lambda_{qr} + p.\lambda_{dr}
\end{aligned}
\tag{1}
$$

***Corresponding Author:** Hendi Purnata, Electrical Engineering Department, Sepuluh Nopember Institut of Technology, Surabaya 60111.
E-mail: hendipurnata@gmail.com

Where $p = \frac{d}{dt}$ Equation for flux of parts coil get in

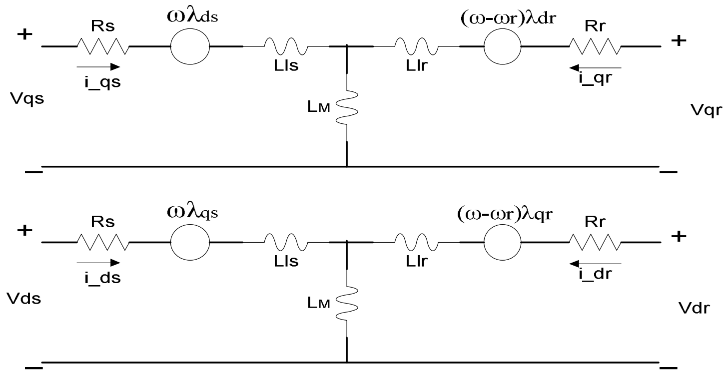

Figure 1. Equivalen Circuit of Three Phase Induction Motor

Induction motor equivalent circuit Three-phase d-q axis can be seen in Figure 1. Based on the above, the circuit may be written on the stator and rotor voltage [10]

$$\begin{aligned} \lambda_{qs} &= L_s.i_{qs} + L_m.i_{qr} \\ \lambda_{ds} &= L_s.i_{ds} + L_m.i_{dr} \\ \lambda_{qr} &= L_r.i_{qr} + L_m.i_{qs} \\ \lambda_{dr} &= L_r.i_{dr} + L_m.i_{ds} \end{aligned} \tag{2}$$

So that (2) substitution in (1) then in the form of a matrix can be declared to be

$$\begin{bmatrix} V_{qs} \\ V_{ds} \\ V_{qr} \\ V_{dr} \end{bmatrix} = \begin{bmatrix} R_s + pL_s & \omega.L_s & pL_m & \omega.L_m \\ -\omega.L_s & R_s + pL_s & -\omega.L_m & pL_m \\ pL_m & (\omega-\omega_r)L_m & R_r + pL_r & (\omega-\omega_r)L_r \\ -(\omega-\omega_r)L_m & pL_m & (\omega-\omega_r)L_r & R_r + pL_r \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix} \tag{3}$$

with,

$$\begin{aligned} L_s &= Ll_s + L_m \\ L_r &= Ll_r + L_m \end{aligned} \tag{4}$$

Where,

V_{qs}, V_{ds}	=	Voltage dq frame (Volt)
V_{qr}, V_{dr}	=	Rotor voltage dq frame (Volt)
i_{qs}, i_{ds}	=	Current stator of dq frame (Ampere)
i_{qr}, i_{dr}	=	Current rotor of dq frame (Ampere)
λ_{qs}, λ_{ds}	=	Stator flux of dq frame (Webber)
λ_{qr}, λ_{dr}	=	Rotor flux of dq frame (Webber)
R_s	=	Stator Resistance (Ohm)
R_r	=	Rotor Resistance (Ohm)
L_s	=	Stator Inductance (Henry)
L_r	=	Rotor Inductance (Henry)
L_M	=	Mutual Inductance (Henry).

The electromagnetic torque is raised can be found using (5) [5], and speed rotor (ω_r) use this equation (6) [4].

$$T_{em} = \frac{3}{2}\frac{P}{2}(\lambda_{ds}i_{qs} - \lambda_{qs}i_{ds}) \tag{5}$$

$$T_{em} = T_L + J\frac{d\omega_m}{dt} = T_L + \frac{2}{P}J\frac{d\omega_r}{dt} \tag{5.1}$$

$$\omega_r = \int \frac{T_{em} - T_L}{J} \cdot \frac{P}{2} \tag{6}$$

Where,

T_L = Load Torque (N.m)
T_{em} = Electromagnetic Torque (N.m)
J = Inertia Momen (kg.m^2)
P = Pole
ω_r = Speed in rotor (rad/detik)
ω_m = Speed in rotor mechanic (rad/detik)

B. Vector Control [11]

Vector control or so-called field-oriented control is found by Blaschke to match the characteristics of DC motors at the induction motor. In general, the electric motor can be initiated on controlling the source of torque. The motor torque is the result of the interaction between the magnetic field in the stator field and the current.

Vector control consists in controlling stator current component, indicated by a vector, in the form of reference synchronous rotation *d-q*, which are expressed toward the electromagnetic torque on the smooth air grap the motor as well as the DC motor circuit. This technique is based on the transformation of the three-phase and speed depending on the coordinate system into two time varies. This transformation is performed in order to facilitate the analysis of induction motor control. Transformation vectors are two in Clarke transformation and Park transformation.

