ELGC06
3-phase Inverters

ORGANIZATION

I. Voltage Source Inverter (VSI)

A. Six-Step VSI

B. Pulse-Width Modulated VSI

II. PWM Methods

A. Sine PWM

B. Hysteresis (Bang-bang)

C. Space Vector PWM

III. References

I. Voltage Source Inverter (VSI)
A. Six-Step VSI (1)

➢ **Six-Step three-phase Voltage Source Inverter**

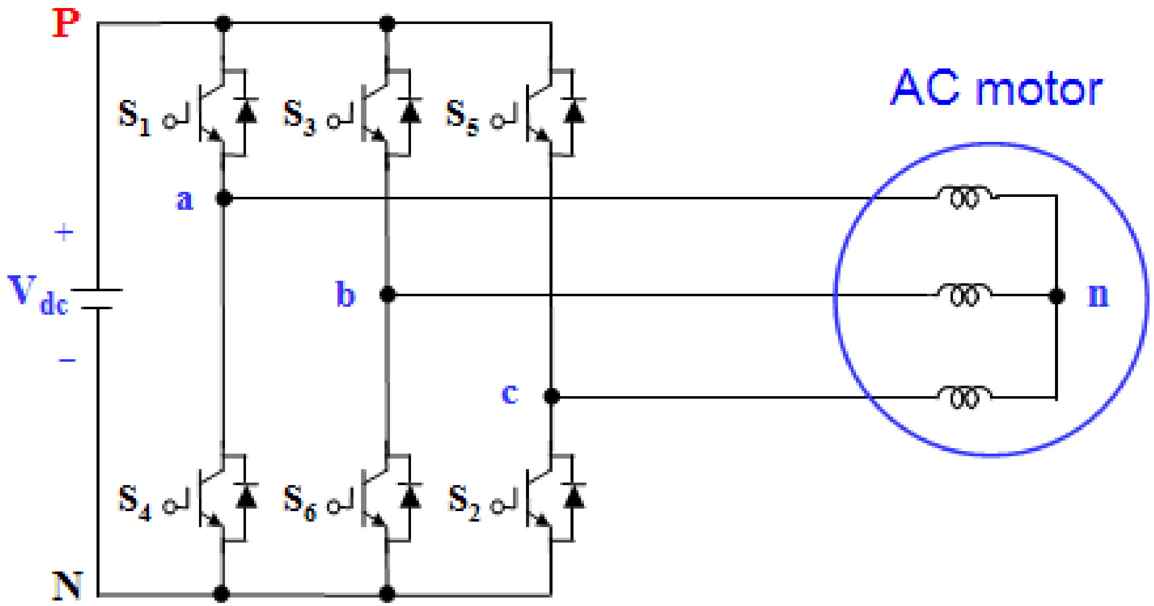

Fig. 1 Three-phase voltage source inverter.

