Sistemas Elétricos de Potência

Aula 03-P2 – Método das Componentes Simétricas Aplicado aos Equipamentos: Gerador, Transformador e Linhas de Transmissão

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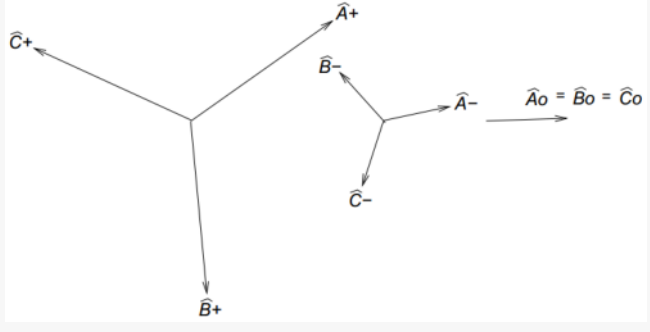
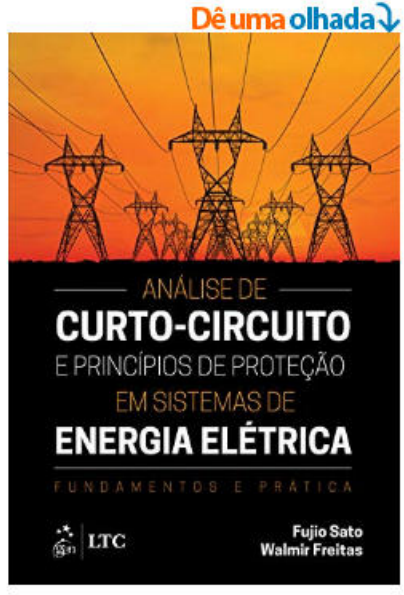


Tópicos abordados

- Capítulo 4

- Propriedades da TCS
  - TCS nas fórmulas de potência
  - TCS nos elementos passivos
    - ✓Linha de Transmissão
    - ✓Transformadores
    - ✓Máquina síncrona



TCS nas fórmulas de potência

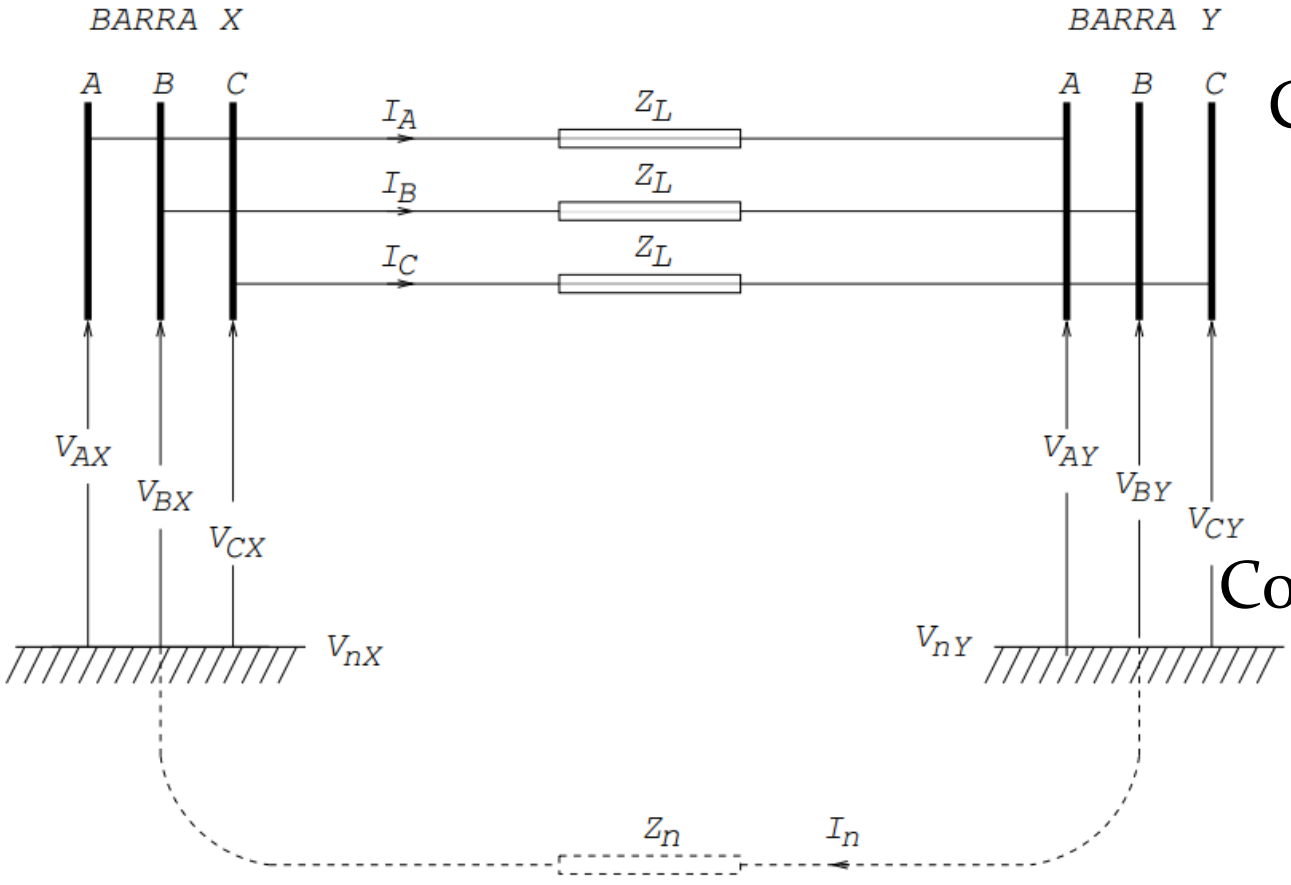
$$S = \hat{V}_A \hat{I}_A^* + \hat{V}_B \hat{I}_B^* + \hat{V}_C \hat{I}_C^* = \underline{V}_P^T \underline{I}_P^*$$