1) Clarke Transformation

Clarke transformation is the transformation of the three-phase coordinate system (abc) into two phases (αβ). In figure 2, seen that the coordinates α parallel to the coordinates of a three-phase while the coordinates β perpendicular to coordinate with other words a difference 90^0 with coordinates α. Therefore, the vector sum of the field α and β can be written as Equation (2.11).

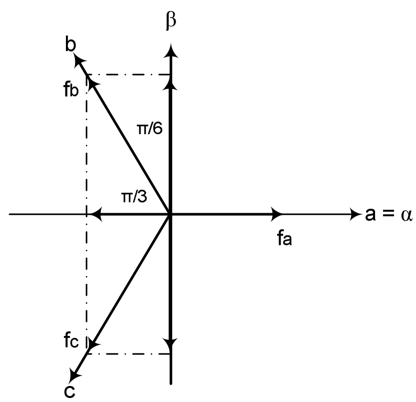

Figure 2. Coordinate Clarke Transformation

$$\begin{bmatrix} f_\alpha & f_\beta & f_0 \end{bmatrix} = \frac{2}{3} \cdot \begin{bmatrix} f_a & f_b & f_c \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 & \frac{1}{2} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & \frac{1}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} & \frac{1}{2} \end{bmatrix} \tag{7}$$

Note f declare functions that exist in induction motors, both function of current, flux and voltage while f_o is the central axis with a constant value of 1 (one) and 2/3 is constant of matrix Clarke transformation.

2) Park Transformation

Park transformation is the transformation of the coordinate system stationer (αβ) into a rotary coordinate system (d-q) as shown in figurer 3. Characteristics of induction motor that was originally located on a stationary axis (αβ) then working and going round the rotor, so that the voltage-current function, and the flux is also changing value. Transformation of the axis αβ becomes the axis d-q can be written as Equation (8).

$$\begin{bmatrix} f_d & f_q & f_0 \end{bmatrix} = \frac{2}{3} \cdot \begin{bmatrix} f_\alpha & f_\beta & f_0 \end{bmatrix} \cdot \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{8}$$

From equation (8) Clarke and Park transformation matrix, then the general equation transformation from abc coordinates into d-q coordinates is shown in equation (2.13).

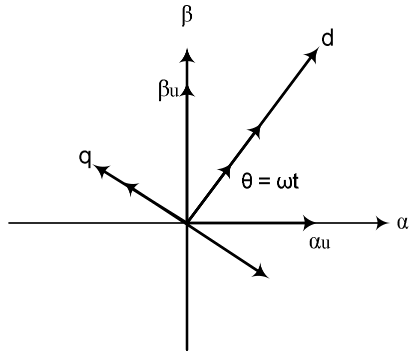

Figure 3. Coordinate Park Transformation

$$[f_d \quad f_q \quad f_0] = \frac{2}{3}\cdot[f_a \quad f_b \quad f_c]\cdot\begin{bmatrix} \cos\theta & \sin\theta & \frac{1}{2} \\ \cos\left(\theta-\frac{2\pi}{3}\right) & -\sin\left(\theta-\frac{2\pi}{3}\right) & \frac{1}{2} \\ \cos\left(\theta+\frac{2\pi}{3}\right) & -\sin\left(\theta+\frac{2\pi}{3}\right) & \frac{1}{2} \end{bmatrix} \tag{9}$$

C. Space Vector Pulse Width Modulation [12]

SVPWM a method of switching on the inverter that works by space voltage vector in the field of the field α-β. Component α-β sought to Clarke transformation. Three Phase half-bridge inverter used where the structure inverter is shown in Figure 4.

