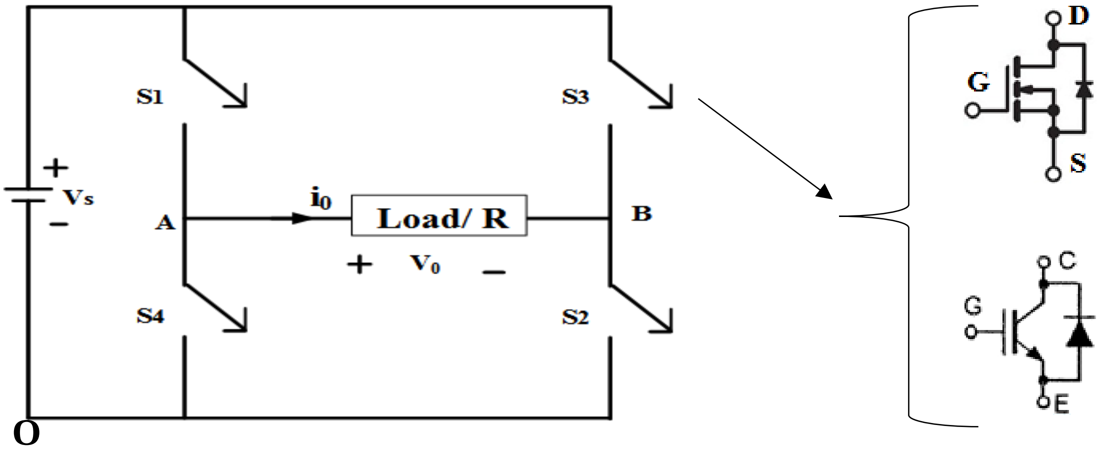
STUDY OF SINGLE-PHASE AND THREE PHASE INVERTERS AND THEIR MODULTION TECHNIQUES

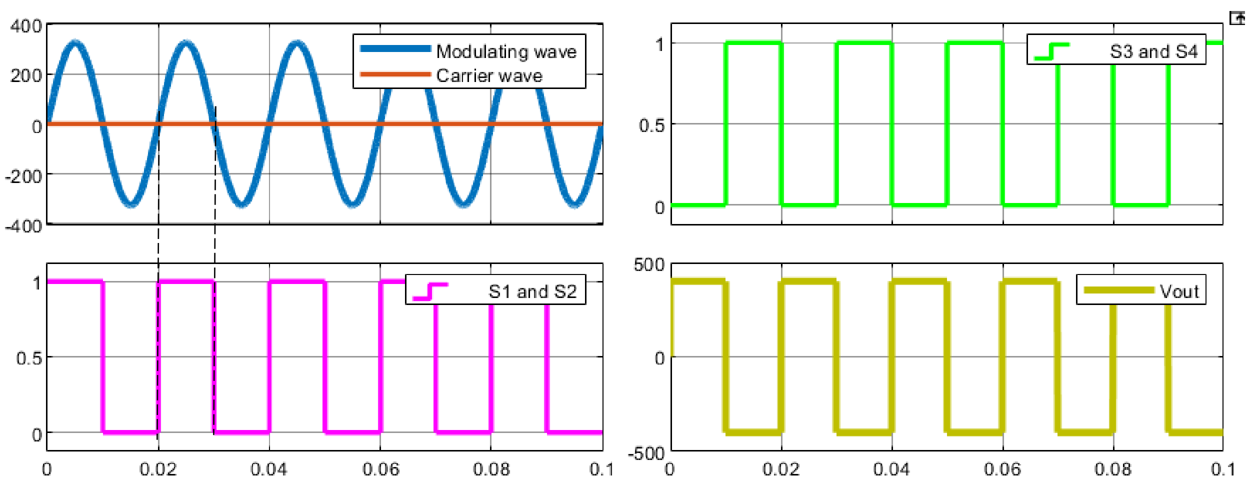
Single Phase Voltage Source Inverter:

Circuit diagram:

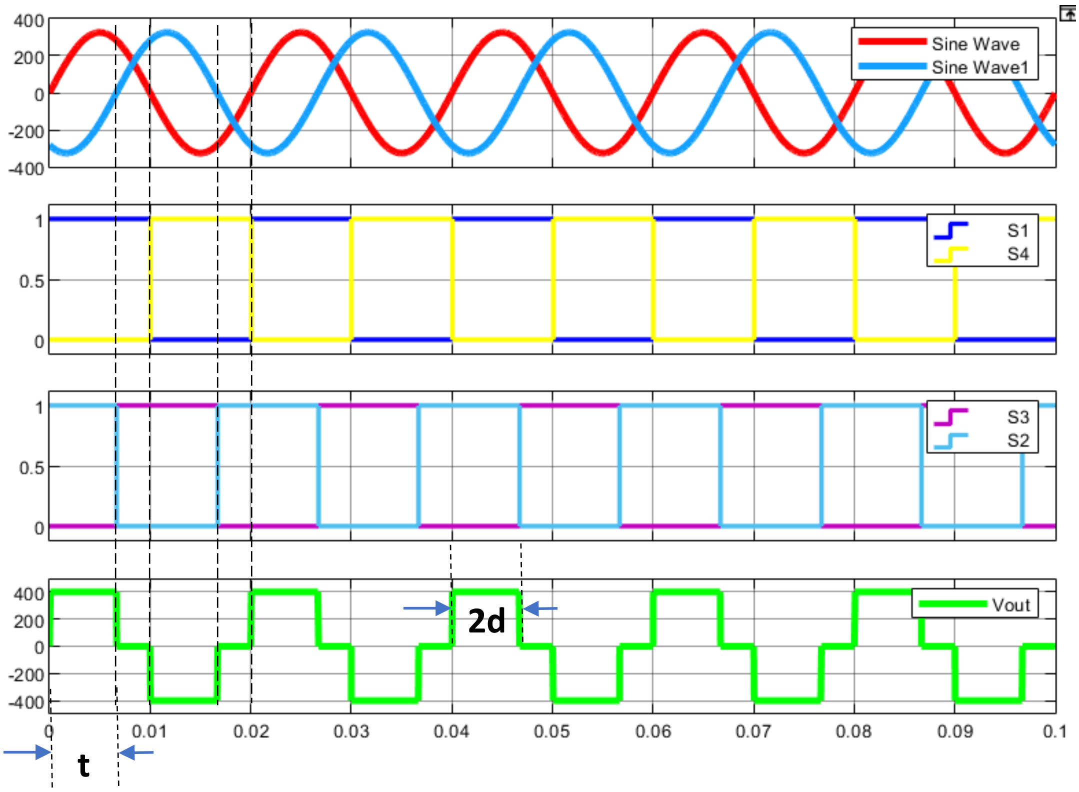


Various Modulation schemes:

A. SQUARE WAVE MODULATION:



B. QUASI SQUARE WAVE MODULATION:



The output voltage can be calculated as

$$v_0 = \sum_{n=1,3,5\ldots}^{\infty} \frac{4V_s}{n\pi} * sin\frac{n\pi}{2} * \sin nd * \sin nwt$$

Now, if "$2d$" is made equal to π, then the peak value of the fundamental output voltage can be written as

