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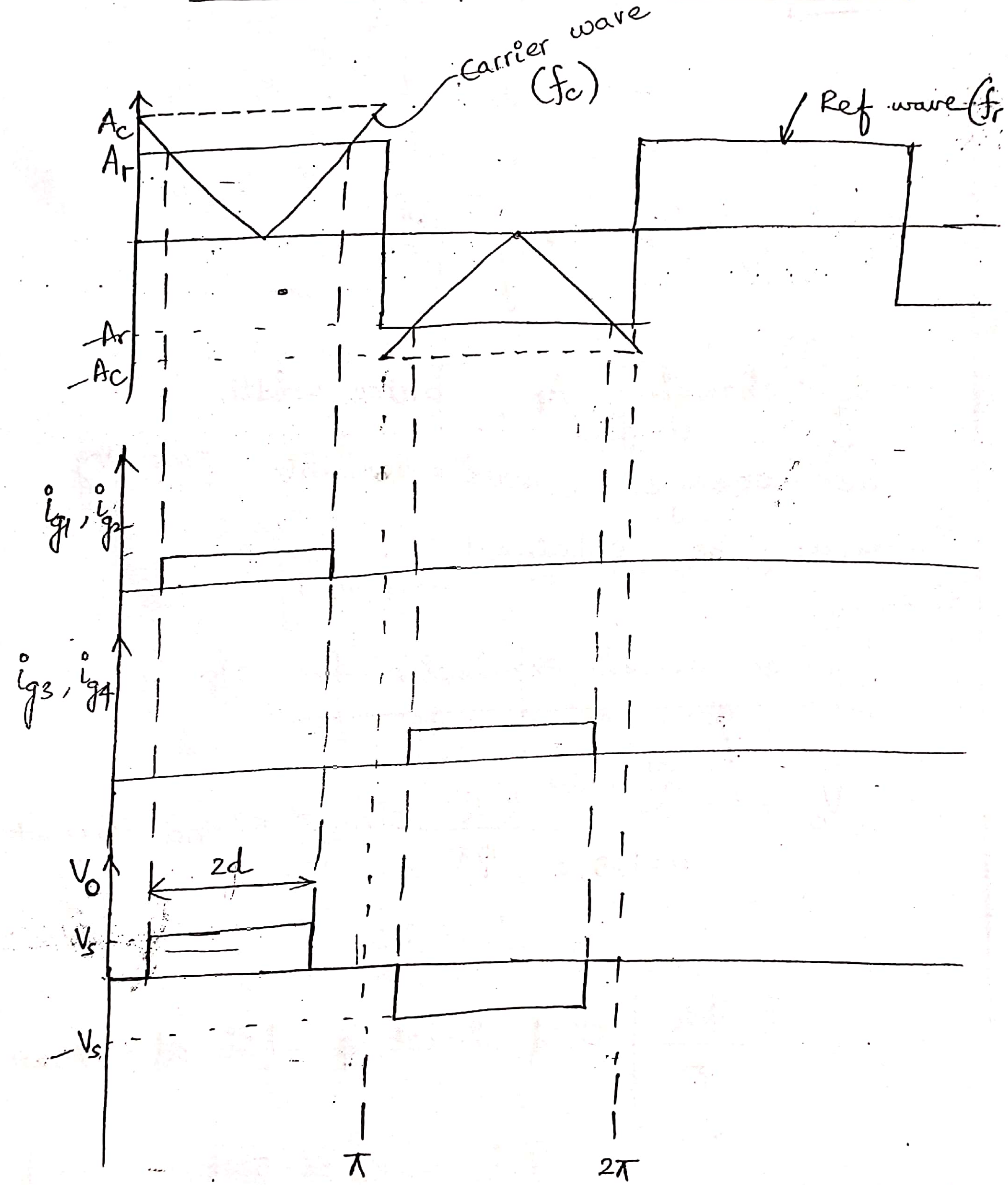
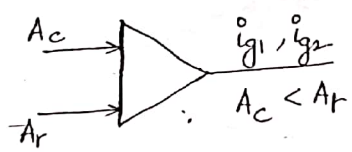
# SINGLE PULSE WIDTH MODULATION (PWM)




$$V_{or} = V_s \sqrt{\frac{2d}{\pi}}$$




$$V_{or} = V_s\sqrt{\frac{2d}{\pi}}$$

→ By changing $A_r$, pulse width can be changed, thus variable rms vg can be obtained.

