DC to AC Converter: Inverter

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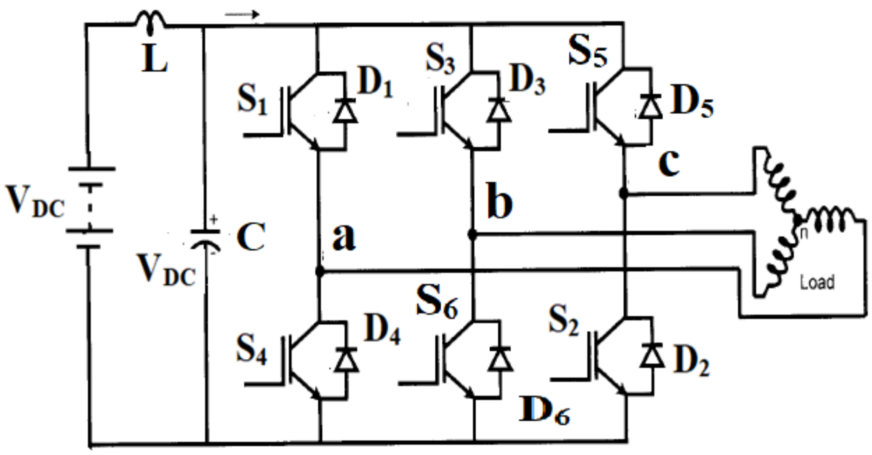
Three Phase VSI Bridge Inverter

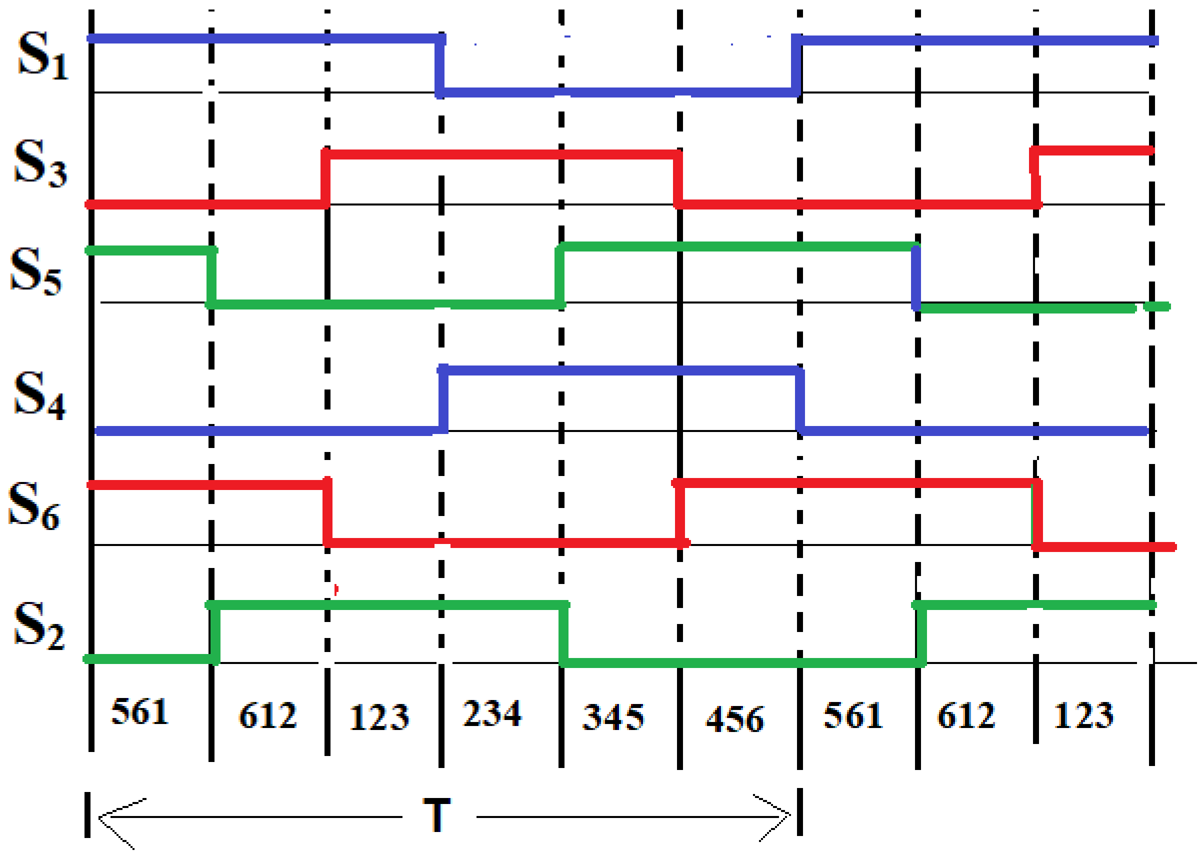
- It consists of 3 legs
- Devices are named as per conducting sequence
- Controlled quantities
  Voltage, frequency
  and phase sequence
- Operating modes

$180^0, 120^0$ and PWM



180^0 mode of conduction

- Switching signal



180^0 mode of conduction

- Each device conducts for 180^0
- One device from each leg is ON
- Three deices are on simultaneously
- Devices are named as per conducting sequence
- Dead time is required to avoid the short circuit of DC link
- Phase shift between the legs is 120^0.

180^0 mode of conduction

- V_{ab}

Switch ON	O/P Voltage
S_1 S_6	$+V_{DC}$
S_3, S_4	$-V_{DC}$
S_1 S_3 OR S_4 S_6	O

- V_{bc}

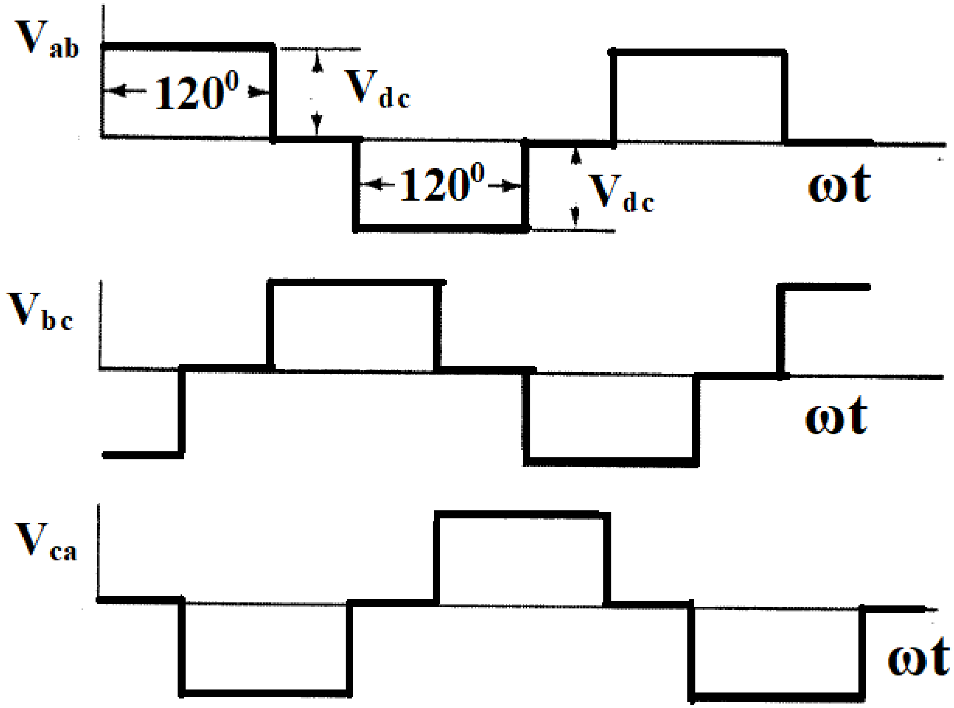
Switch ON	O/P Voltage
S_2 S_3	$+V_{DC}$
S_5 S_6	$-V_{DC}$
S_3 S_5 OR S_2 S_6	O

V_{ca}

Switch ON	O/P Voltage
S_4 S_5	$+V_{DC}$
S_1 S_2	$-V_{DC}$
S_1 S_5 OR S_2 S_4	O

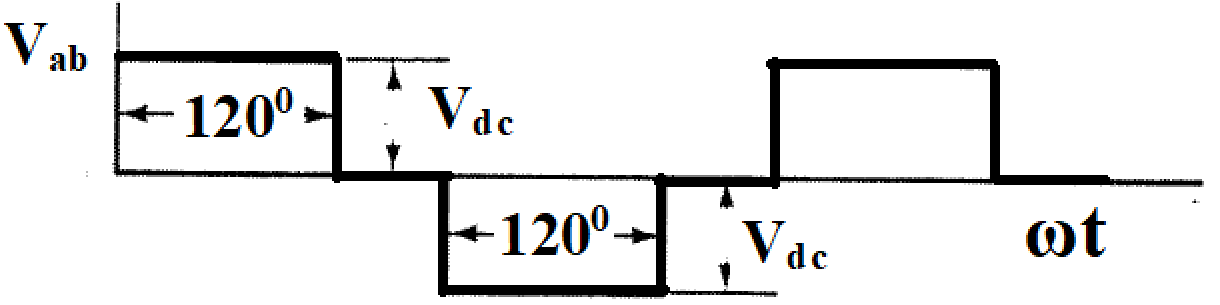
180^0 mode of conduction

- line voltages

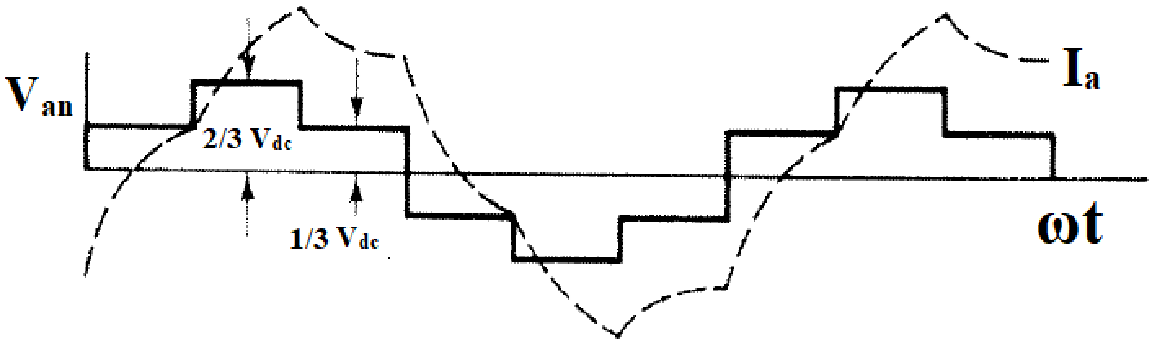


180^0 mode of conduction

- Line voltage

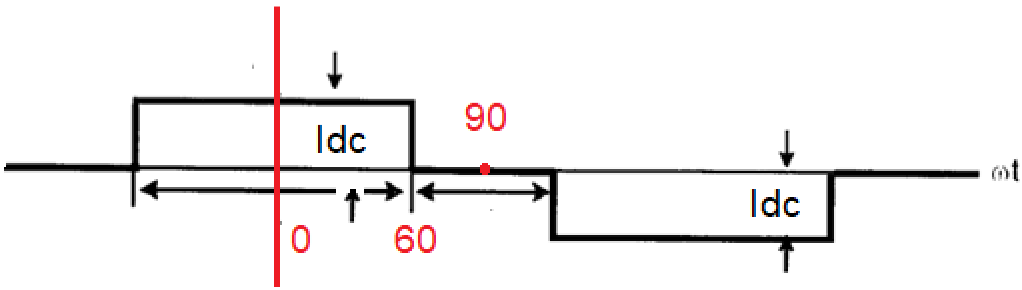


- Phase voltage



Harmonic spectrum of a waveform

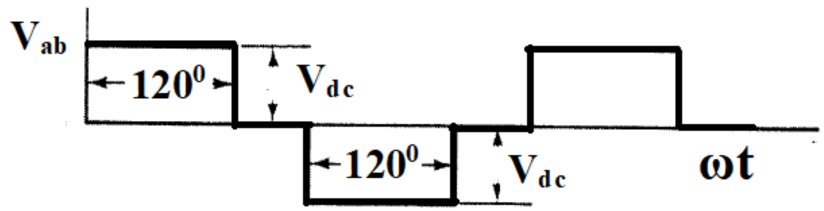
- $An = \frac{8}{2\pi} \int_0^{\pi/2} F(\theta) \cos(n\theta)\, d\theta$



- $An = \frac{8}{2\pi} \int_0^{\pi/3} Idc \cos(n\theta)\, d\theta$
- $A_n = (4/n\pi)\, I_{dc} \sin(n\pi/3)$
- $I^2 = I_1^2 + I_h^2$
- $A_1 = \frac{2\sqrt{3}}{\pi} I_{dc}$ $\qquad I_1 = \frac{\sqrt{6}}{\pi} I_{dc}$

180^0 mode of conduction

- Harmonic analysis
- It is also called as square wave inverter



- Harmonic spectrum is given by

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

- It contains 6m+1 and 6m-1 harmonics
- THD = 30.4%

180^0 mode of conduction

- o/p voltage

$$\text{R.M.S of L-L is } \sqrt{\frac{2}{3}}\, V_{dc} = 0.816\, V_{dc}$$

- Fundamental component of line voltage

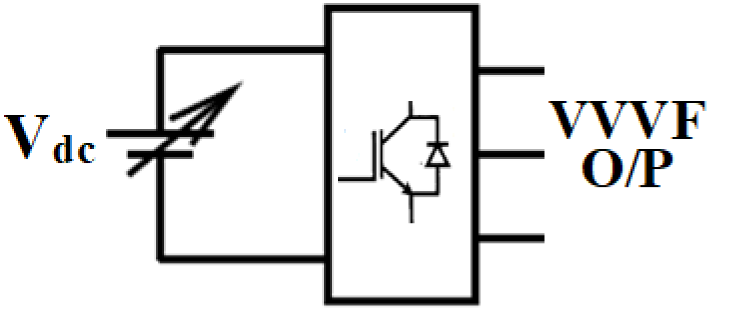
$$\text{Fundamental} = \frac{\sqrt{6}}{\pi} V_{dc} = 0.78\, V_{dc}$$