$$v_{01m} = \frac{4V_s}{\pi}$$

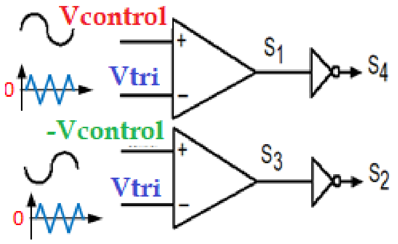
For other values 2d $< \pi$,

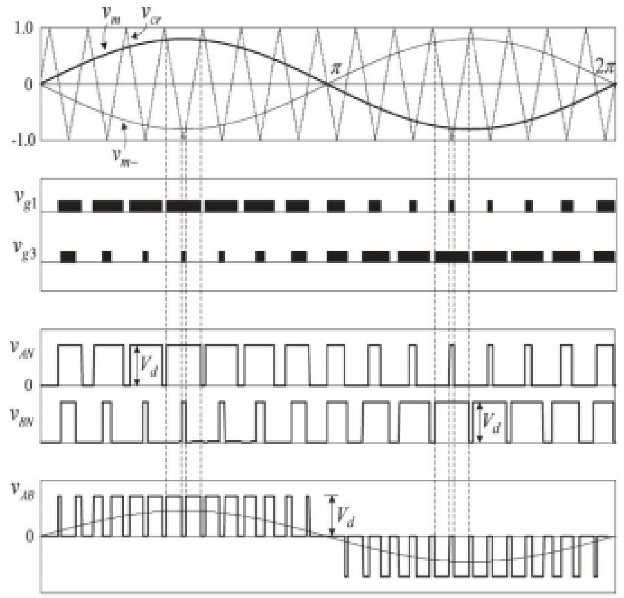
$$v_{01m} = \frac{4V_s}{\pi} * \sin d$$

The phase shift between the two modulating signals can be calculated as:

$$\alpha = \frac{2\pi t}{T} radians$$

C. UNIPOLAR MODULATION SCHEME:

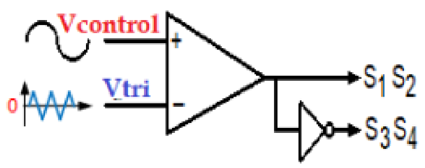


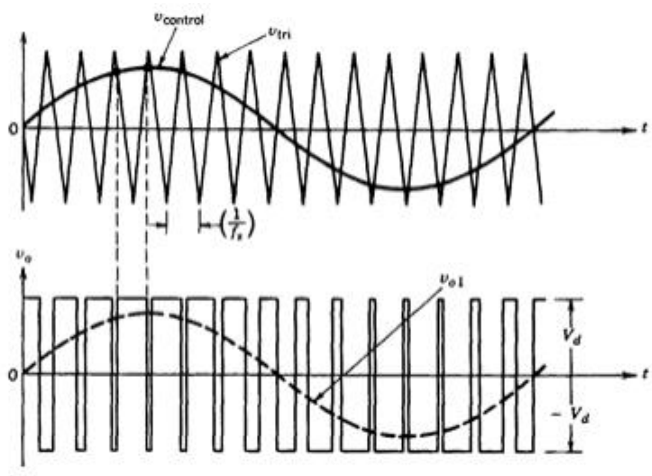


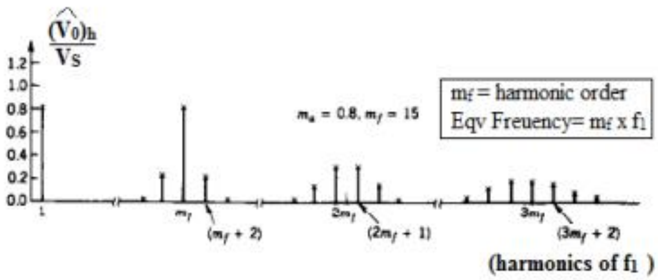
(a) Waveforms

(b) Harmonic spectrum

D. BIPOLAR MODULATION SCHEME:

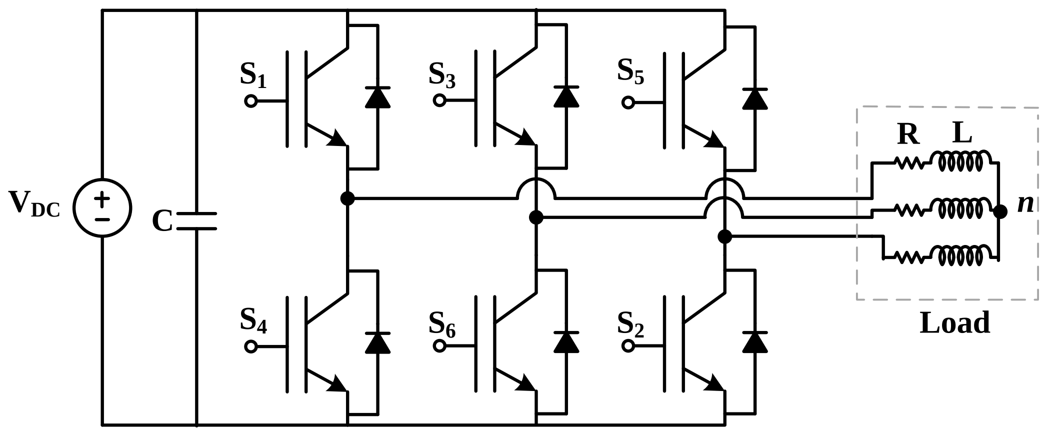




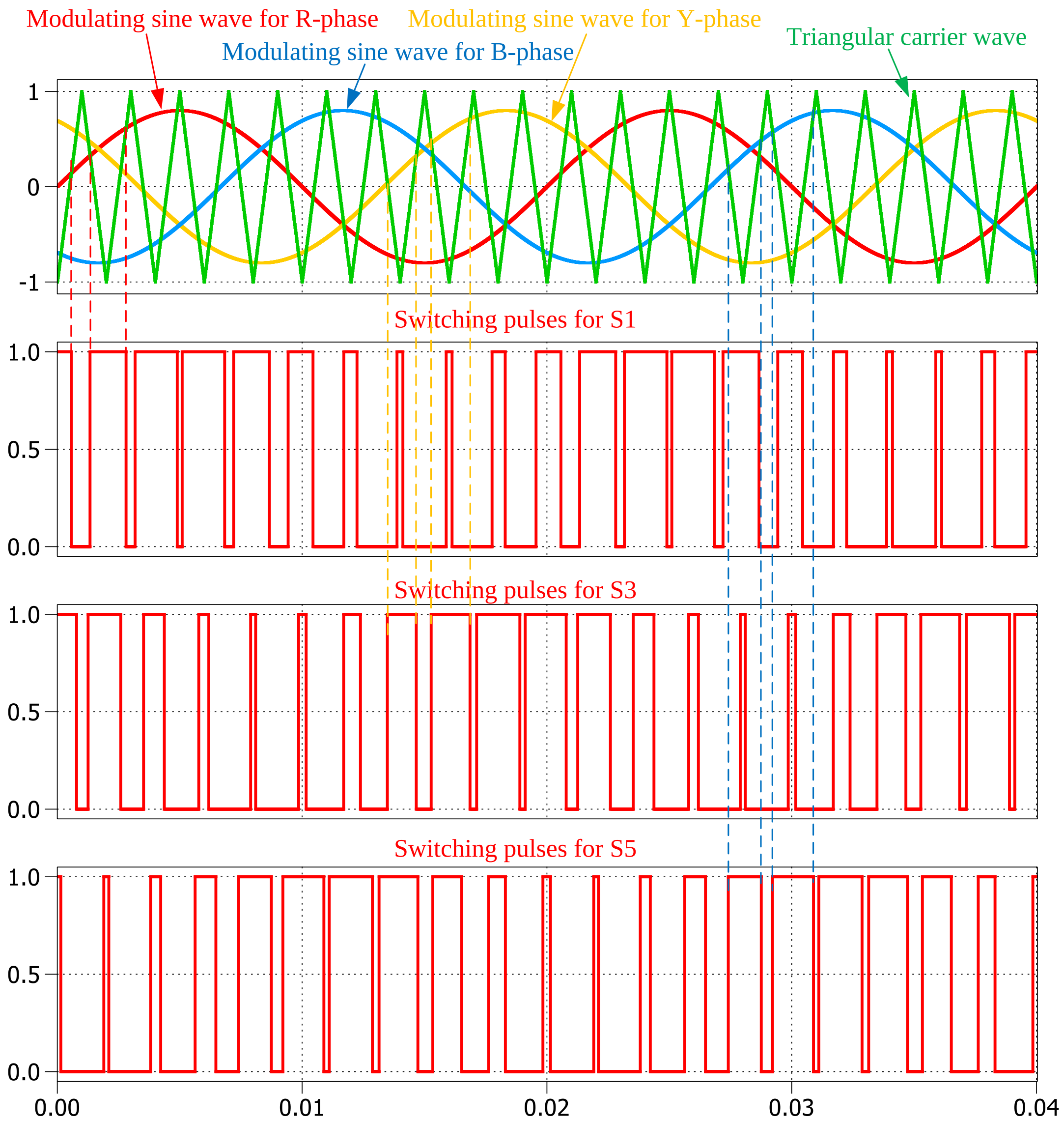


Three Phase Voltage Source Inverter:

Circuit diagram:

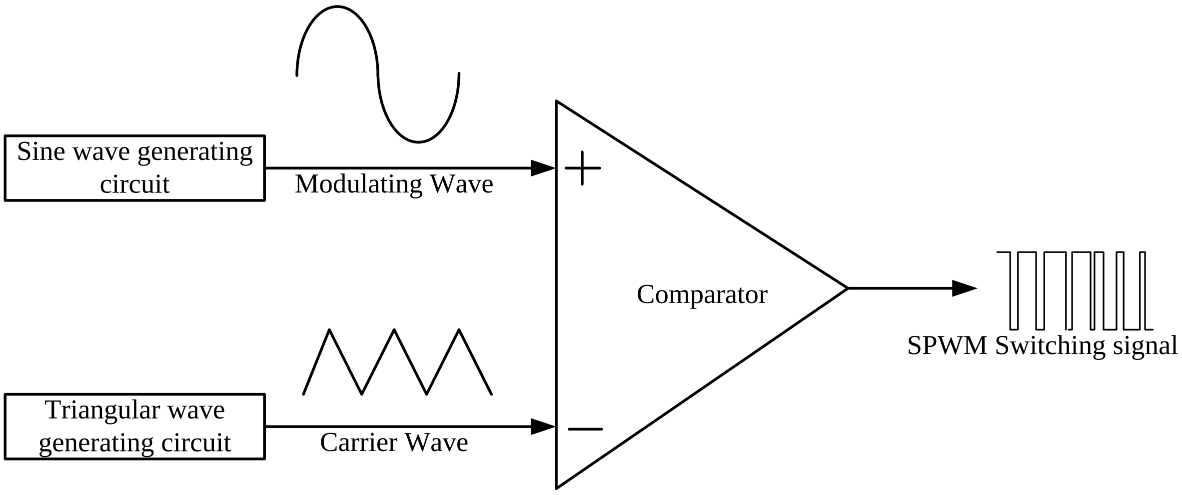


SPWM Modulation scheme:



Switches in the same leg will have complementary switching pulses.

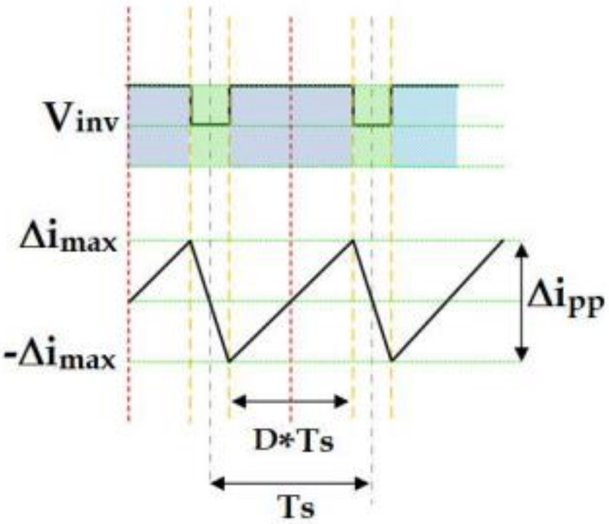
Analog scheme for SPWM implementation:



Advantages of SPWM compared to 180-degree mode of operation:

- The output voltage control can be obtained without addition of any external components.
- Minimizes the lower order harmonics, while the higher order harmonics can be eliminated using a filter.
- Easy to implement and control.
- Compatible with today's digital microprocessors.
- Allows linear amplitude control of the output voltage/current.
- Lower switching losses.
- Lower power dissipation and better utilization of DC power supply.

Filter selection for single phase off grid inverter:



$$\Delta i_{pp} = \frac{D \times T_s \times (V_{DC} - V_{out})}{L_f}$$

$$\Delta i_{pp} = \frac{V_{DC} \times T_s \times m_a \times \sin(\omega t) \times (1 - m_a \sin(\omega t))}{L_f}$$

The ripple will be maximum at $Sin(wt) = \frac{1}{2 * m_a}$

The L can be calculated as

$$\Delta i_{pp}\big|_{max} = \frac{V_{DC} \times T_s}{4 \times L_f}$$

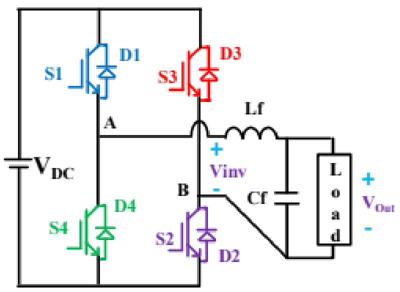
$$L_f = \frac{V_{DC}}{4 \times F_{sw} \times \Delta i_{pp}\big|_{max}}$$

