

# ***TE-158: Operação de Sistemas Elétricos de Potência***

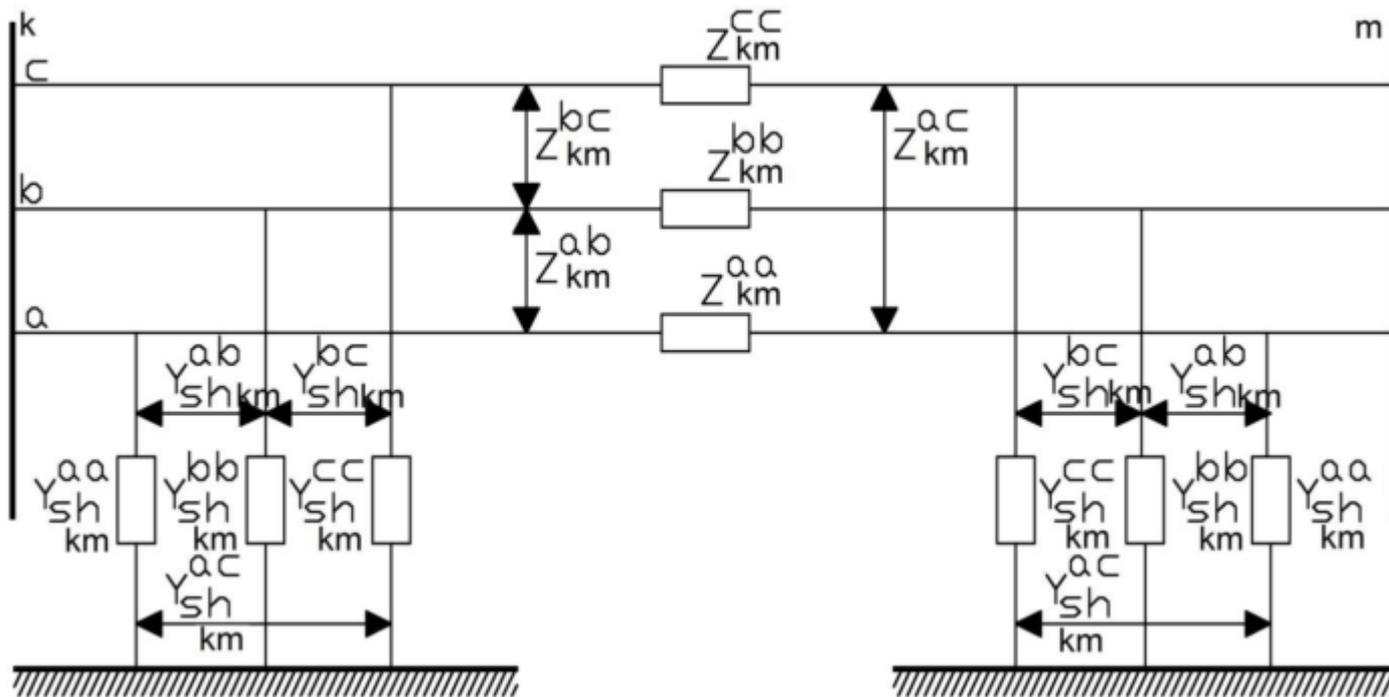
## ***SISTEMAS DE DISTRIBUIÇÃO DE ENERGIA***

