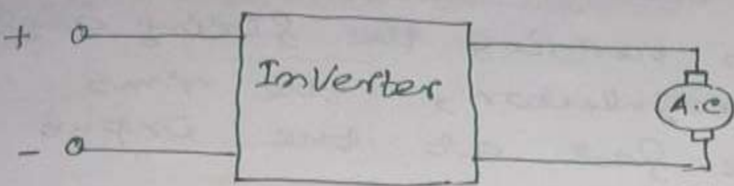
Harmonic Reduction technique in Inverter

Voltage Control

VOLTAGE CONTROL TECHNIQUES IN SINGLE PHASE INVERTERS



In many inverters, it is often required to control the output voltage of the inverter because –

1. To cope up with the variation in the dc input voltage

The AC voltage fed to the load terminals must be maintained constant at a desired level. Whenever there is change in the D.C input voltage, there must be suitable compensation in order to maintain the constant AC voltage at the terminals.

Voltage Control

2. Whenever the inverter circuit is fed for the speed control of the induction motor, V/f ratio is maintained constant. If the ratio is varied, it leads to the saturation of the device.

3. To compensate for the regulation of the inverters, the various methods for controlling the output voltage of the inverter are-

   a. External control of A.C output voltage.

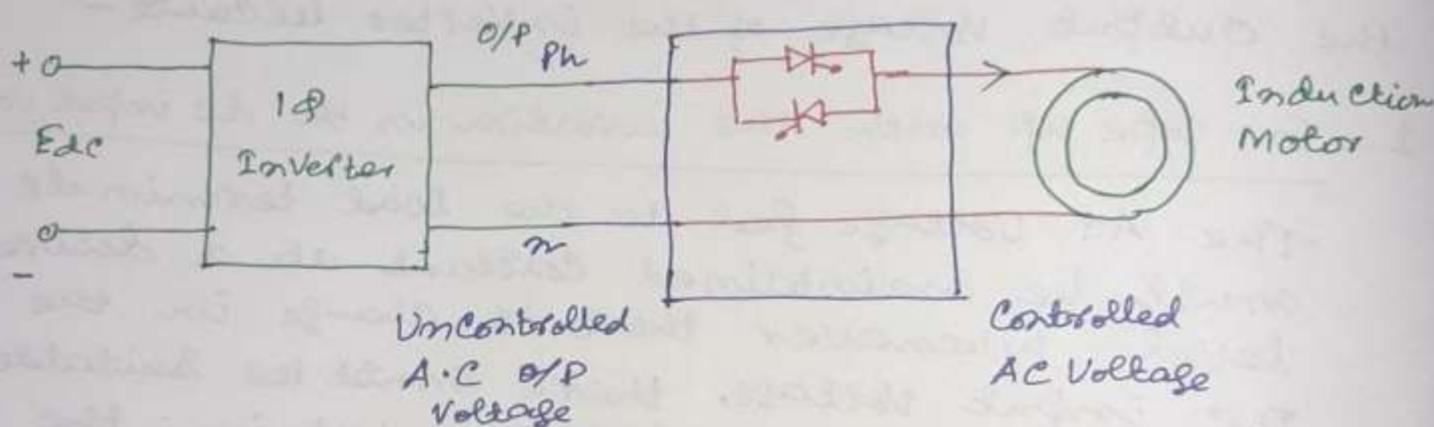
   b. External control of DC. input voltage

   c. Internal control of Inverter.

Voltage Control

External Control of AC Output Voltage

In this method, an AC Voltage Controller is inserted in between the inverter O/P terminals and the AC load. By varying the firing angle of the AC Voltage regulator, the rms value of the voltage fed at the input of the load is varied.



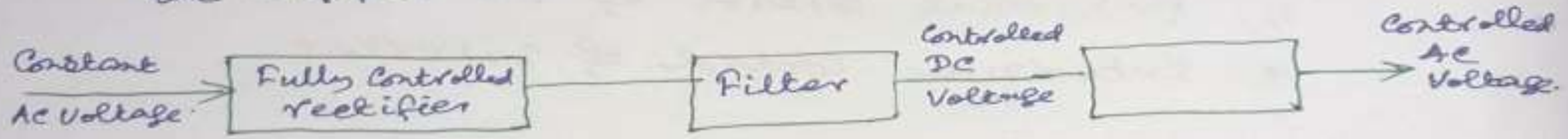
Voltage Control

Voltage

This method will introduce a large Value of the harmonic content in the output Voltage, particularly when the output Voltage from the AC Voltage controller is at low level.