Fourier Series expansion for o/p vg:

$$V_o = \sum_{n=1,3,5..}^{\infty} \frac{4V_s}{n\pi} \sin\frac{n\pi}{2} \sin nd \sin n\omega t$$

$$= \frac{4V_s}{\pi}\left[\sin d \sin\omega t - \frac{1}{3}\sin 3d \sin 3\omega t + \frac{1}{5}\sin 5d \sin 5\omega t - \cdots\right]$$



$$V_{on} = -\frac{4V_s}{n\pi} \sin\frac{n\pi}{2} \sin nd \sin n\omega t$$

$V_{on} = 0$ if $nd = \pi, 2\pi, 3\pi, \ldots$

i.e, $d = \frac{\pi}{n}, \frac{2\pi}{n}, \frac{3\pi}{n}, \ldots$

$$\Rightarrow \underset{\text{(pulse width)}}{2d} = \underbrace{\frac{2\pi}{n}, \frac{4\pi}{n}, \frac{6\pi}{n}, \ldots}_{2d \leq \pi}$$

[Condition to eliminate ~~3rd~~ $n^{th}$ harmonic]

Q. what is the pulse width required to eliminate $3^{rd}$ harmonic?

Sol:

$$2d = \frac{2\pi}{n}, \frac{4\pi}{n}, \ldots$$

$$= \frac{2\pi}{3}, \frac{4\pi}{3}$$

i.e., $2d = 120°$

→ To eliminate $5^{th}$ harmonic,

$$2d = \frac{2\pi}{5}, \frac{4\pi}{5}, \frac{6\pi}{5}, \ldots$$

✓ ✓ ✗

$$\boxed{2d = 72^\circ, 144^\circ}$$

→ To eliminate $7^{th}$ harmonic,

$$2d = \frac{2\pi}{7},$$

$g = ?$

$$(V_{on})_{rms} = \frac{2\sqrt{2}V_s \sin nd}{n\pi}$$

$$V_{o1} = \frac{4V_s}{\pi} \sin d \sin \omega t$$

$$(V_{o1})_{rms} = \frac{2\sqrt{2}V_s}{\pi} \sin d$$

$$V_{or} = V_s \sqrt{\frac{2d}{\pi}}$$

$$g = \frac{(V_{o1})_{rms}}{V_{or}} = \frac{2\sqrt{2} \sin d}{\sqrt{(2d)\pi}}$$

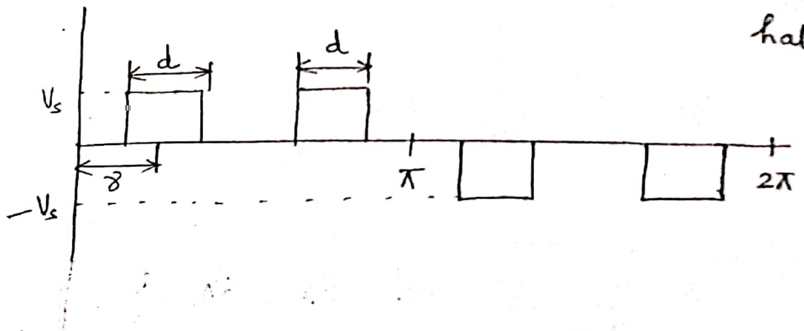


$$g = \frac{2\sqrt{2} \sin d}{\sqrt{\underbrace{(2d)}_{\text{in radians}}\pi}}$$

$$T.H.D = \left(\frac{1}{g^2} - 1\right)^{1/2}$$

## Multiple pulse width Modulation Technique

2d = Total pulse width each half cycle




$$V_{or} = V_s \sqrt{\frac{2d}{\pi}}$$

Length of each gap $= \frac{\pi - 2d}{3}$

$$\therefore \gamma = \frac{\pi - 2d}{3} + \frac{d}{2} \Rightarrow N = 2 \text{ pulse}$$

$$\gamma = \frac{\pi - 2d}{N+1} + \frac{d}{N} \Rightarrow N \text{ pulse}$$

⑥

Finding the Fourier Series expansion for o/p waveform,

$$V_o = \sum_{n=1,3,5\ldots}^{\infty} \frac{8V_s}{n\pi} \sin n\gamma \sin\frac{nd}{2} \sin n\omega t$$

