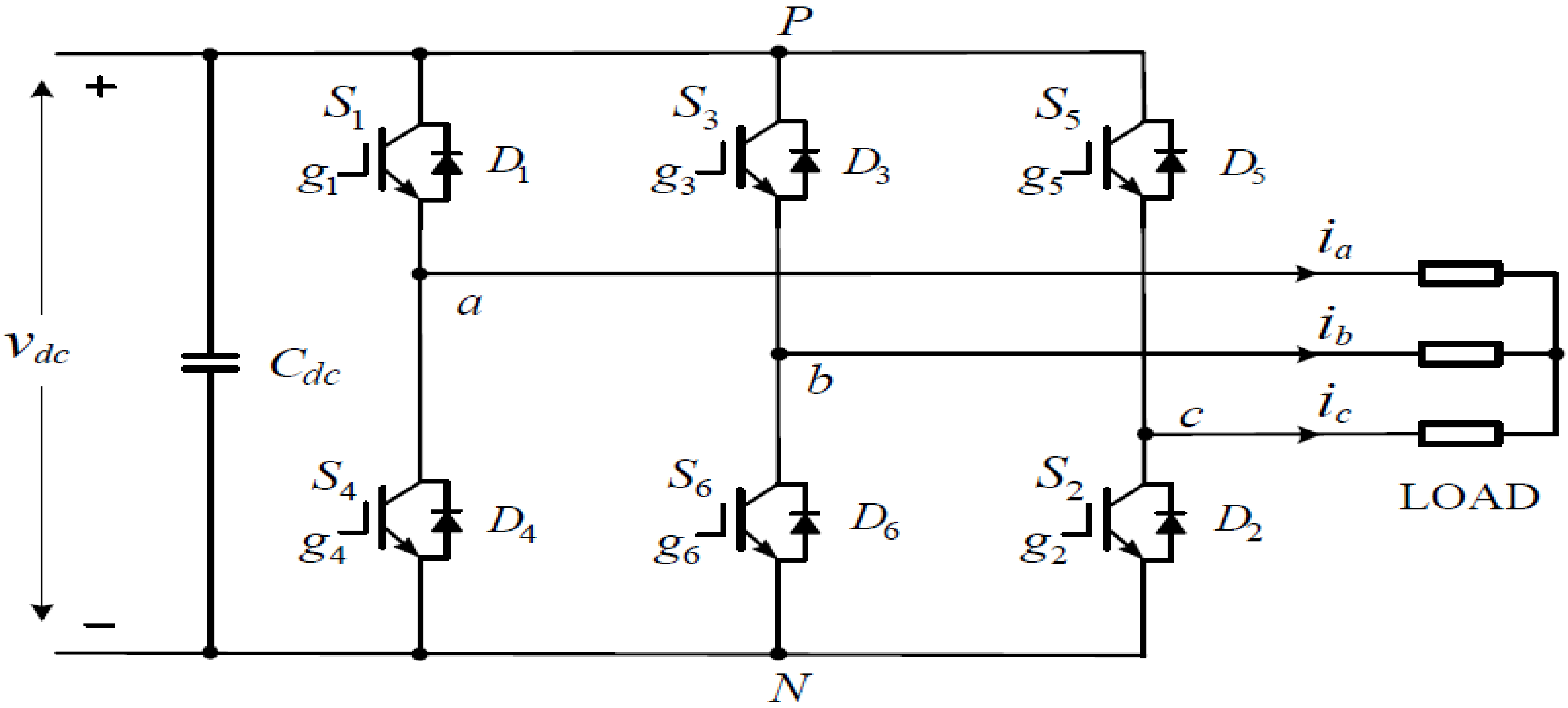
Lecture#

4.4 Two-Level Voltage Source Converters

4.4.1 Sinusoidal PWM

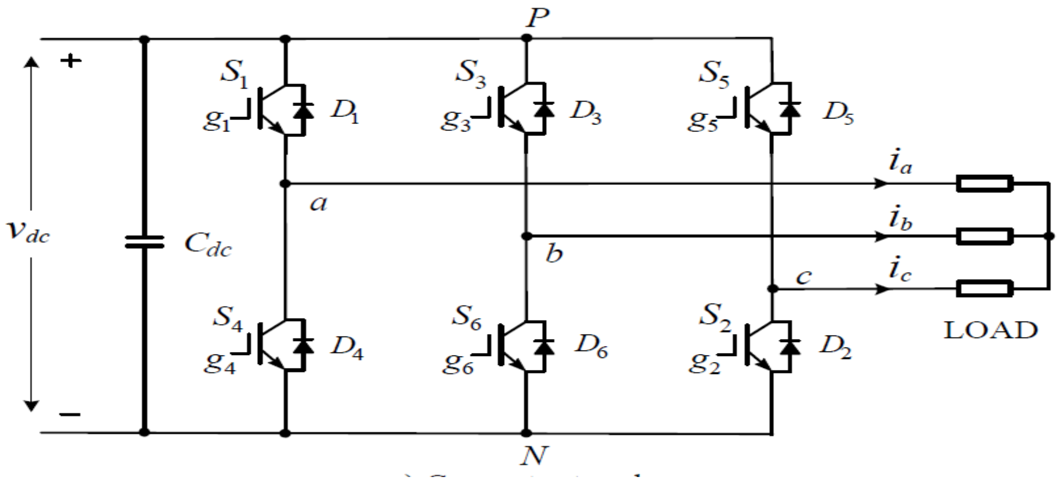
4.4 Two-Level Voltage Source Converters

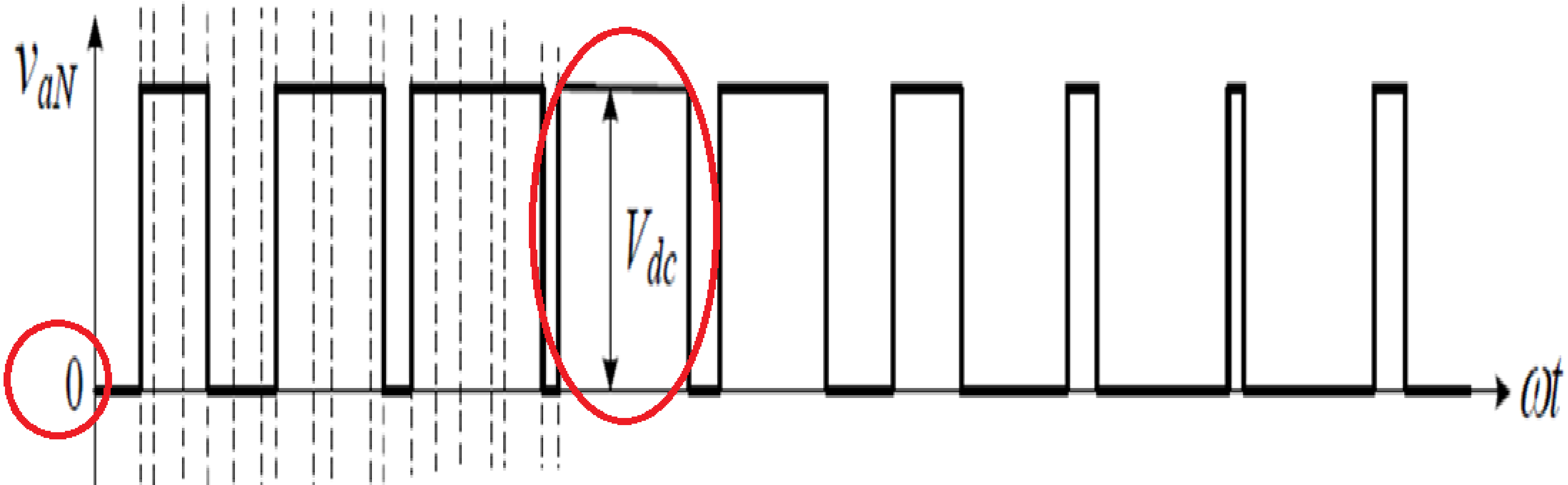
Simplified circuit diagram for 3-phase 2-level voltage source converter.



Q. What is meant by 2-level?

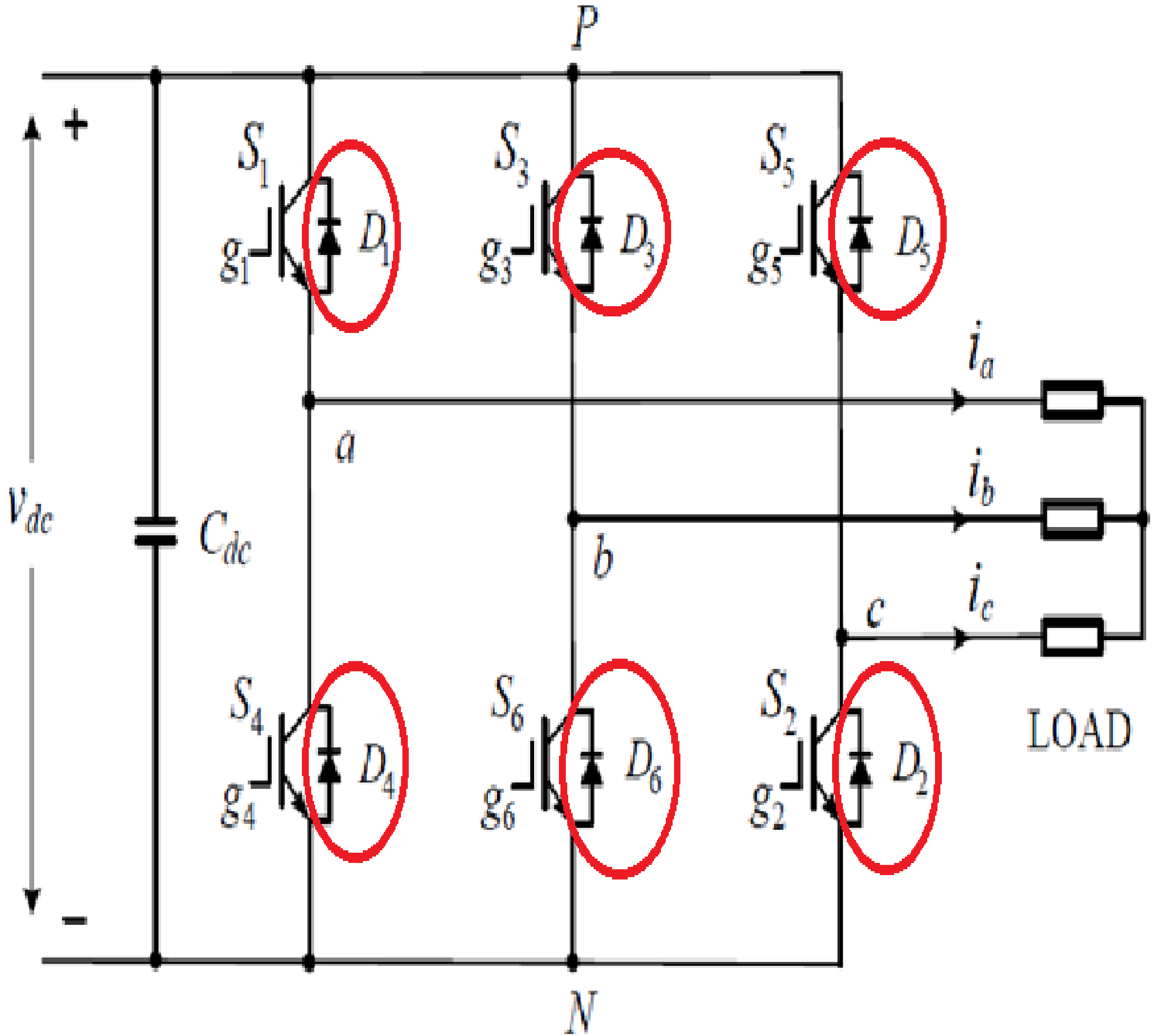
Waveform of v_{aN} will have only 2 levels, (i)Vdc & (ii)0