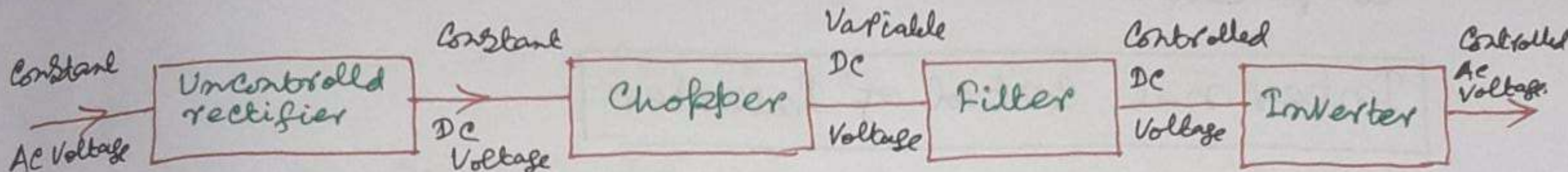
External Control of the DC Input Voltage

1. When the A.C source is available, the DC Voltage fed to the inverter is controlled through a fully controlled rectifier. After this, filter circuit is placed in order to reduce the ripple.

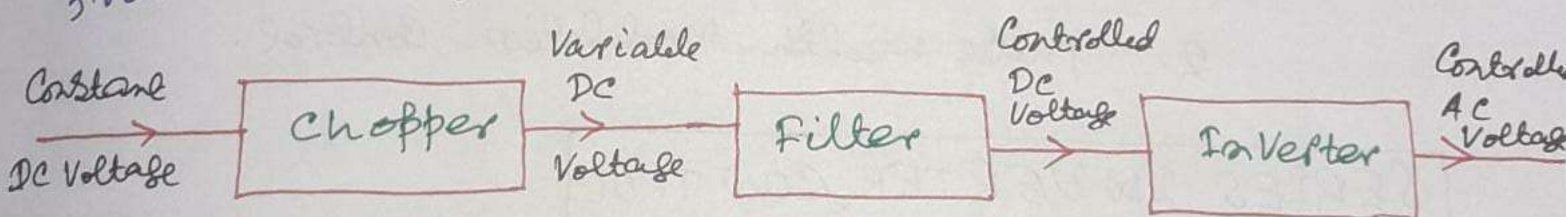


Voltage Control

2. When the AC source is available, the controlled DC input voltage is obtained from the choppers filter, and uncontrolled rectifier.



3. If the voltage available is constant DC voltage the controlled DC voltage can be obtained from the chopper and filter



Voltage Control

Disadvantages

① Number of stages are increased. It becomes difficult or controlling the inverter output voltage because of the more number of stages which leads to more power losses and less efficiency.

② Filter circuit is used to reduce the ripple. The cost, weight, size of the filter is increased.

③ If the input DC voltage is decreased the voltage across the commutating device is decreased.

Voltage Control

The SCR turn off time is reduced from the following expression.

$$\downarrow t_q = C \cdot \frac{V\downarrow}{I} \quad \text{(for constant load current)}$$

If there is a large variation in the o/p voltage of converter, control of the DC input voltage is not desirable.

The commutating capacitor can be charged from a separate fixed dc voltage source, which makes the scheme costly and complicated.

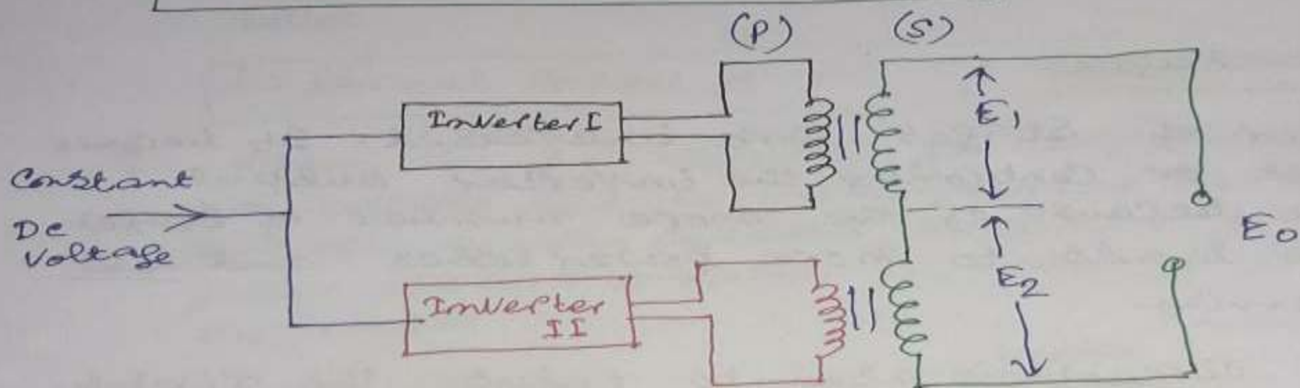
Internal Control

Internal Control of Inverter

There are two methods of controlling the inverter o/p voltage. Control can be within the inverter itself.

