Power Electronics

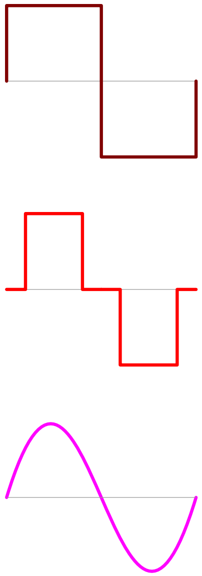
INVERTERS

2018

Dr. Francis M. Fernandez

Inverter Classification

Classification of inverters based on wave shape

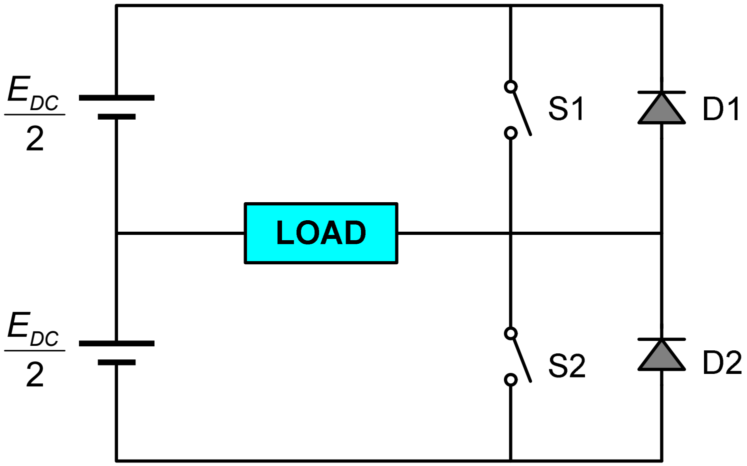


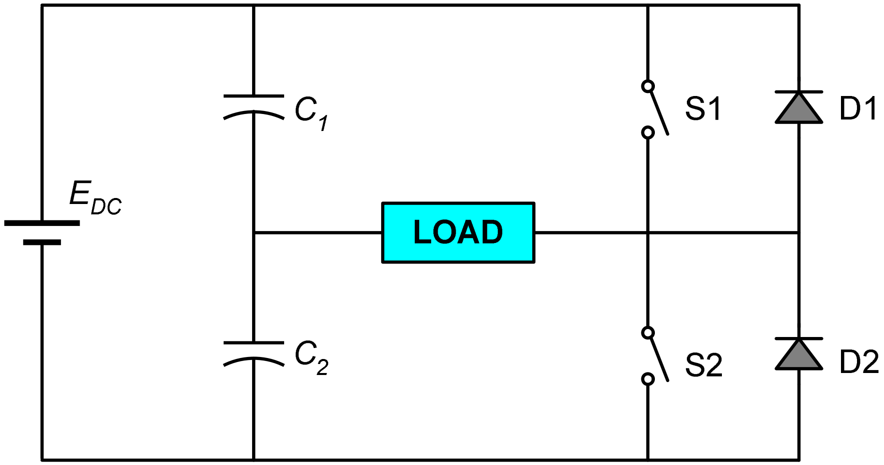
- Square wave
- Quasi square wave
- Sine wave

Classification of inverters based on Input

- Voltage source
- Current source

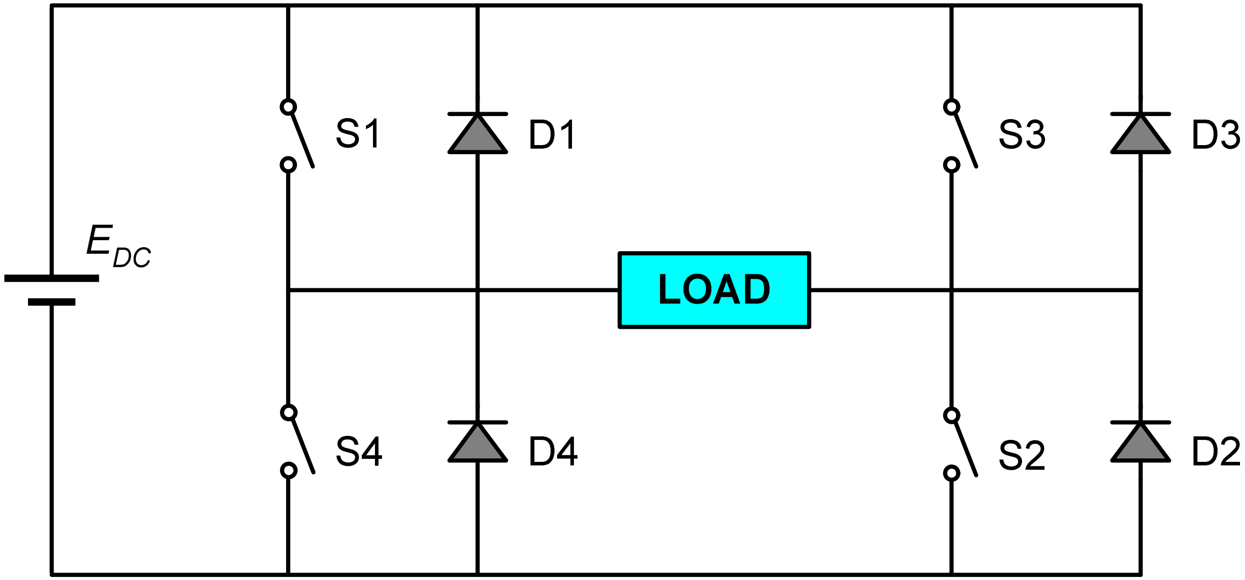
Half bridge inverter





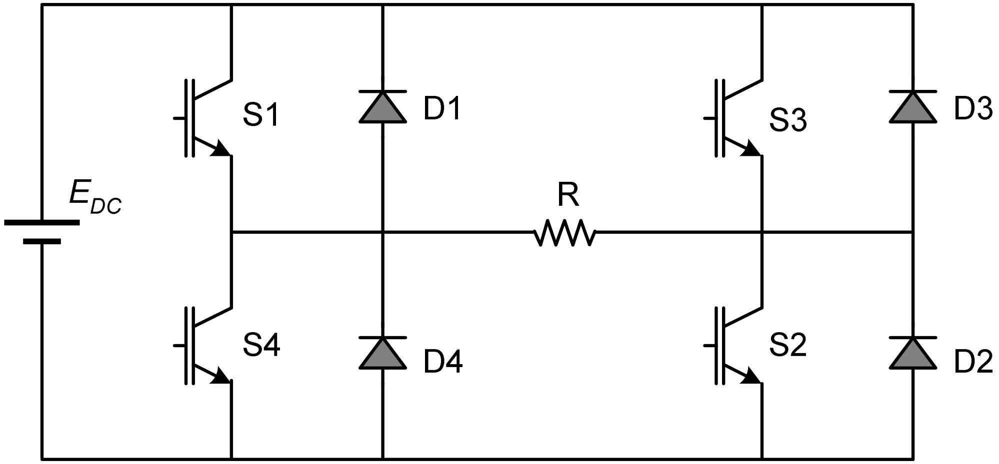
- Switches S1 and S2 used are gate commutated devices such as BJT, MOSFET, IGBT, GTO etc
- S1 and S2 are turned on alternately to produce an ac voltage across the load
- Each switch is ON for half time period (T/2) of the desired frequency

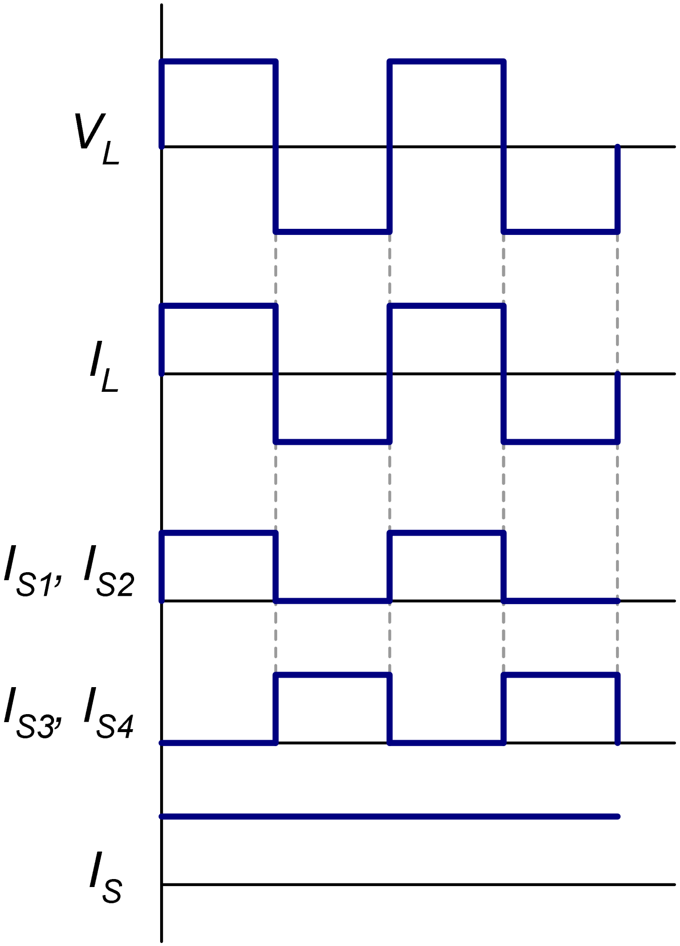
Full bridge inverter



- S1 and S2 turned on in the first half cycle (T/2)
- S3 and S4 turned on in the second half cycle (T/2)

