Washington State University

School of Electrical Engineering and Computer Science

EE 582 Advanced Power Electronics

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Project #2

Space Vector Modulation Schemes for Two-Level Voltage Source Inverter

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Overview

Space vector modulation topology is a two-level inverter developed from vector modulation to pulse width modulation. It is an advanced method for obtaining sinusoids with low THD. This method has been developed rapidly in recent years because of its easy implementation and short computation time. In this project, we need to understand the principle of space vector modulation, and investigate the harmonic performance of the two-level voltage source inverter (Matlab/Simulink).

Theory

Space vector modulation topology is widely used in power electronics and its applications. Voltage source inverter is the main component of the interface between power electronics and power system. On the voltage source, the output voltage of the inverter can be controlled by adjusting the voltage inside the inverter. The best way to control the inverter output is to adjust the pulse width applied inside the inverter. Pulse width modulation (PWM) applies a constant DC voltage to the input of the inverter and limits the AC output voltage by adjusting the duty cycle. Inverter output voltage regulation has different topology, such as sinusoidal pulse width modulation (SPWM) topology, space vector pulse width modulation (SVPWM) topology and so on. In recent decades, the space vector modulation topology has been easily used to adjust the terminal voltage of inverters because it reduces commutation loss and harmonic content of terminal voltage compared to the traditional sinusoidal PWM topology[1].

The three-phase sinusoidal voltages shown as,

$$V_{Ao} = v_M sin\omega t$$

$$V_{Bo} = v_M sin(\omega t - \frac{2\pi}{3})$$

$$V_{Co} = v_M sin(\omega t - \frac{4\pi}{3})$$

The three-phase voltage shown as,

$$V(t) = \frac{2}{3}[V_{Ao(t)ej0} + V_{Bo(t)ej2}\pi/3 + V_{Co(t)ej4}\pi/3]$$

Three phase voltage components are transformed into equivalent two phase components as shown below

$$\begin{bmatrix} V_\alpha(t) \\ V_\beta(t) \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_{AO}(t) \\ V_{BO}(t) \\ V_{CO}(t) \end{bmatrix}$$

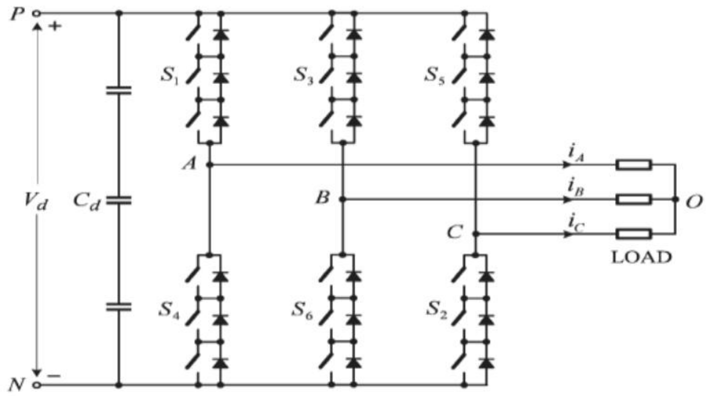

Fig 1. Simplified two-level VSI

Switching State	Leg A			Leg B			Leg C		
	S_1	S_4	v_{AN}	S_3	S_6	v_{BN}	S_5	S_2	v_{CN}
P	On	Off	V_d	On	Off	V_d	On	Off	V_d
O	Off	On	0	Off	On	0	Off	On	0

Table 1. Definition of conducting state

Space Vector		Switching State (Three Phases)	On-State Switch	Vector Definition
Zero Vector	$\vec{V}_0$	[PPP] [OOO]	S_1, S_3, S_5 S_4, S_6, S_2	$\vec{V}_0 = 0$
Active Vector	$\vec{V}_1$	[POO]	S_1, S_6, S_2	$\vec{V}_1 = \frac{2}{3} V_d e^{j0}$
	$\vec{V}_2$	[PPO]	S_1, S_3, S_2	$\vec{V}_2 = \frac{2}{3} V_d e^{j\frac{\pi}{3}}$
	$\vec{V}_3$	[OPO]	S_4, S_3, S_2	$\vec{V}_3 = \frac{2}{3} V_d e^{j\frac{2\pi}{3}}$
	$\vec{V}_4$	[OPP]	S_4, S_3, S_5	$\vec{V}_4 = \frac{2}{3} V_d e^{j\frac{3\pi}{3}}$
	$\vec{V}_5$	[OOP]	S_4, S_6, S_5	$\vec{V}_5 = \frac{2}{3} V_d e^{j\frac{4\pi}{3}}$
	$\vec{V}_6$	[POP]	S_1, S_6, S_5	$\vec{V}_6 = \frac{2}{3} V_d e^{j\frac{5\pi}{3}}$

Table 2. Zero vector and Active vector switching state

The zero vector V_0 consists of two states [PPP] and [OOO], one of which is redundant.

The excess switching state is used to minimize the switching frequency of the inverter or to perform other effective operations. The zero vector and the active vector do not shift in space and are called the rest vector. Instead, the reference vector V_{ref}, shown in Figure 2, moves through space with angular velocity ω.

