Review :

1) One of the applications of fully controlled bridge in HVDC (preferred for bulk power transmission).

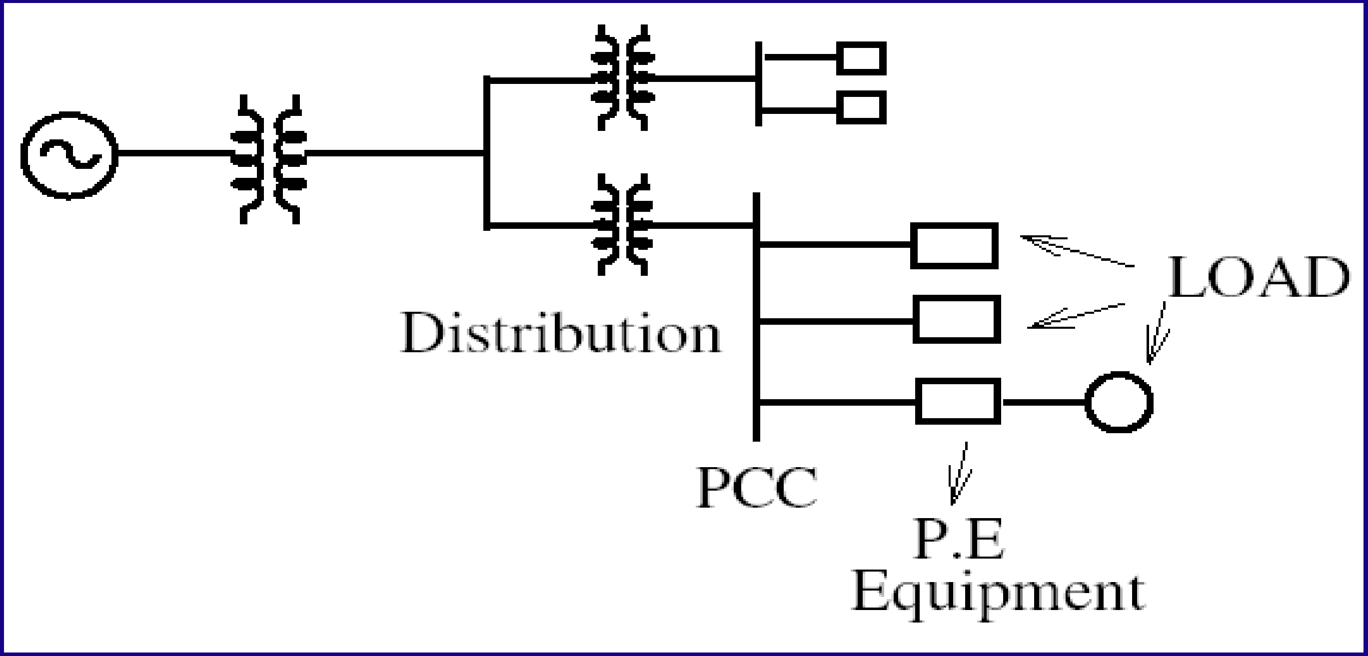
2) Main limitations of line commutated bridges are
   a. Low power factor.
   b. Harmonics.

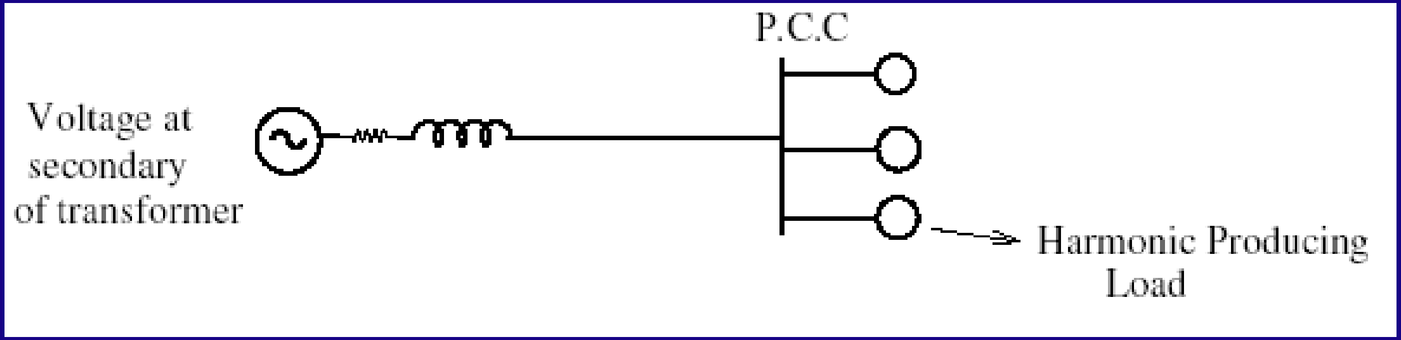
3) $$P.F = \frac{I_{s1}}{I_{rms}} \times D.F$$