$$S = (T\underline{V}_S)^T (T\underline{I}_S)^* = \underline{V}_S^T (T^T T^*) \underline{I}_S^*$$

$$S = 3\underline{V}_S^T \underline{I}_S^* = 3\hat{V}_+ \hat{I}_+^* + 3\hat{V}_- \hat{I}_-^* + 3\hat{V}_o \hat{I}_o^*$$

$$S = P + jQ = 3\hat{V}_+ \hat{I}_+^* + 3\hat{V}_- \hat{I}_-^* + 3\hat{V}_o \hat{I}_o^*$$

Linha de Transmissão



Condições equilibradas

$$V_{nX} = V_{nY} = 0$$

$$I_n = 0$$

Condições desequilibradas

$$I_n = I_A + I_B + I_C$$

Linha de Transmissão

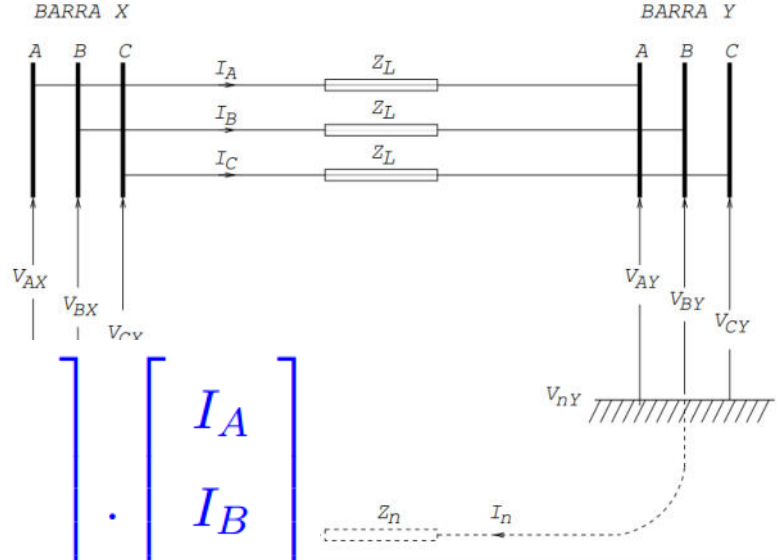
Condições desequilibradas

$$I_n = I_A + I_B + I_C$$

$$V_{AX} - V_{AY} = I_A Z_L + (I_A + I_B + I_C) Z_n$$

$$V_{BX} - V_{BY} = I_B Z_L + (I_A + I_B + I_C) Z_n$$

$$V_{CX} - V_{CY} = I_C Z_L + (I_A + I_B + I_C) Z_n$$



