ECE 404-TD / 504-TD

ST: T&D APPLICATIONS OF VOLTAGE SOURCE CONVERTERS

SESSION no. 20

ECE 404 / 504 T&D Applications of Voltage Sourced Converters Due: Monday 4 March
Homework #4
Multilevel Converters

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 hextant; that's plenty. You can check your plot using Prof. Corzine's reference.

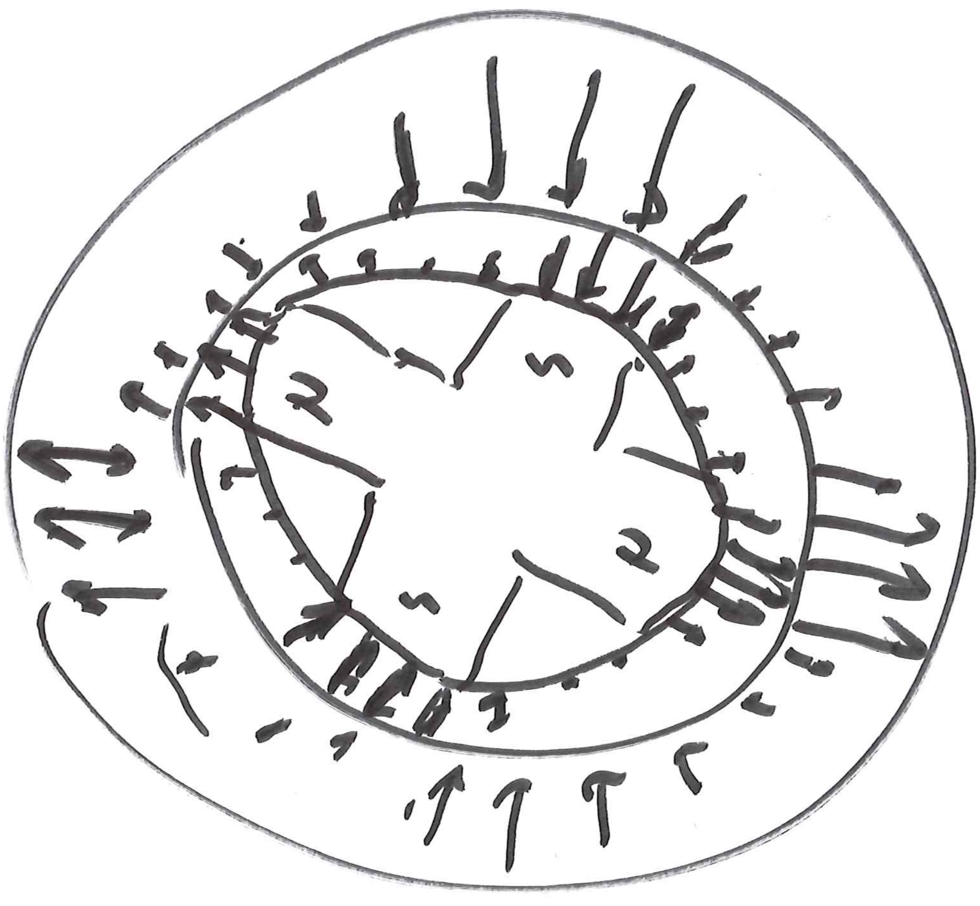
2. Find and plot one cycle of the dc current that accompanies a <u>three-level</u> space vector PWM that yields a vector of $0.60\ V_{dc} \angle 40°$ Volts. The load current is 200 Amps with a power factor of 1.00. A number for V_{dc} is not necessary, but if you want one, make one up and declare it.

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 ¾ 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~~ 2kV / switch. 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.



