

Transformers

- **Equivalent Series Impedance:**

- ◆ Transformer bank of three single-phase transformers

$$Z_0 = Z_1 = Z_2 = Z_\ell$$

- ◆ Three-phase transformer with a three-leg core

$$Z_1 = Z_2 = Z_\ell \quad Z_0 > Z_\ell$$

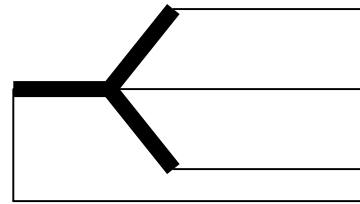
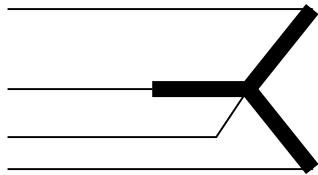
- **Wye-Delta Wound Transformers**

- ◆ Wiring connection will always cause a phase shift
- ◆ Positive Sequence rotates by a +30 degrees from HV to LV side
- ◆ Negative Sequence rotates by a -30 degrees from HV to LV side
- ◆ Zero Sequence does not rotate

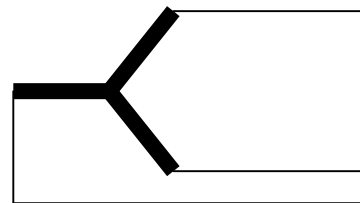
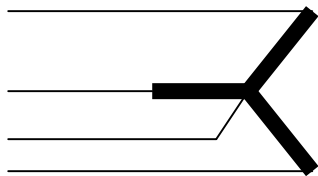
Zero-Sequence in a Transformer

- **Dependent on the winding connection on each side**
 - ◆ wye or delta
- **Dependent on the ground connection**
 - ◆ ungrounded or grounded
- **Types of connections**
 - ◆ wye-grounded to wye-grounded
 - ◆ wye-grounded to wye
 - ◆ wye-grounded to delta
 - ◆ wye to wye
 - ◆ wye to delta
 - ◆ delta to delta

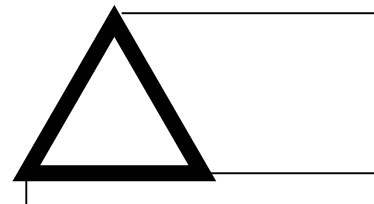
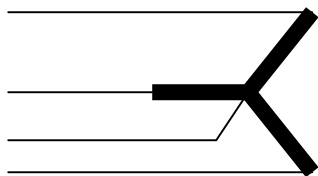
Zero-Sequence in a Transformer