$D.F = 1$; for 1-Φ uncontrolled bridge.

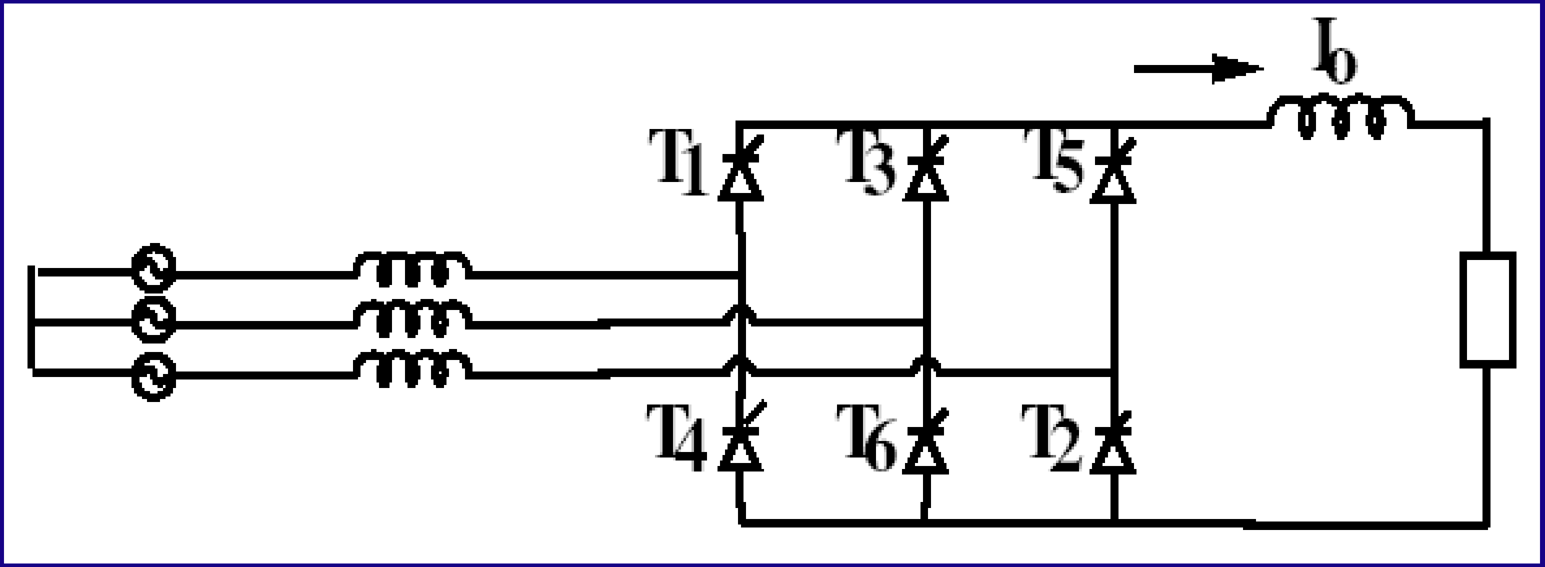
How to improve the P.F ?

