

SUMMER TERM – IIT H

- DC – AC conversion : Inverter topologies
- Analysis of various types of inverters



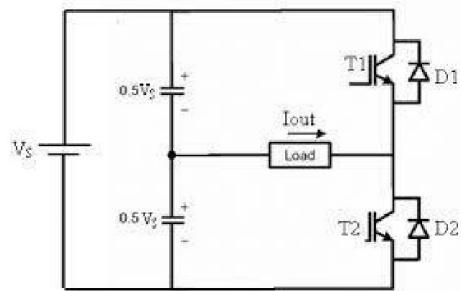
INTRODUCTION

- There are 2 types of power transfer : Alternating and Direct currents, i.e., AC & DC.
- We have **Rectifiers** to convert from **3 phase AC to DC**.
- Similarly, we have **Inverters** to convert from **DC to 3 phase AC**.
- Also, **DC to DC conversion** is employed using a **Buck-Boost converter**, in which we can alter the DC voltage magnitude (increase/decrease).
- Furthermore, we have **AC to AC conversion** taken care by a **Transformer**, which can alter the peak-peak voltage of the AC voltage (increase/decrease), but not altering its frequency.

Our **discussion is about DC to AC conversion** and hence we are going to discuss about inverters.



SINGLE PHASE HALF BRIDGE INVERTERS



The switches $T_1 \& T_2$ are complementary, so voltage across node a and pole O will be,

$$V_{ao} = +V_{DC}/2 \quad T_1=1, T_2=0$$
$$-V_{DC}/2 \quad T_1=0, T_2=1$$

Advantages with this configuration:

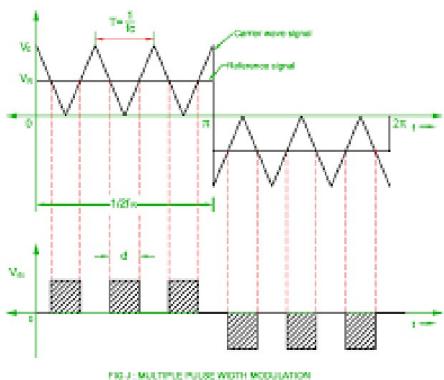
- No DC offset in output.
- When connected to an RL load, the output currents are approximately sinusoidal, due to filtering effect due to RL circuit.

Drawbacks with this configuration are:

- Contains harmonics of lower order in with magnitudes comparable to the fundamental component. High THD%
- Low DC bus Utilization $\sim 45\%$
- No control over fundamental component of output voltage.



CONTROL SIGNAL IMPLEMENTATION - PWM



The modulating wave $m(t)$ and the carrier wave $c(t)$, are the 2 signals which are compared using a comparator and we implement logic HIGH, when $m(t) > c(t)$ and LOW otherwise.

$$m = V_m/V_p \quad (\text{modulating index})$$

Where V_m & V_p are the amplitudes of the modulating and the carrier wave respectively.

So, Average Component of voltage of Single Phase Half Bridge Inverters will be,

$$\overline{V_{ao}} = \frac{V_{DC}}{2} \left(\frac{m(t)}{V_p} \right)$$

Where $m(t)$ is the modulating wave and V_p is the amplitude of carrier wave.



MAJOR ISSUES WITH INVERTER

- Inability to control output voltage.
- High torque ripple resulted due to current ripple in the load (preferably an induction motor), due to high THD % presence.
- Reduced DC bus utilization for a half bridge inverter. Higher DC bus utilization is expected as the bus can be rated for a lower value.

Possible solutions for these problems are:

- We use 2 legs of the switching pole and connect the load between both the poles, also referred to as the H-bridge inverter topology. This topology increases the DC bus utilization to 90%.
- Now, since we have optimised DC bus utilization, let us look at the other issues with this converter.



- The THD ratio still remains the same, even in the H-bridge inverter.
- The control on the fundamental component of the voltage is still not established.

So, we employ another switching scheme to gain control over the fundamental component of the voltage and also reducing harmonics of lower order.