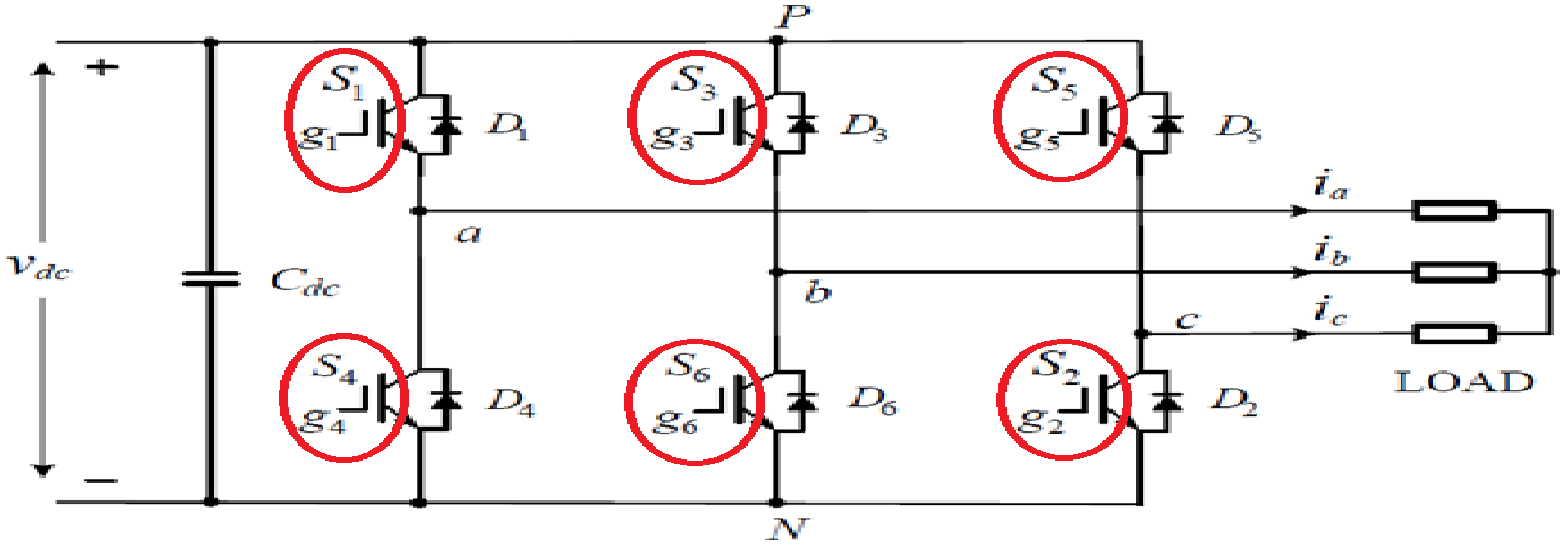
Composition of 2-Level Voltage Source Converters

- Converter is composed of 6 switches, $S1 \sim S6$,
- with an anti-parallel free-wheeling diode with each switch.



Switches of 2-Level Voltage Source Converters

- Switches can be IGBT or IGCT devices, depending on power & voltage ratings of converter.

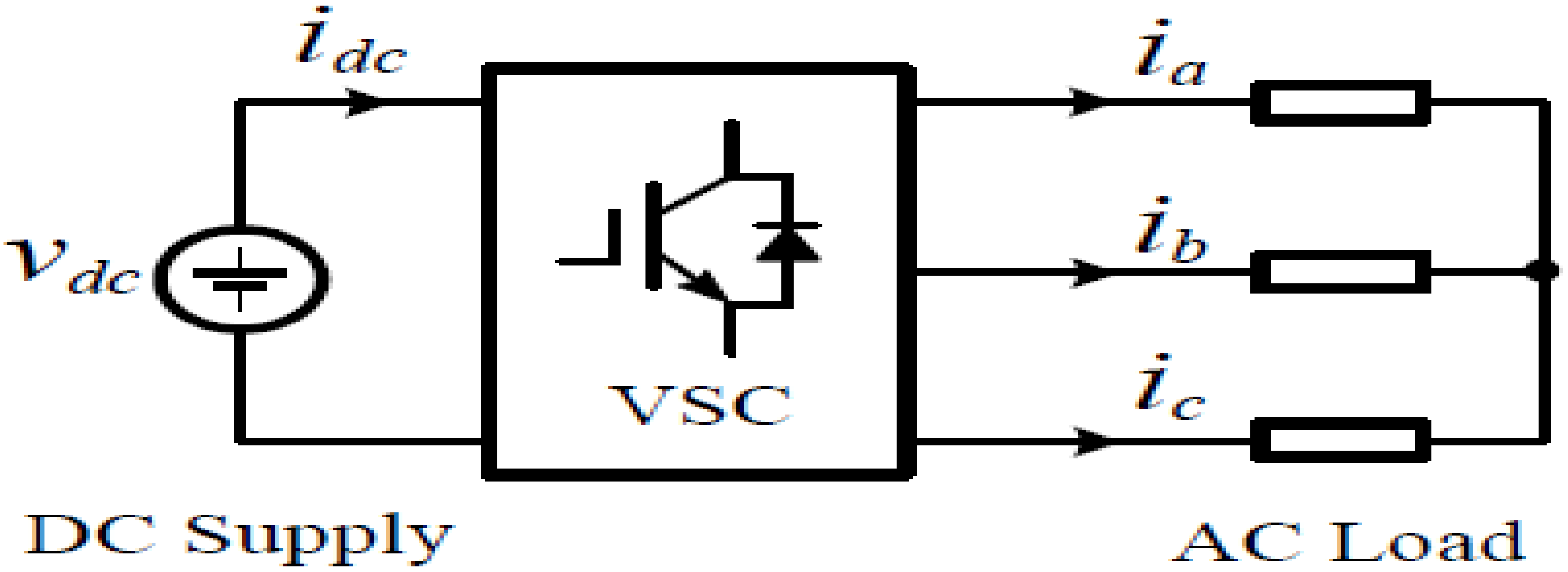


What are IGBT or IGCT devices?

IGBT Vs IGCT

- In industrial applications, Insulated Gate Bipolar Transistor (**IGBT**) is favourable. **IGBT** is a voltage controlled **device**, hence it requires less gate drive power, thus simplifies gate driver design.
- Integrated gate-commutated thyristor (**IGCT**)…….Low losses, small size, reliable, modular & cost-effective — uncompromising implementation of IGCT technology creates medium voltage converters with entirely new characteristics

Converter has been widely used in industry for many different applications



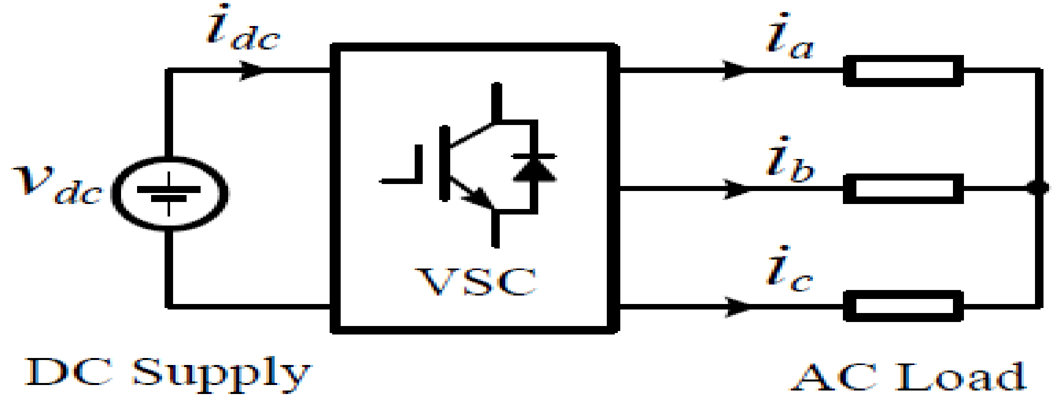
b) Inverter

Difference between inverter & rectifier?

Difference between inverter & rectifier

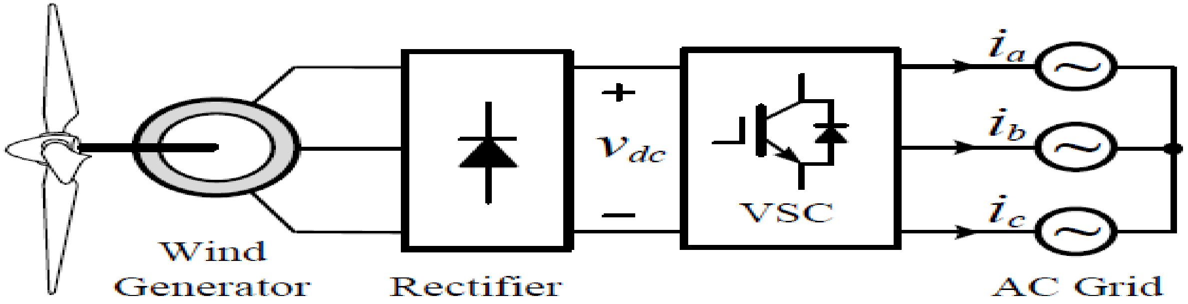
Inverter

When converter converts a fixed dc voltage to 3-phase ac voltage with variable magnitude & frequency for an ac load, it is called **inverter.**