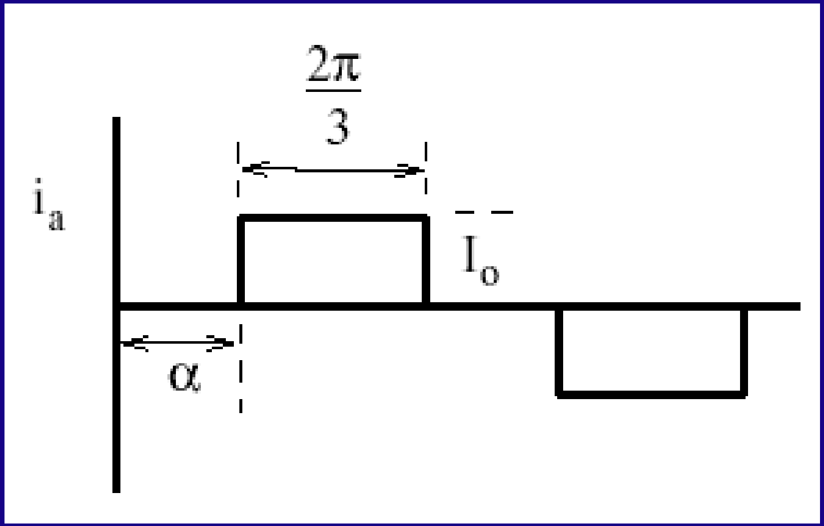
P.C.C → Point of common coupling

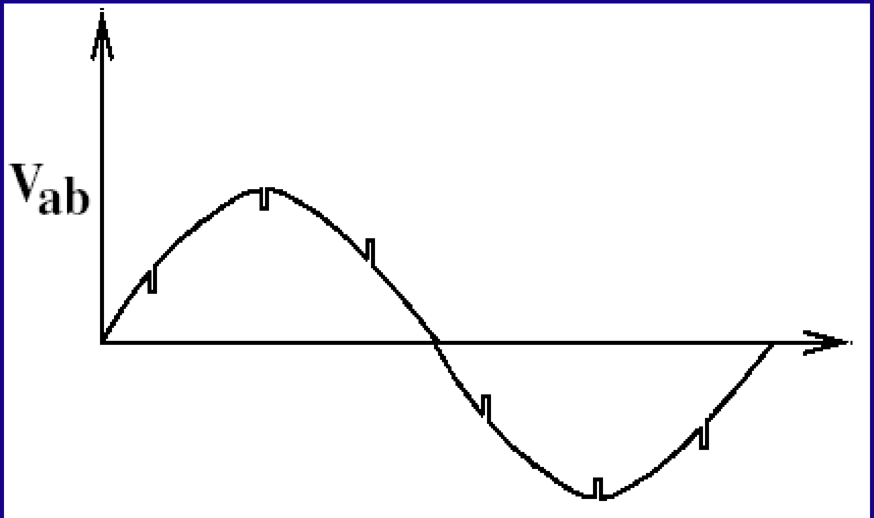




Current drawn by the load fed from P.E. equipment flows through system impedance.
Voltage at P.C.C is non-sinusoidal
(We had assumed that 'V' is sinusoidal).







$$i_a = \frac{2\sqrt{3}}{\pi} I_0 \left[\sin\omega t - \frac{1}{5}\sin 5\omega t + \frac{1}{7}\sin 7\omega t - \ldots\ldots\ldots\ldots \right]$$

$= 6N \pm 1$, Harmonics

$\Rightarrow$ Line Commutated converter $\rightarrow$ causes notches in the source voltage waveform.

$\rightarrow$ Source current has harmonics.

Effect of harmonics:

A. In the Rotating machine → Increases heating.
→ They produce noise.
→ Torque pulsations.

B. In Transformers → Cu losses ↑ .
→ Audible noise & heating.

C. In Cables → Additional heating.

D. P.F correction capacitors. → Thermal voltage stress.

E. Electronic Equipments → Affects control system.
→ Maloperation of relays.

Various IEEE & IEC standards (International Electro Technical commission) impose specific limits on the level of current harmonics & voltage notches.

Philosophy - "Prevents harmonic currents travelling back to power system and affecting other customers".

Voltage distortion at P.C.C. is of concern.

$\Rightarrow$ Depends on the short circuit current capacity at P.C.C.