Switching angles in PWM

By retaining the Odd nature of the output voltage, Half wave symmetry and quarter wave symmetry, we provide switching signal one or multiple times per quarter in order to establish the required control.

When we turn on and off the switch for a single instance, then we the output voltage fundamental component will be,

$$V_1 = \frac{4V_{DC}}{n\Pi} (1 - 2\cos\alpha)$$

Hence by adjusting the firing angle α , we can control the output voltage.

Also, by introducing multiple switching operations per quarter, we can eliminate the harmonics in the output voltage also by choosing a certain combination of values of α .



Control over fundamental voltage component

- From using Multiple Switchings per quarter, we can control the output fundamental using the firing angle α .
- Also, Space Vector PWM can be used.

Elimination of lower order harmonics in output voltage

- N switchings per quarter eliminate $(N-1)$ lower order harmonics.
- Also, when we use induction motor as a load, the windings are RL load which act as a filter.

Higher DC bus Utilization

- By using a **Full bridge inverter** instead of the **Half bridge/single leg inverter**, we can increase the DC bus utilization by 2 times, from $\sim 45\%$ to $\sim 90\%$.



SINE Δ^{LE} PWM SCHEME

- The **modulating wave $m(t)$** is now a sinusoidal wave whereas the **carrier wave $c(t)$** remains to be a triangular wave.
- By this means, the average of the output voltage produced will be,