$$V_{on} = \frac{8V_s}{n\pi} \sin n\gamma \sin\frac{nd}{2} \sin n\omega t,$$

$V_{on} = 0$ if $n\gamma = \pi$ (or) $\frac{nd}{2} = \pi, 2\pi, \ldots$

$\gamma = \frac{\pi}{n}$ (or) $d = \frac{2\pi}{n}, \frac{4\pi}{n}, \ldots$

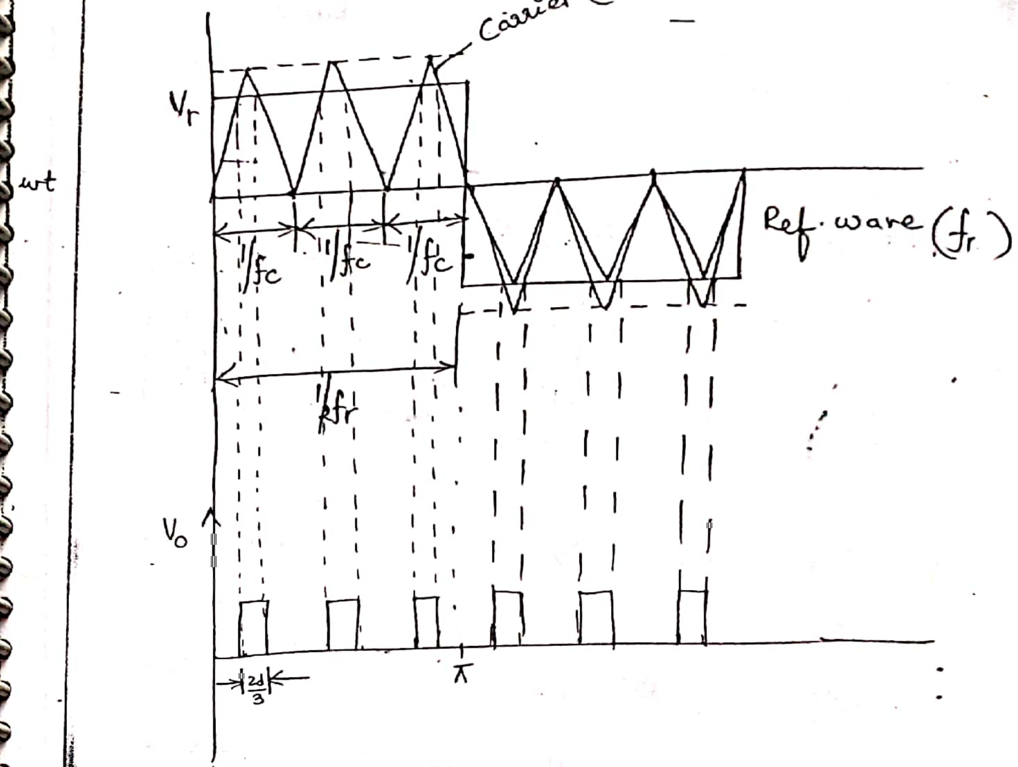
$$\boxed{\gamma = \frac{\pi}{n} \text{ (or) } 2d = \frac{4\pi}{n}, \frac{8\pi}{n}, \ldots}$$

$2d \le \pi$

[Condition to eliminate $n^{th}$ harmonic]

⑦

3-pulse PWM




$$\frac{3}{f_c} = \frac{1}{2f_r}$$

$$\boxed{3 = \frac{f_c}{2f_r}}$$

$$\boxed{\frac{f_c}{2f_r} = N}$$ for N pulse in each half cycle.

Length of each pulse, $= \frac{2d}{N}$

$$\boxed{\frac{2d}{N} = \left(1 - \frac{V_r}{V_c}\right)\frac{\pi}{N}}$$

Q. The carrier & reference wave have the amplitude & frequency of ~~4V~~ 4V, 6 KHZ & 1V, 1KHZ respectively. The no. of pulses in each half cycle & pulse width of each pulse is ?

(a) 3, 40° (b) 3, 45° (c) 6, 45° (d) 6, 40°



Sol:

$$\rightarrow \frac{f_c}{2f_r} = N = \frac{6}{2\times 1} = \underline{\underline{3}}$$

$$\rightarrow \frac{2d}{N} = \left(1 - \frac{V_r}{V_c}\right)\frac{\pi}{N}.$$

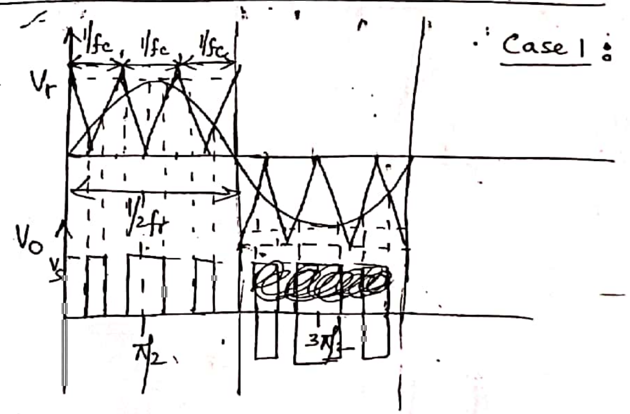
$$\frac{2d}{N} = \left(1 - \frac{1}{4}\right) * \frac{\pi}{3}$$