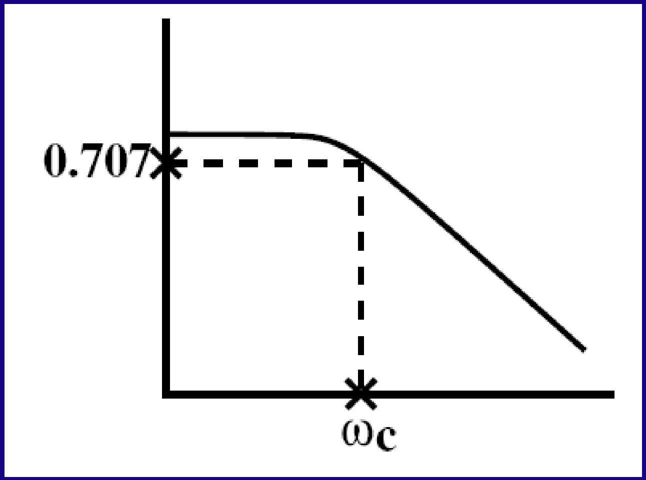
$\Rightarrow$ Stricter limits for low value of S.C. current capacity.

IEEE 519

Bus voltage	Max. Individual harmonic component(%)	Max. THD(%)
69kV	3	5

How to filter the source current :

1-Φ	3^{rd}	– 150Hz
	5^{th}	– 250Hz
3-Φ	5^{th}	– 250Hz
	7^{th}	– 350Hz



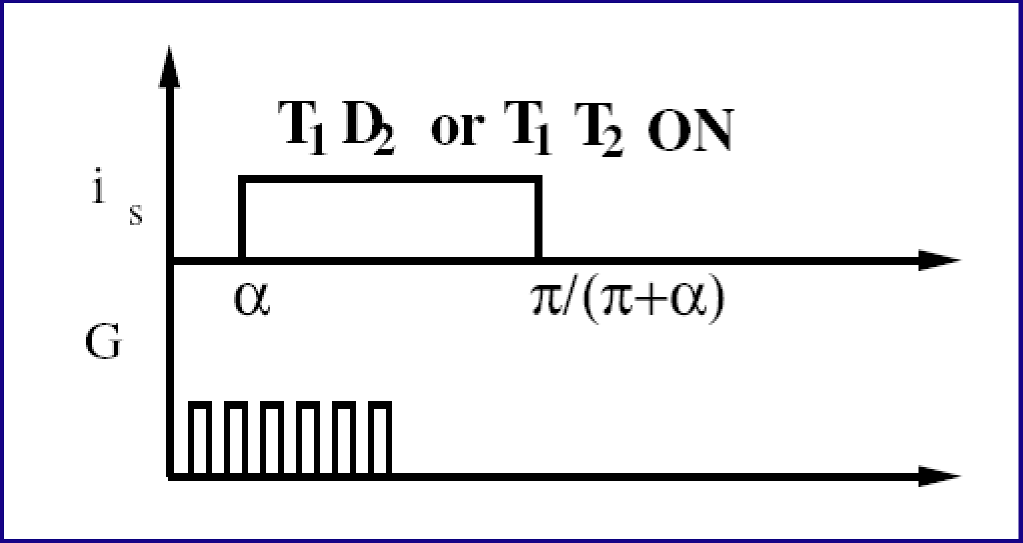
Use of L-C filter (2^{nd} order, -40 dB/decade),Fundamental should not get attenuated(1^{st} order is not possible).

$$\Rightarrow \omega_c = \frac{1}{\sqrt{LC}}$$

As $\omega_c \uparrow$, Size of L & C $\downarrow$.

$\Rightarrow$ There is only one pulse/$\frac{1}{2}$ cycle in input source current.

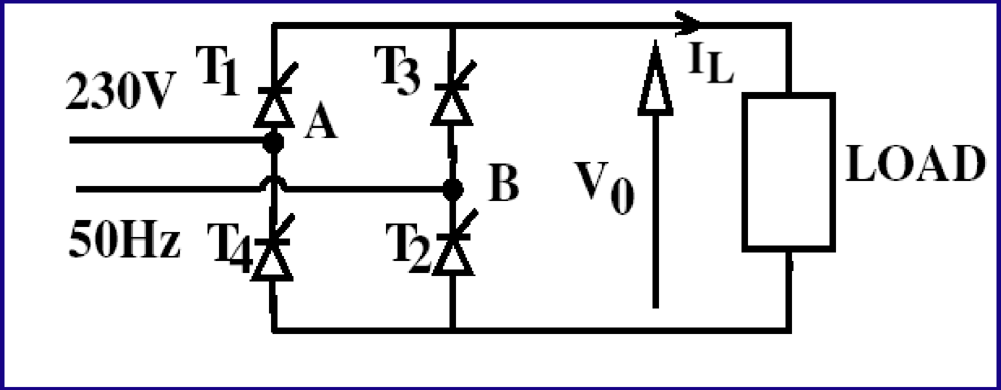
$\Rightarrow$ If there are large number of pulses/$\frac{1}{2}$ cycle, frequency of the predominant harmonic can be $\uparrow$.