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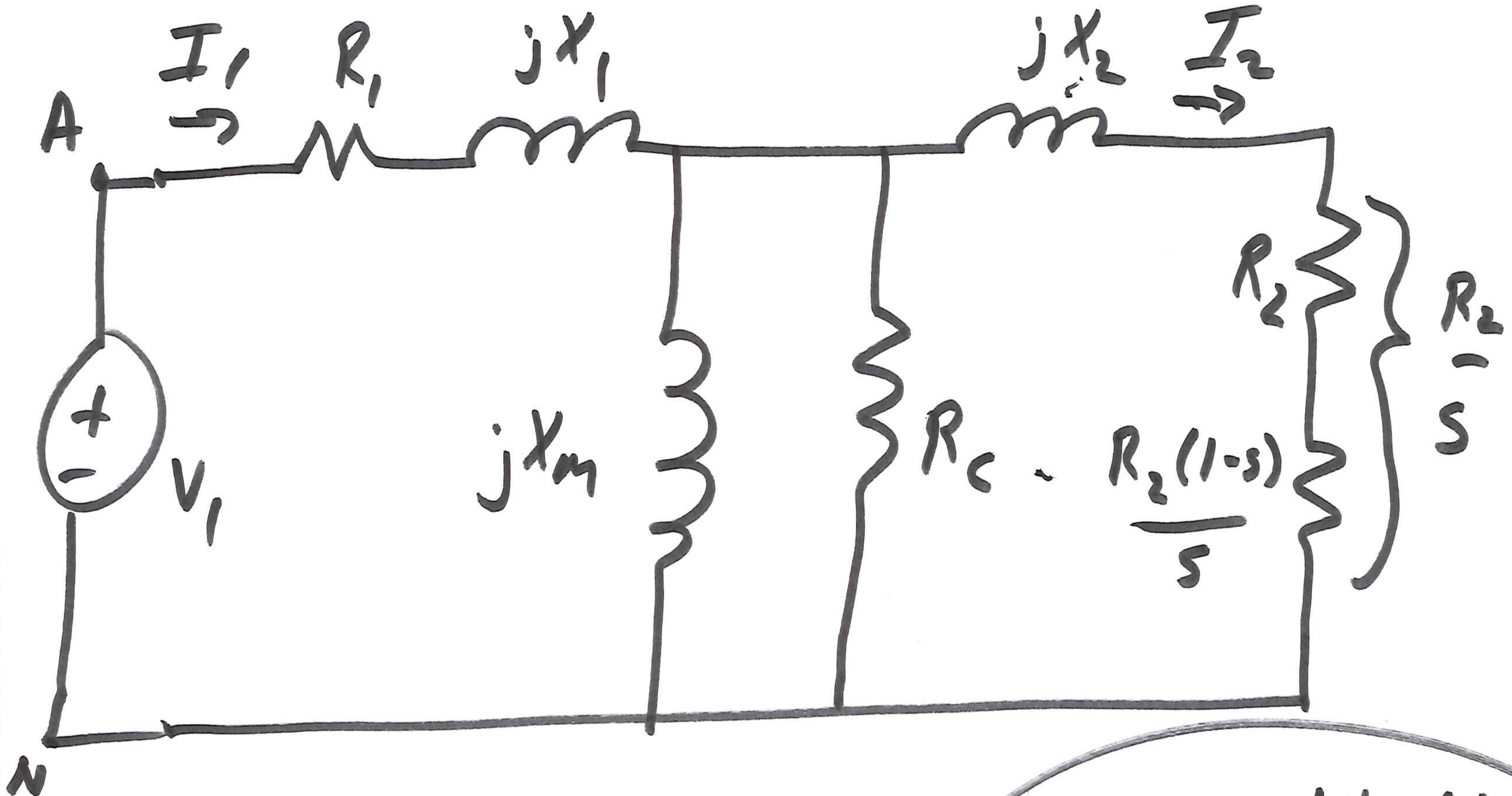


$$s = \text{slip} = \frac{\omega_s - \omega_m}{\omega_s}$$

ECE 404 / 504

T & D Applications of Voltage Sourced Converters

Lesson 20

NO CLASS Lesson 24; Exam compensatory time

Induction Machine…

2 complete three phase sets of windings give us 4 poles

Squirrel cage

Wound rotor

Advantages

- Ruggedness
- Variable speed
- Maintenance
- Efficiency
- Low speed performance
- Size and weight
- Protection

Specific advantages:

- **A stable, useful performance AS A GENERATOR with a slight overspeed**
- **Ability to use both stator and rotor as higher bandwidth ports for control, energy I/O, and protection.**

Induction Motor Example

$j := \sqrt{-1}$

$R_1 := 0.02$ $\quad R_2 := 0.025$ $\quad$ lagging $:= 1$

$X_1 := 0.06$ $\quad X_2 := 0.04$ $\quad X_m := 3.5$

$V_1 := 1.00$ $\quad \omega_s := 1.00$

Find current input.

