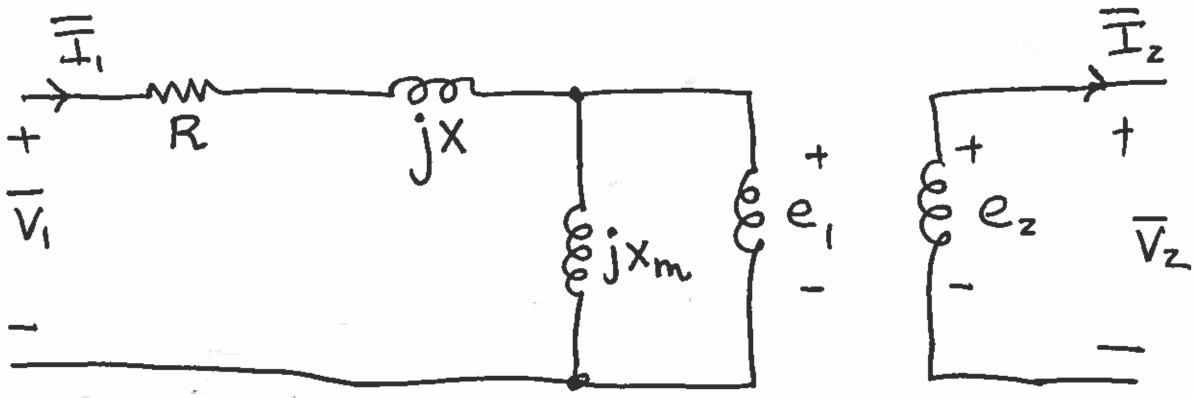
LECTURE 9

09/26/17

CALCULATION OF MODEL PARAMETERS



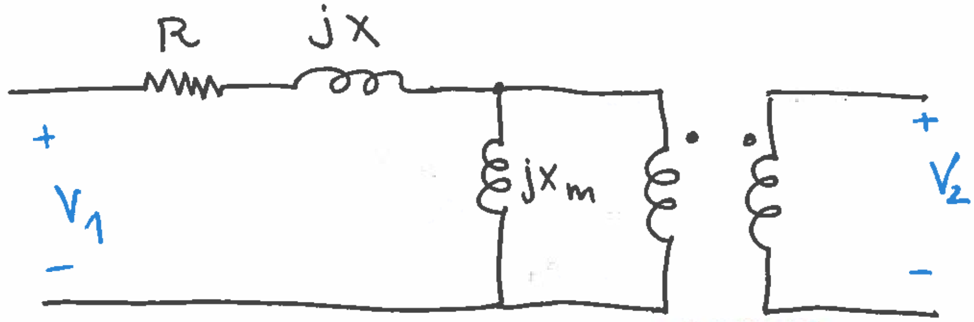
The parameters of the model can be determined based upon:

(i) Nameplate data: Rated voltage and power

(ii) Open-circuit test: rated voltage is applied to primary with secondary open; measure the primary current (and losses)

(iii) Short-circuit test: with secondary shorted, apply voltage to primary to get rated current to flow; measure voltage and losses.

Example

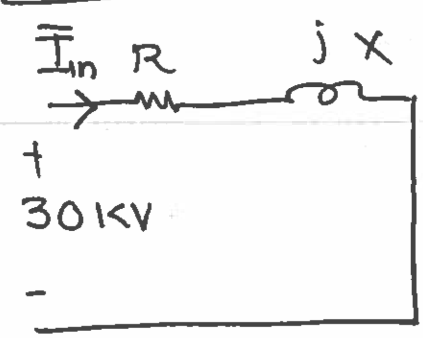


$$\frac{V_1}{V_2} = 2.5$$

1∅ transformer: $S = 100\,MVA$, 80/200 kV

- Open-circuit test: 20A, 10kW losses
- Short-circuit test: 30kV, 500kW losses.