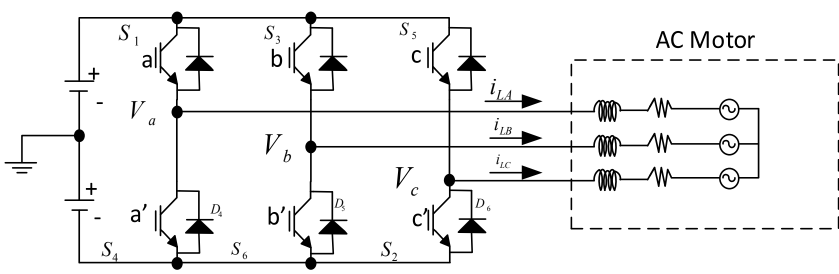

Figure 4. The Basic Scheme of Three-Phase Inverter in Induction Motor

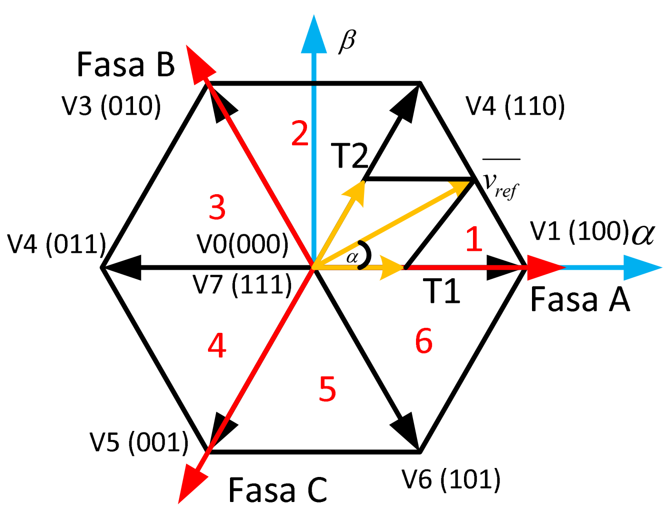

Figure 5. Basic Switching Vectors and Sectors

D. Hysteresis Pulse Width Modulation [13]

Hysteresis controller is a flow control techniques which enable switching on the phase voltage that is connected as a result of the current sensor feedback form. Phase current is determined whether the value of the hysteresis tolerance can manipulate around the desired current value. The hysteresis control to simplify and robustness on the load parameters that vary as to determine the width of the switching frequency can not be predicted and there are also difficulties in the safety circuit for the inverter system.

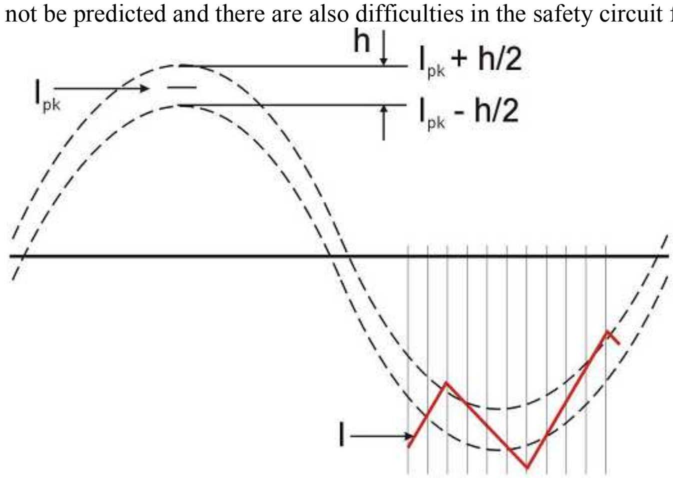

Figure 6. Shape Wave Flow Control Hysteresis

III. SYSTEM DESIGN

The below system there are certain functions in order to achieve the desired research. Plant of the system is a three-phase induction motor. These systems are rectifier (DC Link) is a controlled rectifier so that a DC voltage. Inverter comprise the a device whose function is to change from DC voltage to AC voltage, Inverter controlled using PWM techniques by the method of hysteresis space vector pulse width modulation. Induction motors use a model which separates the d-q between flux and torque.