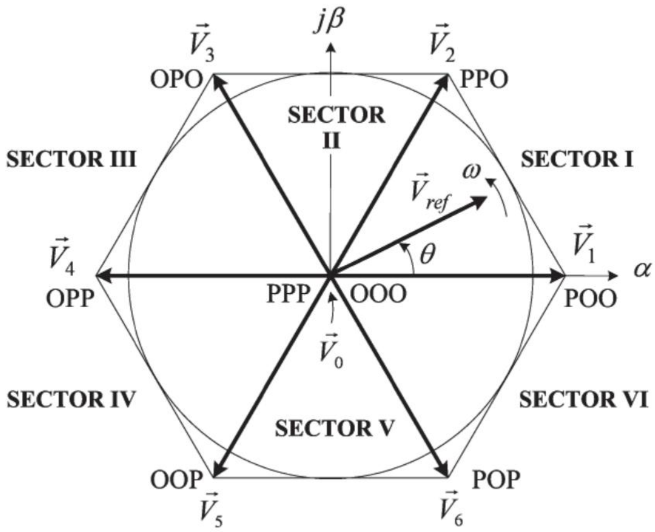

Fig 2. V_{ref} at different sectors for two level VSI

System Specifications

Rated inverter output power	10kVA
Rated inverter output voltage	416V (line-to-line,rms)
Rated inverter output voltage	13.9A (rms)
Rated dc input voltage	Canstant dc (TBD)
Load	RL load with a per-phase resistance of 15.6ohms and inductance of 14.2 mH
Switching devices	Ideal switch (no power losses)

Simulation Results

Part A)

Determine the dc input voltage V_d that can produce a fundamental line-to-line voltage of

4160 V (rms) at the modulation index of m_a =1.0.

For three phase system, $V_d = 4160 * \sqrt{2} = 5883V$

Part B)

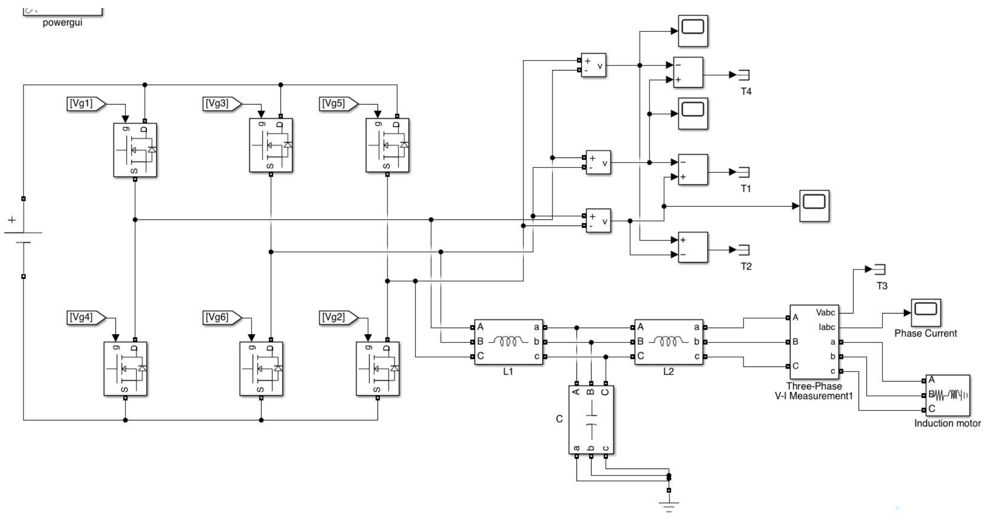

Fig 3. Two level VSI

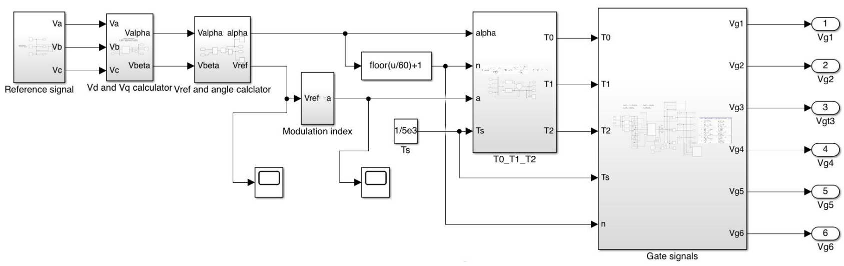

Fig 4. Space Vector PWM

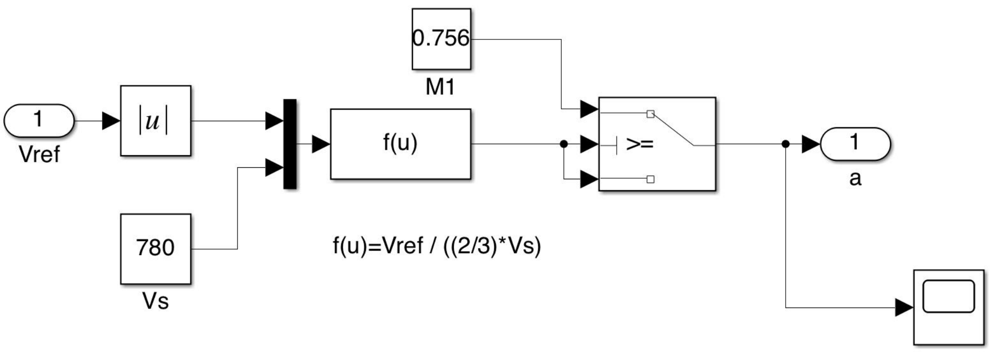

Fig 5. Modulation index

Simulation Task 1 (f_1=30, $m_a = 0.4$, $T_s = 1/3600$)