180^0 mode of conduction

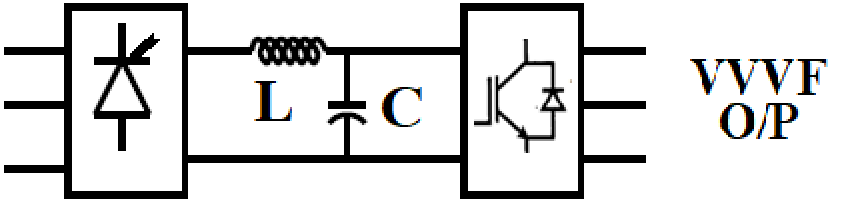
- O/P voltage control by controlling the input dc voltage applied to the inverter.
- Switching signal will not control the output voltage
- Switching signal will control the o/p frequency
- It is controlled by controlling T period of the switching signal

180^0 mode of conduction

- Variable voltage can be obtained from converter

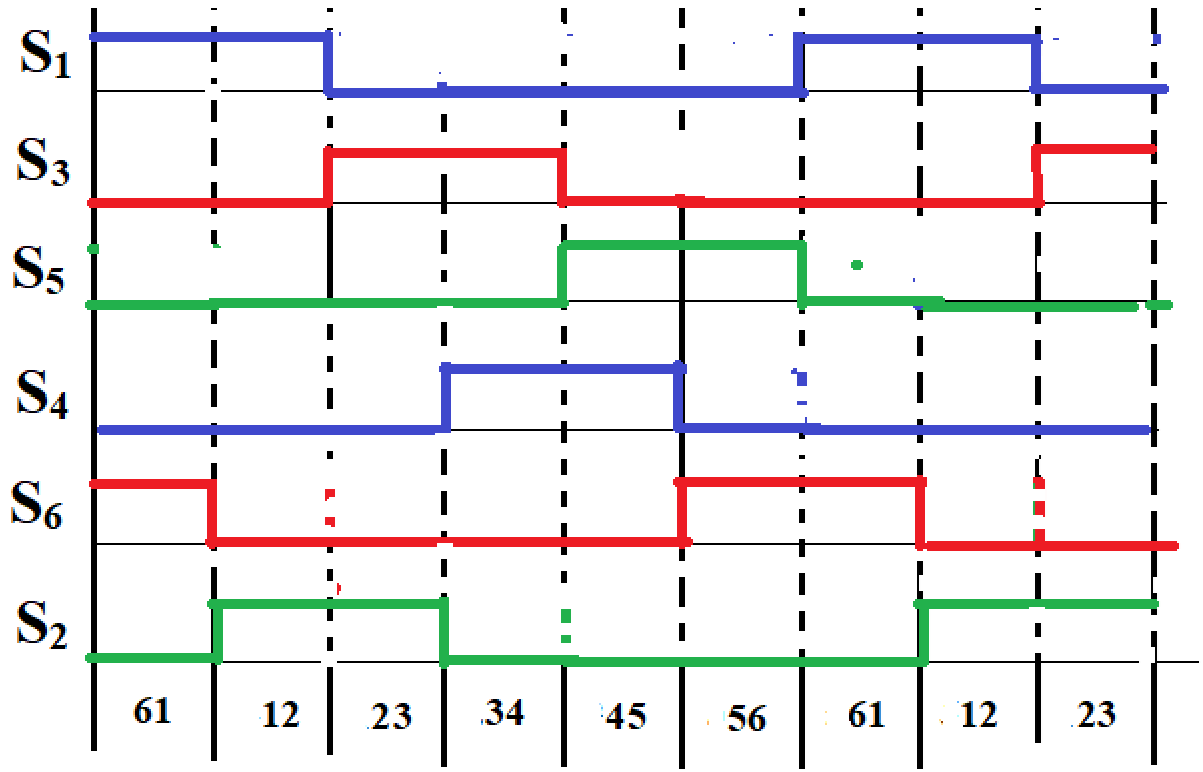


- As Vdc decreases α increase and PF decreases



120^0 mode of conduction

- Switching signal

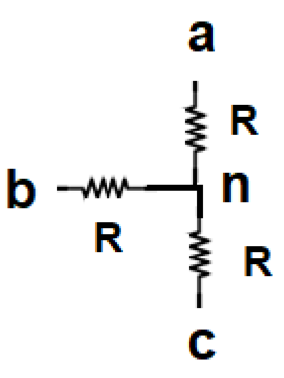


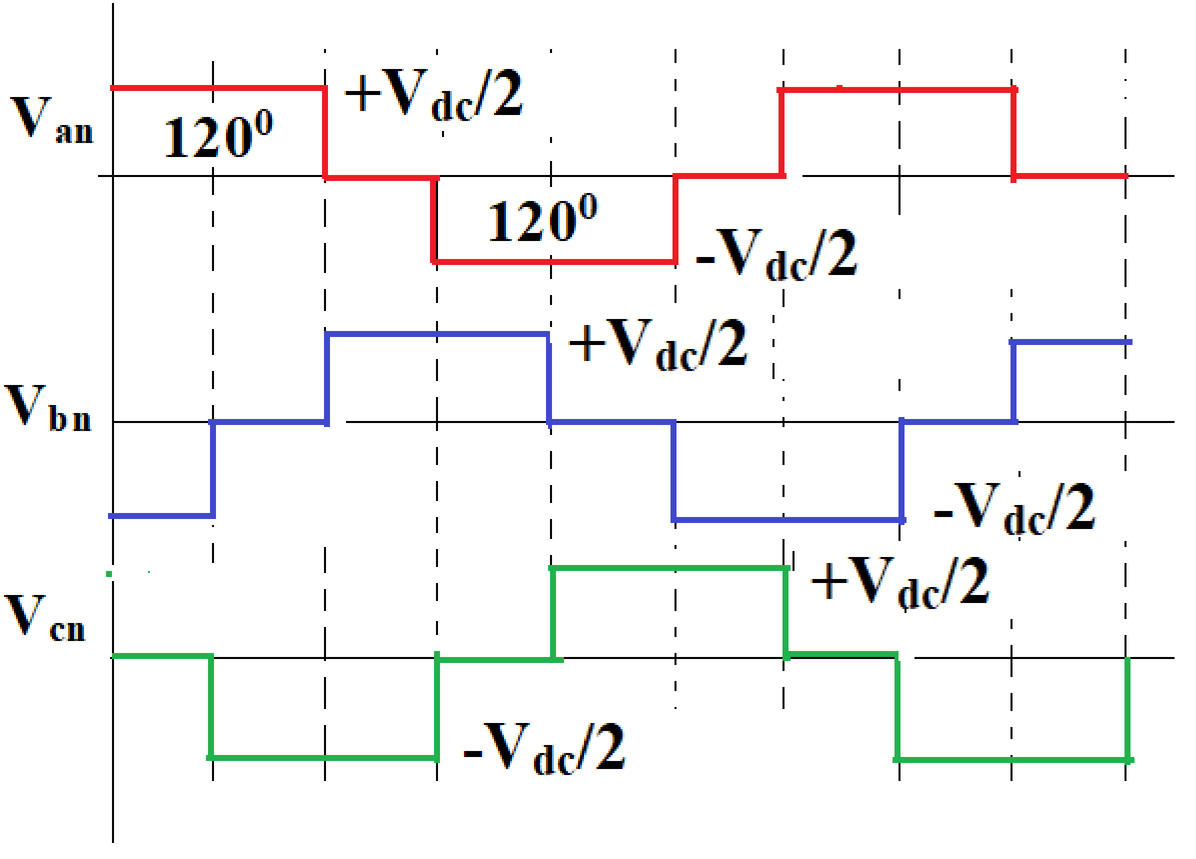
120^0 mode of conduction

- Each device conducts for 120^0
- Two deices are on simultaneously
- Devices are named as per conducting sequence
- Dead time is not required
- Phase shift between the legs is 120^0.

120^0 mode of conduction

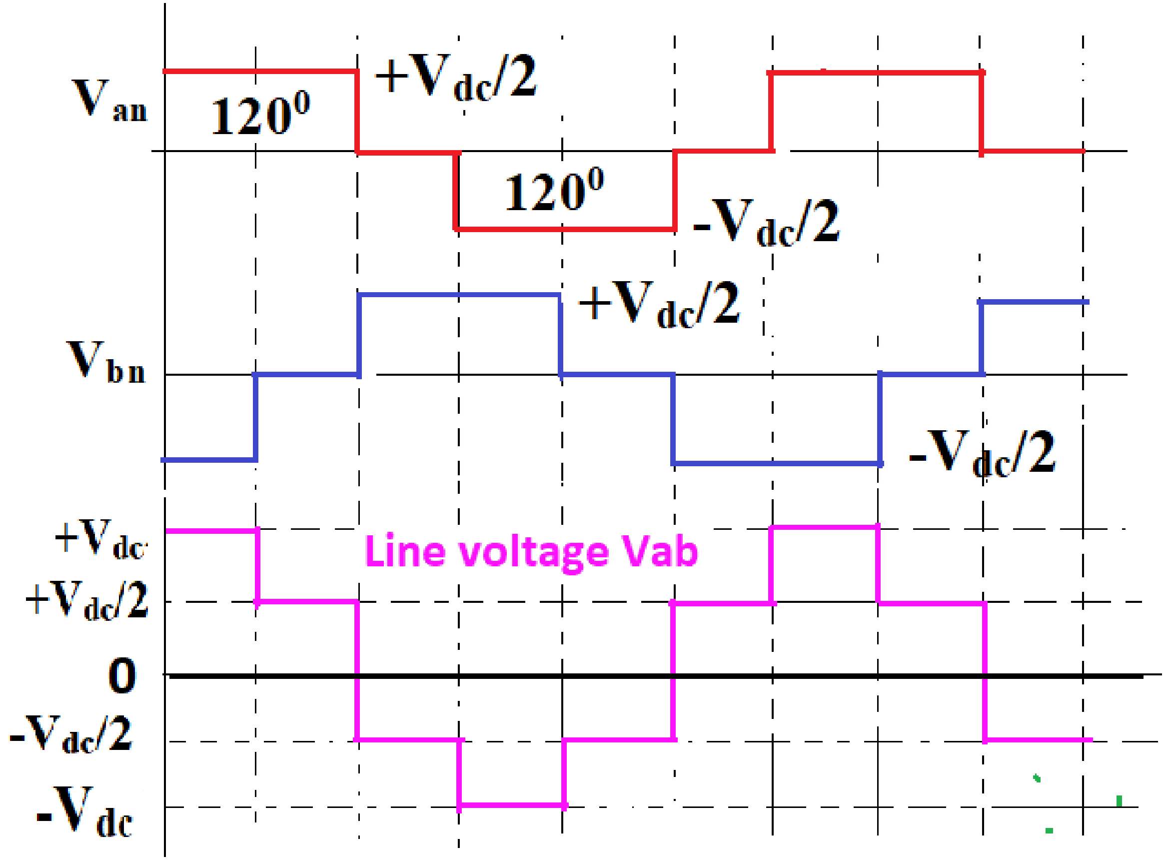
- Phase voltages





120^0 mode of conduction

- Line voltages

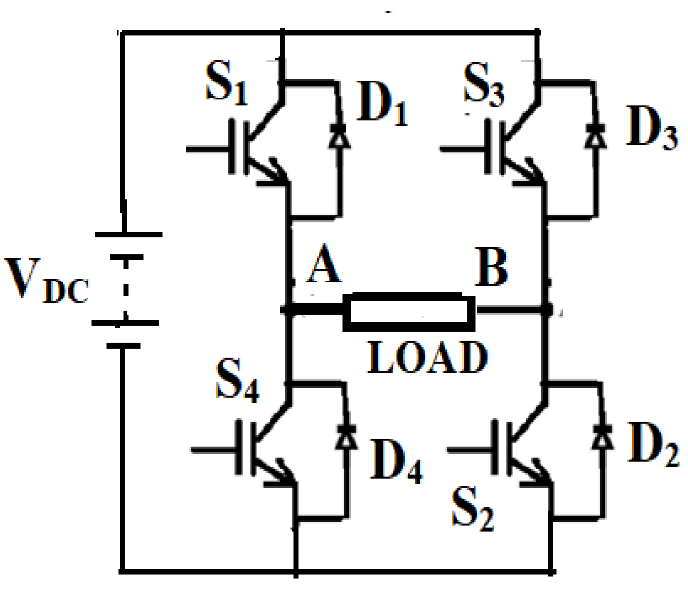


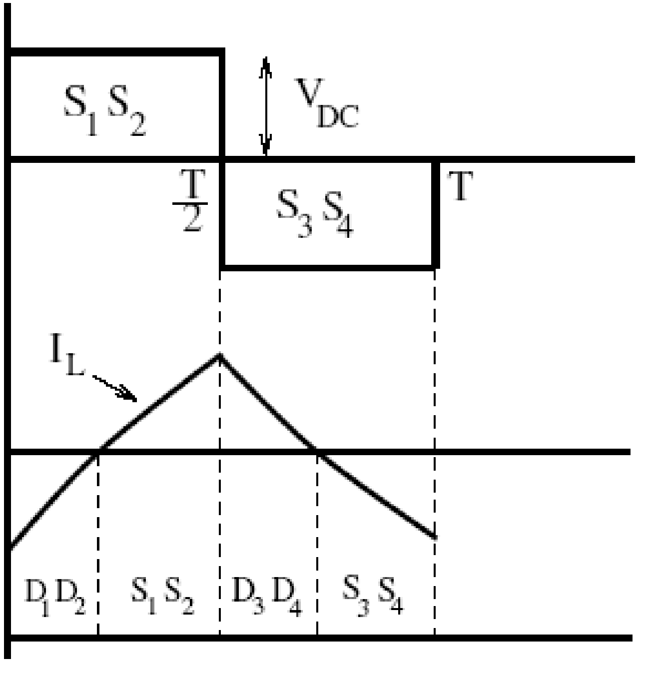
120^0 mode of conduction

- Disadvantages
- Output voltage is less as compared to square wave inverter.