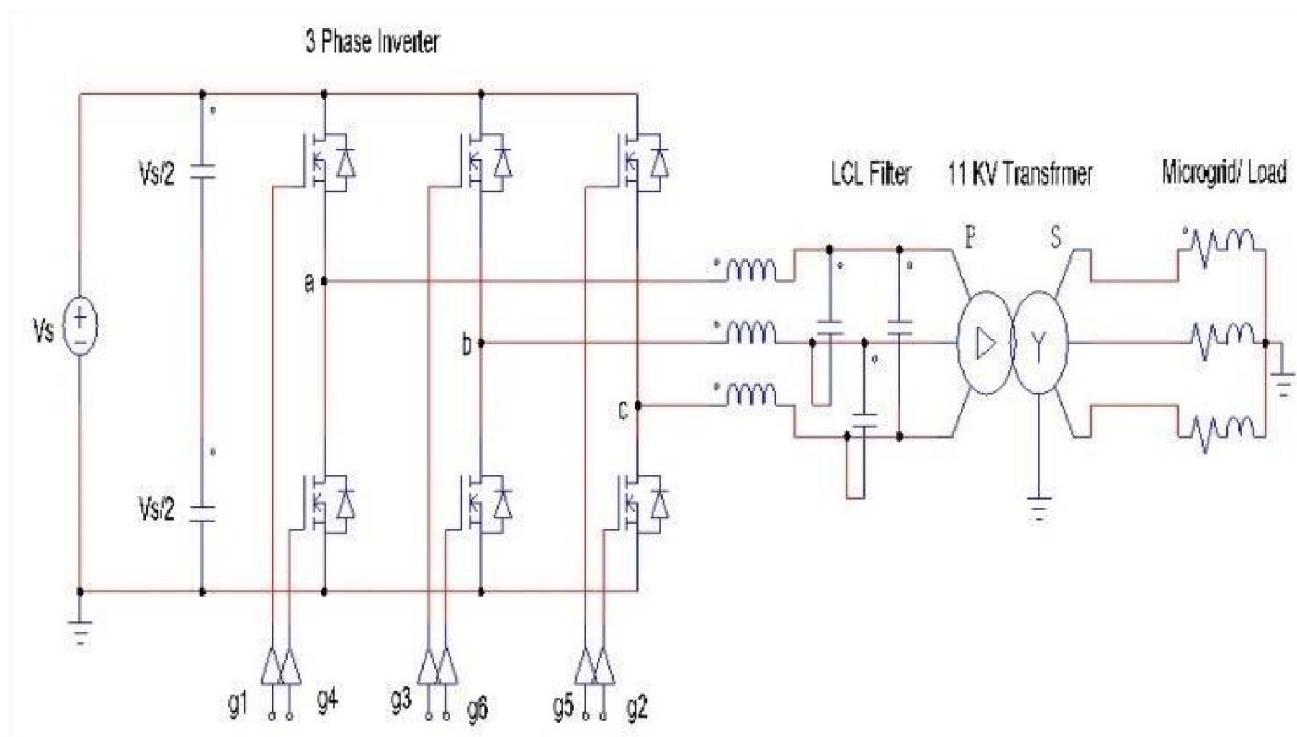
For half bridge inverter,

$$\overline{V_{ao}} = \frac{V_{DC}}{2} \left(\frac{m(t)}{V_p} \right) = \frac{V_{DC}}{2} \left(\frac{V_m \sin(\omega t)}{V_p} \right)$$

- Also, by DFT (Double Fourier Transform), the **fundamental component of the output voltage** is equal to the **average component of the output voltage**.
- For single phase H-bridge inverter, we have 2 switching schemes: **Unipolar & Bipolar**.
- Unipolar involves generation of 2 switching signals whereas Bipolar requires a single switching signal for all switches.