I. Voltage Source Inverter (VSI)

A. Six-Step VSI (2)

➢ **Gating signals, switching sequence and line to negative voltages**

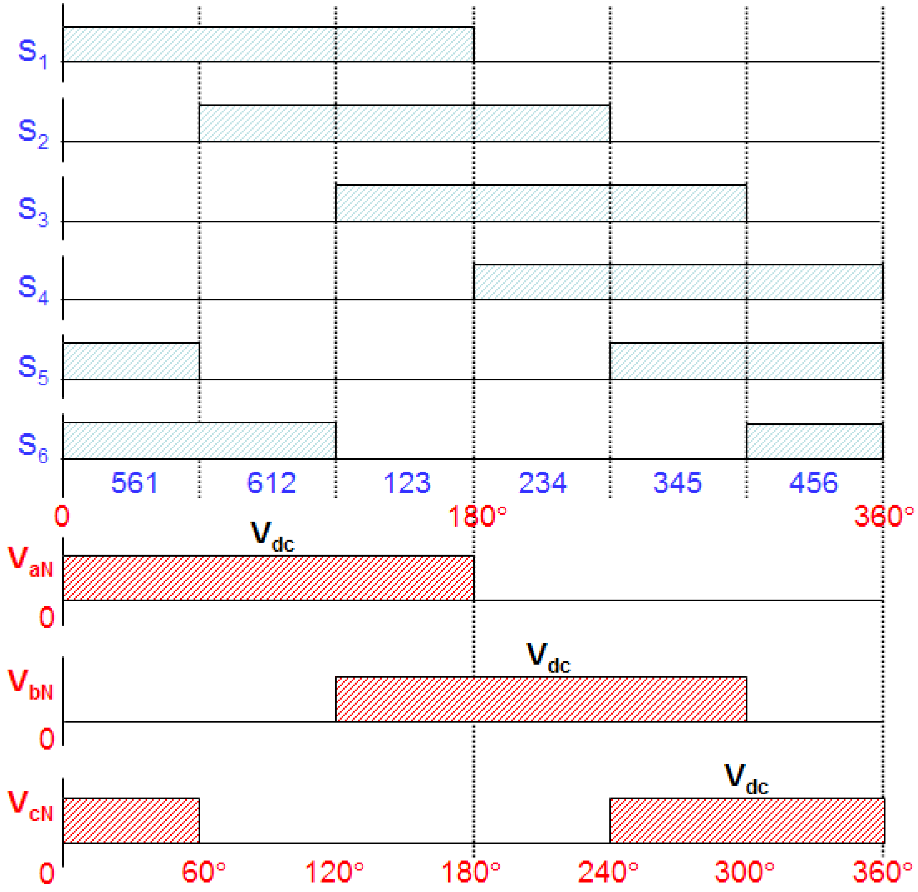

Fig. 2 Waveforms of gating signals, switching sequence, line to negative voltages for six-step voltage source inverter.

I. Voltage Source Inverter (VSI)
A. Six-Step VSI (3)

➢ **Switching Sequence:**

561 (V_1) → 612 (V_2) → 123 (V_3) → 234 (V_4) → 345 (V_5) → 456 (V_6) → 561 (V_1)

where, 561 means that S_5, S_6 and S_1 are switched on

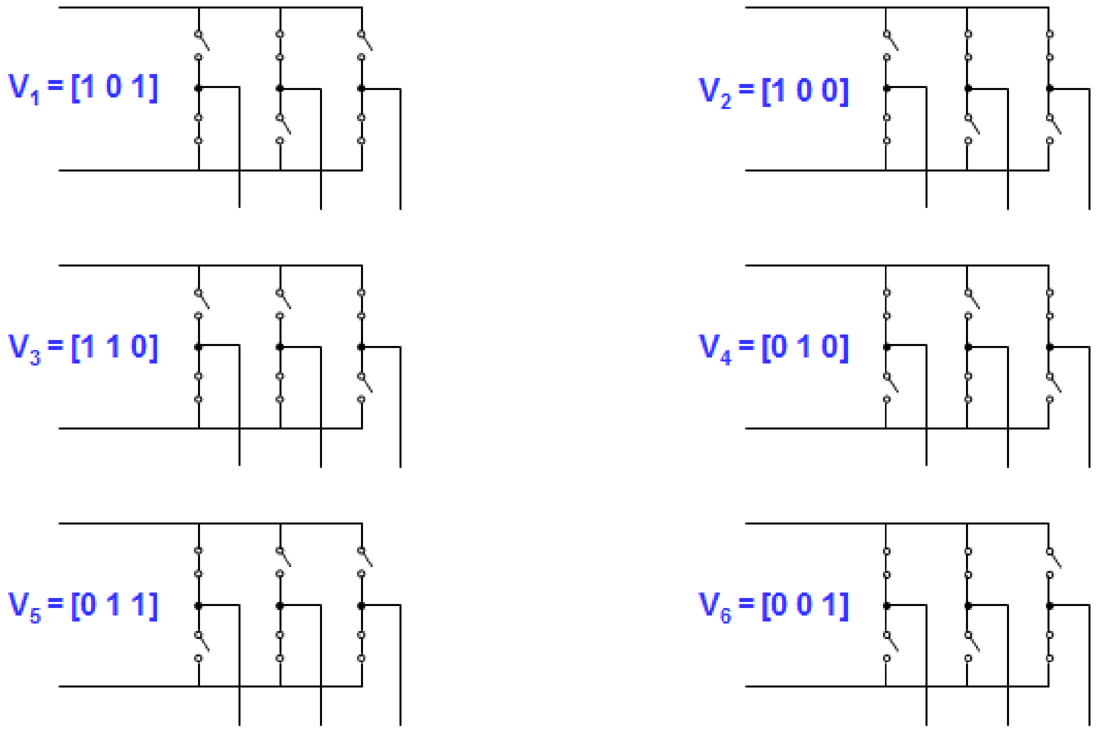

Fig. 3 Six inverter voltage vectors for six-step voltage source inverter.