1ϕ full bridge Inverter

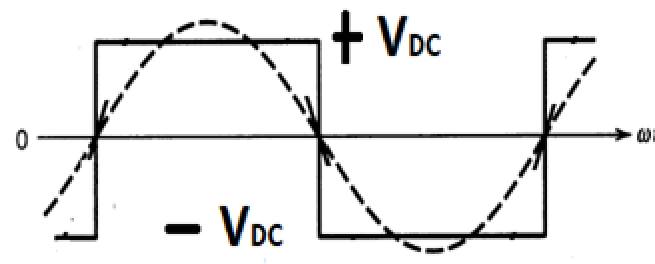
- Square wave Mode
- Two devices are conducting simultaneously
- Center point of DC link is not required

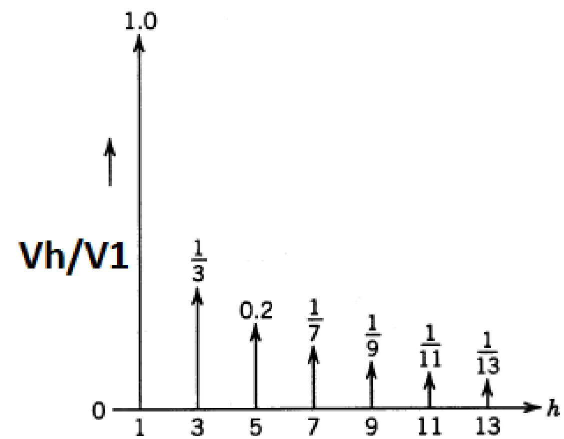




1ϕ full bridge Inverter

- Output voltage and harmonic spectrum
- Output voltage is square wave (V_{DC} Amplitude)
- It contains all
- odd harmonics
- V_1 peak = $4Vdc/\pi$
- THD is 48 %
- AC o/p voltage(rms) = V_{DC}



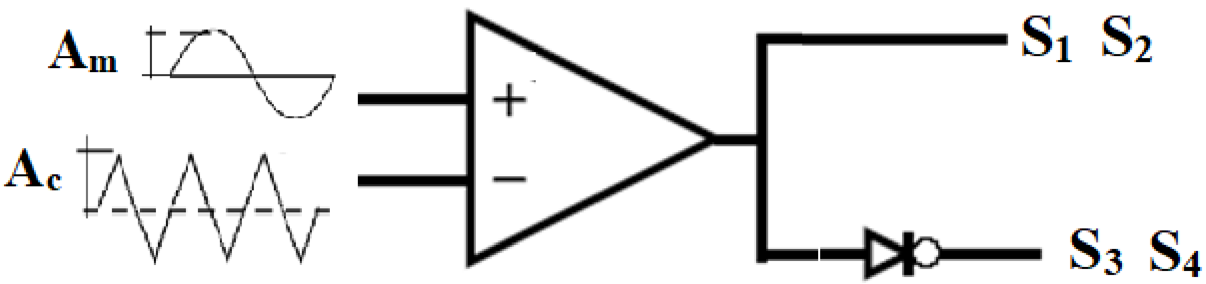


1ϕ full bridge Inverter

- Square wave mode
- Output is square wave and contains harmonics, THD = 48%
- Output voltage control within inverter is not possible.

PWM Switching

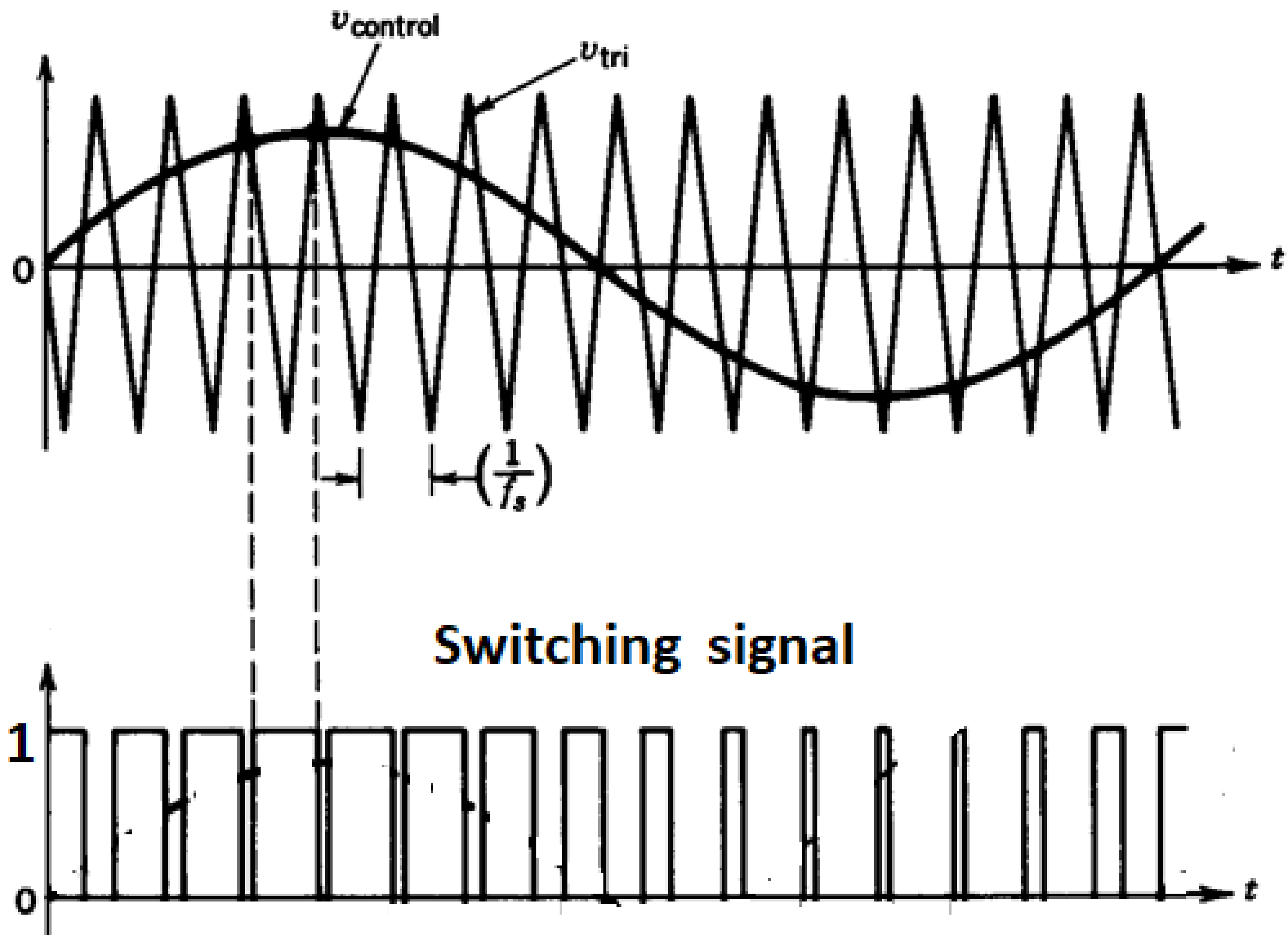
- 1ϕ Bridge Inverter – bipolar switching



- Switching signals are obtained by comparison of modulating (sine) wave with carrier (triangular) wave.

PWM Switching – Bipolar switching

- Switching signal for S1 and S2

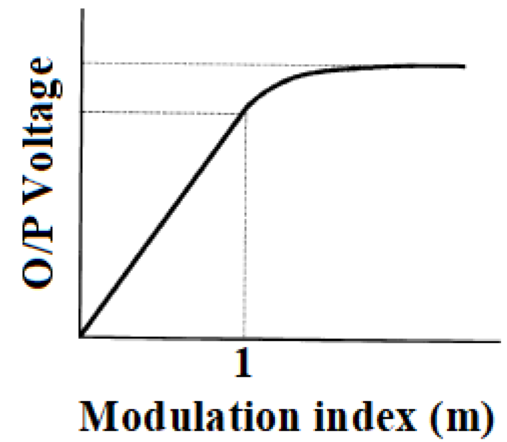


PWM Switching – Bipolar switching

- Modulating (sine) wave: Its frequency and amplitude can be changed
- Carrier (triangular) wave : Its frequency and amplitude is fixed.
- Modulation index $m = A_m / A_c$
- Output frequency is same as modulating wave frequency.
- Switching frequency of inverter depends upon carrier wave frequency

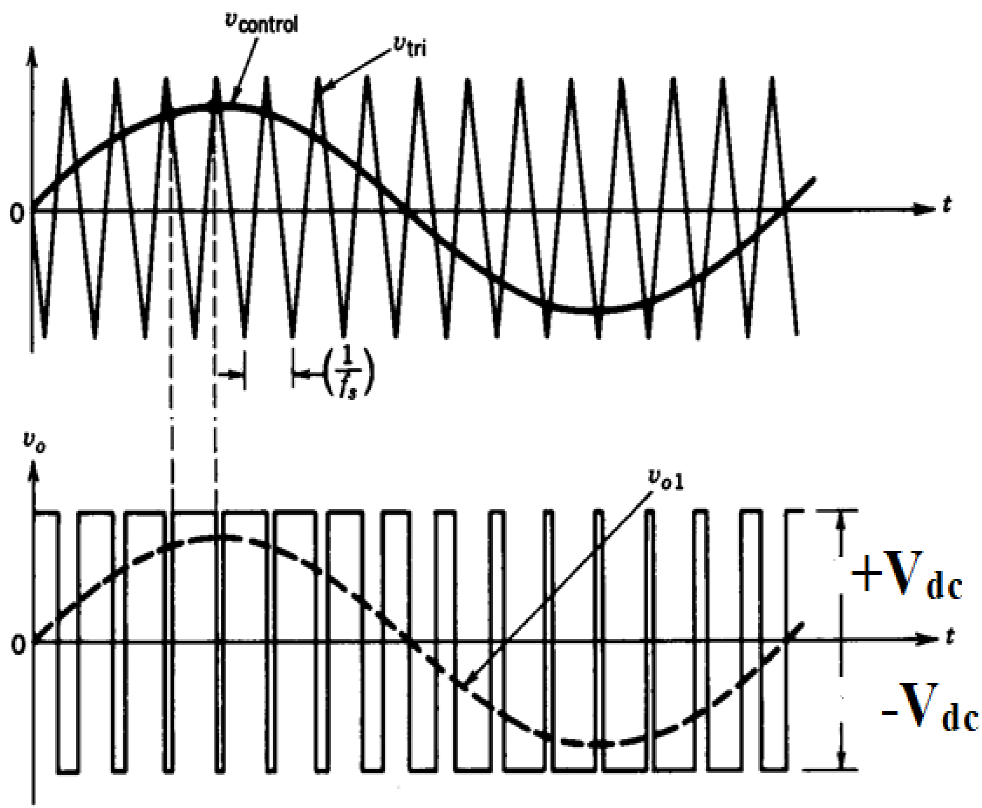
PWM Switching – Bipolar switching

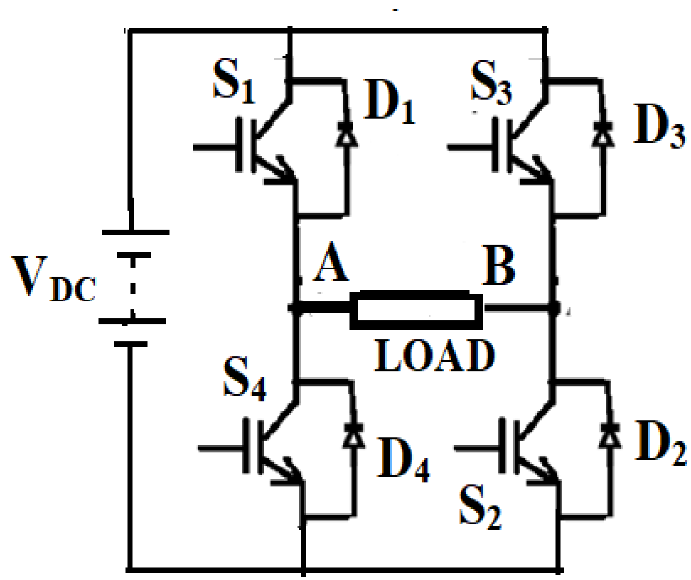
- Output voltage is proportional to m
- M is controlled by
- Controlling amplitude of
- Modulating wave