$$\begin{bmatrix} V_{AX} - V_{AY} \\ V_{BX} - V_{BY} \\ V_{CX} - V_{CY} \end{bmatrix} = \begin{bmatrix} Z_L + Z_n & Z_L & Z_L \\ Z_L & Z_L + z_n & Z_L \\ Z_L & Z_L & Z_L + Z_n \end{bmatrix} \cdot \begin{bmatrix} I_A \\ I_B \\ I_C \end{bmatrix}$$

$$\Delta \underline{V}_P = Z_C \underline{I}_P$$

Linha de Transmissão

Condições desequilibradas

$$\Delta \underline{V}_P = Z_C \underline{I}_P \qquad T\Delta \underline{V}_S = Z_C T \Delta I_S \qquad \Delta \underline{V}_S = T^{-1} Z_C T \Delta I_S$$

$$Z_S = T^{-1} \begin{bmatrix} Z_L + Z_n & Z_L & Z_L \\ Z_L & Z_L + Z_n & Z_L \\ Z_L & Z_L & Z_L + Z_n \end{bmatrix} T \qquad T = \begin{bmatrix} 1 & 1 & 1 \\ a^2 & a & 1 \\ a & a^2 & 1 \end{bmatrix}$$

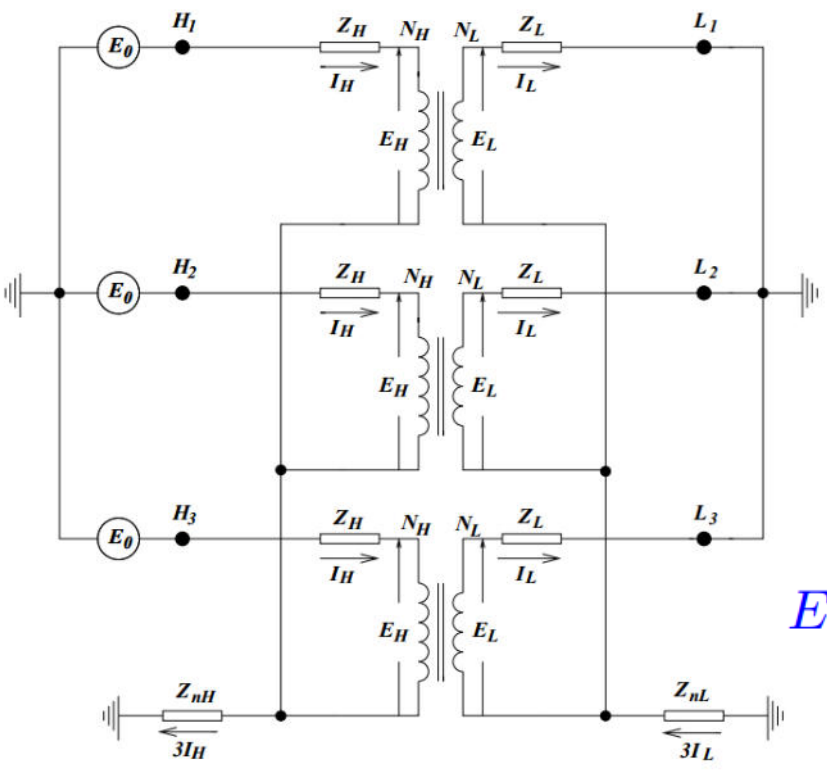
Z_+

Z_-

Z_o

$$Z_S = \begin{bmatrix} Z_L & 0 & 0 \\ 0 & Z_L & 0 \\ 0 & 0 & Z_L + 3Z_n \end{bmatrix} \qquad T^{-1} = \frac{1}{3} \begin{bmatrix} 1 & a & a^2 \\ 1 & a^2 & a \\ 1 & 1 & 1 \end{bmatrix}$$

