# SUMMER TERM – IIT H

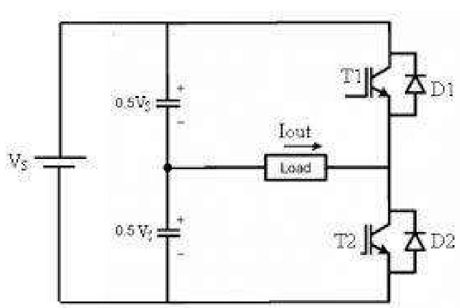
- DC – AC conversion : Inverter topologies
- Analysis of various types of inverters
- Pole phase modulation
- Simulation of 3 phase & 9 phase Induction motors in ANSYS

# 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,

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

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

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 ~ 45%
- No control over fundamental component of output voltage.

# CONTROL SIGNAL IMPLEMENTATION - PWM

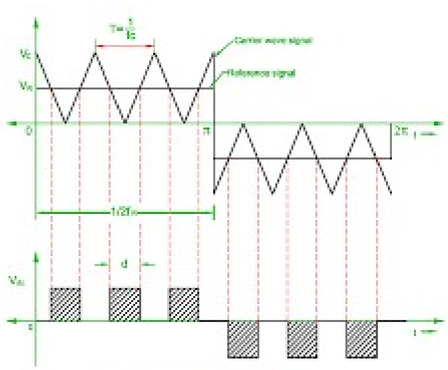


FIG 3 : MULTIPLE PULSE WIDTH MODULATION

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.

$m = V_m/V_p$ (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 the 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,

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

Hence by adjusting the firing angle $\alpha$, 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 $\alpha$.

## Control over fundamental voltage component

- From using Multiple Switchings per quarter, we can control the output fundamental using the firing angle $\alpha$.
- 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 ~ 45% to ~90%.

# SINE $\Delta^{LE}$ PWM SCHEME

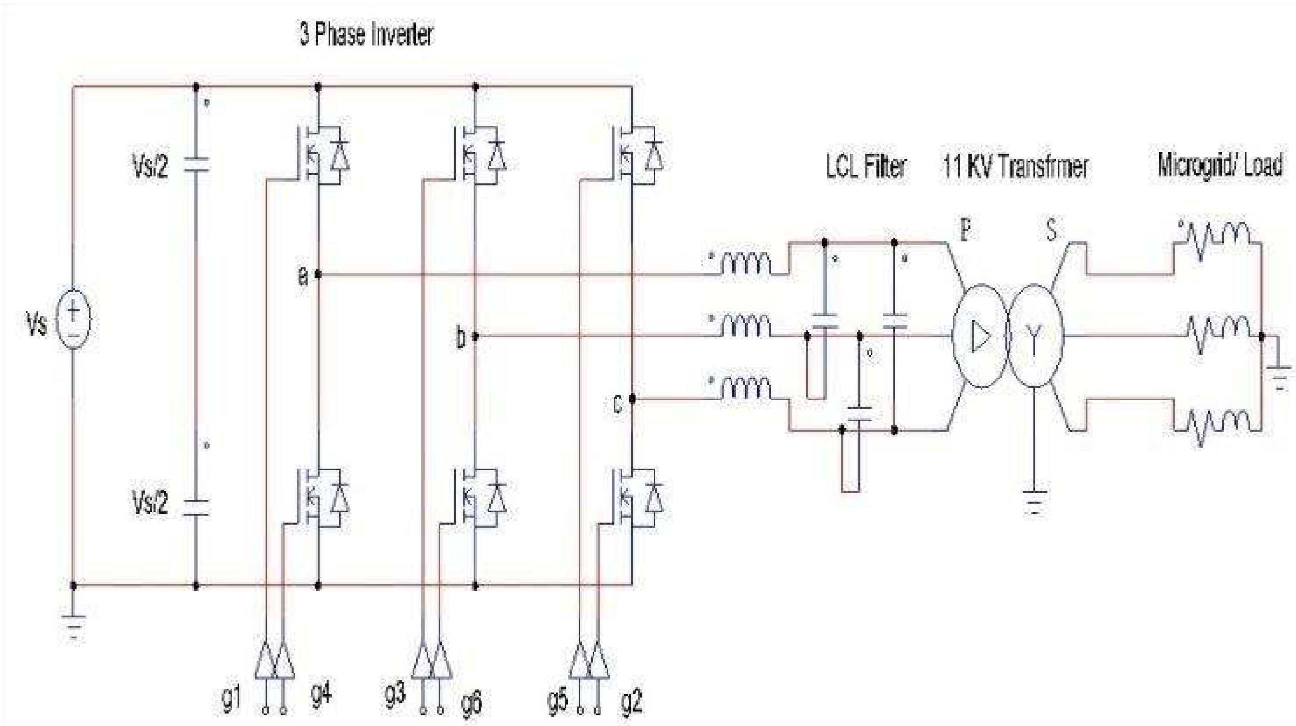
- The **modulating wave m(t) is now a sinusoidal wave** whereas the **carrier wave c(t) remains to be a triangular wave**.
- By this means, the average of the output voltage produced will be,