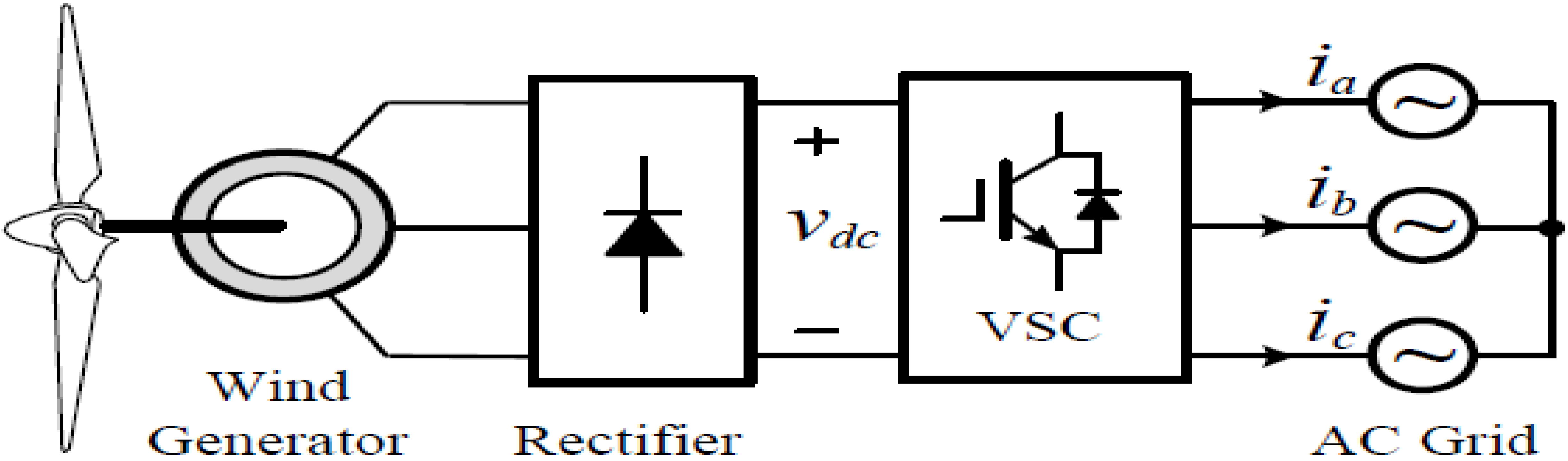


Rectifier

When converter converts an ac grid voltage with fixed magnitude & frequency to an adjustable dc voltage for a dc load, it is active rectifier or PWM rectifier.



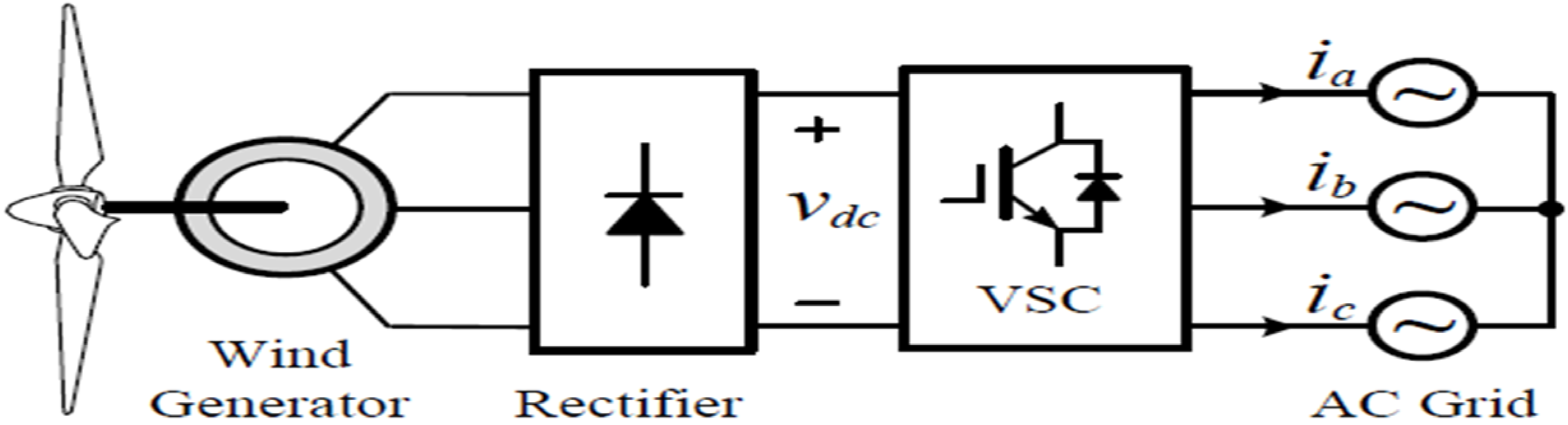
Whether it serves as an inverter or a rectifier, power flow in converter circuit is bidirectional: power can flow from its dc side to ac side, & vice versa.



d) Grid-tied Converter

In wind energy conversion systems, converter is connected to an electric grid & delivers power generated from generator to grid

- Converter in this application is referred to **as grid-connected or grid-tied converter**.



Grid-tied Converter

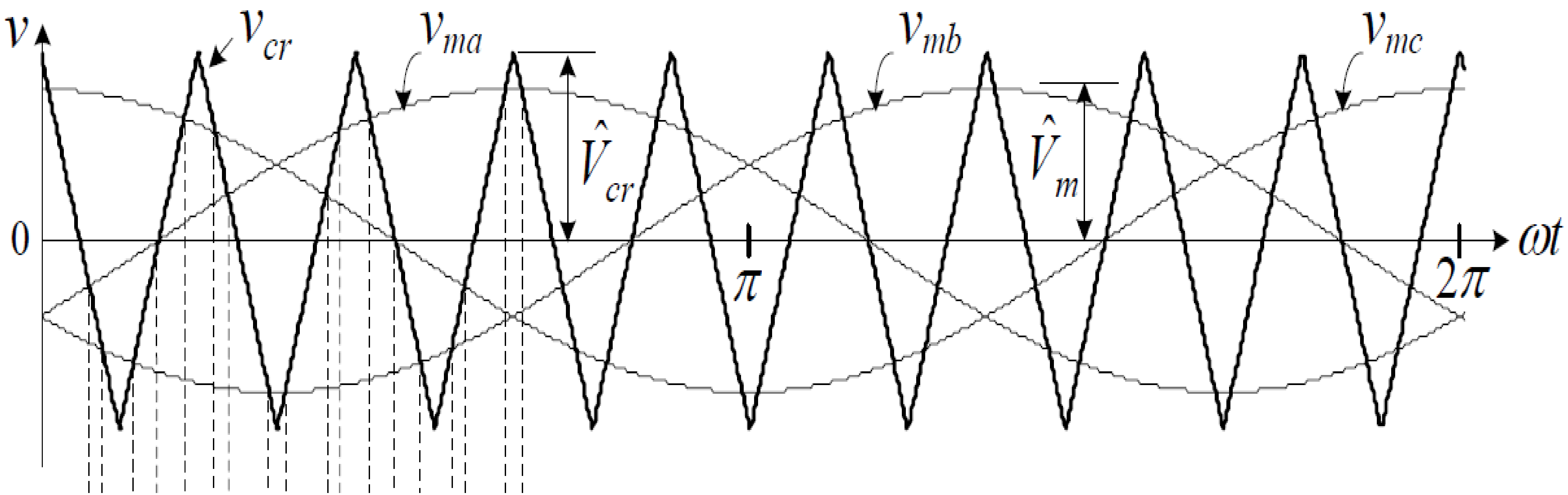
This section will focus on:

1. Pulse Width Modulation (PWM) schemes for 2-level voltage source converter.
2. An introduction to carrier based Sinusoidal PWM (SPWM) schemes,
3. Detailed analysis on Space Vector Modulation (SVM) algorithms.

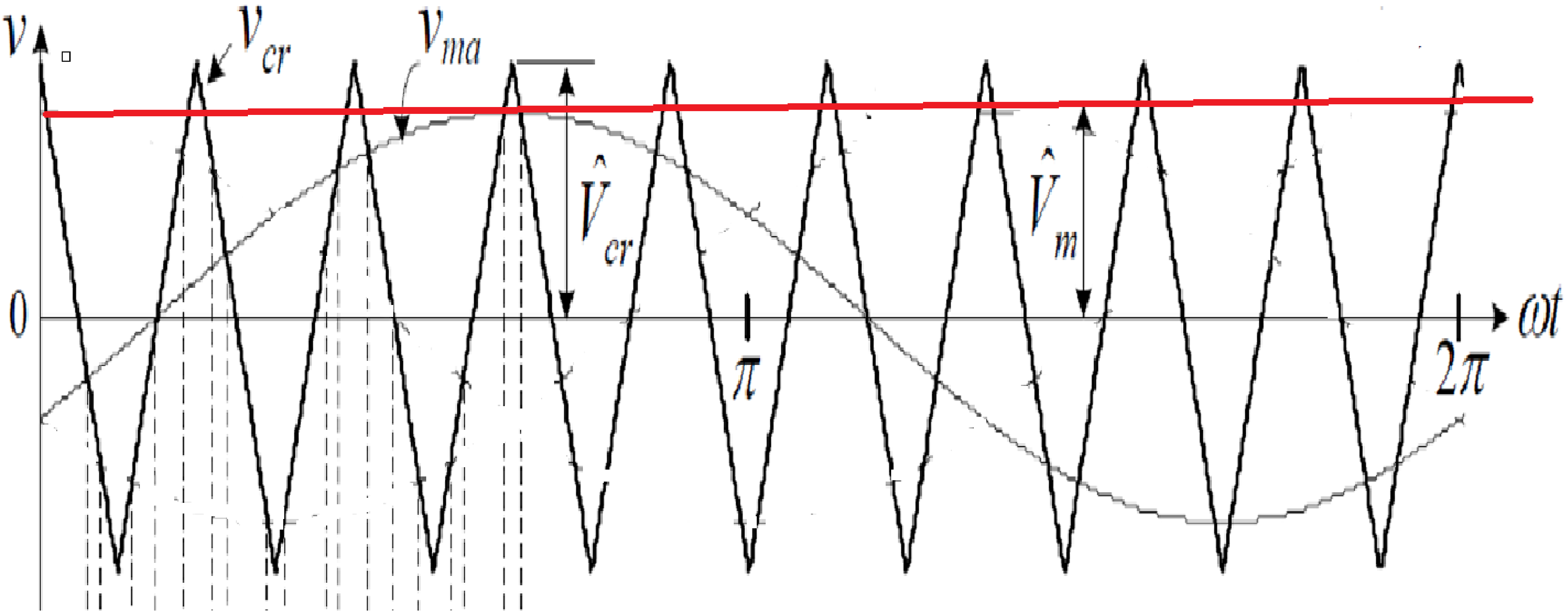
Sinusoidal PWM

Principle of sinusoidal PWM scheme for 2-level converter

- where v_{ma}, v_{mb} and v_{mc} are 3-phase sinusoidal modulating waves & v_{cr} is triangular carrier wave.