wye-grounded to wye-grounded

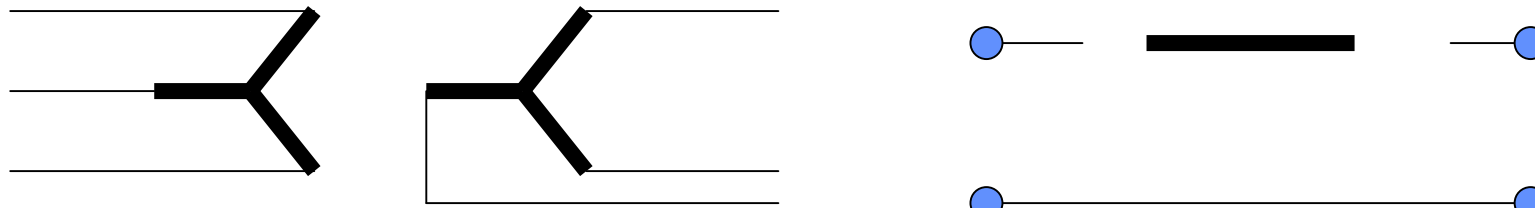


wye-grounded to wye



wye-grounded to delta

Zero-Sequence in a Transformer



wye to wye



wye to delta



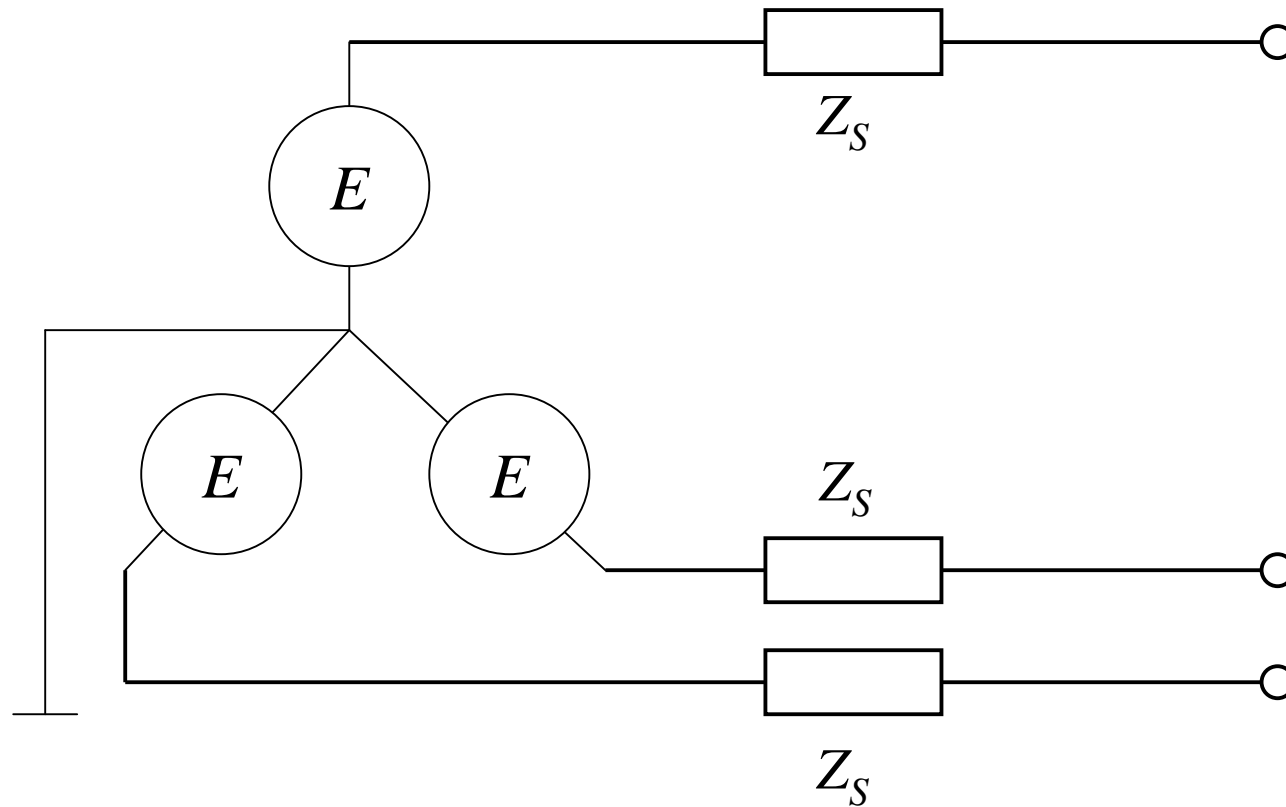
delta to delta

Generators

- **Synchronous Reactance**

- ◆ Dependent on the time period of the study
 - Steady-state
 - Transient
 - Sub-transient
- ◆ Generator is modeled as a wye-connected machine for the positive- and negative-sequence impedances
- ◆ The zero-sequence is dependent on the winding connections of the machine
 - wye-grounded
 - wye-grounded through an impedance
 - wye
 - delta