I. Voltage Source Inverter (VSI)
A. Six-Step VSI (4)

➢ **Line to line voltages (V_{ab}, V_{bc}, V_{ca}) and line to neutral voltages (V_{an}, V_{bn}, V_{cn})**

- **Line to line voltages**
  - ⇨ $V_{ab} = V_{aN} - V_{bN}$
  - ⇨ $V_{bc} = V_{bN} - V_{cN}$
  - ⇨ $V_{ca} = V_{cN} - V_{aN}$
- **Phase voltages**
  - ⇨ $V_{an} = 2/3V_{aN} - 1/3V_{bN} - 1/3V_{cN}$
  - ⇨ $V_{bn} = -1/3V_{aN} + 2/3V_{bN} - 1/3V_{cN}$
  - ⇨ $V_{cn} = -1/3V_{aN} - 1/3V_{bN} + 2/3V_{cN}$

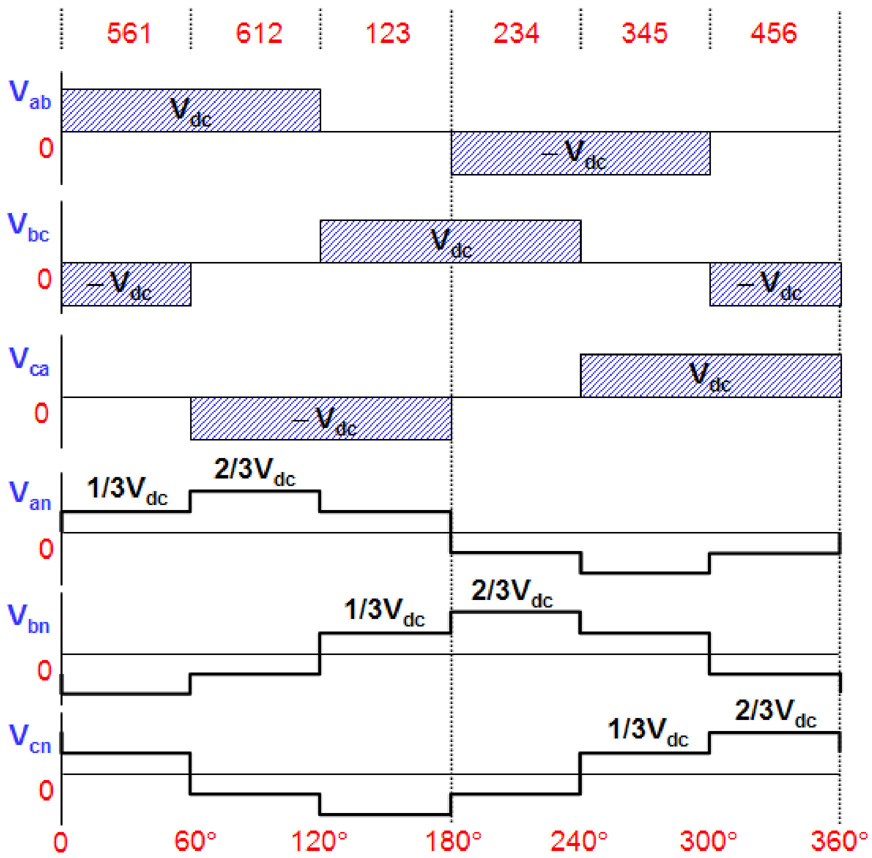

Fig. 4 Waveforms of line to neutral (phase) voltages and line to line voltages for six-step voltage source inverter.