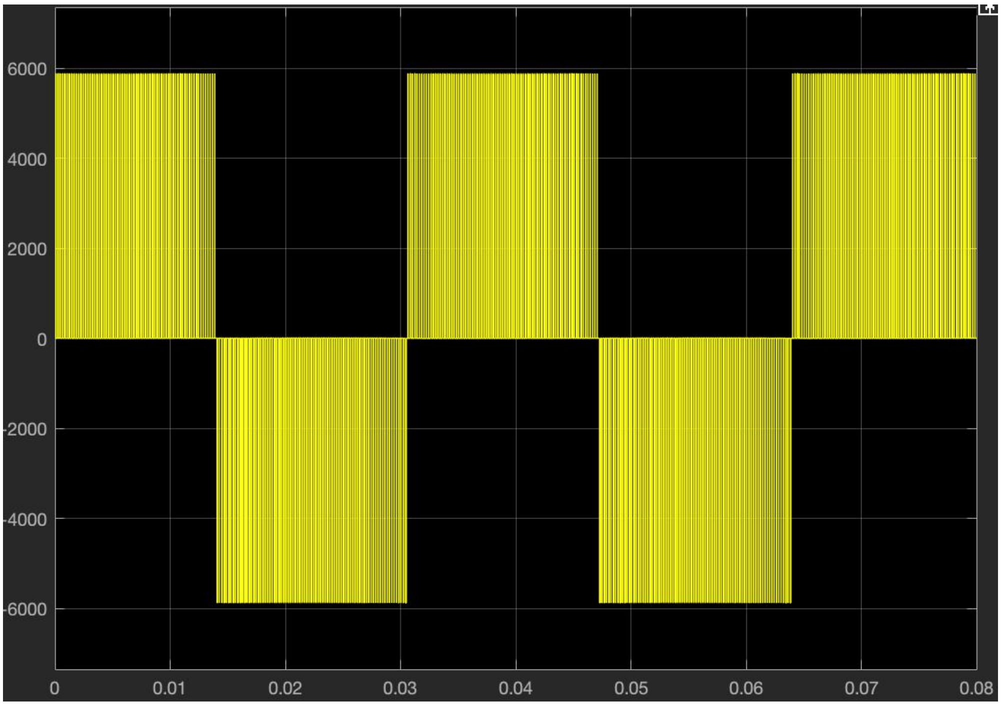

Fig 6. Vab

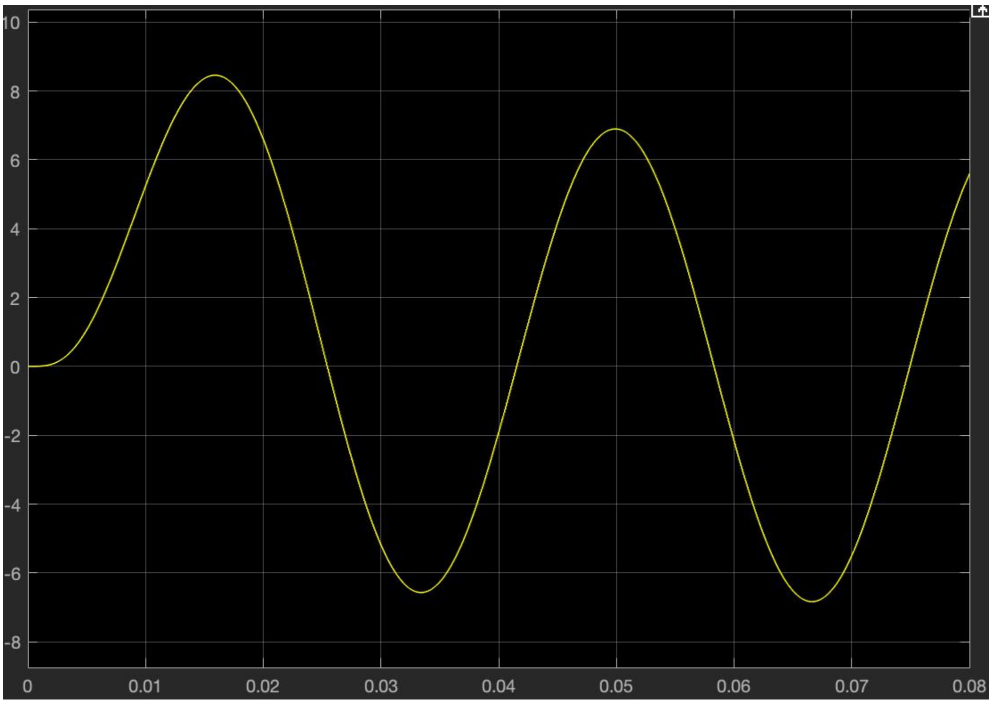

FIg 7. Ia

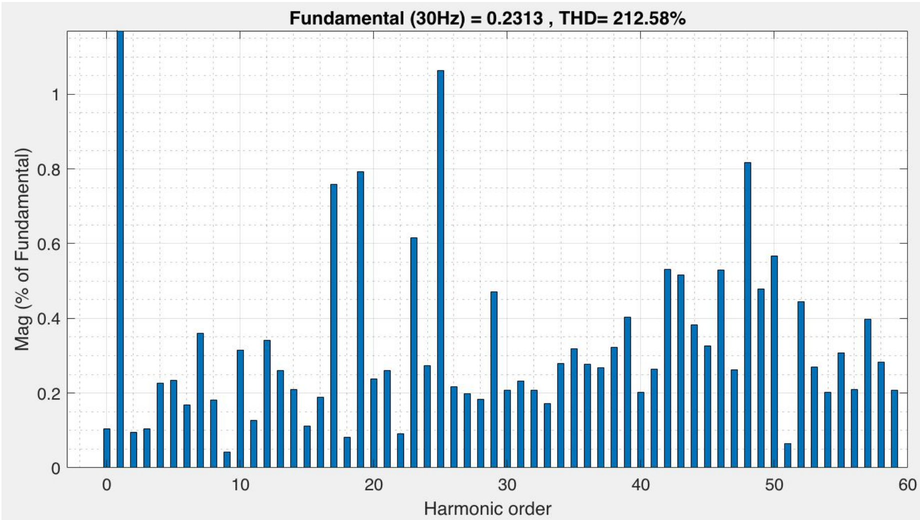

Fig 8. The harmonic spectrum of Vab

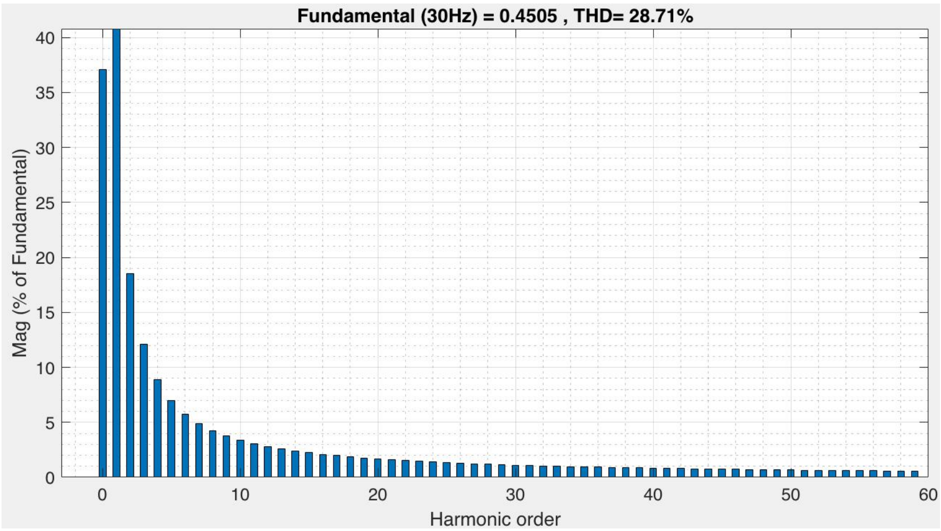

Fig 9. The harmonic spectrum of Ia

Simulation Task 2 (f_1=30, $m_a = 0.8$, $T_s = 1/3600$)