Full bridge inverter – R load

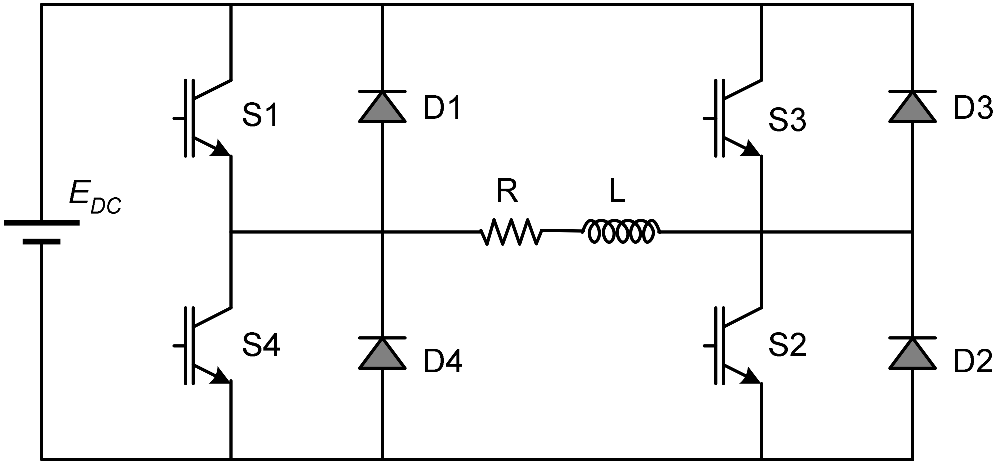


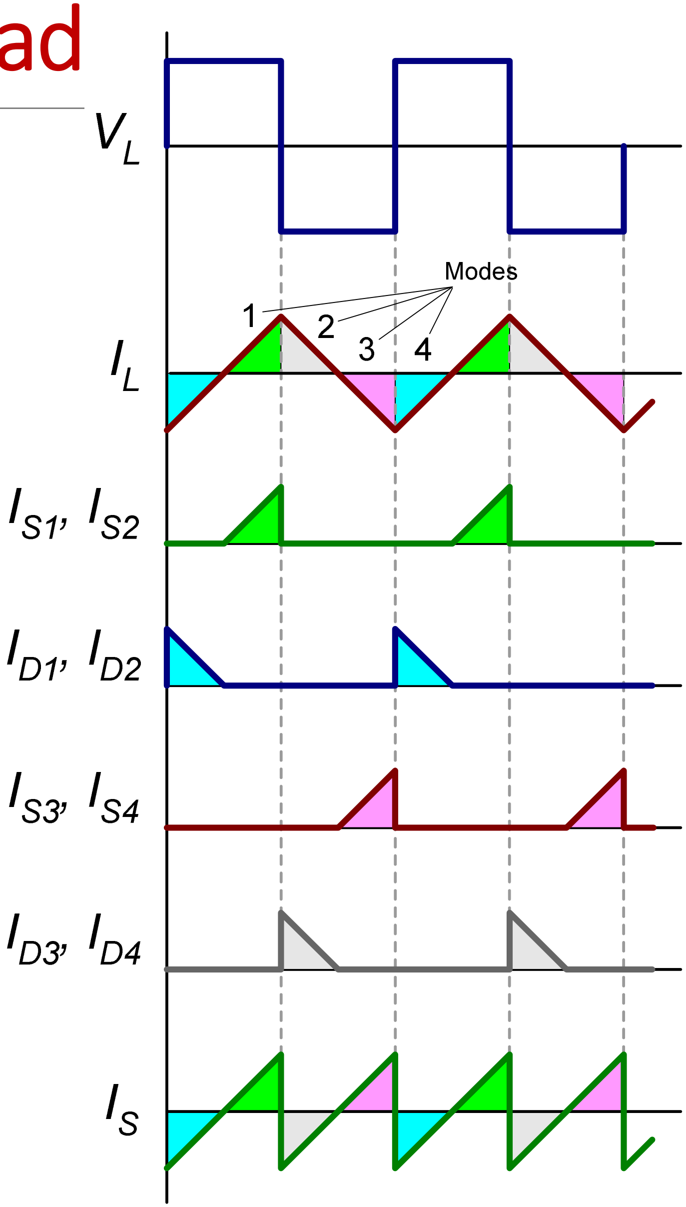


Two modes of operation:

- Mode 1:
  - S1 and S2 are ON
- Mode 2
  - S3 and S4 are ON

Full bridge inverter – RL load





Four modes of operation:

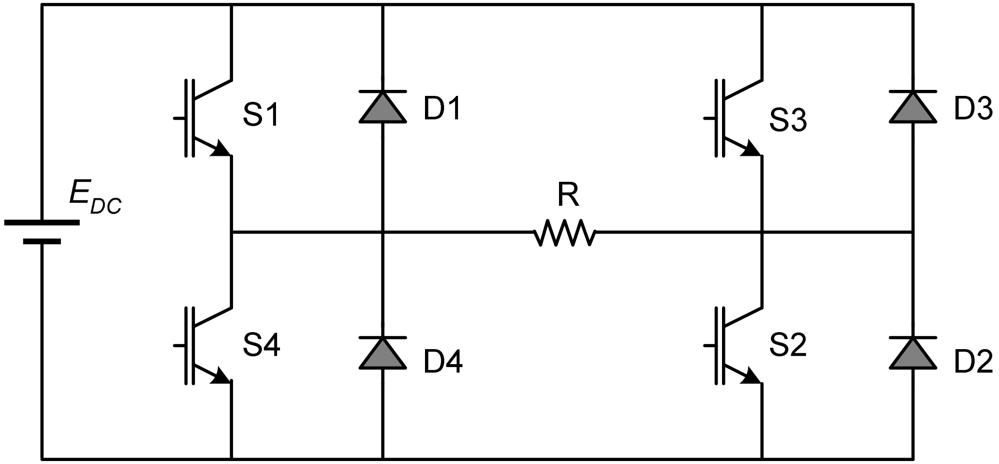
Mode 1: S1 and S2 are ON, Output +ve

Mode 2: D3, D4 conducts, Output -ve

Mode 3: S3 and S4 are ON, Output –ve

Mode 4: D1, D2 conducts, Output +ve

Full Bridge Inverter – Transistor Ratings

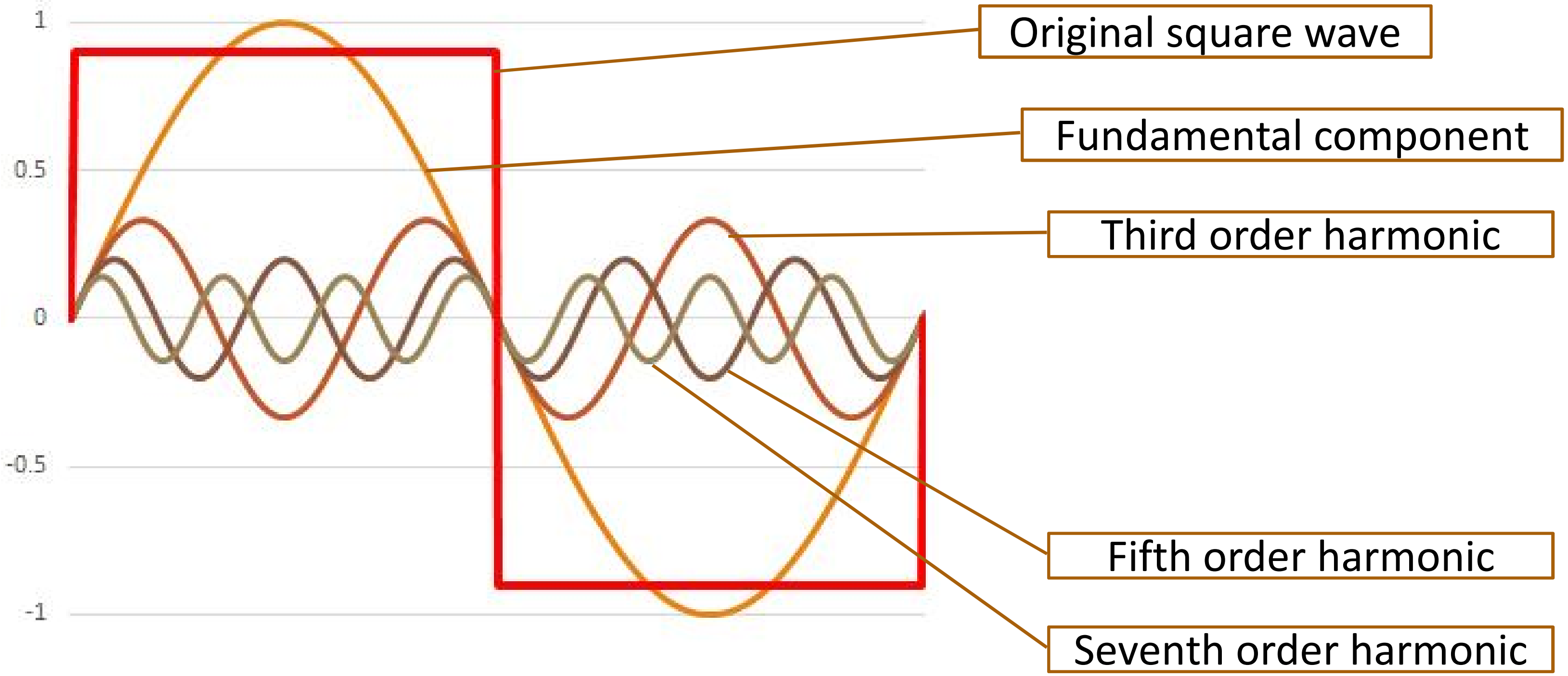


$$V_{CE(0)} \geq E_{DC}$$

$$I_{T(ave)} = \frac{E_{DC}}{2R}$$

$$I_{T(peak)} = \frac{E_{DC}}{R}$$

Harmonics



Fourier series for symmetrical square wave, $e = \sum_{n=1,3,5,..}^{\infty} \frac{4E_{DC}}{n\pi}\sin\left(n\,\omega t\right)$

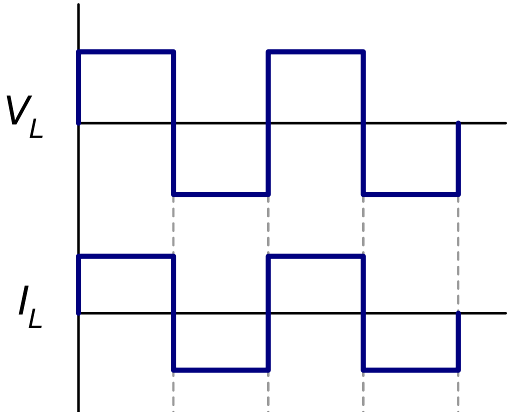
Harmonics

Fourier Series, $e = \sum_{n=1,3,5,..}^{\infty} \frac{4E_{DC}}{n\pi} \sin(n\,\omega t)$

Fundamental output voltage, $E_1 = \frac{2\sqrt{2}}{\pi} E_{DC}$

(rms)

ie. $E_1 = 0.9\ E_{DC}$



n$^{\text{th}}$ order output voltage, $E_n = \frac{E_1}{n}$

RMS value, $E_{(rms)} = \sqrt{E_1^{\,2} + E_3^{\,2} + E_5^{\,2} + \ldots}$

Harmonic voltage, $E_h = \left(\sum_{n=3,5,..}^{\infty} E_n^{\,2} \right)^{1/2} = \left(E^2 - E_1^{\,2}\right)^{1/2} = 0.4352\ E_{DC}$

Harmonic Parameters

Harmonic factor for nth harmonic measures the individual harmonic contribution

$$\text{Harmonic Factor, } HF_n = \frac{E_n}{E_1}$$

Total harmonic distortion is a measures of how different is the actual waveform from its fundamental component

$$\text{Total Harmonic Distortion, } THD = \frac{1}{E_1}\left(\sum_{n=3,5,..}^{\infty} E_n{}^2\right)^{1/2} = \frac{E_h}{E_1}$$

Harmonic factor is a measures of effectiveness in reducing unwanted harmonics using filters

$$\text{Distortion Factor, } DF = \frac{1}{E_1}\left(\sum_{n=3,5,..}^{\infty}\left(\frac{E_n}{n^2}\right)^2\right)^{1/2}$$

Comparison of parameters in Half Bridge and Full Bridge Inverters

	Full Bridge	Half Bridge
Output voltage	$E_O = E_{DC}$	$E_O = \frac{E_{DC}}{2}$
Fundamental output voltage	$E_1 = \frac{2\sqrt{2}}{\pi} E_{DC} = 0.9\ E_{DC}$	$E_1 = \frac{2\sqrt{2}}{\pi} \frac{E_{DC}}{2} = 0.45\ E_{DC}$
Harmonic output voltage	$E_h = 0.4352\ E_{DC}$	$E_h = 0.2176\ E_{DC}$
Peak breaking voltage of switches	$E_{BR} = E_{DC}$	$E_{BR} = E_{DC}$

Example

A single phase full bridge inverter is operated from 48 V battery and supplying power to a 24 ohm load. Determine output power THD of output and transistor ratings.

