Review :

1) V.S.I with device conduction period = 180°
is known as "square wave inverter"

$\Rightarrow$ 6 step/cycle in line current
6 step/cycle in phase voltage
load is Y connected

$$V_{ab} = \frac{2\sqrt{3}}{\pi} V_{dc} \left\{ \sin \omega t - \frac{1}{5} \sin 5\omega t - \frac{1}{7} \sin 7\omega t - \ldots \right\}$$

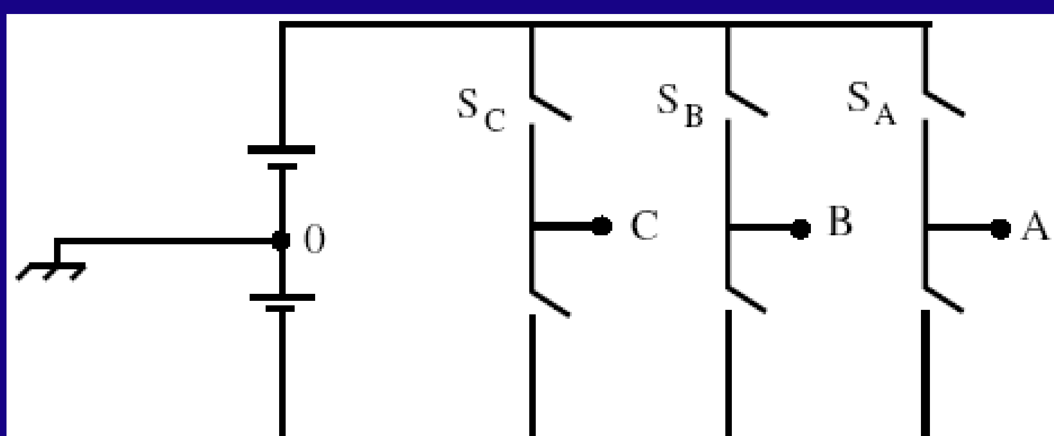
$= (6N \pm 1)$ harmonics

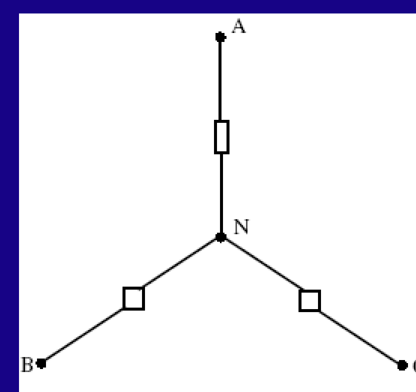
$$V_{AN} = \frac{2}{\pi} V_{dc}[\sin\ \omega t + \frac{1}{5} \sin 5\omega t + \frac{1}{7} \sin 7\omega t]$$

V_{A0}, V_{B0}, V_{C0} have triple harmonics

Q Isolated neutral, all triple harmonics = 0

$\therefore$ V_{N0} $\rightarrow$ Will have tripplen harmonics

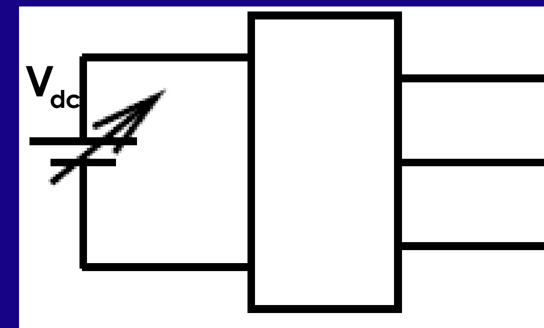




- ⇒ Frequency of the Fundamental itself is changing
- ⇒ Frequency of the Pre-dominant Harmonic will also change
- ⇒ Difficult to design a filter
- ⇒ Frequency of the fundamental can be varied by varying the duration of half a cycle

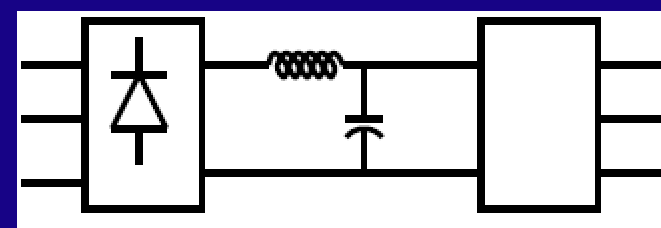
How to vary the magnitude?