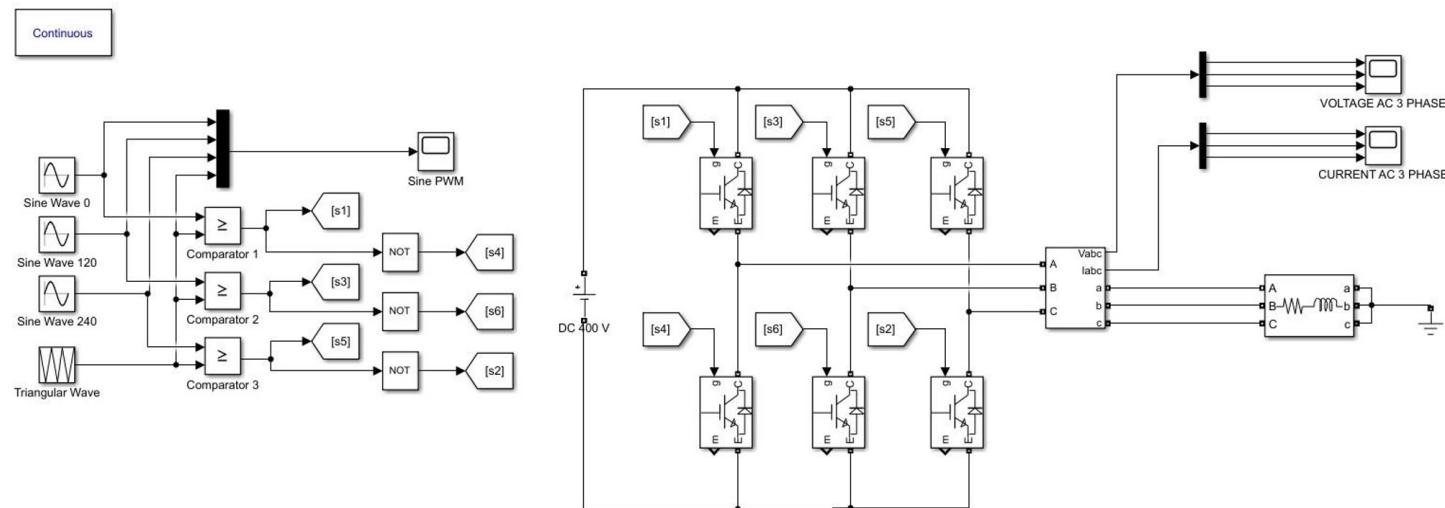


3Φ INVERTER DESIGN

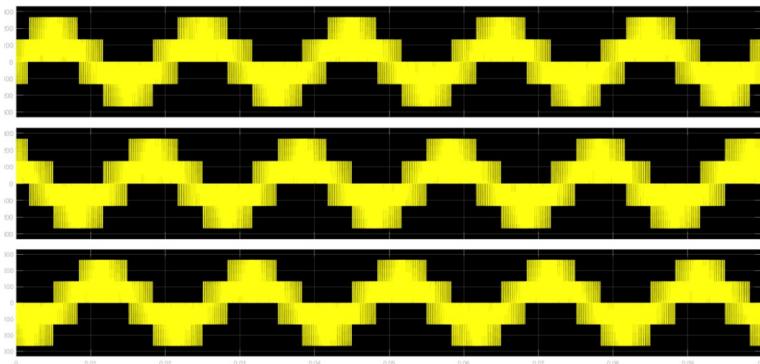


To produce 3 phase output, we generate 3 different switching signals for 3 legs of the inverter. This is done through using the same carrier wave and 3 sinusoidal waves at 120° phase shifted as modulating waves for each leg.

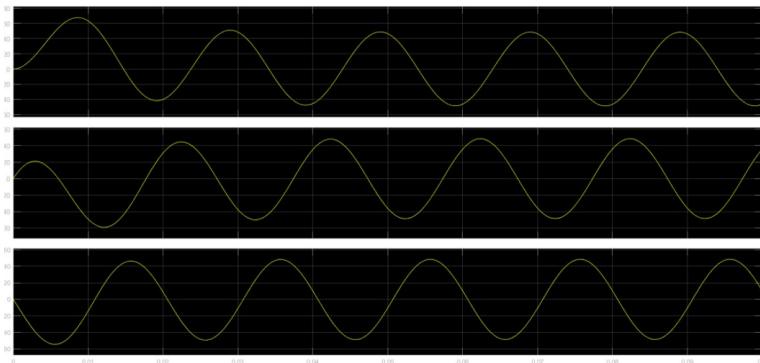
We employ 180° conduction mode for the switches and 120° phase shift for the modulating waves to get the required PWM output.