Solution:

$$\text{RMS Power, } P = \frac{E^2}{R} = \frac{48^2}{24} = 96 \text{ W}$$

$$E_1 = 0.9\, E_{DC} = 0.9 \times 48 = 43.2 \text{ V}$$

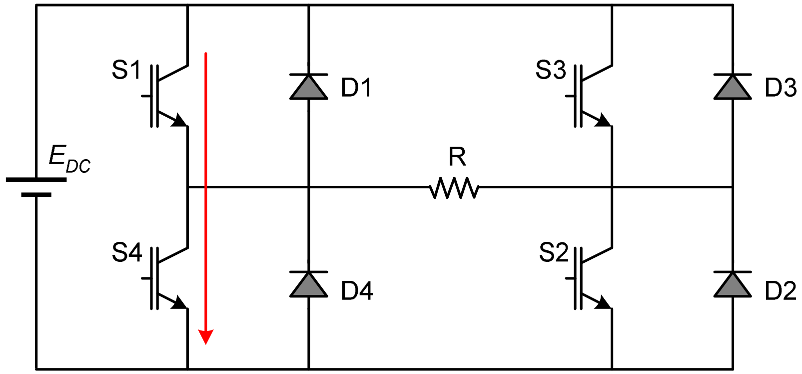
$$E_h = 0.4352\, E_{DC} = 0.4352 \times 48 = 20.89 \text{ V}$$

$$THD = \frac{E_h}{E_1} = \frac{20.89}{43.2} = 48.36\,\%$$

$$V_{CE} \geq 48 \text{ V}$$

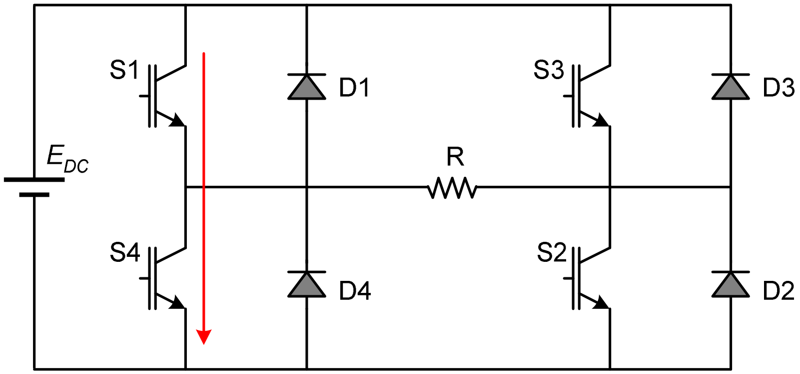
$$I_{T(peak)} = \frac{E_{DC}}{R} = \frac{48}{24} = 2\text{A}$$

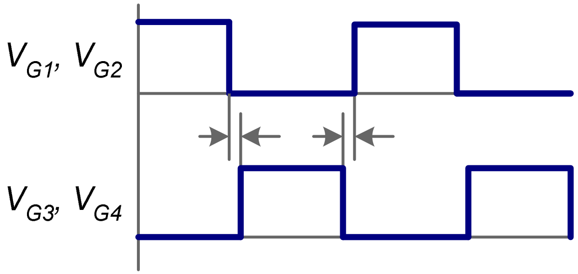
Cross Conduction or Shoot Through Fault



- Normally the switches in the bridge switch on in pairs – S1-S2 turn on first and after they are off, S3-S4 turn on
- Therefore the switches in the same leg (say S1 and S4) may not turn on at the same time
- Due to turn off delay, incoming device and outgoing device of the same leg in the bridge conduct at the same instant and short circuits the DC source.
- This fault damages both the devices

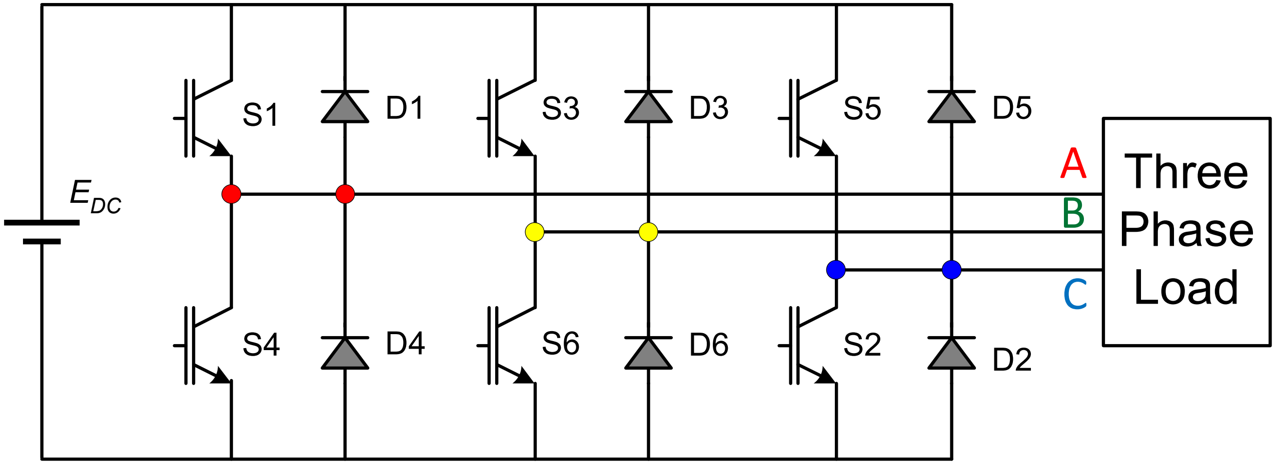
Cross Conduction or Shoot Through Fault



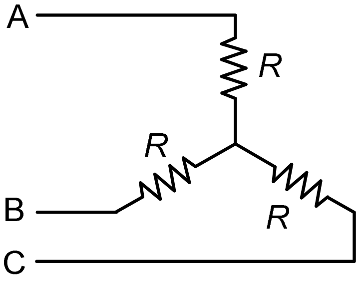


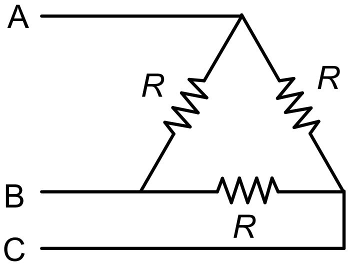
- A solution for cross conduction fault is to introduce a dead band or delay between the trailing edge of the gate input of outgoing device and the leading edge of the gate input of incoming device
- Dead band should be longer than the turn off time of the inverter