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# ***MODELAGEM TRIFÁSICA***

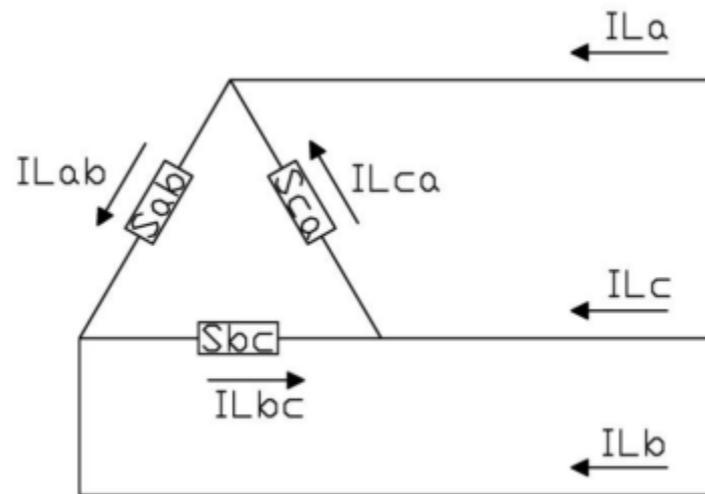
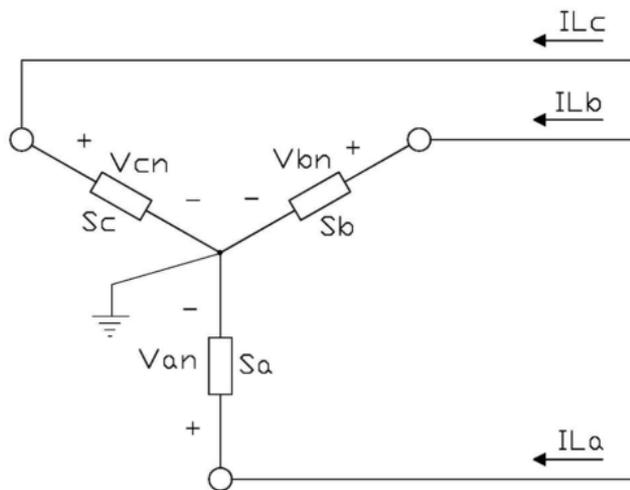
- Trechos e cargas trifásicas, bifásicas e monofásicas
- Linhas sem transposição
- Cabos instalados assimetricamente
- Rede desbalanceada e desequilibrada

# MODELAGEM TRIFÁSICA



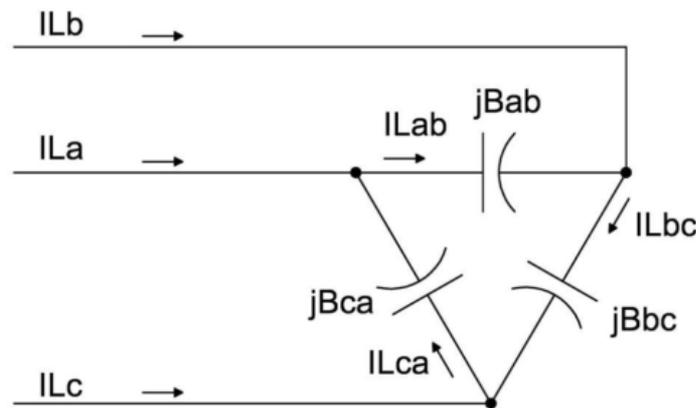
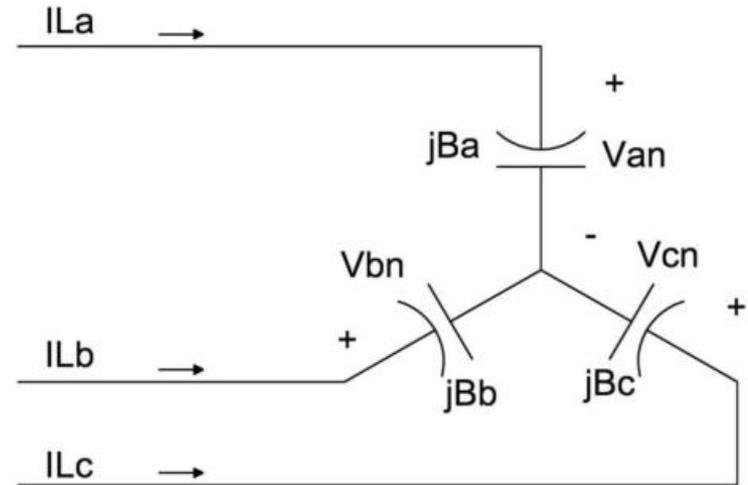
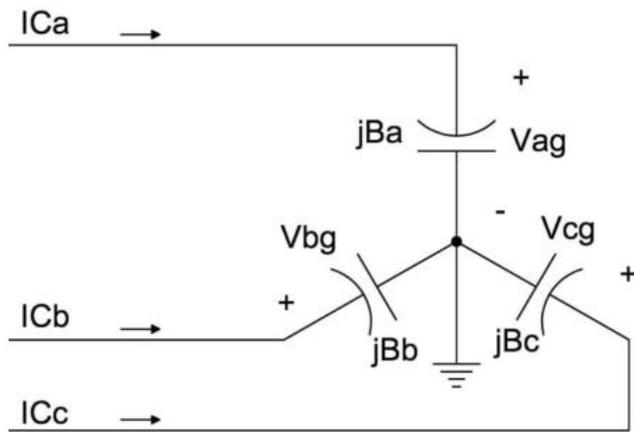
# MODELAGEM TRIFÁSICA