PWM Switching – Bipolar switching

- Bipolar switching

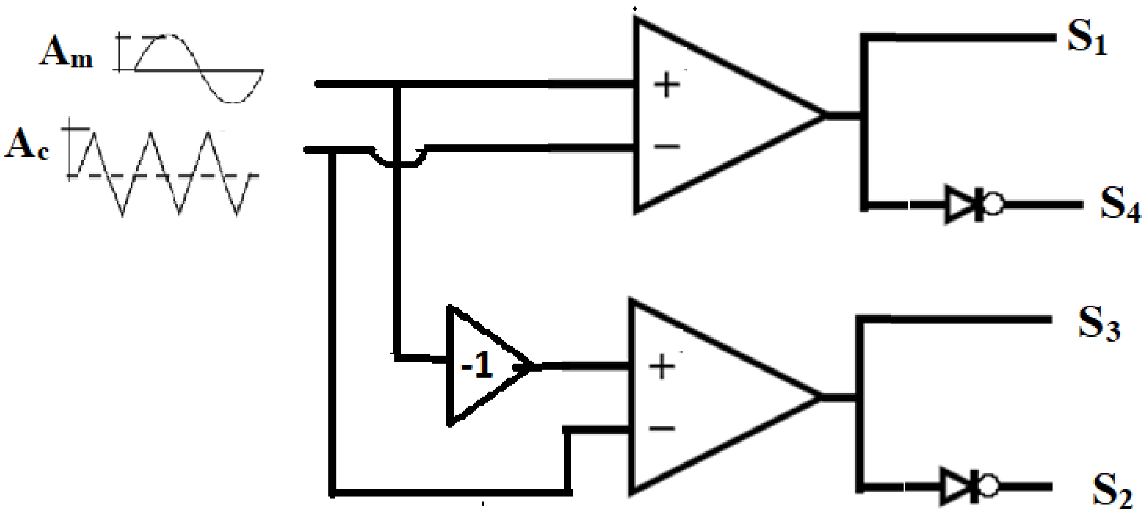


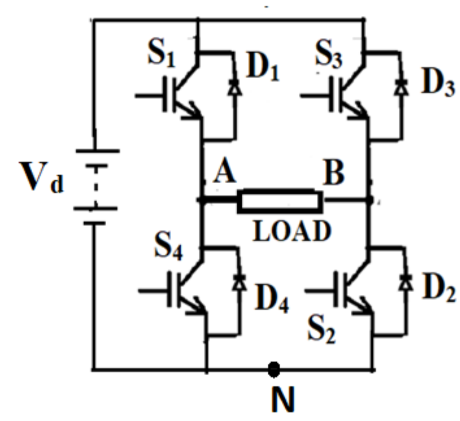


On switches	O/P Voltage
S1 and S2	$+ V_{DC}$
S3 and S4	$- V_{DC}$

Unipolar PWM Switching

- switching signal generation

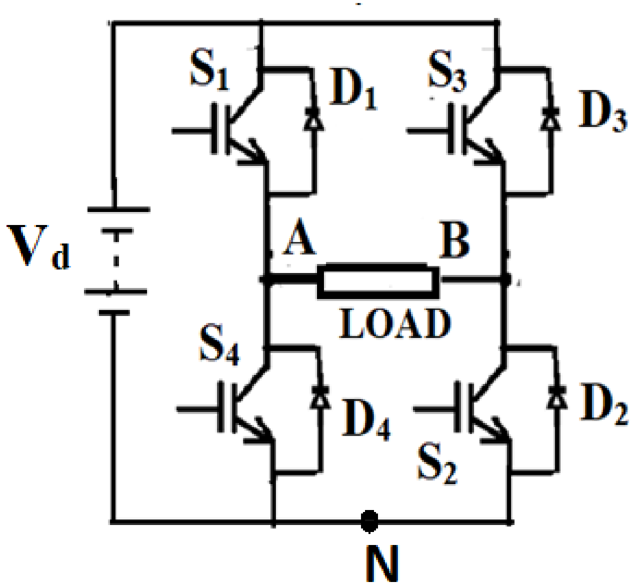


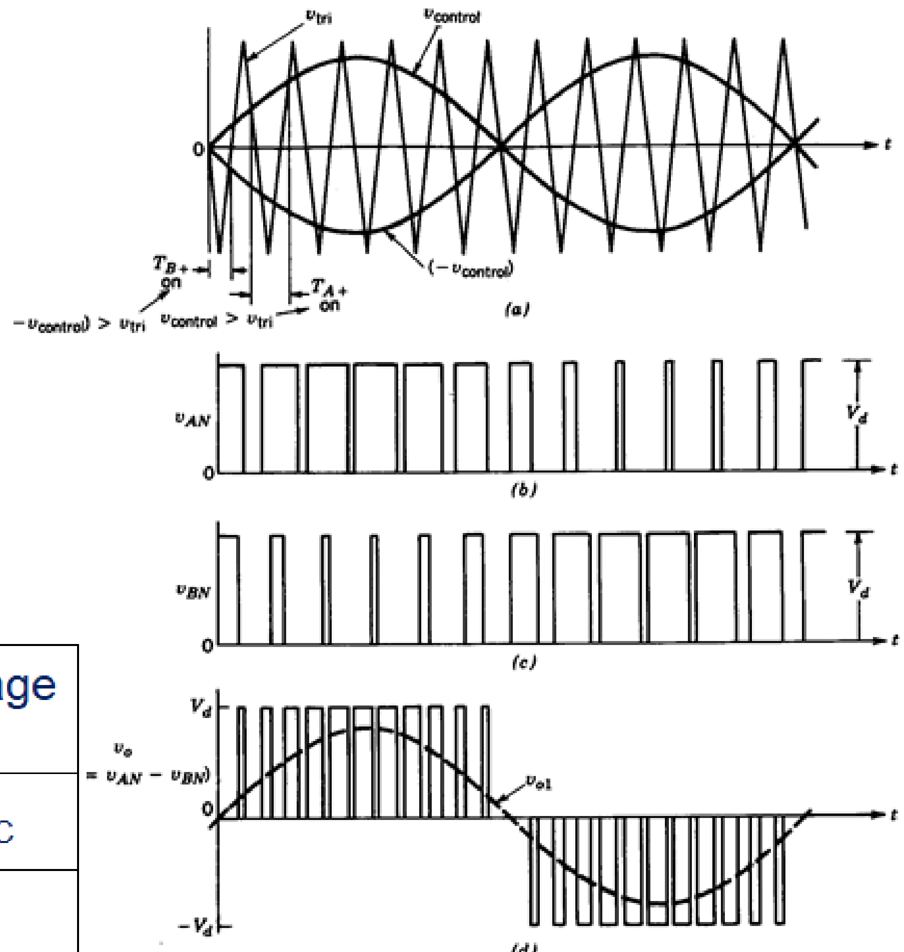


- It requires two modulating waves which are out of phase
- One leg is controlled by one modulating wave

Unipolar PWM Switching

- Output voltage





On switch	Voltage Van
S1	+ V_{DC}
S4	0

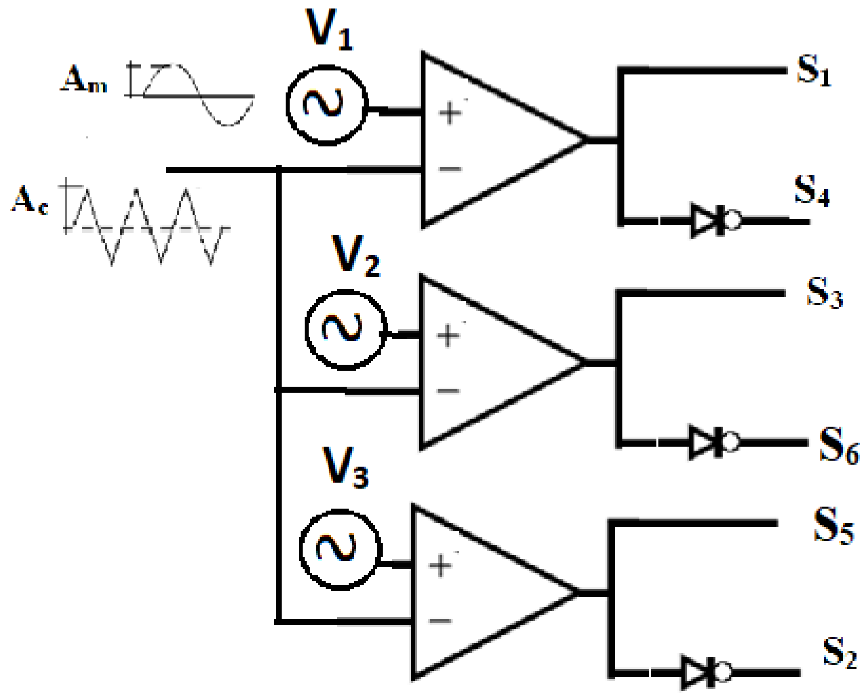
On switch	Voltage Vbn
S3	+ V_{DC}
S2	0

PWM techniques for 3ϕ Bridge inverter

- Various PWM techniques
- Sinusoidal PWM (SPWM)
- Selective harmonic elimination (SHE) PWM
- Space vector PWM (SVM)
- Hysteresis band current controlled PWM
- Sinusoidal PWM with instantaneous current control

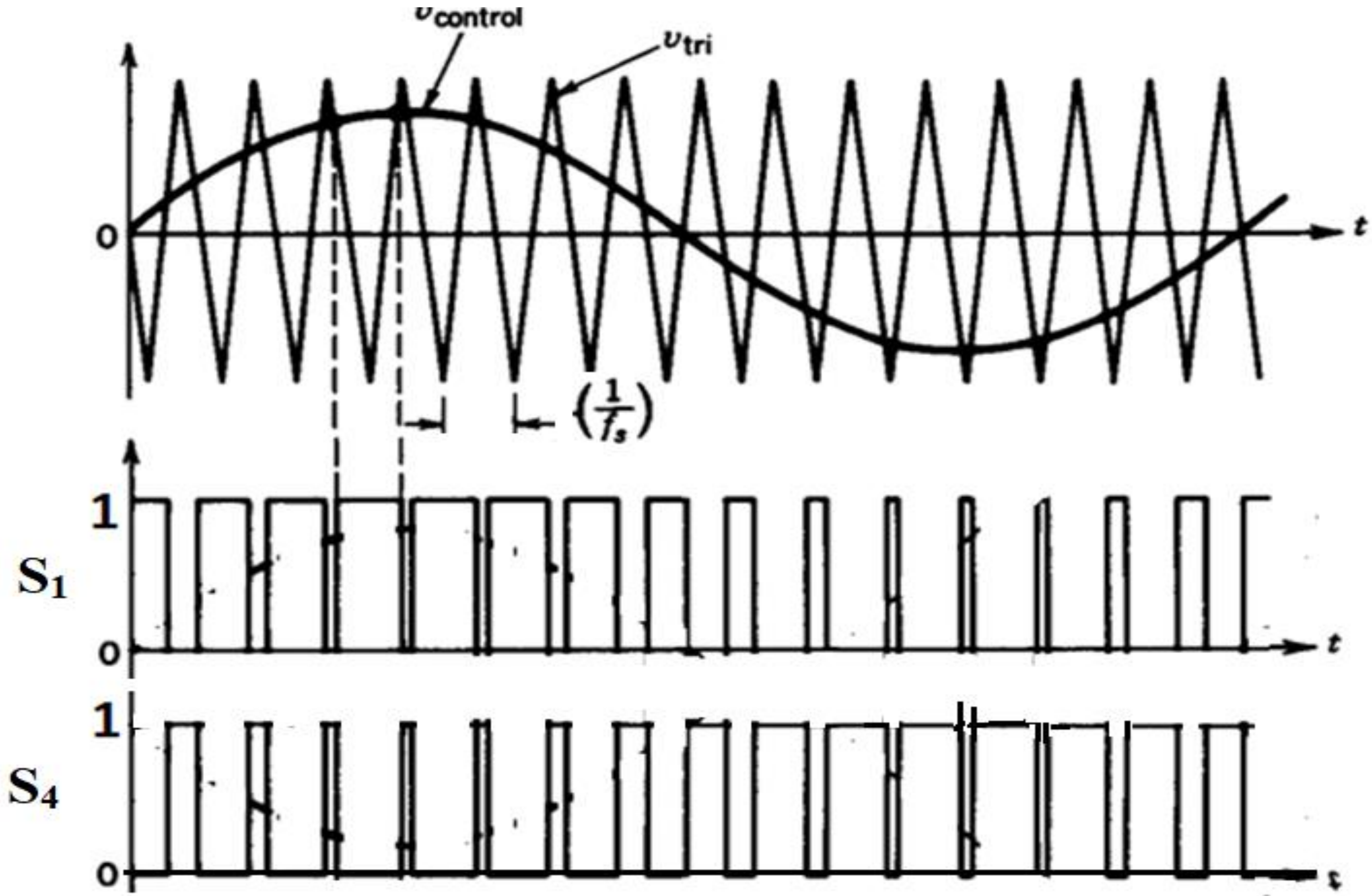
Sinusoidal PWM

- Three sinusoidal modulating wave are given by
- $V_1 = A_m \sin(\omega t)$
- $V_2 = A_m \sin(\omega t - 120)$
- $V_3 = A_m \sin(\omega t + 120)$
- Carrier wave is triangular wave with const. amplitude & F



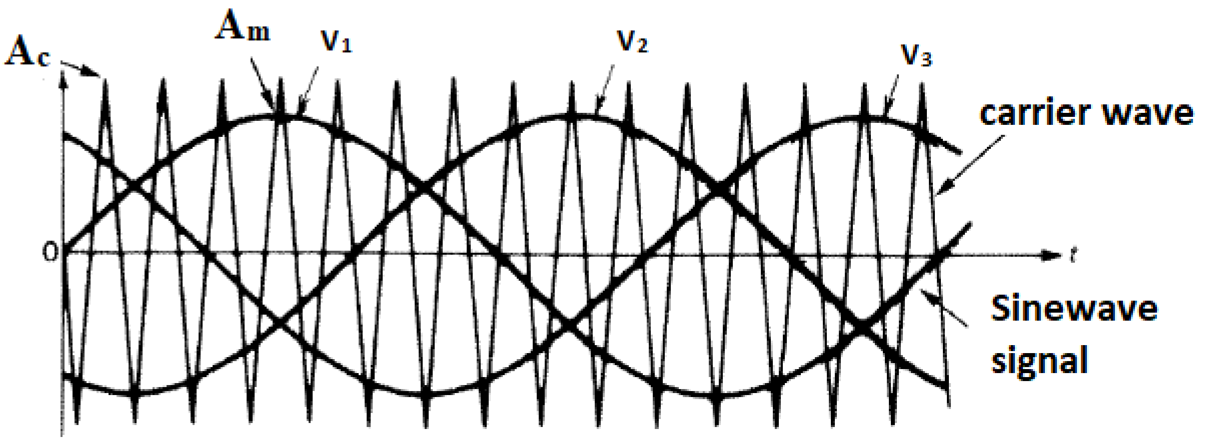
Sinusoidal PWM

- Switching signal



Sinusoidal PWM

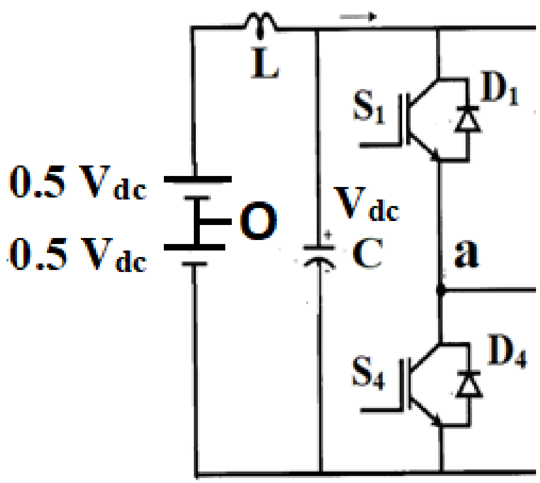
- Switching signal generation

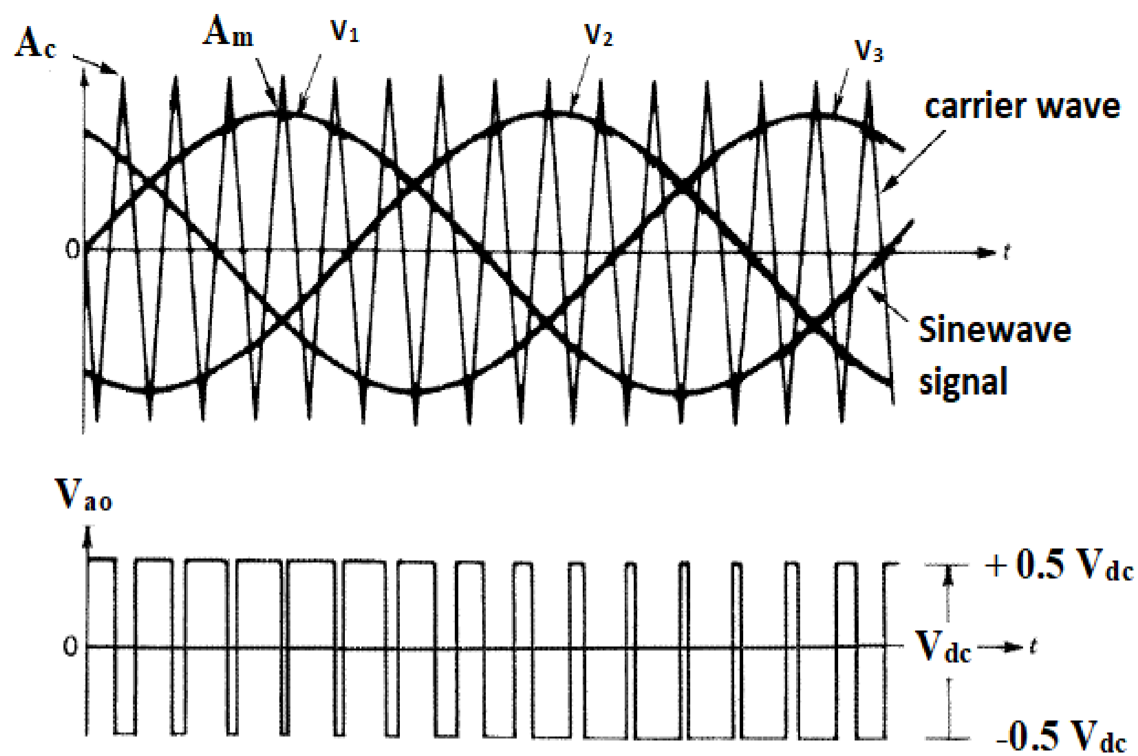


- Six switching signals are generated.