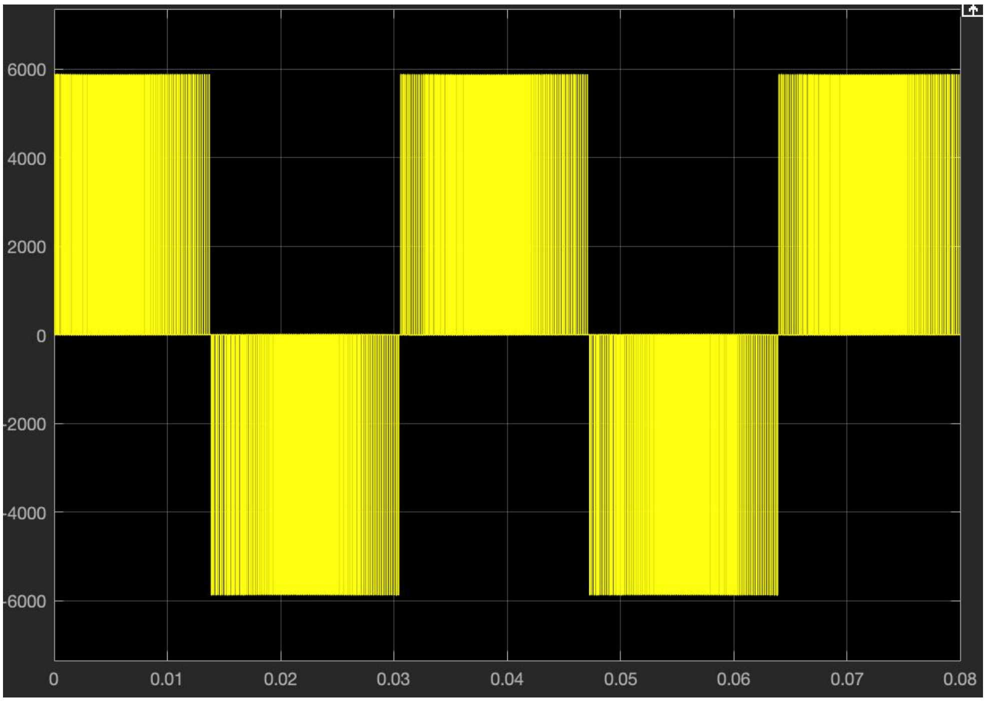

Fig 10. Vab

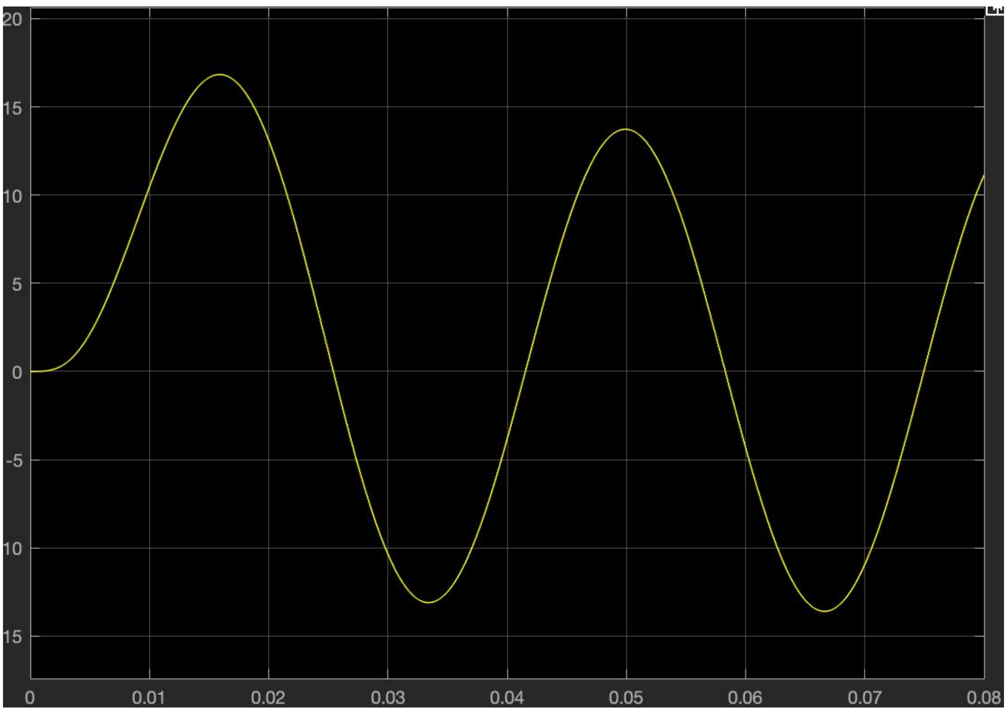

Fig 11. Iab

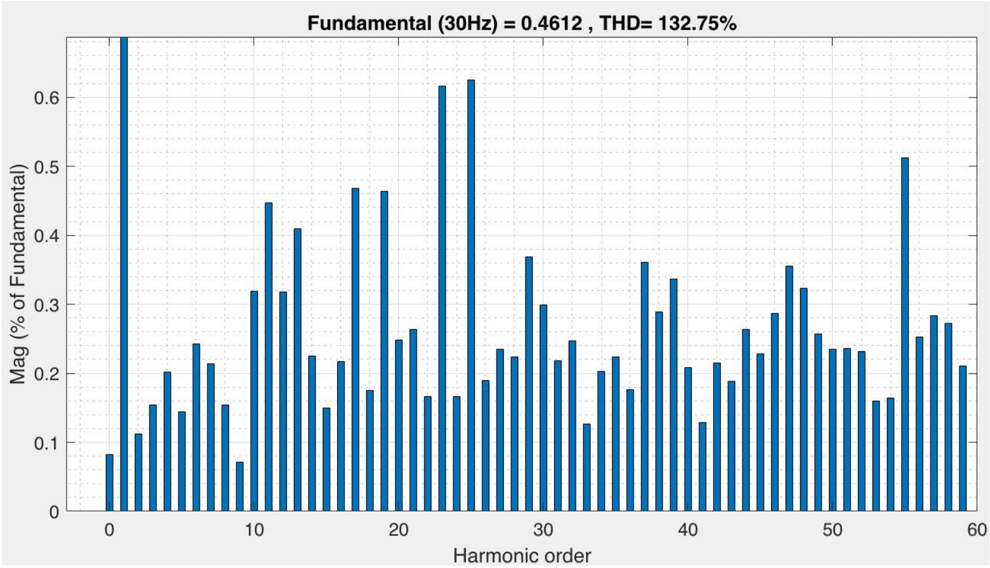

