Re view :

1) If there are large no. of pulses/cycle, frequency of predominant harmonic can be ↑.

2) Sinusoidal PWM Technique:

$\rightarrow$ Modulating Wave: Rectified AC of 2F & variable amplitude.

$\rightarrow$ Δ wave of constant frequency & magnitude.

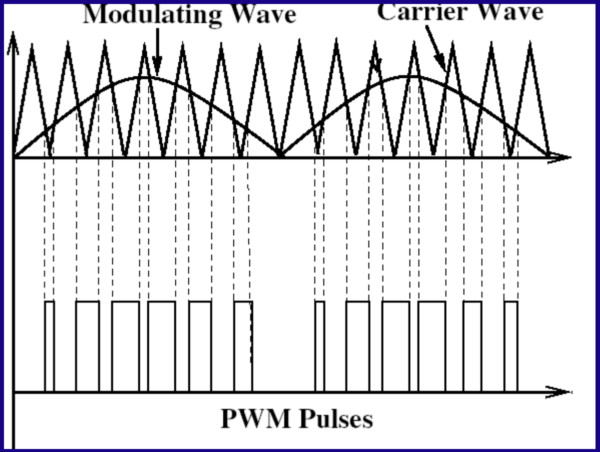
$\Rightarrow$ $F_{\Delta} >> F$

$\Rightarrow$ 'N' pulses / $\frac{1}{2}$ cycle

Freqency of predominant harmonic = $(N+1)F_S$

$\Rightarrow$ F_{Δ} is determined by the Power Rating and type of device.

How to vary the o/p voltage ?



o/p voltage $V_0 \propto m = \dfrac{A_m}{A_c}$

$\Rightarrow$ A_c is held constant.

$\Rightarrow$ As $A_m \uparrow, V_o \uparrow$ till m=1

$\Rightarrow$ Conduction has started at +ve zero crossing .