The filter capacitance can be calculated considering the cut-off frequency of the filter is at max 1/10th of the switching frequency

$$F\_cut\text{-}off = \frac{1}{2\pi\sqrt{L_f C_f}}$$

$$C_f = \frac{1}{Lf\,(2\pi F\_cut\_off)^2}$$

Loss calculation for single phase Inverter:



$$D_{S1} = \frac{1}{2} + \frac{\text{Ma Sin } \omega t}{2}$$

$$D_{S4} = D_{S3} = (1 - DS_1)$$

$$D_{S3} = \frac{1}{2} - \frac{\text{Ma Sin } \omega t}{2}$$

- The average currents for the switches and diodes can be calculated as

- $Is1(avg) = \frac{1}{2\pi}\int_0^{\pi}(iL * Ds1)\, d\theta$
- $Is1(avg) = \frac{1}{2\pi}\int_0^{\pi}(Im \sin(\omega t - \Phi) * (\frac{1}{2}(1 + \text{Ma Sin } \omega t))\, d\theta$
- $Is1(avg) = Im(\frac{1}{2\pi} + \frac{\text{Ma } cos\Phi}{8})$

$$D_{S4} = 1 - D_{S1} = \frac{1}{2} - \frac{\text{Ma Sin } \omega t}{2}$$

- $I_{D4}(avg) = Im\,(\frac{1}{2\pi} - \frac{\text{Ma } cos\Phi}{8})$

- Similarly, the rms current expression for the switches and diodes can be written as:

- $Is1(RMS) = \sqrt{\frac{1}{2\pi}\int_0^{\pi}(iL^2 * Ds1)\, d\theta}$
- $Is1(RMS) = Im\sqrt{\frac{1}{8} + \frac{\text{Ma } cos\Phi}{3\pi}}$

$$I_{D4}(Avg) = Im\sqrt{\frac{1}{8} - \frac{\text{Ma } cos\Phi}{3\pi}}$$

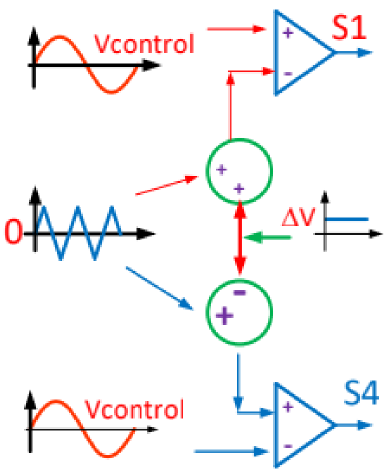
- The total conduction loss can be calculated as

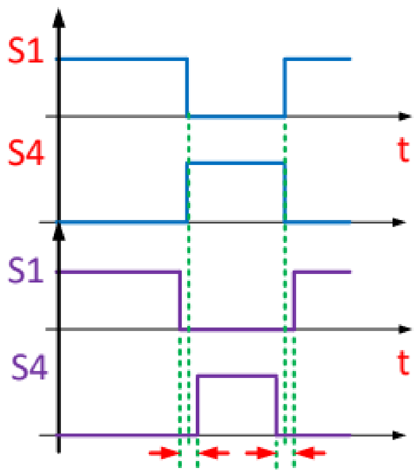
  - $P_{s1\_}cond = \{Vs1_{drop} * Is1(avg)\} + \{Rs_1 * Is1(RMS)^2\}$
  - $P_{D4\_}cond = \{V_{D4\_drop} * ID_4(avg)\} + \{RD_4 * ID_4(RMS)^2\}$

  - Total loss
  - P_tot_cond= 4 (P_{s1_cond} +P_{d4_cond})

<u>The concept of Dead Time:</u>

- To avoid the simultaneous conduction of the switches of the same leg of the inverter a small amount of Dead Time is important.
- This can be achieved by shifting the carrier signal by a small dc value as shown in fig below:





-