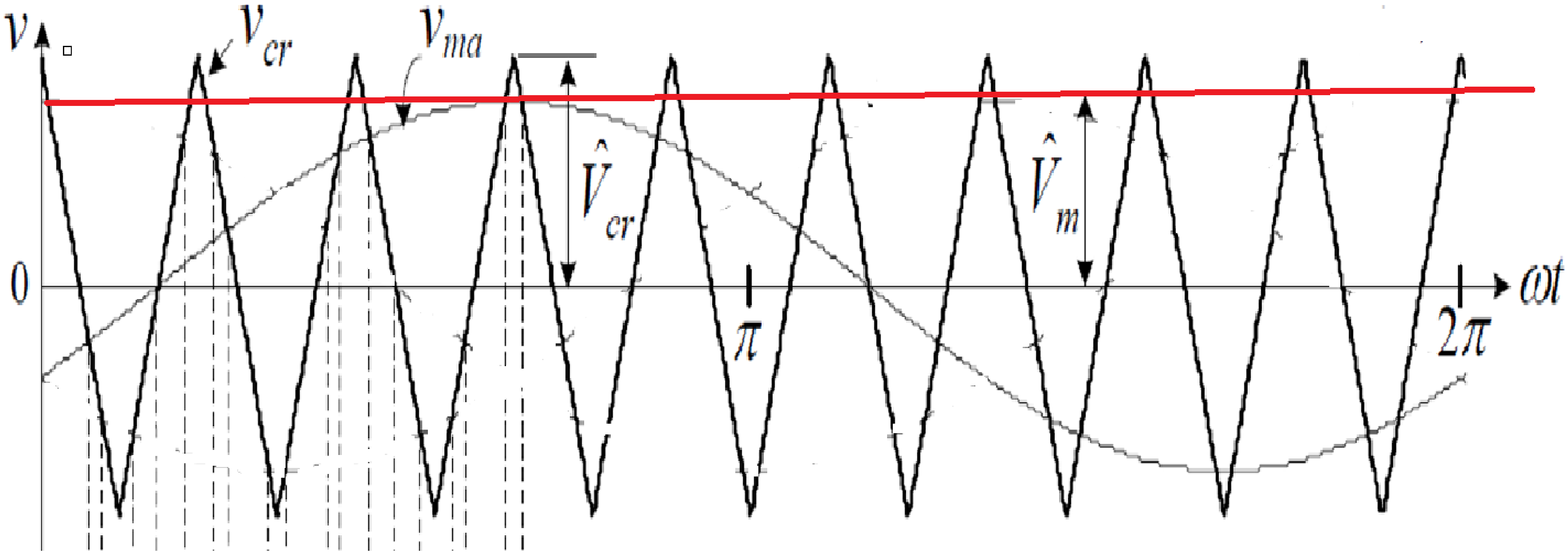
v_{ma} *is* 1-phase sinusoidal modulating wave and v_{cr} is triangular carrier wave.



Q. What is definition of Amplitude modulation index m_a.

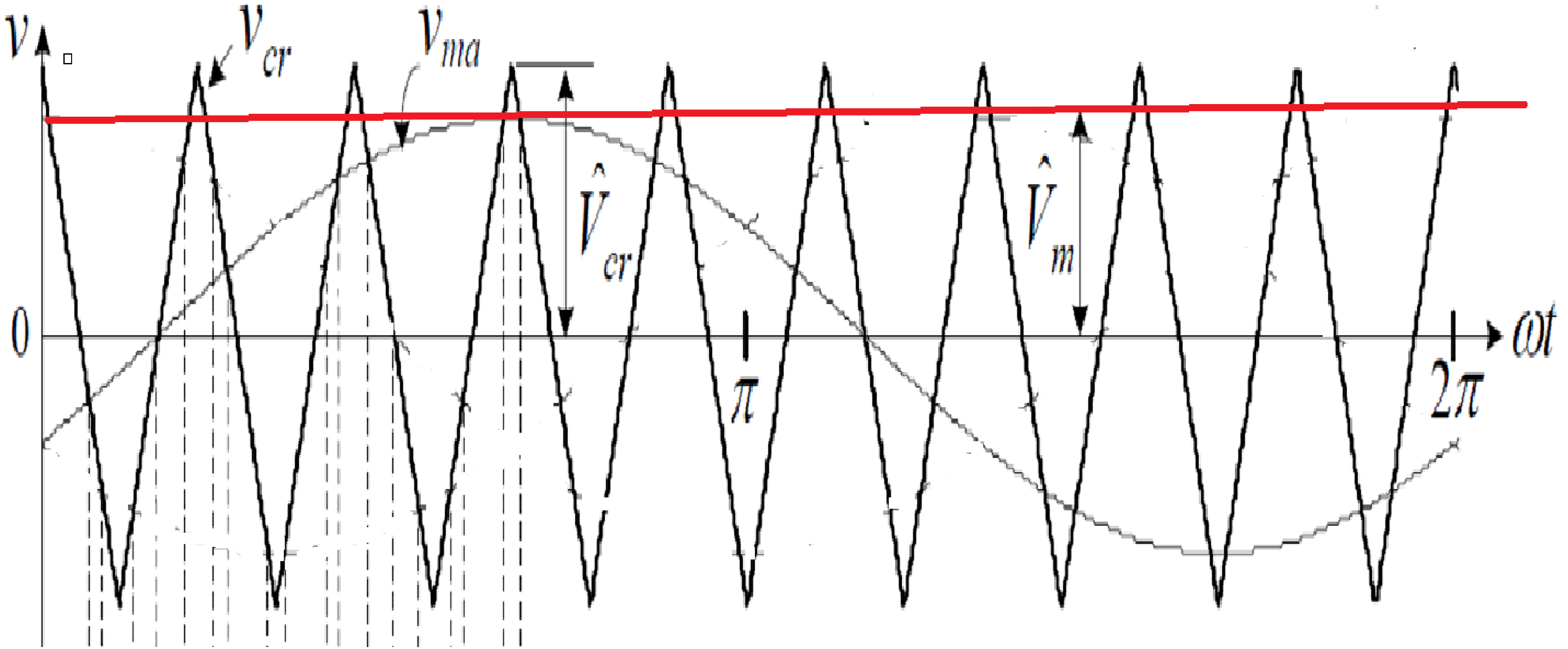
Amplitude modulation index m_a is ratio of modulating & carrier waves.

$$m_a = \frac{\hat{V}_m}{\hat{V}_{cr}}$$



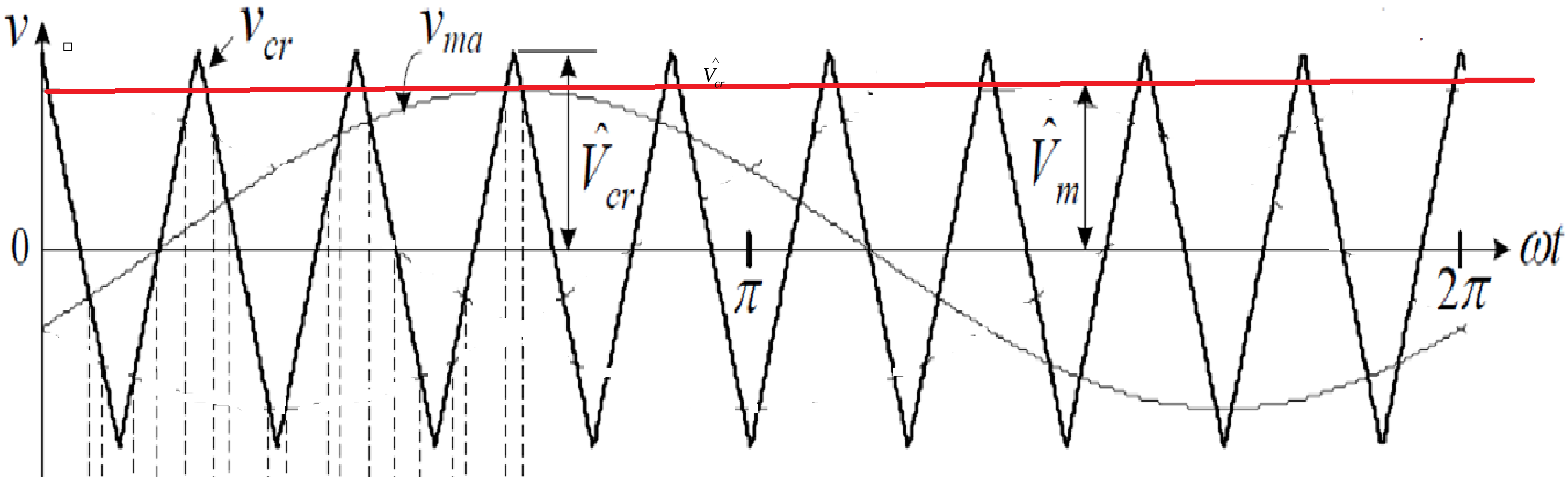
$\hat{V}m$ and $\hat{V}cr$ are peak values of modulating & carrier waves.

$$m_a = \frac{\hat{V}_m}{\hat{V}_{cr}}$$

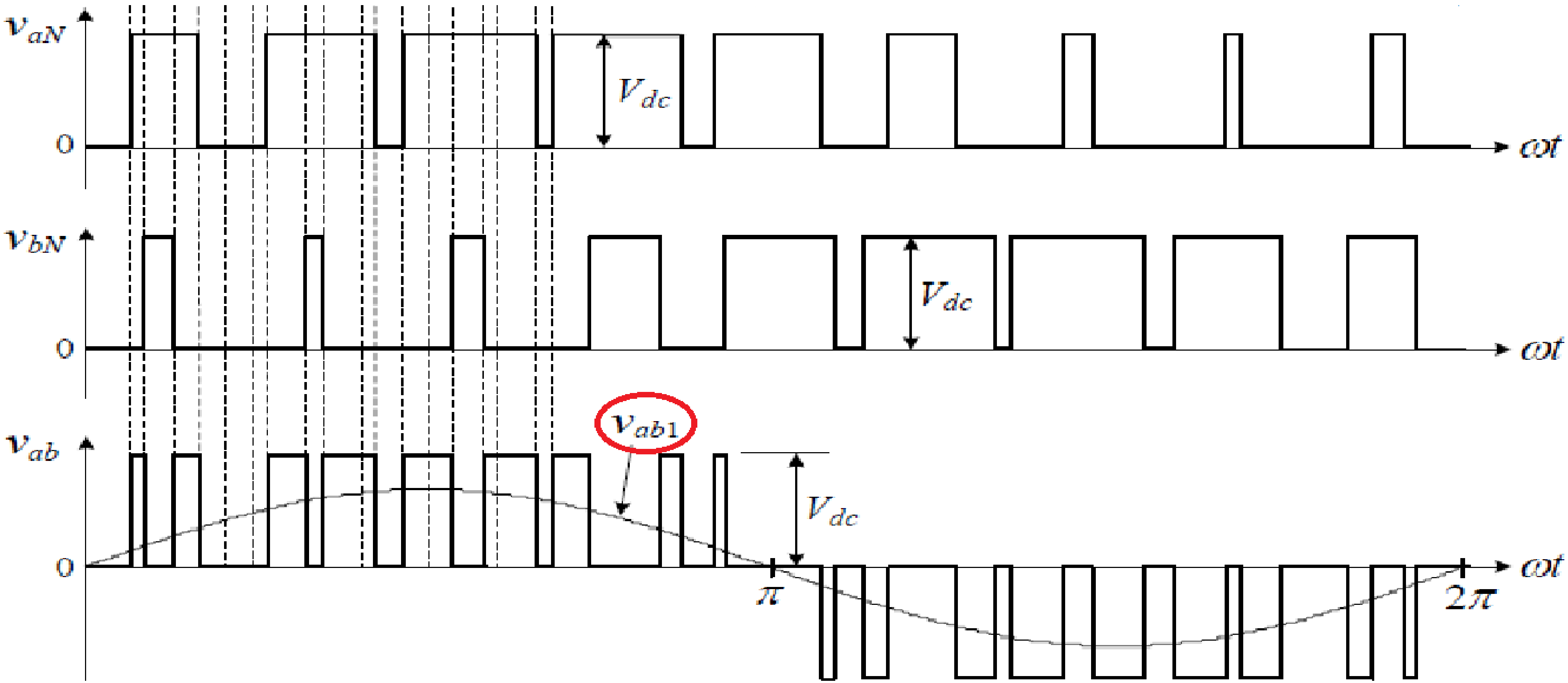


Amplitude modulation index ma is usually adjusted by varying $\hat{V}_m$ while keeping $\hat{V}_{cr}$ fixed.

$$m_a = \frac{\hat{V}_m}{\hat{V}_{cr}}$$



Fundamental-frequency component in inverter output voltage v_{ab1} can be controlled by amplitude modulation index m_a.