For half bridge inverter,

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

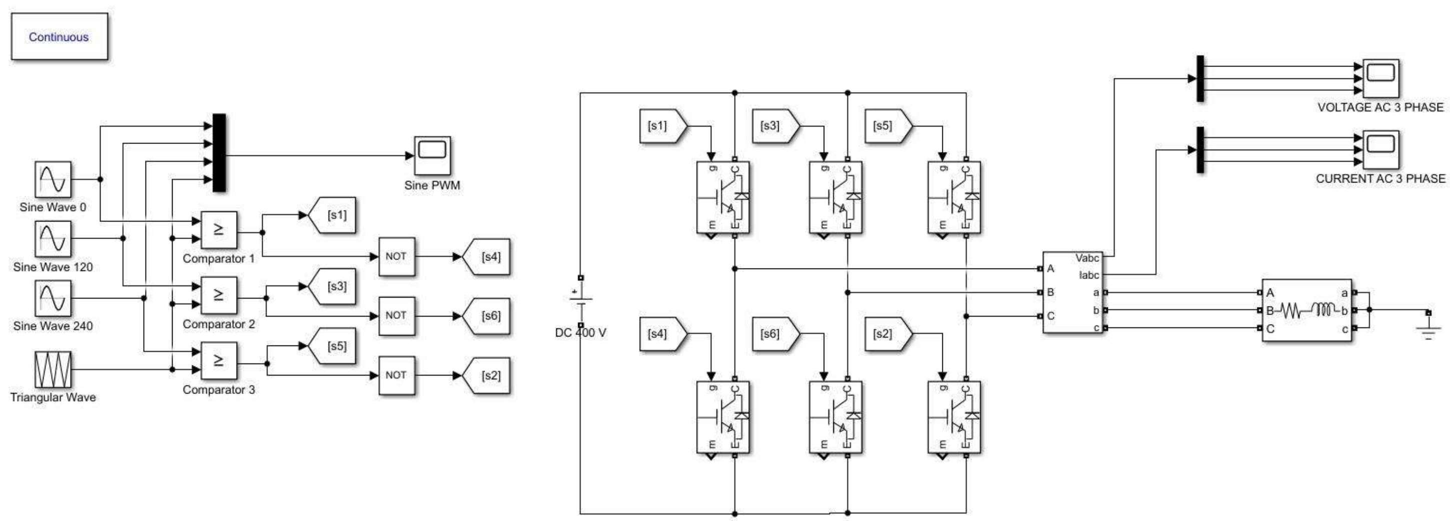
- Also, by DFT (Double Fourier Transform), the **fundamental component of the output voltage** is equal to the **average component of the output voltage**.
- For single phase H-bridge inverter, we have 2 switching schemes: **Unipolar & Bipolar.**
- Unipolar involves generation of 2 switching signals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

# 3Φ INVERTER DESIGN

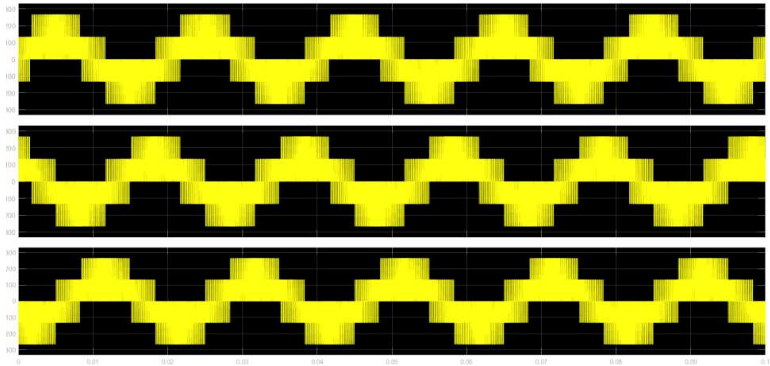


To produce 3 phase output, we generate 3 different switching signals for 3 legs of the inverter. This is done through using the same carrier wave and 3 sinusoidal waves at 120° phase shifted as modulating waves for each leg.