## Cargas trifásicas



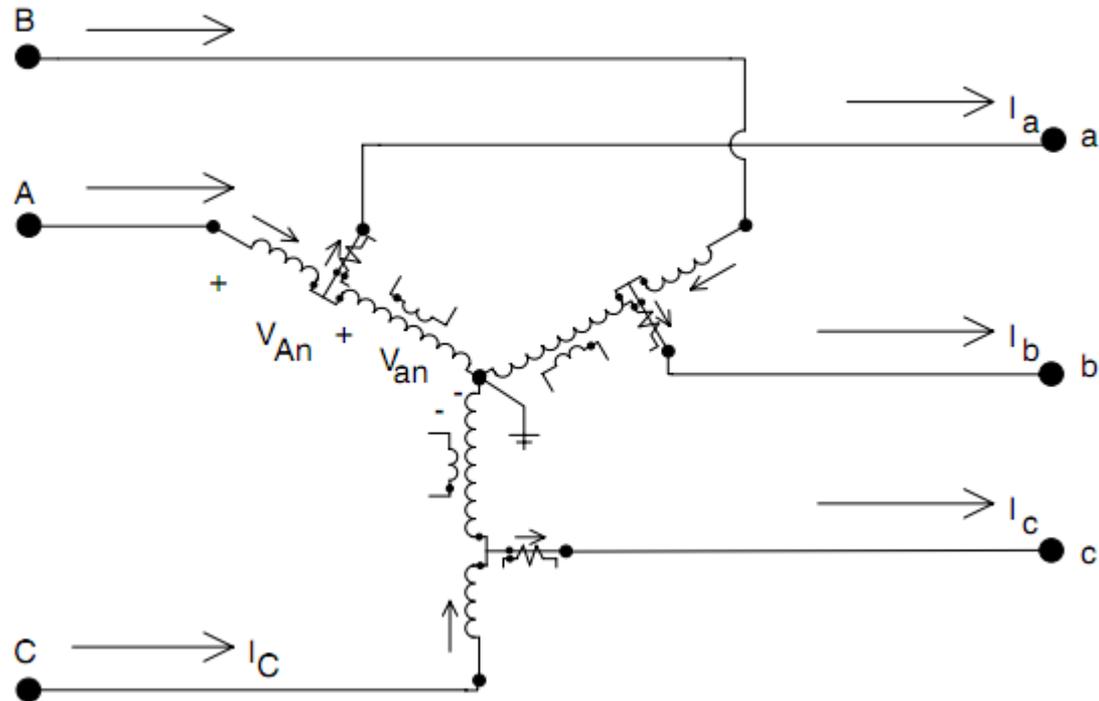
# MODELAGEM TRIFÁSICA

## Bancos de capacitores



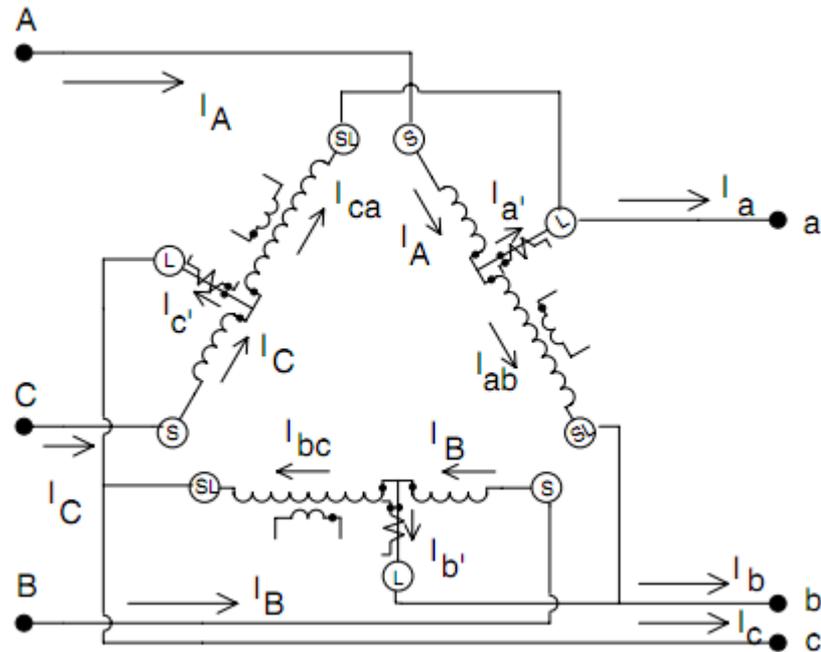
# MODELAGEM TRIFÁSICA

## Reguladores de tensão



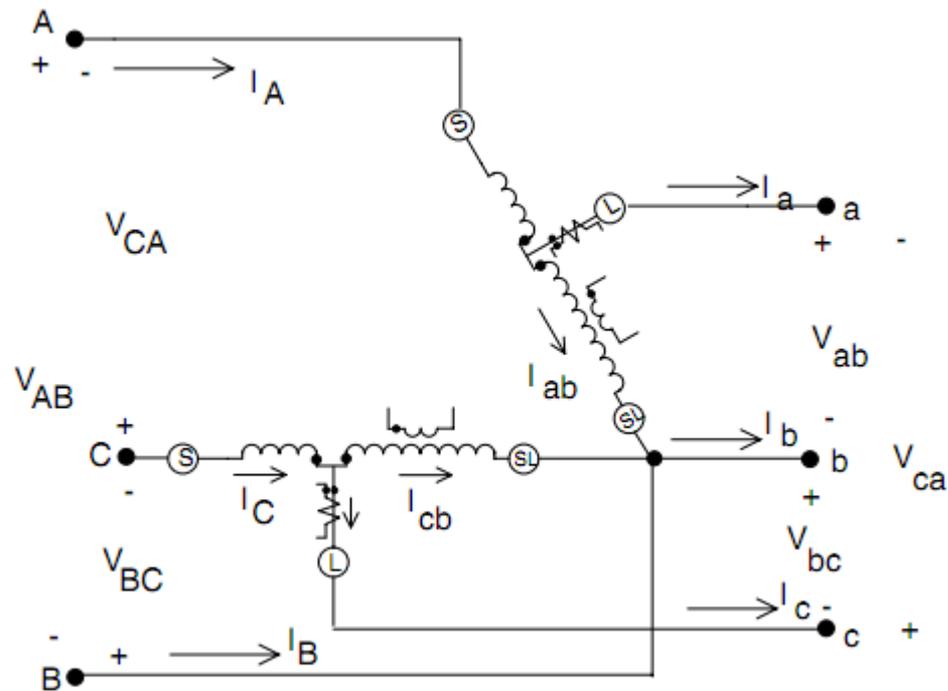
# MODELAGEM TRIFÁSICA

## Reguladores de tensão



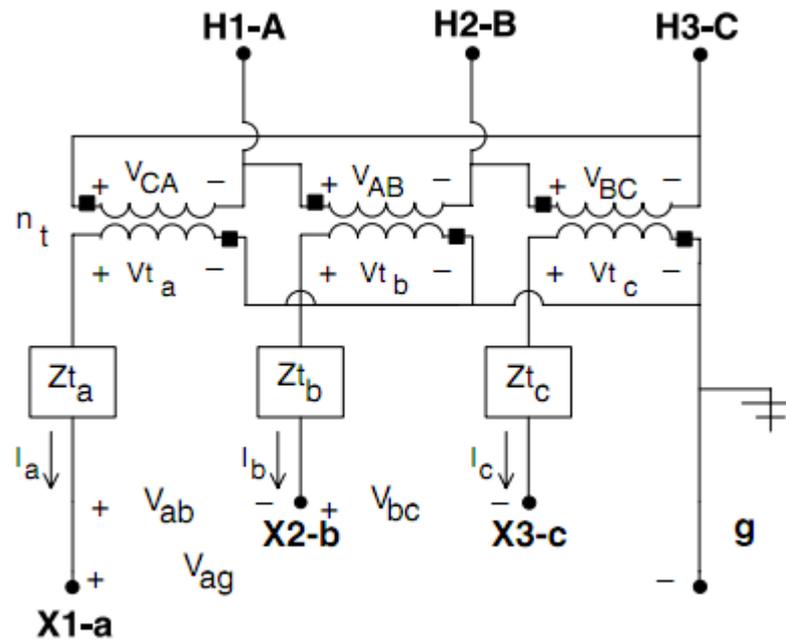
# MODELAGEM TRIFÁSICA

## Reguladores de tensão



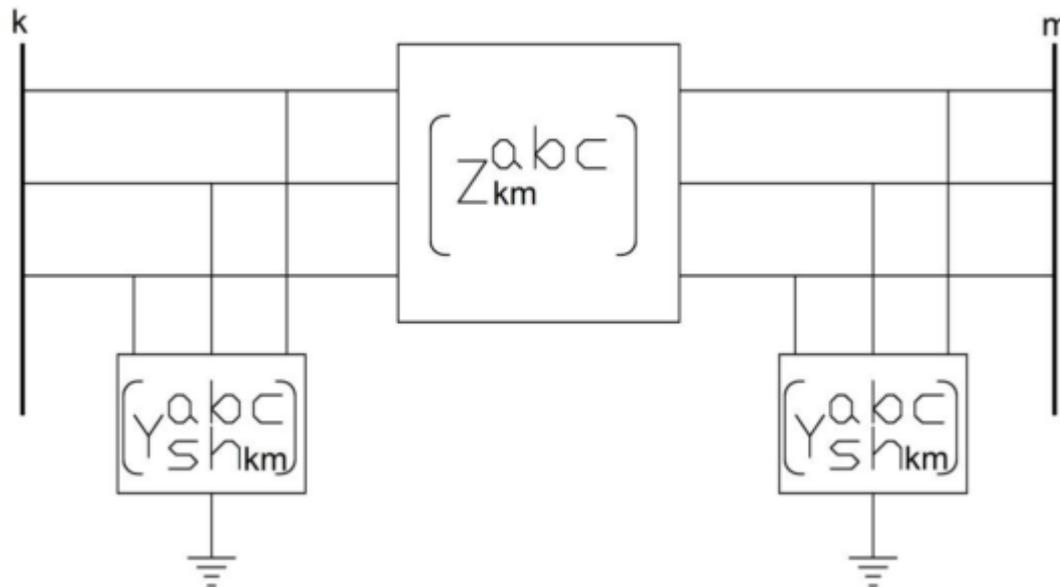
