Power-flow Controls

Power-Flow Controls

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Power-Flow Control Devices

- Transformers
  - Tap changing
  - Phase shifting
- Shunt Capacitor/Reactor Banks
- Synchronous Condensers
- Power electronic controls

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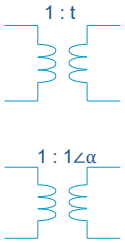
Control Devices

- Transformers
  - Tap changing
    - t changes voltage
    - V_{ref} voltage reference
  - Phase shifter
    - α introduces a phase shift
    - MW power-flow depends on angle difference
    - regulates active power-flow



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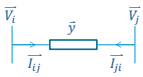
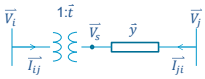
Control Transformers



$$\begin{bmatrix}\vec{I}_{ij}\\ \vec{I}_{ji}\end{bmatrix} = \begin{bmatrix}\vec{y} & -\vec{y}\\ -\vec{y} & \vec{y}\end{bmatrix}\begin{bmatrix}\vec{V}_i\\ \vec{V}_j\end{bmatrix}$$



$$\vec{V}_s = \vec{t}\vec{V}_i$$

$$\vec{I}_{ji} = (\vec{V}_j - \vec{t}\vec{V}_i)\vec{y} = -\vec{t}\vec{y}\vec{V}_i + \vec{y}\vec{V}_j$$

$$\begin{bmatrix}\vec{I}_{ij}\\ \vec{I}_{ji}\end{bmatrix} = \begin{bmatrix}|t|^2\vec{y} & -\vec{t}^*\vec{y}\\ -\vec{t}\vec{y} & \vec{y}\end{bmatrix}\begin{bmatrix}\vec{V}_i\\ \vec{V}_j\end{bmatrix}$$

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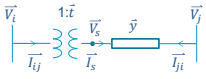
Transformers



$$\vec{V}_s\vec{I}_s^* = \vec{V}_i\vec{I}_{ij}^*$$
$$\Rightarrow \vec{t}\,\vec{V}_i\vec{I}_s^* = \vec{V}_i\vec{I}_{ij}^*$$
$$\Rightarrow \vec{I}_{ij} = \vec{t}^*\vec{I}_S = -\vec{t}^*\,\vec{I}_{ji}$$
$$\vec{I}_{ji} = -\vec{t}\vec{y}\vec{V}_i + \vec{y}\vec{V}_j$$
$$\vec{I}_{ij} = |t|^2\vec{V}_i\,\vec{y} - \vec{t}^*\vec{y}\vec{V}_j$$

$$\begin{bmatrix}\vec{I}_{ij}\\ \vec{I}_{ji}\end{bmatrix} = \begin{bmatrix}|t|^2\vec{y} & -\vec{t}^*\vec{y}\\ -\vec{t}\vec{y} & \vec{y}\end{bmatrix}\begin{bmatrix}\vec{V}_i\\ \vec{V}_j\end{bmatrix}$$

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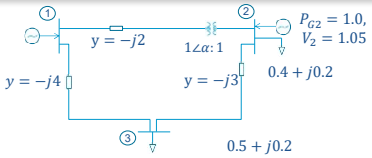
Example 1



$i = 2, j = 1$
$\vec{t} = 1\angle\alpha, \vec{y} = -j2$

$$\begin{bmatrix}|t|^2\vec{y} & -\vec{t}^*\vec{y}\\ -\vec{t}\vec{y} & \vec{y}\end{bmatrix}$$

$$\overrightarrow{Y_{Bus}} = \begin{bmatrix}-j2 - j4 & j2\angle\alpha & j4\\ j2\angle -\alpha & -j2 - j3 & j3\\ j4 & j3 & -j4 - j3\end{bmatrix}$$
$$= \begin{bmatrix}6\angle -90^o & 2\angle(90^o+\alpha) & 4\angle 90^o\\ 2\angle(90^o-\alpha) & 5\angle -90^o & 3\angle 90^o\\ 4\angle 90^o & 3\angle 90^o & 7\angle -90^o\end{bmatrix}$$

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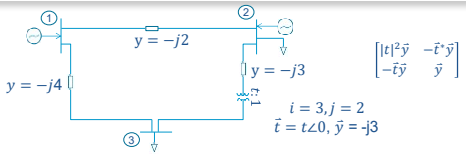
Example 2



$$\overrightarrow{Y_{Bus}} = \begin{bmatrix} -j2-j4 & j2 & j4 \\ j2 & -j2-j3 & j3t \\ j4 & j3t & -j4-j3t^2 \end{bmatrix} = \begin{bmatrix} 6\angle -90^o & 2\angle 90^o & 4\angle 90^o \\ 2\angle 90^o & 5\angle -90^o & 3t\angle 90^o \\ 4\angle 90^o & 3t\angle 90^o & (4+3t^2)\angle -90^o \end{bmatrix}$$

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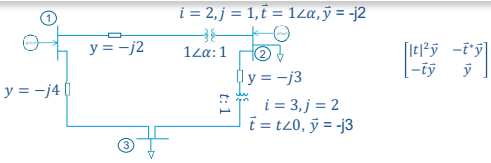
Example 3



$$\overrightarrow{Y_{Bus}} = \begin{bmatrix} -j2-j4 & j2\angle\alpha & j4 \\ j2\angle -\alpha & -j2-j3 & j3t \\ j4 & j3t & -j4-j3t^2 \end{bmatrix} = \begin{bmatrix} 6\angle -90^o & 2\angle(90^o+\alpha) & 4\angle 90^o \\ 2\angle(90^o-\alpha) & 5\angle -90^o & 3t\angle 90^o \\ 4\angle 90^o & 3t\angle 90^o & (4+3t^2)\angle -90^o \end{bmatrix}$$

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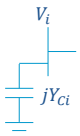
Control Devices



- Capacitor Banks
  - Include in the diagonal term $\overrightarrow{Y_{ii}}$ in $\overrightarrow{Y_{Bus}}$
  - ⇒ Y_{Ci} automatically varied to keep $V_i = V_{specified}$
  - ⇒ Y_{Ci} becomes an unknown $V_i = V_{specified}$

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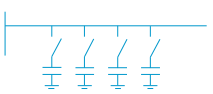
Shunt Capacitor banks



Controlled by local voltage control logic

- $V_i < V_{refi}$ ⇒ switch on capacitors
- $V_i > V_{refi}$ ⇒ switch off capacitors
- We may assume $V_i = V_{refi}$ (like a PV bus)

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Synchronous condensers

- Synchronous machines
- P_{Gi}=0 (or small negative) (“motor”)
- $V_i < V_{ref}$ ⇒ Q_{gi} increased
- $V_i > V_{ref}$ ⇒ Q_{gi} decreased
- Q_{gi} adjusted to keep $V_i = V_{refi}$ (PV bus)
- Old generators not efficient to produce active power (Keep exciter circuits)
- Can be used as voltage control device; Synchronous condenser

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Power electronic controls

- Static VAR Compensator (SVC)
- Static Synchronous Compensator (STATCOM)
- Thyristor Controlled Series Compensation (TCSC)

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