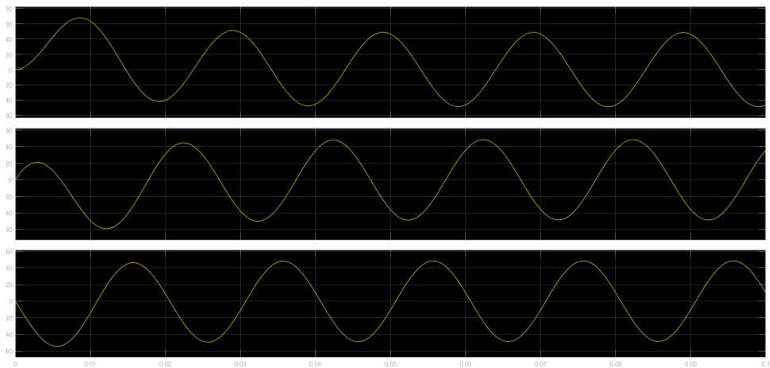
We employ 180° conduction mode for the switches and 120° phase shift for the modulating waves to get the required PWM output.



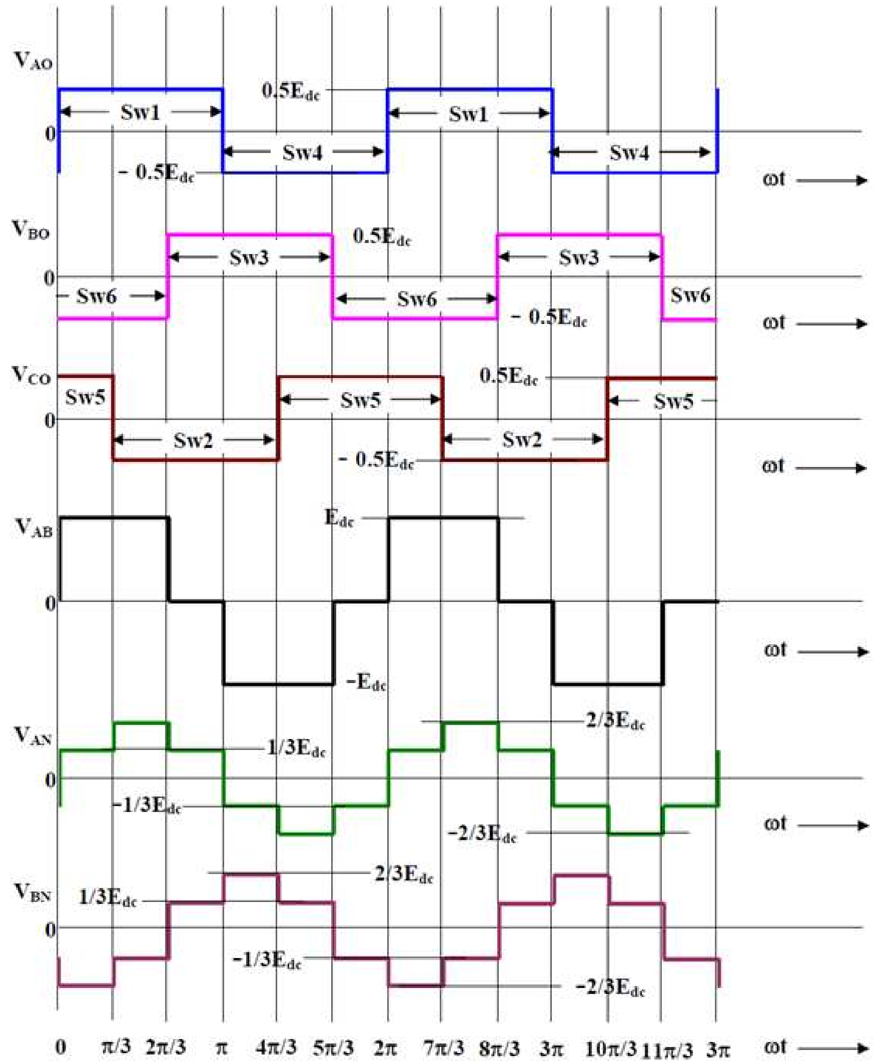
# OUTPUTS OF 3Φ INVERTER



**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 $(6n \pm 1)^{th}$ 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.