# MODELAGEM TRIFÁSICA

## Transformadores



# MODELAGEM TRIFÁSICA

## Circuito equivalente



$$\begin{bmatrix} Z_{km}^{aa} & Z_{km}^{ab} & Z_{km}^{ac} \\ Z_{km}^{ba} & Z_{km}^{bb} & Z_{km}^{bc} \\ Z_{km}^{ca} & Z_{km}^{cb} & Z_{km}^{cc} \end{bmatrix} = \begin{bmatrix} r_{km}^{aa} & r_{km}^{ab} & r_{km}^{ac} \\ r_{km}^{ba} & r_{km}^{bb} & r_{km}^{bc} \\ r_{km}^{ca} & r_{km}^{cb} & r_{km}^{cc} \end{bmatrix} + j \begin{bmatrix} x_{km}^{aa} & x_{km}^{ab} & x_{km}^{ac} \\ x_{km}^{ba} & x_{km}^{bb} & x_{km}^{bc} \\ x_{km}^{ca} & x_{km}^{cb} & x_{km}^{cc} \end{bmatrix} \quad \begin{bmatrix} Y_{sh_{km}}^{aa} & Y_{sh_{km}}^{ab} & Y_{sh_{km}}^{ac} \\ Y_{sh_{km}}^{ba} & Y_{sh_{km}}^{bb} & Y_{sh_{km}}^{bc} \\ Y_{sh_{km}}^{ca} & Y_{sh_{km}}^{cb} & Y_{sh_{km}}^{cc} \end{bmatrix} = j \begin{bmatrix} b_{km}^{aa} & b_{km}^{ab} & b_{km}^{ac} \\ b_{km}^{ba} & b_{km}^{bb} & b_{km}^{bc} \\ b_{km}^{ca} & b_{km}^{cb} & b_{km}^{cc} \end{bmatrix}$$

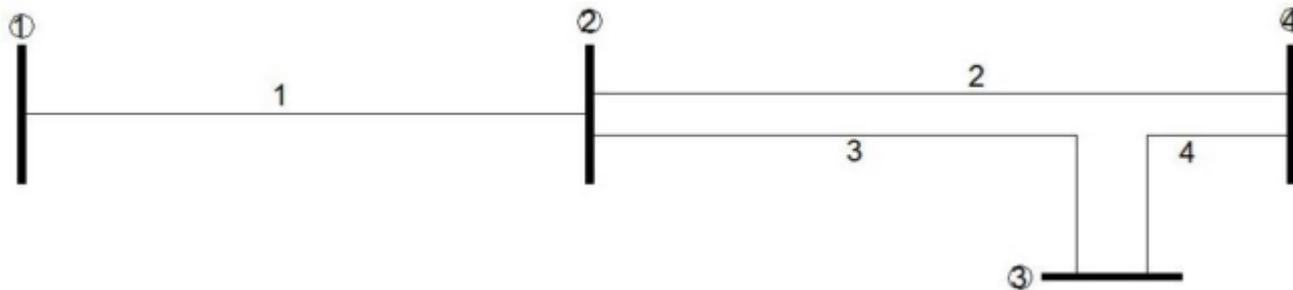
# ***MODELAGEM TRIFÁSICA***

**Matriz de impedância primitiva para matriz de admitância nodal**

$$\dot{\mathbf{Y}}_L = [\mathbf{A}^{abc}]^t \cdot (\dot{\mathbf{z}}_{prim}^{abc})^{-1} \cdot \mathbf{A}^{abc}$$