$\Rightarrow$ D.F =1

$\Rightarrow$ Using a filter (frequency is high), $I_{s1} \approx I_s$

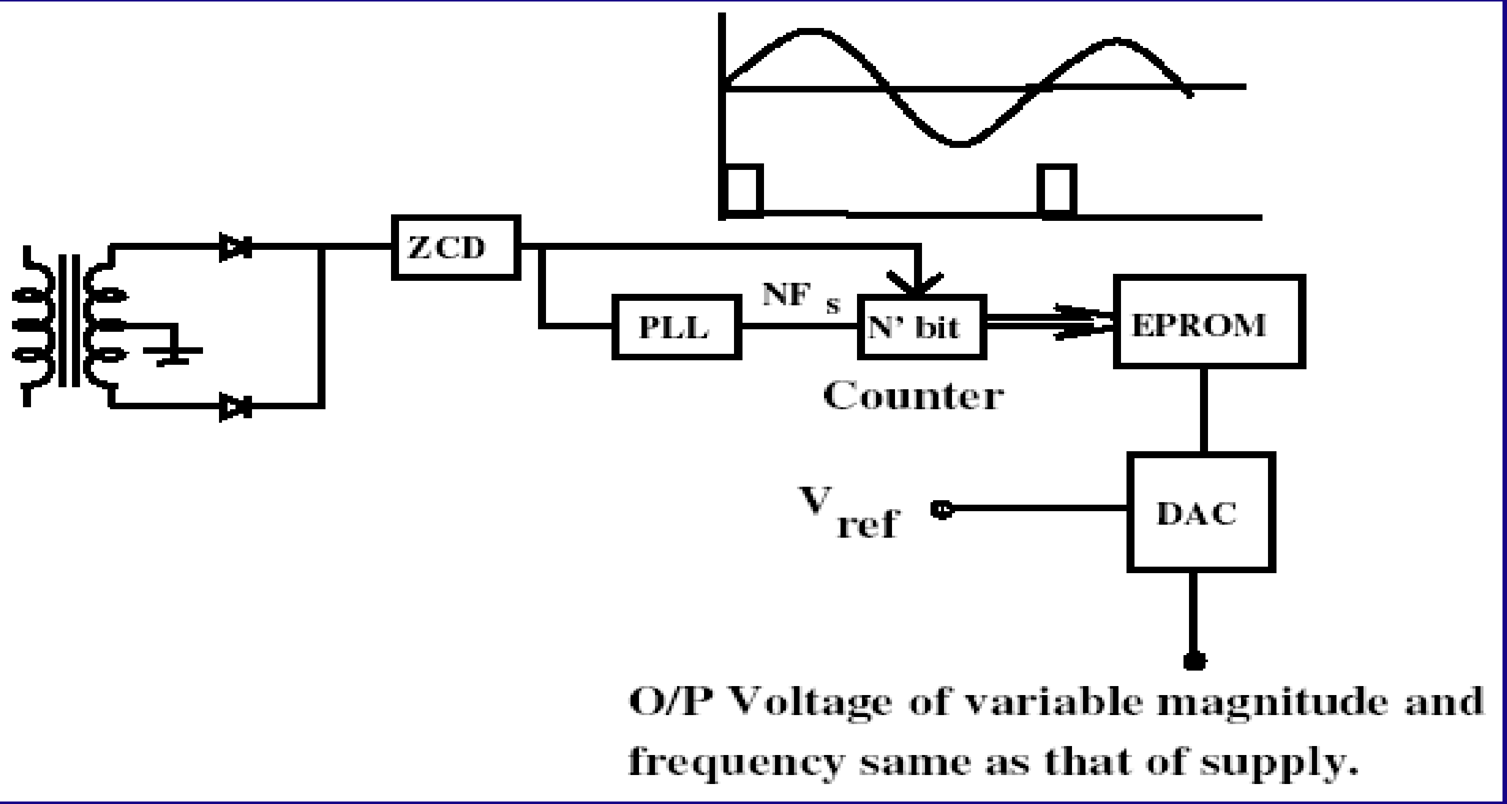
$\therefore$ P.F. $\rightarrow 1$

How to get a sine wave of variable magnitude & synchronized with the mains ?

$\Rightarrow$ Step down transformer & a potential divider.

$\Rightarrow$ Digital synthesizer.

Simple scheme:



→ Other sophisticated schemes using DSP are available.

Switched Mode Rectification:

To decrease THD of source I using low frequency passive elements:

$\Rightarrow$ Large size, weight.

$\Rightarrow$ size of passive elements $\downarrow$ IF converter devices are switched at high frequency.

$\Rightarrow$ size of L & C depend on switching frequency and NOT on source frequency.

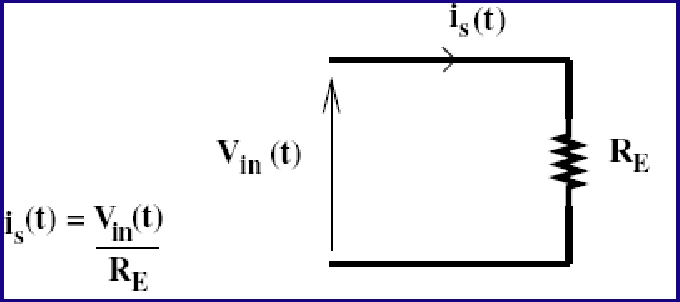
$\Rightarrow$ PWM recitifer $\rightarrow$ P.F. and THD improves.

$|V_o| < V_m$

$\Rightarrow$ Application requires constant DC power supply (Low ripple in V_0)

- Harmonics in source I should be low.
- Reactive VA should be minimum.

- ⇒ Desired that source P.F. = 1
- ⇒ Source I and V are in phase.
- ⇒ Rectifier system presents a resistive load to AC system.
- ⇒ R_E is the 'emulated resistance' of the converter.
- ⇒ Power is not dissipated as heat.
- ⇒ Transferred to the o/p port.
- ⇒ Model representation.



