Gontapon PROMNIGON[1], Jagraphon OBMA[2],Krittanon PRATHEPHA[1], Narongkorn UTHATHIP[1], Nuttapon CHAIDUANGSRI[1] , Worawat SA-NGIAMVIBOOL[1]

Faculty of Engineering, Mahasarakham University, Mahasarakham 44150, Thailand (1)
Faculty of Engineering, Rajamangala University of Technology ISAN Khonkaen Campus, Khonkaen 40000, Thailand (2)
ORCID: 1. 0000-0003-1319-3174; 2. 0000-0001-8984-2287; 3. 0000-0003-2870-1581; 4. 0000-0001-6927-143X; 5. 0000-0002-4365-9724; 6. 0000-0001-8580-8962

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Induction Motor Drive Based on Vector Control Technique and Active Power Factor Correction for The Three-Phase Rectifier Systems Using The Three-Level Converters

***Abstract**. This paper presents a comparison of the modulation methods of space vector power control in combination with a Vienna three-phase rectifier using two control methods: 1. Power Control 2. Current Control There are three modulations tested: 1. Pulse width modulation using a phase-shifted triangle signal 2. Modulating pulse width with a shifted triangle signal 3. Pulse width modulation by vector and d-q axis control is also used to stabilize the distortion of the input current and DC output voltage. The pulse width modulation method with a phase-shifted triangle signal was discovered to have a total input current distortion of as low as 2.28 percent, and the DC output can be stabilized at 800 VDC with a rated power of 10 kW. All results were obtained from the programs MATLAB and the test suites DSP. The simulation confirmed the effectiveness of control and modulation for the design and selection of suitable methods for the Vienna three-phase rectifiers.*

Streszczenie.** W artykule przedstawiono porównanie metod modulacji wektora przestrzennego sterowania mocą w połączeniu z wiedeńskim prostownikiem trójfazowym przy użyciu dwóch metod sterowania: 1. Sterowanie mocą 2. Sterowanie prądem Testowane są trzy modulacje: 1. Modulacja szerokości impulsu z wykorzystaniem fazy -sygnał z przesuniętym trójkątem 2. Modulacja szerokości impulsu z przesuniętym sygnałem trójkąta 3. Modulacja szerokości impulsu za pomocą sterowania wektorowego i osi d-q jest również wykorzystywana do stabilizacji zniekształceń prądu wejściowego i napięcia wyjściowego DC. Odkryto, że metoda modulacji szerokości impulsu z przesuniętym w fazie sygnałem trójkątnym powoduje całkowite zniekształcenie prądu wejściowego na poziomie zaledwie 2,28 procent, a napięcie wyjściowe prądu stałego można ustabilizować na poziomie 800 VDC przy mocy znamionowej 10 kW. Wszystkie wyniki uzyskano z programów MATLAB oraz zestawów testowych DSP. Symulacja potwierdziła skuteczność sterowania i modulacji przy projektowaniu i doborze odpowiednich metod dla wiedeńskich prostowników trójfazowych.* (Napęd silnika indukcyjnego oparty na technice sterowania wektorowego i korekcji współczynnika mocy czynnej dla trójfazowych układów prostownikowych z wykorzystaniem przekształtników trójpoziomowych***)

Keywords: Pulse width modulation using a phase-shifted triangle signal, Current control, d-q control, Pulse
Słowa kluczowe: napęd, silnik indukcyjny, przekształtnik trójpoziomowy

Introduction

The Vienna rectifier in Figure 1 is a three-phase, three-level voltage rectifier with high reliability, high efficiency, and minimal occurrences of total harmonic distortion, which is an active filter circuit, smaller size, higher efficiency, and higher power factor compared to the passive filter method.

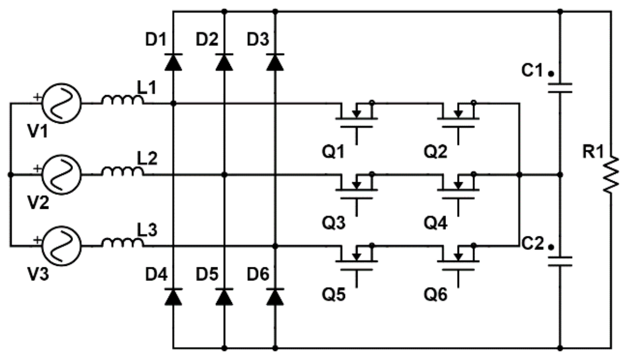

Fig.1. Vienna three-phase rectifier

The Vienna three-phase rectifier uses control by the d-q method and the modulation method. The control of switching devices in Vienna rectifiers is the space-vector pulse width modulation, which is a three-level vector space consisting of 27 states in switching and 19 voltage vectors as shown in Figure 2.

