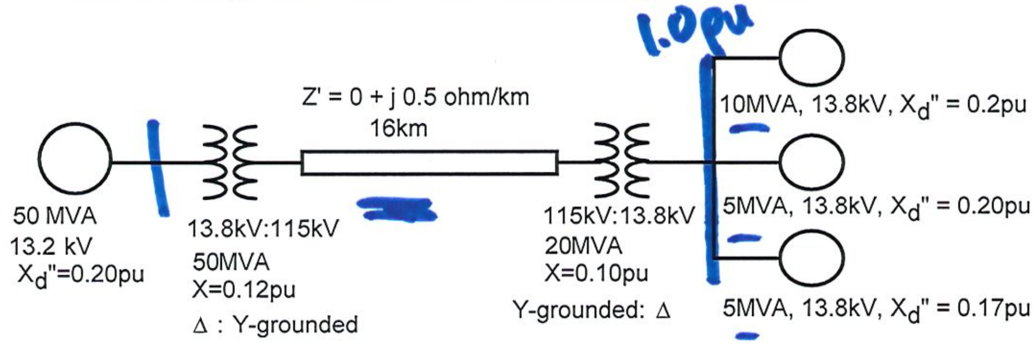
ECE 523
Symmetrical Components

Session 4

3. A three-phase generator feeds three large synchronous motors over a 16 km, 115 kV transmission line, through a 115 kV:13.8 kV transformer bank, as shown below.

(a) Draw a per unit, per phasequivalent circuit with all reactances indicated in per unit on a 100 MVA base. Start the voltage bases from 13.8 kV base on the generator source



(b) The generator is controlled to maintain the voltage at the motor bus at 1.0 pu at an angle of 0 degrees. The three motors are operating at full rating and 90% PF lagging. Determine the voltage required at the generator terminals assuming that there is no voltage regulating taps or similar equipment in this system.

(c) Calculate the voltage required behind the subtransient reactance for the generator and each of the motors

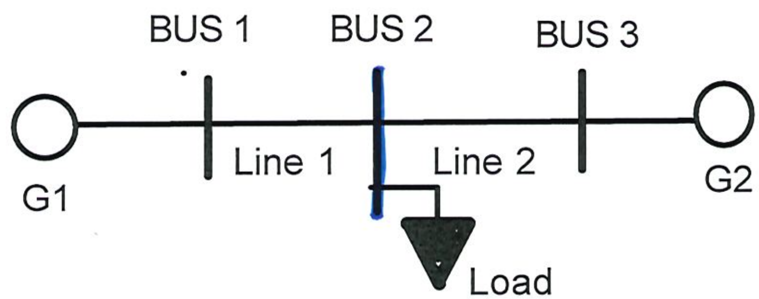
(d) Calculate the line current in Amperes

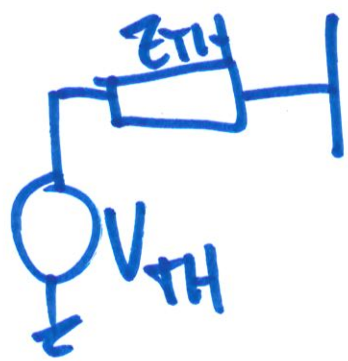
4. Draw the per unit, Thevenin equivalent circuit for the system below looking out from the load bus if:

(a) The generator internal voltages are equal in magnitude and angle (label both as E_1 and present your results as a function of E_1)
(b) The generator internal voltages are not equal (label one as E_1 and the other E_2 in your solution, and present your results as a function of E_1 and E_2)

Impedance values (all on consistent bases, no change of base needed):

G1: $X = 0.1$ pu
G2: $X = 0.1$ pu
Line 1: $X = 0.1$ pu
Line 2: $X = 0.1$ pu
Load: $Z = j\,0.1$ pu





admittance

5. The following table of values has been prepared for the various line sections.. Find the total pu impedance and shunt susceptance of each line on a 10 MVA base, using the line nominal voltage as a voltage base. Sketch a nominal pi model for each line.