# MODELAGEM TRIFÁSICA

Matriz de incidência



Linhas \ Barras	Barras			
	①	②	③	④
1	1	-1	0	0
2	0	1	0	-1
3	0	1	-1	0
4	0	0	1	-1

# MODELAGEM TRIFÁSICA

## Matriz de Impedância Primitiva

nl	1			2			3			4		
	a	b	c	a	b	c	a	b	c	a	b	c
a	$Z_{12}^{aa}$	$Z_{12}^{ab}$	$Z_{12}^{ac}$	0	0	0	0	0	0	0	0	0
1b	$Z_{12}^{ba}$	$Z_{12}^{bb}$	$Z_{12}^{bc}$	0	0	0	0	0	0	0	0	0
c	$Z_{12}^{ca}$	$Z_{12}^{cb}$	$Z_{12}^{cc}$	0	0	0	0	0	0	0	0	0
a	0	0	0	$Z_{24}^{aa}$	$Z_{24}^{ab}$	$Z_{24}^{ac}$	0	0	0	0	0	0
2b	0	0	0	$Z_{24}^{ba}$	$Z_{24}^{bb}$	$Z_{24}^{bc}$	0	0	0	0	0	0
c	0	0	0	$Z_{24}^{ca}$	$Z_{24}^{cb}$	$Z_{24}^{cc}$	0	0	0	0	0	0
a	0	0	0	0	0	0	$Z_{23}^{aa}$	$Z_{23}^{ab}$	$Z_{23}^{ac}$	0	0	0
3b	0	0	0	0	0	0	$Z_{23}^{ba}$	$Z_{23}^{bb}$	$Z_{23}^{bc}$	0	0	0
c	0	0	0	0	0	0	$Z_{23}^{ca}$	$Z_{23}^{cb}$	$Z_{23}^{cc}$	0	0	0
a	0	0	0	0	0	0	0	0	0	$Z_{34}^{aa}$	$Z_{34}^{ab}$	$Z_{34}^{ac}$
4b	0	0	0	0	0	0	0	0	0	$Z_{34}^{ba}$	$Z_{34}^{bb}$	$Z_{34}^{bc}$
c	0	0	0	0	0	0	0	0	0	$Z_{34}^{ca}$	$Z_{34}^{cb}$	$Z_{34}^{cc}$



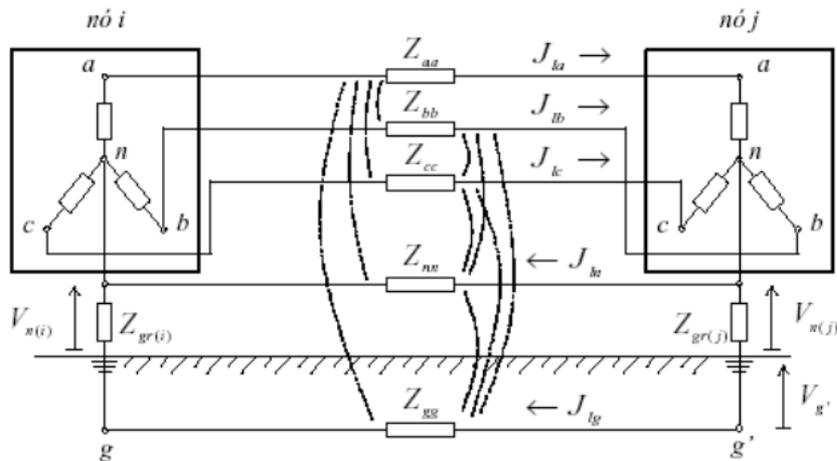
# MODELAGEM TRIFÁSICA

Matriz de admitância nodal (sistema de duas barras)

$$\dot{\mathbf{Y}}_L = \begin{bmatrix} \dot{Y}_{11}^a & 0 & 0 & \dot{Y}_{12}^a & \dot{Y}_{12}^{ab} & \dot{Y}_{12}^{ac} \\ 0 & \dot{Y}_{11}^b & 0 & \dot{Y}_{12}^{ba} & \dot{Y}_{12}^b & \dot{Y}_{12}^{bc} \\ 0 & 0 & \dot{Y}_{11}^c & \dot{Y}_{12}^{ca} & \dot{Y}_{12}^{cb} & \dot{Y}_{12}^b \\ \dot{Y}_{21}^a & \dot{Y}_{21}^{ab} & \dot{Y}_{21}^{ac} & \dot{Y}_{22}^a & 0 & 0 \\ \dot{Y}_{21}^{ba} & \dot{Y}_{21}^b & \dot{Y}_{21}^{bc} & 0 & \dot{Y}_{22}^b & 0 \\ \dot{Y}_{21}^{ca} & \dot{Y}_{21}^{cb} & \dot{Y}_{21}^c & 0 & 0 & \dot{Y}_{22}^c \end{bmatrix}$$