Due to a large number of switching states and voltage vectors, complex calculations are possible. Therefore, this paper will introduce how to use three levels of vector space as a two-level vector computation method, which will make it easier to calculate active vector space. Together with the Vienna three-phase rectifier, the circuit performance remains the same.

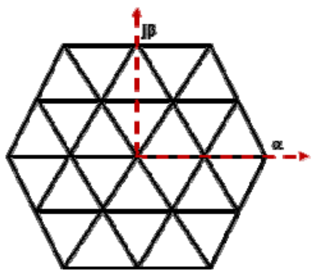

Fig.2. three-level vector space

The method for controlling a three-phase Vienna rectifier

The control method on the d-q axis is shown in Figure 3. The input voltage (Va, Vb, Vc) and input current (Ia, Ib, Ic) are converted from a three-phase system into a rotating reference frame using the Clark transform principle as shown in Equations 1, 2, and 3, and the Park transform as shown in Equations 4-6.

(1) $$i_\alpha = \frac{2}{3} i_a - \frac{1}{3}(i_b - i_c)$$

(2) $$i_\beta = \frac{2}{\sqrt{3}}(i_b - i_c)$$

(3) $$i_0 = \frac{2}{3}(i_a + i_b + i_c)$$

(4) $$i_d = i_\alpha \cdot \cos(\theta) + i_\beta \cdot \sin(\theta)$$

(5)
$$i_q = -i_\alpha \cdot \sin(\theta) + i_\beta \cdot \cos(\theta)$$

The Id is the current in the D axis, which is like the real power, and Iq is the current in the Q axis, which is the reactive power. The Id is then derived from the PI controller used to control the DC voltage. The output and the Iq are set to zero in order to control only the power factor close to one. The currents Id and Iq are controlled by a PI regulator used to control the current as in Equations (6) and (7).

(6)
$$u_d = -\left(K_p + \frac{K_i}{s}\right)\left(i_{d_{ref}} - i_d\right) + v_d + \omega L i_q$$

(7)
$$u_q = -\left(K_p + \frac{K_i}{s}\right)\left(i_{q_{ref}} - i_q\right) + v_q - \omega L i_d$$

When converting the voltage in the form of a rotary reference frame back into a three-phase power system for use in modulation by the reversing principle of Park is shown in Equation (8), and Clark's reversal shown in Equation 10-12.

(8)
$$i_\alpha = i_d \cdot \cos(\theta) - i_q \cdot \sin(\theta)$$

(9)
$$i_\beta = i_d \cdot \sin(\theta) + i_q \cdot \cos(\theta)$$

(10)
$$i_a = i_\alpha$$

(11)
$$i_b = -\frac{1}{2} \cdot i_\alpha + \frac{\sqrt{3}}{2} \cdot i_\beta$$

(12)
$$i_c = -\frac{1}{2} \cdot i_\alpha - \frac{\sqrt{3}}{2} \cdot i_\beta$$

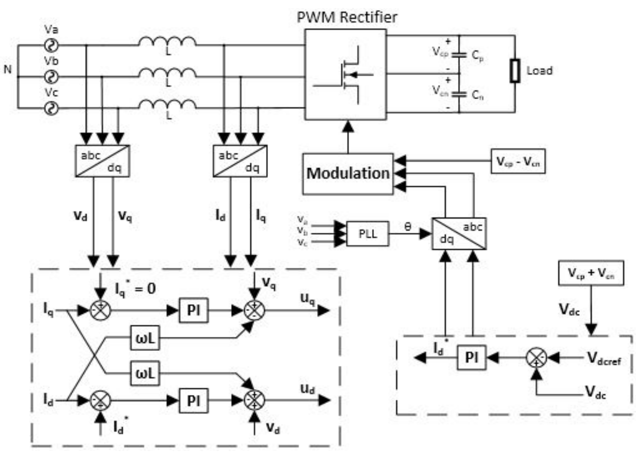

Fig.3. Control diagram on the d-q axis.