Transformador YY



$$E_L = E_H(\frac{N_L}{N_H})$$

$$E_L = I_L(Z_L + 3Z_{nL})$$

$$I_L = I_H(\frac{N_H}{N_L})$$

$$E_H(\frac{N_L}{N_H}) = I_H(\frac{N_H}{N_L})(Z_L + 3Z_{nL})$$

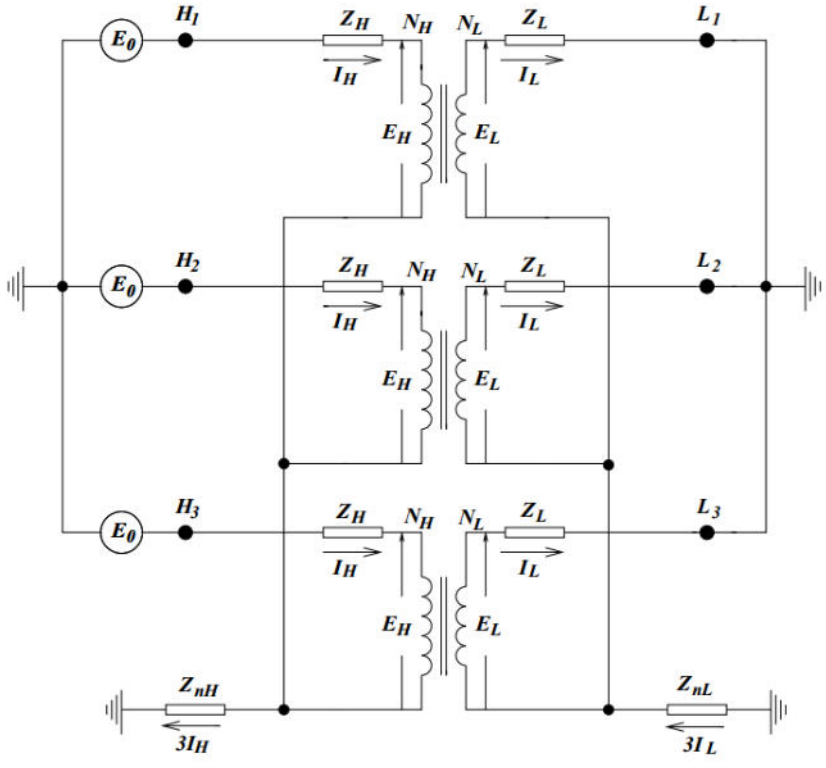
$$E_H = I_H(\frac{N_H}{N_L})^2(Z_L + 3Z_{nL})$$

$$E_0 = E_H + I_H(Z_H + 3Z_{nH})$$

$$E_0 = I_H(3Z_{nH} + Z_H + Z_L(\frac{N_H}{N_L})^2 + 3Z_{nL}(\frac{N_H}{N_L})^2)$$