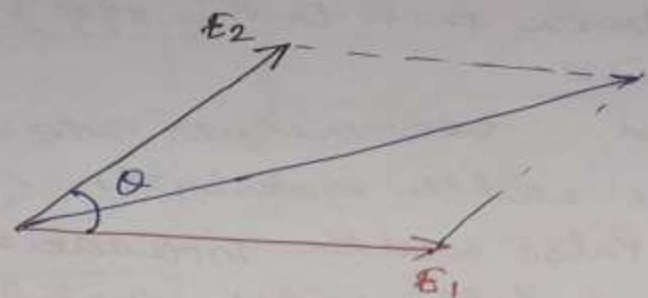
1. Series Inverter Control.
2. Pulse width Modulation Control.

SERIES INVERTER CONTROL



Voltage Control

$$E_R = \left[E_1^2 + E_2^2 + 2E_1E_2 \cos\theta\right]^{1/2}$$



Case I : $\theta = 0$ $\quad \cos\theta = 1$

$$E_R = \left[E_1^2 + E_2^2 + 2E_1E_2\right]^{1/2}$$

If $E_1 = E_2$; $\quad E_R = 2E_1$ or $2E_2$

Case II : $\theta = 180^\circ$, $\cos 180^\circ = -1$

$$E_R = \left[E_1^2 + E_2^2 - 2E_1E_2\right]^{1/2}$$

If $E_1 = E_2$, $\quad E_R = 0.$

Pulse Width Modulation

PULSE WIDTH MODULATION CONTROL

The most efficient method of Controlling the output Voltage is to incorporate pulse width modulation within inverters.

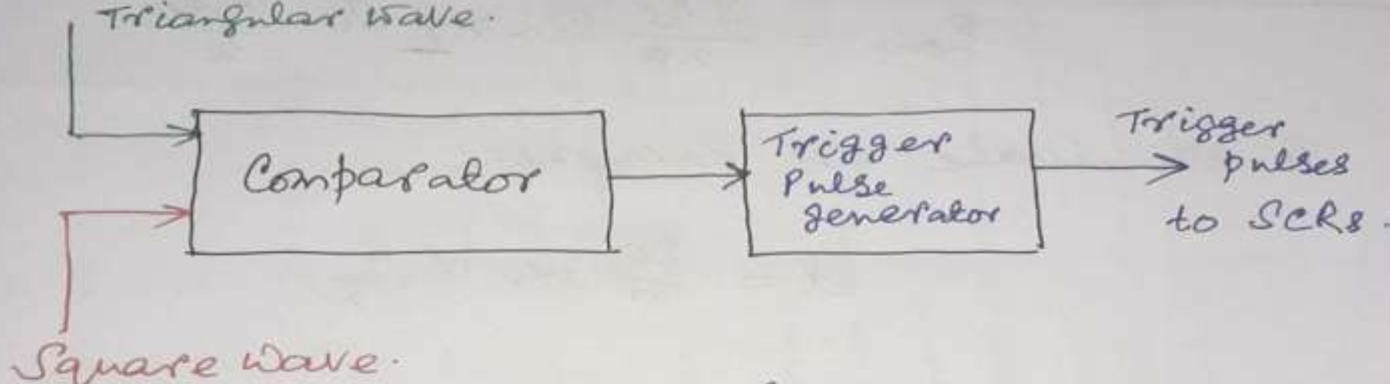
In this control, width of the pulse is varied and amplitude of the pulse is kept constant in order to have the Variation in the output voltage.

Low frequency harmonic contents can be elliminated in this method.

The output voltage can be controlled without any additional components.

Higher order harmonics can be elliminated easily with filters. The lower order harmonics can be elliminated / reduced. Hence, filtering requirements are less.

Pulse Width Modulation



$$E_0 = \sum_{n=1,3,5,7}^{\infty} A_n \sin n\omega t + \sum_{n=1,3,5,7}^{\infty} B_n \sin n\omega t.$$

$B_n = 0$. (Because of symmetry)