Sinusoidal PWM

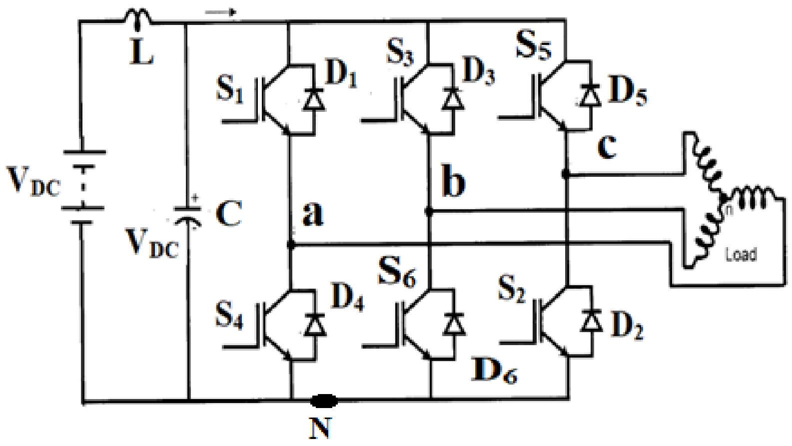
- Node Voltages :

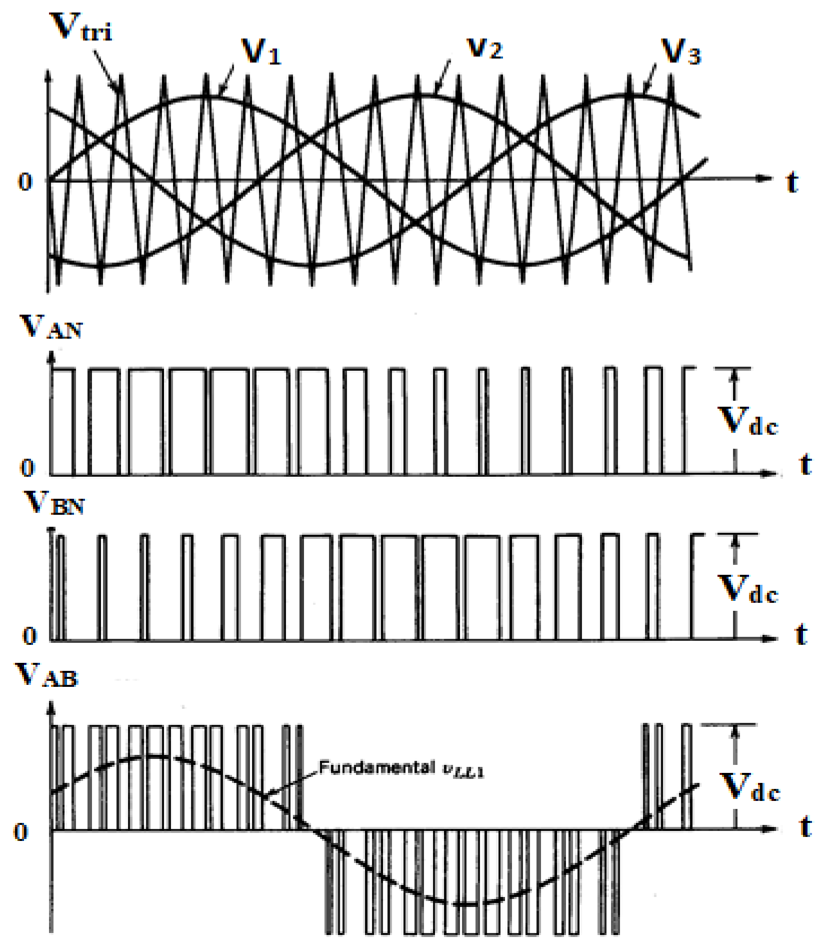




Sinusoidal PWM

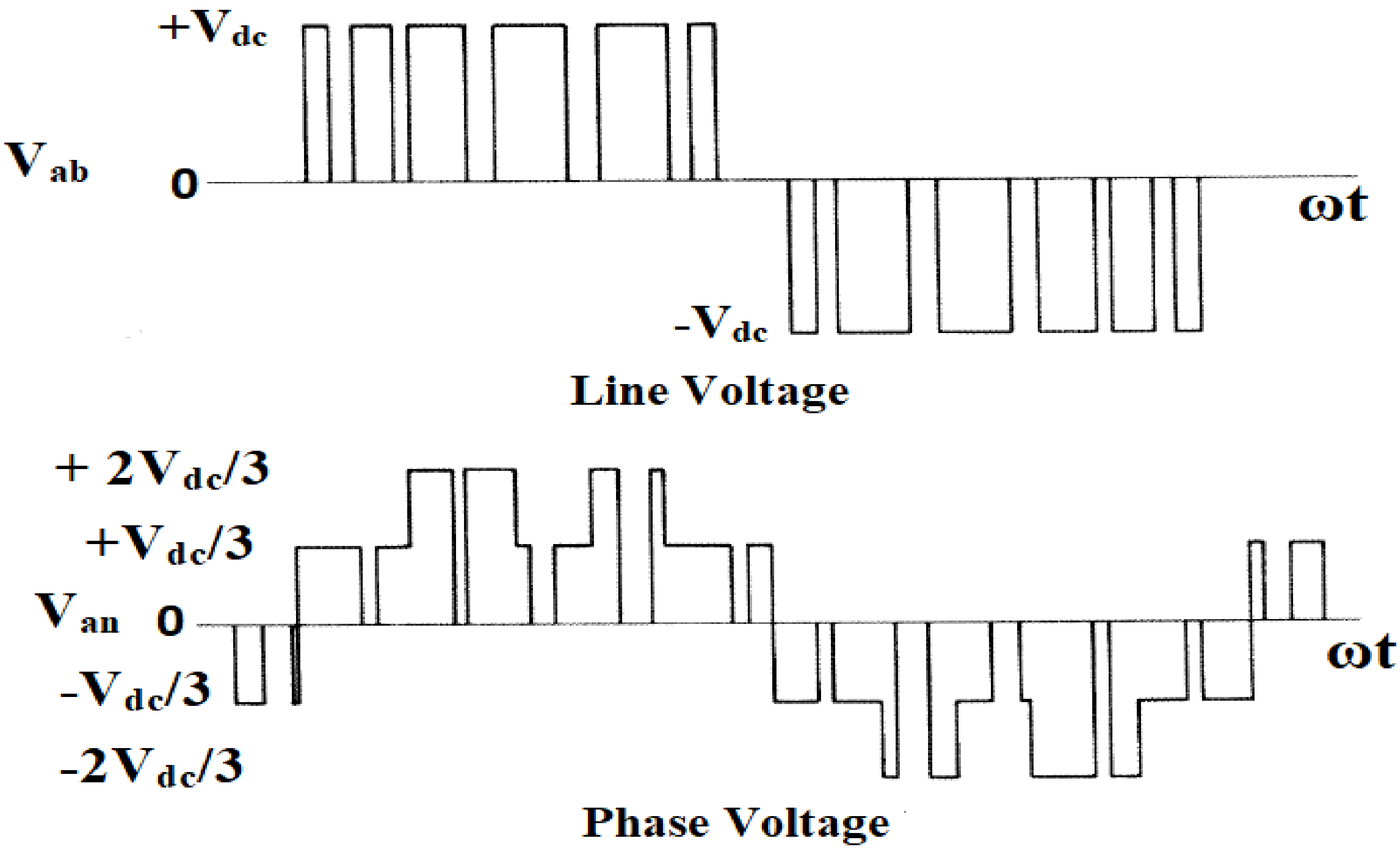
- line voltage





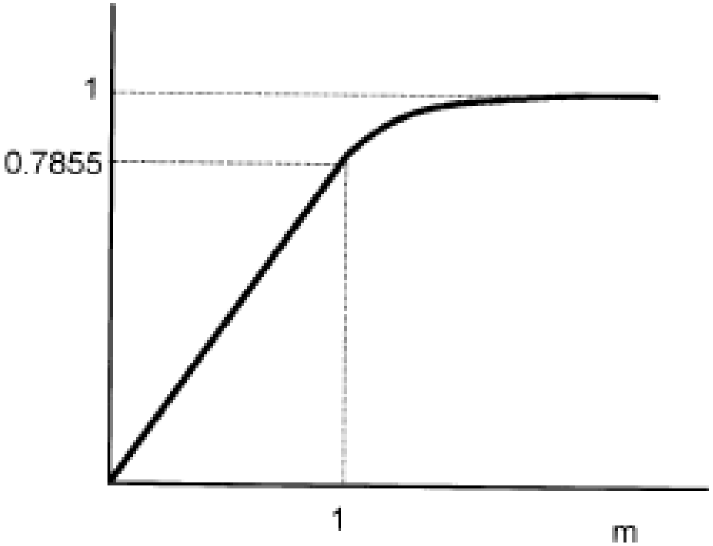
Sinusoidal PWM

- Phase and Line voltages



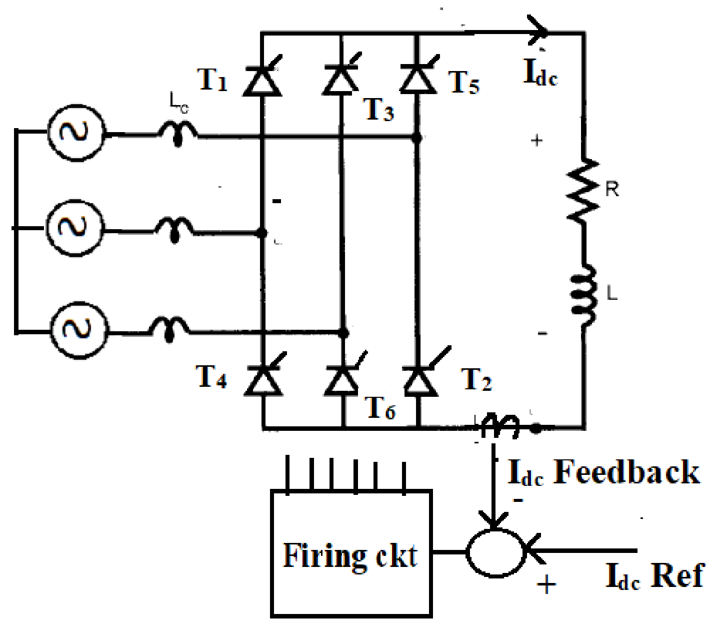
Sinusoidal PWM

- Voltage Controlled by modulation Index (m)
- Linear modulation = O/P is proportional to m
- Sinusoidal PWM provides 78.55% that of square wave Inverter
- Large value of m results into square wave inverter



DC Current Source

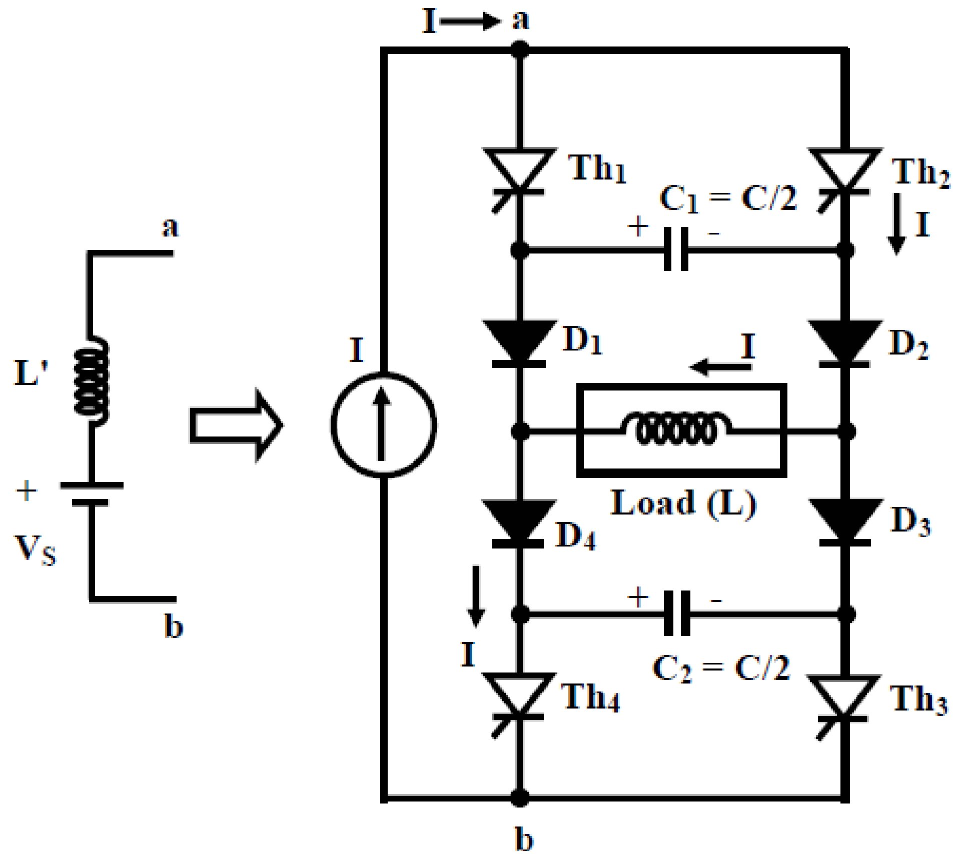
- Circuit diagram
- DC current source is obtained from AC to DC converter with closed loop current control
- I_{dc} is always maintained to a set value by adjusting α of the 6 pulse converter