Fig 12. The harmonic spectrum of Vab

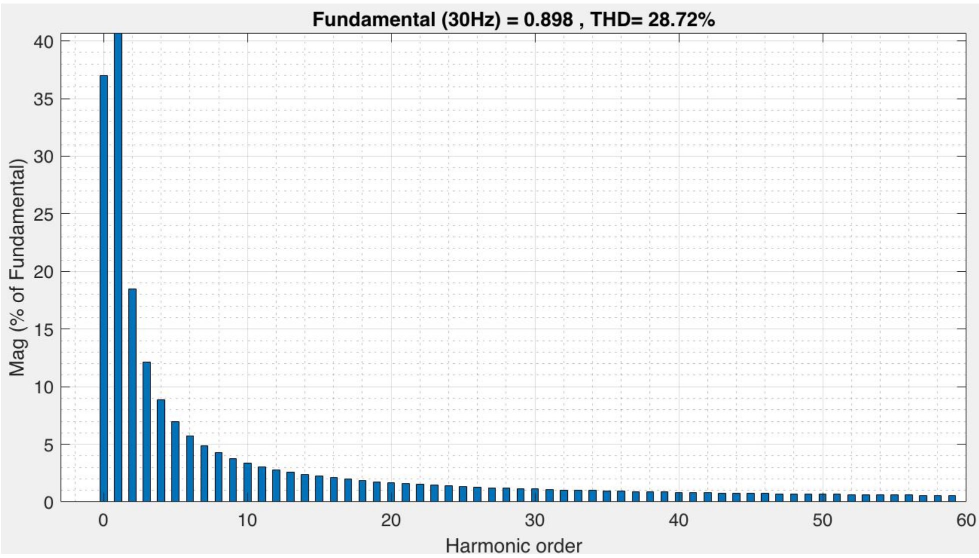

Fig 13. The harmonic spectrum of Ia

Simulation Task 1 (f_1=60, $m_a = 0.4$, $T_s = 1/3600$)