$s := 0.025$

$$\frac{V_m - V_1}{R_1 + j \cdot X_1} + \frac{V_m}{j \cdot X_m} + \frac{V_m}{\frac{R_2}{s} + j \cdot X_2} = 0$$

This V_m is the air gap voltage.

$$V_m := \frac{\left(\frac{V_1}{R_1 + j \cdot X_1}\right)}{\frac{1}{R_1 + j \cdot X_1} + \frac{1}{j \cdot X_m} + \frac{R_2}{s} + j \cdot X_2} = 0.964 - 0.051i$$

Input Current is

$$I_1 := \frac{V_1 - V_m}{R_1 + j \cdot X_1} = 0.951 - 0.288i \qquad |I_1| = 0.994$$

$$\arg(I_1) = -16.852 \cdot deg$$

Find torque.

$$I_2 := \frac{V_m}{\frac{R_2}{s} + j \cdot X_2} = 0.96 - 0.09i$$

$$torque := \frac{(|I_2|)^2 \cdot R_2}{s \cdot \omega_s} = 0.93$$

Power in, power out, and efficiency.

$$P_{in} := Re\left(V_1 \cdot \overline{I_1}\right) = 0.951$$

$$P_{out} := (|I_2|)^2 \cdot R_2 \cdot \frac{(1 - s)}{s} = 0.907$$

$$\eta := \frac{P_{out}}{P_{in}} = 95.3 \cdot \%$$

Power Factor

$$pf := \frac{P_{in}}{|V_1| \cdot |\overline{I_1}|} = 0.957 \cdot lagging$$

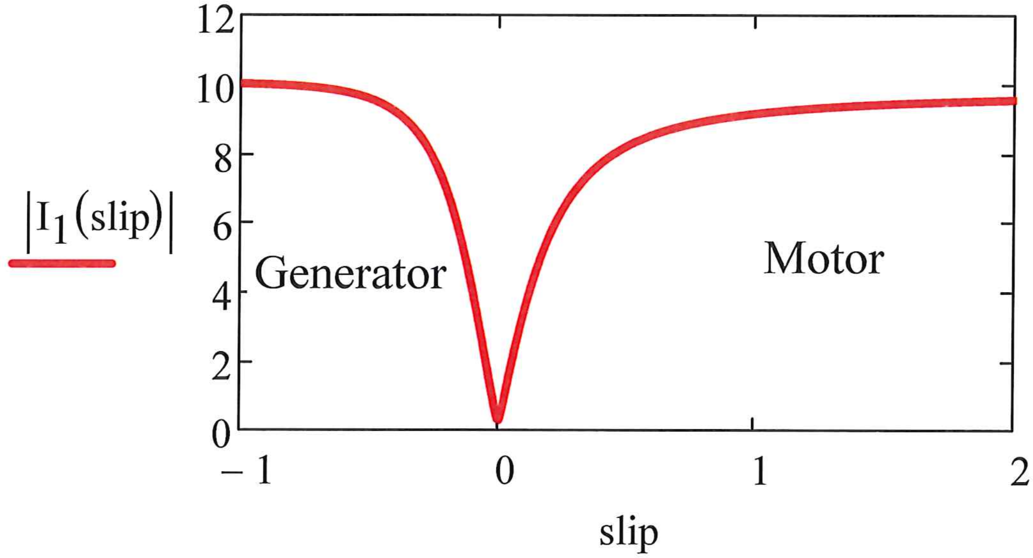
Now let's generalize the equations over a range of slip or rotor speed.

$$V_m(slip) := \frac{\left(\frac{V_1}{R_1 + j \cdot X_1}\right)}{\frac{1}{R_1 + j \cdot X_1} + \frac{1}{j \cdot X_m} + \frac{1}{\frac{R_2}{slip} + j \cdot X_2}}$$