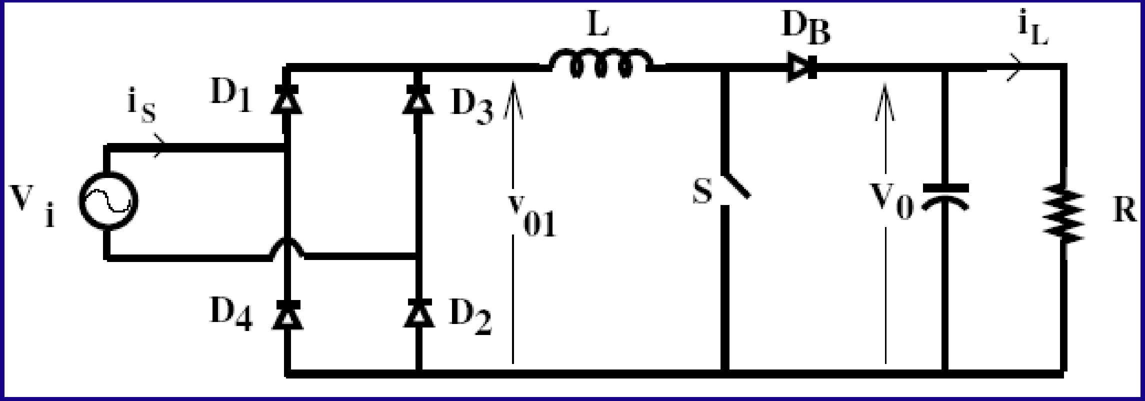
Single phase Switched Mode Rectifier:

Assume 'V_0' is constant and ripple free.

Keep 'S' open & the bridge is energized.

At steady state,

$$\text{Avg}(v_{01}) = \text{Avg}(V_0)$$

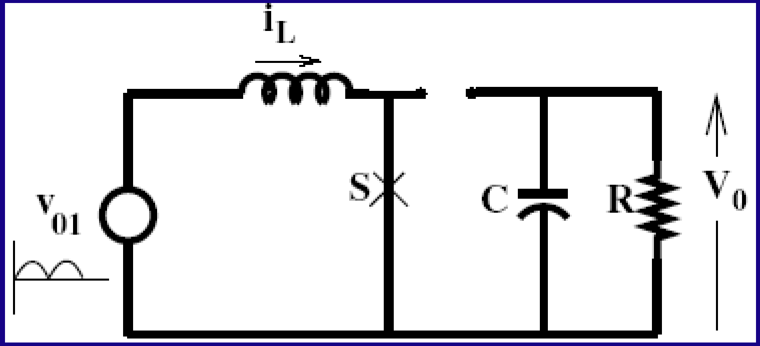


Switch 'S' is closed ON/OFF at a frequency >> F_s

$\Rightarrow$ Under this condition, 'v_{01}' is assumed to remain constant at a value = instantaneous value.

e.g.: at $\omega t = \frac{\pi}{2}$, $v_{01} = V_m$

at $\omega t = \frac{\pi}{3}$, $v_{01} = \frac{\sqrt{3}}{2} V_m$



$\Rightarrow$ When 'S' is closed, $V_L = v_{01} \rightarrow$ constant and +ve.

$i_L \uparrow$ linearly.

Cathode pot. of $D_B = V_0$ w.r.t -ve DC Bus.

$\therefore$ $V_{DB} = -V_0$ (Blocking State)

Capacitor supplies power to the load.