I. Voltage Source Inverter (VSI)
A. Six-Step VSI (5)

- **Amplitude of line to line voltages (V_{ab}, V_{bc}, V_{ca})**

  - **Fundamental Frequency Component $(V_{ab})_1$**

$$(\mathbf{V_{ab}})_\mathbf{1}(\mathbf{rms}) = \frac{\sqrt{3}}{\sqrt{2}}\frac{4}{\pi}\frac{V_{dc}}{2} = \frac{\sqrt{6}}{\pi}V_{dc} \approx 0.78V_{dc}$$

  - **Harmonic Frequency Components $(V_{ab})_h$**

: amplitudes of harmonics decrease inversely proportional to their harmonic order

$$(\mathbf{V}_{ab})_\mathbf{h}(\mathbf{rms}) = \frac{0.78}{h}V_{dc}$$

where, $\mathrm{h} = 6\mathrm{n} \pm 1 \quad (\mathrm{n} = 1, 2, 3, ...)$

I. Voltage Source Inverter (VSI)
A. Six-Step VSI (6)

- **Characteristics of Six-step VSI**
  - **It is called "six-step inverter" because of the presence of six "steps" in the line to neutral (phase) voltage waveform**
  - **Harmonics of order three and multiples of three are absent from both the line to line and the line to neutral voltages and consequently absent from the currents**
  - **Output amplitude in a three-phase inverter can be controlled by only change of DC-link voltage (V_{dc})**

I. Voltage Source Inverter (VSI)
B. Pulse-Width Modulated VSI (1)

- **Objective of PWM**
  - **Control of inverter output voltage**
  - **Reduction of harmonics**

- **Disadvantages of PWM**
  - **Increase of switching losses due to high PWM frequency**
  - **Reduction of available voltage**
  - **EMI problems due to high-order harmonics**