series ωL — shunt cap $\frac{1}{\omega C}$

Nominal Voltage (kV)	Line Length (mi)	Wire Size and Material	R (Ω/mi)	X (Ω/mi)	X_c (MΩ-mi)
13.8	5.0	4/0 Cu	0.278	0.690	0.160
13.8	2.0	4 Cu	1.374	0.816	0.193
13.8	3.9	4/0 Al	0.445	0.711	0.157
13.8	6.2	336.4 Al	0.278	0.730	0.172
13.8	7.3	556.5 Al	0.088	0.330	0.142
69.0	10.0	4/0 Al	0.445	0.711	0.157
69.0	25.0	336.5 Al	0.278	0.730	0.172

- motors or generators with ~~[illegible]~~ power electronic interfaces

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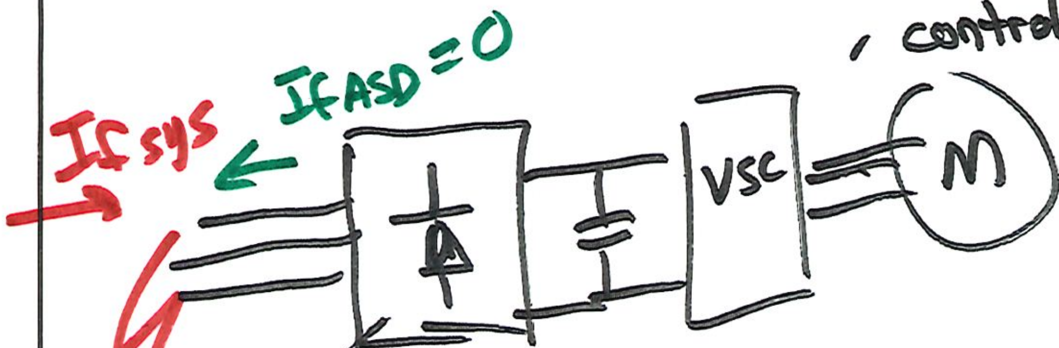
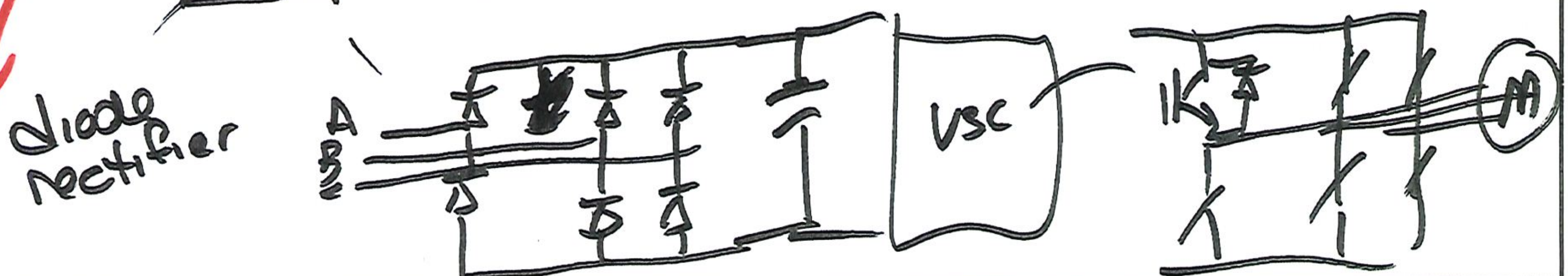
motor drives → variable frequency drive (VFD)
adjustable speed drives (ASD)