Open 'S':

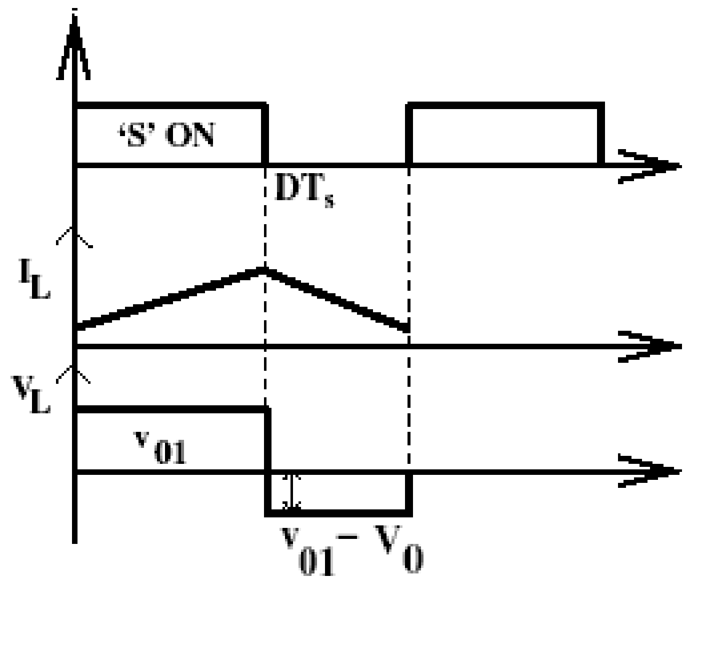
Stored energy in 'L' is transferred to the output.

$\Rightarrow$ i_L increases when 'S' is closed.

$\Rightarrow$ i_L should decrease when 'S' is opened.

$\Rightarrow$ $i(t) = i(t+T)$

$\Rightarrow$ V_L should be negative.



Let 'D' be the duty cycle.

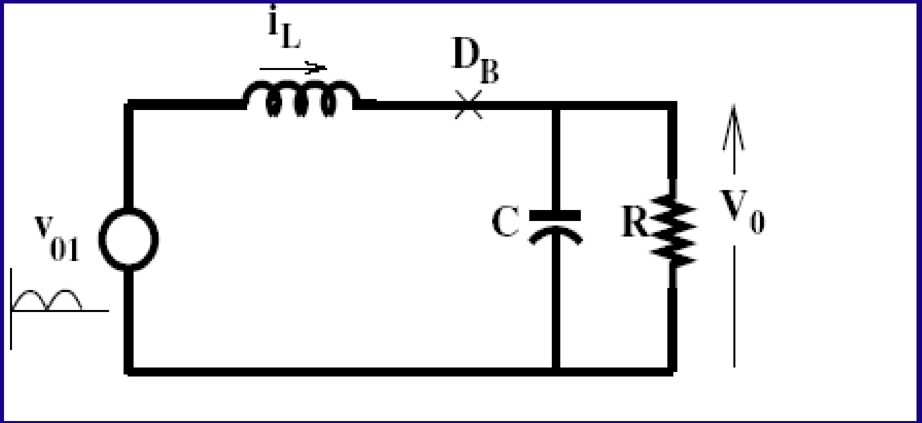
$$D = \frac{T_{ON}}{T_{ON} + T_{OFF}} = \frac{T_{ON}}{T_S}$$

Switch is ON for DT_S and OFF for $(1\text{-}D)T_S$

Assume that i_L is continuous.

Switch is OFF for $(1\text{-}D)T_S$.