~~Short-circuit test~~



$$I_{in} = \frac{100 \cdot 10^6}{80 \cdot 10^3} = 500\,A$$

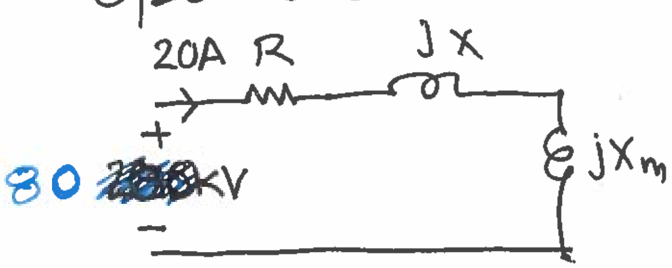
$$\bar{Z} = R + jX \longrightarrow Z = \frac{V}{I} = \frac{30 \cdot 10^3}{500} = 60\,\Omega$$

$$P_{loss} = I^2 \cdot R = 500 \cdot 10^3$$

$$R = \frac{500 \cdot 10^3}{500^2} = 2\,\Omega$$

$$Z = \sqrt{R^2 + X^2} \longrightarrow X = \sqrt{60^2 - 2^2} \simeq 60\,\Omega$$

Open-circuit test



$$Z = R + j(X + X_m)$$

$$\frac{80 \cdot 10^3}{20} = Z = 4{,}000\,\Omega$$

$$= \sqrt{R^2 + (X + X_m)^2}$$

$$X_m \simeq 10{,}000\,\Omega$$

PER - UNIT NORMALIZATION

- In power system calculations, a normalization of variables called per-unit normalization is almost always used.
- As we will see, it is especially convenient if many transformers and voltages levels are involved.
- The idea is to pick <u>base values</u> for quantities such as
  (i) Voltages
  (ii) Currents
  (iii) Impedances
  (iv) Power
  ...

  and to define the quantity in per unit as follows:

$$\text{quantity in per unit} = \frac{\text{actual quantity}}{\text{base value quantity}}$$

- A vital point is that the base quantities are picked to satisfy the same kind of relationships as the actual variables.
- For example corresponding to

$$\bar{V} = \bar{Z} \cdot \bar{I}$$ (actual variables in complex number)

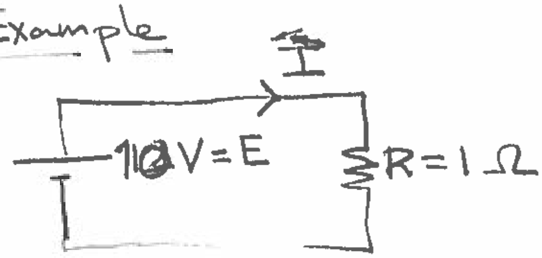
we have the eqn. for base quantities $V_B = Z_B I_B$

Dividing, we obtain

$$\bar{V}_{pu} = \bar{Z}_{pu}\bar{I}_{pu},$$

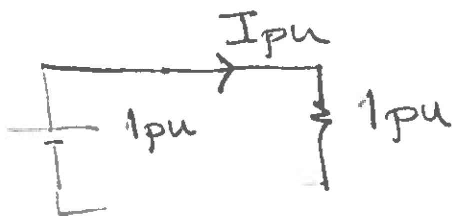
which has the same form as $\bar{V} = \bar{Z}\bar{I}$, i.e., we can do circuit analysis with the p.u. quantities.

Example



$$I = \frac{10}{1} = 10\,A$$

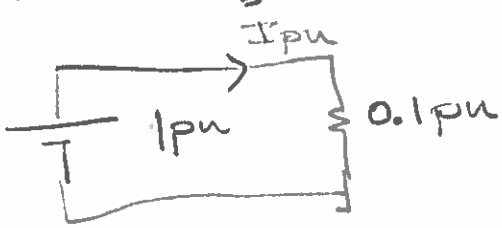
Pick: $V_B = 10\,V$, $Z_B = 1\,\Omega$, then $I_B = 10A$