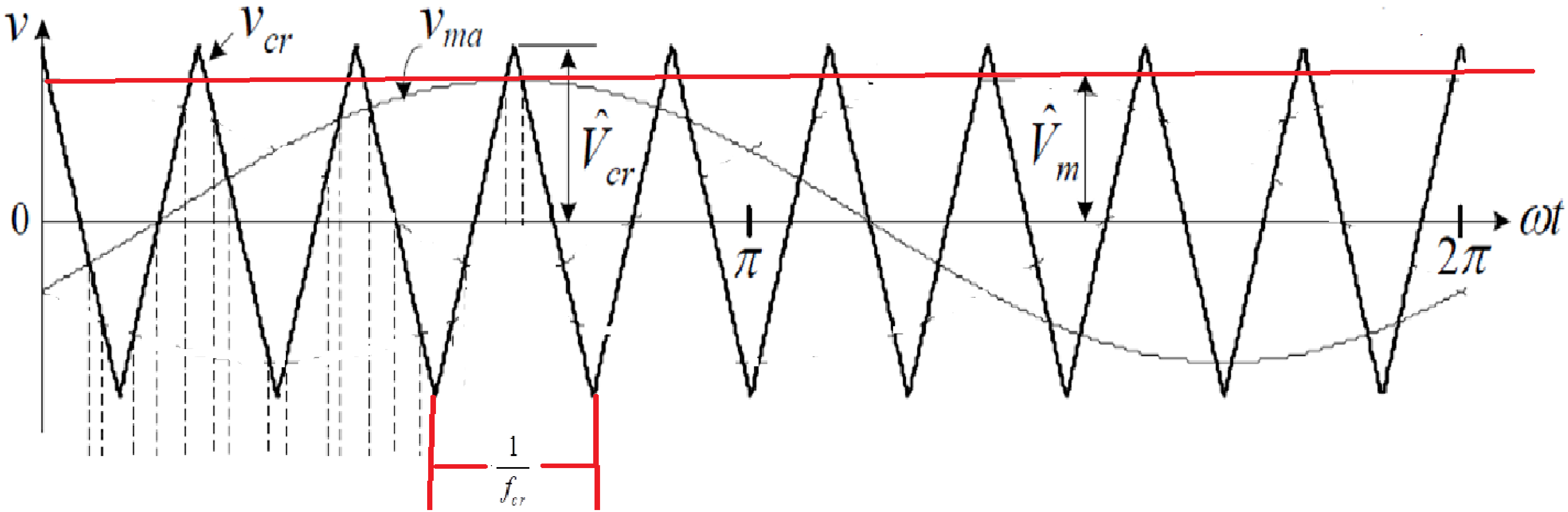
$$m_a = \frac{\hat{V}_m}{\hat{V}_{cr}}$$

Frequency modulation index m_f ?

Frequency modulation index m_f

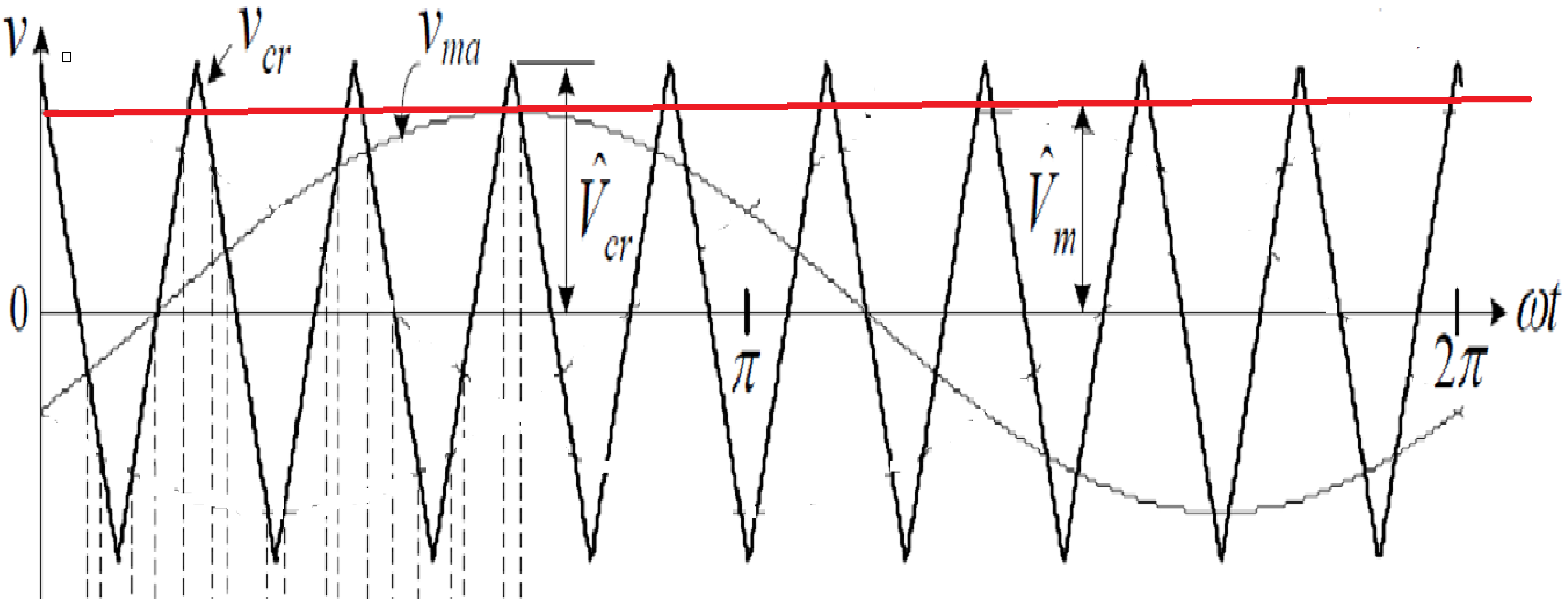
$$m_f = \frac{f_{cr}}{f_m}$$

- *fm & fcr* are frequencies of modulating and carrier waves respectively.

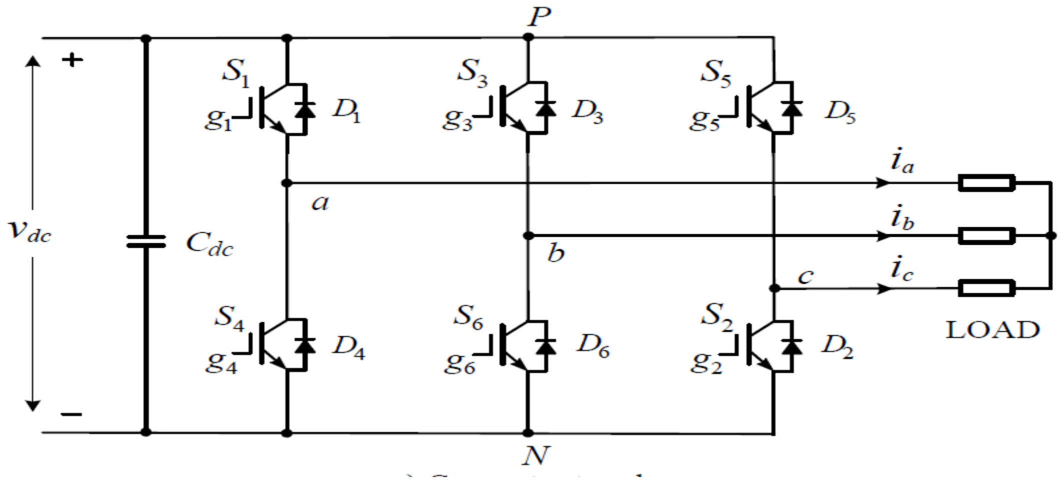


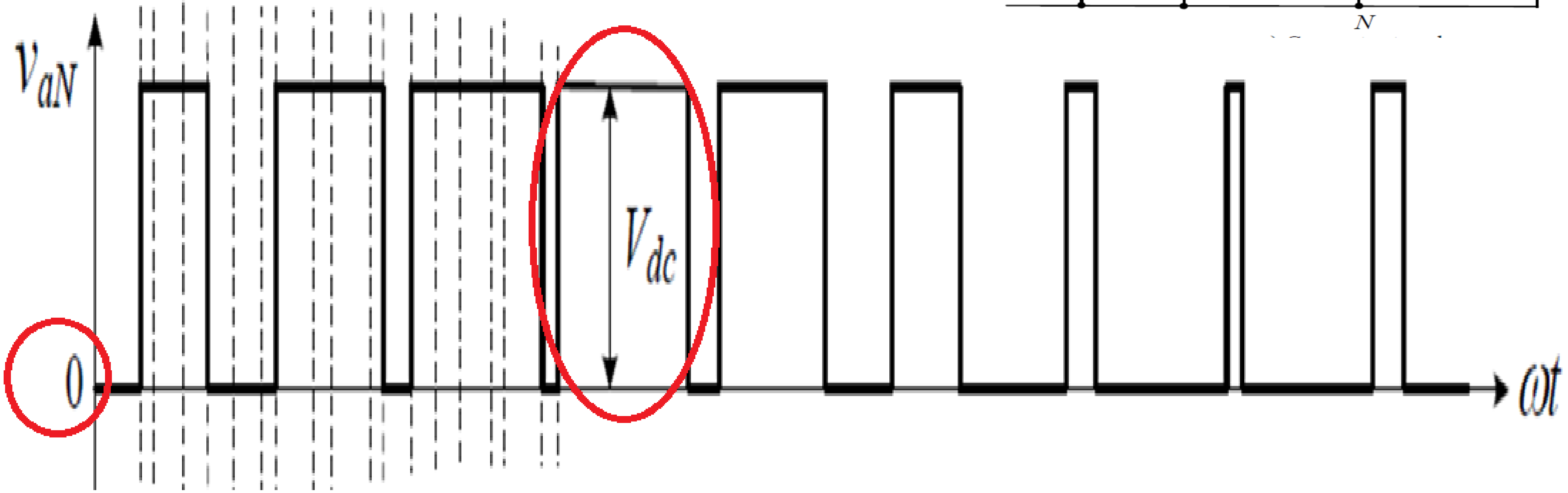
Operation of switches $S1$ to $S6$ can be determined:

- By comparing modulating waves with carrier wave.