$$= \frac{\cancel{3}}{4} * \frac{\pi}{\cancel{3}}$$

$$\boxed{\frac{2d}{N} = 45^\circ}$$

Sinusoidal PWM technique

Case 1 : Peak carrier coincident with zero of Referen

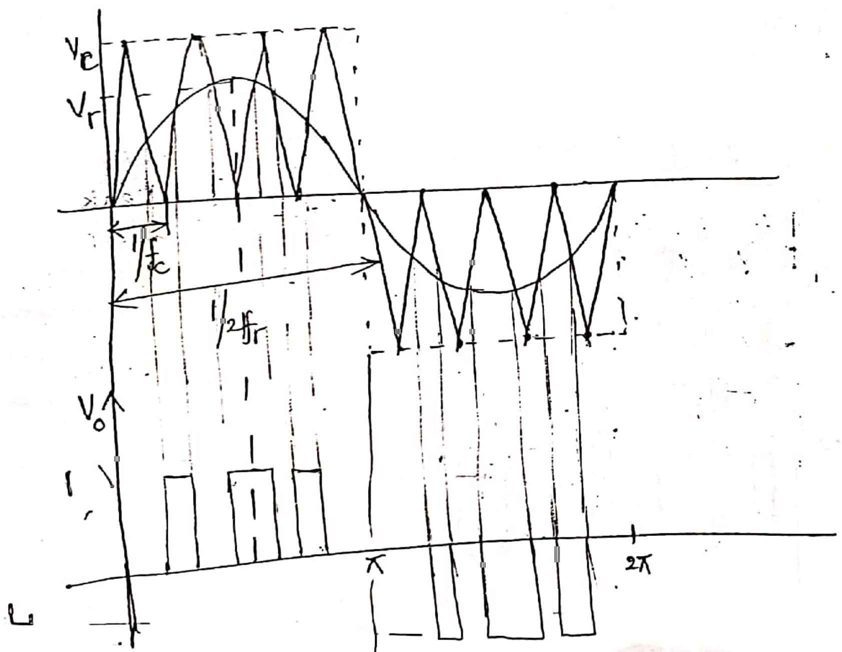


$$\frac{3}{f_c} = \frac{1}{2f_r}$$

$$\Rightarrow \frac{f_c}{2f_r} = 3$$

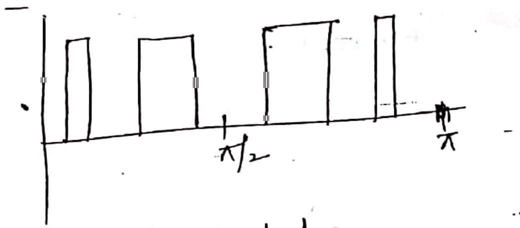
In general, $\boxed{\frac{f_c}{2f_r} = N}$

<u>Case 2:</u> Zero of Carrier Coincident with Zero of reference

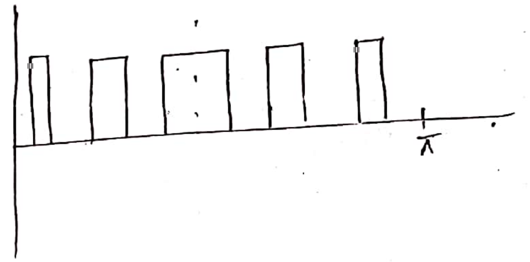





$$N = \frac{f_c}{2f_r} - 1$$




4 pulse




→ In sinusoidal PWM technique, the dominant harmonics are given by

$2N \pm 1$,

where $N$ = No. of pulses in each half cycle

For $N = 3$, dominant harmonics are 5 & 7

For $N = 10$, dominant harmonics are 19 & 21



→ Higher order harmonics can be filtered easily using smaller size filters.

→ In sinusoidal PWM technique, by increasing the no. of pulses in each half cycle, we can raise the order of dominant harmonics. If the domination is shown by higher order we can easily filter them using small size filters. But if the domination is shown by lower order harmonics we require very large filter to reduce the harmonics.

Thus, by using PWM techniques, we generally eliminate the lower order harmonics & filters are used to eliminate the higher order harmonics.