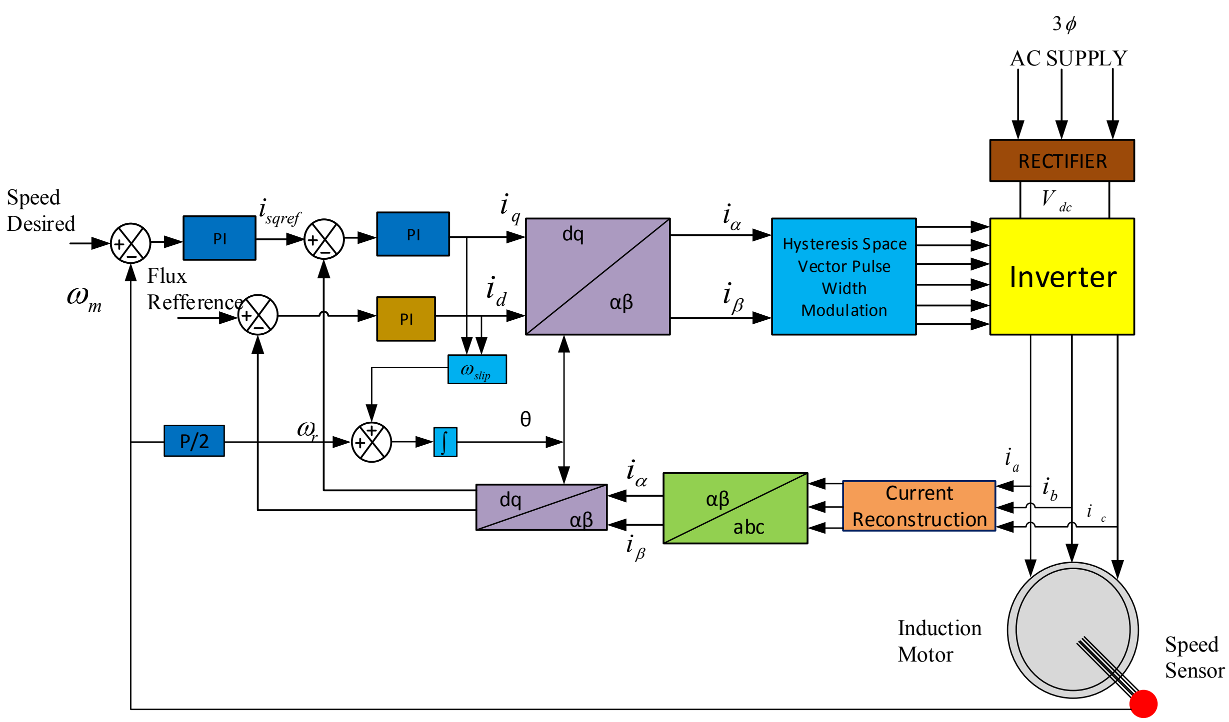

Figure 7. Block Diagram

IV. SIMULATION AND ANALYSIS SYSTEM

At this stage the researchers expressed the inverter design simulation results in a three-phase induction motor. This stage analyzes and compares each method.

a. Hysteresis Pulse Width Modulation

Hysteresis is a method of setting current that can be controlled directly.

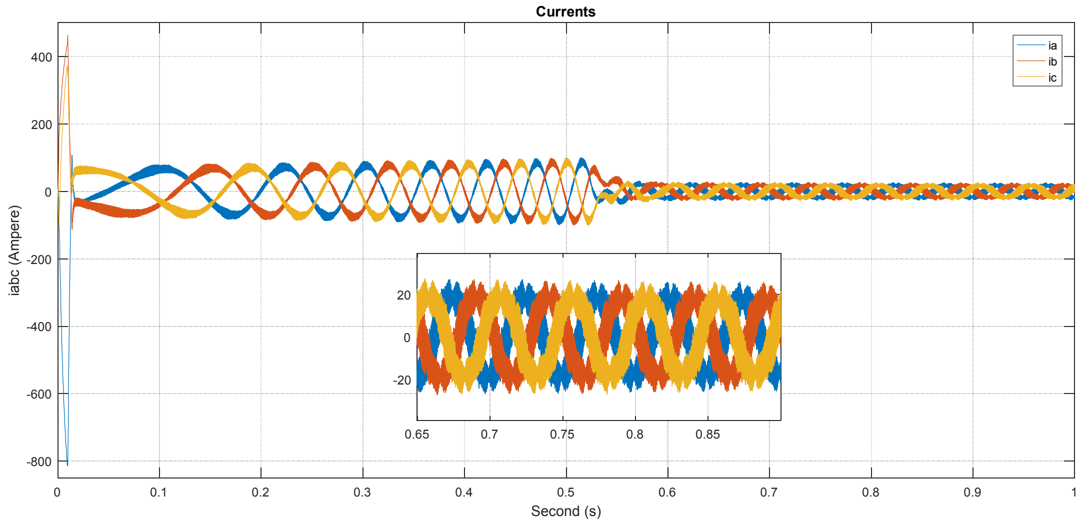

Figure 8. Current Response

The image above is a signal flow graph on the method of hysteresis. Results showed that at the beginning of the motor is then the current flowing source of 462A, after the second time in 0635 to change the amplitude of the signal 26A or steady state. This method produces a sinusoidal ripple current of 29.7A, when the peak ripple current of 5.82A and valleys of 5.3a.

b. Space Vector Pulse Width Modulation

PWM is a combination of vector control with PWM technique. This section displays the current and voltage at the output of the inverter by using SVPWM

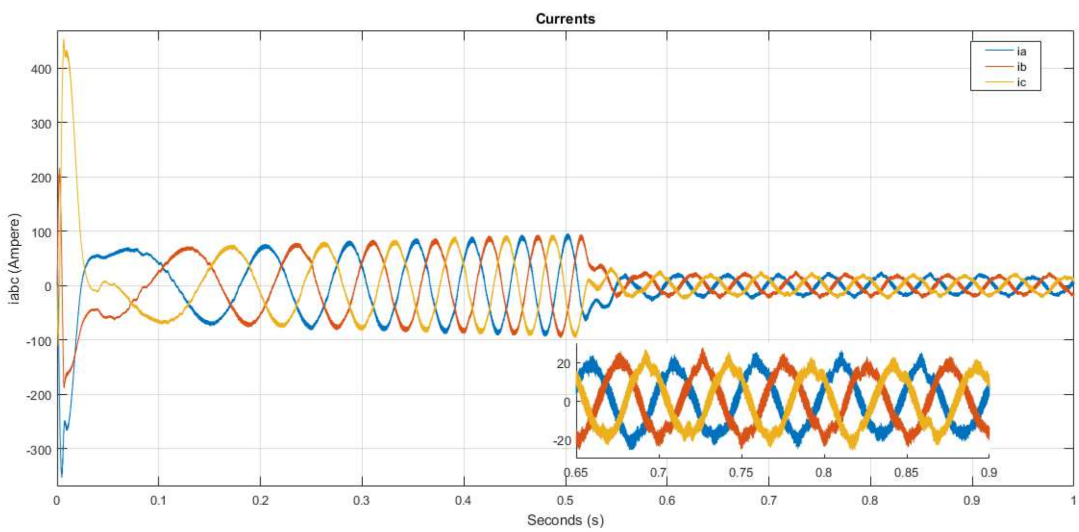

Figure 9. Current Response

This phase addresses SVPWM method where the graphic signal is displayed in the form of current and voltage at the output of the inverter. Figure 4.4 displays the three-phase current IABC which is currently beginning the motor by a power source then reaches 454A peak current, but when the time 0.65 seconds at 24A current flows. This method still produces ripple of 9.68 A sinusoidal current, peak current ripple current of 4A and 4A of the valley

c. Hysteresis Space Vector Pulse Width Modulation

This stage will display the data graph is HSVPWM proposal study. The data will be displayed in the form of graphs current and voltage signals at the output of the inverter