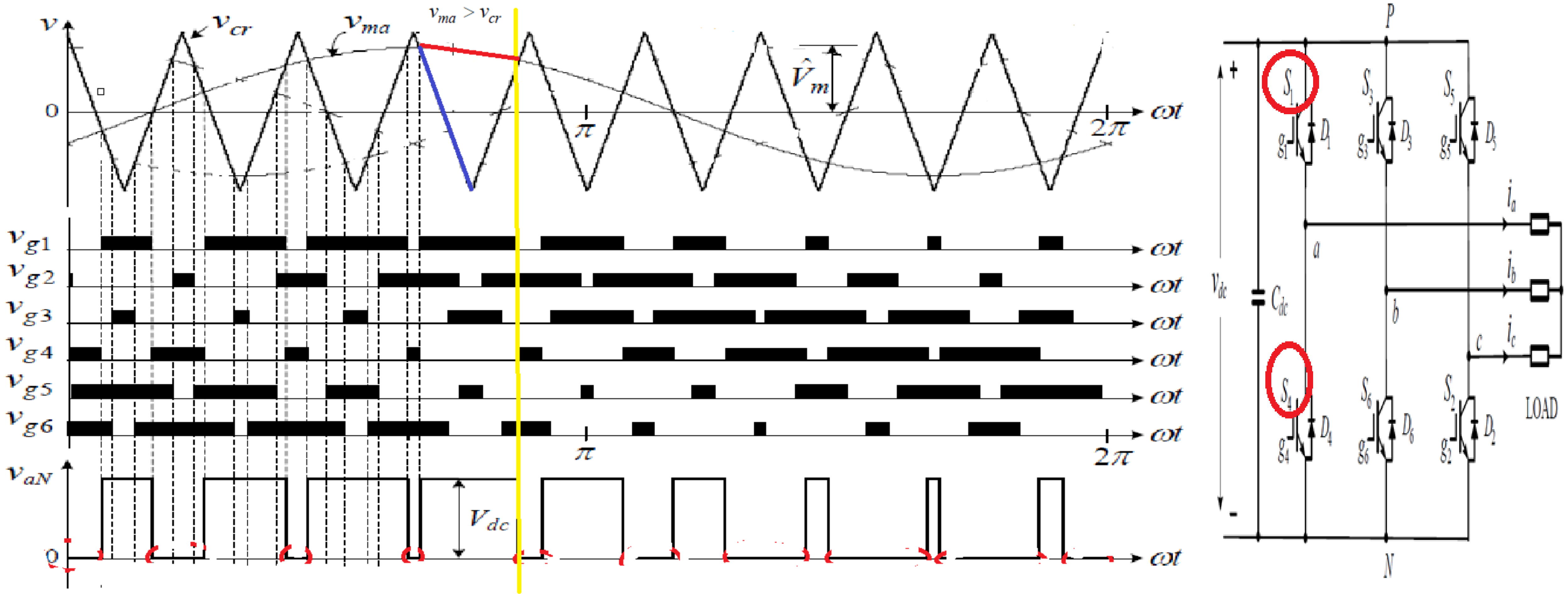


When inverter terminal voltage v_{aN} is equal to the dc voltage vdc viz. ***VaN= Vdc?***

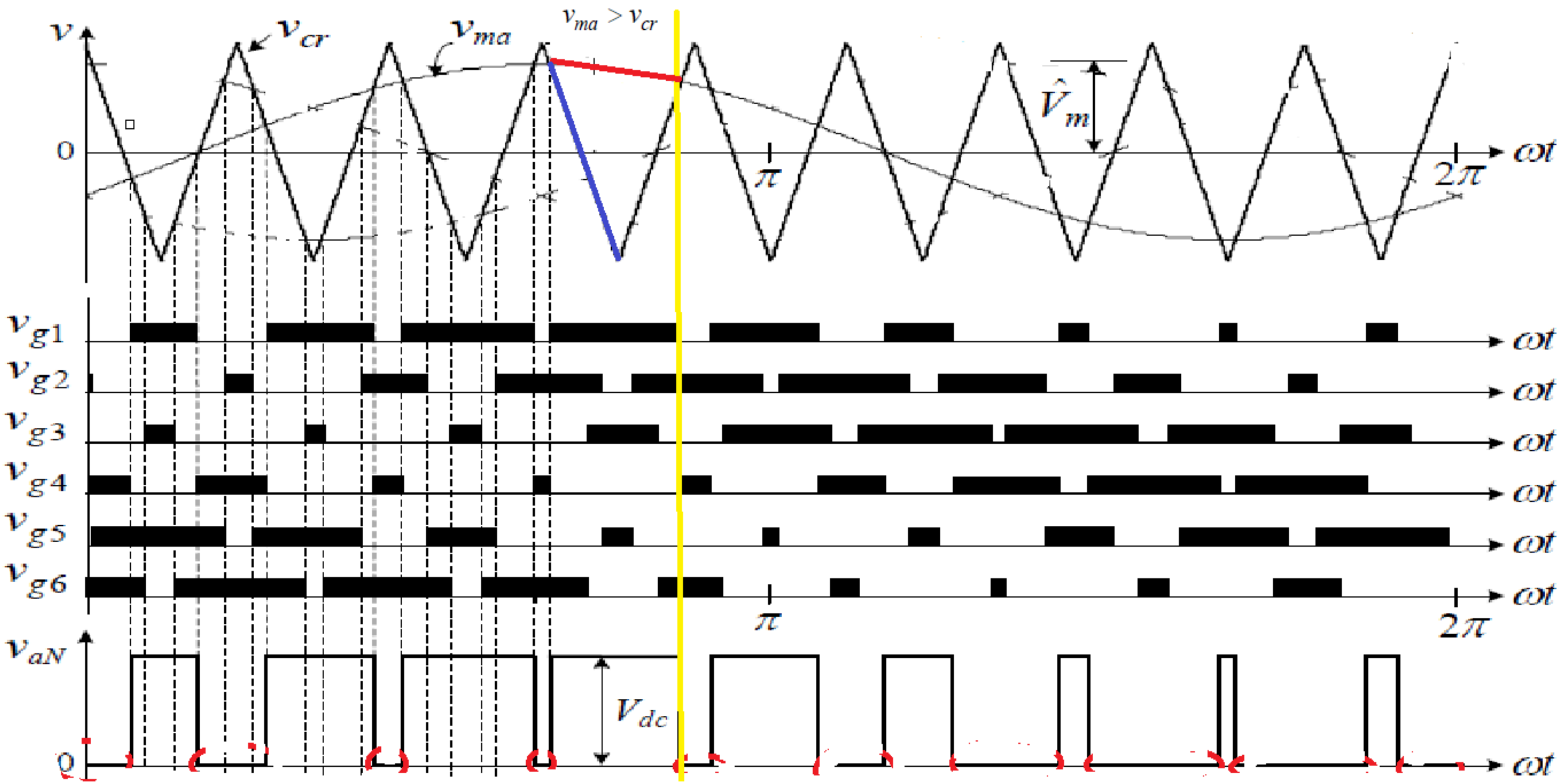


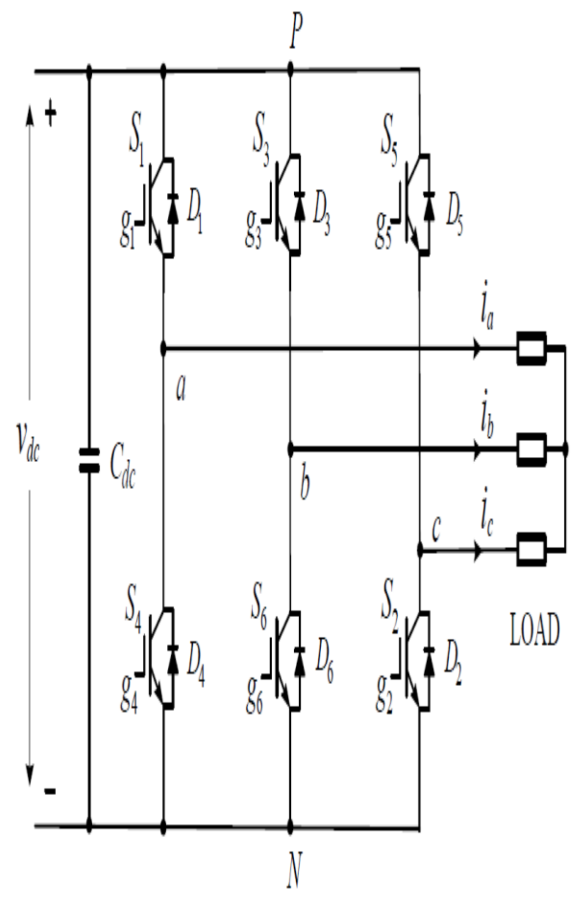


When $v_{ma} > v_{cr}$, upper switch $S1$ in inverter leg a is turned on. Lower switch $S4$ operates in a complementary manner & thus is switched off.



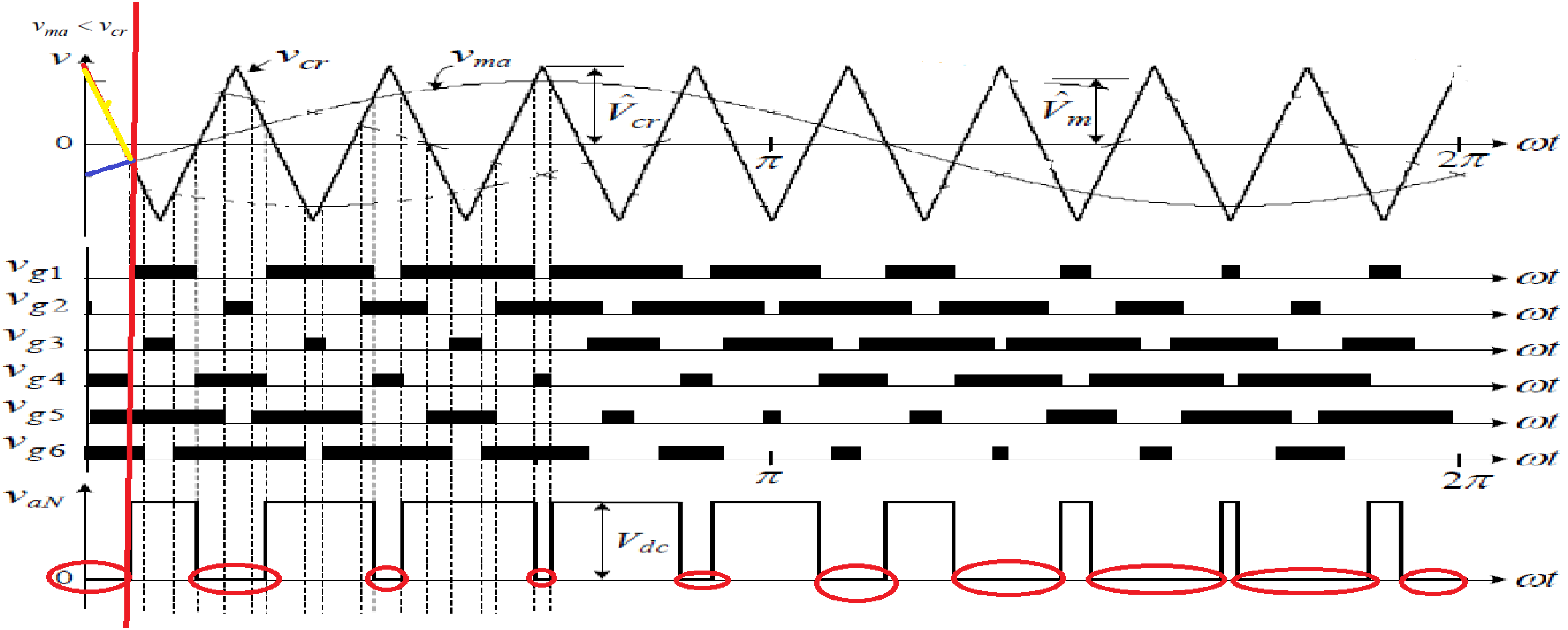
Resultant inverter terminal voltage v_{aN} , which is voltage at phase-*a* terminal w.r.t -ve dc bus *N*, is equal to dc voltage *Vdc* .