Magnitude of phase voltage & line voltage $\propto$ 'V_{dc}'



In V.V.V.F. sources, magnitude of 'V' should vary 'F'

$\Rightarrow$ Vary input 'V'



$\Rightarrow$ In DC to AC converter there is a AC to DC converter

$\rightarrow V_{dc} \propto \cos\alpha$

$\rightarrow$ As to $\downarrow$ $V_{dc} \propto \uparrow$ towards 90°

$\rightarrow$ P.F. $\downarrow$ also $\varphi_1 \uparrow$

$\Rightarrow \varphi_1$ is maximum for α=0 $\Rightarrow$ uncontrolled rectification

$\Rightarrow$ Source line I has $(6N\pm1)$ harmonics

$\Rightarrow$ 'F' of fundamental=50Hz

$\Rightarrow$ Requires filter at the input

Now $V_{out} \propto V_{dc}$ if device is ON for 180°

$\Rightarrow$ Instead keep V_{dc} constant (Corresponding to α=0 $\Rightarrow$ diode bridge) & control conduction period of each device

$\Rightarrow$ Use P.W.M

1) Switching frequency F_s is a function of load.
(as Power Rating $\uparrow$, F_s $\downarrow$)

2) Distortion in the current waveform $\uparrow$ as F_s $\downarrow$.

$\Rightarrow$ PWM strategy must aim at $\downarrow$ this distortion.

$\Rightarrow$ It can be shown that it is leakage reactance that limits the current due to harmonic voltage.

$\Rightarrow$ **As the 'F' of harmonic 'V' $\uparrow$, $|x| \uparrow$ & $\therefore$ I $\downarrow$.**

$\Rightarrow$ **Harmonic I produces torque pulsations in addition to I^2R loss.**

$\Rightarrow$Q **'F' of harmonic I is high, speed pulsations ; 0**

How to choose the no. of pulses/cycle?

Sub-harmonics = 0 if pulse number is an integer.

PWM waveform should have $\frac{1}{2}$ wave symmetry (no even harmonics)

$\therefore$ Pulse number is an odd integer

3-φ symmetry must also be attained.

(Only then will every component be balanced)

$\Rightarrow$ In addition, $\frac{1}{4}$ wave symmetry results in low distortion.

In sinusoidal PWM technique,

$F_c \Rightarrow$ Frequency of the carrier wave

$F_S = F_C \rightarrow$ multiple of frequency of F_{Sine} for synchronization.

$\Rightarrow$ Odd multiples of F_C for $\frac{1}{2}$ wave symmetry.

$\Rightarrow$ Multiples of 3 for 3-φ symmetry.

$\therefore \dfrac{F_C}{F_{Sine}}$ = should be ODD multiples of 3

for synchronization, $\dfrac{1}{2}$ wave symmetry

& 3-φ symmetry.

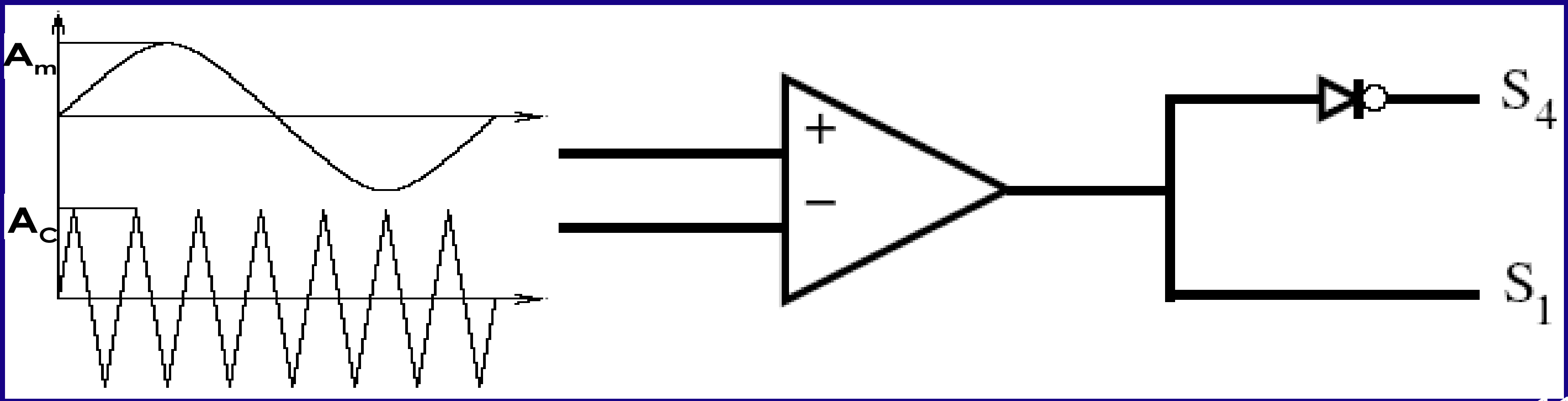
1) Sinusoidal PWM Technique:

3 sinusoids, displaced by 120°.

$V_{an} = V_m \sin \omega_1 t,$

$V_{bn} = V_m \sin(\omega_1 t - 120°)$ &

$V_{cn} = V_m \sin(\omega_1 t + 120°)$



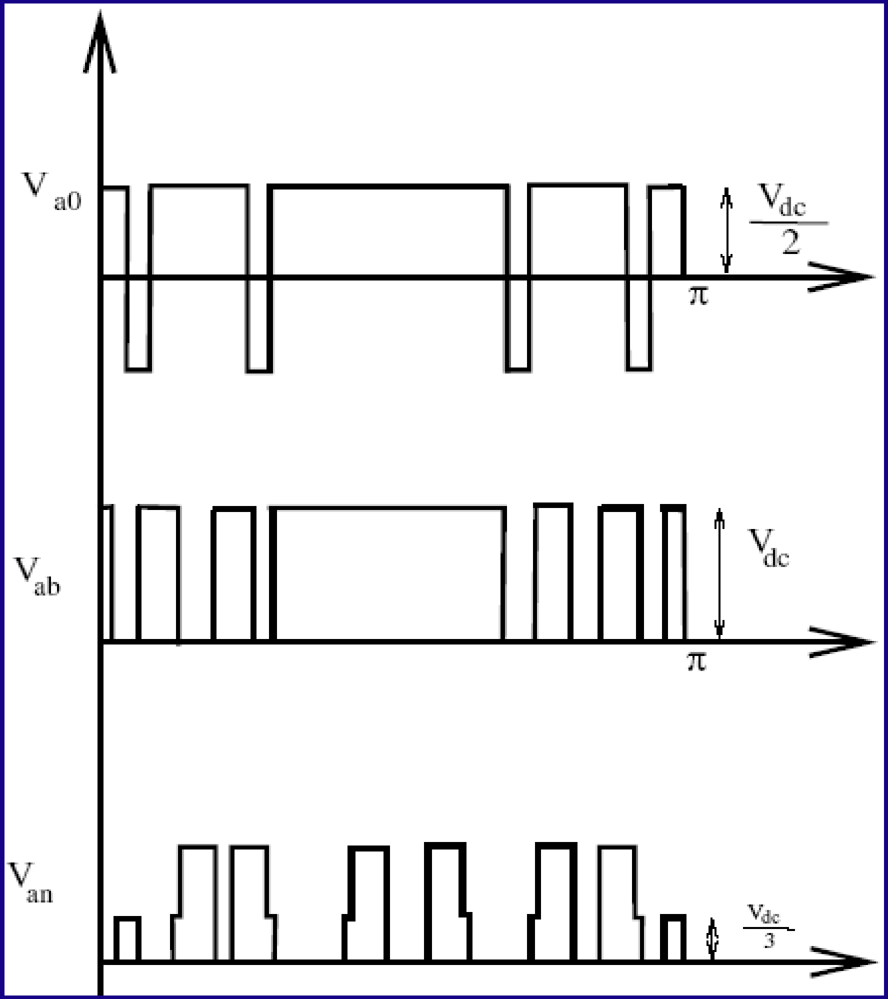
Both A_M and F of sine wave (modulating wave) are varying.