Pulse Width Modulation

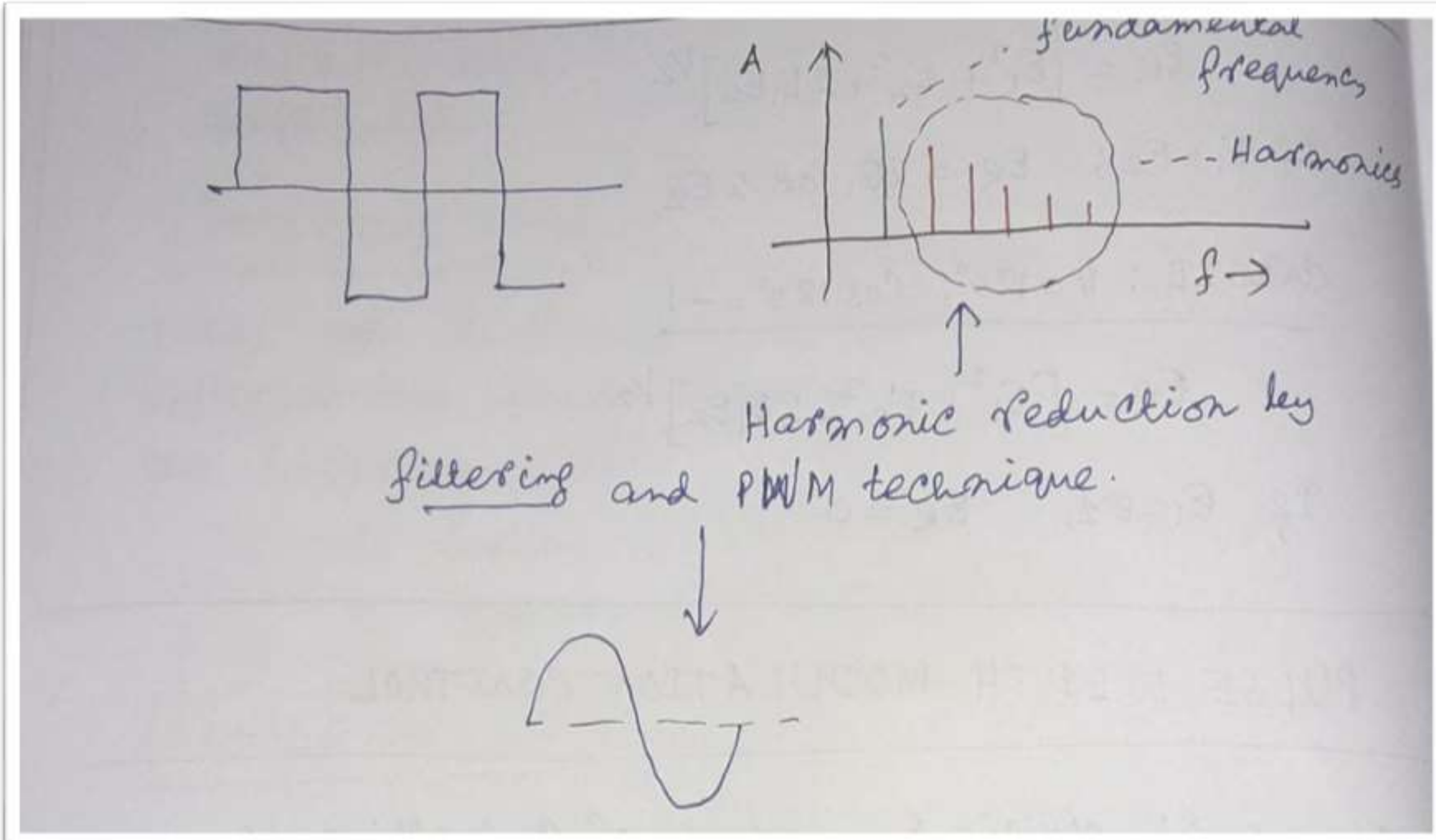
Disadvantage.

As they should possess low switching time characteristics (turn on & turn off), SCRs are very expensive.

The commonly used techniques are-

1. Single Pulse width modulation (SPWM)
2. Multiple Pulse width modulation (MPWM)
3. Sinusoidal Pulse width modulation (SPWM)