3-Phase Inverter



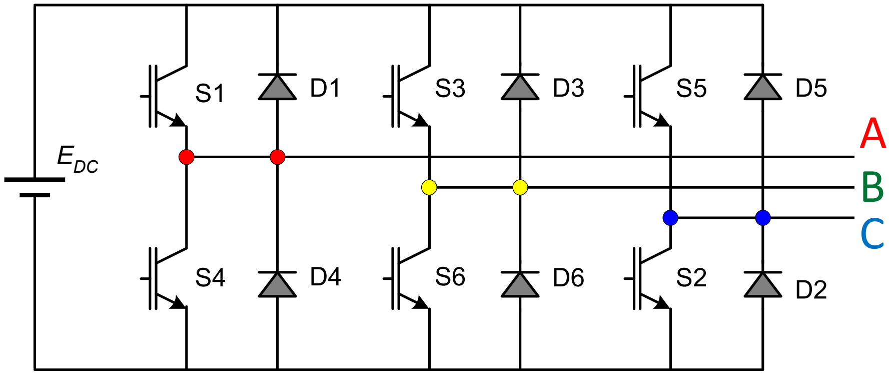
Load configurations



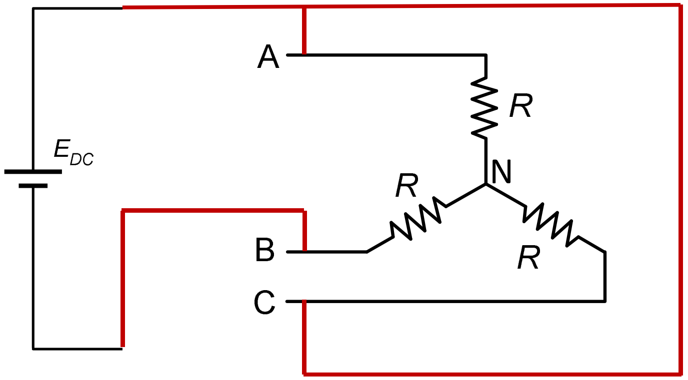


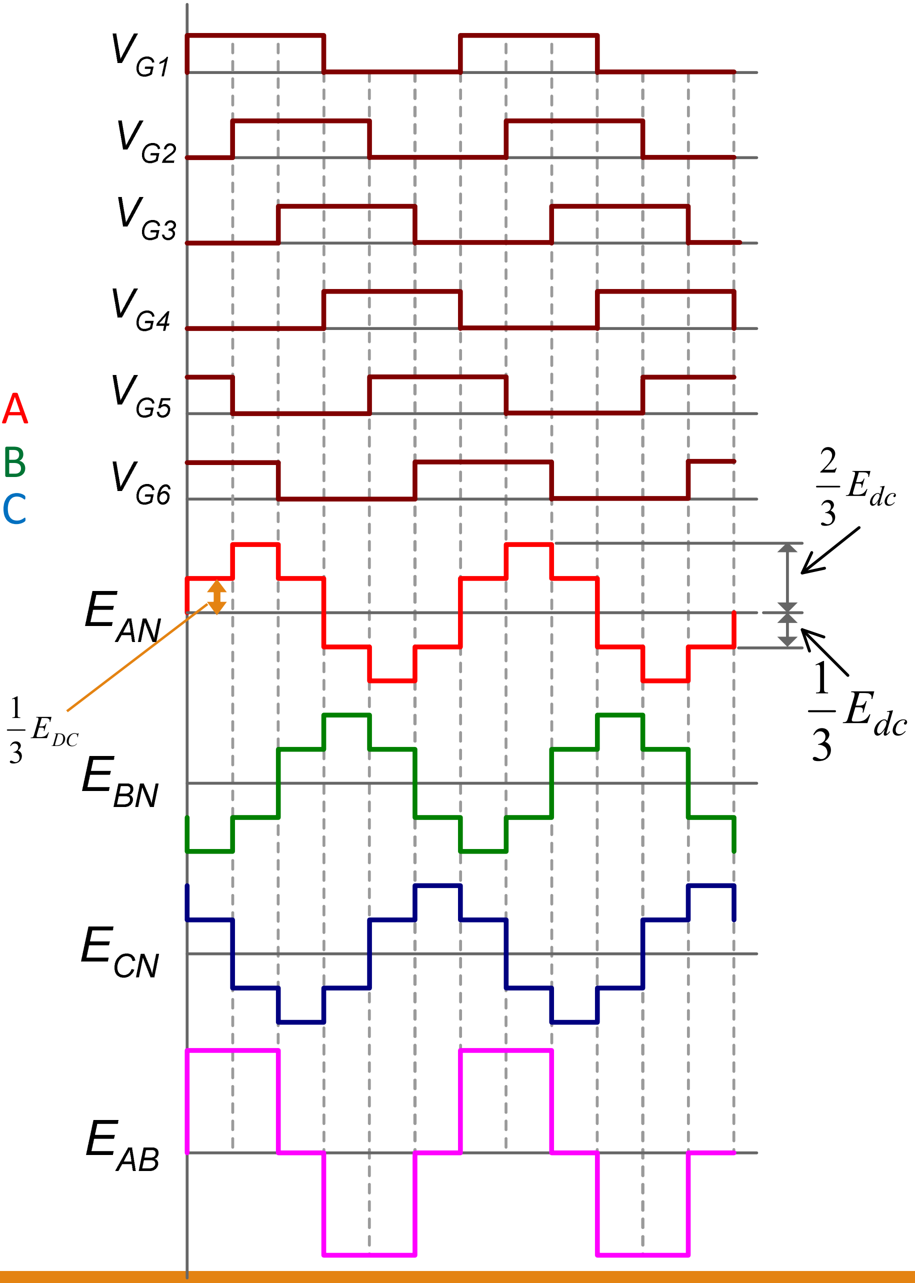
3-Phase Inverter

180° conduction



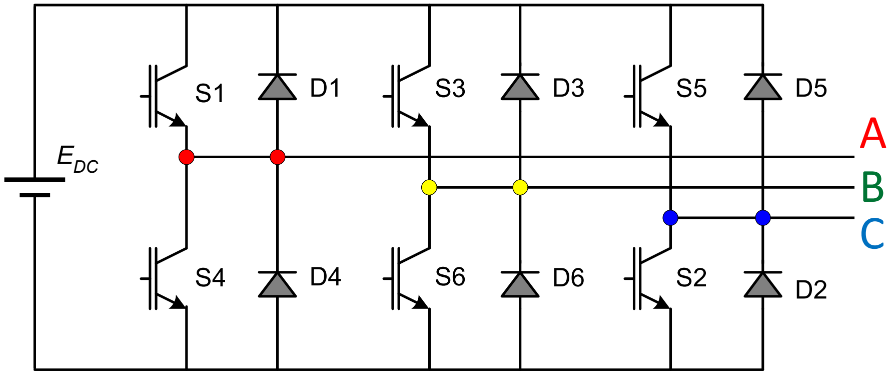
Connection during first interval



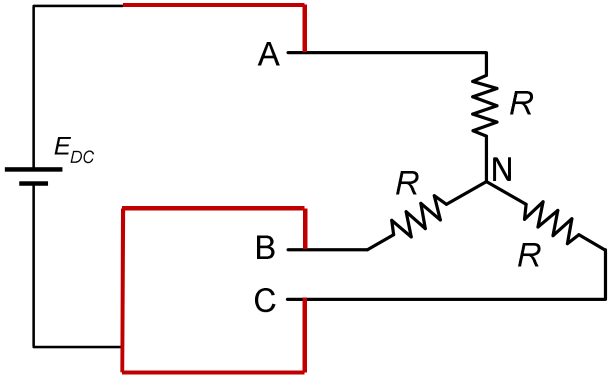


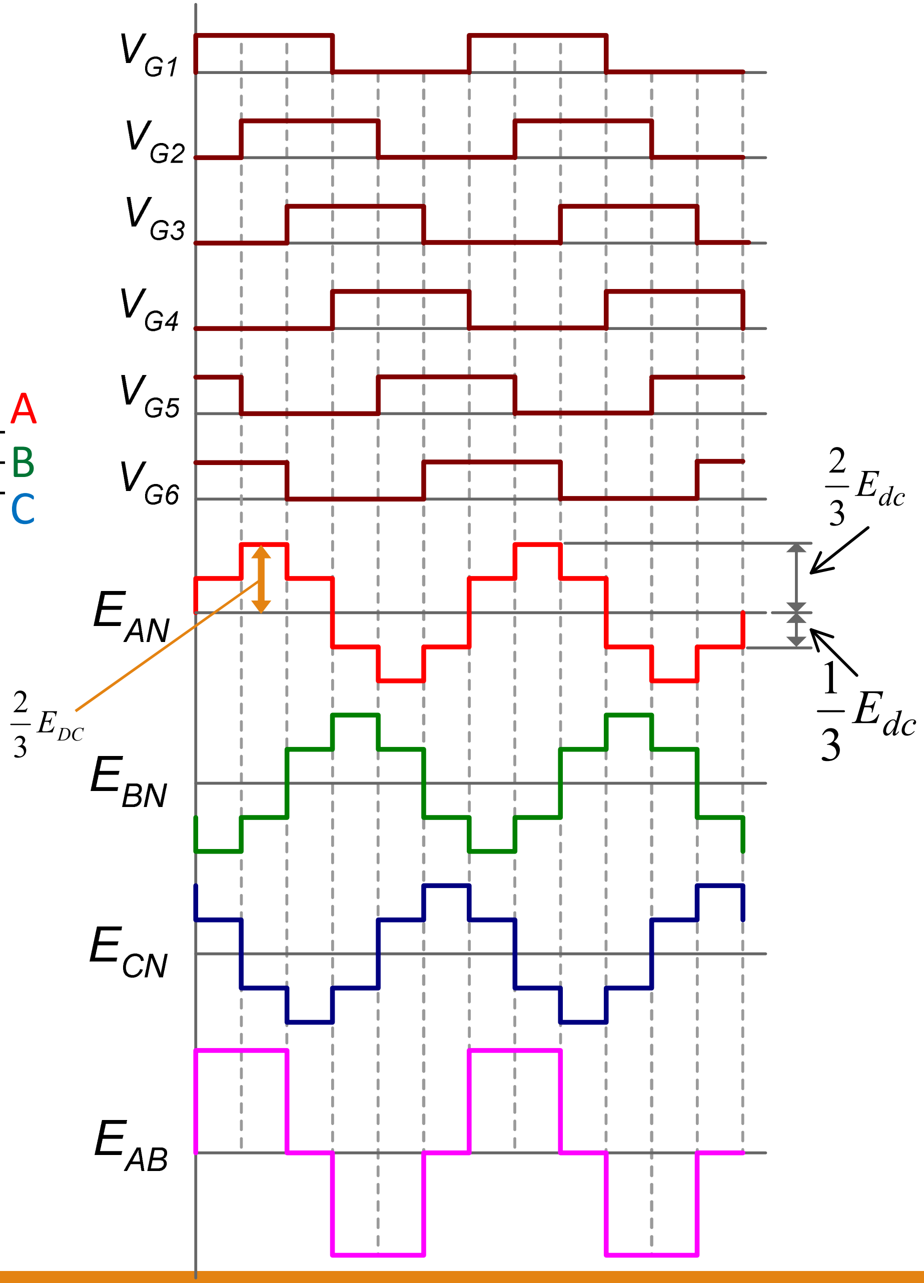
3-Phase Inverter

180° conduction



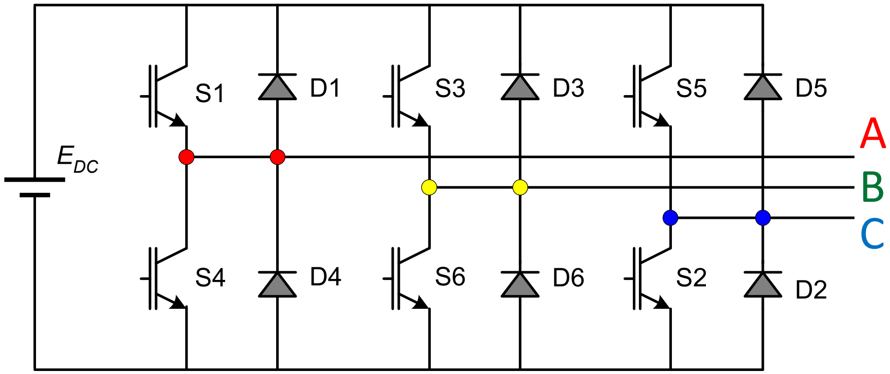
Connection during second interval



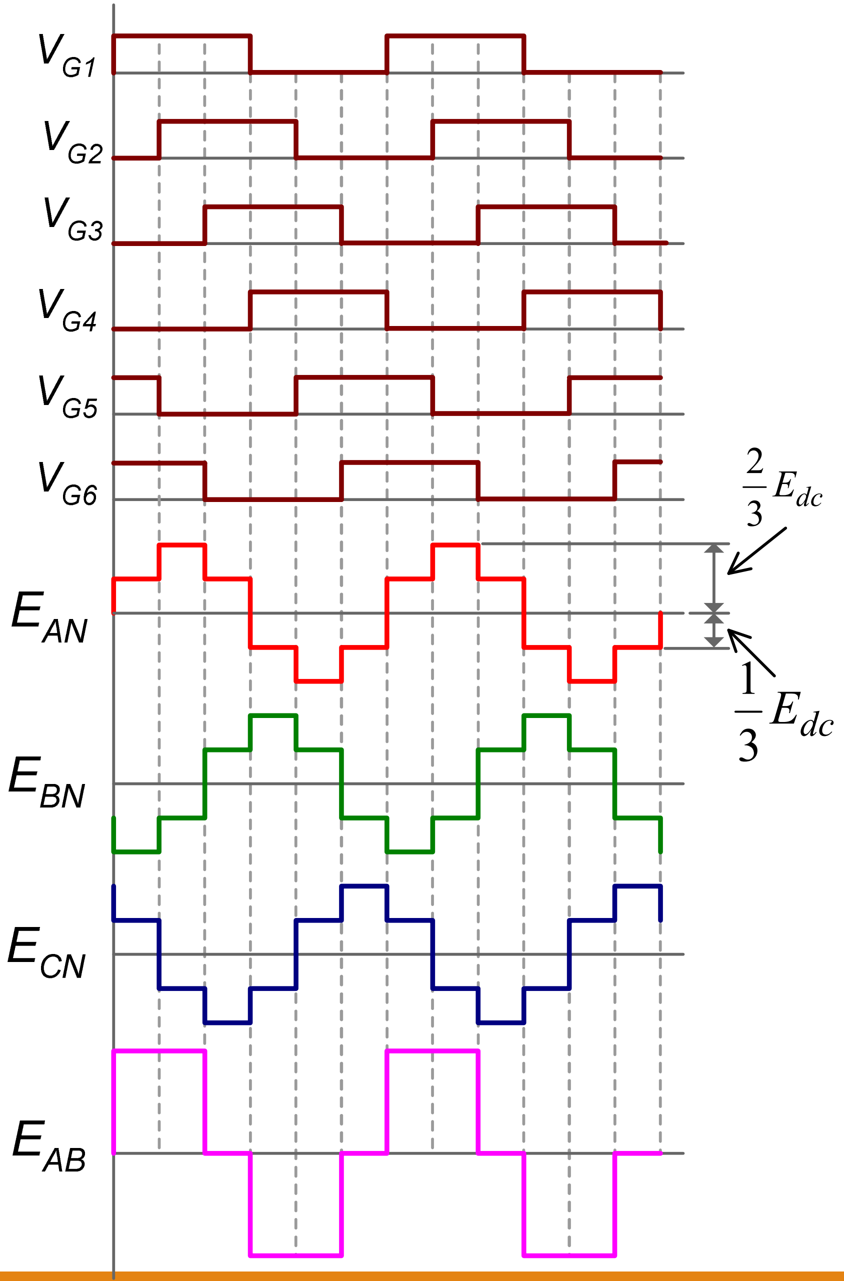


