ECE 404-TD / 504-TD

ST: T&D APPLICATIONS OF VOLTAGE SOURCE CONVERTERS

SESSION no. 27

Simulation studies using Power Converters

- Start simple
  - as develop model do small pieces and test them
    1. AC system equivalent
       - verify against known conditions

- Start out with simple equivalent impedance with voltage sources (not detailed generators)
- compare power flow results
- compare short circuit results

L27 3/14

2. Power converter model

A. - Simple, non-switching model

- open loop controls
  - → Predetermined
    - inputs with known impacts on system

steady state behavior

- then start adding more detail to controls

B. - Build switching model of converter

- again open loop control with very simple AC/DC systems

- compare to results for non switched converter with same AC/DC system

- switching model needs to reach steady-state

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- once confident in this model

then

(1) somewhat more complicated

(a) AC/DC system to match

(b) → add complexity to one at a time

(with non switches)

- Again - match to non-switched model

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(2) Then add detail to controls

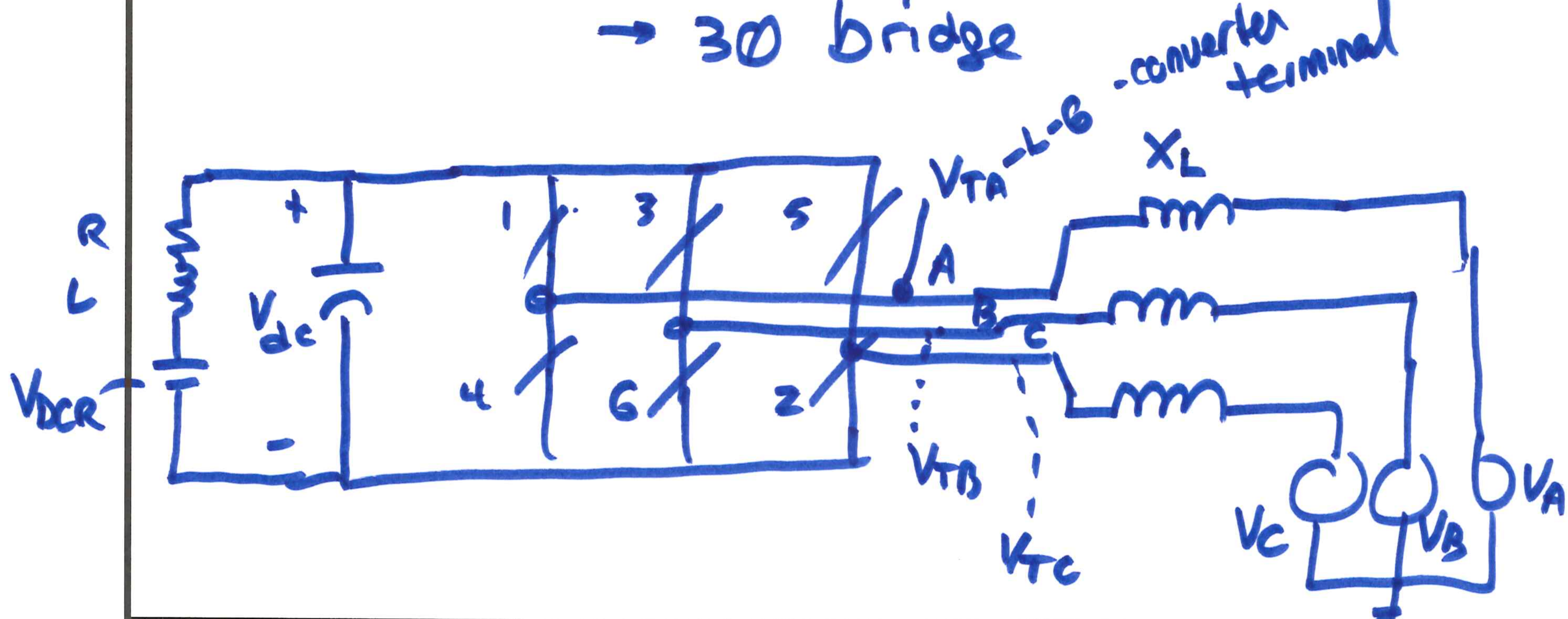
- more detail in
  - synchronization
  - ~~outer con~~
  - outer control loops
  - checks along the way for reasonable performance