Pulse Width Modulation

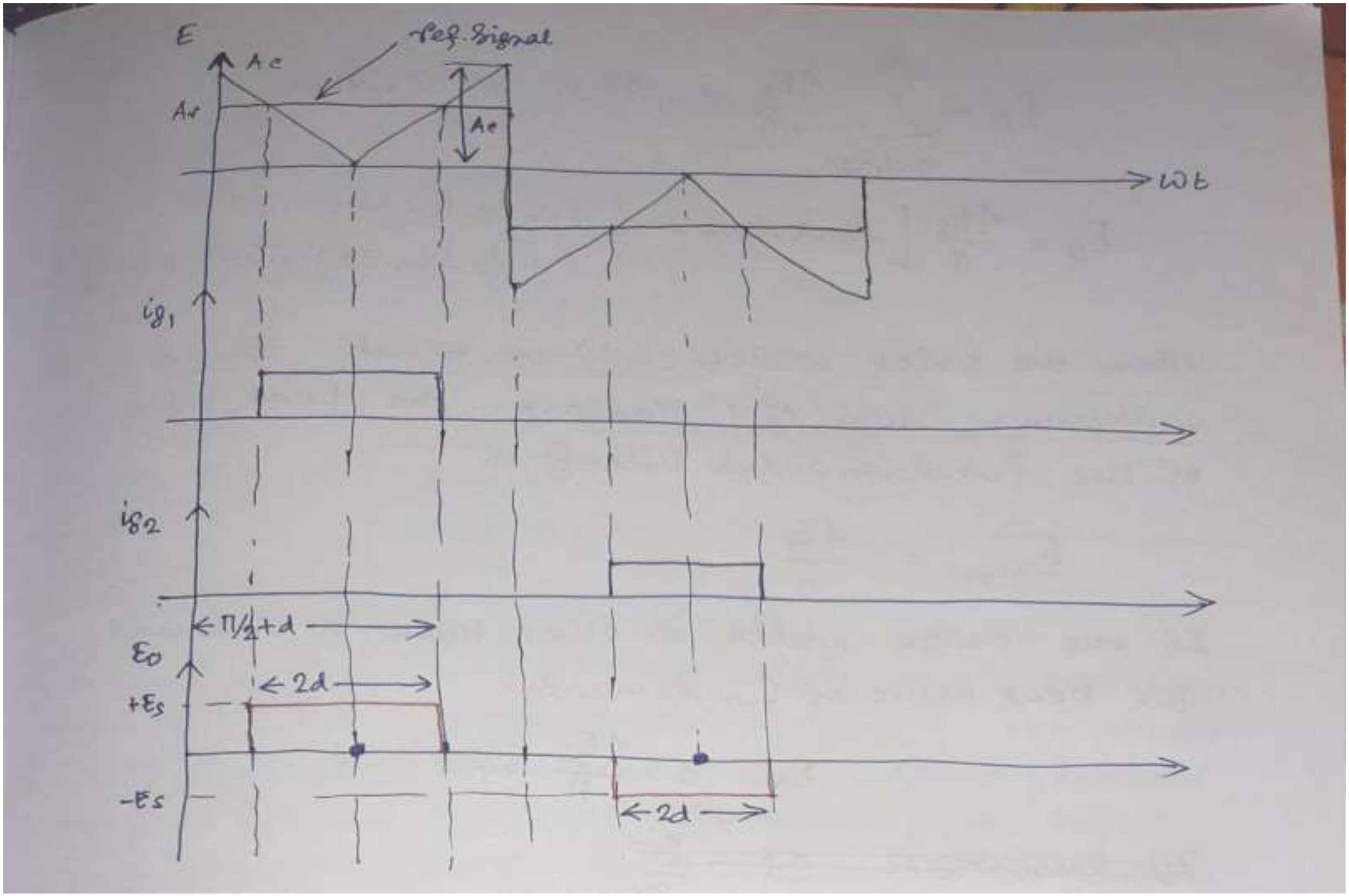


Pulse Width Modulation

Single Pulse Width Modulation

In the SPWM, there is only one pulse per half cycle and width of the pulse is controlled to control the inverter output voltage.
The gating signals are generated by comparing a rectangular referce signal of Amplitude (A_r), with a triangular carrier wave, of Amplitude (A_c). The frequency of the reference signal determines the fundamental frequency. The variation of A_r is from ~~0 to~~ 0 to A_c, the pulse width '$2d$' can be varied from 0 to 180°.

Pulse Width Modulation



Pulse Width Modulation

M.I = Amplitude Modulation index $= \dfrac{A_r}{A_c}$.

The shape of the waveform is quasi-square waveform. +Ve pulse is symmetrical about $\pi/2$ & -Ve pulse is symmetrical about $3\pi/2$. width of the pulse is '2d'.

$$E_0 = \sum_{n=1,3,5}^{\infty} A_n \sin n\omega t \, d(\omega t) + \sum_{n=1,3,5}^{\infty} B_n \sin n\omega t \, d(\omega t)$$ Fourier Series

$B_n = 0$ (Because of symmetry)

$$A_n = \left(\frac{2}{\pi}\right) \int_{\pi/2-d}^{+\pi/2+d} E_s \sin n\omega t \, d(\omega t) = \frac{4 E_s}{n\pi}\left[\sin \frac{n\pi}{2} \cdot \sin nd\right]$$

Pulse Width Modulation

$$E_0 = \sum_{n=1,3,5}^{\infty} \frac{4E_s}{n\pi} \sin\frac{n\pi}{2} \sin n d \sin n\omega t.$$

$$E_0 = \frac{4E_s}{\pi}\left[\sin d \sin \omega t - \frac{1}{3}\sin 3d \sin 3\omega t + \frac{1}{5}\sin 5d \sin 5\omega t + \dots\right]$$

When the pulse width (2d) is equal to its maximum value of π radians, the peak value of the fundamental voltage is

$$E_{01m} = \frac{4E_s}{\pi}$$

If the pulse width is other than π radians, the peak value of fundamental

$$E_{01} = \frac{4E_s}{\pi}\sin d$$

Pulse Width Modulation

If $n\alpha = \pi$, $\alpha = \pi/n$ $\therefore$ i.e $2\alpha = \frac{2\pi}{n}$.

If $2\alpha = \frac{2\pi}{n}$, the nth harmonic is elliminated totally from the inverter output voltage.