3-Phase Inverter

180° conduction

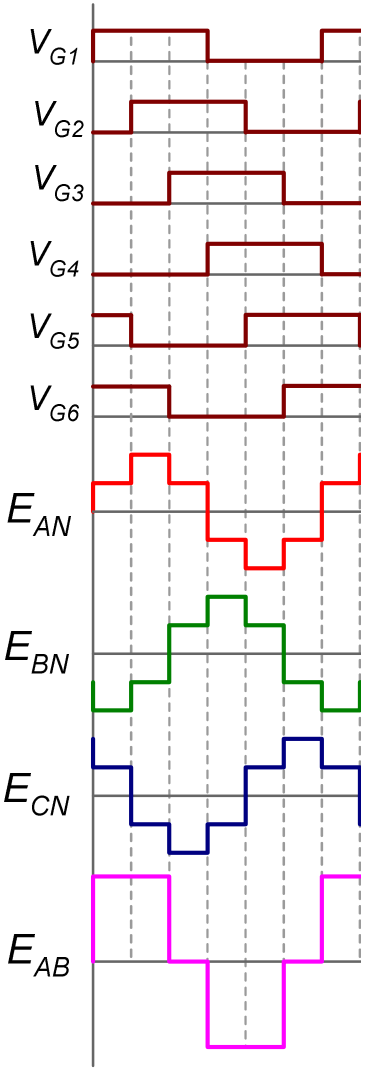


Interval	Incoming Device	Conducting Devices
1	S1	5,6,1
2	S1	6,1,2
3	S3	1,2,3
4	S4	2,3,4
5	S5	3,4,5
6	S6	4,5,6



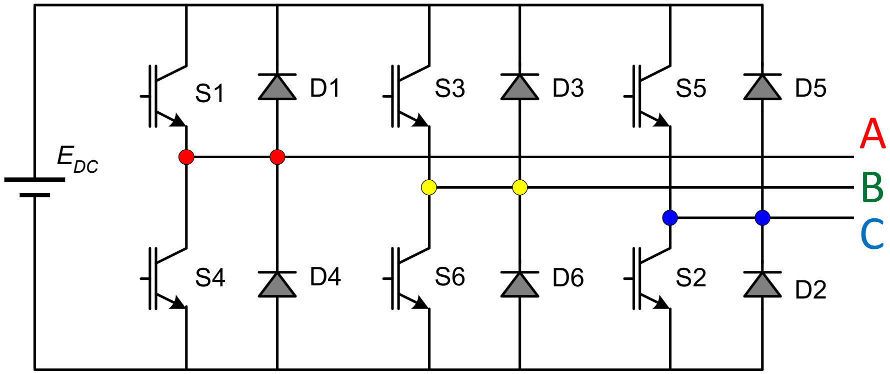
Features of 180 degree conduction

- Conduction period for each switch is 180°
- Three switches conduct at a time
- There is possibility of cross conduction if a dead band delay is not deliberately introduced.
- Phase voltages are six step waves
- Line voltages are quasi square waves