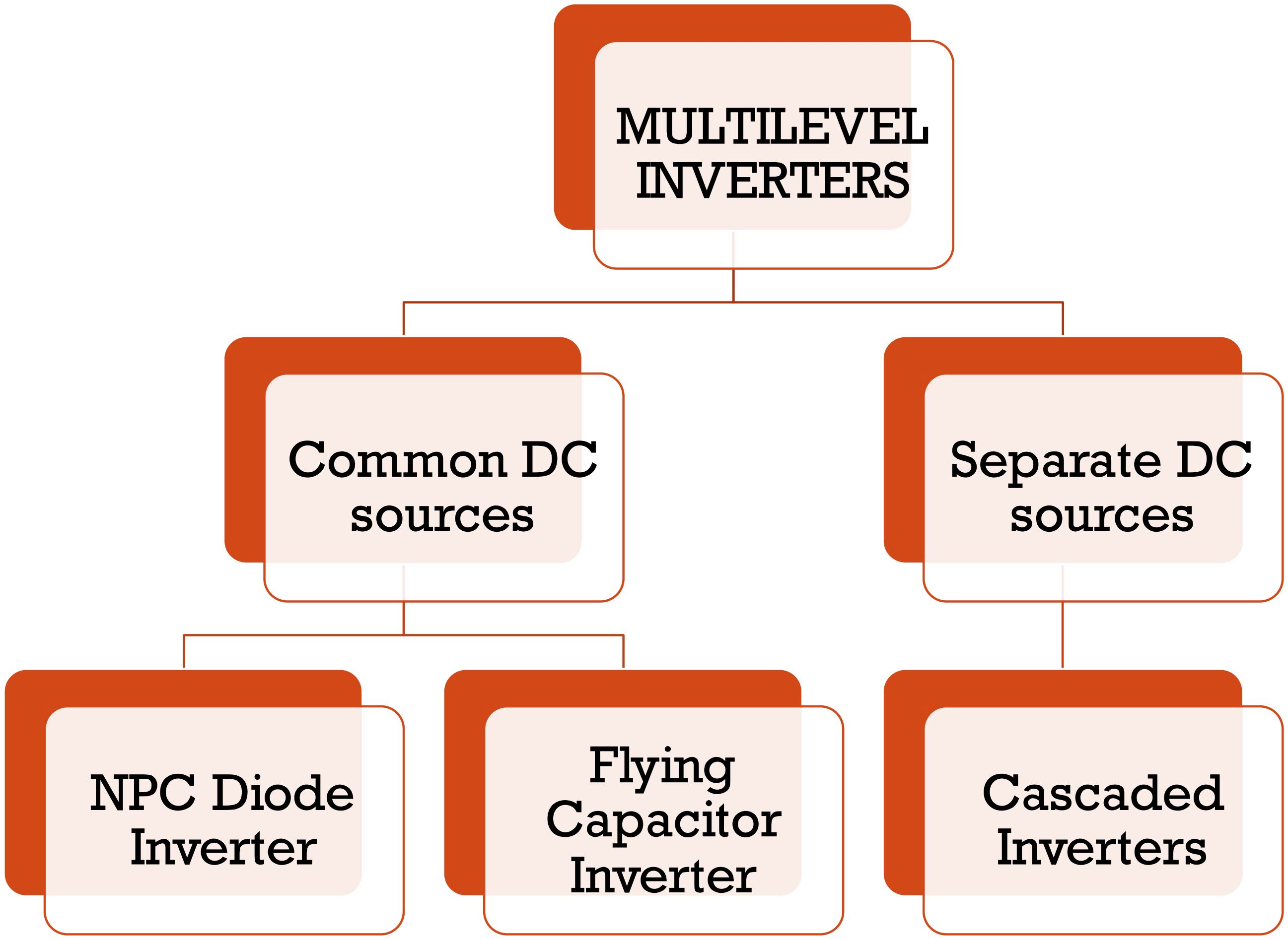
Different Topologies which function as multilevel inverters are:

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

Advantages of these topologies are:

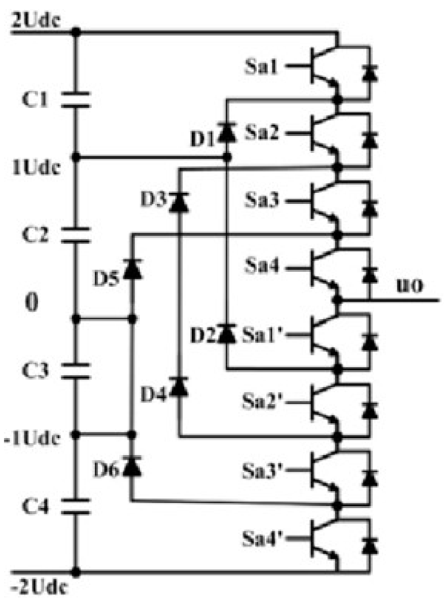
- Reduced harmonic distortion and THD%
- Higher no. of voltage levels established

| MULTILEVEL INVERTER | CONVENTIONAL INVERTER |
| --- | --- |
| THD is Low in the output waveform | THD is high in the output waveform |
| High voltage levels can be produced | High voltage levels cannot be produced |
| Low dv/dt and EMI | High dv/dt and EMI |


MULTILEVEL INVERTERS
Common DC sources
Separate DC sources
NPC Diode Inverter
Flying Capacitor Inverter
Cascaded Inverters

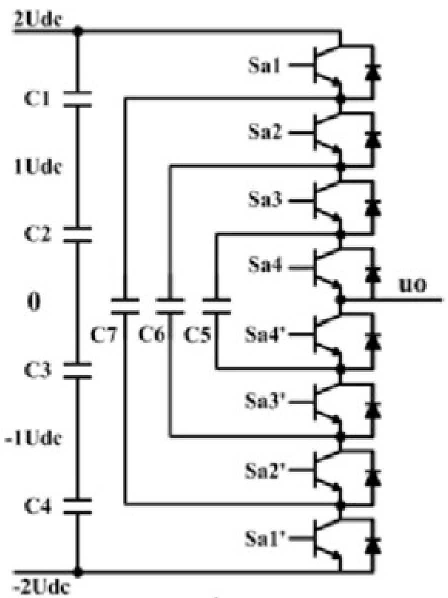
# MULTILEVEL INVERTERS TOPOLOGIES

- 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.