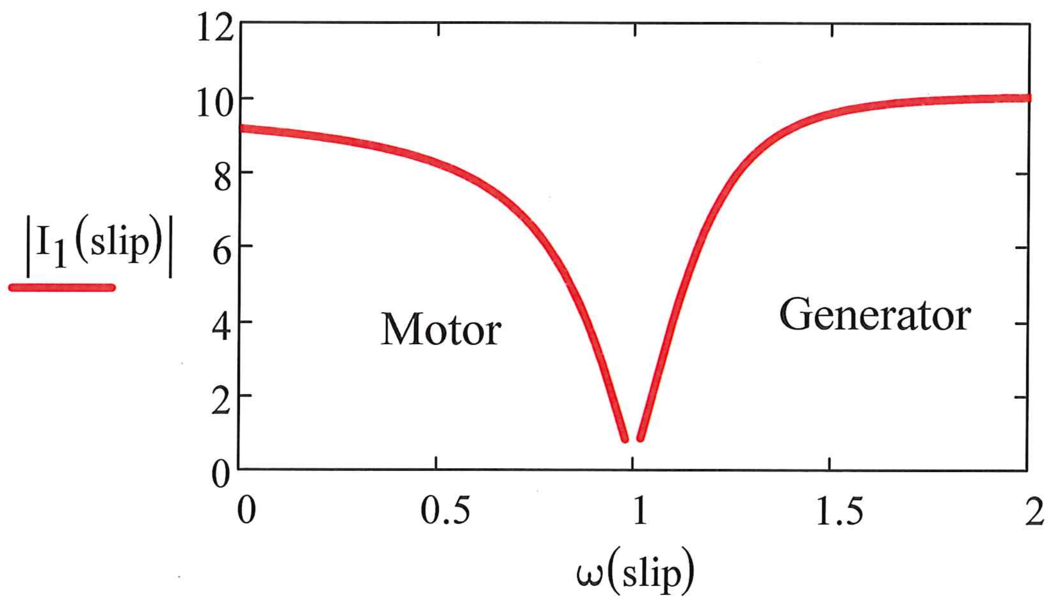
$$I_1(slip) := \frac{V_1 - V_m(slip)}{R_1 + j \cdot X_1}$$

$\omega(slip) := \omega_s \cdot (1 - slip)$ Rotor Speed

Find current input for a range of slip...