The three-level space vector modulation method is a two-level space vector

1. Conversion to the origin of the three-level space vector

As shown in Figure 4(a), this method converts the origin of the three-level space vector, which consists of 19 voltage vectors, as follows: The zero vector (v0) has a size of zero. A small vector (v_1, v_2, v_3, v_4, v_5, v_6) has a size of Vdc/3, a medium vector (v_8, v_{10}, v_{12}, v_{14}, v_{16}, v_{18}) has a size of 3Vdc/3, and large vectors (v_7, v_9, v_{11}, v_{13}, v_{15}, v_{17}) have the same size as 2Vdc/3 points to a small vector v_1, v_2, v_3, v_4, v_5, v_6. This method gives the vector space a shape similar to the two-level vector space shown in Figure 4(b), and the reference voltage vector can be written as shown in Equations 13 and 14.

(13)
$$T_x V_x + T_y V_y + T_z V_z = T_s V_{REF\_MAP}$$

(14)
$$T_x + T_y + T_z = T_s$$

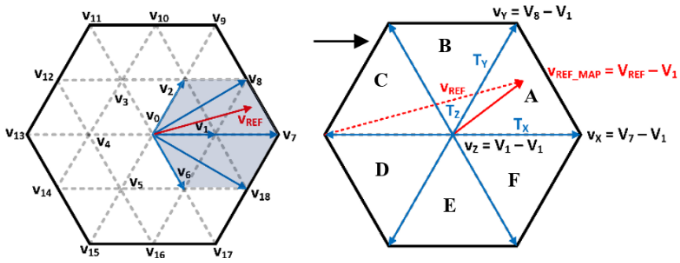

Fig.4. The reference voltage vector in a three-level vector space, (b) The reference voltage vector after moving the starting point in a two-level vector space

A two-level vector space sector can be divided into six three-level vector space sectors as shown in Figure 5 and will get the size of vz in each sector according to Table 1.

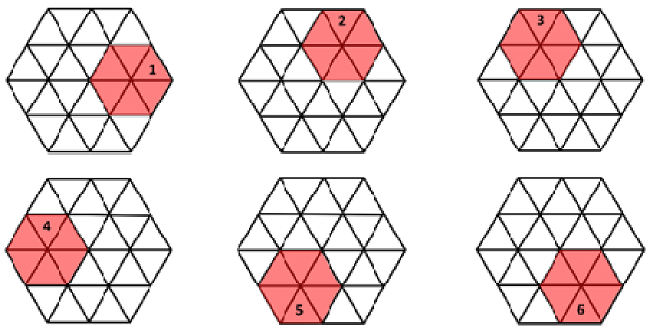

Fig.5. Divides the three-level vector space into 6 sectors.

Table 1. The zero vector position of each sector and its magnitude.

Sectors.	The zero vector position	The size of **Vz**
1	V_1	$V_{dc}/3$
2	V_2	$V_{dc}/6$
3	V_3	$-V_{dc}/6$
4	V_4	$-V_{dc}/3$
5	V_5	$-V_{dc}/6$
6	V_6	$V_{dc}/6$

2. Calculation of the duty cycle time T_x, T_y, T_z

The duty cycle time equation [13–15] can be used in the same way as for a two-level vector space as in Equation 15.

(15)
$$\begin{bmatrix} V_x \\ V_y \end{bmatrix} \frac{T_s}{2} = \frac{V_{dc}}{3} \begin{bmatrix} \cos\left(\frac{(n-1)\pi}{3}\right) & \cos\left(\frac{n\pi}{3}\right) \\ \sin\left(\frac{(n-1)\pi}{3}\right) & \sin\left(\frac{n\pi}{3}\right) \end{bmatrix} \begin{bmatrix} T_x \\ T_y \end{bmatrix}$$

When n denotes the 1-6 subsectors of the two-level vector space and Ts denotes the random time. Therefore, when calculating the duty cycle time, it will be as shown in Equations 16-18. The position vectors and duty cycle times of each subsector in sector 1 can be summarized in Table 2.

(16)
$$X = 2\sqrt{3} V_y \times \frac{T_s}{V_{dc}}$$

(17)
$$Y = 3V_x + \sqrt{3} V_y \times \frac{T_s}{V_{dc}}$$

(18) $$Z = 3V_x - \sqrt{3}V_y \times \frac{T_s}{V_{dc}}$$

Table 2. Summarize the position value of the vector and the duty cycle time of sector 1.