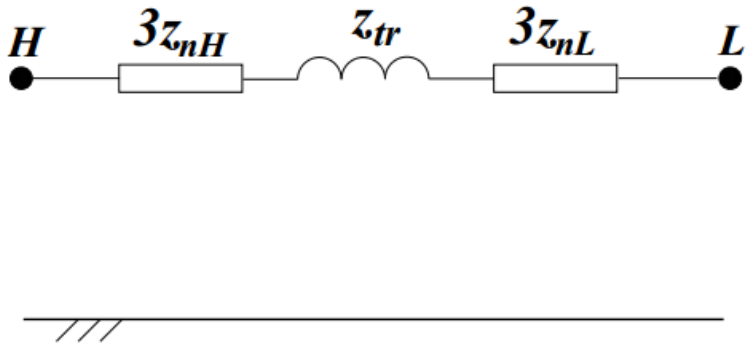
$$z_0 = (3z_{nH} + z_{tr} + 3z_{nL})$$

Transformador YY

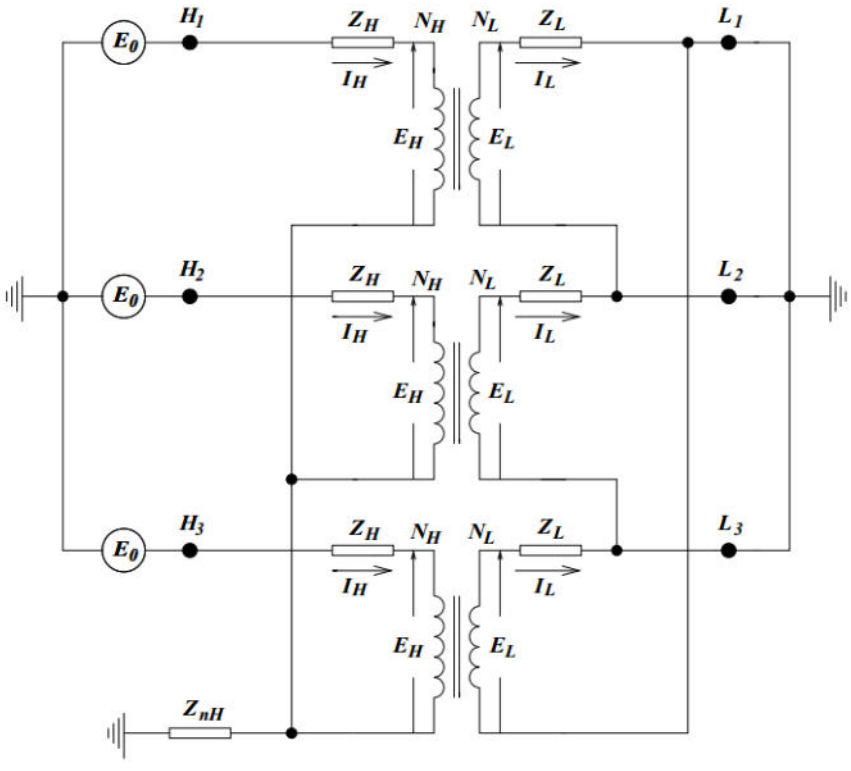


$$z_0 = (3z_{nH} + z_{tr} + 3z_{nL})$$

Sequência zero



Transformador YΔ



$$E_L = I_L Z_L$$

$$I_L = I_H(\frac{N_H}{N_L})$$

$$E_L = E_H(\frac{N_L}{N_H})$$

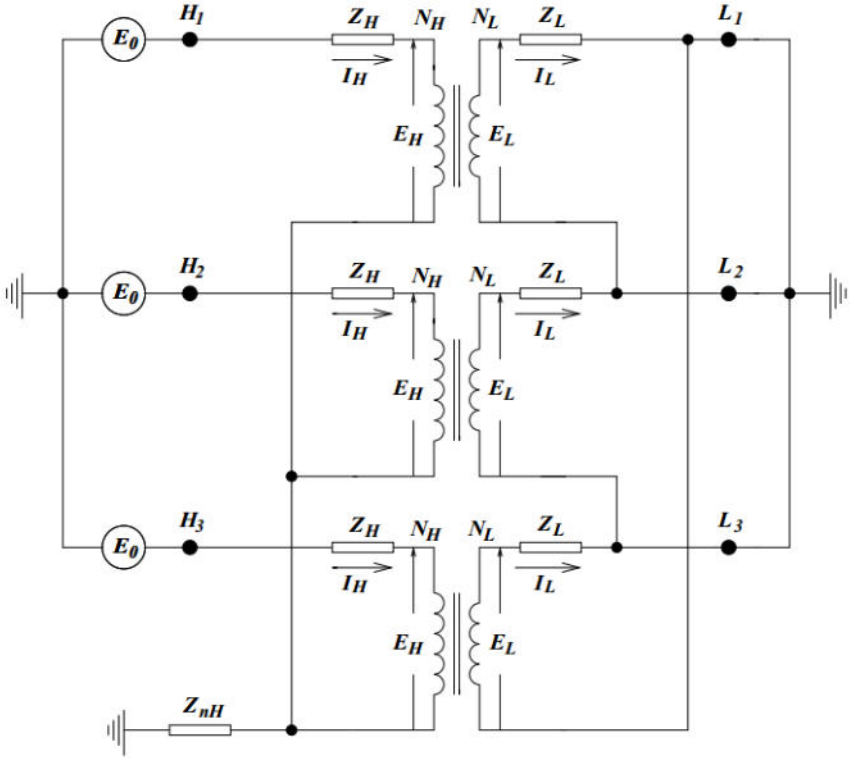
$$E_H(\frac{N_L}{N_H}) = I_H(\frac{N_H}{N_L})Z_L$$