$V_L = (V_{01} - V_0)$

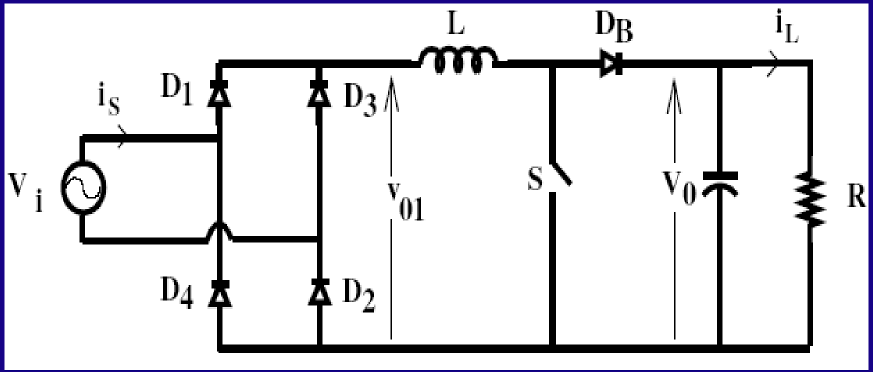


$\Rightarrow$ At steady state, V_L should be -ve during $(1\text{-}D)T_S$.

$\therefore\ V_0 > V_{01}$

$\Rightarrow$ Peak value of $V_{01} = V_m$

$\therefore\ V_0 > V_m$



⇒ **BOOST CONVERTER:**

$$V_{01}\,DT_s = (V_0 - V_{01})(1-D)T_s$$

$$\therefore V_0 = \frac{V_{01}}{(1-D)}$$

⇒ **Energy is stored in the inductor when 'S' is ON.**

⇒ **Stored energy is transferred to the load when 'S' is opened.**

How to choose D:

Case 1:

Switching frequency is held constant.

Also, keep D constant.

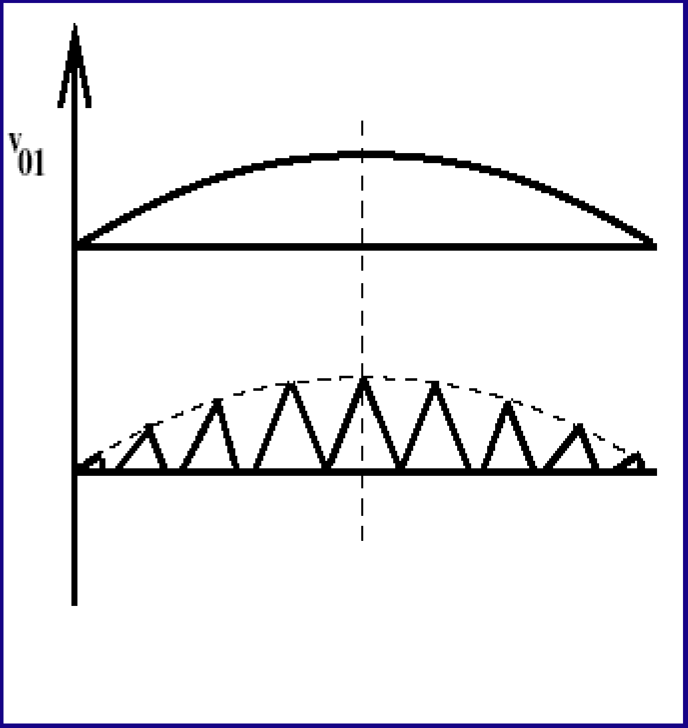
Choose D in such a way that i_L is

JUST CONTINUOUS at $\omega t = \dfrac{\pi}{2}$.

$\Rightarrow$ i_L will be discontinuous at $\omega t \neq \dfrac{\pi}{2}$.

$\Rightarrow$ $\dfrac{di_L}{dt}$ is maximum at $\omega t = \dfrac{\pi}{2}$ $(v_{01} = V_m)$

$\Rightarrow$ $\dfrac{di_L}{dt}$ is minimum at $\omega t = \dfrac{\pi}{2}$ $(V_0 - v_{01})$



$$i_{peak} = \frac{V_{01}}{L} DT$$

$$i_{peak} \propto V_{01}$$

$$\therefore \; \max(i_{peak}) \text{ is at } \omega t = \frac{\pi}{2}.$$

$$\Rightarrow \; -\frac{di_L}{dt} \text{ is max. when } |V_0 - V_{01}| \text{ is max.}$$

$$\Rightarrow \; V_0 \text{ is held constant.}$$

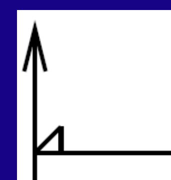
$$\Rightarrow \; -\frac{di_L}{dt} \text{ is max. when } V_{01} = 0 \text{ at } \omega t = 0, \pi$$