sub sector	The position value of the vector			the duty cycle time		
	V_x	V_y	V_z	T_x	T_y	T_z
A	$V_7 - V_1$	$V_8 - V_1$	$V_1 - V_1$	Z	X	T_s-X-Z
B	$V_8 - V_1$	$V_2 - V_1$	$V_1 - V_1$	Y	-Z	T_s-Y+Z
C	$V_2 - V_1$	$V_0 - V_1$	$V_1 - V_1$	X	-Y	T_s-X+Y
D	$V_0 - V_1$	$V_6 - V_1$	$V_1 - V_1$	-Z	-X	T_s+Z+X
E	$V_6 - V_1$	$V_{18} - V_1$	$V_1 - V_1$	-Y	Z	T_s+Y-Z
F	$V_{18} - V_1$	$V_7 - V_1$	$V_1 - V_1$	-X	Y	T_s+X-Y

3.Determination of the switching sequence

A vector symmetric method is used to determine the switching sequence in a two-level vector space. For example, the switching sequence of sub-sector 1 in sector 1 is shown in Figure 6, and the switching sequence is as shown in equation 19.

(19) $$V_{1+} - V_8 - V_7 - V_{1-} - V_{1-} - V_7 - V_8 - V_{1+}$$

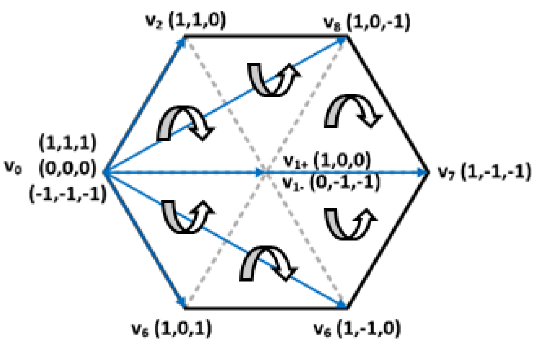

Fig.6. Switching sequence for sector 1

The modulation condition is determined by the direction of the input current. For example, the current in phase A of sector 1 is positive and thus modulated by the positive triangle signal. The currents in phase B and phase C are negative, so they are modulated by the negative triangle signal as shown in Figure 7.

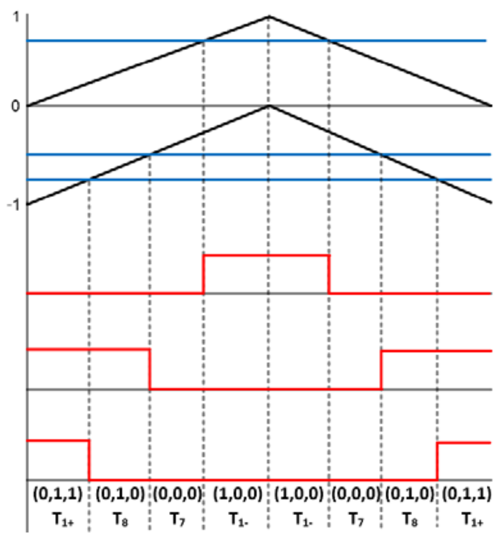

Fig.7. S Modulation in sub-sector 1 of sector 1

Results

In this test, the DSP is used to determine the operation resulting in a sinusoidal input current, control the output DC voltage, and measure the total distortion of the input current with the following in table 3 parameters:

Table 3. Parameters in this test

Parameters	Value
Input Voltage	380 V_{AC}
Output Voltage	800 V_{DC}
Output Power	10 kW
Switching Frequency	20 kHz
Inductor	3 mH
Capacitor	220 uF
Sample Time	$1e^{-6}$ s

In Figure 8, the input current is controlled by modulation, resulting in a sinusoidal nature and low input current distortion. From Figure 9, the input voltage (Va) and the input current (Ia) in the steady state do not overlap, causing the power factor to approach one. From Figure 10, the output DC voltage is regulated at a constant of 800Vdc. When the line-to-line voltage is represented by three voltages, as shown in Figure 11, and the distortion of the input current is measured, as shown in Figure 12, the distortion is 2.28 percent.

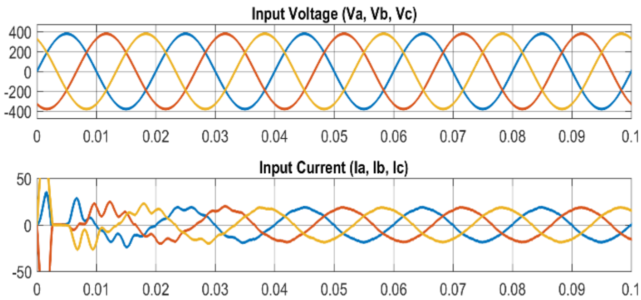

Fig.8. Input voltage (Va, Vb, Vc) and input current (Ia, Ib, Ic)