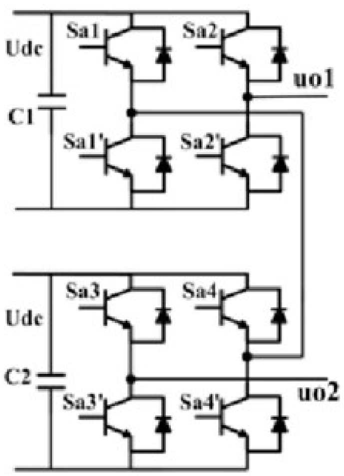

a

NPC Diode Inverter




b

Flying Capacitor Inverter




c

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

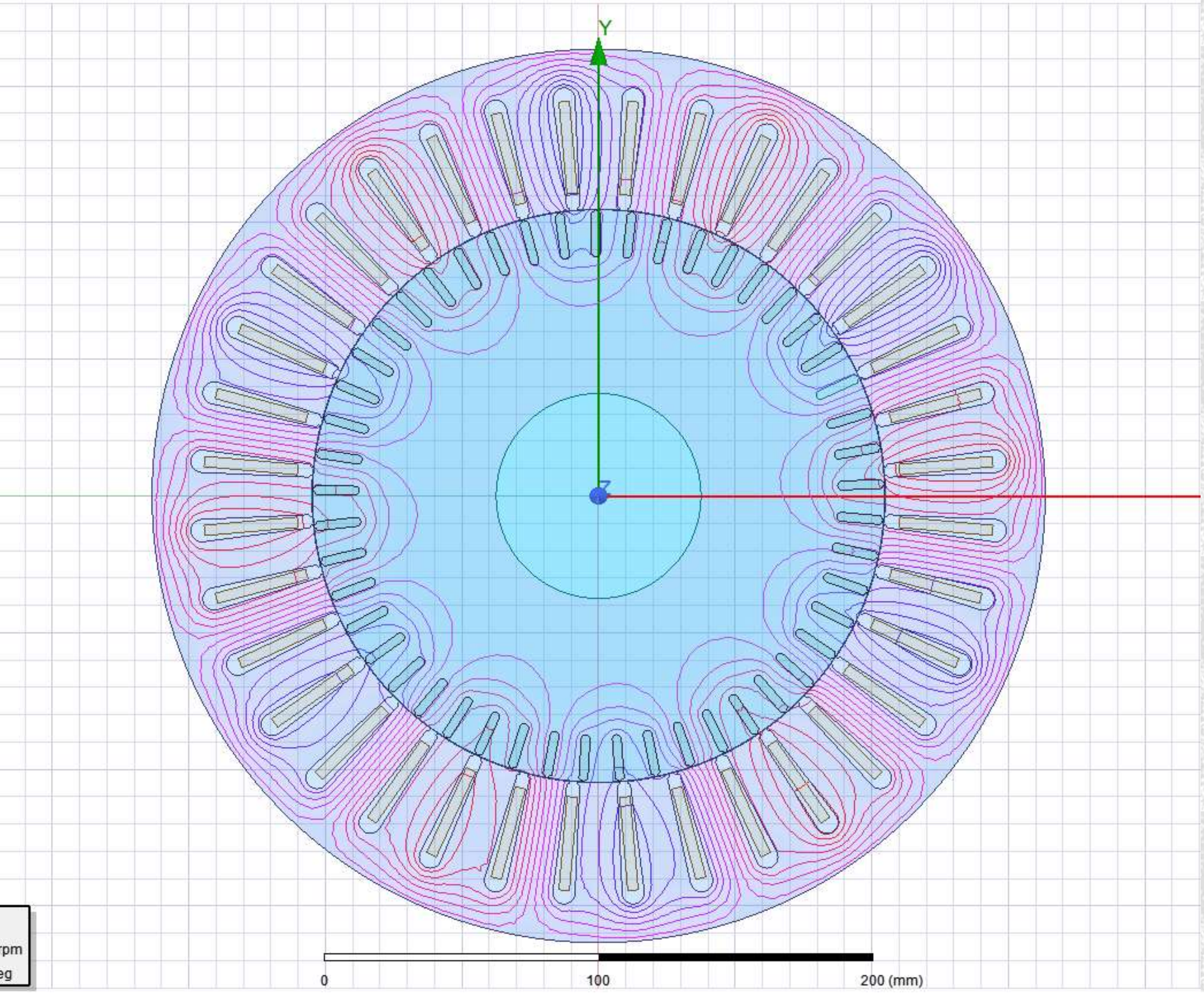
> 1 MW rating VSI

Thyristors :
$f_{SW}$ < 1kHz

# SIMULATION OF INDUCTION MOTOR IN ANSYS

The brief steps to be followed while attempting to perform a simulation in ANSYS Electronics Desktop 2020 R2 version are :

- Building of a model of machine in **RMxprt** by giving the machine parameters for machine, stator, rotor, shaft, and creation of setup with relevant parameters and **validation and analysis** of setup.
- Conversion of **RMxprt model** into **MAXWELL 2D model** and giving the required excitation currents for **observing pole formation** using **flux lines & magnetic vector plots**, **torque, speed, currents, voltages, induced voltages, flux linkages** for all phases, after validation and analysis.
- Changing the **excitation currents from 3 phase to 9 phase** to observe the similar above-mentioned simulation results.