$+\dfrac{di_L}{dt}$ is min. near the zero crossing

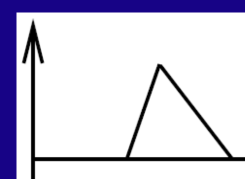
(for low values of ωt)

$-\dfrac{di_L}{dt}$ is max. near the zero crossing

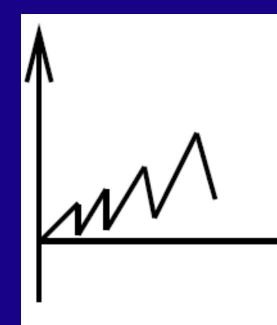
$\Rightarrow \; +\dfrac{di_L}{dt}$ is max. near $\omega t = \dfrac{\pi}{2}$



$\Rightarrow \; -\dfrac{di_L}{dt}$ is min. near $\omega t = \dfrac{\pi}{2}$



$\Rightarrow$ If i_L is JUST CONTINUOUS near the zero crossing as $\omega t \uparrow$ towards 90°, 'i' will be contiuous and may saturate the inductor.



$\Rightarrow$ **Peak value of 'i_s' is $\propto$ instantaneous value of V_i**

$\Rightarrow$ **displacement factor = 1**

$\Rightarrow$ **Using a small filter, high frequency components can be filtered out.**

$\Rightarrow$ **P.F. □ 1.**

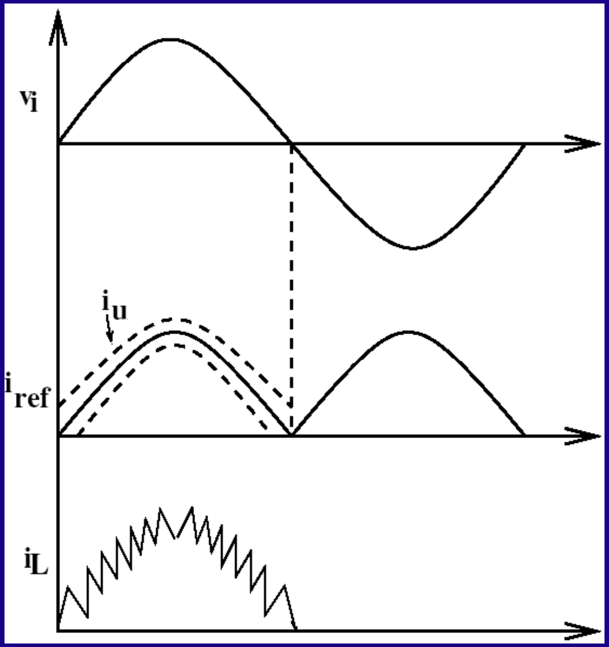
Case 2:

Take a Full wave rectified sine wave of required magnitude and in phase with v_{01}.

$\Rightarrow$ Call this as i^*_{ref}.

$\Rightarrow$ Choose an upper band $\rightarrow$ i^*_U & a lower band $\rightarrow$ i^*_L.

$\Rightarrow$ Measure inductor current and control it in such a way that it lies within i^*_U & i^*_L.



⇒ Closing 'S' increases i_L & opening 'S' decrease i_L.

⇒ When $i_L = i_L^*$, close 'S' ⇒ $i_L \uparrow$ and

$i_L = i_U^*$, open 'S' ⇒ $i_L \downarrow$.

⇒ i_L current □ rectified sinusoid

⇒ i_s □ sine wave.

⇒ Smaller the band, Higher the switching frequency.

⇒ Switching Frequency is function of Load.