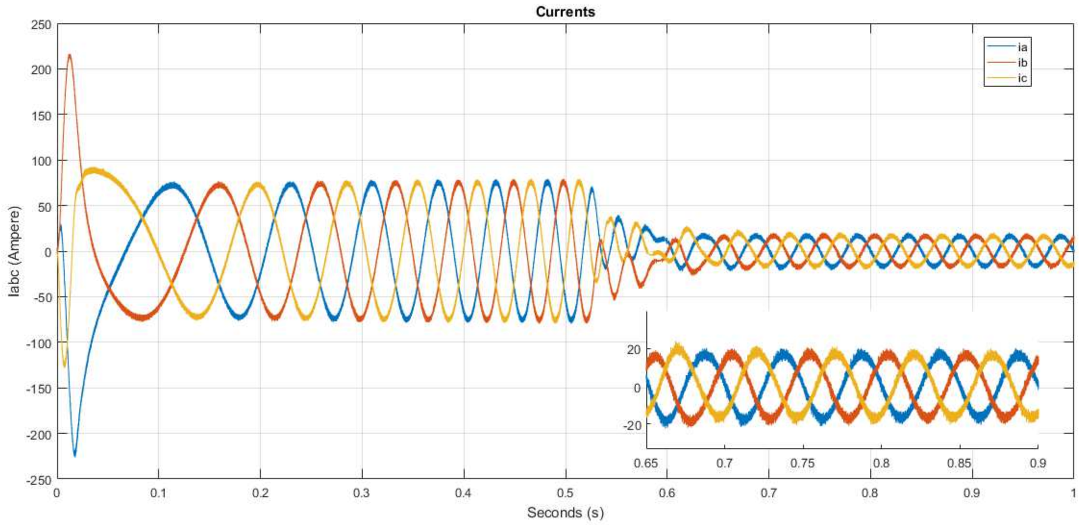

Figure 10. Current Response

HSVPWM is the combination of two methods, Hysteresis PWM and SVPWM. This stage combined the two methods shows the output current signal can be corrected that ripple on the current signal. This method produces a sinusoidal ripple current of 4.2a, when peak ripple current of 4.5A and 4.5A of the valley