To elliminate 5th harmonic

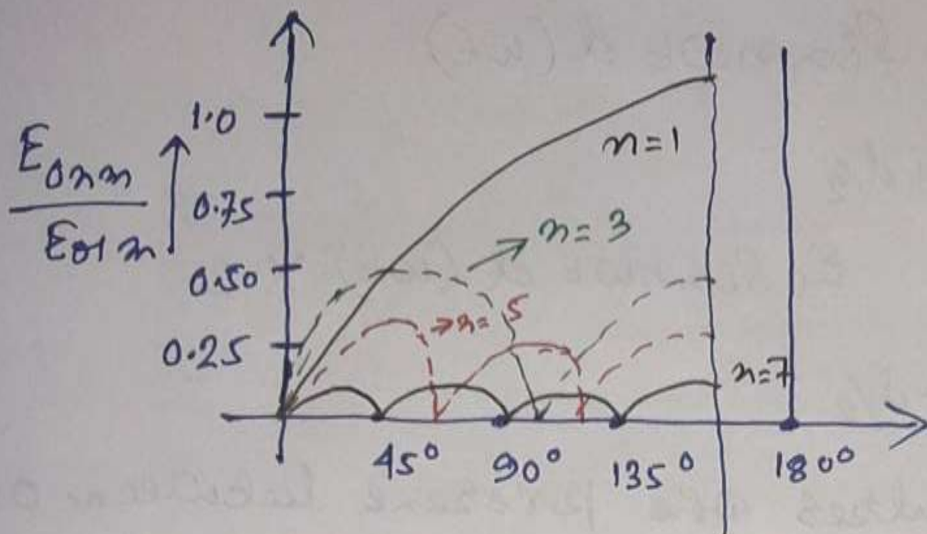
$$2\alpha = \frac{2\pi}{5} = 72^\circ$$

$$E_{onm} = \frac{4E_s}{n\pi} \sin n\alpha.$$

$$E_{o1m} = \frac{4E_s}{\pi} \quad \text{(1st harmonic)}$$

$$\frac{E_{onm}}{E_{o1m}} = \frac{\sin n\alpha}{n}.$$

Pulse Width Modulation



The RMS of the O/P Voltage

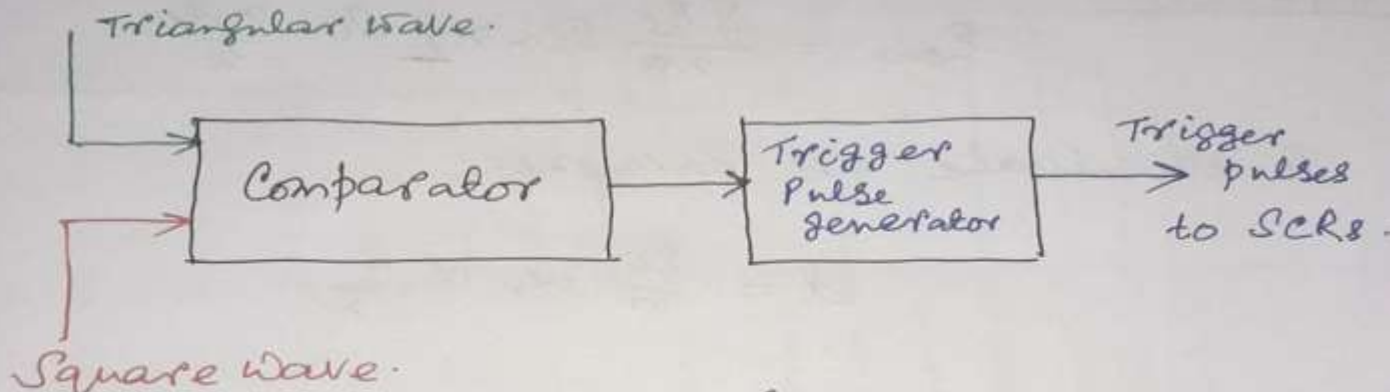
$$E_{or} = \left[\frac{E_s^2 \times 2d}{\pi}\right]^{1/2} = E_s \cdot \left[\frac{2d}{\pi}\right]^{1/2}$$

Pulse Width Modulation

Mutiple Pulse width Modulation (MPWM)

It is the extension of single pulse width modulation. The harmonic content can be reduced, by several pulses in each half cycle. In MPWM, several equidistant pulses per half cycle are used. This is also known as Uniform pulse width modulation (UPWM).