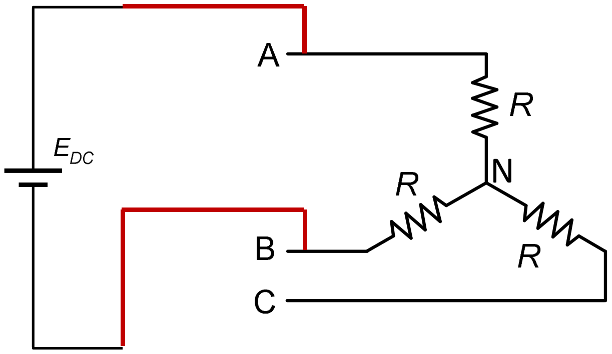


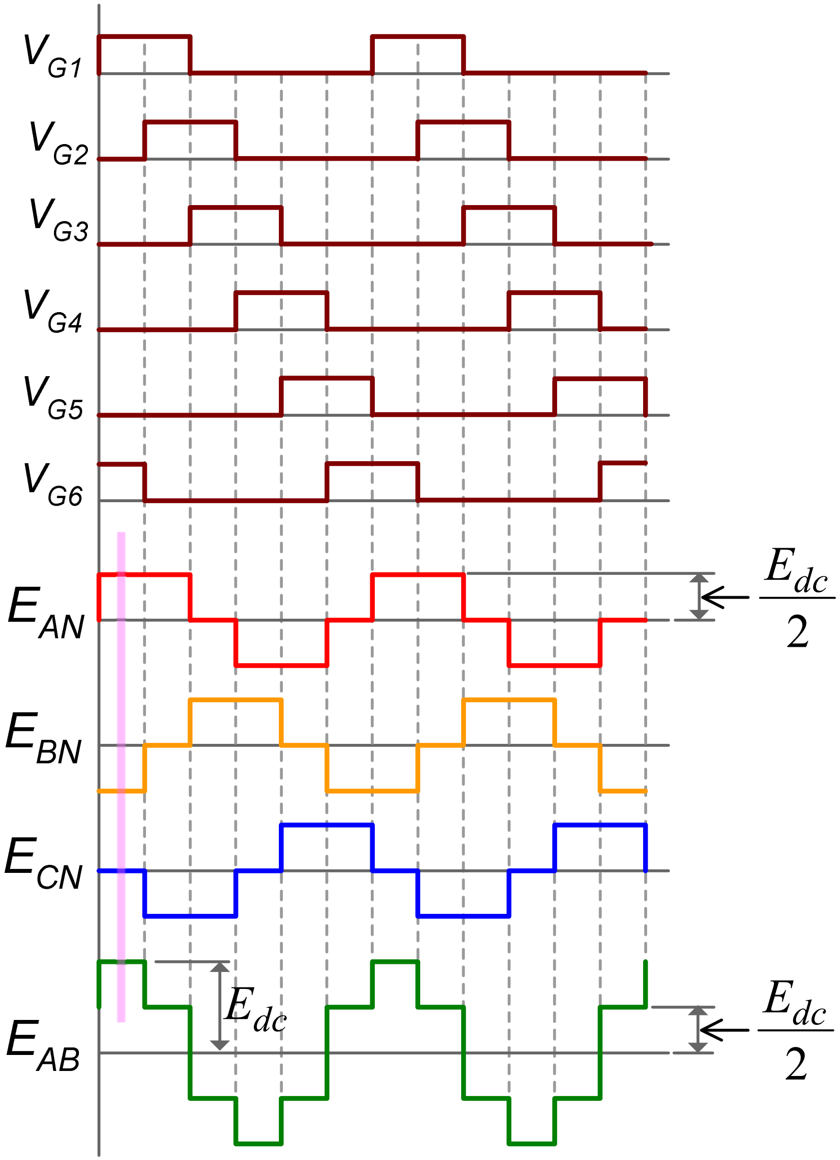
3-Phase Inverter

120° conduction



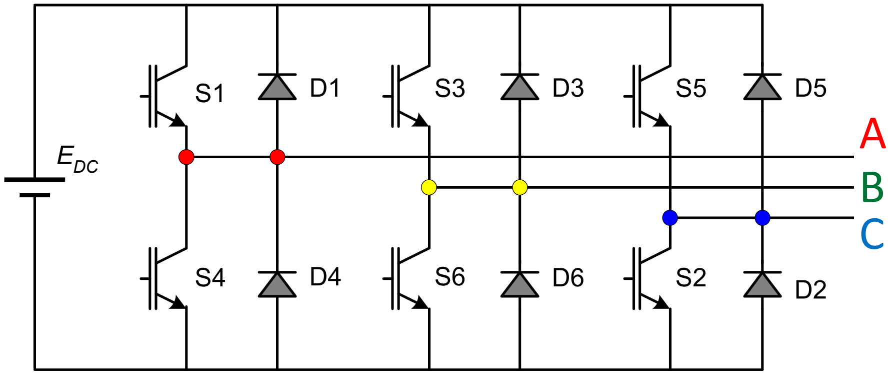
Connection during first interval



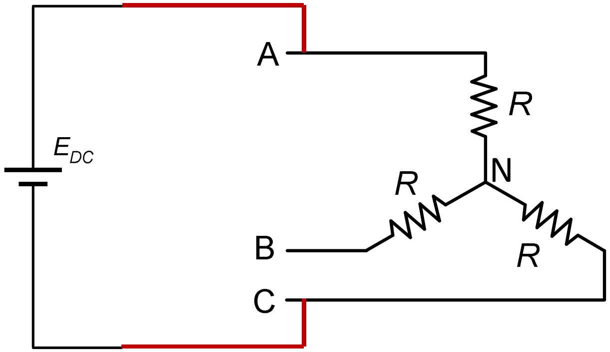


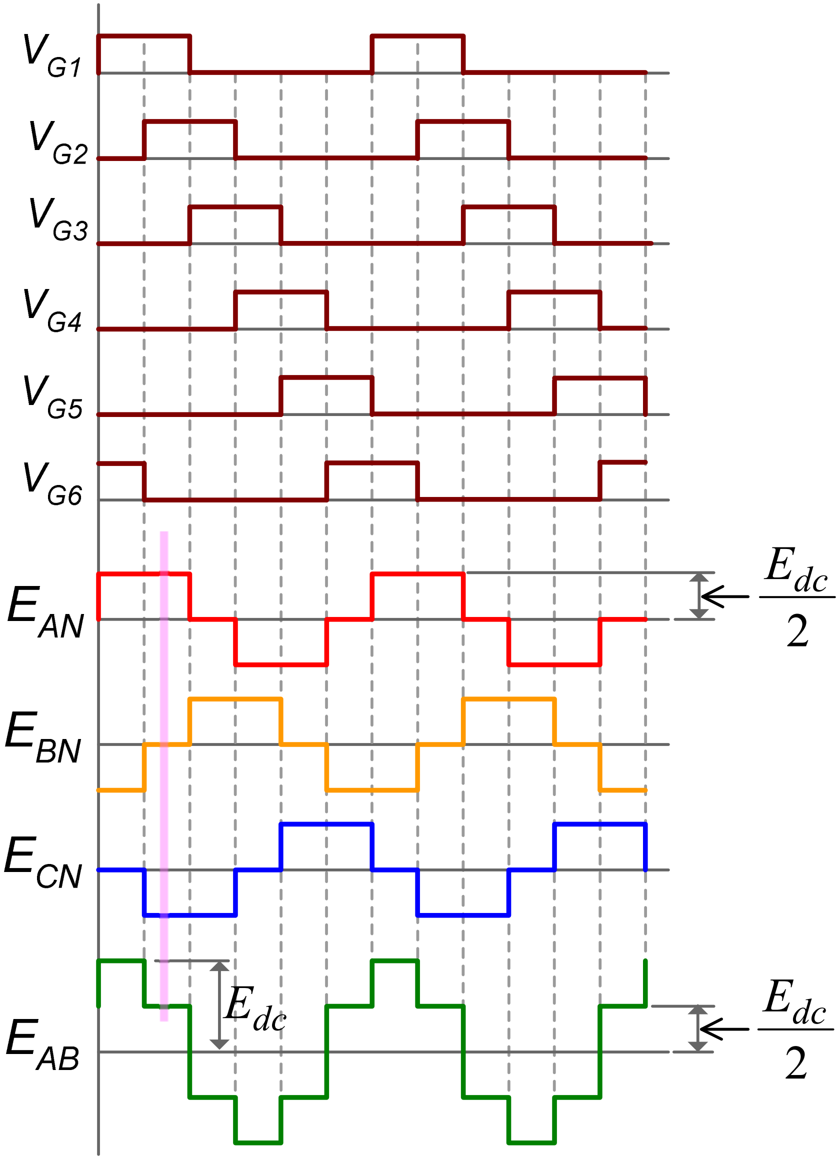
3-Phase Inverter

120° conduction



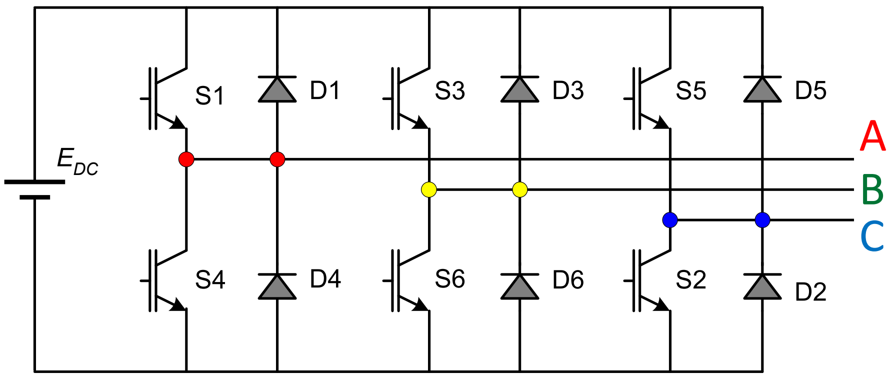
Connection during second interval



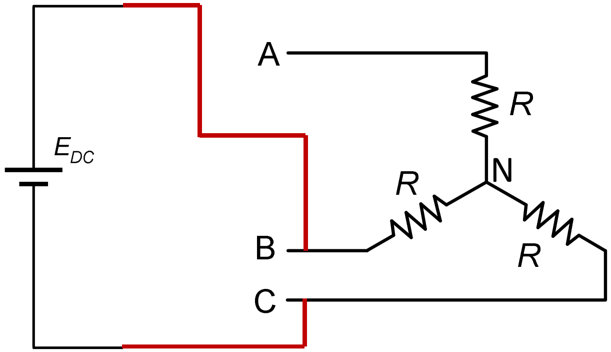


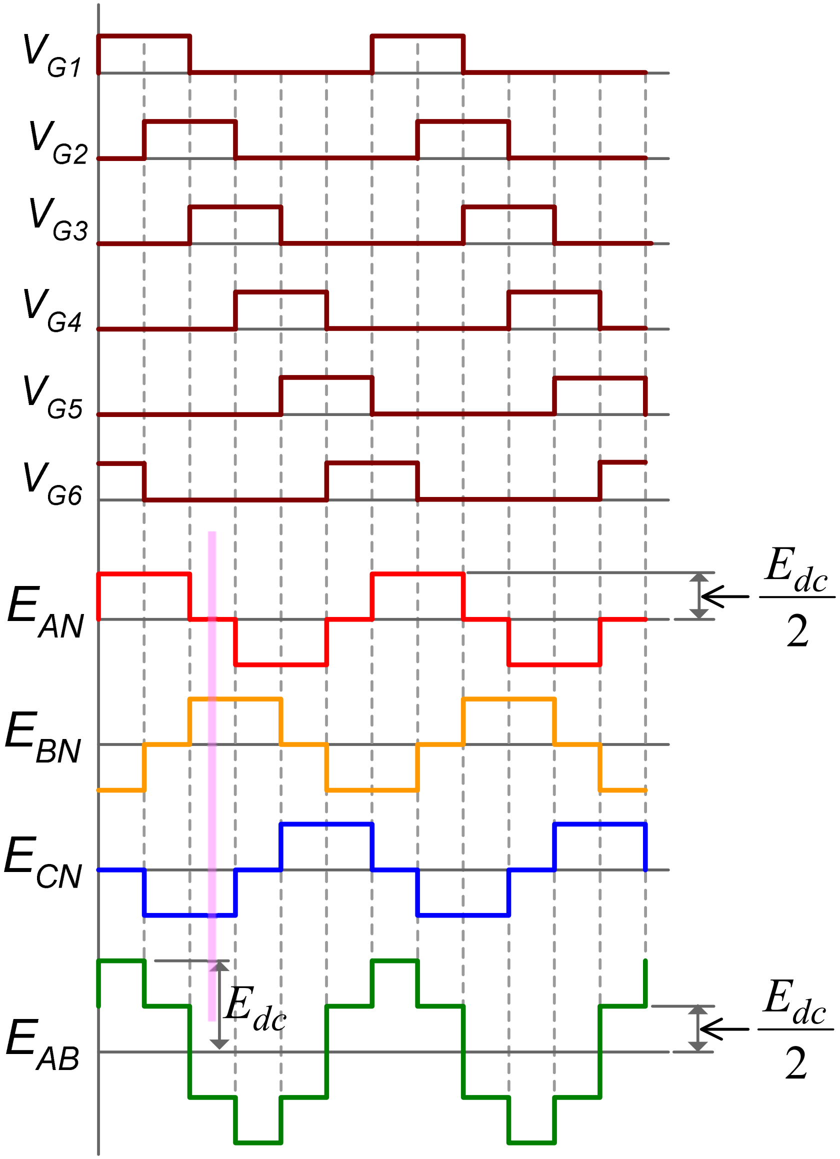
3-Phase Inverter

120° conduction



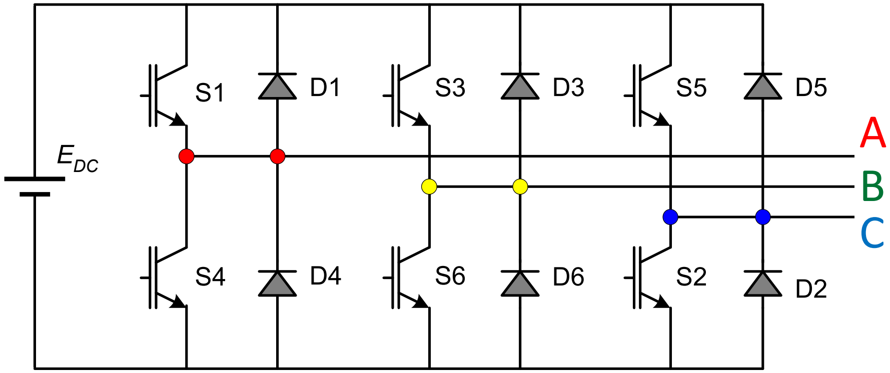
Connection during third interval



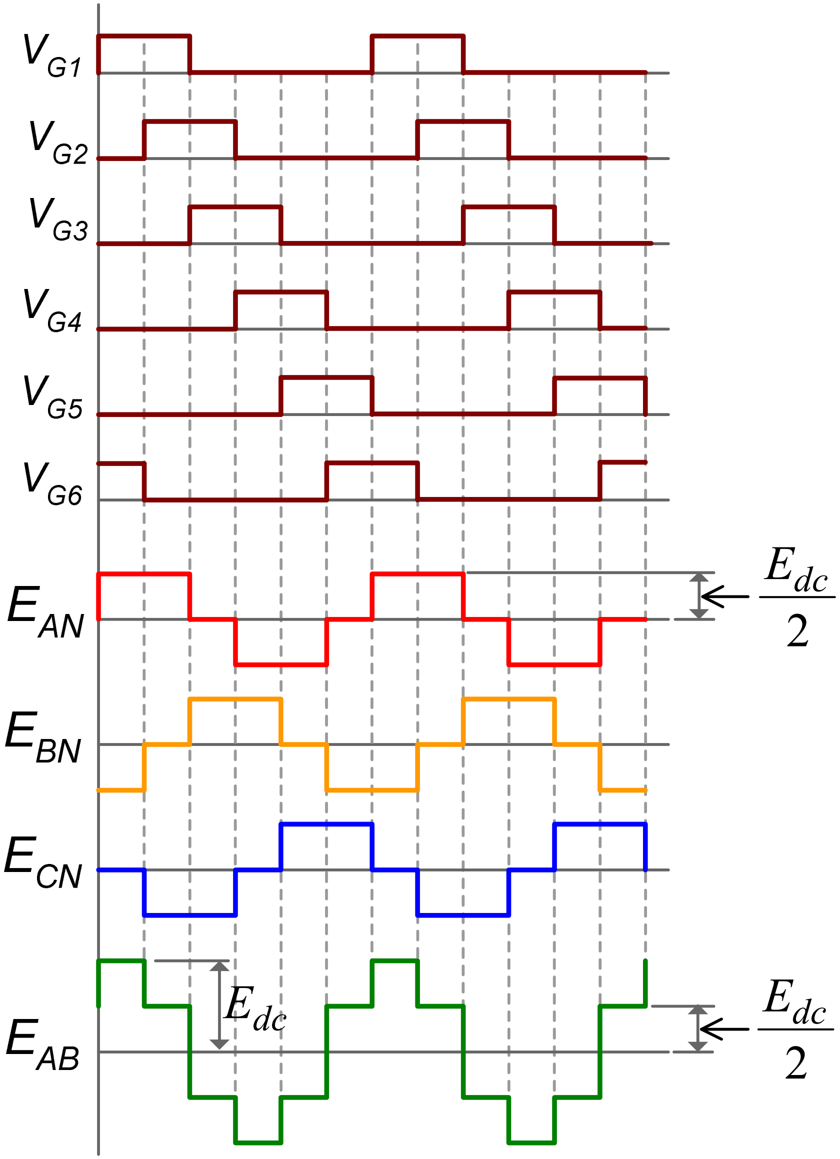


3-Phase Inverter

120° conduction

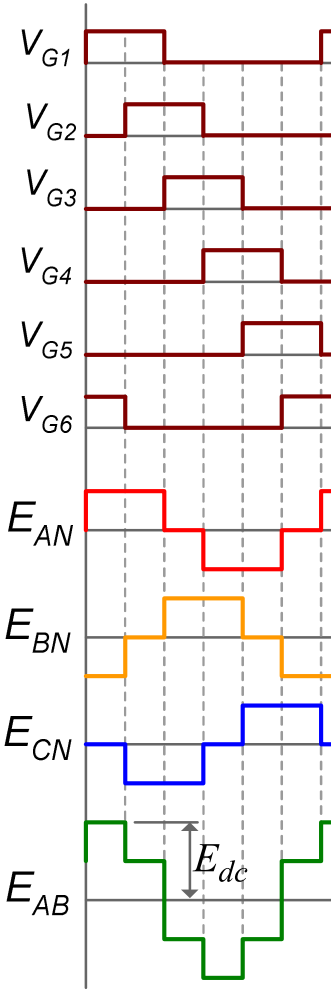


Interval	Incoming Device	Conducting Devices
1	S1	6,1
2	S1	1,2
3	S3	2,3
4	S4	3,4
5	S5	4,5
6	S6	5,6

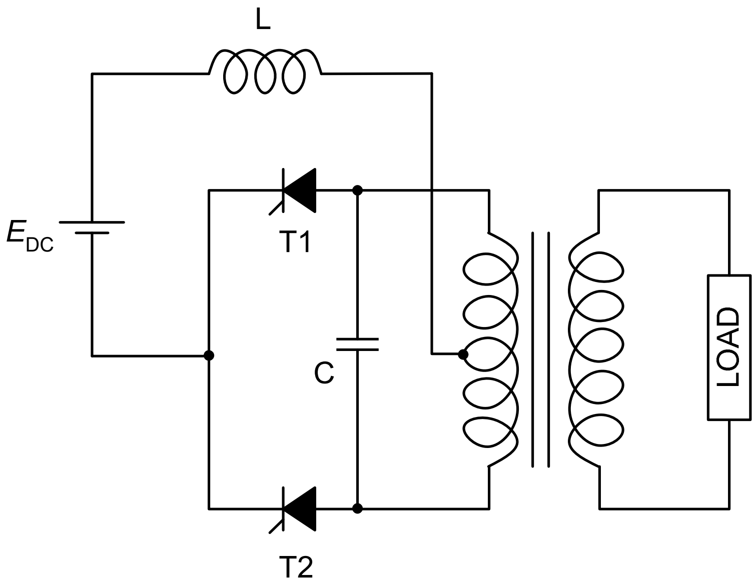


Features of 120 degree conduction

- Conduction period for each switch is only 120°
- Only two switches conduct at a time
- Two switches in the same leg of bridge have inherent dead band of 60° and there is no possibility of cross conduction
- Phase voltages are quasi square waves
- Line voltages are six step waves



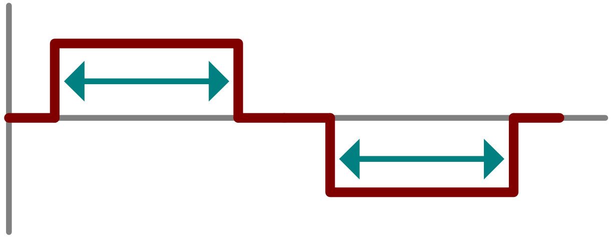
Parallel Inverter



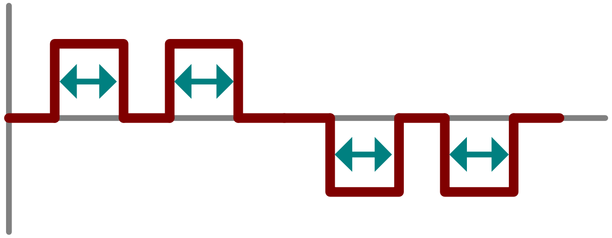