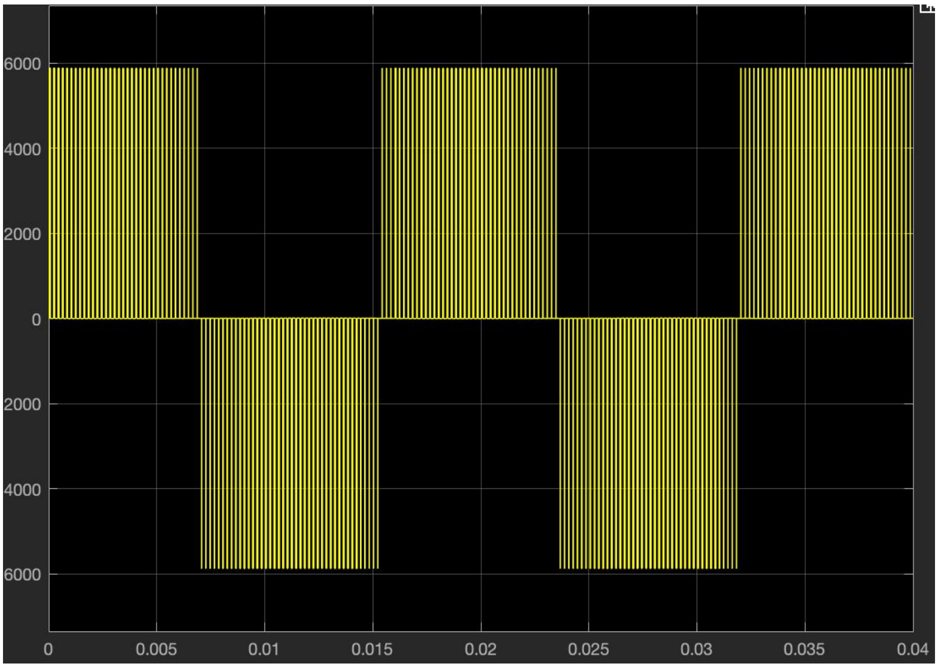

Fig 14. Vab

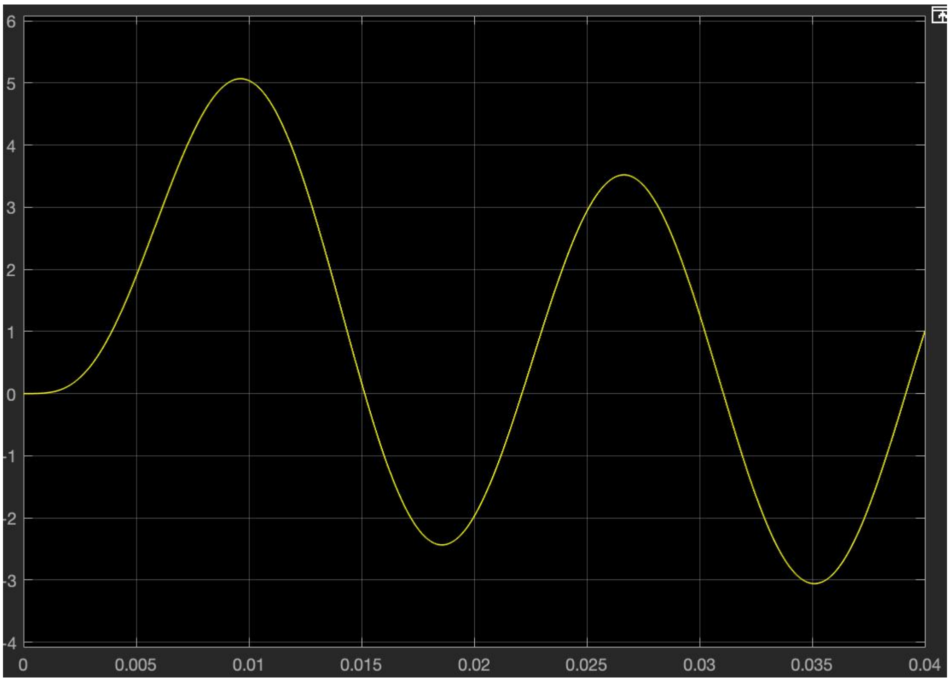

Fig 15. Ia

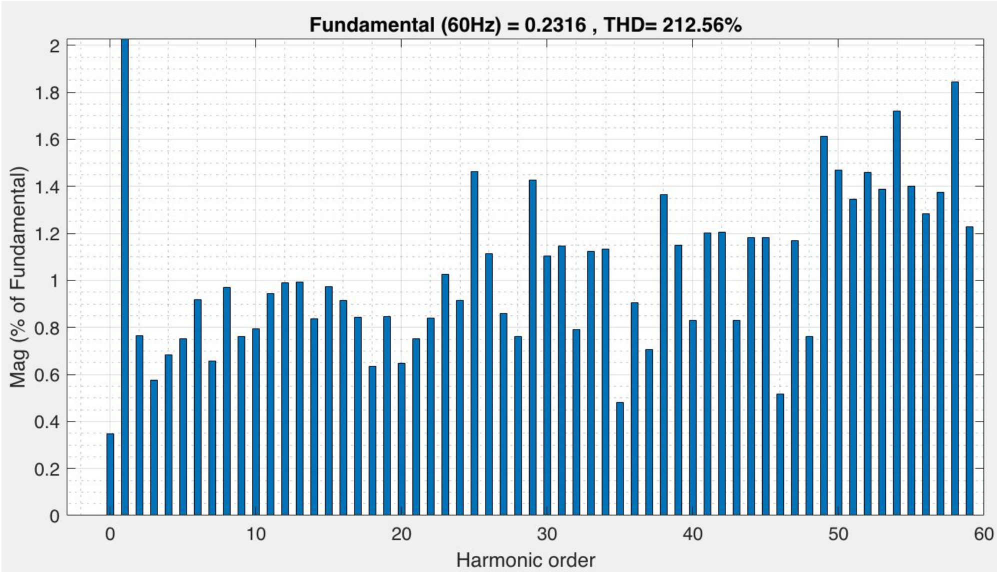

Fig 16. The harmonic spectrum of Vab

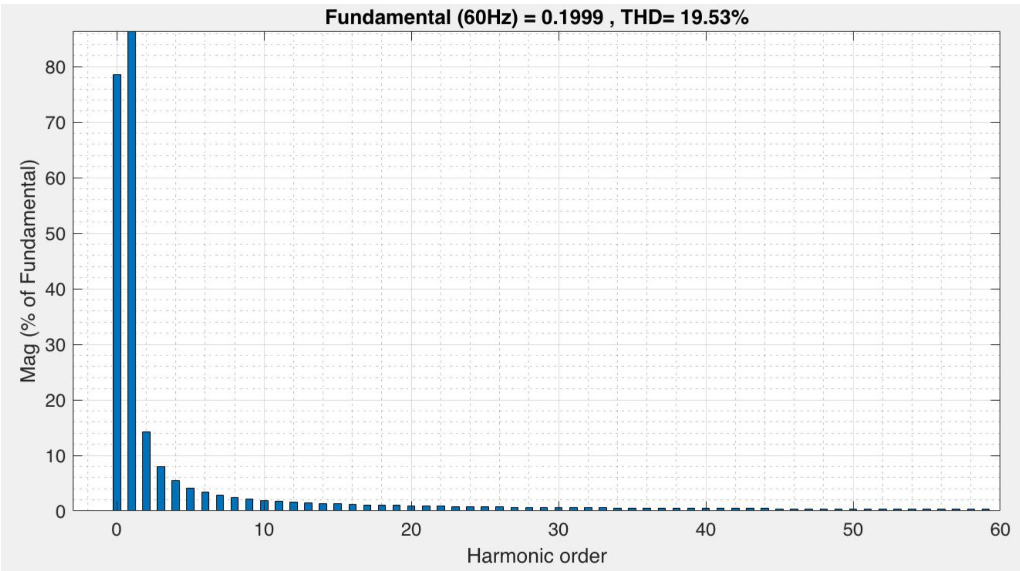

Fig 17. The harmonic spectrum of Ia

Simulation Task 1 (f_1=60, $m_a = 0.8$, $T_s = 1/3600$)