$\Rightarrow$ To have large number of pulses / $\frac{1}{2}$ cycle

Devices should be turned ON/OFF

several times / $\frac{1}{2}$ cycle.



$\Rightarrow$ In the + ve half having triggered T_1 & T_2.

They cannot be turned off by triggering

T_3 T_4 till $\omega t = \pi^+$

(T_3 & T_4 cannot be turned ON).

$\Rightarrow$ Either apply $-$ve voltage across the conducting thyristor using additional voltage source & other passive elements(L & C) or use devices having Gate Turn $-$ OFF capability.(They should be able to withstand $-$ve voltage)

$\Rightarrow$ Self commutating devices

$\Rightarrow$ First option $\rightarrow$ Forced commutation

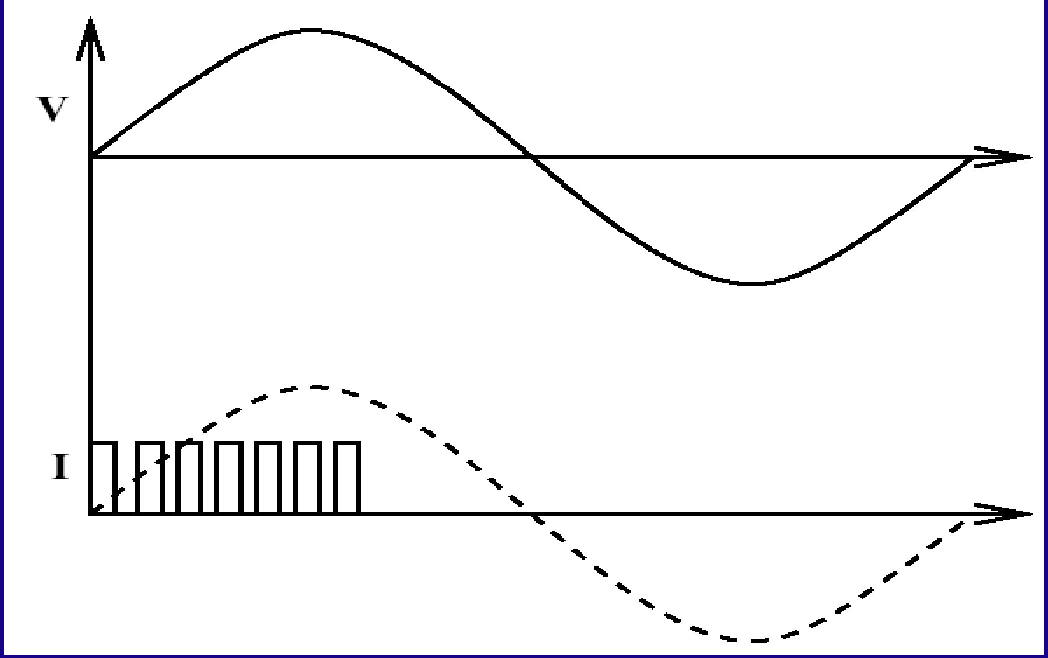
$\Rightarrow$ Size, Noise $\uparrow$

$\Rightarrow$ Second option $\Rightarrow$ Elegant, costly.

How many Pulses / $\frac{1}{2}$ cycle & what are the instants of turn ON/OFF.

$\Rightarrow$ Conduction should begin at $\omega t = 0^+$

So that $\varphi_1 = 0$ or D.F. $= 1$



Use Sinusoidal Pulse Width Modulation Technique to generate large No. of pulses.

$*$ Magnitude of lower order harmonics $\downarrow$ or $\rightarrow 0$

$*$ Magnitude of predominant harmonics $\uparrow$

$\because$ Frequency of predominant harmonics is high.