, controls frequency & amplitude & phase of <u>motor current</u>





L4 5/13

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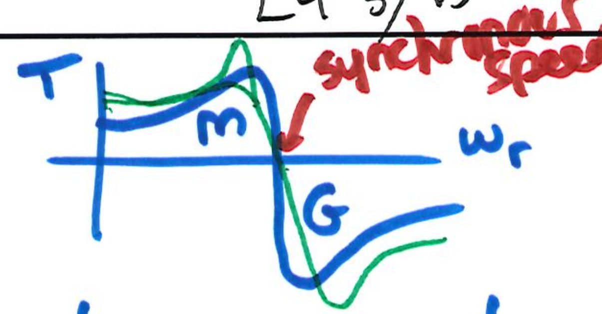


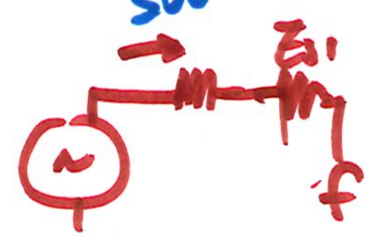
Wind Turbines

fault model is volt behind reactor [Type 1 – standard squirel cage induction machine.

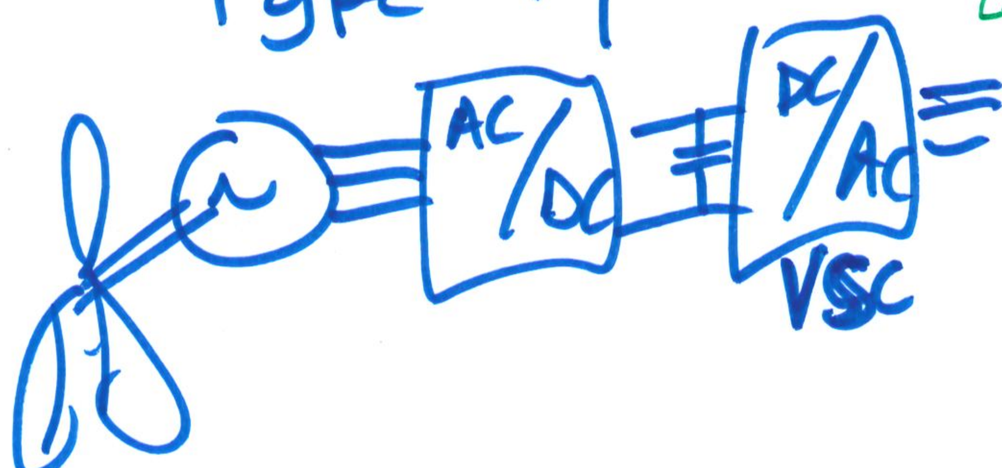
Type 2 – wound rotor induction machine

Type 3 – doubly fed induction machine