$$E_H = I_H(\frac{N_H}{N_L})^2 Z_L$$

$$E_0 = E_H + I_H(Z_H + 3Z_{nH})$$

$$E_0 = I_H(3Z_{nH} + Z_H + Z_L(\frac{N_H}{N_L})^2)$$

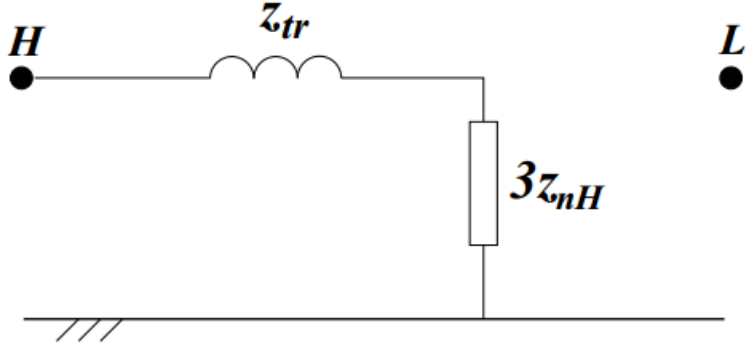
Transformador YΔ



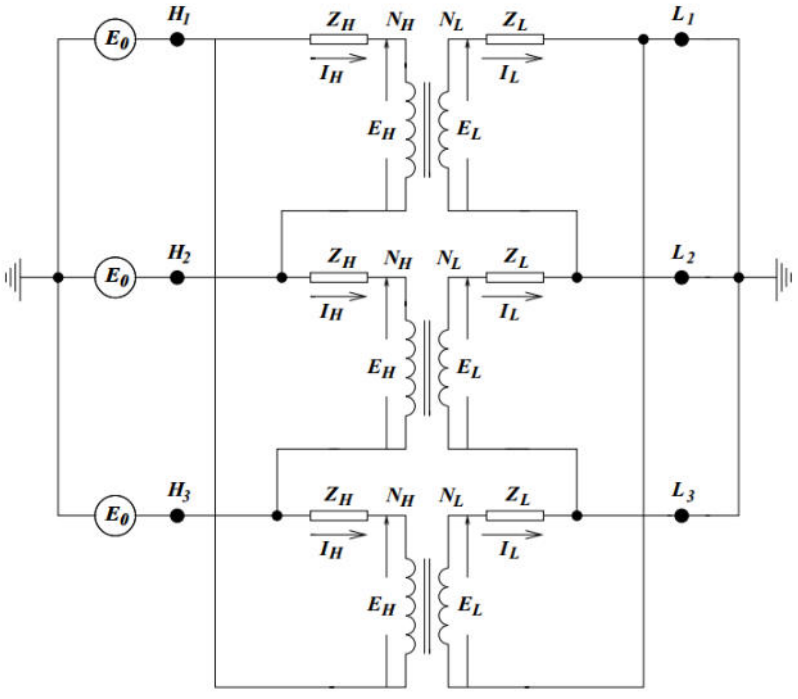
$$Z_0 = \frac{E_0}{I_H} = (3Z_{nH} + Z_H + Z_L(\frac{N_H}{N_L})^2)$$