OUTPUTS OF 3Φ INVERTER

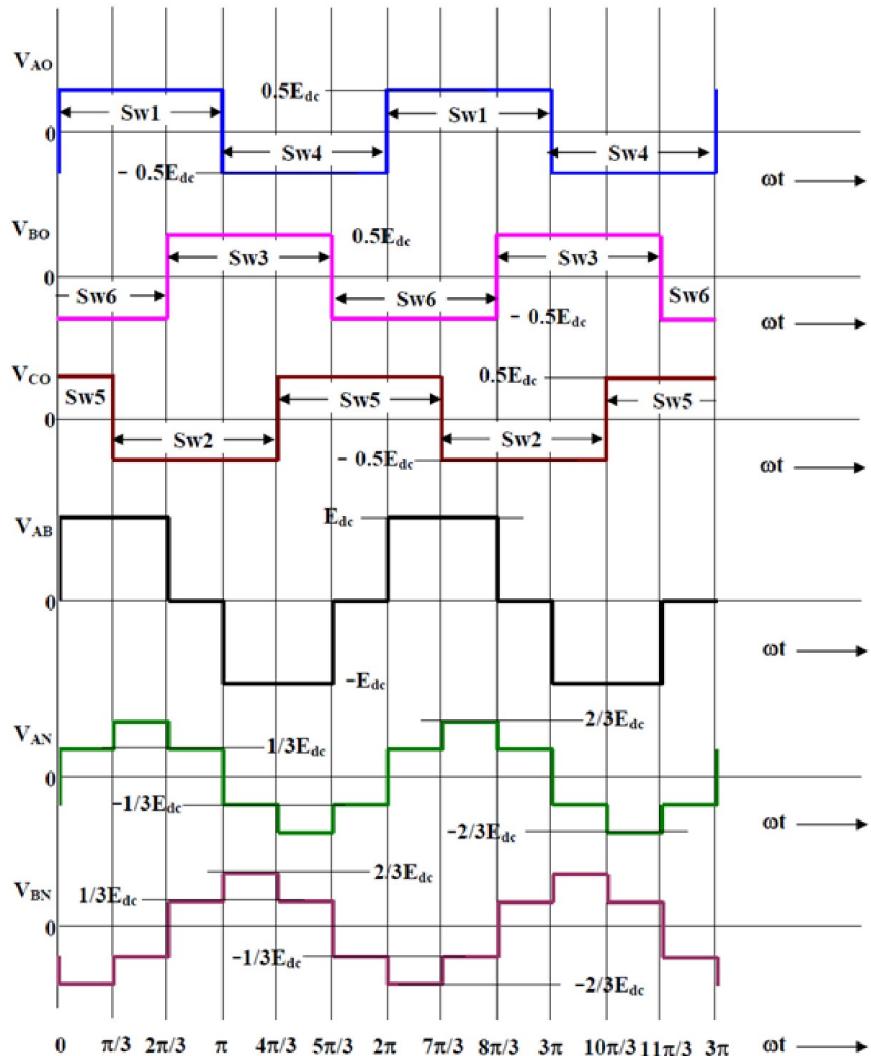


The voltage output waveform for a 3Φ inverter circuit.



The current output waveform for a 3Φ inverter circuit for an RL load of 1Ω and 0.01 H





LINE, PHASE AND POLE VOLTAGES OF 3Φ INVERTER

- The pole voltages will be similar to that of half bridge inverter and will contain higher order harmonics, whereas the line-line voltages and phase voltages will not contain 3rd order harmonics in them.
- Hence, the only $(6n \pm 1)^{\text{th}}$ order harmonics will be present in line-line voltages and phase voltages, and this results in less ripple in load currents and torque if the load is an induction motor.



MULTILEVEL INVERTERS

Multilevel inverters nowadays are **used for medium voltage and high power applications**. The different field of applications include its use as UPS, High voltage DC transmission, Variable Frequency Drives, in pumps, conveyors etc.

Different Topologies which function as multilevel inverters are:

- Cascaded H-bridge multilevel inverter
- Neutral Point Diode Clamped (NPC) inverter
- Flying Capacitor Inverter

Advantages of these topologies are:

- Reduced harmonic distortion and THD%
- Higher no. of voltage levels established