$$I_{pu} = \frac{1}{1} = 1$$

$$I = I_B \times I_{pu} = 10A$$

Pick $V_B = 10$, $Z_B = 10\,\Omega$, then $I_B = 1A$



$$I_{pu} = \frac{1}{0.1} = 10pu$$

$$I = I_B \times I_{pu} = 10pu \times 1A = 10A$$

What we have done for ohm's law, can be done in the case of power calculations

$$\bar{S} = \bar{V} \cdot \bar{I}^*$$

$$\Rightarrow S_B = V_B\, I_B$$

$$\Rightarrow \bar{S}_{pu} = \bar{V}_{pu} \cdot \bar{I}^*_{pu},$$

where
$$\bar{S}_{pu} = \frac{\bar{S}}{S_B}$$
$$\bar{V}_{pu} = \frac{\bar{V}_1}{V_B}$$
$$\bar{I}_{pu} = \frac{\bar{I}}{I_p}$$

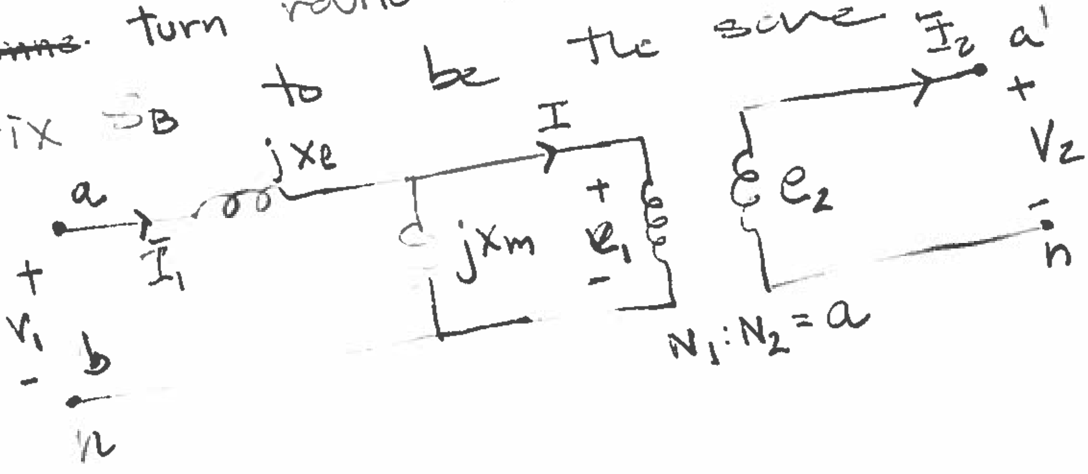
Note that $\left.\begin{matrix} V_B = Z_B I_B \\ S_B = V_B I_B \end{matrix}\right\}$ 4 variables, two eqns.

If we fix <u>two base variables</u>, the others are automatically determined.

- Pick S_B and V_B, then $\begin{cases} Z_B = \dfrac{V_B^2}{S_B} \\ I_B = \dfrac{S_B}{V_B} \end{cases}$ and $I_B = \dfrac{V_B}{Z_B}$

DEALING WITH TRANSFORMERS

- If the network includes transformers, there is an advantage to picking different bases for the two sides of the transformers
- Suppose that we make the ratio of voltage bases equal to the transformers ~~turns~~ turn ratio of the transformers
- Fix S_B to be the same



S_B, V_{1B}, $V_{2B} = \frac{1}{a} V_{1B}$, I_{1B}, $I_{2B} = a I_B$,

$Z_{2B} = \left(\frac{1}{a}\right)^2 Z_{1B}$

$$\begin{cases} V_{2pu} = \dfrac{V_2}{V_{2B}} = \dfrac{\frac{1}{a} e_1}{\frac{1}{a} V_{1B}} = e_{1pu} \\[2ex] I_{2pu} = \dfrac{I_2}{I_{2B}} = \dfrac{a I}{a I_{1B}} = I_{pu} \end{cases}$$

We can redraw the circuit to show relations between per unit quantities but without the ideal transformer!