$$z_0 = (z_{tr} + 3z_{nH})$$

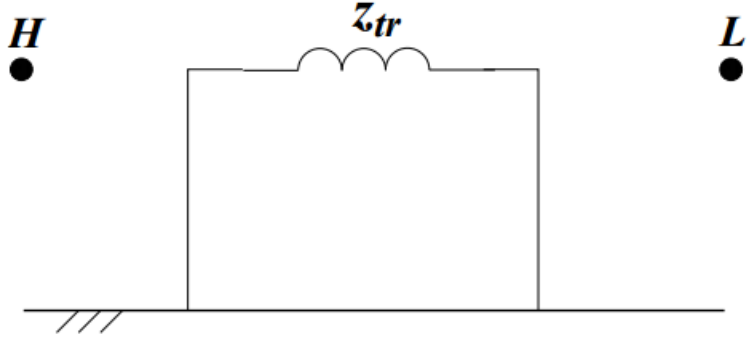
Sequência zero



Transformador ΔΔ

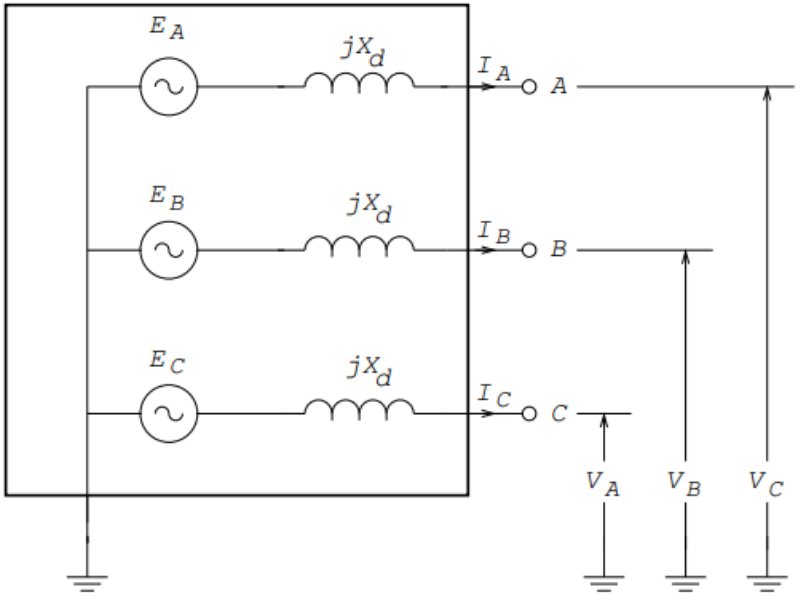


Sequência zero



Máquina Síncrona

Condições equilibradas



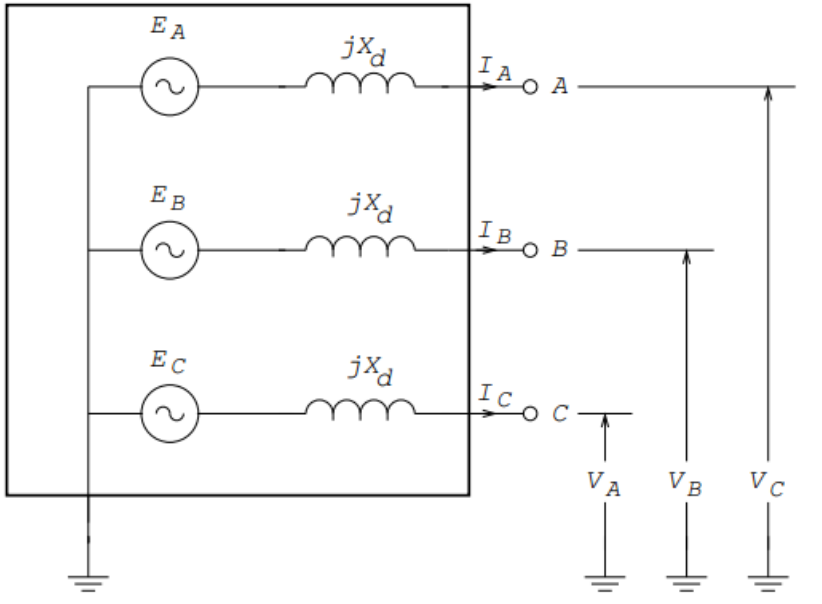
$$\hat{V}_A = \hat{E}_A - j\hat{I}_A X_d$$
$$\hat{V}_B = \hat{E}_B - j\hat{I}_B X_d$$
$$\hat{V}_C = \hat{E}_C - j\hat{I}_C X_d$$

$$\underline{V}_P = \underline{E}_P - Z_C \underline{I}_P$$

$$Z_C = \begin{bmatrix} jX_d & 0 & 0 \\ 0 & jX_d & 0 \\ 0 & 0 & jX_d \end{bmatrix}$$

Máquina Síncrona

Condições desequilibradas



$$Z_C = \begin{bmatrix} Z1 & Z_2 & Z_3 \\ Z_3 & Z_1 & Z_2 \\ Z_2 & Z_3 & Z_1 \end{bmatrix}$$