– fault current is regulated
current source



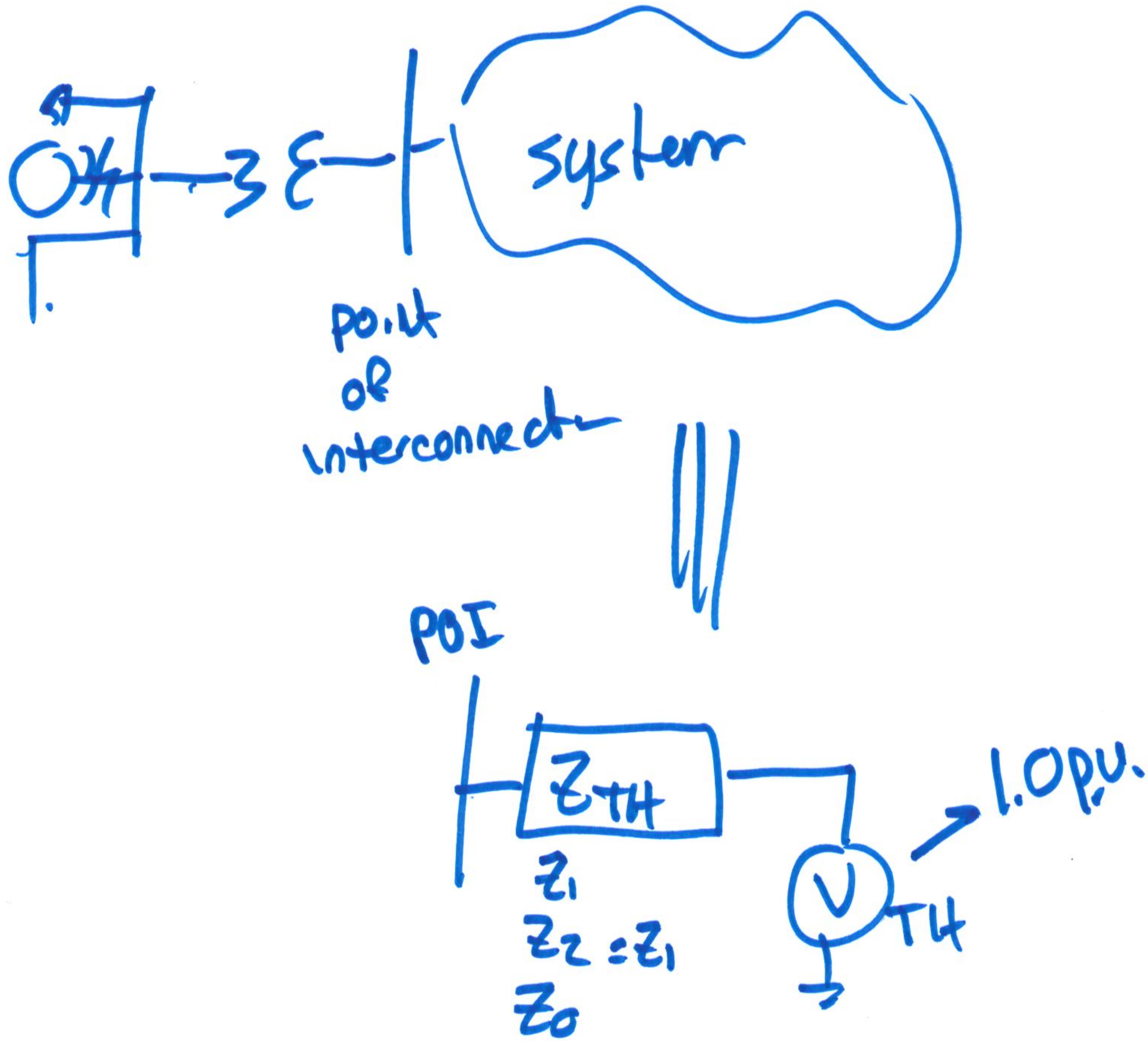
Type 4]



- Representing connection to neighboring system (or subsystem)
  - → Thevenin' Equivalent for system studies
- How do you store this information?

MVA_{sc} } → positive & zero sequence

I_{sc} }

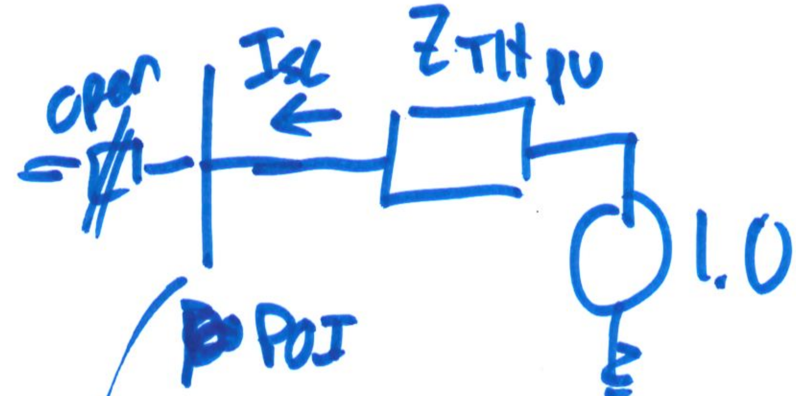

system
point
of
interconnection
POI
Z_{TH}
Z_1
$Z_2 = Z_1$
Z_0
V_{TH}
1.0 p.u.