- Voltage of the converter changes as per change in load to maintain I_{dc} constant

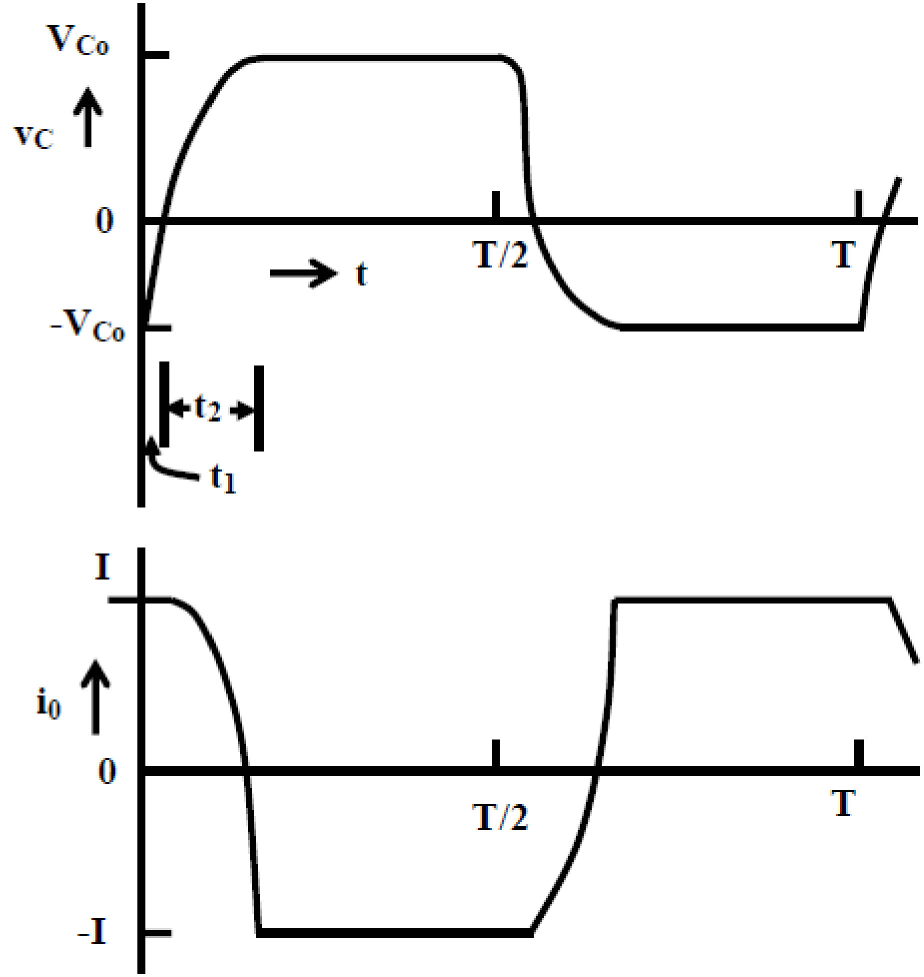
1ϕ CSI

- Circuit diagram

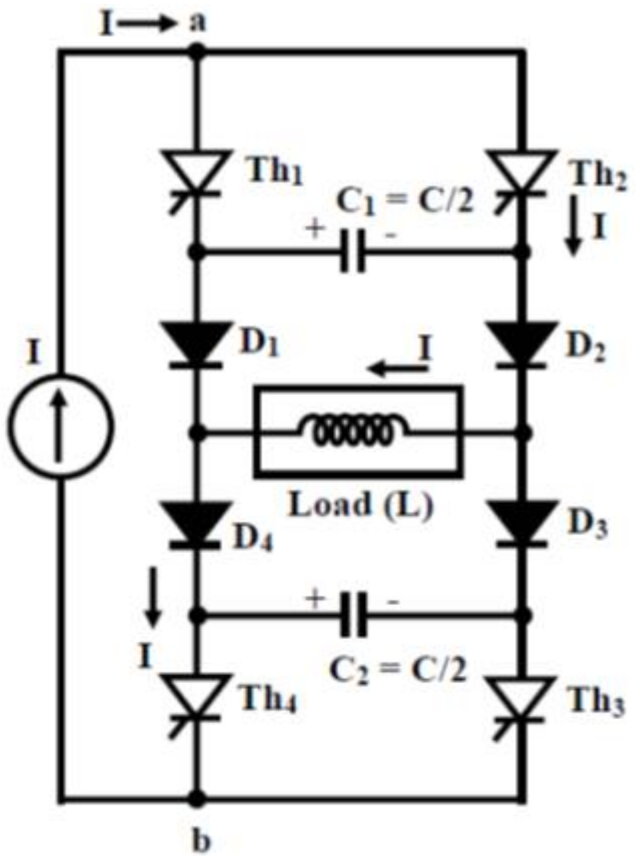


1ϕ CSI

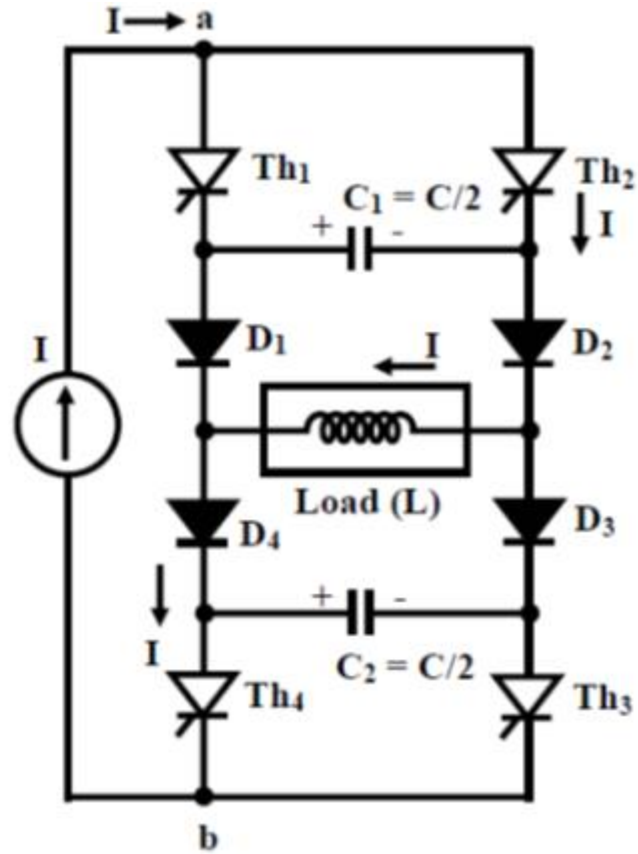
- Wave forms



1ϕ CSI

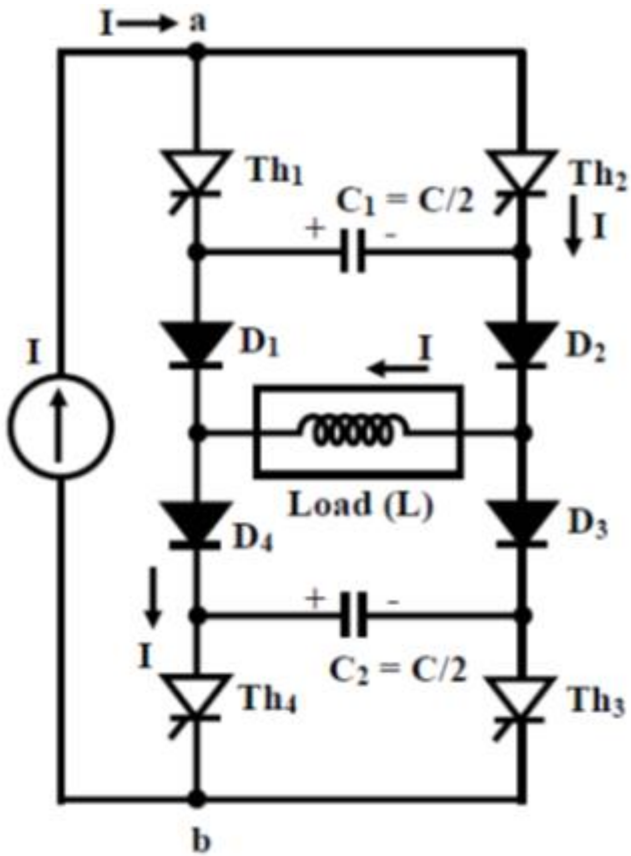


I
a
Th1
C1 = C/2
Th2
I
D1
I
D2
I
Load (L)
D4
D3
I
C2 = C/2
Th4
Th3
b

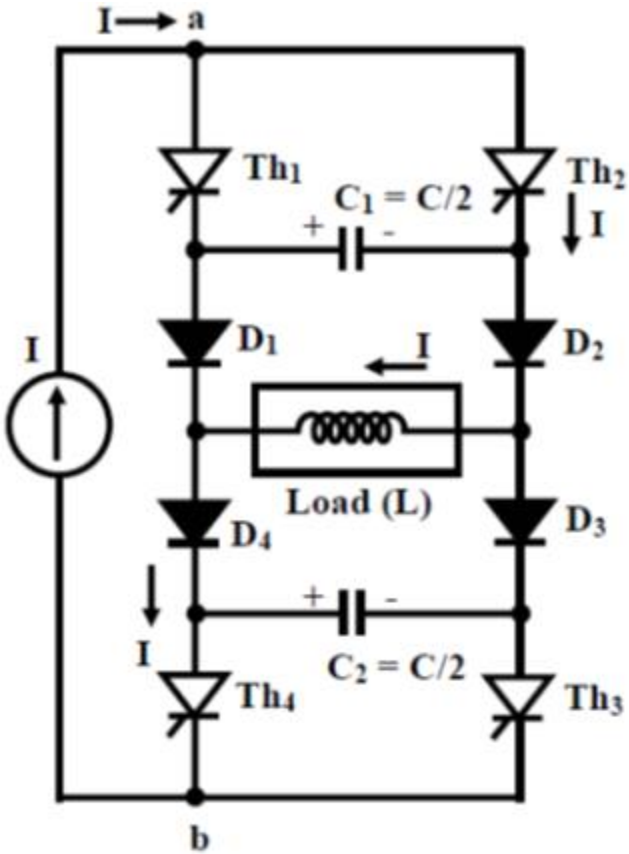


I
a
Th1
C1 = C/2
Th2
I
D1
I
D2
I
Load (L)
D4
D3
I
C2 = C/2
Th4
Th3
b

1ϕ CSI



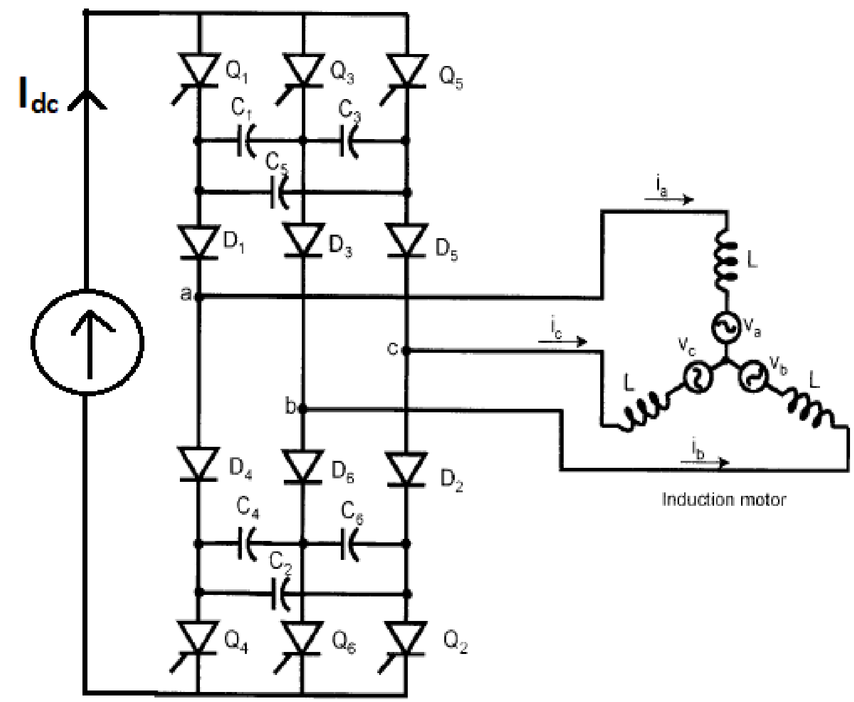
I
a
Th1
C1 = C/2
Th2
I
+
-
D1
I
D2
I
Load (L)
D4
D3
I
+
-
C2 = C/2
Th4
Th3
b



I
a
Th1
C1 = C/2
Th2
I
+
-
D1
I
D2
I
Load (L)
D4
D3
I
+
-
C2 = C/2
Th4
Th3
b

3ϕ ASCI

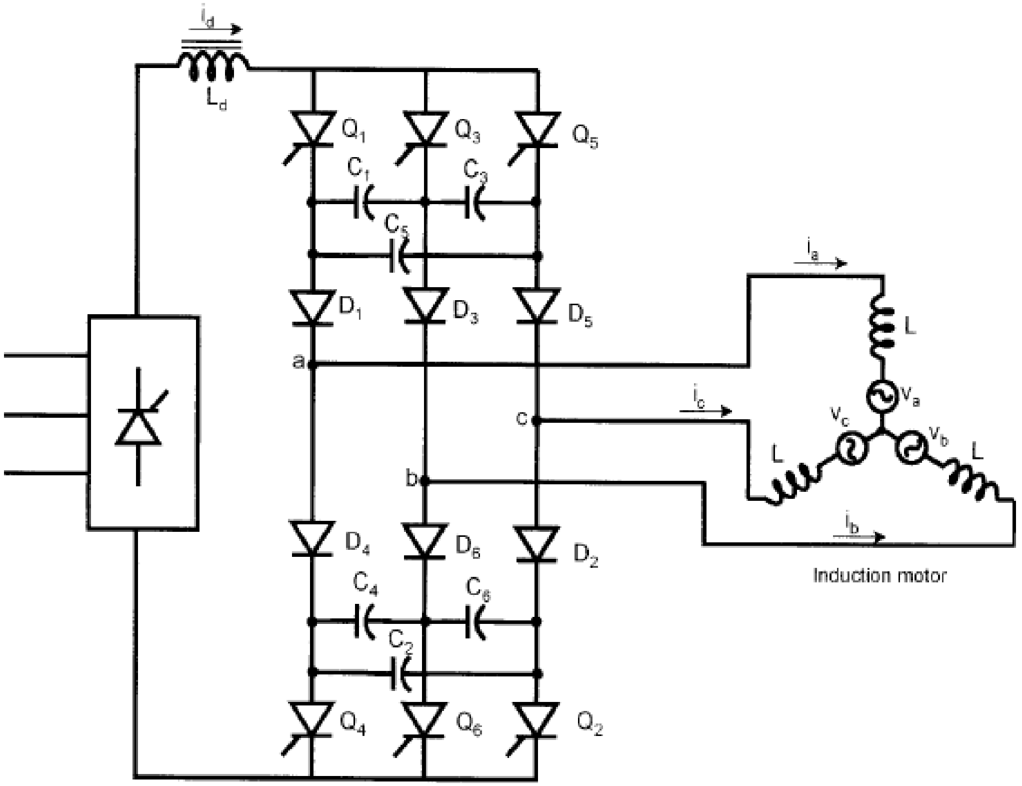
- Auto sequentially current fed Inverter (ASCI)
- It consists of current source and force commutated inverter