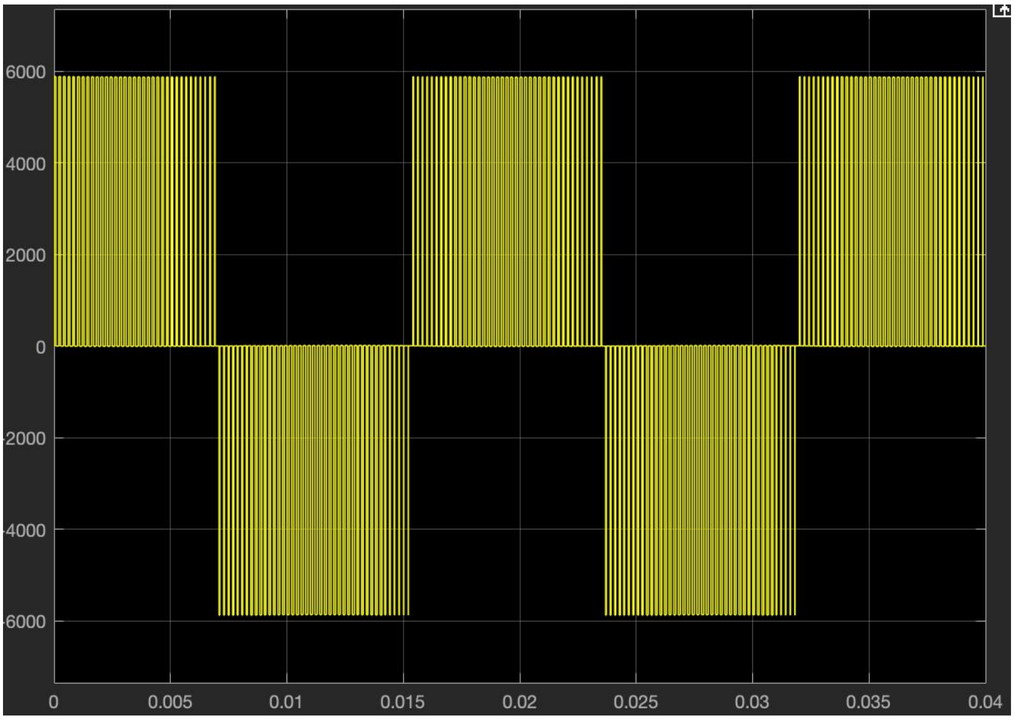

FIg 18. Vab

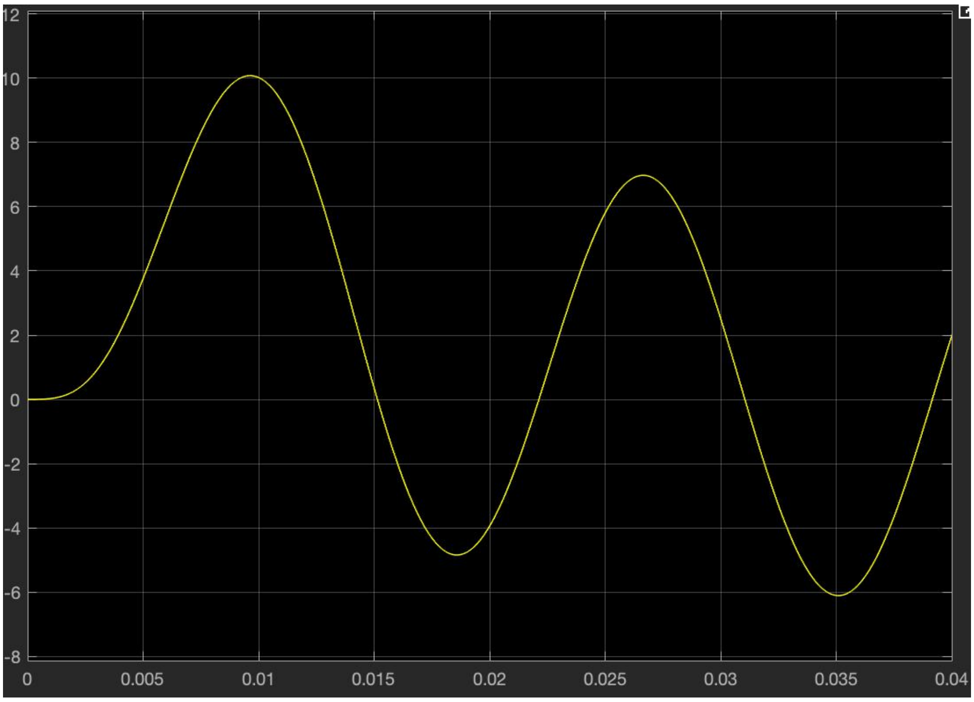

Fig 19. Ia

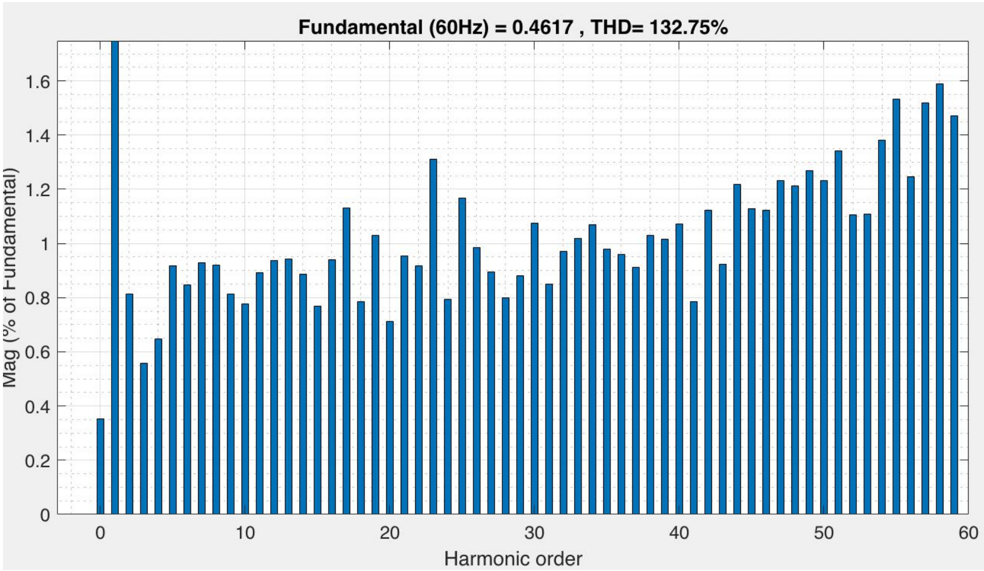

Fig 20. The harmonic spectrum of Vab

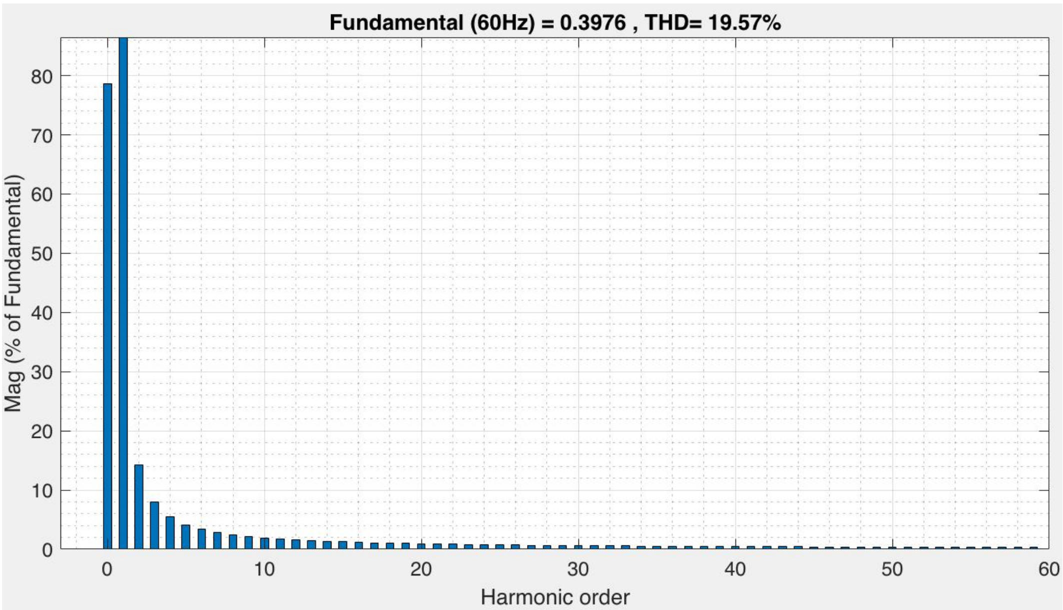

Fig 21. The harmonic spectrum of Ia

Conclusion

Space vector modulation is a kind of topology which is widely used in output voltage control of voltage source inverter. The SVPWM topology is presented and analyzed by simulation. When f1=30 Hz, FFT simulation results show that THD is 212.56% at $m_a =$

0.4 and THD is 132.75% at $m_a = 0.8$. When the modulation index is 0.4 and 0.8, the total harmonic distortion (THD) of voltage inverter is reduced.