Options

1. R_1, jX_1
   $R_2, X_2 \Rightarrow R_1 + jX_1$
   $R_0 \ X_0$

   } $|Z_1|, X/R$
   $|Z_0|, X/R$

2. $|I_{sc}|, X/R$



3ϕ fault at POI → pos (neg)

SLG → Zero

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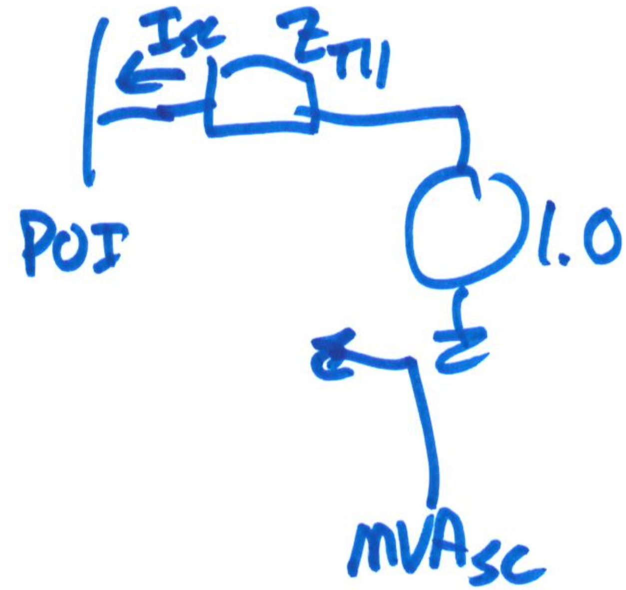
3. MVA_{SC}



$$MVA_{SC_{3\phi}} = |V_{TH}| \cdot |I_{SC}|$$

$$= |V_{TH}| \cdot \frac{|V_{TH}|}{|Z_{TH}|}$$

$$\underset{(pu)}{MVA_{SC}} = \frac{|V_{TH}|^2}{|Z_{TH}|} \quad |V_{TH}|^2 \rightarrow 1.0$$

$$= 1/|Z_{TH}|$$

$X/R \rightarrow$ angle of Z_{TH}

$MVA_{SC} = 20{,}000\ MVA$

→ put on 100 MVA

$MVA_{SC} = 20\ pu$

$Z_{TH_{pu}} = \frac{1}{20}$

$X/R = 20$ $\theta_Z = ATAN(X/R)$

$MVA_{SLG} \Rightarrow$

$$I_0 = I_1 = I_2 = \frac{V_F}{Z_1 + Z_2 + Z_0}$$

$V_F \rightarrow 1pu$

$Z_1, Z_2 \leftarrow Z_{TH1} = Z_{TH2}$; $Z_0 \leftarrow Z_{0TH}$

$$\underline{I_{Af}} = I_0 + I_1 + I_2$$
$$= 3I_0$$

$\uparrow$

$$MVA_{SCSLG_{pu}} = \frac{3V_{TH}^2}{Z_1 + Z_2 + Z_0}$$

Symmetrical Components

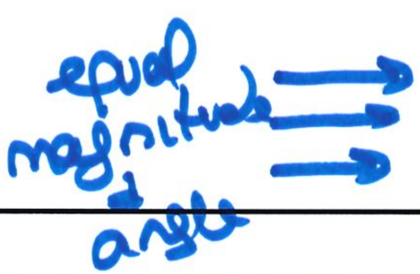
Paper by Fortesque in early 1900s

Arbitrary number of phases, n-phases

→ Any unbalanced set of phasors can be transformed linearly to decompose to

① n-1 balanced n-phase sets

② A single common mode (zero mode) sequence set



example case