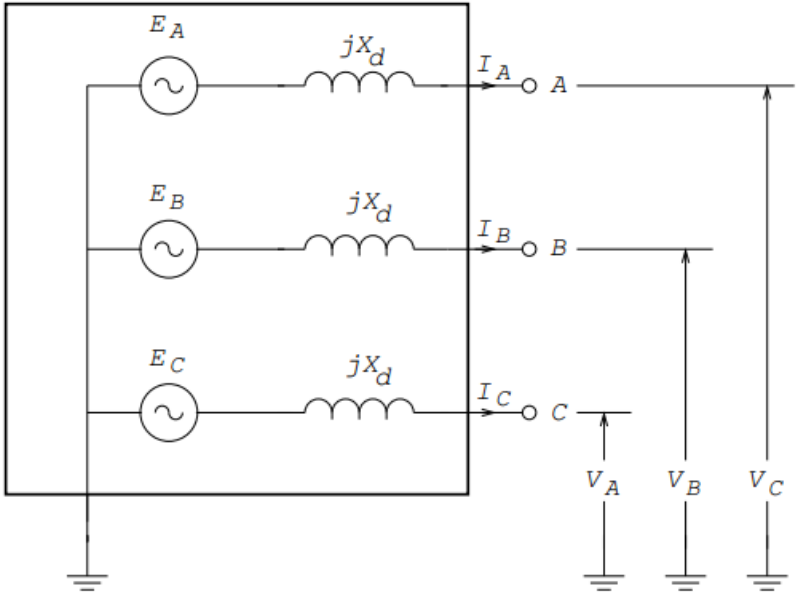
$$T\underline{V}_S = \underline{E}_P - Z_C T \underline{I}_S$$

$$\underline{V}_S = T^{-1}\underline{E}_P - T^{-1} Z_C T \underline{I}_S$$

$$\underline{V}_S = T^{-1}\underline{E}_P - Z_S \underline{I}_S$$

Máquina Síncrona

Condições desequilibradas



$$\underline{V}_S = T^{-1}\underline{E}_P - Z_S\underline{I}_S$$

$$\underline{E}_P = \begin{bmatrix} \hat{E}_A \\ \hat{E}_B \\ \hat{E}_C \end{bmatrix} = \begin{bmatrix} \hat{E}_A \\ a^2\hat{E}_A \\ a\hat{E}_A \end{bmatrix}$$

Máquina Síncrona

Condições desequilibradas

$$\underline{V}_S = T^{-1}\underline{E}_P - T^{-1}Z_C T\underline{I}_S$$

$$T^{-1}\underline{E}_P = \frac{1}{3}\begin{bmatrix} 1 & a & a^2 \\ 1 & a^2 & a \\ 1 & 1 & 1 \end{bmatrix} \cdot \begin{bmatrix} \hat{E}_A \\ a^2\hat{E}_A \\ a\hat{E}_A \end{bmatrix} = \frac{1}{3}\begin{bmatrix} \hat{E}_A(1+a^3+a^3) \\ \hat{E}_A(1+a^4+a^2) \\ \hat{E}_A(1+a^2+a) \end{bmatrix} = \begin{bmatrix} \hat{E}_A \\ 0 \\ 0 \end{bmatrix}$$

$$T^{-1}\begin{bmatrix} Z_1 & Z_2 & Z_3 \\ Z_3 & Z_1 & Z_2 \\ Z_2 & Z_3 & Z_1 \end{bmatrix} T = \begin{bmatrix} Z_1 + a^2 Z_2 + aZ_3 & 0 & 0 \\ 0 & Z_1 + aZ_2 + a^2 Z_3 & 0 \\ 0 & 0 & Z_1 + Z_2 + Z_3 \end{bmatrix}$$

Z_+

Z_-

Z_o

Máquina Síncrona

Condições desequilibradas

$$\underline{V}_S = T^{-1}\underline{E}_P - Z_S\underline{I}_S$$

$$T^{-1}\underline{E}_P = \begin{bmatrix} \hat{E}_A \\ 0 \\ 0 \end{bmatrix}$$

$$\hat{V}_{A+} = \hat{E}_A - \hat{I}_+ Z_+$$

$$\hat{V}_{A-} = 0 - \hat{I}_- Z_-$$

$$\hat{V}_{Ao} = 0 - \hat{I}_o Z_o$$

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Obrigado!

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