Pulse Width Modulation



$$E_0 = \sum_{n=1,3,5,7}^{\infty} A_n \sin n\omega t + \sum_{n=1,3,5,7}^{\infty} B_n \sin n\omega t.$$

$B_n = 0$. (Because of Symmetry)

Pulse Width Modulation

$$A_n = \left(\frac{2}{\pi}\right)\int_0^{\pi} E_0 \sin n\omega t \, d(\omega t)$$

$$= \left(\frac{2}{\pi}\right)\int_{\gamma - d/2}^{\gamma + d/2} E_s \sin n\omega t \, d(\omega t) \times 2$$

[Say two pulses are present between 0 to π for understanding.

$$A_n = \frac{4E_s}{n\pi}\Big[-\cos n\omega t\Big]_{\gamma - d/2}^{\gamma + d/2}$$

$$= \frac{8E_s}{n\pi}\sin n\gamma \cdot \sin\frac{nd}{2}.$$

$$E_0 = \sum_{n=1,3,5}^{\infty} \frac{8E_s}{n\pi}\sin n\gamma \sin\frac{nd}{2}\sin n\omega t.$$

$$= \frac{8E_s}{n\pi}\Big[\sin\gamma \sin\frac{d}{2}\sin\omega t + \frac{1}{3}\sin 3\gamma \sin\frac{3d}{2}\sin 3\omega t + \frac{1}{5}\sin 5\gamma \sin\frac{5d}{2}\sin 5\omega t + \cdots\Big]$$

Pulse Width Modulation

Amplitude

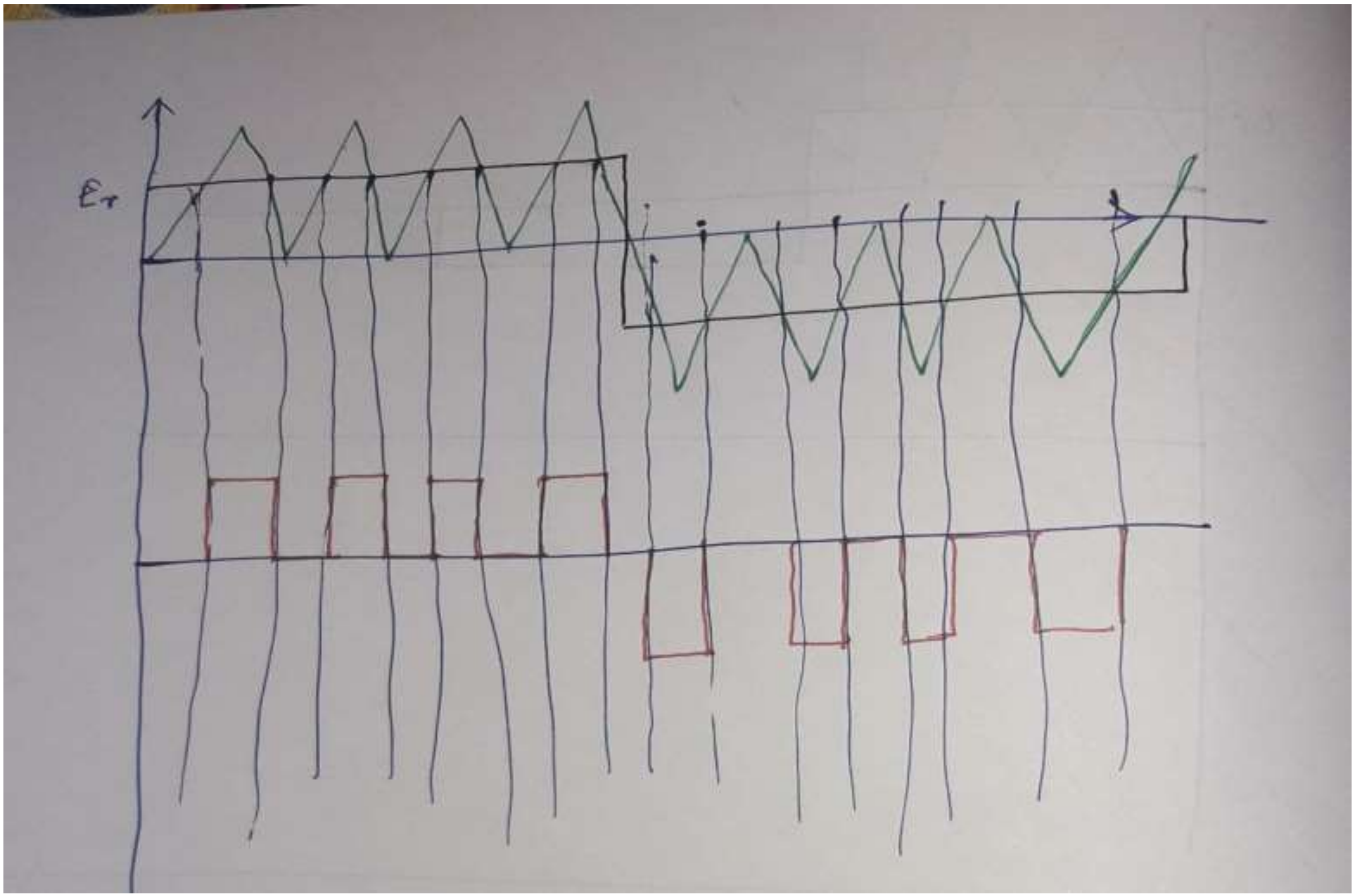
$$E_{on} = \frac{8E_s}{n\pi} \sin n\gamma \sin \frac{n\delta}{2}.$$