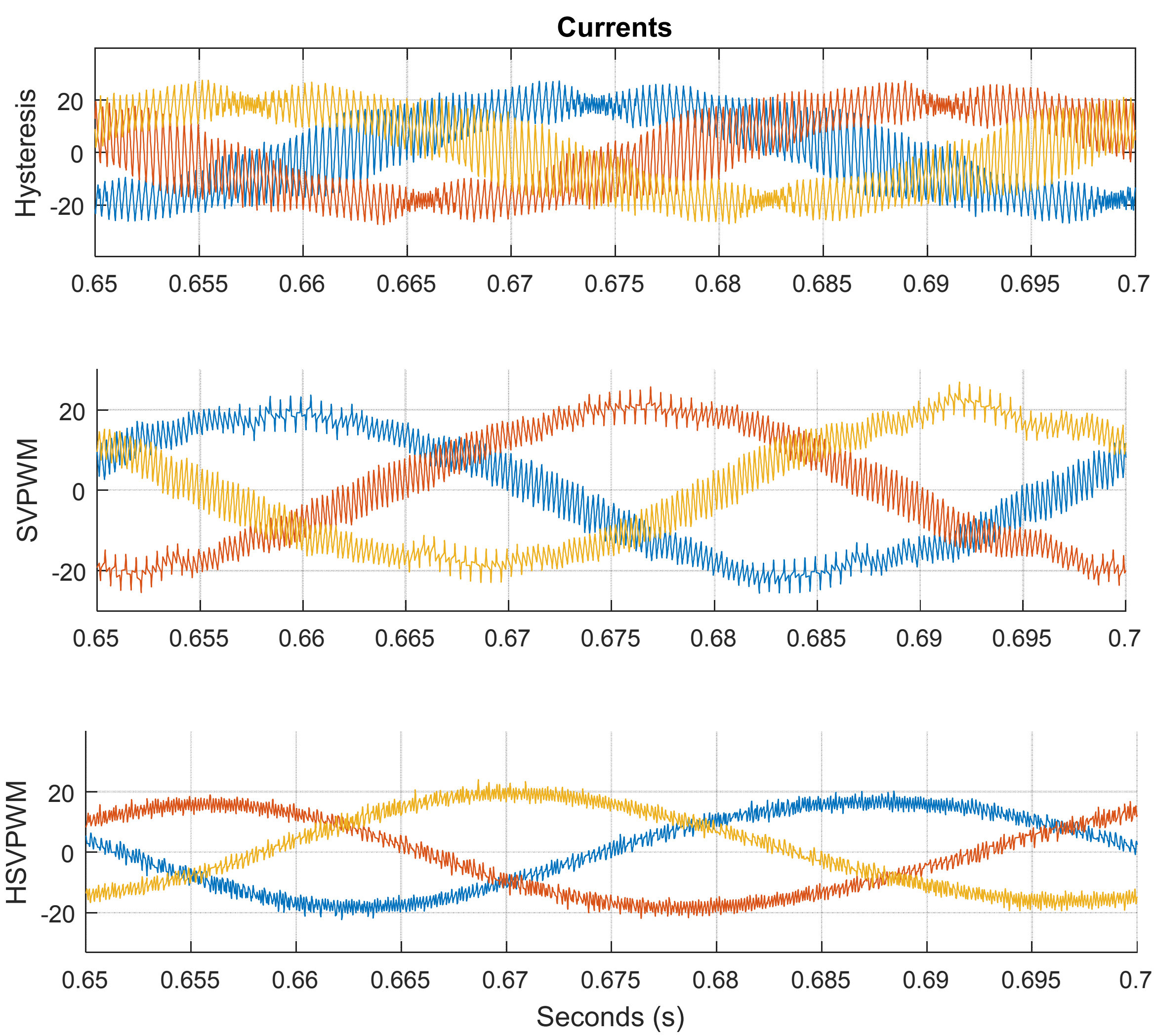

Figure 11. Comparison of Respon se Flow

In Figure 11, a comparison of the inverter output current on each method. Comparison of ripple on the third method can be seen in Table 1 data is taken when the ripple sinusoidal, peaks and valleys on the inverter output. The above data also be ripple effective and effective signal.

Table 1. Comprasion of Methode

	Effektif Ripple	Effektif Signal
Hysteresis	33.1017	33.8467
SVPWM	19.32	27.57
HSVPWM	1.6071	27.6113

The image above in figure 11 shows that the sinusoidal ripple on the method of hysteresis to ripple SVPWM method is reduced by 32% or 20.02A, while on SVPWM method to HSVPWM reduced by 43% or 5.48A. Ripple peak by the method of hysteresis to SVPWM reduced by 68% or 1.82A while on SVPWM to HSVPWM increased by 112.5% or an increase of 0.5A. When the current ripple valley of the method of hysteresis is reduced by 75% or less of 1.3A, the current method of SVPWM to HSVPWM increased by 112.5% or increased 0.5A. Comparison between effective ripple with effective signals can be displayed in table 2

Table 2. Comparison of percentage Ripple

	Ripple Persentase (%)	Ripple Frekuensi (Hz)
Hysteresis	97	3.33 K
SVPWM	70	3.33 K
HSVPWM	5	5 K

In Table 2 that the percentage ripple SVPWM reduced hysteresis to 27%, while the percentage ripple compared HSVPWM SVPWM reduced 65%. The data shows the percentage ripple HSVPWM method can reduce the ripple of the two methods. The ripple frequency Hysteresis SVPWM method for 3.33 KHz, HSVPWM ripple frequency of 5 KHz. This data shows the smaller the ripple frequency can cause the heat contained in the motor field.

d. Speed response

This section displays the response speed chart with a comparison between the three methods.