- Each Thyristor conducts for 120^0.
- Capacitors are used for commutation and diodes are used to isolate capacitors from load

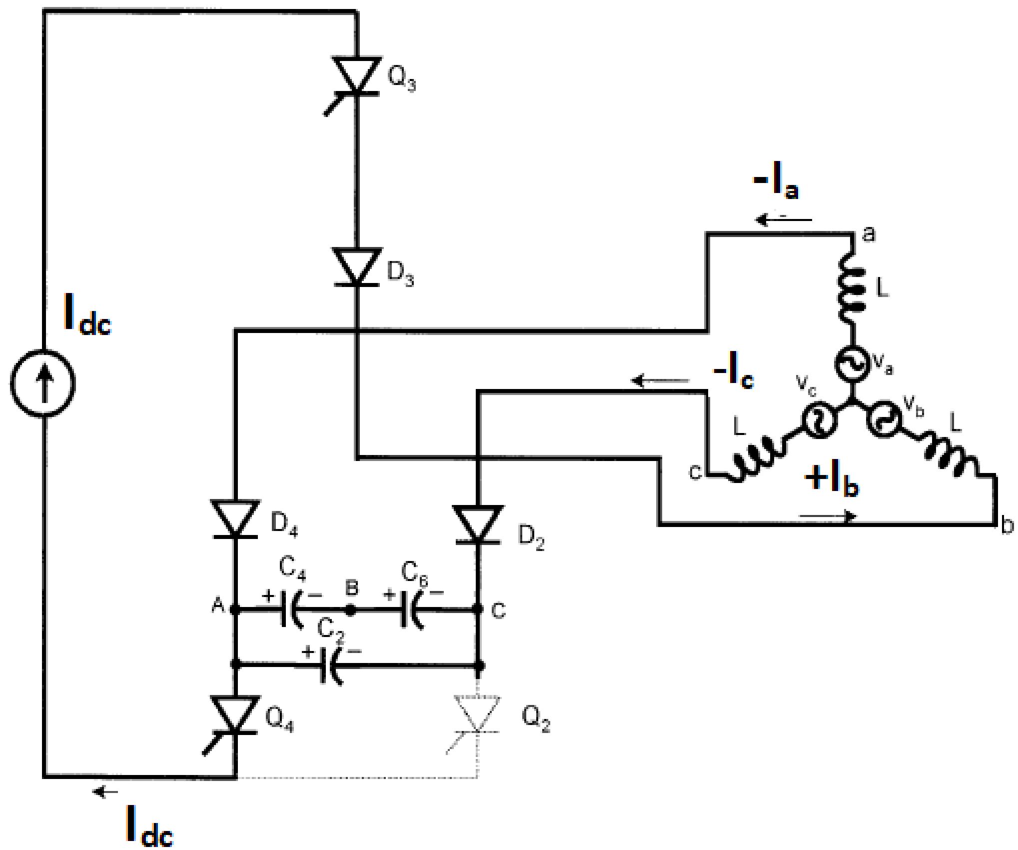
3ϕ ASCI

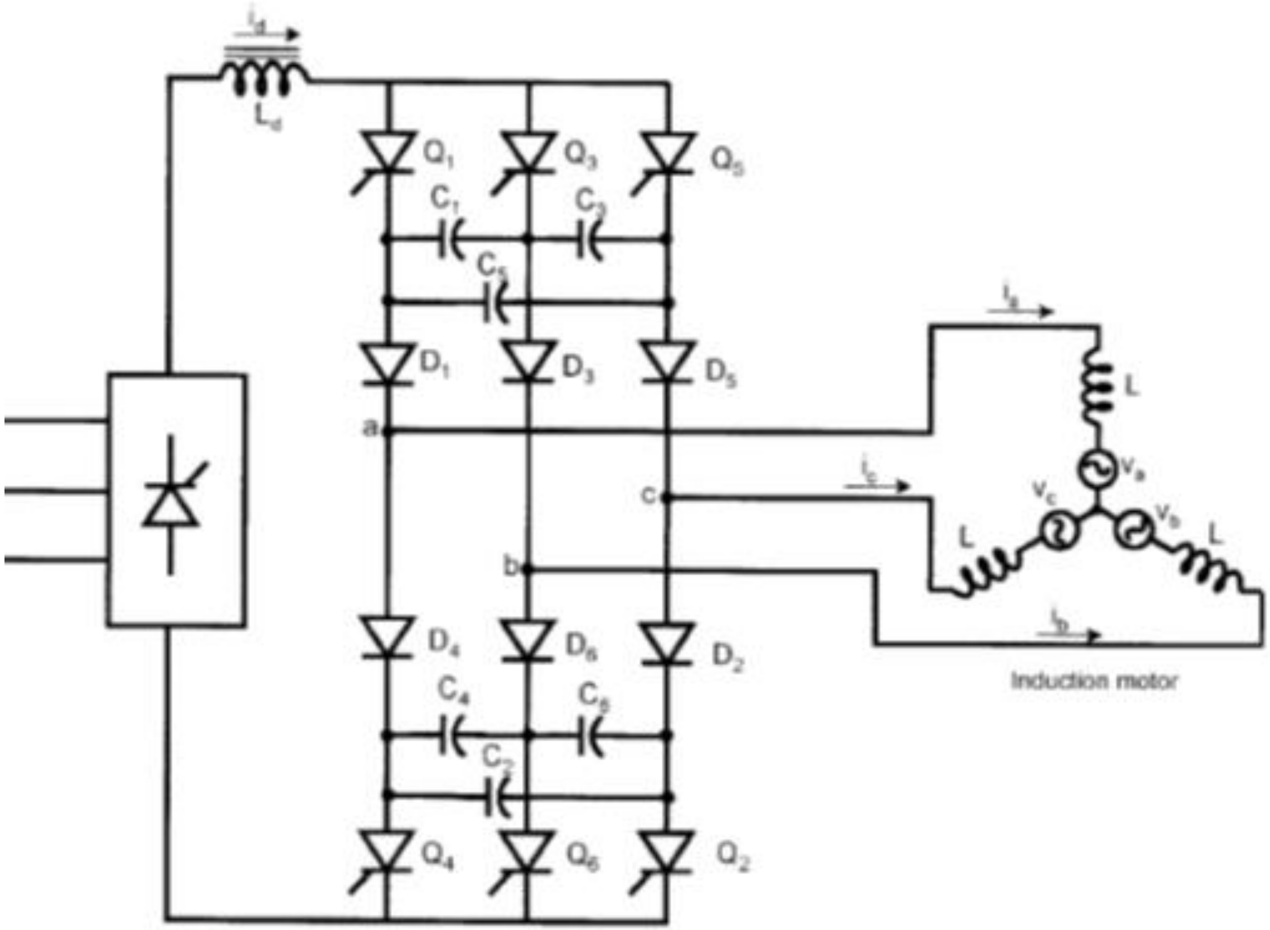
- Thyristors Q1 Q3 and Q5 forms one group
- Thyristors Q2 Q4 and Q6 forms other group
- Commutation takes place within a group.
- Nature of load current is quasi square wave.



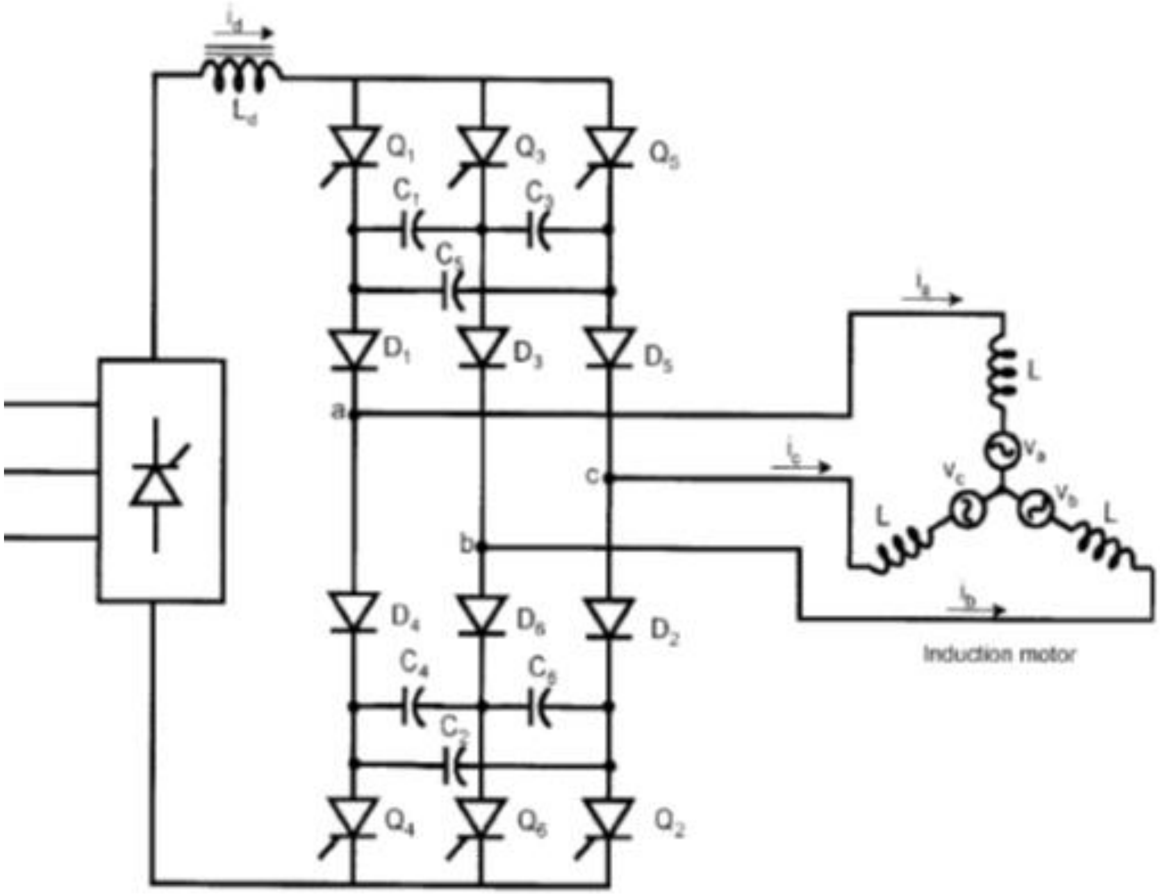
3ϕ ASCI

- Commutation from Q_2 to Q_4
- When Q2 is ON the capacitors C2, C4 & C6 will charge as shown polarity
- When Q4 is turned ON capacitor voltage is applied across Q2 to turn it off
- After Q4 turns ON, capacitors charge with reverse polarity





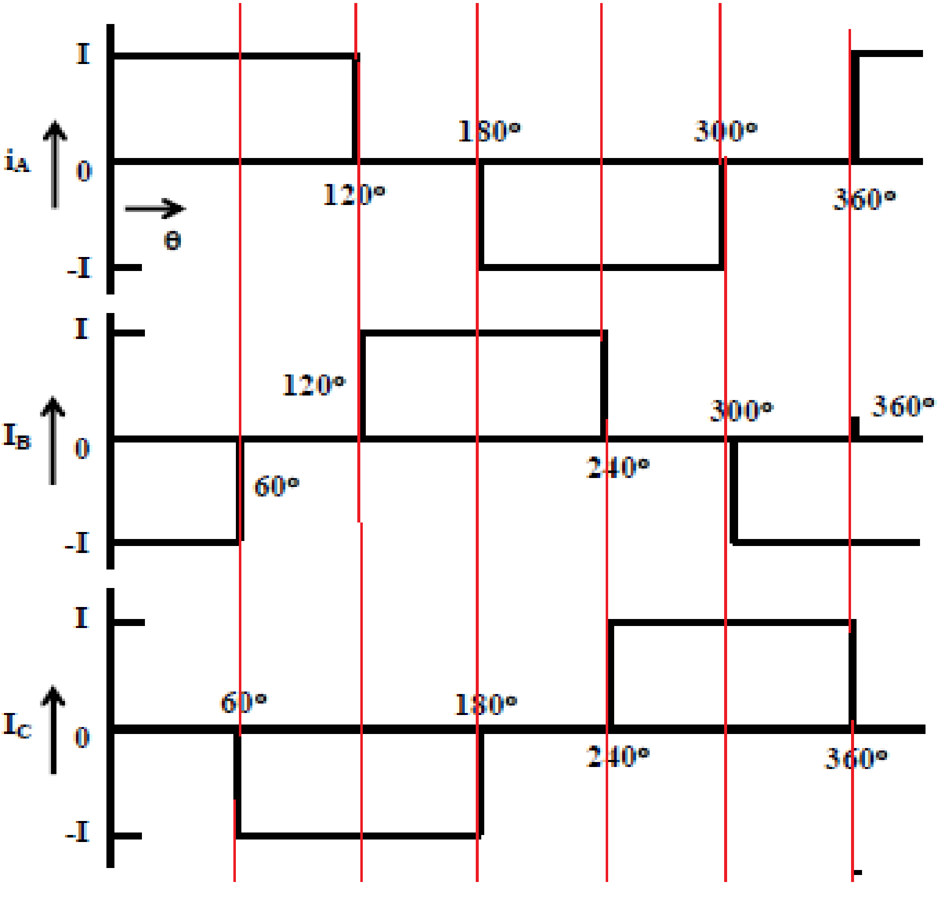
i_d
L_d
Q_1
Q_3
Q_5
C_1
C_3
C_5
D_1
D_3
D_5
a
b
c
i_a
i_c
i_b
L
V_a
V_b
V_c
D_4
D_6
D_2
C_4
C_6
C_2
Q_4
Q_6
Q_2
Induction motor



i_d
L_d
Q_1
Q_3
Q_5
C_1
C_3
C_5
D_1
D_3
D_5
a
c
b
D_4
D_6
D_2
C_4
C_6
C_2
Q_4
Q_6
Q_2
i_a
i_c
i_b
L
V_a
V_c
V_b
Induction motor