To eliminate nth harmonic,

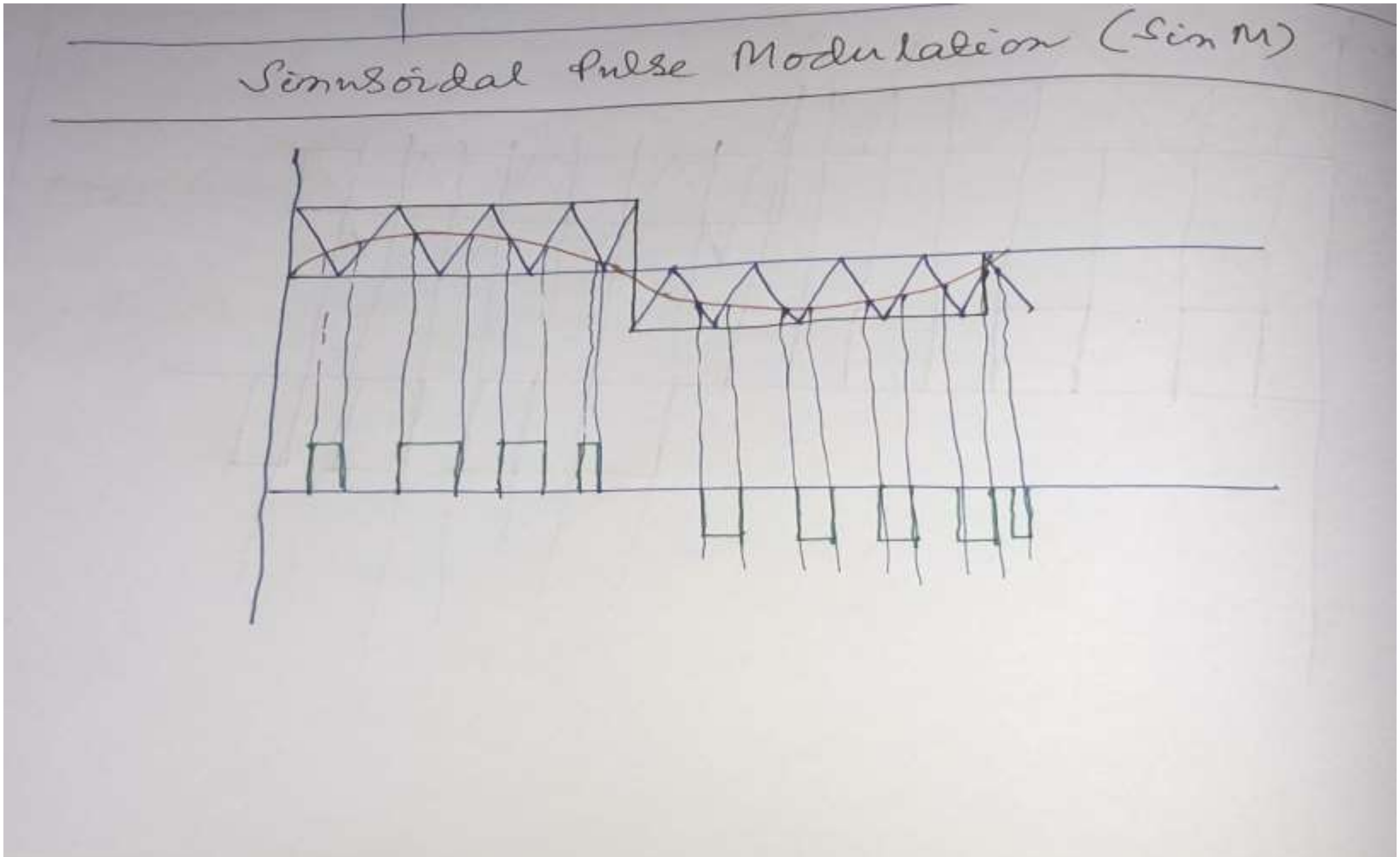
$$\delta = \frac{2\pi}{n} \text{ or, } \gamma = \frac{\pi}{n}.$$

$$E_{or} = E_s \left(\frac{2\delta}{\pi}\right)^{1/2}$$

Pulse Width Modulation



Pulse Width Modulation



Pulse Width Modulation

In this method of modulation also, number of pulses per each half cycle are used as in the case of multiple pulse modulation.

In the case of multiple pulse width modulation, the pulse width is equal in all the pulses.

But in this case the pulse width is a sinusoidal function of the angular position of the pulse in each half cycle.

In sinusoidal pulse width modulation, the modulation of triangular carrier signal of Amplitude Ac is carried by using a sinusoidal modulating signal.

The high frequency triangular carrier signal is compared with a sinusoidal reference signal.

Here also the intersection point of carrier and reference signals determines the switching and commutation of the modulated pulses.

Advantage.

Lower order harmonics are substantially reduced.