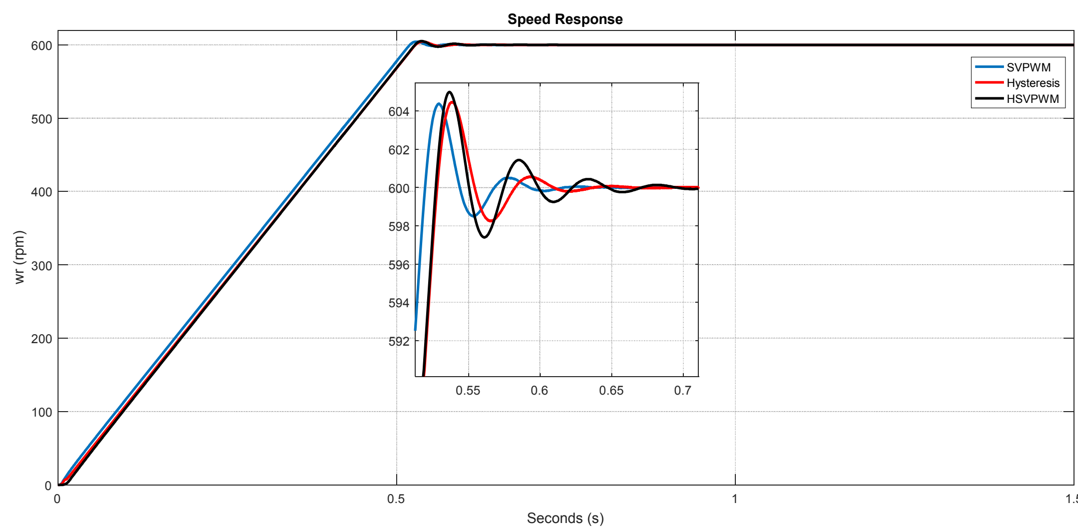

Figure 12. Comparison of Speed Response

The result of the response speed comparison shows that to achieve steady state more rapidly SVPWM method that takes 0.628 seconds. HSVPWM method slower than SVPWM method that requires time for 0723 seconds to reach steady state. The value of the time constant (τ) in the third method of difference is not seen significantly between 0.33 seconds. The response characteristics shown in Table 4.3 where the delay time around 0227 seconds, settling time of about 0.6 seconds later rise time is around 0.5 seconds.

Table 3 Speed comparisons in each method

	t_d (Second)	τ (Second)	t_s (Second)	t_r (Detik)	t_s (Detik)
Hysteresis	0.227	0.328	0.623	0.519	0.656
SVPWM	0.233	0.336	0.598	0.528	0.628
HSVPWM	0.233	0.337	0.686	0.527	0.723

e. comparison of Torque

This section displays a comparison of electromagnetic torque on the three methods.

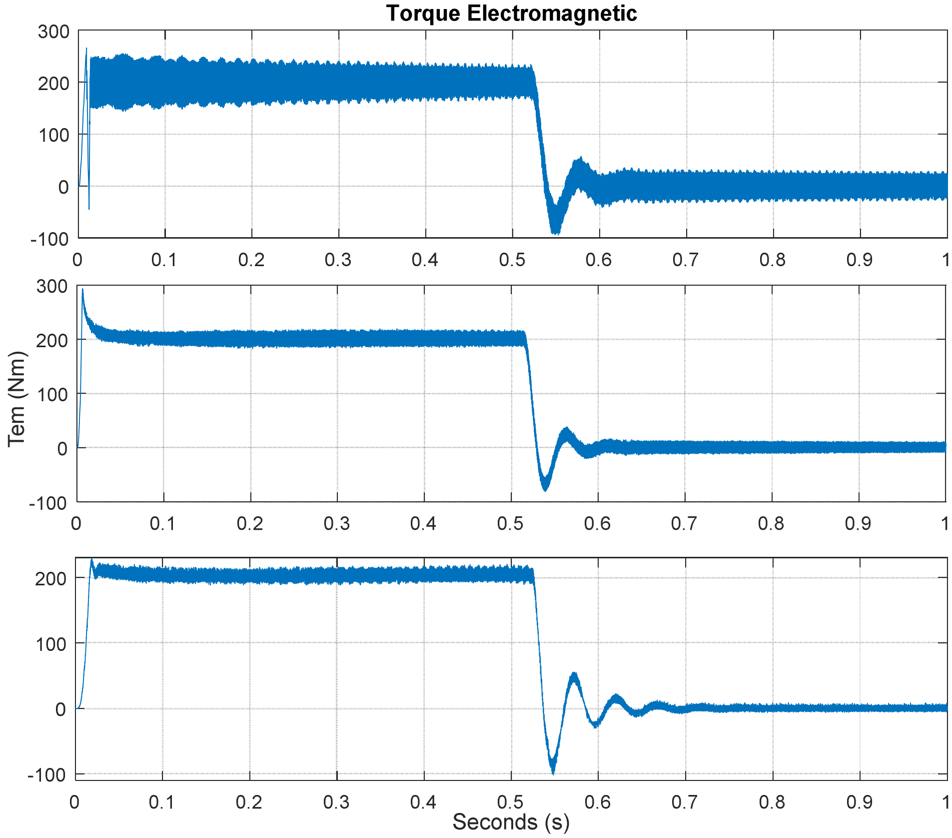

Figure 13 Comparison of Electromagnetic Torque

The result of the response to the electromagnetic torque comparison shows that the method is more favored because HSVPWM starting torque is only reached 228.8 N.m than starting torque that reaches 293 N.m SVPWM and hysteresis torque of 263.6 N.m. Ripple average torque in the steady state is equal to HSVPWM smaller than the torque 12:36 N.m hysteresis method which reaches 18 N.m and torque SVPWM reached 16.77 N.m. The comparative value of each method can be seen in Table 4

Table 4 Electromagnetic Torque comparison of each method

	Starting Torque (N.m)	Torque in Steady State (N.m)
hysteresis	263.6	18.00
SVPWM	293.0	16.77
HSVPWM	228.8	12.36

f. calculations Efficiency

Once you know which form the input power voltage and current on each method and then note also the output power in the form of torque and speed. This section menghutung how much efficiency three-phase induction motors by using each method. Table .5 Motor Efficiency Calculation