# MODELAGEM TRIFÁSICA

## Representação do neutro e do terra



$$Z_L = \begin{bmatrix} Z_{aa} & Z_{ab} & Z_{ac} & Z_{an} & Z_{ag} \\ Z_{ab} & Z_{bb} & Z_{bc} & Z_{bn} & Z_{bg} \\ Z_{ac} & Z_{bc} & Z_{cc} & Z_{cn} & Z_{cg} \\ Z_{an} & Z_{bn} & Z_{cn} & Z_{nn} & Z_{ng} \\ Z_{ag} & Z_{bg} & Z_{cg} & Z_{ng} & Z_{gg} \end{bmatrix}$$

# FLUXO DE POTÊNCIA TRIFÁSICO

1ª etapa: Cálculo nodal da corrente para todos os nós

$$\begin{bmatrix} I_{ia} \\ I_{ib} \\ I_{ic} \end{bmatrix}^{(k)} = \begin{bmatrix} \left( S_{ia}/V_{ia}^{(k-1)} \right)^* \\ \left( S_{ib}/V_{ib}^{(k-1)} \right)^* \\ \left( S_{ic}/V_{ic}^{(k-1)} \right)^* \end{bmatrix} - \begin{bmatrix} Y_{ia}^* & & \\ & Y_{ib}^* & \\ & & Y_{ic}^* \end{bmatrix} \begin{bmatrix} V_{ia} \\ V_{ib} \\ V_{ic} \end{bmatrix}^{(k-1)}$$

# FLUXO DE POTÊNCIA TRIFÁSICO

2ª etapa: varredura *Backward* – cálculo das correntes em todos os ramos

$$\begin{bmatrix} J_{la} \\ J_{lb} \\ J_{lc} \end{bmatrix}^{(k)} = - \begin{bmatrix} I_{ja} \\ I_{jb} \\ I_{jc} \end{bmatrix}^{(k)} + \sum_{m \in M} \begin{bmatrix} J_{ma} \\ J_{mb} \\ J_{mc} \end{bmatrix}^{(k)}$$

# FLUXO DE POTÊNCIA TRIFÁSICO

3ª etapa: varredura *Forward* – cálculo das tensões para todos os nós

$$\begin{bmatrix} V_{ja} \\ V_{jb} \\ V_{jc} \end{bmatrix}^{(k)} = \begin{bmatrix} V_{ia} \\ V_{ib} \\ V_{ic} \end{bmatrix}^{(k)} - \begin{bmatrix} z_{aa,l} & z_{ab,l} & z_{ac,l} \\ z_{ab,l} & z_{bb,l} & z_{bc,l} \\ z_{ac,l} & z_{bc,l} & z_{cc,l} \end{bmatrix} \begin{bmatrix} J_{la} \\ J_{lb} \\ J_{lc} \end{bmatrix}^{(k)}$$

# ***REFERÊNCIAS***

**Baran, A. Fluxo de Potência Ótimo Trifásico. Dissertação UFPR, 2013.**

**Pantuzi, A. Desempenho de um Algoritmo BackWard - Forwar Sweep de Cálculo de Fluxo de Potência. Dissertação UNESP, 2006.**

**Cheng e Shirmohammadi. A Three-Phase Power Flow Method for Real-Time Distribution System Analysis. IEEE Transactions on Power Systems, vol. 10, no. 2, 1995.**