F of sine wave = F of fundamental component o/p V

A_C & F_C $\rightarrow$ constant

$$V_0 \propto m = \frac{A_M}{A_C}$$

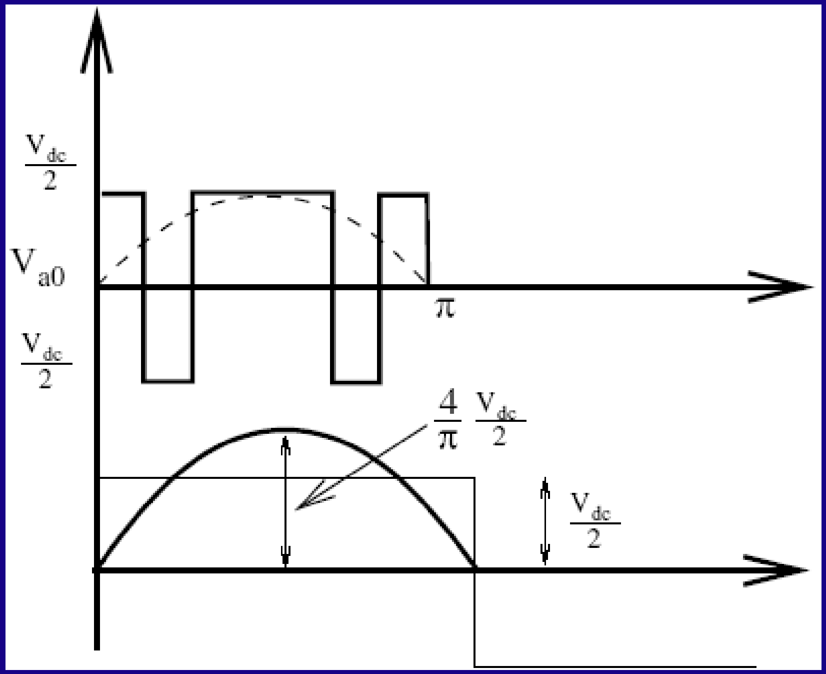
All phase voltages are identical & out of phase by 120°
(no even harmonics)



Peak of fundamental component of

$$V_{a0} = \frac{V_{dc}}{2} * m$$

$$= \frac{V_{dc}}{2} \text{ when } m=1$$



Peak of fundamental for 180° conduction

$$= \frac{4}{\pi} * \frac{V_{dc}}{2} = 1.27\,\frac{V_{dc}}{2}$$

$$\therefore\ V_{ab(PWM)} = \sqrt{3}\ \frac{V_{dc}}{2}$$

$$V_{ab1(square)} = \frac{2\sqrt{3}}{\pi}\ V_{dc}$$

Magnitude of n^{th} harmonic for fundamental frequency > F_{rated}

$$= \frac{1}{n} * \frac{2\sqrt{3}}{\pi}\ V_{dc}$$

$\Rightarrow$ **Frequency spectrum :**

Let $F_N = \dfrac{F_C}{F_{sine}}$

$\therefore n = j\,F_N \pm k$

where j = 1,3,5... for k = 2,4,6... and

= 2,4,6... for k = 1,5,7...