Table .5 Motor Efficiency Calculation

	Pout	Pin	Effisiensi (%)
Hysteresis	10800	11960	90
SVPWM	10062	11040	91
HSVPWM	7414	7820	94

The table above is a calculation of parameters to calculate the efficiency of the motor. Hysteresis method produces 90% efficiency of the motor in which the input power with a voltage of 460 Volt, 26 Ampere current and the output power of the motor is a torque of 18 Nm and a speed of 600 rpm. SVPWM method produces 91% efficiency of the motor in which the input power with a voltage of 460 Volt, 24 Ampere current and the output power of the motor is a torque of 16.77 Nm and a speed of 600 rpm. HSVPWM method produces 94% efficiency of the motor in which the input power with a voltage of 460 Volt, 17 Ampere current and power output torque of the motor is 12.36 Nm and a speed of 600 rpm. In the above data shows that the method is more efficient HSVPWM which increased by 3% with a percentage of 94%.

V. CONCLUSION

The results show the ripple current at the inverter output using methods HSVPWM can be reduced 65%. The setting speed three phase induction motor vector control using indirect methods are successfully applied. A change of pace on HSVPWM method successfully achieves the set point of 600 rpm with a rise time of 0.5267 seconds, 0.723 seconds steady state and has over shoot of 0.8%. Testing the motor current ripple not load obtain effective at 13.35 N.m, when loaded 40 N.m get effective ripple at 13.12 N.m and when laden 80 N.m get effective ripple of 13.71 N.m.

BIBLIOGRAPHY

[1] Parekh, R., 2003. AC Induction Motor Fundamentals. Microchip Technology Inc.

[2] Mohan, N., 2014. Advanced electric drives: analysis, control, and modeling using MATLAB/Simulink. John wiley & sons.

[3] Chengaiah, C. and Prasad, S., 2013. Performance of Inductoin Motor Drive by Indirect vector controlled method using PI and Duzzy Controllers. International Journal of Science, Environment, 2(3), pp.475-469.

[4] Arulmozhiyal, R. and Baskaran, K., 2009. Space Vector Pulse Width Modulation BasedSpeed Control of Induction Motor using FuzzyPI Controller. International Journal of Computer and Electrical Engineering, 1(1), p.98.

[5] Lakshmi, N.S., Adhavan, B., Jagannathan, V. and Ravichandran, C.S., 2013, March. Reduction of transient and steady state speed pulsation in permanent magnet synchronous motor using Space Vector Pulse Width Modulation control. In Circuits, Power and Computing Technologies (ICCPCT), 2013 International Conference on (pp. 252-257). IEEE.

[6] Yi, H., Zhuo, F., Zhang, Y., Li, Y., Zhan, W., Chen, W. and Liu, J., 2014. A source-current-detected shunt active power filter control scheme based on vector resonant controller. IEEE Transactions on Industry Applications, 50(3), pp.1953-1965.

[7] Arulmozhiyal, R., Baskaran, K. and Manikandan, R., 2010, December. An intelligent speed controller for indirect vector controlled induction motor drive. In Computational Intelligence and Computing Research (ICCIC), 2010 IEEE International Conference on (pp. 1-5). IEEE.

[8] Singh, M. and Hussain, M.S.S., Implementation of an Intelligent Controller for Three Phase Vector Controlled Induction Motor Drive.

[9] Bimal, K., 2002. Bose. Modern power electronics and AC drives.

[10] Behera, P.K., Behera, M.K. and Sahoo, A.K., 2014. Comparative Analysis of scalar & vector control of Induction motor through Modeling & Simulation. international journal of innovative research in electrical, electronics, instrumentation and control engineering, 2(4), pp.1340-1344.

[11] Jung, J.W. and DStudent, P.H., 2005. PROJECT# 2 Space vector PWM inverter. Mechatronic Systems Laboratory, Dept. of Electrical and Computer Engg., The Ohio State University.

[12] Dos Santos, E. and da Silva, E.R., 2014. Advanced Power Electronics Converters: PWM Converters Processing AC Voltages (Vol. 46). John Wiley & Sons.

[13] Arulmozhiyal, R., Baskaran, K. and Manikandan, R., 2010, December. An intelligent speed controller for indirect vector controlled induction motor drive. In Computational Intelligence and Computing Research (ICCIC), 2010 IEEE International Conference on (pp. 1-5). IEEE.

BIOGRAPHIES

Hendi Purnata, S.Pd born in Tanjung Enim 13 November 1992 and currently student of Electrical Engineering in Institute Tekhnology Sepuluh Nopember, Surabaya, Indonesia.

Dr. Ir. Mochmmad Rameli currently lecture of Electrical Enginnering in Institute Tekhnologi Sepuluh Nopember, Surabaya, Indonesia. His area of interest include Control System, Power Electronics and Drive System

Ir. Rusdhianto Effendy A.K, MT. Currently lecture of Electrical Engginering in Institute Tekhnologi Sepuluh Nopember, Surabaya, Indonesia. His area of interest include Control System, Robotic, Power Electronics and Drive System