I. Voltage Source Inverter (VSI)
B. Pulse-Width Modulated VSI (2)

➢ **Pulse-Width Modulation (PWM)**

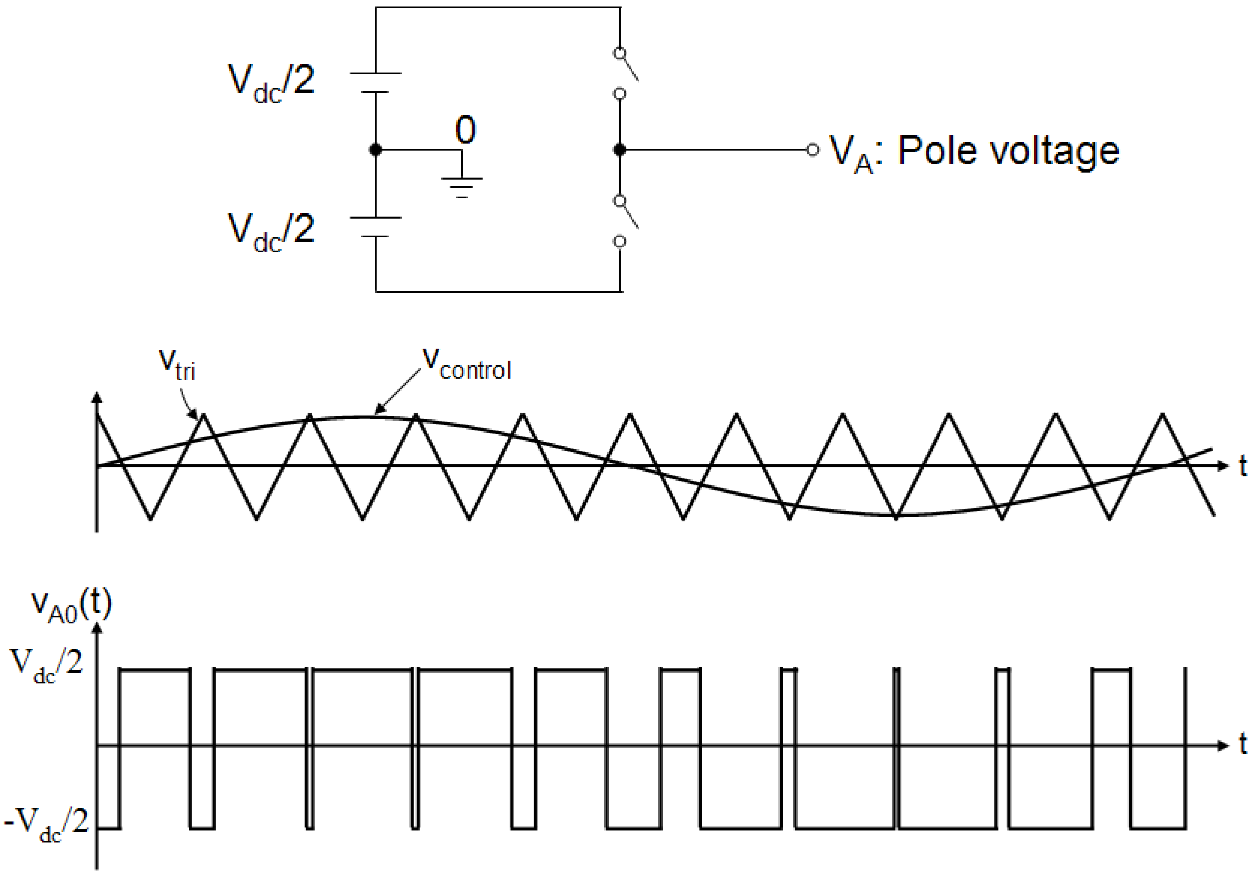

Fig. 5 Pulse-width modulation.

I. Voltage Source Inverter (VSI)

B. Pulse-Width Modulated VSI (3)

- **Inverter output voltage**
  - **When $v_{control} > v_{tri}$, $V_{A0} = V_{dc}/2$**
  - **When $v_{control} < v_{tri}$, $V_{A0} = -V_{dc}/2$**
- **Control of inverter output voltage**
  - **PWM frequency is the same as the frequency of v_{tri}**
  - **Amplitude is controlled by the peak value of $v_{control}$**
  - **Fundamental frequency is controlled by the frequency of $v_{control}$**
- **Modulation Index (m)**

$$\therefore m = \frac{v_{control}}{v_{tri}} = \frac{peak \quad of \quad (V_{A0})_1}{V_{dc}/2},$$