Q. When inverter terminal voltage $v_{aN}=0$

When $v_{ma} < v_{cr}$, S_4 is on & S_1 is off, leading to $v_{aN} = 0$



What is Blanking time?

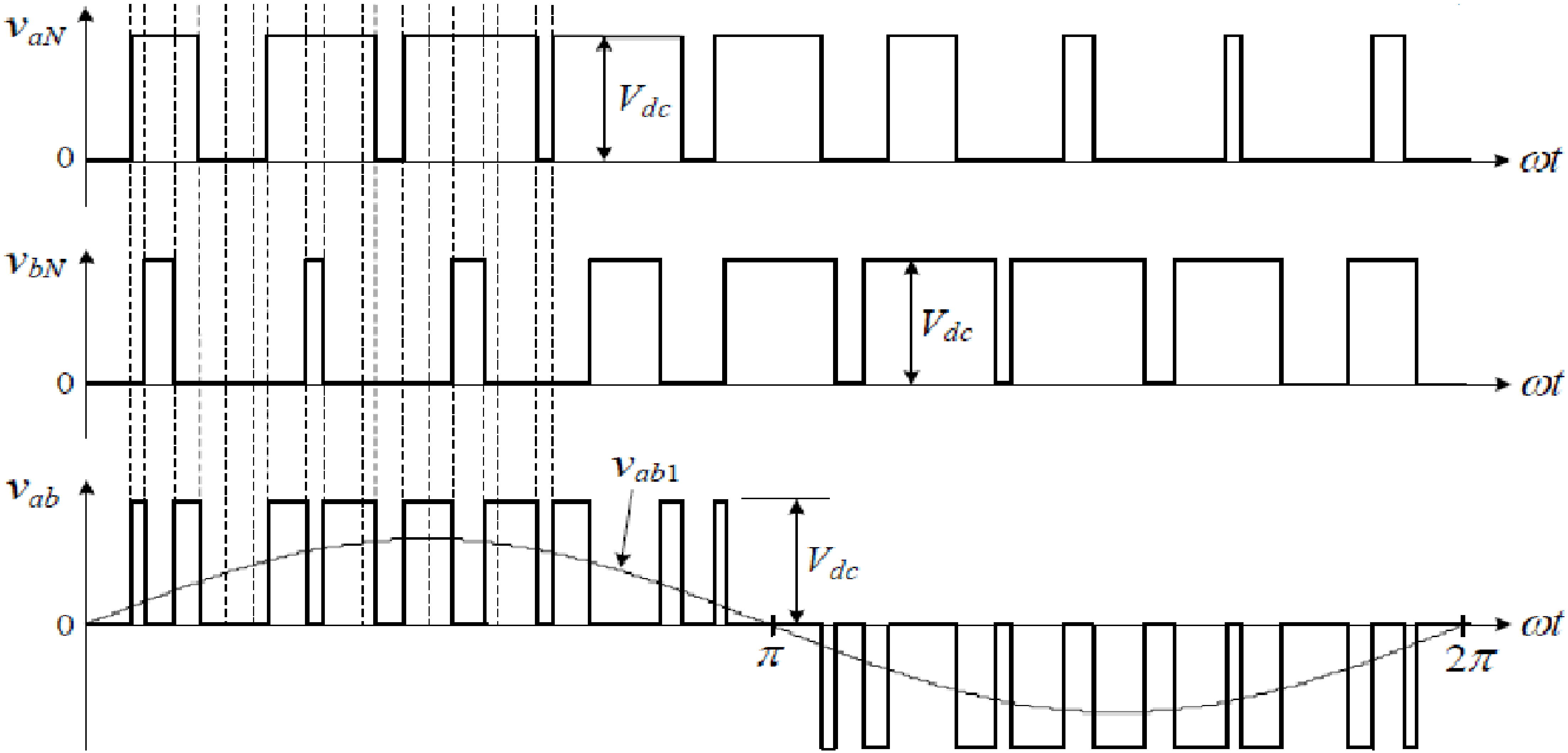
Blanking time

- To avoid possible short circuit during switching transients of upper & lower devices in an inverter leg,
- a blanking time should be implemented, during which both switches are turned off.

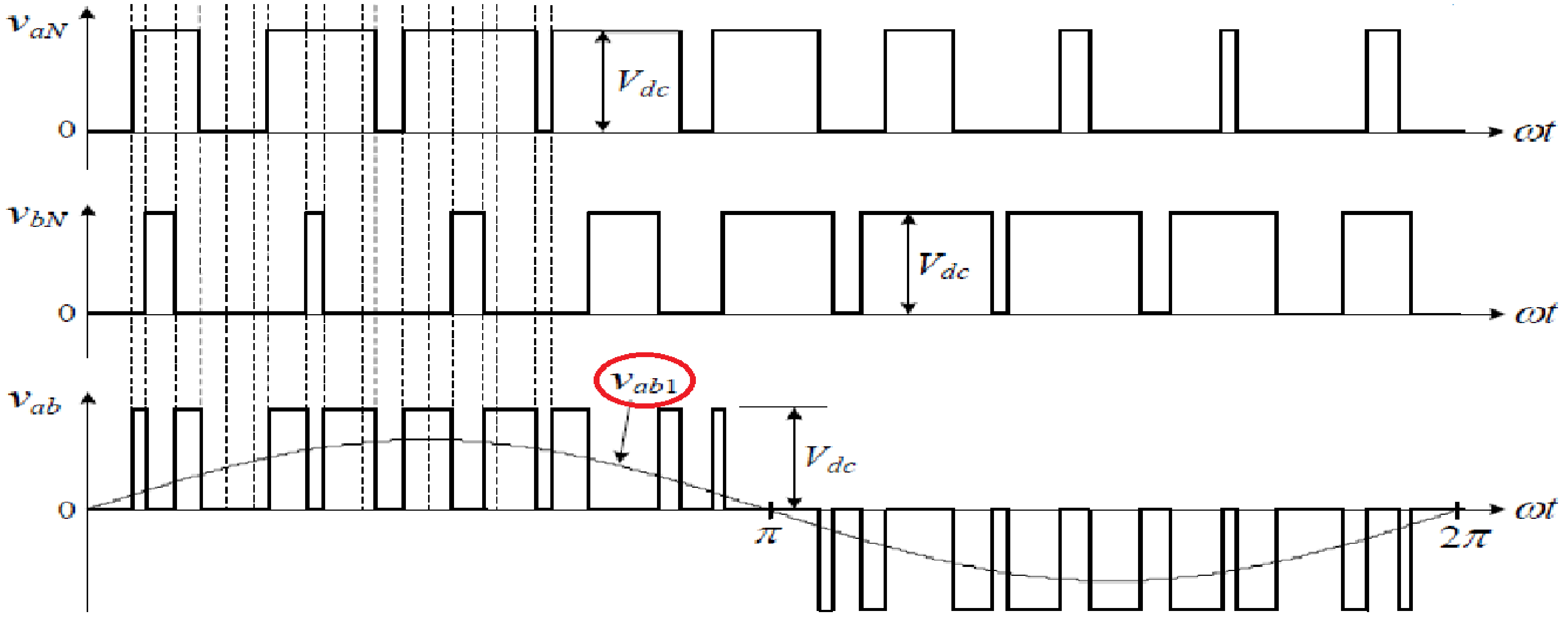
Q.How to obtain Inverter line-to-line voltage *vab* ?

Inverter line-to-line voltage

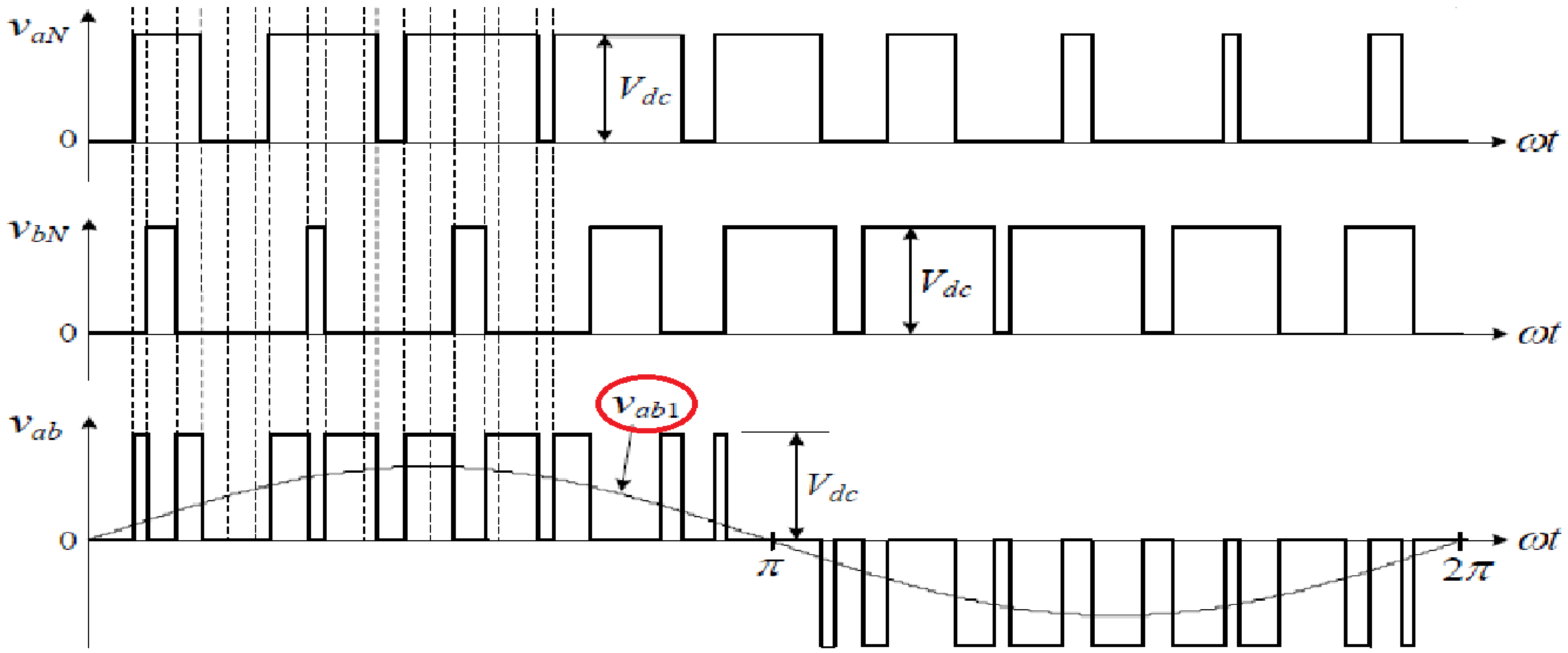
$v_{ab} = v_{aN} - v_{bN}$



Waveform of fundamental-frequency component v_{ab1} of line-to-line voltage v_{ab}