(3) Then add more to the AC system - <u>in steps</u>

Non-switching models of voltage sourced converters

1. Fundamental component model

→ 3Ø bridge



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$$v_{TA}(t) = v_{TA1}(t) + \underbrace{\cancel{v_{tA3}(t)}}_{0} + \dots + v_{tAh}(t)$$

- concentrate on fundamental component
- Transfers useful P & Q for system commands

- all multiples of 3 = 0
- control of switch should have symmetry to eliminate even harmonics
- most of harmonics around or above modulation frequency for PWM

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$$i_a(t) = \underbrace{i_{A1}(t)}_{\text{point of interest}} + \sum_{i=2}^{n} i_{nA}(t)$$

$$\bar{S}_{AC_{3\phi 1}} = 3\,\bar{V}_{tA1}\,\bar{I}_A^{*} = 3\bar{V}_{tA}\left(\frac{\bar{V}_{tA} - \bar{V}_A}{jX_L}\right)^{*}$$

phasor

$$P_{3\phi} = \mathrm{Re}\left(3\,\bar{V}_{tA}\left(\frac{V_{tA} - V_A}{jX_L}\right)^{*}\right)$$

$$= \frac{3\,|V_{tA}|\,|V_A|}{X_L}\sin\left(\theta_{V_{tA}} - \theta_{V_A}\right)$$

$\delta - 0$ → if $\theta_{VA} = 0$

control scheme for power converter

- $|V_{tA}|$ from modulation index

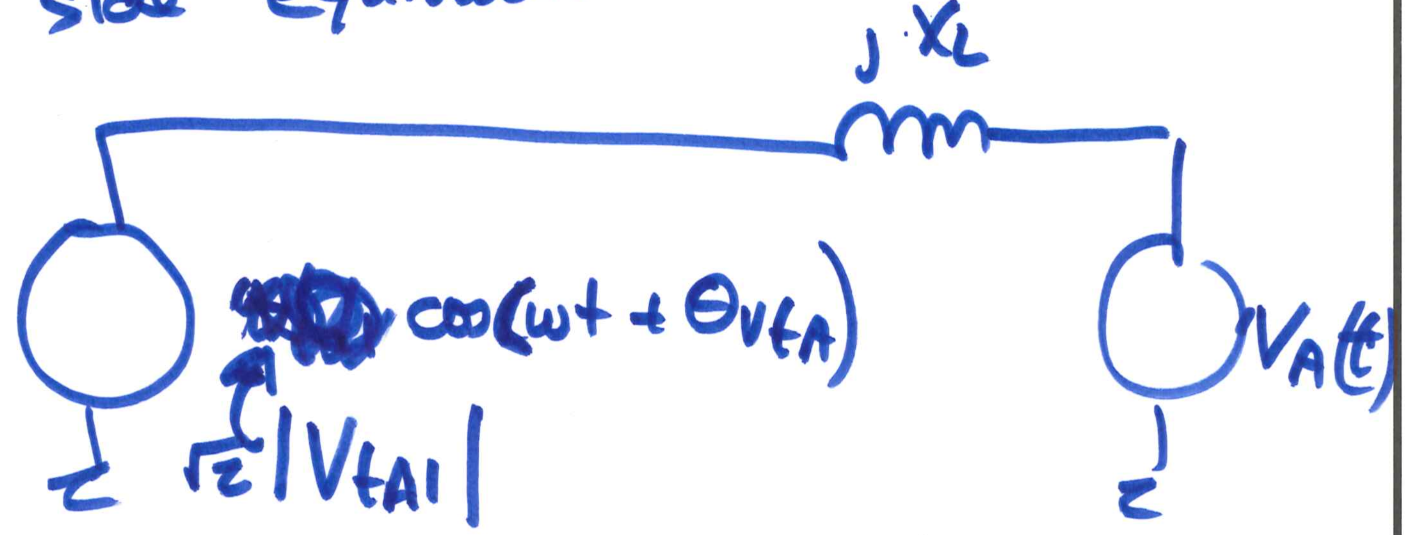
- θ_{tVA} from reference waveform if sine $-\Delta$ pwm

- $\omega \rightarrow |V_{tA}| \cos(\omega t + \theta_{VtA})$

  ↑ synchronization with power system

AC side equivalent

DC equiv ⇔



Now we need to represent dc side
plus interaction ...