Solidly Grounded Generators



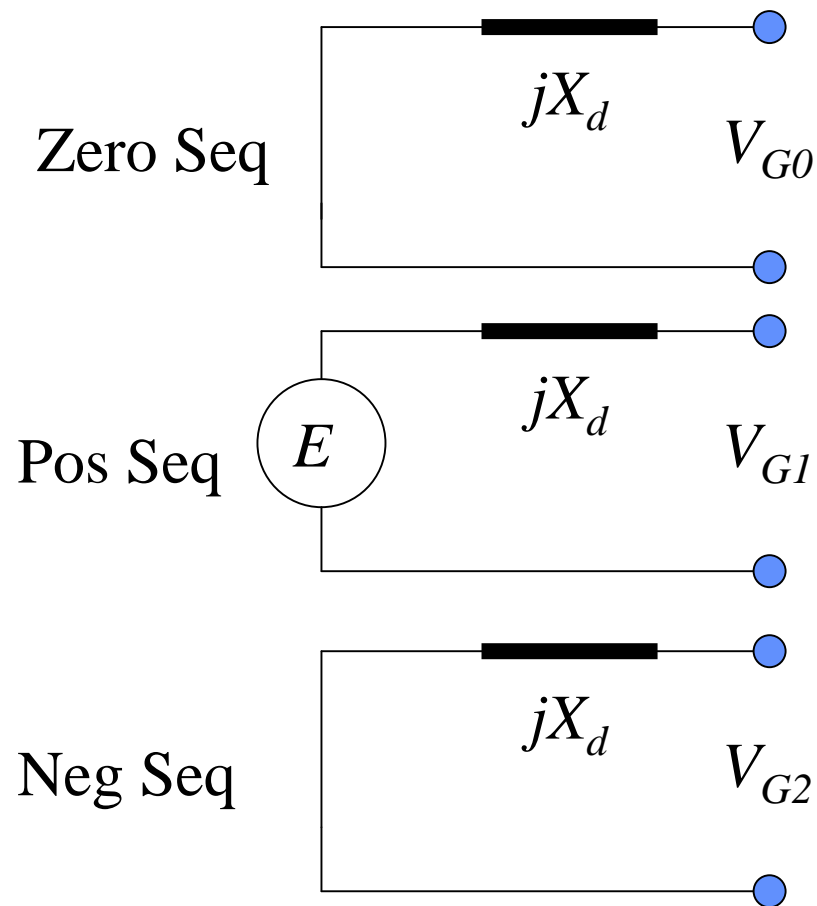
Solidly Grounded Generators

$$\mathbf{A} \mathbf{E}_{012} = \mathbf{E}_{abc}$$

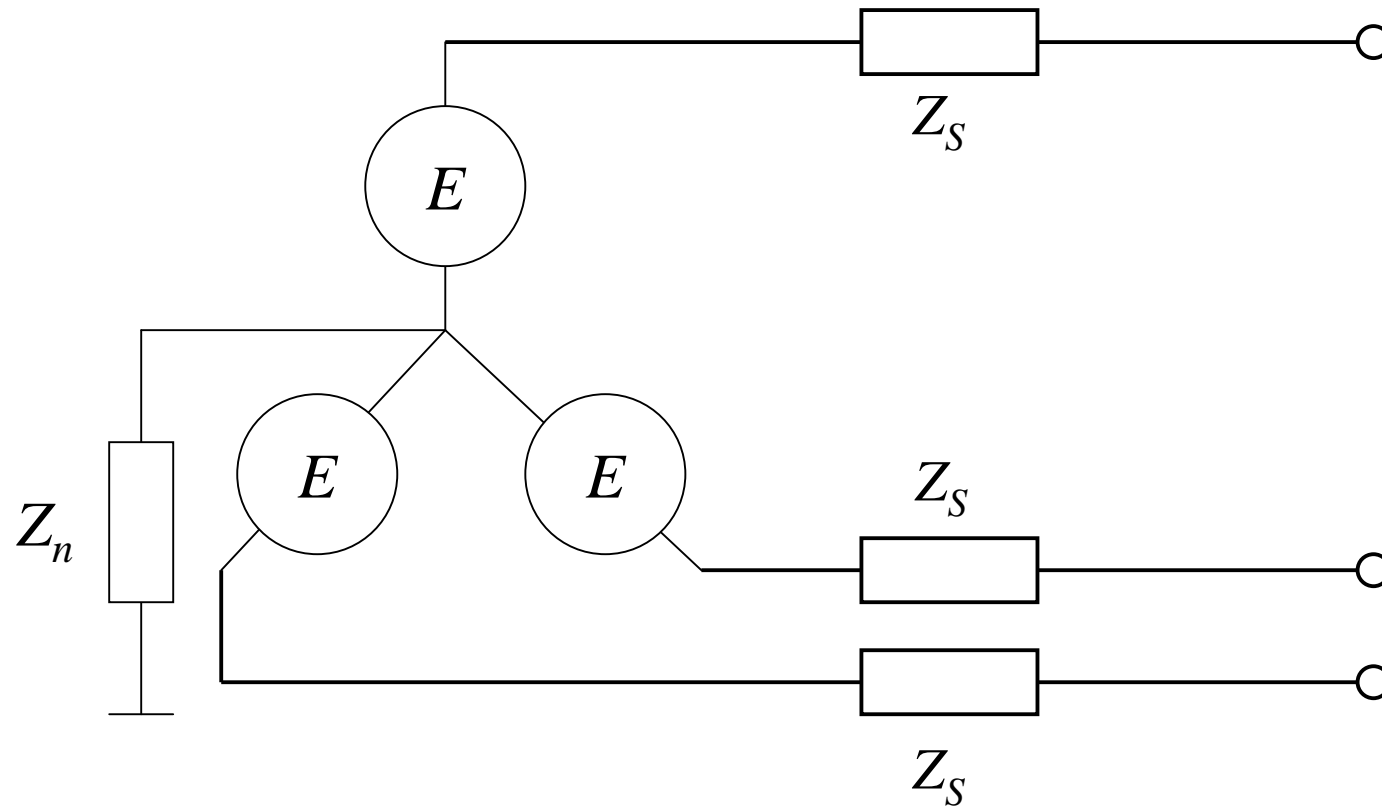
$$\mathbf{E}_{abc} = \begin{bmatrix} E_a \\ E_b \\ E_c \end{bmatrix}$$