Magnitude & frequency of vab1 can be independently controlled by ma(Amplitude modulation index) & *fm*(Frequency modulation index)



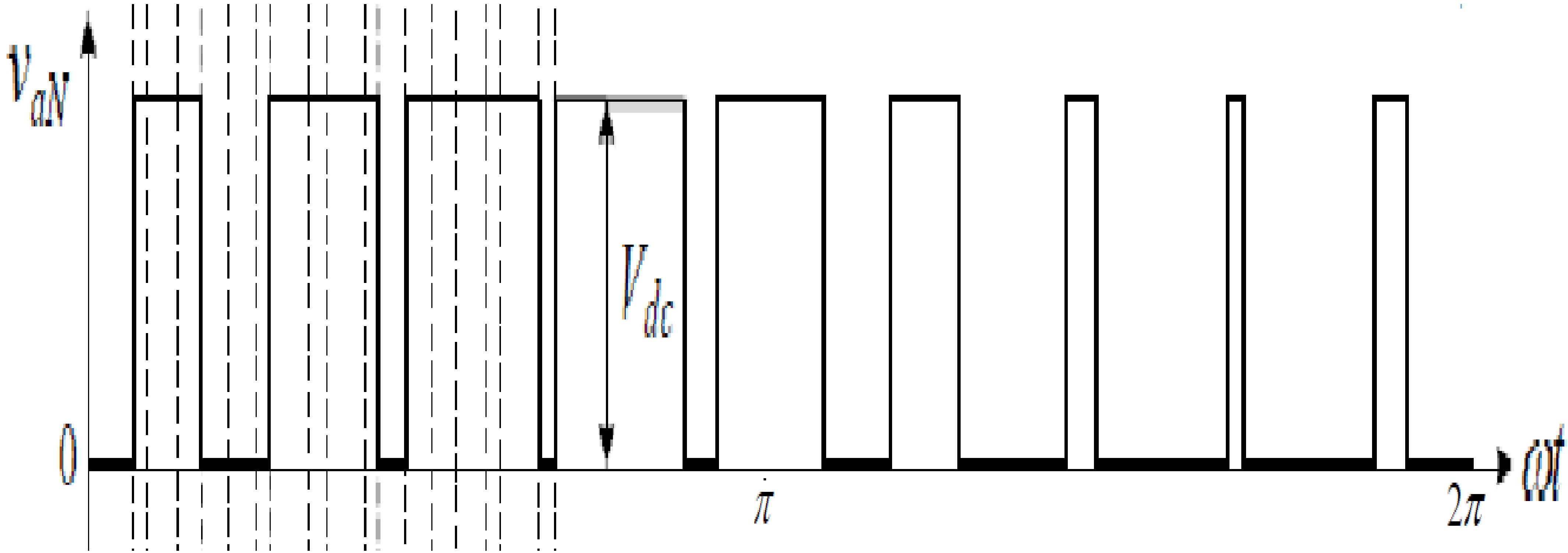
How to find Switching frequency *fsw* of active switches in 2-level inverter?

By using Frequency modulation index m_f

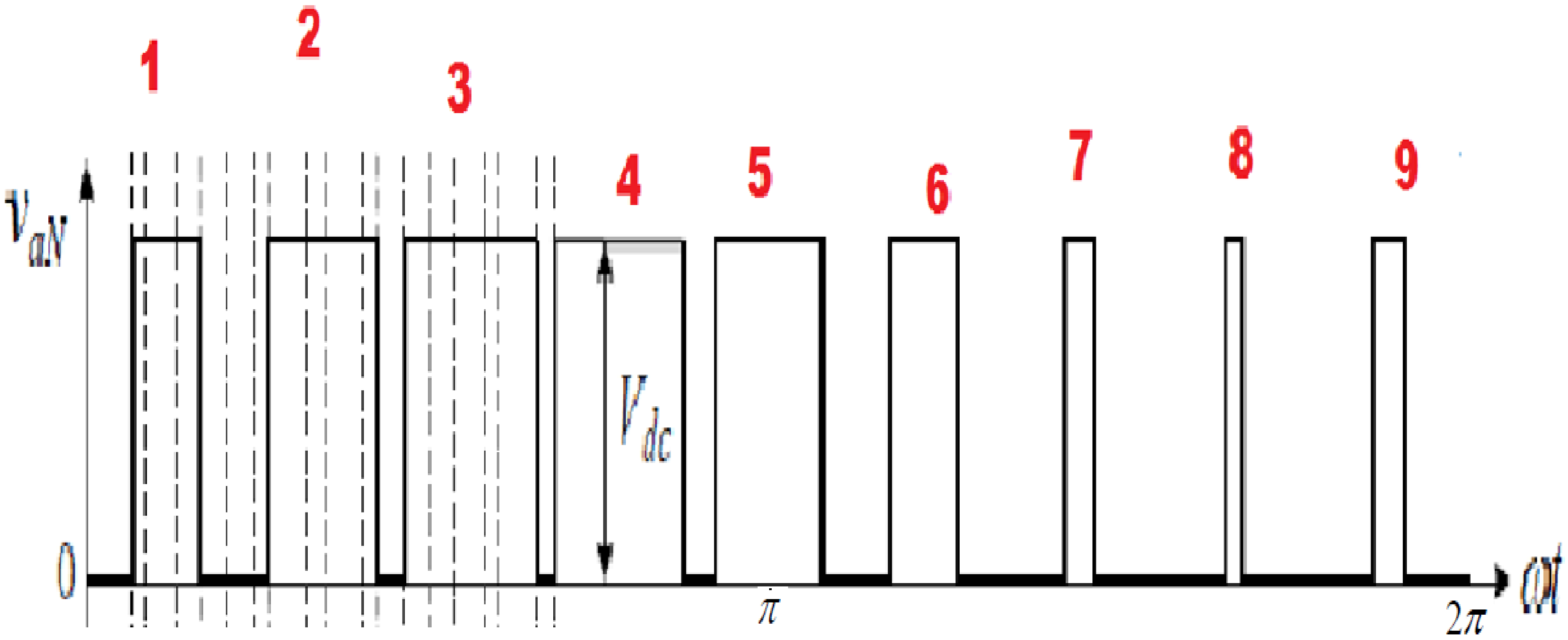
$$m_f = \frac{f_{cr}}{f_m}$$

Switching frequency of active switches in 2-level inverter can be found from $f_{sw} = f_{cr} = f_m \times m_f$.

*Q.*How many pulses *vaN* contains per cycle of fundamental frequency?



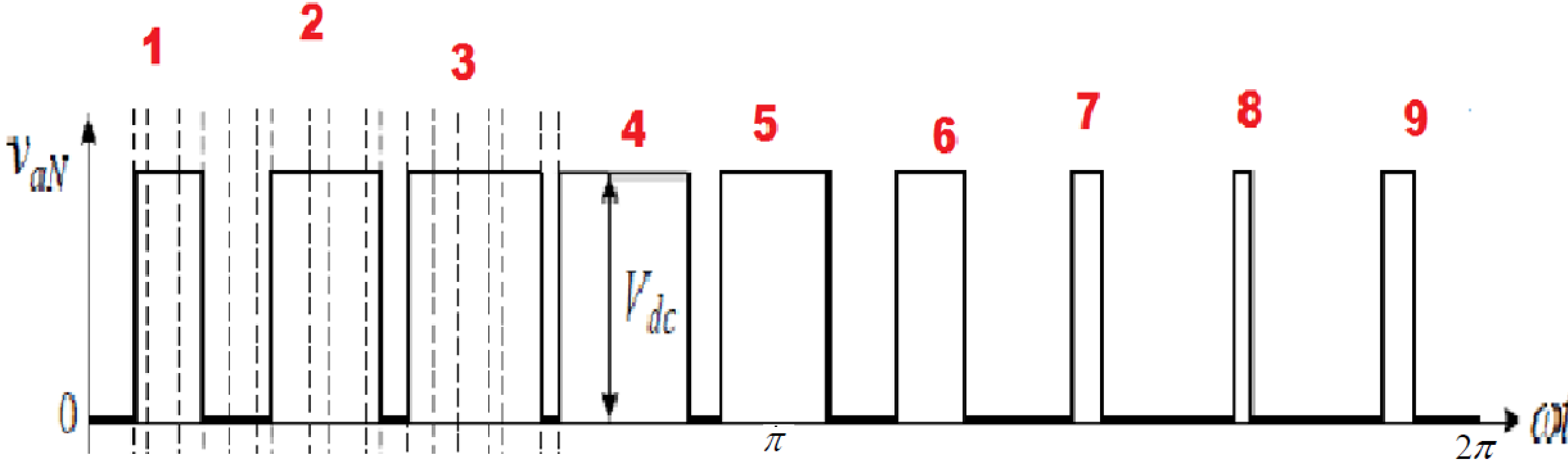
vaN contains 9 pulses per cycle of fundamental frequency. Each pulse is produced by turning $S1$ on and off once.



Q. Fundamental frequency *fm* should be?

Fundamental frequency=60Hz

- *As* *fsw* = *fcr* = *fm* ×*mf* .With *fm*=60Hz, the resultant switching frequency for *S*1 is *fsw* = 60×9 = 540Hz , which is also carrier frequency *fcr* .



The device switching frequency may not always be equal to the carrier frequency in multilevel inverters.

Synchronous Vs asynchronous PWM

- When carrier wave is synchronized with modulating wave (*mf* is an integer), modulation scheme is known as synchronous PWM
- In asynchronous PWM carrier frequency *fcr* is usually fixed and independent of *fm* .

Synchronous Vs asynchronous PWM

- Asynchronous PWM features a fixed switching frequency and easy implementation with analog circuits.
- Asynchronous PWM may generate non-characteristic harmonics, whose frequency is not a multiple of fundamental frequency.
- Synchronous PWM scheme is more suitable for implementation with a digital processor.