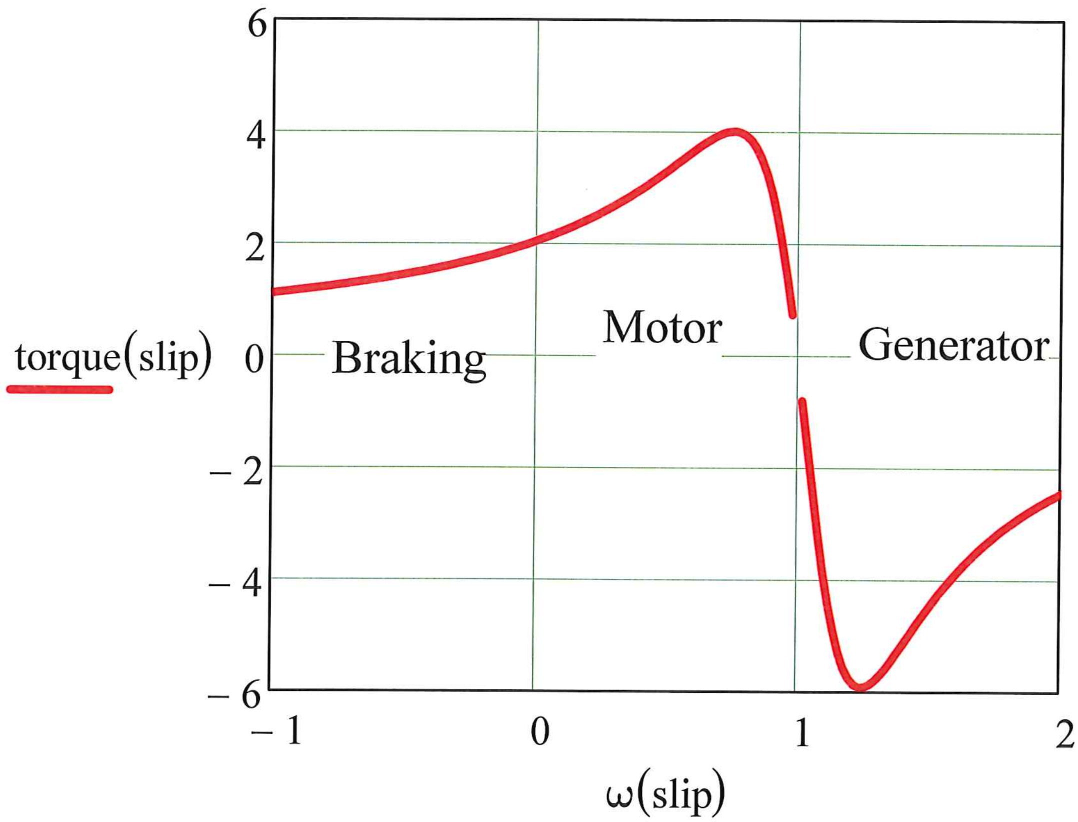
...and rotor speed



torque

$$I_2(slip) := \frac{V_m(slip)}{\frac{R_2}{slip} + j \cdot X_2}$$

$$torque(slip) := \frac{\left(\left|I_2(slip)\right|\right)^2 \cdot R_2}{slip \cdot \omega_s}$$

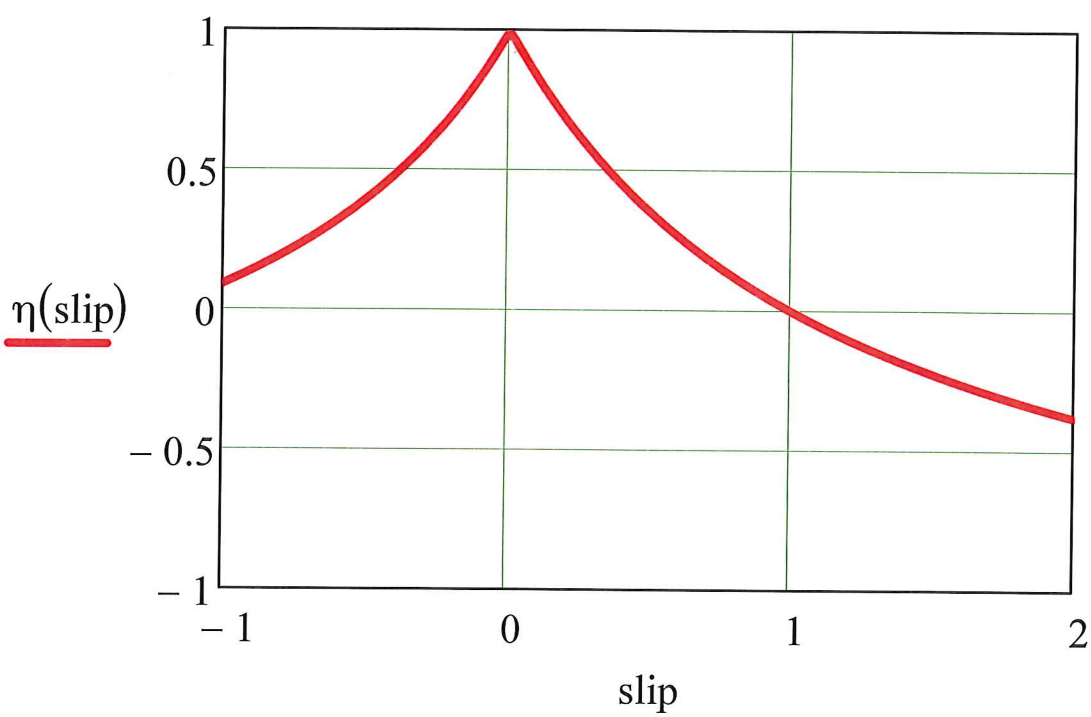


Power in, power out, and efficiency

$$P_{in}(slip) := Re\left(V_1 \cdot \overline{I_1(slip)}\right)$$

$$P_{out}(slip) := \left(\left|I_2(slip)\right|\right)^2 \cdot R_2 \cdot \frac{(1 - slip)}{slip}$$

$$\eta(slip) := \begin{cases} \dfrac{P_{out}(slip)}{P_{in}(slip)} & \text{if } slip > 0 \\ \dfrac{P_{in}(slip)}{P_{out}(slip)} & \text{if } slip < 0 \end{cases}$$



Power factor

$$pf(slip) := \frac{|P_{in}(slip)|}{|V_1| \cdot |I_1(slip)|}$$