where, $(\mathrm{V}_{A0})_1$: fundamental frequecny component of V_{A0}

II. PWM METHODS

A. Sine PWM (1)

➢ **Three-phase inverter**

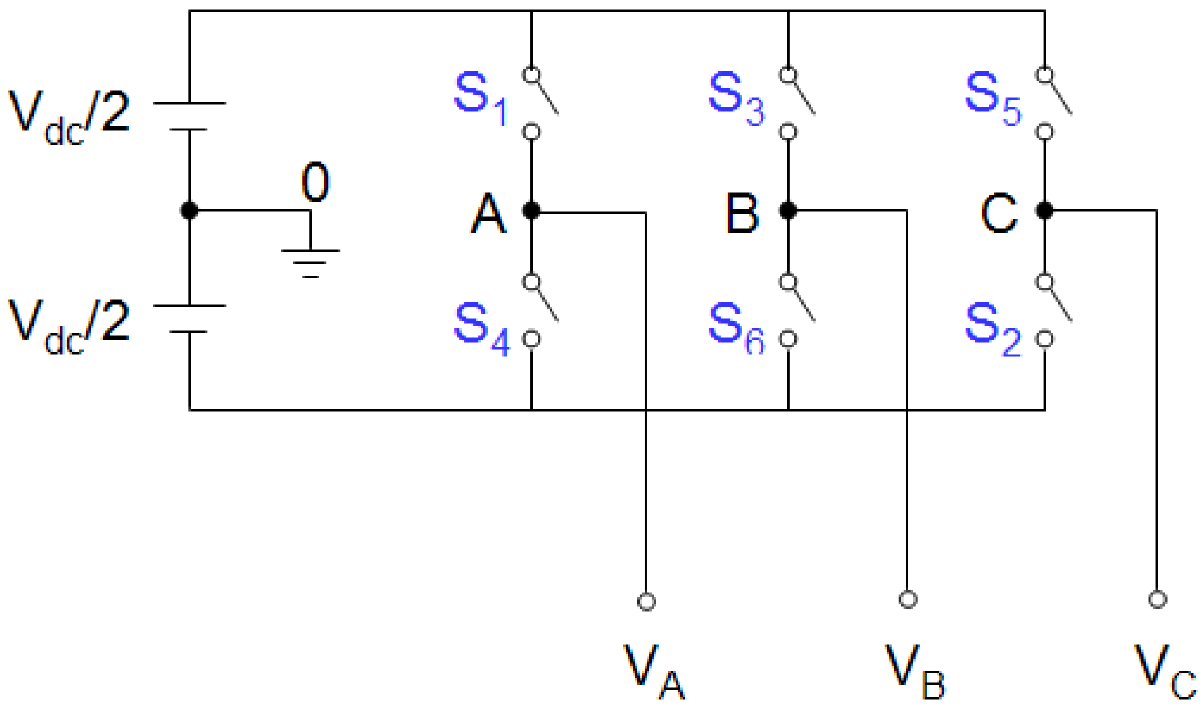

Fig. 6 Three-phase Sine PWM inverter.

II. PWM METHODS
A. Sine PWM (2)

➢ **Three-phase sine PWM waveforms**

- **Frequency of v_{tri} and $v_{control}$**
  - ⇨ **Frequency of $v_{tri} = f_s$**
  - ⇨ **Frequency of $v_{control} = f_1$**

where, f_s = PWM frequency
f_1 = Fundamental frequency

- **Inverter output voltage**
  - ⇨ **When $v_{control} > v_{tri}$, $V_{A0} = V_{dc}/2$**
  - ⇨ **When $v_{control} < v_{tri}$, $V_{A0} = -V_{dc}/2$**