Size of filter component $\downarrow$

$$\omega_c = \frac{1}{\sqrt{LC}}$$

Sinusoidal PWM Techniques:

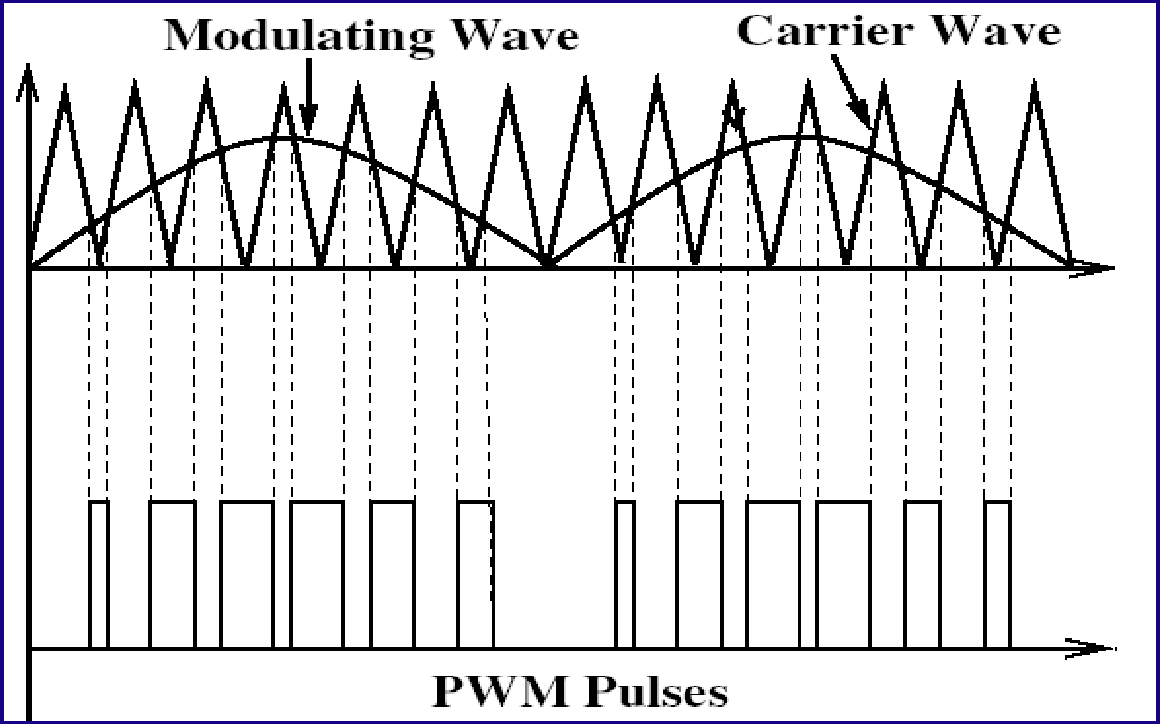
A. Full wave rectified sine wave of 2*supply frequency & variable magnitude$\left(A_m\right)$.

$\rightarrow$ Known as modulating wave.

B. High frequency triangular wave of fixed amplitude

$\rightarrow$ Known as carrier wave.

$\rightarrow$ Compared, intersection of sine wave with triangular wave determines the switching instants.



$\rightarrow$ o/p of the comparator has large number of pulses of varying width.

$\rightarrow$ How to distribute them $S_1 - S_4$?

$\rightarrow$ Modulating wave should be synchronized with the mains.

In the +ve half of input supply if S_1& S_2 are ON, source supplies power to the load.

⇒ Current is established in the load.

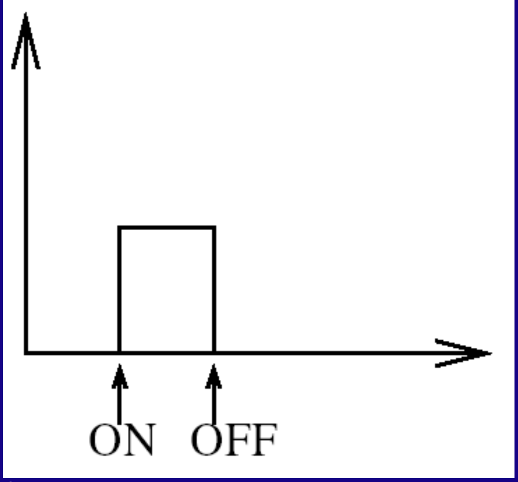
⇒ Assume load current is constant & ripple free
Alternative path for the load current should be provided while opening S_1& S_2.