such that 'n' is not a multiple of 3

If F_N =45

'F' of harmonic = $45\ F_{sine} \pm 2\ F_{sine}$

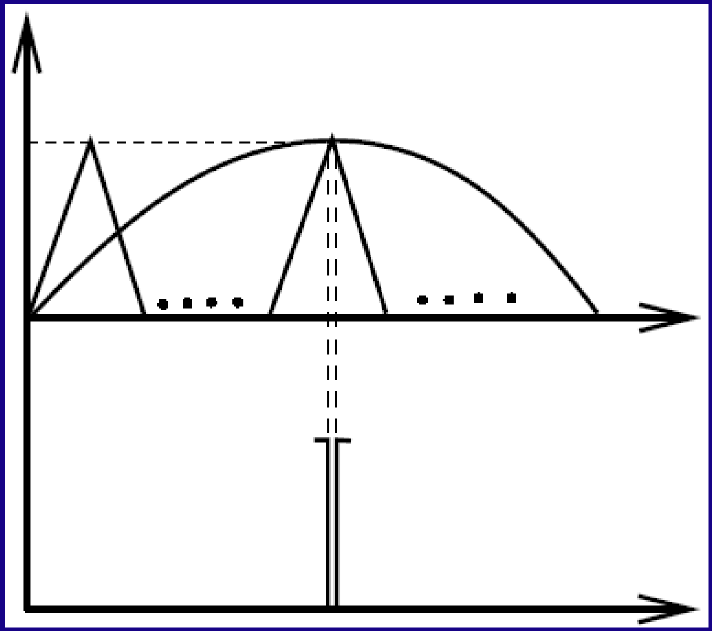
$45\ F_{sine} \pm 4\ F_{sine}$

…

$90\ F_{sine} \pm F_{sine}$

$90 F_{sine} \pm 5 F_{sine}$

As $m \rightarrow 1$, narrow pulses near the center



$\Rightarrow$ To complete switching operation of the devices, minimum notch and pulse width must be maintained.

⇒ These narrow pulses may be blocked.

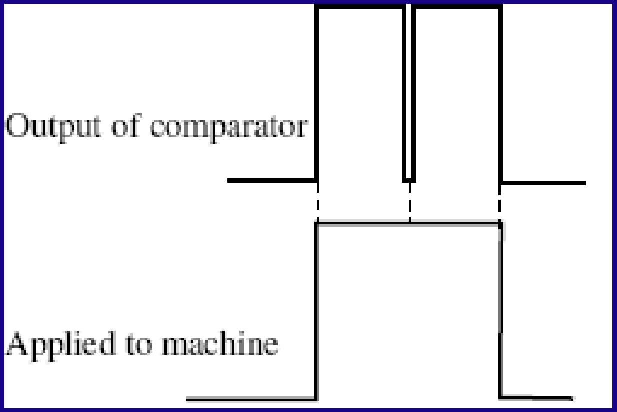
⇒ Affects the machine performance

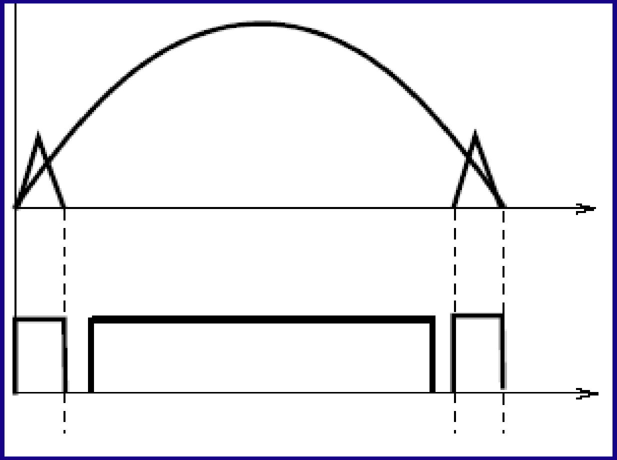
⇒ As m↑, operation ⇒ 6 step operation

⇒ harmonics will re-appear 5^{th} & 7^{th}

⇒ This happens at F > 50 Hz

⇒ Frequency of F_5 > 250





- ⇒ Possible to design a filter <u>or</u> get filtered by machine leakage 'L'
- ⇒ 'F' of predominant harmonic till rated F ; F_C
- ⇒ 'F' of predominant harmonic above the rated F = $5F_1$
- ⇒ May not have a choice !

$\Rightarrow$ Peak of fundamental = 78.55% of the peak of square wave (1/1.27)