3ϕ ASCI

- Waveforms



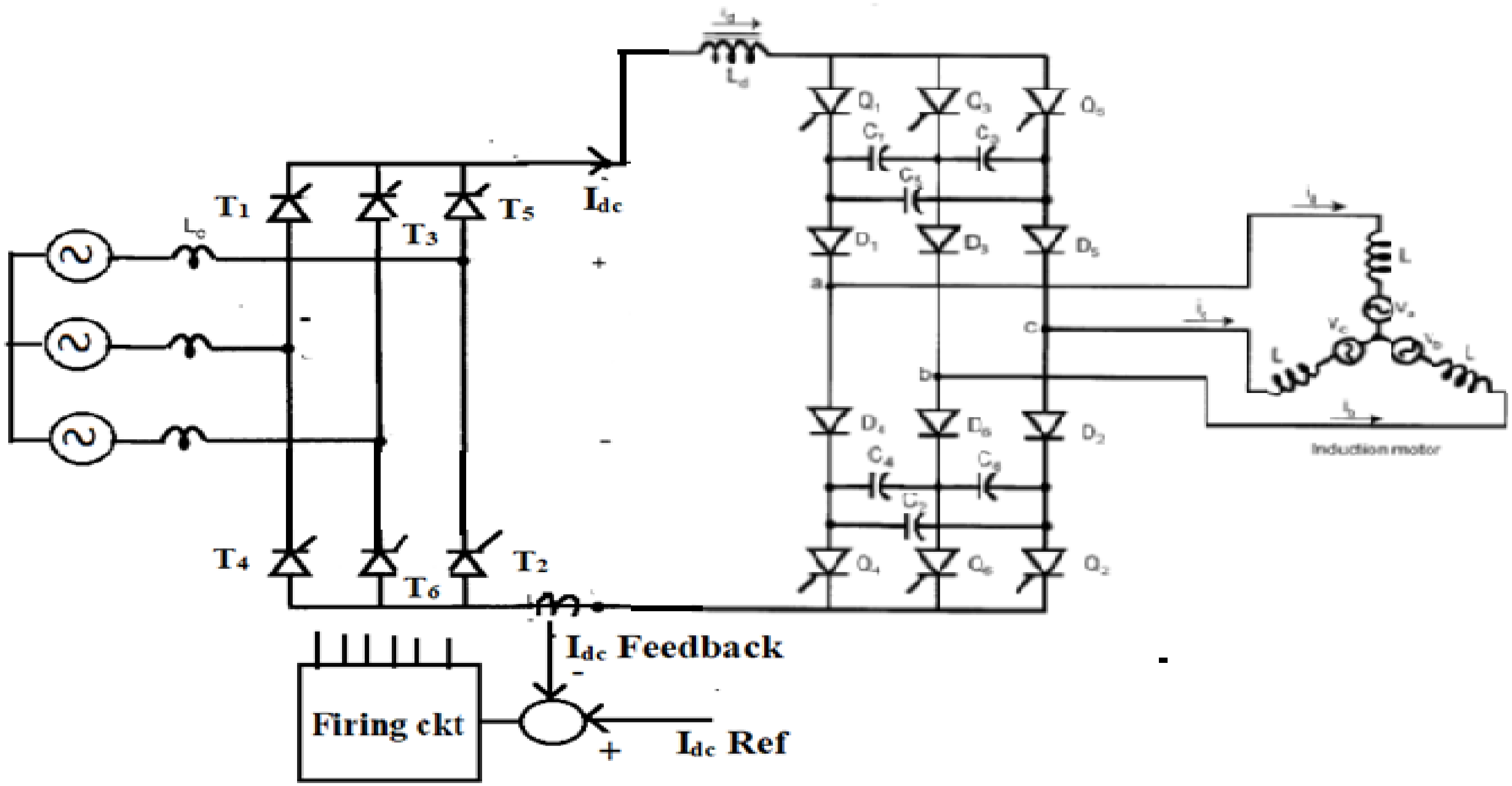
3ϕ ASCI

- Advantages
- Converter grade thyristors are used
- Thyristor have high voltage blocking capability and sustain large voltage and current spikes.
- Current source converter inverter combination can work in four quadrant for Large IM drive.
- Disadvantages
- Minimum load is required as commutation depends upon load
- High frequency light load, stability problem

3ϕ ASCI

- Applications
- This inverter is used in large capacity AC drives
- Load current is quasi square wave
- It is desirable to design motor with low leakage inductance to reduce voltage spikes

Auto sequentially commutated CSI for IM

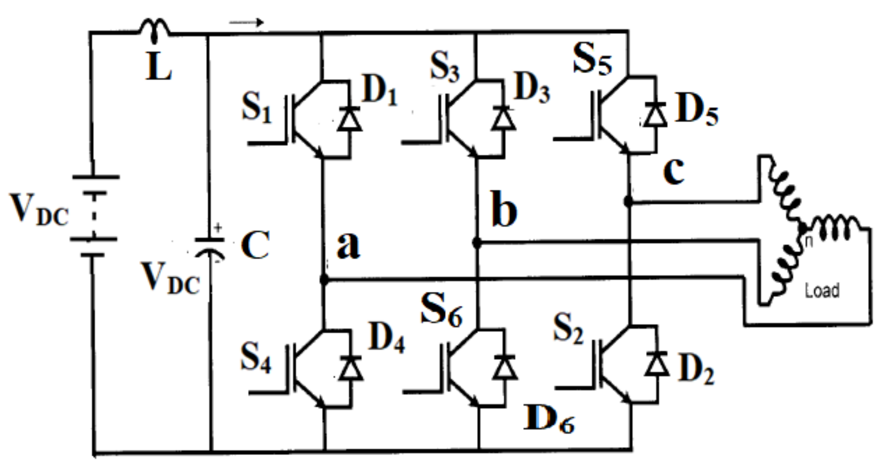


Conclusion

- Voltage source Inverters are widely used for speed control of Induction motor and synchronous motor
- Normally PWM technique is used to control voltage and frequency.
- Switching frequency is kept high to reduce harmonics in the load current

Numerical Problem - 120^0 mode

- A star connected load of 15 ohm per phase is fed from 550 V DC source through a three-phase bridge inverter. For 120-degree mode of conduction, determine i) power dissipated in resistive load, ii) RMS value of fundamental component of phase and line voltage, iii) average and rms current through the devices.

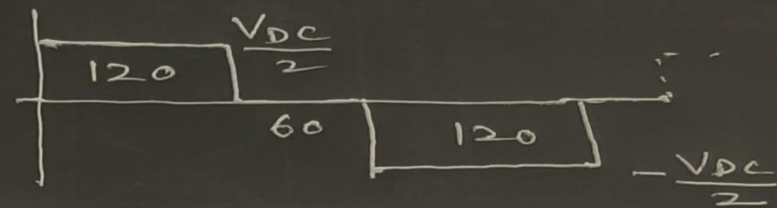


Numerical problem - 120^0 mode

120 Degree Mode of conduction

Power dissipated in R-load

V_{ph} wave form



$$V_{ph(rms)} = \sqrt{2/3} \cdot \frac{V_{dc}}{2} = \sqrt{2/3} \times \frac{550}{2}$$

$$= 224.53\ V$$

Power dissipated in 3ϕ load

$$= 3 \cdot \frac{V_{ph(rms)}^2}{R} = \frac{3 \times (224.53)^2}{15}$$

$$= 10{,}083.33\ W = 10.083\ KW$$

Numerical Problem - 120^0 mode

RMS value of fundamental component of phase voltage:

$$a_n = \frac{8}{T}\int_0^{T/4} F(\theta)\cos n\theta . d\theta = \frac{8}{2\pi}\int_0^{\pi/3} \frac{V_{dc}}{2}\cos n\theta . d\theta$$

$$\therefore a_n = \frac{2V_{dc}}{\pi}\,\frac{\sin n\pi/3}{n}$$

$$a_1 = \frac{2V_{dc}}{\pi} \times \frac{\sqrt{3}}{2} = \frac{\sqrt{3}\,V_{dc}}{\pi}$$

$$V_{1ph(rms)} = \frac{\sqrt{3}\,V_{dc}}{\sqrt{2}\,\pi} = 214.41V$$

$$V_{Lph(rms)} = \sqrt{3} \times 214.41 = 371.369V$$

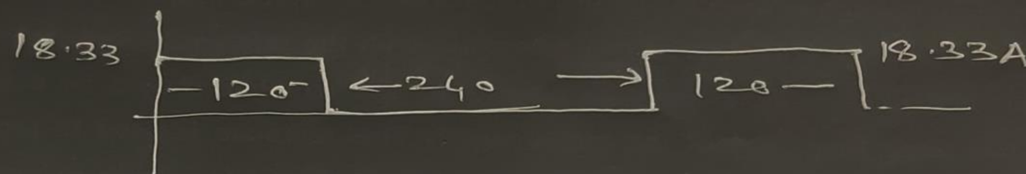
Numerical Problem - 120^0 mode

Current through the Device

Current (Peak) through switch

$$= \frac{550}{2 \times 15} = 18.33\,A$$

Current through switch



Average current through switch

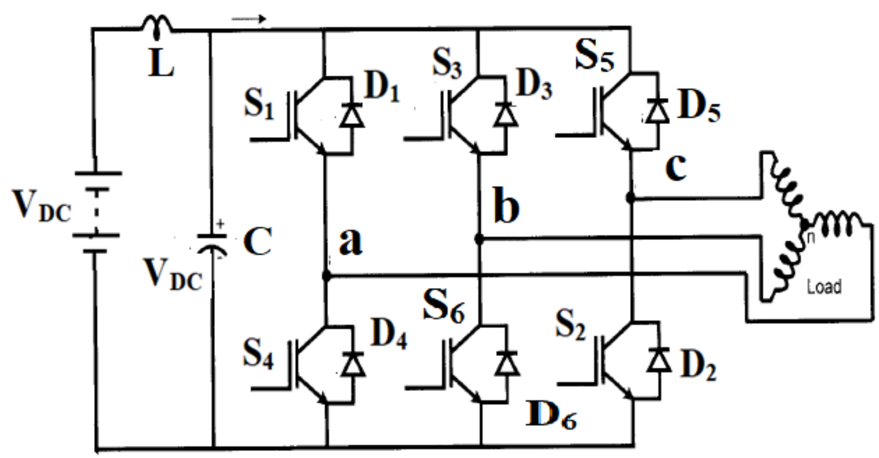
$$I_{av(th)} = 18.33 \times \frac{120}{360} = 6.11\,A.$$

RMS current through switch

$$I_{rms(th)} = 18.33 \times \sqrt{\frac{120}{360}} = 10.58\,A$$

Numerical Problem – 180^0 mode

A three phase bridge inverter deliver the power to the resistive load from a 600 V DC source. For a star connected load of 20 ohm per phase. Determine for 180 degree mode of conduction i) RMS value of load current, ii) RMS value of device current, iii) power dissipated in resistive load. iv) Fundamental component of output voltage.



Numerical Problem – 180^0 mode

180° mode of conduction

RMS value of line voltage $= \sqrt{2/3}\, V_{dc}$

$= \sqrt{2/3} \times 600 = 489.89V$

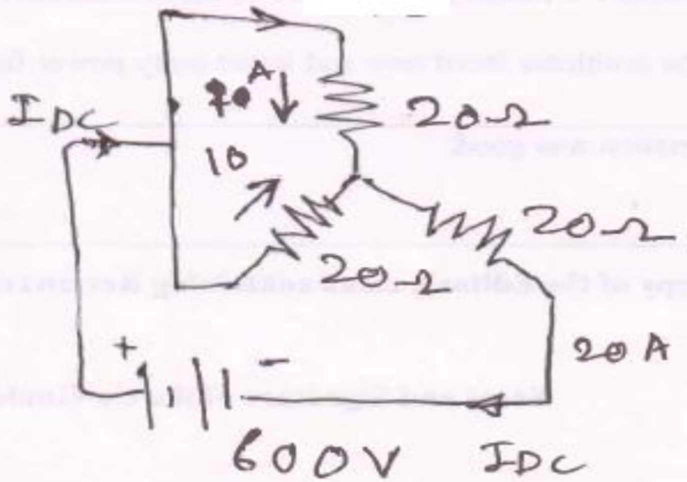
RMS value of phase voltage $= \dfrac{489.89}{\sqrt{3}}$

$\therefore V_{ph(rms)} = 282.84\ V$

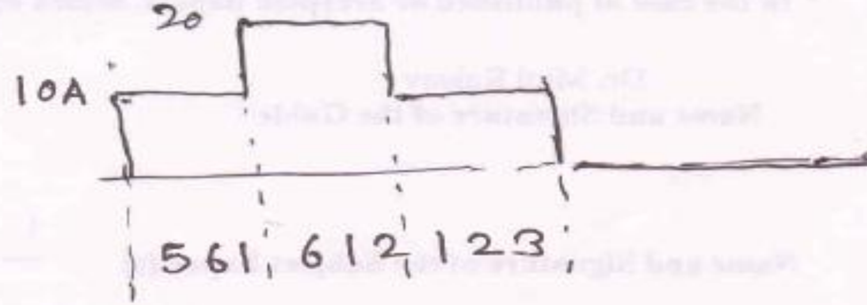
$\therefore I_{rms}/ph = \dfrac{V_{ph(rms)}}{R} = \dfrac{282.84}{20}$

$\therefore I_{rms}/ph = 14.142\ A$

Numerical Problem – 180^0 mode



$$I_{DC} = \frac{600}{20+10} = 20A$$



$$I_{rms\ device} = \sqrt{\frac{10^2 \times 120 + 20^2 \times 60}{360}}$$

device Irms = 10.0 Amps

Numerical Problem – 180^0 mode

Power dissipated in R load

$= 3\ V_{ph(rms)} \times I_{ph(rms)}$

$= 3 \times 282.84V \times 14.142$

$= 11999.76 \simeq 12000W$

$= 12\ KW$

$V_{1(rms)}$ line $= \frac{\sqrt{6}}{\pi} \cdot V_{dc}$

RMS value of fun. comp. (Line) $= \frac{\sqrt{6}}{\pi} \times 600 = 467.81V$

RMS value of fundamental component of phase voltage $= 467.81/\sqrt{3} = 270.09V$

THANKS !

Any Questions?