⇒ Either have a freewheeling diode across the load

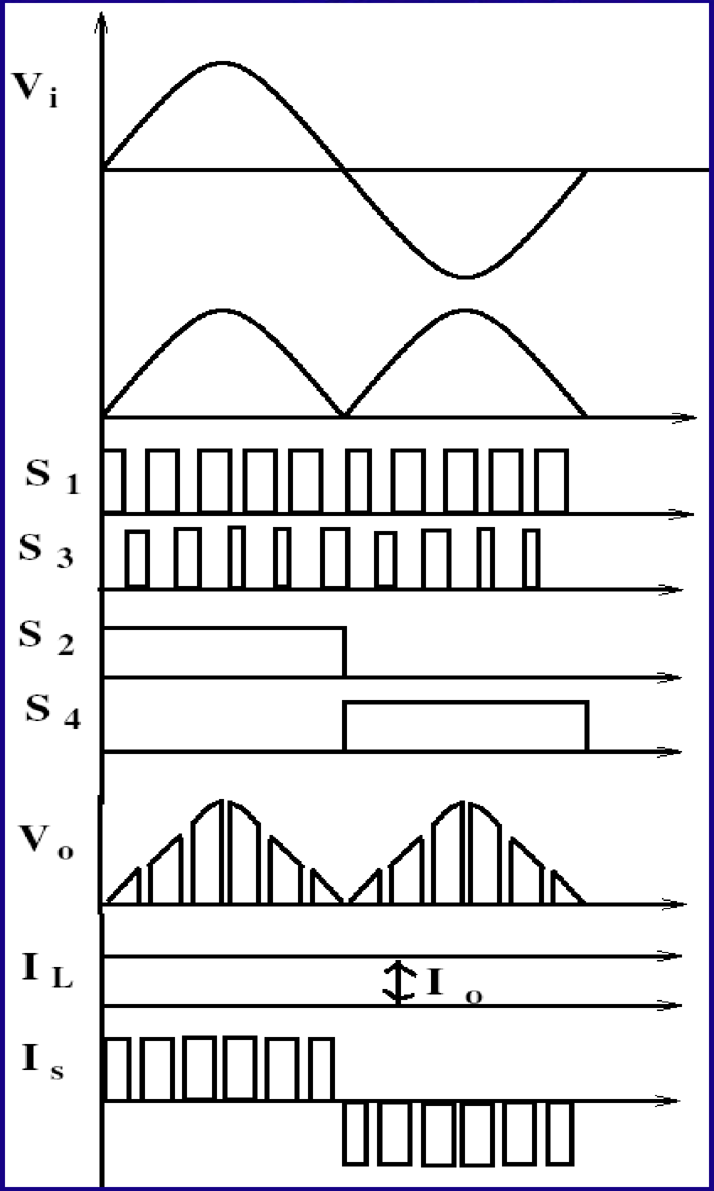
OR

Open S_1 only & close S_3

⇒ Load 'I' freewheels through S_2-S_3.



- $\Rightarrow$ In the + ve half keep S_2 permanently closed & swithching signals for S_1 & S_3 are complimentry. When S_1 S_2 are ON $V_o=V_i$, $i_s=i_L$ & S_2 S_3 are ON $V_o=0$ Similarly in the -ve half closing of S_3 & S_4 results in power transfer to the load.
- $\Rightarrow$ While opening S_3 close S_1.
- $\Rightarrow$ S_4 closed for entire π radians.



How to choose the no. of pulses/$\frac{1}{2}$ cycle

No. of pulses/$\frac{1}{2}$ cycle depends on frequency of triangular wave (Carrier wave).

$\Rightarrow$ It can be proved that if there are 'N' pulses/$\frac{1}{2}$ cycle,

Frequency of predominant harmonic$=(N+1)F$,

Where $F \rightarrow$ Frequency of the modulating wave or supply.

As $N\uparrow$, Frequency of predominant also $\uparrow$

$\Rightarrow$ Easier to Filter.

$\Rightarrow$ Switching loss $\uparrow$ (& $\therefore$ converter $\eta \downarrow$)

$\Rightarrow$ As $N\uparrow$ fast switching devices are required.