$$\mathbf{E}_{012} = \begin{bmatrix} 0 \\ E_a \\ 0 \end{bmatrix}$$

$$X_0 = X_1 = X_2 = X_d$$



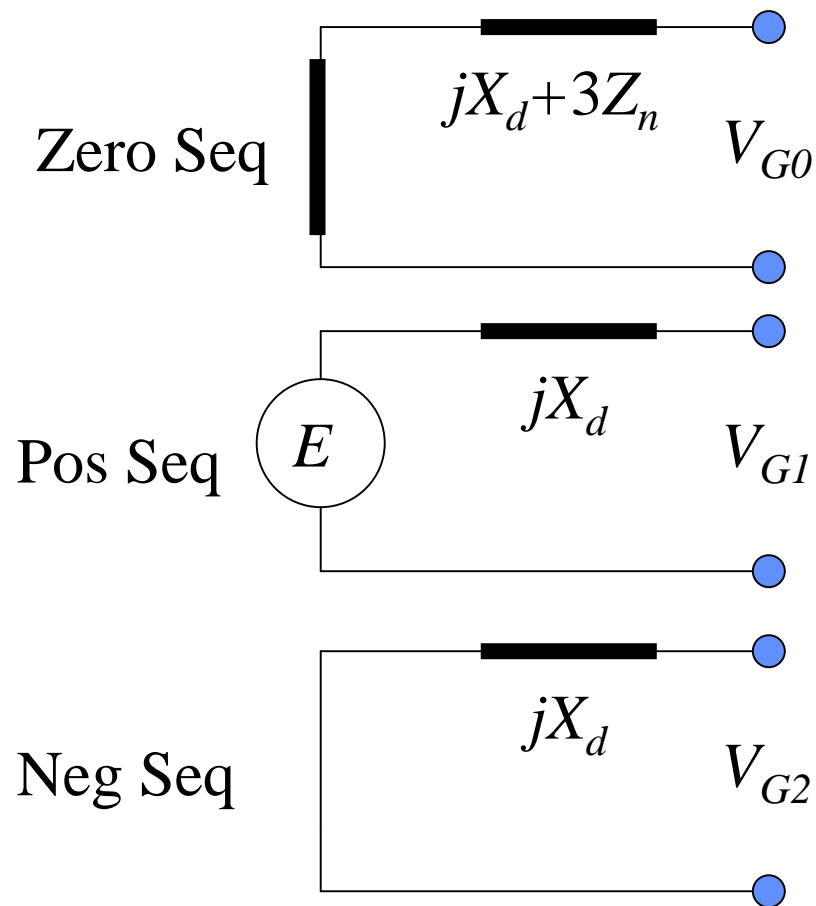
Impedance Grounded Generators



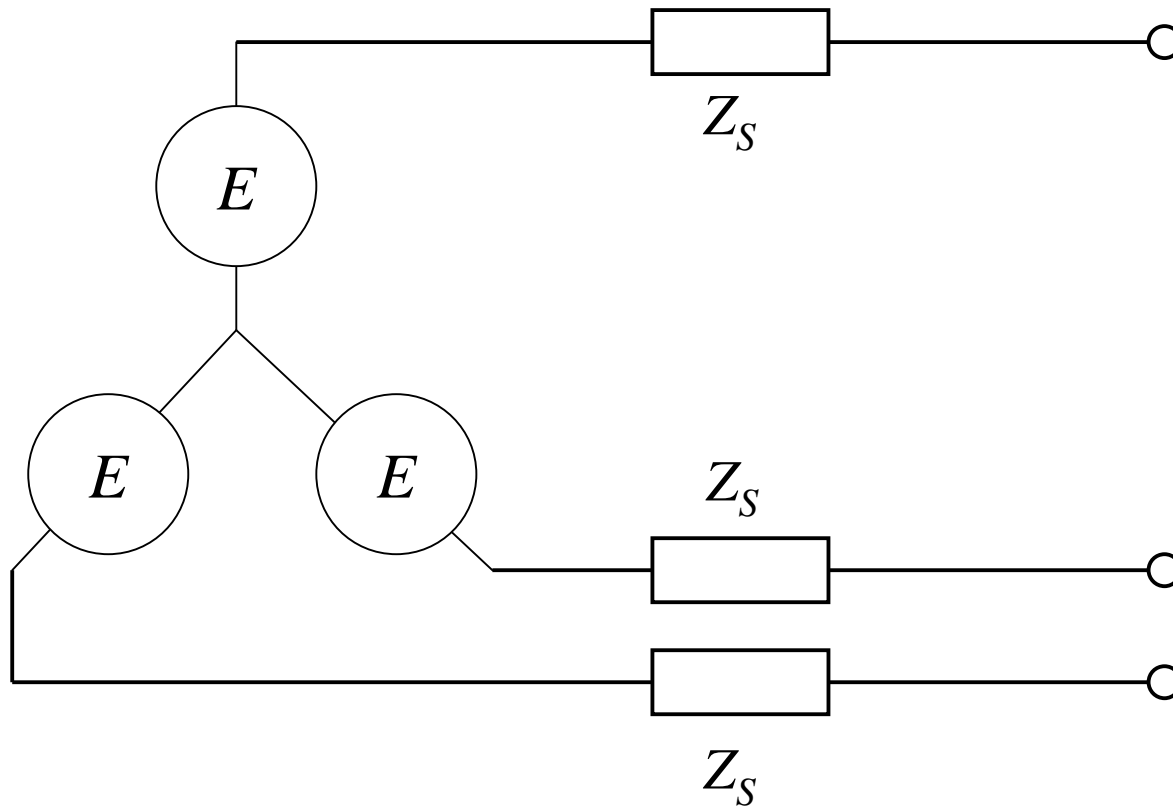
Impedance Grounded Generators

$$\mathbf{E}_{012} = \begin{bmatrix} 0 \\ E_a \\ 0 \end{bmatrix}$$

$$\mathbf{Z}_{012} = \begin{bmatrix} jX_d + 3Z_n & 0 & 0 \\ 0 & X_d & 0 \\ 0 & 0 & X_d \end{bmatrix}$$