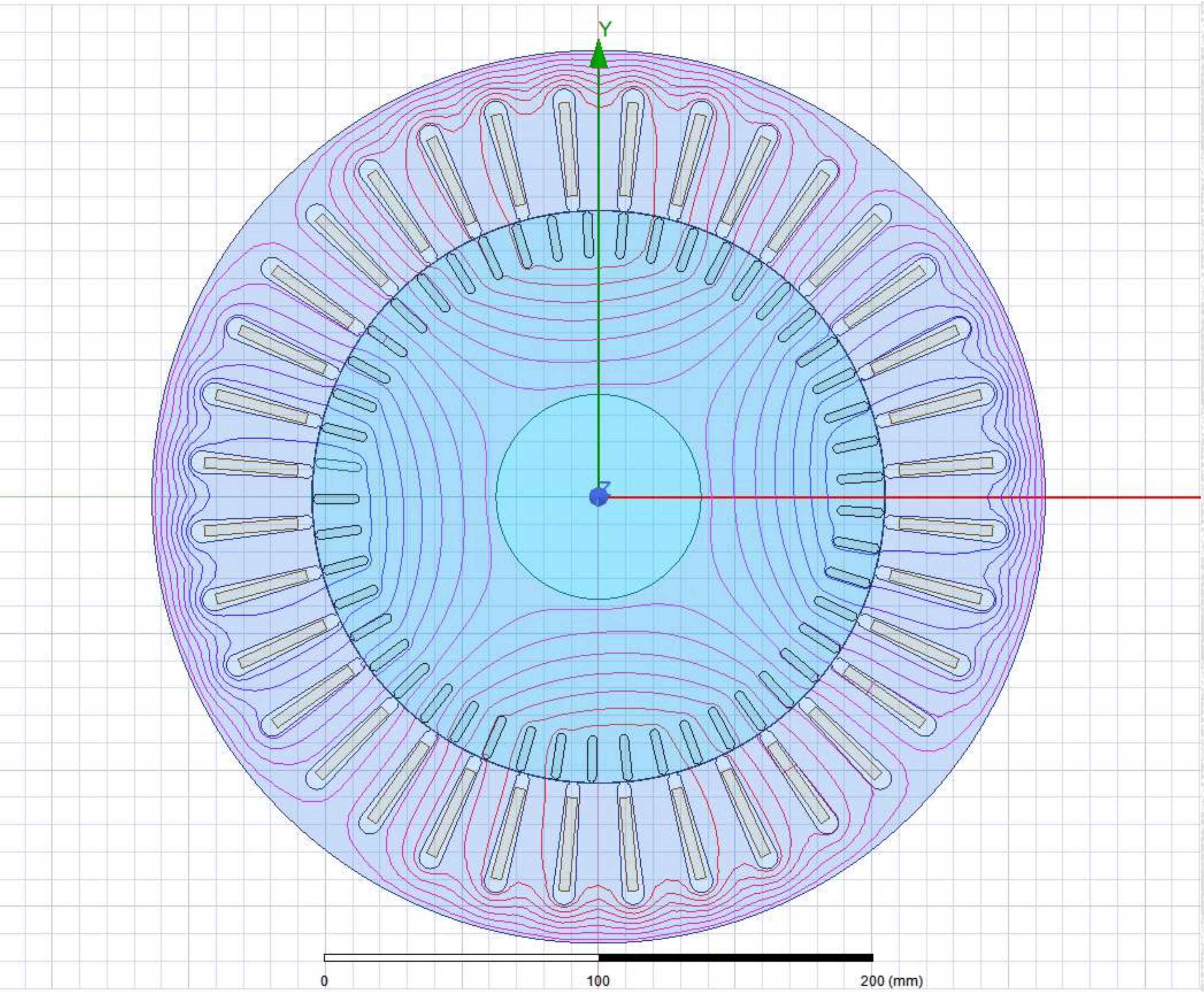

# 3 PHASE 12 POLE CONFIGURATION

Input excitation currents are :

- Given a voltage of 415 Volts for all the 3 phases, each phase gets about 239.6 V rms.
- So, the Voltage waveform equation will be.

**V = 338.846 sin(100πt + Φ)**

Where Φ is the phase difference which is 0°, 120°, 240° respectively.