$\Rightarrow$ Using sinusoidal P.W.M

$\rightarrow$ Frequency of predominant harmonic $\uparrow$

$\rightarrow$ Distortion in I $\downarrow$

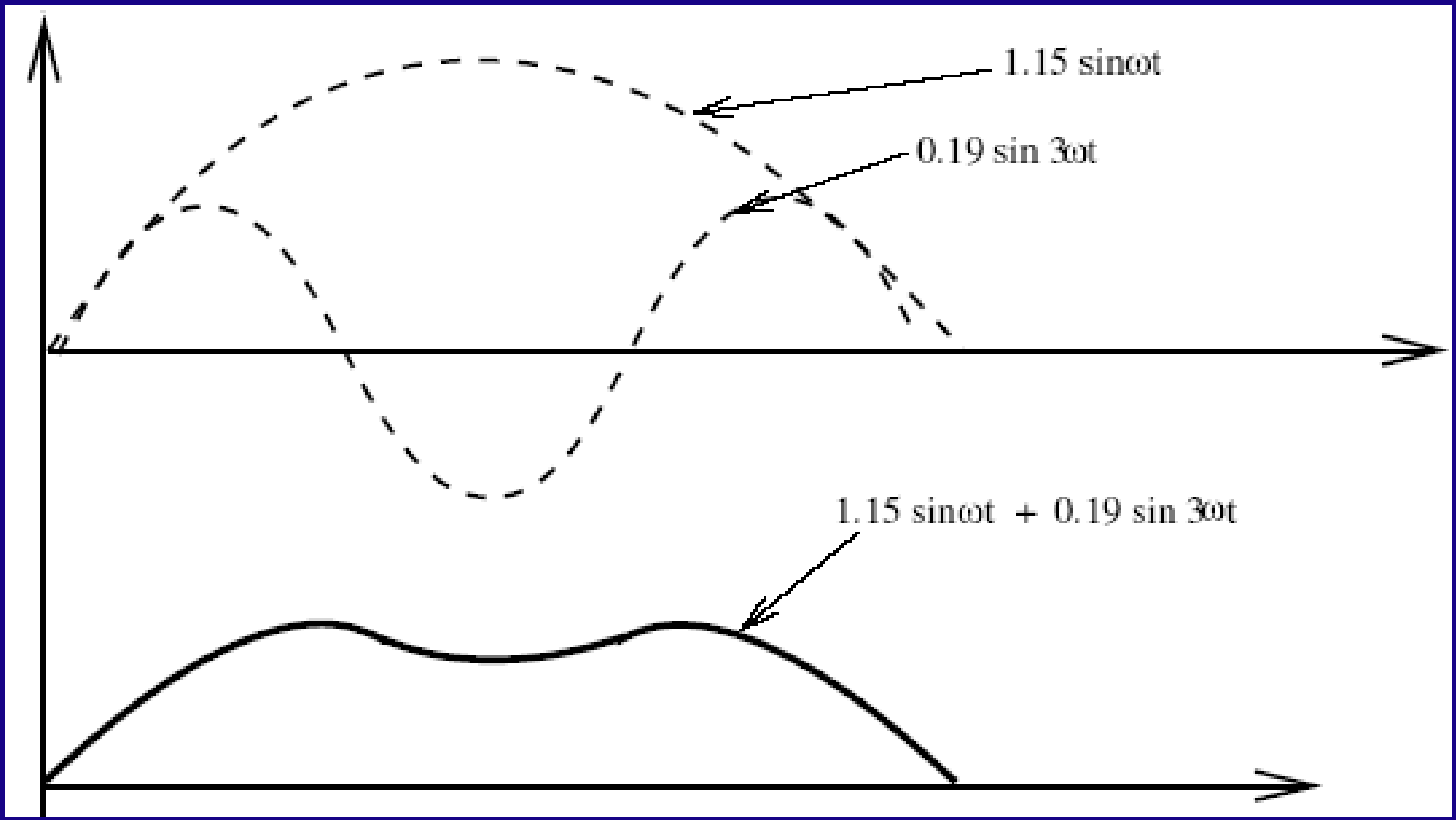
$\rightarrow$ Utilization of DC link voltage $\downarrow$

$\rightarrow$ Δ wave intersects only near the zero crossings as m $\uparrow$ above 1

Is it possible to change the shape of the modulating waveform without $\uparrow$ harmonic content & $\uparrow$ DC link utilization?

$\Rightarrow$ Add 3^{rd} harmonic component to the sinusoidal modulating wave.

$\Rightarrow$ Cannot appear in line-line voltage waveform


1.15 sinωt
0.19 sin 3ωt
1.15 sinωt + 0.19 sin 3ωt