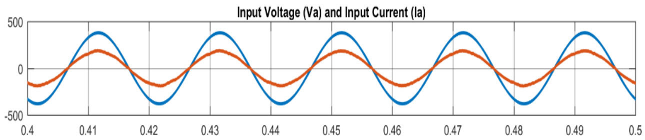

Fig.9. Input voltage (Va, Vb, Vc) and input current (Ia, Ib, Ic)

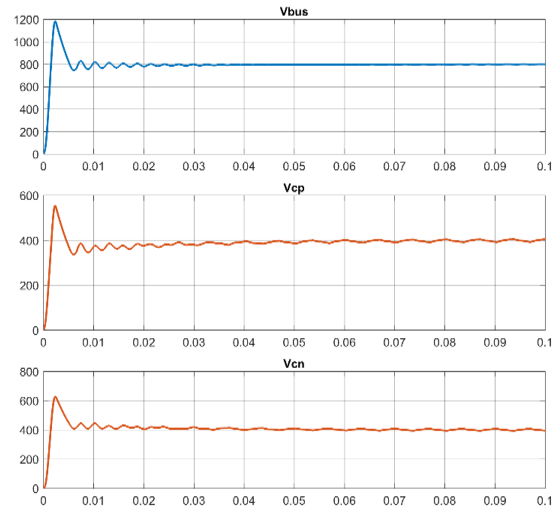

Fig.10. Input voltage (Va, Vb, Vc) and input current (Ia, Ib, Ic)

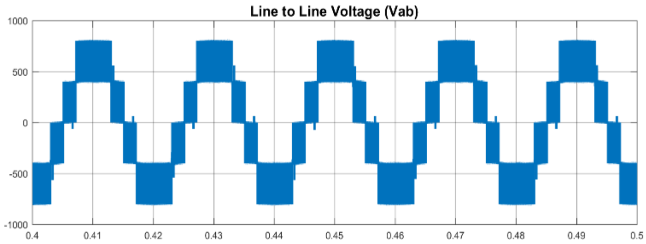

Fig.11. line-to-line voltage (Vab)

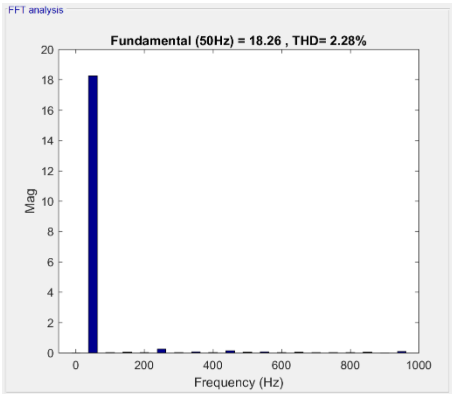

Fig.12. Distortion of input current

Conclusions

This paper presents a space vector pulse width modulation method of a three-level converter circuit in a Vienna rectifier using the three-level space vector from a two-level vector space. Three-level vector spaces are typically complex computations, whereby they simplify computations by using duty-cycle-time computations, and the switching sequence is the same as the two-level vector method, which can also reduce the total input current distortion to as low as 2.28 percent. It is also able to maintain a constant DC output voltage of 800 Vdc.

Authors: *Gontapon Promnigon , Ph.D.(Candidate), Faculty of Engineering Mahasarakham University, Tambon Khamriang, Kantharawichai District, Maha Sarakham 44150 Thailand.*

Jagraphon OBMA, Ph.D., Faculty of Engineering, Rajamangala University of Technology ISAN Khonkaen Campus, Khonkaen 40000, Thailand.

Krittanon Prathepha Ph.D., Faculty of Engineering, Mahasarakham University, Tambon Khamriang,Kantharawichai District, Maha Sarakham 44150 Thailand.

Narongkorn UTHATHIP Ph.D., Faculty of Engineering, Mahasarakham University, Tambon Khamriang,Kantharawichai District, Maha Sarakham 44150 Thailand.

Nuttapon CHAIDUANGSRI Ph.D., Faculty of Engineering, Mahasarakham University, Tambon Khamriang,Kantharawichai District, Maha Sarakham 44150 Thailand.

Assoc.Prof.Worawat Sa-ngiamvibool, Ph.D., Faculty of Engineering, Mahasarakham University, Tambon Khamriang, Kantharawichai District, Maha Sarakham 44150 Thailand.
e-mail : wor.nui@gmail.com (Corresponding Author)

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