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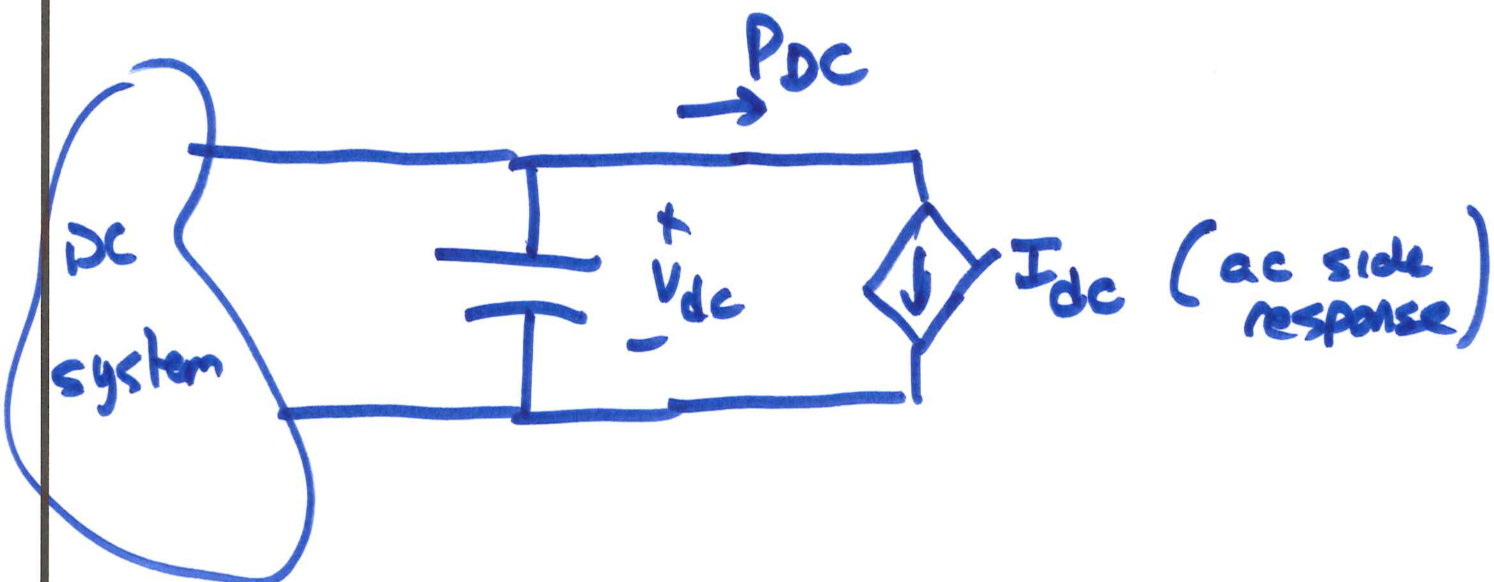

$$P_{DC} = V_{dc} I_{dc}$$

$$P_{AC} = \frac{3|V_{tA1}||V_A|}{X} \sin(\theta_{VtA} - \theta_{VA})$$

If we ignore converter losses $P_{DC} = P_{AC}$
(can add later)

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$$V_{dc} I_{dc} = \frac{3|V_{EA1}||V_A|}{X} \sin(\theta_{VEA} - \theta_{VA})$$

$$\rightarrow |V_{EA1}| = m \cdot k V_{dc}$$

m ← modulation index from switching scheme

k – represents fundamental component scaling of V_{dc} → topology dependent

3Ø bridge $k = \frac{\sqrt{2}}{\pi}$

$$|V_{tA1}| = m \frac{\sqrt{2}}{\pi} V_{dc}$$

- substitute →

divide both sides by V_{dc}

$$I_{dc} = \frac{3m \frac{\sqrt{2}}{\pi} |V_A| \sin(\theta_{V_{tA}} - \theta_{V_A})}{X_L}$$