- SCRs can be used as switch, simple forced commutation is possible
- When T1 is turned on, the transformer is energised in one direction and the capacitor C is charged with a voltage of $2E_{DC}$
- When T2 is turned on capacitor voltage is applied to T1 in reverse direction and commutates it; the capacitor C is charged with a voltage of $-2E_{DC}$
- T1 is turned on again forcing T2 to turn off and the cycle repeats
- Higher output voltage is possible by suitable transformer turns ratio

Voltage Control with Pulse Width Modulation

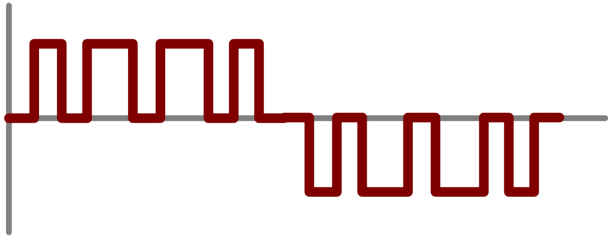
- **Single Pulse width Modulation**
  - Consists of a pulse with variable width in each half cycle
  - width varies from 0 to π



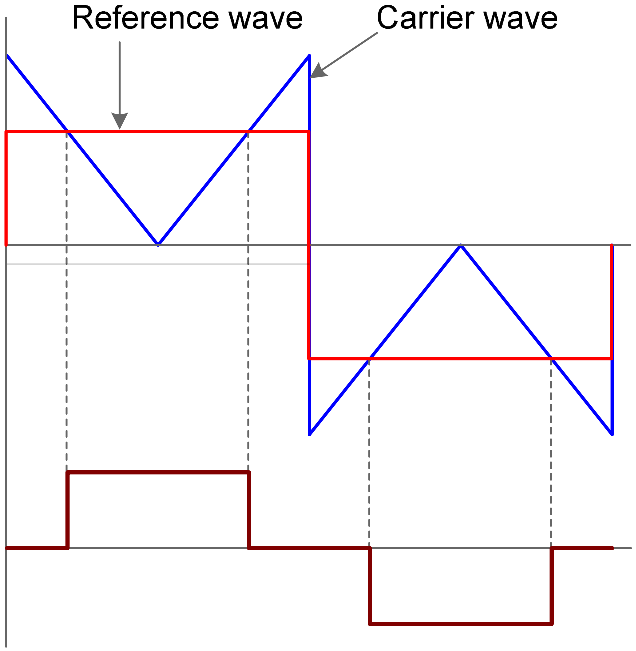
- **Multiple Pulse Width Modulation**
  - Is an extension of single PWM and uses several equidistant pulses in each half cycle

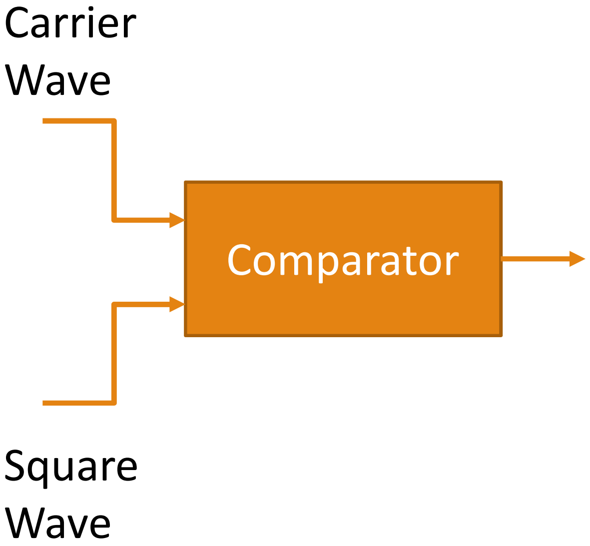


- **Sinusoidal Pulse Width Modulation**
  - Pulse width is a sinusoidal function of angular position of the pulse in a cycle



Single Pulse PWM

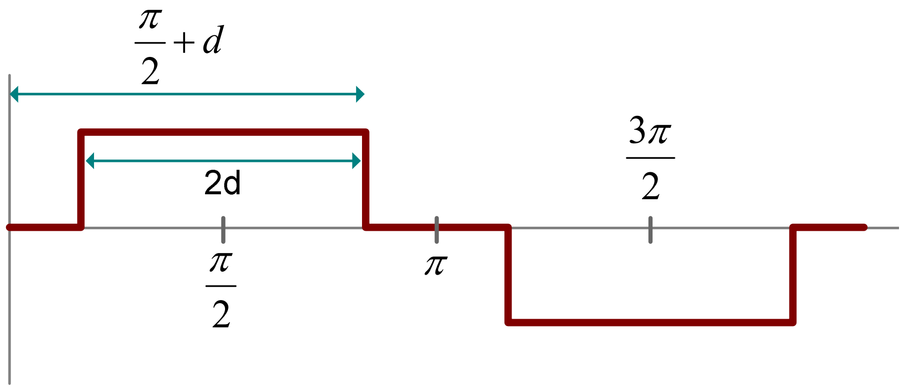



Carrier Wave

Comparator

Square Wave

Single Pulse PWM



RMS value of output voltage, $V = V_{DC}\left[\frac{2d}{\pi}\right]^{\frac{1}{2}}$