where, $V_{AB} = V_{A0} - V_{B0}$
$V_{BC} = V_{B0} - V_{C0}$
$V_{CA} = V_{C0} - V_{A0}$

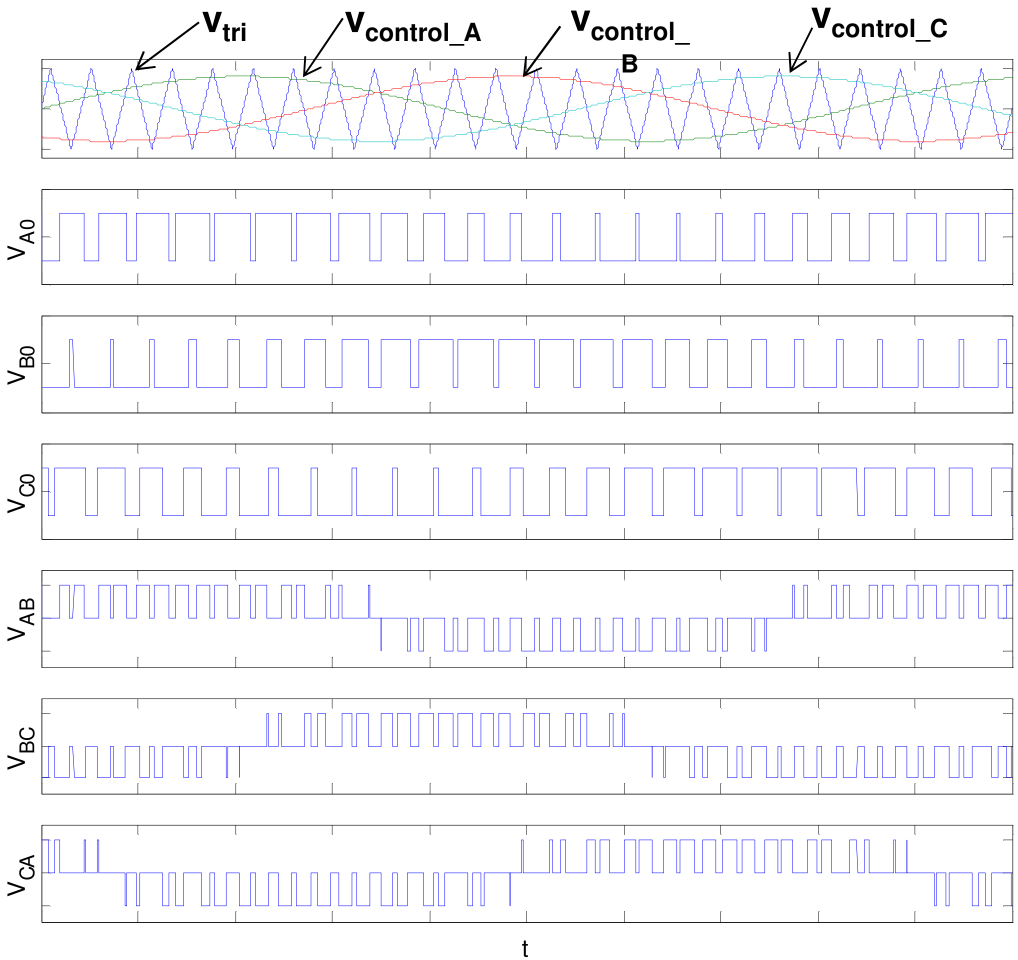

Fig. 7 Waveforms of three-phase sine PWM inverter.

II. PWM METHODS
A. Sine PWM (3)

➢ **Amplitude modulation ratio (m_a)**

$$\therefore m_a = \frac{peak \quad amplitude \quad of \quad v_{control}}{amplitude \quad of \quad v_{tri}} = \frac{peak \quad value \quad of \quad (V_{A0})_1}{V_{dc}/2},$$

where, $(V_{A0})_1$: fundamental frequecny component of V_{A0}

$$U_{ab1,rms} = m_a \frac{U_i}{2}\sqrt{\frac{3}{2}},\ U_i = 0{,}95 U_{i,rms}\sqrt{2},\ U_{i,rms} \text{ the rms line voltage value (phase or phase to phase)}$$

➢ **Frequency modulation ratio (m_f)**

$$m_f = \frac{f_s}{f_1}, \quad \text{where, } f_s = \text{PWM frequency and } f_1 = \text{fundamental frequency}$$

- **m_f should be an odd integer**
  - ⇨ **if m_f is not an integer, there may exist sunhamonics at output voltage**
  - ⇨ **if m_f is not odd, DC component may exist and even harmonics are present at output voltage**
- **m_f should be a multiple of 3 for three-phase PWM inverter**
  - ⇨ **An odd multiple of 3 and even harmonics are suppressed**

II. PWM METHODS

B. Hysteresis (Bang-bang) PWM (1)

➢ **Three-phase inverter for hysteresis Current Control**

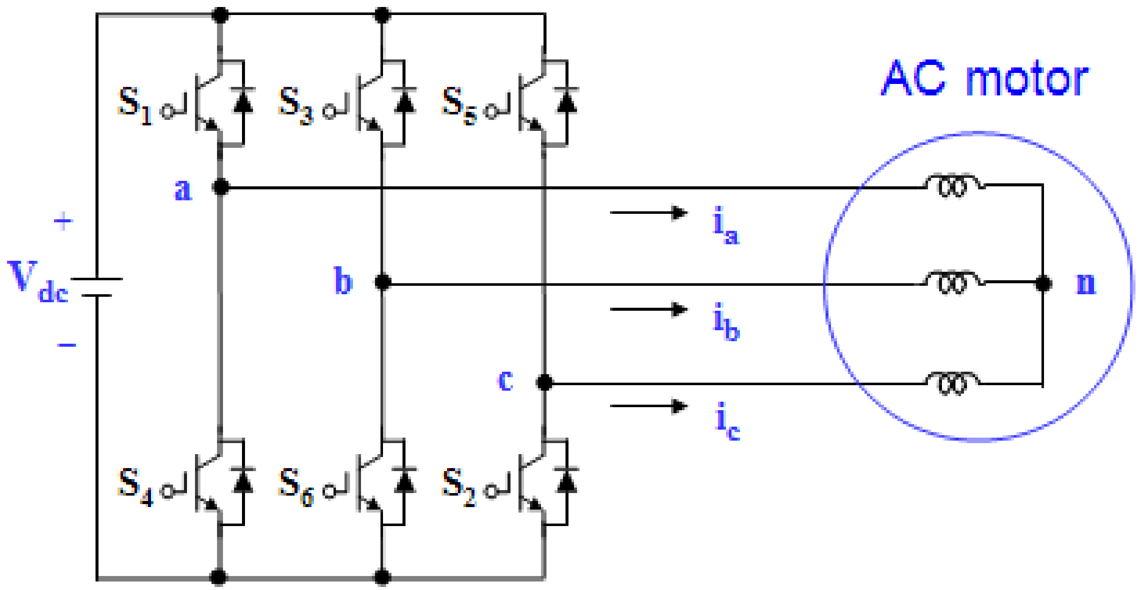

Fig. 8 Three-phase inverter for hysteresis current control.

