1. For a four-level NPC converter, find all the available switching states. Let the total dc link voltage be 8.0kV.
   a. List the switching states in a table showing the voltage across each switch and the components of a space vector representation thereof. You may work in a per unit system of your choice if you prefer.
   b. Create a plot similar to what was presented in class. Plot all the vectors. Label each vector in the first quadrant; that’s plenty. You can check your plot using Prof. Corzine’s reference.

2. Find and plot one cycle of the dc current that accompanies a three-level space vector PWM that yields a vector of $V_{dc} \angle 40^\circ$ Volts. The load current is 200 Amps with a power factor of 1.00. A number for $V_{dc}$ is not necessary, but if you want one, make one up and declare it.

3. For a four-level NPC, apply sine-triangle modulation at a 5kHz:50Hz frequency ratio between triangle and sine wave frequencies. Set the sine wave’s amplitude at $3/4$ of the sum of the applied triangle wave. Let the dc link voltage be 8kV.
   a. Plot the triangle waves superimposed on a three phase sine wave.
   b. Show one (sine) cycle of the resulting pulse width modulation.
   c. Show a harmonic spectrum that reveals at least the first half dozen nonzero voltage harmonics.

4. For a Multimodal Multilevel Converter (MMC) with four-modules in each leg and balanced capacitor voltages of 2kV for each switch and diode,
   a. Determine the voltage stair step waveform with the same switching losses as the NPC converter of problem 3. Use a fundamental output frequency of 50 Hertz.
   b. Identify the fundamental and lowest nonzero harmonic output line-to-neutral voltage, magnitude and frequency. Assume the inductors have no voltage drop.
   c. For a machine load that is modeled as a 50 Hz voltage source of the same amplitude as the fundamental component of the terminal voltage, but lagging three degrees, behind a reactance of 0.35 Ohms at 50 Hz, find the fundamental current and the lowest nonzero current harmonic, magnitude and frequency.
\[ \frac{V}{f_{\text{req}}} = \text{FLUX} \]

SATURATION!
ECE 404 / 504

T & D Applications of Voltage Sourced Converters

Lesson 21

I want to look at the machine and how various influences can affect its behavior. In so doing, I’ll find ways to control the machine better.
Wound rotor machine: resistance added to the rotor terminals. The peak torque is unchanged, but the curve gets flattened out.

😊 This allows us to conveniently control the speed.

😊 Immunity to torque pulsations. High slip machines are favored for flywheels.
Less torque at operating point for pump or fan load.

Efficiency degrades quickly. Rotor losses are $|I_2|^2 R_2$. The efficiency is NEVER greater than (1-s).

Speed control by varying the frequency

The speed responds nicely to change in synchronous speed (frequency); operation
is at the same slip frequency or close to it.

😢 Saturation! It gets worse and worse at lower and lower frequencies. 😞

Voltage control alone...

😢 gives speed control

😢 the loss of torque capability is proportional to voltage squared.
😊 Most machines operate on the edge of saturation.

V/Hz control

😊 I can control the speed nicely... speed follows the synchronous speed (frequency) readily and I can operate at the same slip frequency to get performance.

😢 Conservation of sorrows: Peak torque degrades greatly
at very low speeds. So I add a little “voltage boost” at low speeds.

😊 This affects motor operation. Generator operation is at HIGHER speeds.