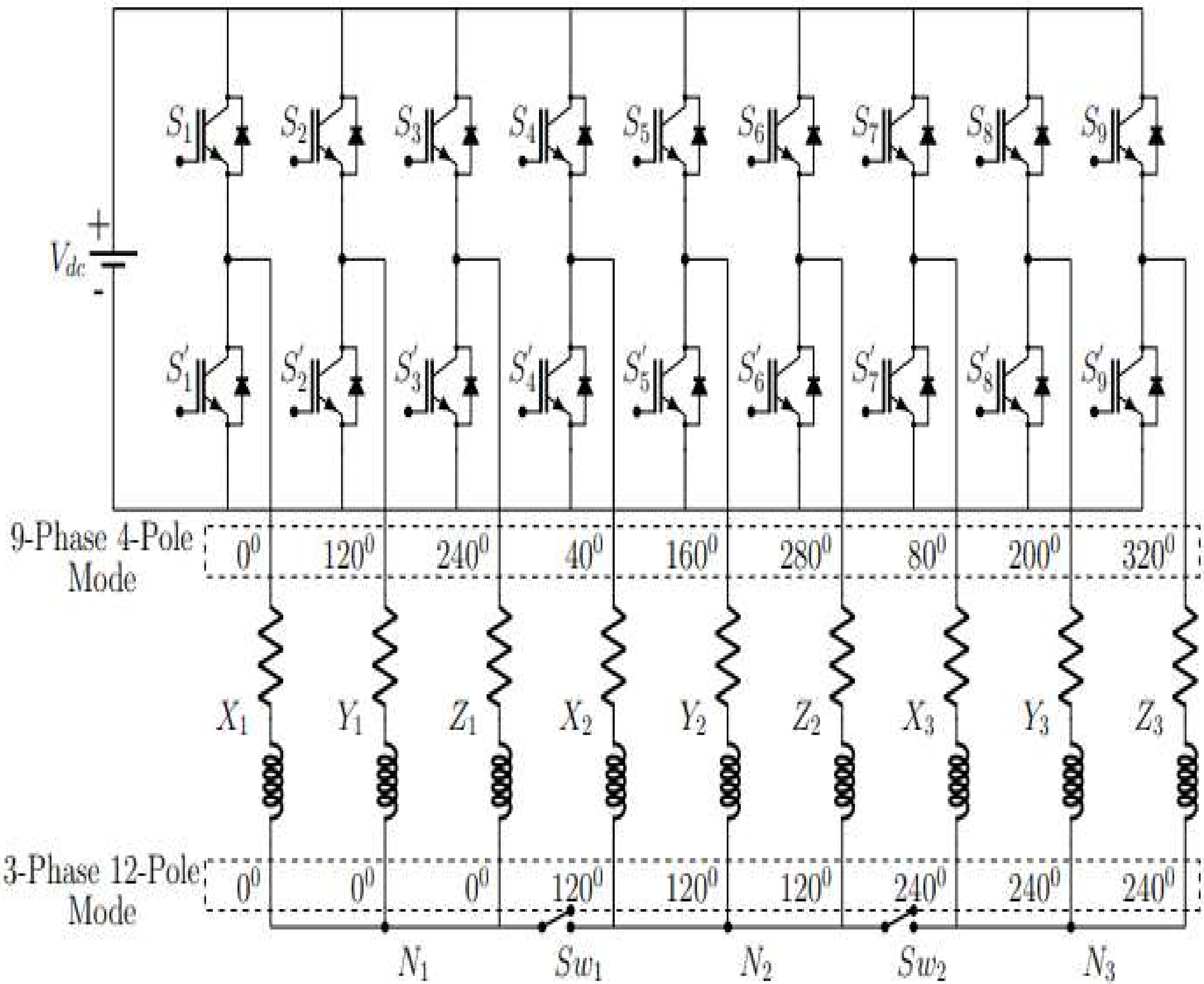

# 9 PHASE 4 POLE CONFIGURATION

Input excitation currents are :

- Given a voltage of 415 Volts for all the 9 phases, each phase gets about 138.33 V rms.
- So, the Voltage waveform equation will be.

**V = 195.633 sin(100πt + Φ)**

Where Φ is the phase difference which is 0°, 40°, 80°, 120°, 160°, 200°, 240°, 280°, 320° respectively.




# POLE PHASE MODULATION

***We use pole phase modulation to while operating an induction motor with an inverter for a 9-phase machine and changing the switching schemes accordingly to operate a 36-slot machine into 3 phase 12 pole and 9 phase 4 pole machine, respectively.***

# LEARNING OUTCOMES OF THIS INTERNSHIP PERIOD

- DC-AC power conversion using inverters, Sine PWM techniques.
- Exposure to Multi level inverters – NPC, Flyback capacitor, Cascaded H-bridge.
- Machine design for multiphase induction machines.
- Familiarity with ANSYS electronics software for simulation of multiphase induction machines.
- Why should we use Pole phase modulation techniques ?

**Answer** : It would ideally take a **15-kW** machine to produce **~100 N-m of torque and 1500 rpm speed** simultaneously, but we achieve this using a **36 slot 5-kW induction motor** by pole phase modulation, where **~100 N-m of torque is produced by 3 phase** 12 pole configuration and **1500 rpm speed is taken care by the 9 phase** 4 pole configuration.

# REFERENCES


- A Brief Review on Multi Level Inverter Topologies : https://ieeexplore.ieee.org/document/7530373
- SVPWM Control Techniques for Pole-Phase Modulated Nine-Phase Induction Machine Drives for Extended Speed-Torque Range Applications – PhD Thesis by Dr. V Janaki Ramaiah, IIT Hyderabad.
- Study and analysis the effect of variable applied voltage on SCIM performances based on FEA – IJPEDS Journal by Waleed Khalid Shakir Al-jubori , Yasir Abdulhafedh Ahmed.
- **Electrical Machine Design –** Unit 6 : Design of Induction Motors.
- Lectures of EE 6230: Modeling and Control of Electric Drives – IIT Hyderabad.
- Dual-Inverter-Fed Pole-Phase Modulated Nine-Phase Induction Motor Drive With Improved Performance - IEEE Journal by B. S. Umesh and K. Sivakumar : https://ieeexplore.ieee.org/document/7463509


Thank You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