II. PWM METHODS

B. Hysteresis (Bang-bang) PWM (2)

➢ **Hysteresis Current Controller**

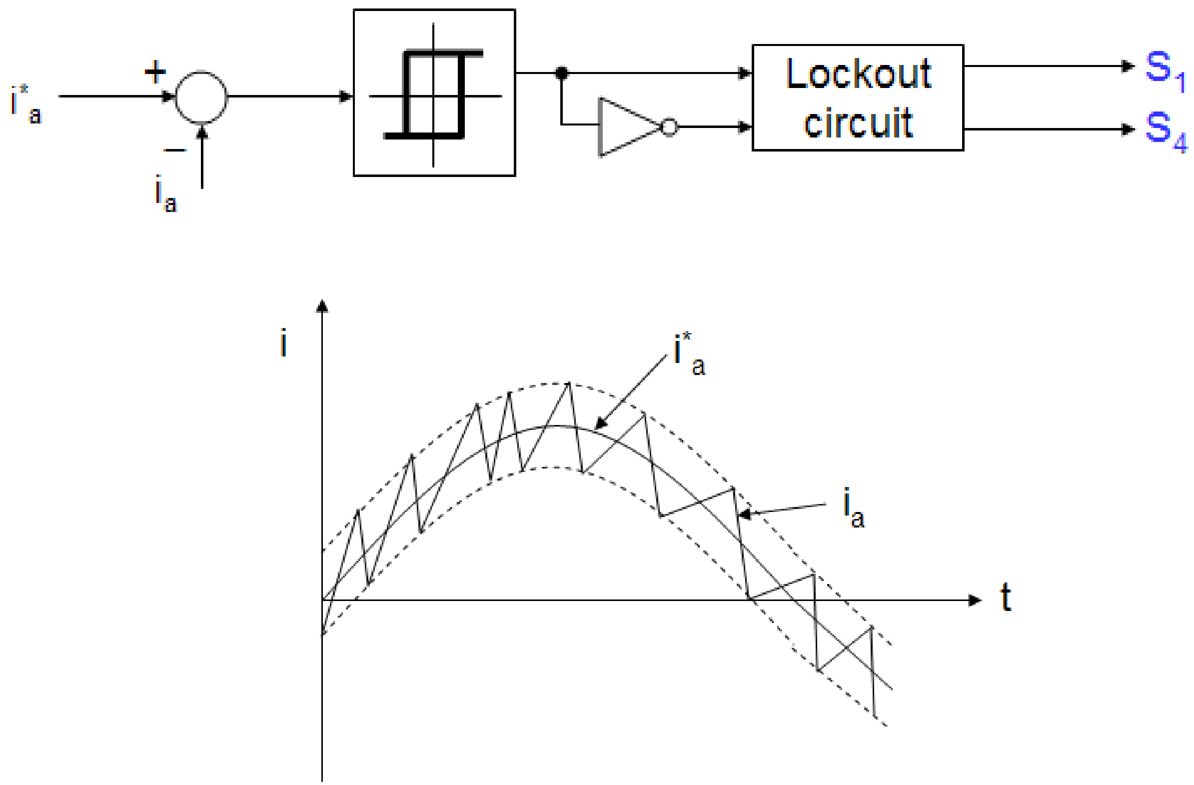

Fig. 9 Hysteresis current controller at Phase "a".

II. PWM METHODS
B. Hysteresis (Bang-bang) PWM (3)

- Characteristics of hysteresis Current Control

  - **Advantages**

    ⇨ Excellent dynamic response

    ⇨ Low cost and easy implementation

  - **Drawbacks**

    ⇨ Large current ripple in steady-state

    ⇨ Variation of switching frequency

    ⇨ No intercommunication between each hysterisis controller of three phases and hence no strategy to generate zero-voltage vectors.
    As a result, the switching frequency increases at lower modulation index and the signal will leave the hysteresis band whenever the zero vector is turned on.

    ⇨ The modulation process generates subharmonic components