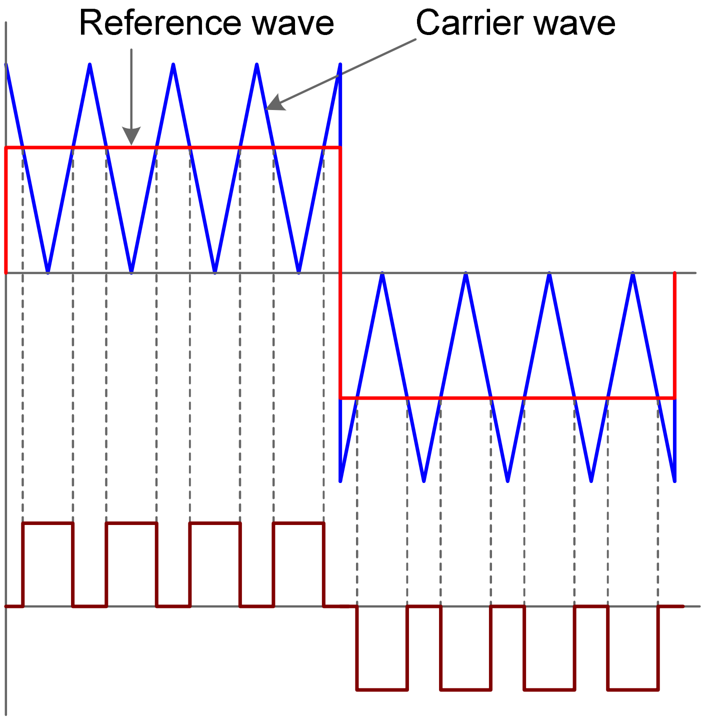
Peak value of nth harmonic, $V_{onm} = \frac{4\,V_{DC}}{n\pi}\sin nd$

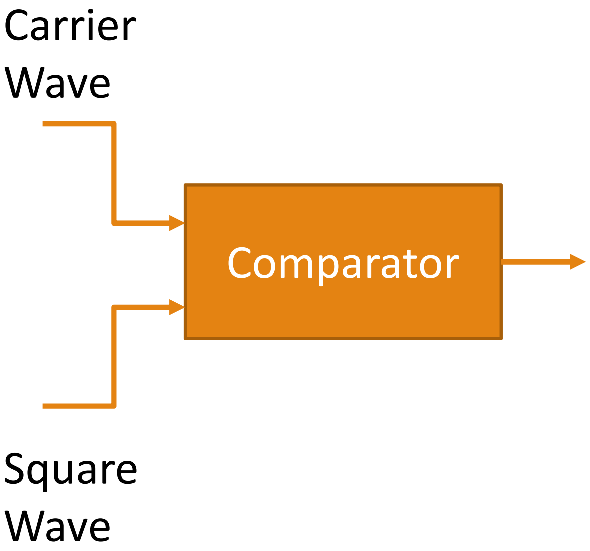
When pulsewidth is 120°, d = 60°

Then peak value of 3rd harmonic, $V_{o3m} = \frac{4\,V_{DC}}{3\pi}\sin 3\times 60 = 0$

This implies, when the pulse width is 120°, third harmonics will be eliminated

Multiple Pulse PWM




Carrier Wave

Comparator

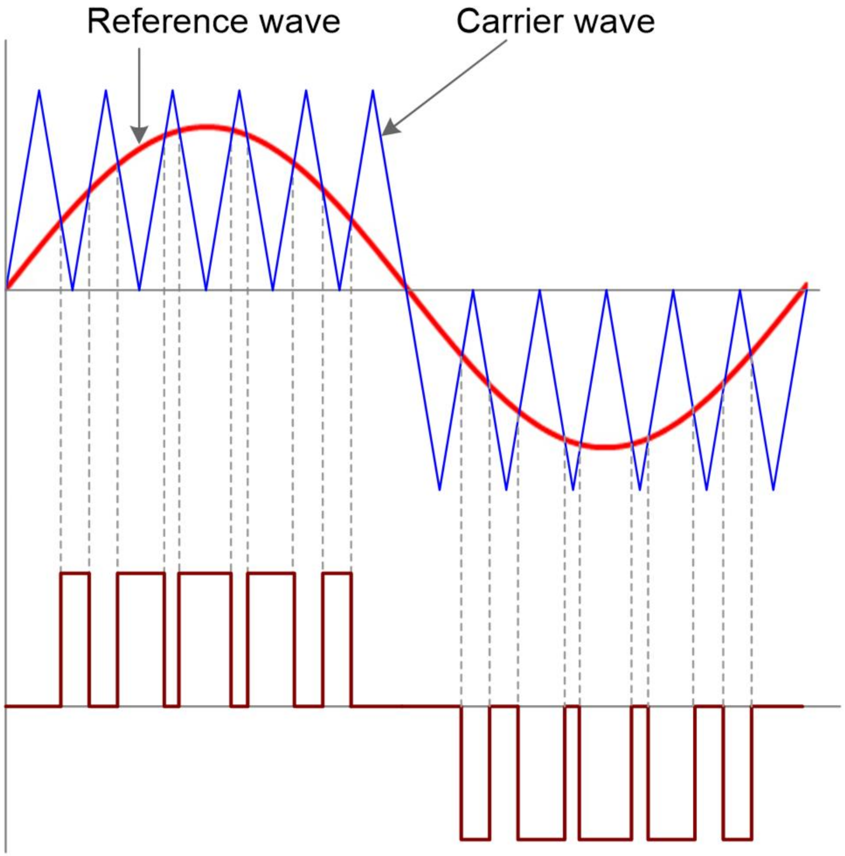
Square Wave

RMS value of output voltage, $V = V_{DC}\left[\frac{N_p \times P}{\pi}\right]^{\frac{1}{2}}$

N_p = number of pulses in a half cycle

P = pulse width

Sine PWM



$$\text{Modulation Index, } MI = \frac{V_r}{V_c}$$

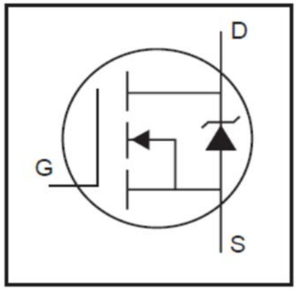
where V_r is the peak of reference wave and V_c is the peak of carrier wave

There will be low order harmonics when *MI* is greater than 1

Typical MOSFETS

IRFP250N

HEXFET® Power MOSFET



V_{DSS} = 200V

$R_{DS(on)}$ = 0.075Ω

I_D = 30A

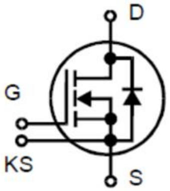
utilize advanced processing
er silicon area. This benefit,
edized device design that
vides the designer with an
ide variety of applications.

dustrial applications where
ices. The TO-247 is similar
f its isolated mounting hole.

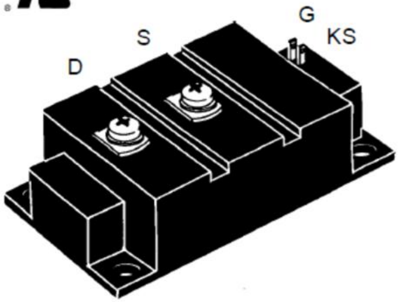
TO-247AC

VMO 650-01F

V_{DSS} = 100 V
I_{D25} = 690 A
$R_{DS(on)}$ = 1.8 mΩ



E 72873

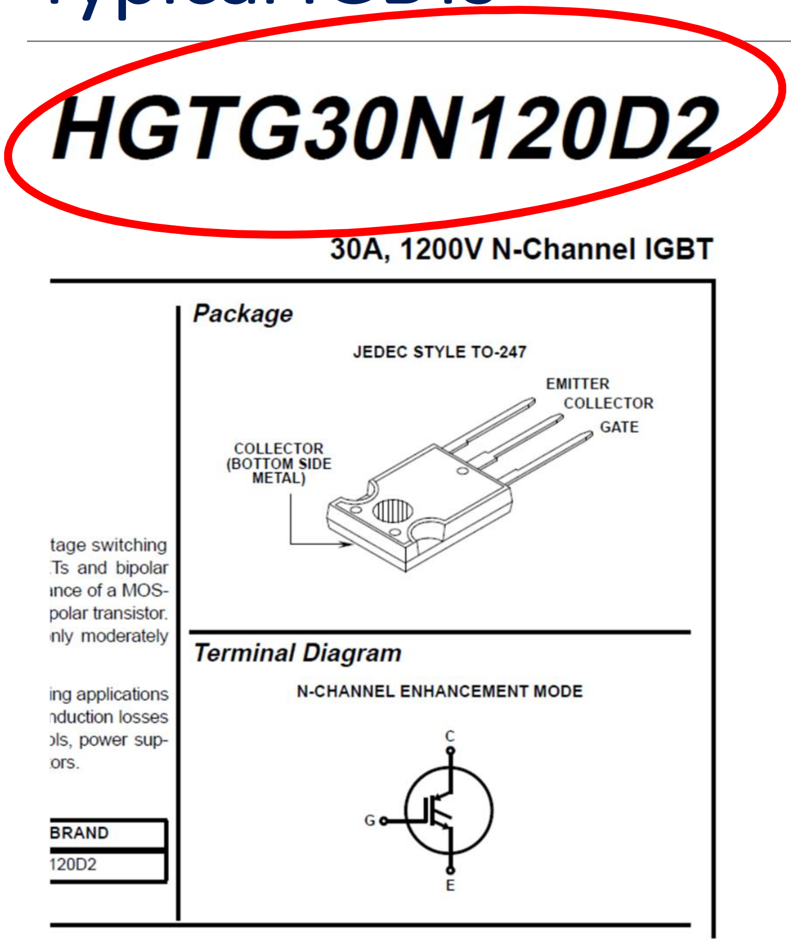


D = Drain
S = Source
KS = Kelvin Source
G = Gate

Maximum Ratings

100	V
100	V
±20	V
±30	V

Typical IGBTs



HGTG30N120D2

30A, 1200V N-Channel IGBT

Package

JEDEC STYLE TO-247

tage switching
Ts and bipolar
ınce of a MOS-
polar transistor.
nly moderately

ing applications
nduction losses
ıls, power sup-
ors.

BRAND
120D2

Terminal Diagram

N-CHANNEL ENHANCEMENT MODE

MITSUBISHI IGBT MODULES

CM50DY-28H

MEDIUM POWER SWITCHING USE
INSULATED TYPE