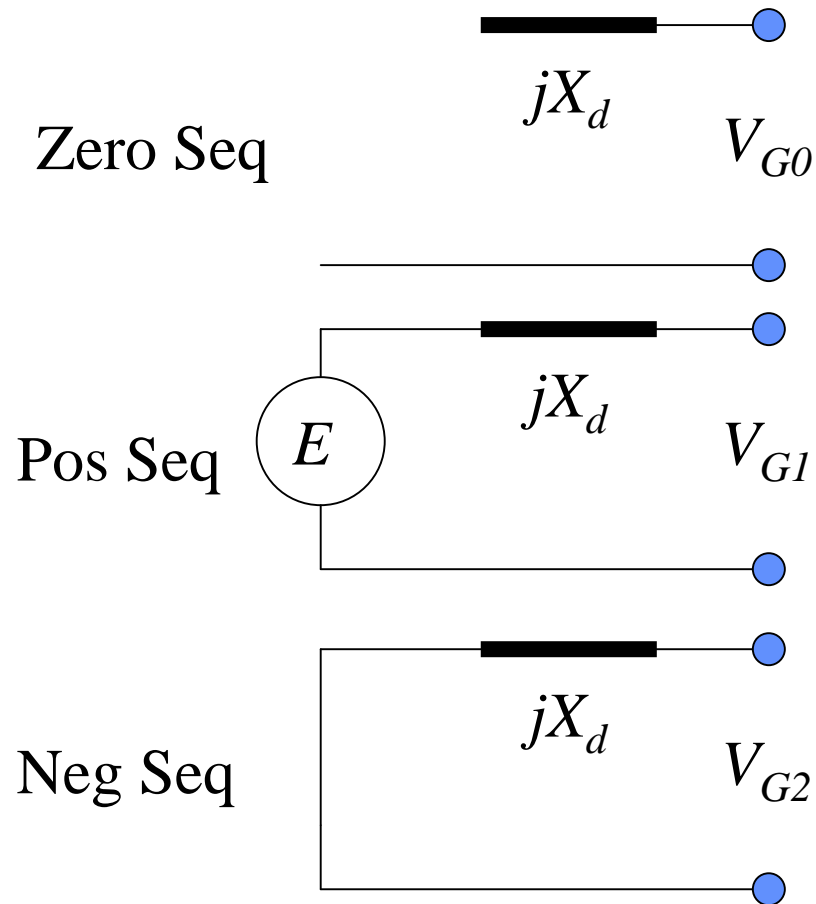
Wye Connected Generators



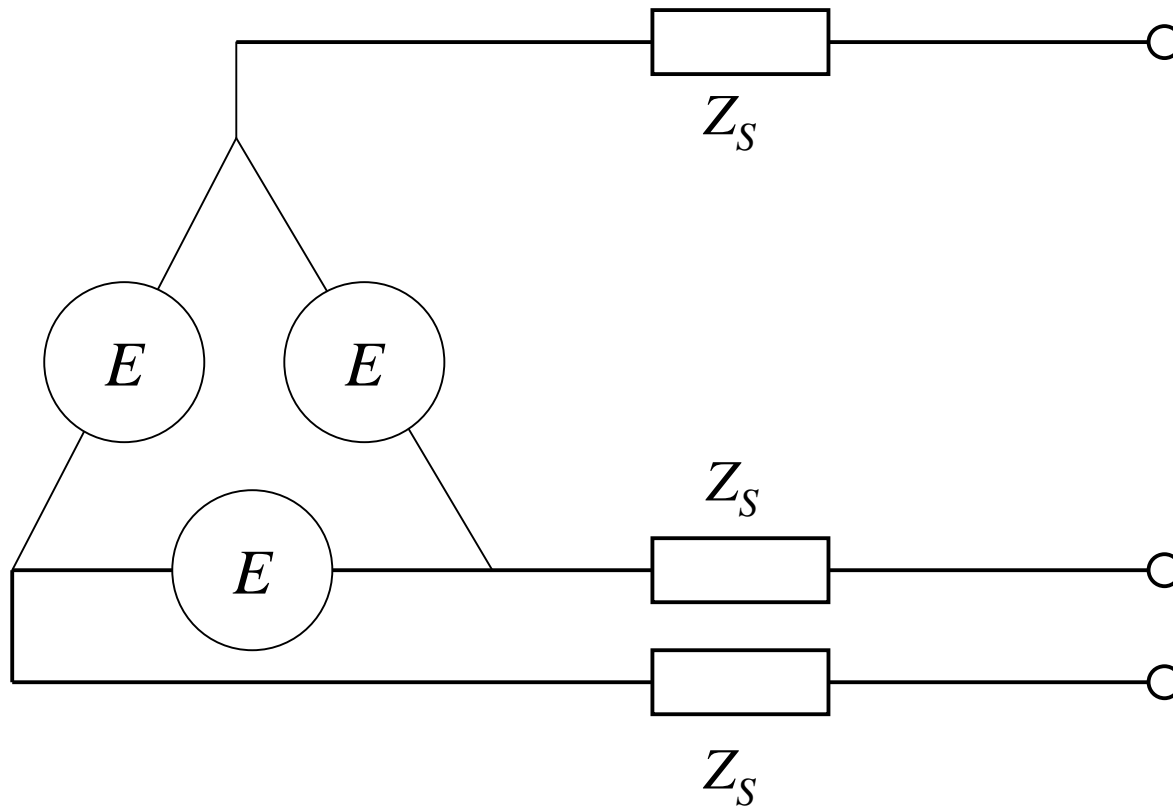
Wye Connected Generators

$$\mathbf{E}_{012} = \begin{bmatrix} 0 \\ E_a \\ 0 \end{bmatrix}$$

$$\mathbf{Z}_{012} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & X_d & 0 \\ 0 & 0 & X_d \end{bmatrix}$$



Delta Connected Generators



Delta Connected Generators

$$\mathbf{E}_{012} = \begin{bmatrix} 0 \\ E_a \\ 0 \end{bmatrix}$$

$$\mathbf{Z}_{012} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & X_d & 0 \\ 0 & 0 & X_d \end{bmatrix}$$