MULTILEVEL INVERTER

THD is Low in the output waveform

High voltage levels can be produced

Low dv/dt and EMI

THD is high in the output waveform

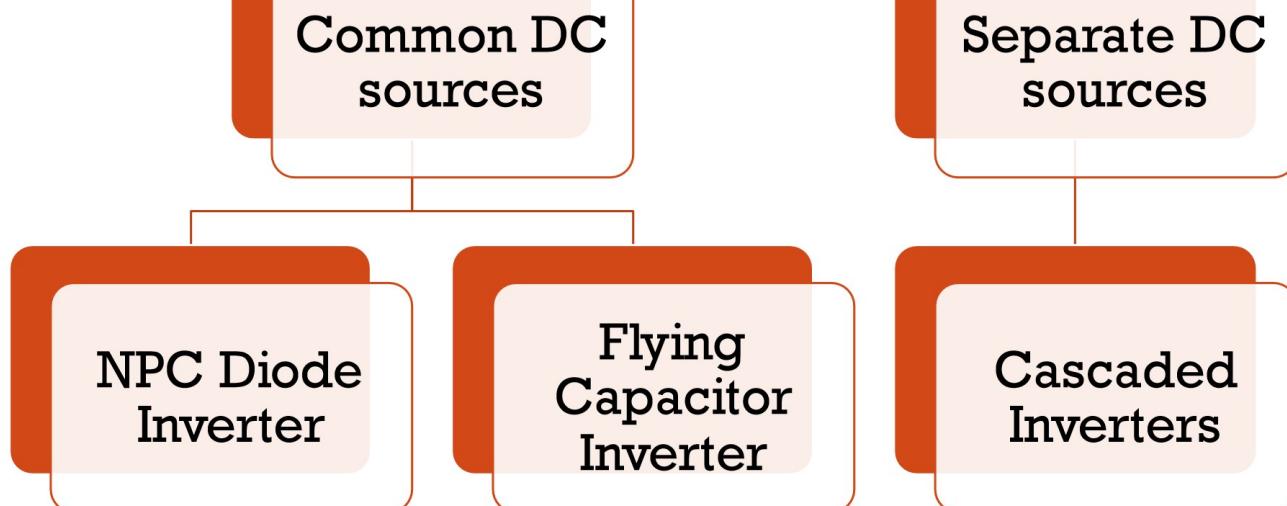
High voltage levels cannot be produced

High dv/dt and EMI

CONVENTIONAL INVERTER

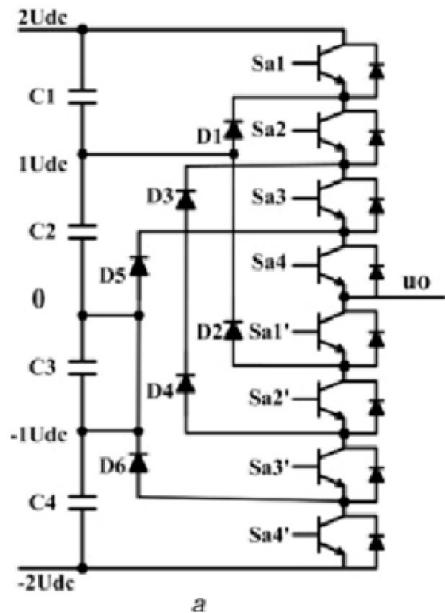


MULTILEVEL INVERTERS

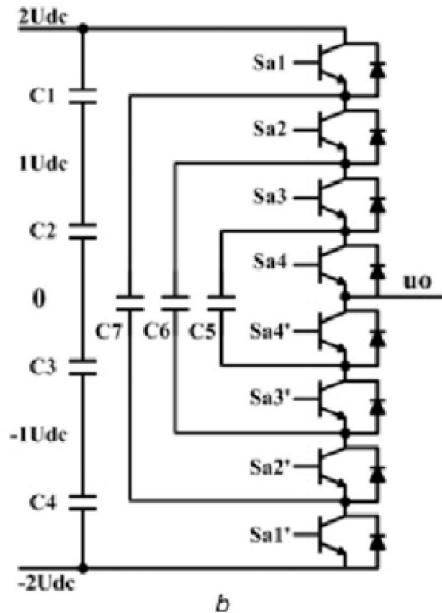


MULTILEVEL INVERTERS TOPOLOGIES

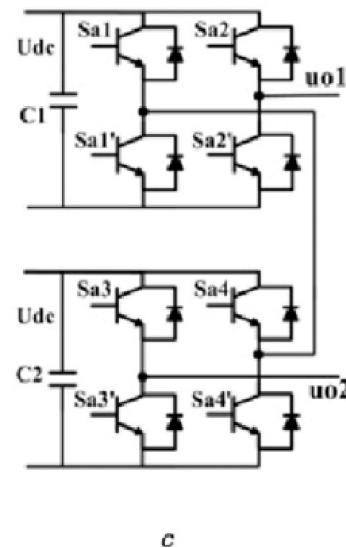
- Different multilevel power converter topologies with related structures
- We can produce any number of levels using these topologies but the complexity and the components number increase along with increase in the number of levels.



NPC Diode Inverter



Flying Capacitor Inverter



Cascaded Inverter

USAGE OF SWITCHES BASED ON POWER LEVEL

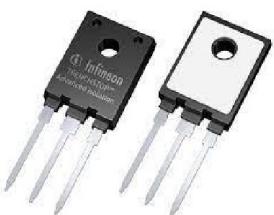
< 10 KW rating
VSI

MOSFETs :
 $f_{sw} = 20-100$ kHz



> 10 KW
rating VSI

IGBTs :
 $f_{sw} = 1-5$ kHz



> 1 MW rating
VSI

Thyristors :
 $f_{sw} < 1$ kHz



REFERENCES

- A Brief Review on Multi Level Inverter Topologies :
<https://ieeexplore.ieee.org/document/7530373>

Thank You

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EE 2020

